

Qingdao , China
21 – 24 July 2019

THE 9th INTERNATIONAL SYMPOSIUM ON COAL COMBUSTION

第9届国际煤燃烧会议



THE 9th INTERNATIONAL SYMPOSIUM ON COAL COMBUSTION

July 21–24, 2019 Qingdao China

Organizer: Department of Energy and Power Engineering

Tsinghua University

Welcome

Welcome to the 9th International Symposium on Coal Combustion (ISCC-9) at DoubleTree by Hilton Qingdao Oriental Movie Metropolis (HQ) on July 21-24, hosted by the Department of Energy and Power Engineering, Tsinghua University, China. The symposium was inaugurated by Tsinghua University in 1987, and subsequent Symposia were held every four years. The symposium is to offer a platform for all attendants to exchange their ideas, experience and information on the science and technology of clean coal and alternative fuel combustion, as well as their low carbon utilization.

The technical program consists of eleven plenary plus six keynote invited lectures, six simultaneous sessions of oral presentations. A total of 186 fullpapers from 14 countries and regions are chosen from 253 submitted abstracts, covering six colloquiums including basic coal quality & combustion, pulverized coal combustion, fluidized bed combustion, low carbon energy, emission controls, and design and operating experiences. All of the fullpapers, after the thorough peer review, are recommended to be collected in the Proceedings of 9th ISCC that published by Springer-Tsinghua Press. Two special issues covering some selected papers will be submitted to two international journals. In particular, a novel panel discussion of NSF-NSFC/DFG-NSFC collaboration is organized in this symposium.

The local organizing committee has put together exciting social programs. The welcome reception on Sunday (July, 21) will be held on Back Garden of HQ. The Symposium Banquet on Tuesday (July, 23) will be held at Haiyue Ballroom of the Liyumen Seafood Hotel. The technical tour to Huangdao Coal Power Plant will be arranged from 14:00 to 17:00 on Wednesday (July, 24).

We would like to thank all the attendees for their contributions to the symposium. We would also like to thank the hard work of the organization team and committee members for making the symposium possible.

On behalf of local organizing committee, we welcome all of you to attend this symposium and hope you enjoy your stay in Qingdao.

Chairman
Prof. Lyu, Junfu
Secretary-of-General
Prof. Li, Shuiqing
Tsinghua University
Beijing, China, July 2019

**THE 9th INTERNATIONAL SYMPOSIUM ON
COAL COMBUSTION**

July 21 - 24, 2019

Qingdao, China

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Sponsors

Organizer



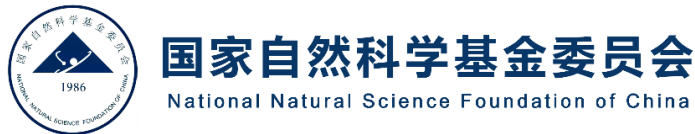
Tsinghua University

Co-organizer



Shandong University of Science and Technology

Sponsors



National Natural Science Foundation of China

Co-sponsors



Qingdao Clear Environment Group Co., Ltd

International Committee

Honorary Chairman

Prof. Yue, Guangxi China Tsinghua University

Chairman

Prof. Lyu, Junfu China Tsinghua University

Secretary-General

Prof. Li, Shuiqing China Tsinghua University

International Members

Prof. Bhattacharya, S.	Australia	Monash University
Prof. Nathan, G.	Australia	University of Adelaide
Prof. Wu, Hongwei	Australia	Curtin University of Technology
Prof. Zhang, Dongke	Australia	University of Western Australia
Prof. Gupta, R.	Canada	University of Alberta
Dr. Zheng, Ligang	Canada	CANMET
Prof. Glarborg, P.	Denmark	Technical University of Denmark
Prof. Hupa, M.	Finland	Abo Akademi Process Chemistry Centre
Prof. Kneer, R.	Germany	RWRH Aachen University
Prof. Scherer, V.	Germany	Ruhr University Bochum
Prof. Senneca, O.	Italy	Istituto di Ricerche sulla Combustione IRC-CNR
Dr. Fujimori, Toshiro	Japan	IHI Corporation
Prof. Hayashi, Jun-ichiro	Japan	Kyushu University
Dr. Makino, Hisao	Japan	Central Research Institute of Electrical Power Industry
Prof. Lee, Jong-Min	Korea	Korea Electric Power Research Institute
Prof. Nowak, W.	Poland	Czestochowa University of Technology
Prof. Costa, M.	Portugal	University of Lisbon
Prof. Grigoriev, K.	Russia	Saint-Petersburg State Polytechnical University
Dr. Ryabov, G.	Russia	All Russia Thermal Engineering Institute
Prof. Johnsson, F.	Sweden	Chalmers University of Technology

Colloquium Chair

Prof. Leckner, B.	Sweden	Chalmers University of Technology
Prof. Anthony, B.J.	UK	Cranfield University
Prof. Sharman, P.	UK	International Flame Research Foundation
Dr. Minchener, A.J.	UK	General Manager of the IEA Clean Coal Centre
Prof. Ghoniem, A.	USA	Massachusetts Institute of Technology
Prof. Gupta, A.	USA	University of Maryland
Dr. Lu, Pisi	USA	SmartBurn, LLC
Prof. Pan, Weiping	USA	Western Kentucky University
Prof. Smith, P.	USA	University of Utah
Prof. Axelbaum, R.	USA	Washington University
Prof. Fletcher, T. H.	USA	Brigham Young University
Prof. Wendt, J. O. L.	USA	University of Utah

Chinese Members

Dr. Gu, Dazhao	China	China Energy Investment Group Co. Ltd
Dr. Wang, Naiji	China	China Coal Research Institute Company of Energy Conservation
Mr. Huo, Suoshan	China	Dong Fang Boiler Group Co. Ltd
Dr. Zhang, Yanjun	China	Harbin Boiler Co. Ltd
Prof. Qin, Yukun	China	Harbin Institute of Technology
Prof. Sun, Shaozeng	China	Harbin Institute of Technology
Prof. Xu, Minghou	China	Huazhong University of Science and Technology
Prof. Yao, Hong	China	Huazhong University of Science and Technology
Prof. Zheng, Chuguang	China	Huazhong University of Science and Technology
Prof. Lyu, Qinggang	China	Institute of Engineering Thermophysics, CAS
Prof. Huang, Qili	China	Northeast Electric Power Company
Prof. Liu, Jizhen	China	North China Electric Power University
Mr. Xu, Xueyuan	China	Shanghai Boiler Co. Ltd
Prof. Zhang, Mingchuan	China	Shanghai Jiao Tong University
Prof. Zhang, Zhongxiao	China	Shanghai Jiao Tong University
Prof. Shen, Laihong	China	Southeast University

The 9th ISCC International Committee

Prof. Zhao, Changsui	China	Southeast University
Prof. Lyu, Junfu (Chair)	China	Tsinghua University
Prof. Ni, Weidou	China	Tsinghua University
Prof. Qi, Haiying	China	Tsinghua University
Prof. Yao, Qiang	China	Tsinghua University
Prof. Yue, Guangxi	China	Tsinghua University
Prof. Zhou, Lixing	China	Tsinghua University
Prof. Zhang, Hai	China	Tsinghua University
Prof. Che, Defu	China	Xi'an Jiaotong University
Prof. Cen, Kefa	China	Zhejiang University
Prof. Luo, Zhongyang	China	Zhejiang University

Local Organizing Committee

Prof. Li, Shuiqing	iscc_office@tsinghua.edu.cn	Tsinghua University
Prof. Liu, Qing	liuqing@tsinghua.edu.cn	Tsinghua University
Prof. Wang, Cuiping	wangcuiping@tsinghua.org.cn	Shandong University of Science and Technology
Prof. Wang, Chongge	chgewang@163.com	Shandong University of Science and Technology
Prof. Cong, Xiaochun	congxiaochun@126.com	Shandong University of Science and Technology
Prof. Zhang, Xiantang	zzxhtm@163.com	Shandong University of Science and Technology

Colloquium Chair

Basic Coal Quality & Combustion

Prof. Costa, Mário	University of Lisbon
Prof. Yu, Dunxi	Huazhong University of Science and Technology
Assoc. Prof. Zhenshan Li	Tsinghua University

Pulverized Coal Combustion

Prof. Fletcher, Thomas H.	Brigham Young University
Prof. Liu, Yinhe	Xi'an Jiaotong University
Prof. Zhang, Hai	Tsinghua University

Fluidized Bed Combustion

Prof. Johnsson, Filip	Chalmers University of Technology
Prof. Cheng, Leming	Zhejiang University
Prof. Yang, Hairui	Tsinghua University

Low Carbon Energy

Prof. Anthony, Edward J.	Cranfield University
Prof. Shen, Laihong	Southeast University
Assoc. Prof. Wang, Shujuan	Tsinghua University

Emission Controls

Prof. Glarborg, Peter	Technical University of Denmark
Prof. Zhao, Haibo	Huazhong University of Science and Technology
Prof. You, Changfu	Tsinghua University

Design and Operating Experiences

Prof. Axelbaum, Richard L.	Washington University at St. Louis
Prof. Li, Zhengqi	Harbin Institute of Technology
Assoc. Prof. Wu, Yuxin	Tsinghua University

Program Chair

Prof. Zhou, Yuegui	Shanghai Jiao Tong University
Prof. Li, Shuiqing	Tsinghua University

Instructions to Delegates

1 Transportation

There are public buses between the DoubleTree by Hilton Qingdao Oriental Movie Metropolis (青岛东方影都融创希尔顿逸林酒店) and the railway stations or the Qingdao Liuting International Airport. Conveniently, you may take a taxi and show the information in the transportation listed below to your taxi driver. More information about the transportation is listed below on **page 11**.

2 Reception Desk

Location:

Lobby (First floor) of DoubleTree by Hilton Qingdao Oriental Movie Metropolis

Open Hours:

Sunday, July 21	9:00 – 23:00
Monday, July 22	7:30 - 17:00
Tuesday, July 23	7:30 - 17:00
Wednesday, July 24	7:30 - 12:00

3. Symposium registration

How to register?

All delegates should register on the official website of the 9th ISCC:

<https://www.bagevent.com/event/9thISCC/p/96421>

For international attendees: Visa, MasterCard, and American Express card are accepted. It will be billed in Chinese RMB and exchanged to your local currency during your online payment authorization. Consequently, the amount charged to your account may vary due to the fluctuation in exchange rates.

For Chinese attendees: Domestic attendees can complete online payment only through Alipay and WeChat.

Credit card payment at the registration desk is available.

Registration Fees

Earlybird registration (payment received before May 15, 2019)

For international attendees - General registrant: USD 450, Student: USD 300;

For Chinese attendees - General registrant: CNY 3100, Student: CNY 2100;

Normal Registration (payment received after May 15, 2019)

Instructions to Delegates

For international attendees - General registrant: USD 500, Student: USD 350;

For Chinese attendees - General registrant: CNY 3500, Student: CNY 2400;

Please register with the symposium first, and pay the fees via your symposium account.

4. Accommodation

The 9th International Symposium on Coal Combustion will be held in the DoubleTree by Hilton Qingdao Oriental Movie Metropolis which is located in the Huangdao District of Qingdao. The detailed introduction of the hotel could be found at <http://doubletree.hilton.com.cn/zh-cn/hotel/Qingdao/doubletree-by-hilton-qingdao-oriental-movie-metropolis-TAOMMDI/index.html>.

There are still three other hotels can be chose and reserved, the detailed information can be found at <https://www.bagevent.com/event/9thISCC/p/96426>.

5. Oral presentation

All oral presenters are requested to copy your PPT into the computer, at least 5 minutes before the start of each session. The time for each paper in the oral session is **20 min**. Please limit your presentation in **15 minutes** and leave **5 minutes** for questions, answers and comments.

6. Poster

All authors of poster session papers shall take your printed poster to conference site (**120 cm×90 cm**). **You are requested to submit your poster to the staff when you make conference registration.** All the entries are to be mounted in the numbered space that has been reserved for it, please refer to the section “Schedule of Papers” for the assigned number and the schedule of the posters.

Set-up

Boards will be in place the first floor of DoubleTree by Hilton Qingdao Oriental Movie Metropolis by 13:30 on Monday (July 22). Please submit your poster (**120 cm×90 cm**) to reception desk at the same floor in time.

Presentation

Poster authors must be by their board for the sessions between **17:20-18:20** on Monday (July 22) and **17:00-18:00** on Tuesday (July 23) during the scheduled hours.

Dismantling

Presenters must dismantle their posters by 12:00 on Wednesday (July 24). After that they will be discarded.

Instructions to Delegates

7. Meal

The hotel offers free breakfast. Lunch and supper are included in the registration fee. You are required to show the meal voucher before the meal.

Breakfast

7:00 - 9:00, July 22-24

All Day Dining Restaurant (refer to the Map of DoubleTree by Hilton Qingdao Oriental Movie Metropolis below).

Lunch

12:00-14:00, July 22-24

All Day Dining Restaurant

Dinner

18:00-21:00, July 22-23

All Day Dining Restaurant

8. Welcome Reception && Banquet

Welcome Reception:

18:00 – 21:00, July 21 (Sunday)

Back Garden (refer to the Map of DoubleTree by Hilton Qingdao Oriental Movie Metropolis below)

Banquet:

18:30 – 21:00, July 23 (Tuesday)

Haiyue Ballroom of the Hong Kong Liyumen Seafood Hotel (The buses for the Hong Kong Liyumen Seafood Hotel will be ready at 18:10 of July 23 at Entrance of DoubleTree by Hilton Qingdao Oriental Movie Metropolis)

9. Committee Meeting

20:00 – 22:00, July 22 (Monday)

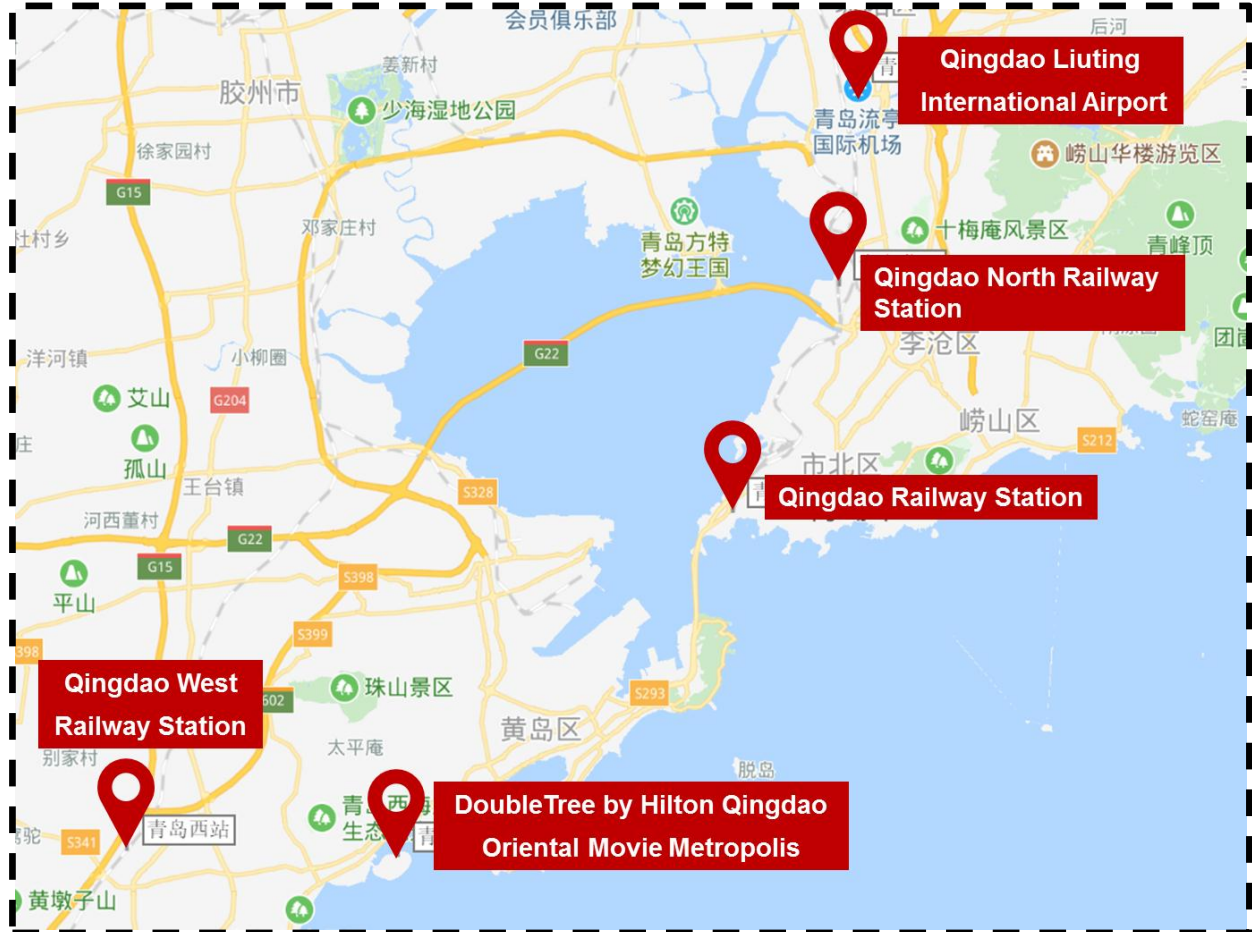
Room #1 (refer to the Map of DoubleTree by Hilton Qingdao Oriental Movie Metropolis below)

10. Technical Tour

The technical tour of the 9th ISCC will be arranged from 14:00 to 17:00 in the afternoon of July, 24th (Wed.). Delegates will visit Huangdao Coal Power Plant.

The buses will be ready at 13:40 of July 24 (Wed.) at the Entrance of DoubleTree by Hilton Qingdao Oriental Movie Metropolis.

Transportation



How to go to the symposium?

1. Qingdao Liuting International Airport - DoubleTree by Hilton Qingdao Oriental Movie Metropolis: 70 km away.

- ✓ Public Bus: At the airport, take the Airport Shuttle Bus Route 2 Bus to Qingdao Municipal Hospital Bus Stop. Take the tunnel No. 7 Bus and get off at the China University of Petroleum Southern Gate Bus Stop, transfer to the Huangdao No. 60 Bus and get off at Xingguangdao Bus Stop. Walk about 800 m from the Xingguangdao Bus Stop to the hotel. The whole journey takes about 160 minutes and costs 23 yuan.

Or at the airport, take the Airport Bus Huangdao Direct Bus to the China University of Petroleum Northern Gate Bus Stop. Get off and walk to Bus Stop across the road. Take the L1 Bus to the Oriental Movie Metropolis Bus Stop, then walk about 2000 m to the hotel. The journey takes about 150 minutes and costs 42 yuan.

- ✓ Taxi: The journey takes about 80 minutes and costs about 200 yuan (28.9 USD).

2. Qingdao North Railway Station - DoubleTree by Hilton Qingdao Oriental Movie Metropolis: 50 km away.

- ✓ Public Bus: From the Qingdao North Railway Station, walk about 150 m to the East Square Bus Stop, then take the No. 325 Bus to Changchun Road Bus Stop. At Changchun Road Bus Stop, transfer to the No. 8 Bus and get off at the China University of Petroleum Southern Gate Bus Stop, then take the Huangdao No. 60 Bus and get off at Xingguangdao Bus Stop. Walk about 800 m from Xingguangdao Bus Stop to the hotel. The journey takes about 140 minutes and costs 4 yuan.

- ✓ Taxi: The journey takes about 65 minutes and costs about 160 yuan (23.1USD).

3. Qingdao Railway Station - DoubleTree by Hilton Qingdao Oriental Movie Metropolis: 35 km away.

- ✓ Public Bus: From the Qingdao Railway Station, walk about 250 m to Lanshanlu Railway Bus

Transportation

Stop, take the No. 5/6/7 Bus to the China University of Petroleum Southern Gate Bus Stop. Then take the Huangdao No. 60 Bus and get off at Xingguangdao Bus Stop. Walk about 800m from Xingguangdao Bus Stop to the hotel. The journey takes about 100 minutes and costs 3 yuan.

- ✓ Taxi: The journey takes about 50 minutes and costs about 100 yuan (14.4USD).

4. Qingdao West Railway Station - DoubleTree by Hilton Qingdao Oriental Movie Metropolis: 35 km away.

- ✓ Public Bus: At the Qingdao West Railway Station, walk 1000m to the Qingdao West Railway Station Bus Stop, and then take the Huangdao K21/306 Bus to the Oriental Movie Metropolis Bus Stop. From Oriental Movie Metropolis Bus Stop, walk about 2000m to the hotel. The journey takes about 90 minutes and costs 2 yuan.

- ✓ Taxi: The journey takes about 40 minutes and costs about 50 yuan (7.2USD).

Tips: You can show the information below to your taxi driver:

Please Take Me To The DoubleTree by Hilton Qingdao Oriental Movie

Metropolis. Thank you!

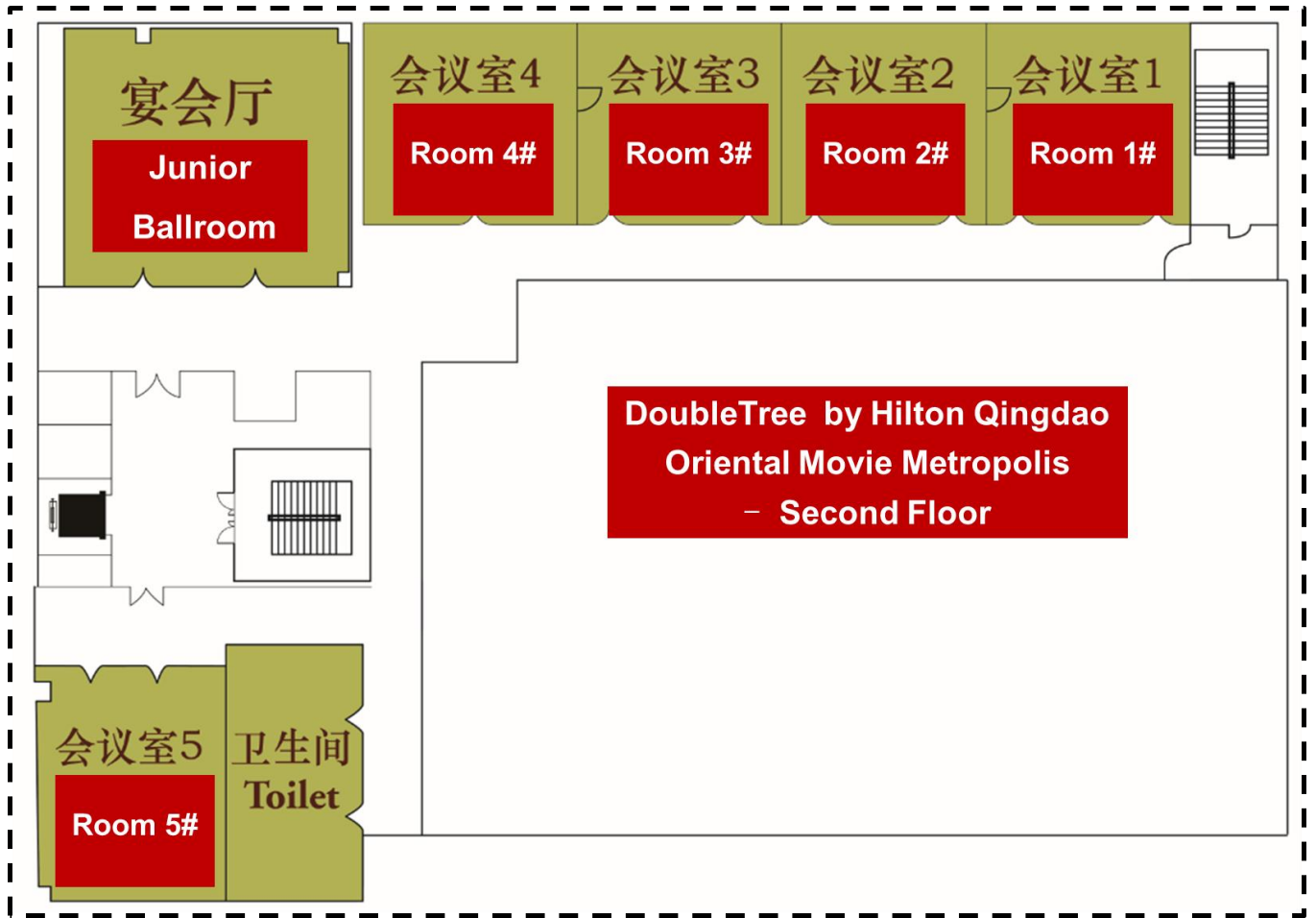
请送我到青岛东方影都融创希尔顿逸林酒店，谢谢您！

地址：黄岛区星海湾路 788 号

Transportation



Transportation



How to leave there ?

1. DoubleTree by Hilton Qingdao Oriental Movie Metropolis - Qingdao Liuting Airport: 70KM.

- ✓ Public Bus: Walk about 800m from the hotel to Xingguangdao Bus Stop, take Huangdao Bus No. 60 to the China University of Petroleum South Gate Bus Stop, transfer to Bus No. 8 to Sifang Bus Stop, walk about 90 m to Sifang Hotel, and then take Airport Bus Line 2 to the airport. The whole journey takes about 160 minutes and costs 23 yuan.

Or walk about 2000 m from the hotel to Oriental Movie Metropolis Bus Stop, take Bus L1 to the China University of Petroleum North Gate Bus Stop, walk about 150m to LanHaiJinGang Hotel and then take Airport Bus Huangdao Special Line to the airport. The journey takes about 150 minutes and costs 42 yuan.

Transportation

- ✓ Taxi: The journey takes about 80 minutes and costs about 200 yuan.

Tips: You can show the information below to your taxi driver:

Please Take Me To Qingdao Liuting Airport. Thank you!

请您送我去青岛流亭机场，谢谢您！

2. DoubleTree by Hilton Qingdao Oriental Movie Metropolis - Qingdao North Railway

Station: 50KM.

- ✓ Bus: Walk about 800 m from the hotel to Xingguangdao Bus Stop, take HuangDao Bus No. 60 to the China University of Petroleum South Gate Bus Stop, transfer to the Tunnel Bus No. 8 to ChangChun Road Stop, and transfer to Bus No. 325 to the East Square of North Railway Station. The journey takes about 140 minutes and costs 4 yuan.
- ✓ Taxi: The journey takes about 65 minutes and costs about 150 yuan.

Tips: You can show the information below to your taxi driver:

Please Take Me To Qingdao North Railway Station. Thank you!

请您送我去青岛北站，谢谢您！

3. DoubleTree by Hilton Qingdao Oriental Movie Metropolis -Qingdao Railway Station:

35KM

- ✓ Bus: Walk about 800 m from the hotel to Xingguangdao Bus Stop, take HuangDao Bus No. 60 to the China University of Petroleum South Gate Bus Stop, and transfer to the Tunnel Bus No. 5/6/7 to Qingdao Railway Station. The journey takes about 100 minutes and costs 3 yuan.

Transportation

- ✓ Taxi: The journey takes about 50 minutes and costs 100 yuan.

Tips: You can show the information below to your taxi driver:

Please Take Me To Qingdao Railway Station. Thank you!

请您送我去青岛站，谢谢您！

4. DoubleTree by Hilton Qingdao Oriental Movie Metropolis -Qingdao West Railway Station: 35KM

- ✓ Bus: Walk about 2000 m from the hotel to Liyumen Seafood Restaurant Bus Stop, take Huangdao Bus No. 306 to the Qingdaoxi Railway Bus Stop, and walk about 1000 m to Qingdao West Railway Station. The journey takes about 90 minutes and costs 2 yuan.
- ✓ Taxi: The journey takes about 40 minutes and costs 50 yuan.

Tips: You can show the information below to your taxi driver:

Please Take Me To Qingdao West Railway Station. Thank you!

请您送我去青岛西站，谢谢您！

City Scenery

Tsingtao, or Qingdao in Chinese, is a major city in the east of Shandong Province on China's Yellow Sea coast. It is also a major nodal city of the One Belt, One Road (OBOR) Initiative that connects Asia with Europe. It has the highest GDP of any city in the province. Administered at the sub-provincial level, Qingdao has jurisdiction over six districts and four county-level cities. As of 2014, Qingdao had a population of 9,046,200 with an urban population of 6,188,100. Lying across the Shandong Peninsula and looking out to the Yellow Sea, it borders Yantai to the northeast, Weifang to the west and Rizhao to the southwest.



Qingdao is a major seaport, centre. The world's longest sea Bridge, links the main urban Huangdao district, straddling the is also the site of the Tsingtao brewery in China.



naval base, and industrial bridge, the Jiaozhou Bay area of Qingdao with Jiaozhou Bay sea areas. It Brewery, the second largest



Qingdao has beautiful scenery and pleasant climate. A harmonious picture of mountains, sea and city is painted, in which one can see the winding coastline, islands and buildings whose red-roof are held in the embrace of verdant trees. It has many famous sights, such as May Fourth Square, Olympic Sailing Center, The Eight Passes, Golden Sand Beach, Laoshan Mountain, Shilaoren Beach, Trestle Bridge and so on.

In 2018, Qingdao ranked 31st in the Global Financial Centres Index published by the Z/Yen Group and China Development Institute, the other Chinese cities on the list being Hong Kong, Shanghai, Beijing, Shenzhen, Guangzhou, Tianjin, Chengdu, Hangzhou and Dalian. In 2007, Qingdao was named as one of China's top ten cities by the Chinese Cities Brand Value Report, which was released at the 2007 Beijing Summit of China Cities Forum. In 2009, Qingdao was named China's most livable city by the Chinese Institute of City Competitiveness. In 2018, Qingdao held the Shanghai Cooperation Organization summit.



Profile of Tsinghua University

Tsinghua University was established in 1911, originally under the name “Tsinghua Xuetang”. The school was renamed "Tsinghua School" in 1912. The university section was founded in 1925. The name “National Tsinghua University” was adopted in 1928.

The faculty greatly valued the interaction between Chinese and Western cultures, the sciences and humanities, the ancient and modern. Tsinghua scholars Wang Guowei, Liang Qichao, Chen Yinke and Zhao Yuanren, renowned as the "Four Tutors" in the Institute of Chinese Classics, advocated this belief and had a profound impact on Tsinghua's later development.

Tsinghua University was forced to move to Kunming and join with Peking University and Nankai University to form the Southwest Associated University due to the Resistance War against the Japanese Invasion in 1937. In 1946 The University was moved back to its original location in Beijing after the war.



After the founding of the People's Republic of China, the University was molded into a polytechnic institute focusing on engineering in the nationwide restructuring of universities and colleges undertaken in 1952. In November 1952, Mr. Jiang Nanxiang became

the President of the University. He made significant contributions in leading Tsinghua to become the national center for training engineers and scientists with both professional proficiency and personal integrity.

Since China opened up to the world in 1978, Tsinghua University has developed at a breathtaking pace into a comprehensive research university. At present, the university has 20 schools and 58 departments with faculties in science, engineering, humanities, law, medicine, history, philosophy, economics, management, education and art. The University has now over 48,739 students, including 15,707 undergraduates and 33,032 graduate students. As one of China’s most renowned universities, Tsinghua has become an important institution for fostering talent and scientific research.

The educational philosophy of Tsinghua is to "train students with integrity". Among over 148,000 students who have graduated from Tsinghua since its founding are many outstanding scholars, eminent entrepreneurs and great statesmen remembered and respected by their fellow Chinese citizens.

With the motto of “Self-Discipline and Social Commitment” and the spirit of “Actions Speak Louder than Words”, Tsinghua University is dedicated to the well-being of Chinese society and to world development.

Introduction to Huangdao Coal Power Plant (Qingdao)

Huangdao Coal Power Plant (Located in Huangdao district of Qingdao, west coast of Jiaozhou Bay) is a first-class thermal power plant in China, whose total installation capacity is 2050MW now.

There are three coal-fired thermal power units (225MW and 670MW) in Huangdao Coal Power Plant. The 670MW supercritical coal-fired units adopt the advanced technology of pulverized coal boiler with the tangential combustion DC burners, equipped with a SCR for NO_x removal, a FGD for SO_x removal and an extra Electrostatic Precipitator (ESP) combined with wet cottrell for fine particulate collection. The greatest desalination system of sea water for power plant running in China was practiced here.

Note: if you are interested in this technical tour, please apply and sign your name to the conference staff at the reception desk (Lobby of DoubleTree by Hilton Qingdao Oriental Movie Metropolis) on Sunday or Monday (July 21-22).

The buses for the technical tour will be ready at 13:40 of July 24 (Wed).



Agenda

Agenda

Sunday	09:00 – 23:00	Registration in the Hotel Lobby	First Floor
July 21, 2019	18:00 – 21:00	Reception	Back Garden
Monday	07:30 – 10:00	Registration	First Floor
July 22, 2019	08:00 – 08:20	Welcome and Opening Ceremony	Grand Ballroom
	08:20 – 09:40	Plenary Lecture Series 1-2	Grand Ballroom
	10:00 – 12:00	Plenary Lecture Series 3-5	Grand Ballroom
	12:00 --14:00	Lunch	All Day Dining Restaurant
	14:00 – 17:20	Technical Sessions 1	Room #1-5, Junior Ballroom
	17:20 – 18:20	Poster Sessions	Second Floor
	18:00 – 20:00	Dinner	All Day Dining Restaurant
	20:00 – 22:00	Committee Meeting	Room #1
Tuesday	08:00 – 10:00	Plenary Lecture Series 6-8	Grand Ballroom
July 23, 2019	10:20 – 12:00	Technical Sessions 2	Room #1-5, Grand Ballroom
	12:00 --14:00	Lunch	All Day Dining Restaurant
	14:00 – 17:00	Technical Sessions 3	Room #1-5, Junior Ballroom
	17:00 – 18:00	Poster Sessions	Second Floor
	18:30 – 21:00	Banquet	Haiyue Ballroom of the Hong Kong Liyumen Seafood Hotel
Wednesday	08:00 – 10:00	Plenary Lecture Series 9-11	Grand Ballroom
July 24, 2019	10:20 – 12:20	Technical Sessions 4	Room #1-5, Grand Ballroom
	12:20 – 12:40	Farewell	First Floor
	12:30 – 14:00	Lunch	All Day Dining Restaurant
	14:00 – 17:00	Technical tour to Huangdao Coal Power Plant	Bus at Entrance of DoubleTree by Hilton Qingdao Oriental Movie Metropolis

Schedule of Papers

Monday, July 22, 2019 p23 - 29

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Monday, July 22, 2019

Schedule of Papers -- Monday, July 22, 2019

The 9th International Symposium on Coal Combustion (ISCC-9) DoubleTree by Hilton Qingdao Oriental Movie Metropolis Monday, July 22 2019	
8:00 – 8:20	Welcome and Opening ceremony Grand Ballroom
	Plenary Lecture series Chair: Prof. Guangxi Yue & Prof. Mário Costa Grand Ballroom
8:20 – 9:00	Plenary Lecture 1: Researches on clean coal combustion technology in China Prof. Junfu Lyu
9:00 – 9:40	Plenary Lecture 2: The potential to integrate concentrating solar thermal energy with solid fuel processes Prof. Gus Nathan
9:40 – 10:00	BREAK
	Plenary Lecture series Chair: Prof. Minghou Xu and Prof. Osvalda Senneca Grand Ballroom
10:00 – 10:40	Plenary Lecture 3: Ash tracer method for determining char yield during solid fuels thermochemical processing: History, fundamentals, validity and alternatives Prof. Hongwei Wu
10:40 – 11:20	Plenary Lecture 4: Grand design of coal/biomass conversion into power and chemicals with carbon-neutral/negative nature Prof. Jun-ichiro Hayashi
11:20 – 12:00	Plenary Lecture 5: Status of discrete element method modelling for industrial furnaces Prof. Viktor Scherer
12:00 – 14:00	LUNCH

Schedule of Papers -- Monday, July 22, 2019

Monday, July 22 2019

Room	Junior Ballroom	Room 1#	Room 2#	Room 5#	Room 3#	Room 4#
	Basic Coal Quality & Combustion 1 Chairs: Osvalda Senneca Hai Zhang	Pulverized Coal Combustion 1 Chairs: Reinhold Kneer Xiaolin Wei	Fluidized Bed Combustion 1 Chairs: Georgy Ryabov Leming Cheng	Low Carbon Energy 1 Chairs: Sankar Bhattacharya Junying Zhang	Emission Controls 1 Chairs: Costa Mário Chuanwen Zhao	Design and Operating Experiences 1 Chairs: Richard L. Axelbaum Shaozeng Sun
14:00	1.1 Experiment of blended coals staged combustion in drop tube furnace <i>Jinzhi Cai, Dan Li, Denggao Chen, Zhenshan Li</i> Tsinghua University	2.1 An Experimental Investigation of Heat Transfer Characteristic for Waterwall under Advanced Ultra-supercritical Conditions <i>Xueli Ge, Zhongxiao Zhang, Yufeng Chu, Haojie Fan, Jiancong Dong, Jian Zhang, Xu Wei</i> Shanghai Jiao Tong University	3.1 Development of Oxy-CFBC technology in FEP convergence research center <i>Changwon Yang, Yongdo Kim, Byungryeul Bang, Soohwa Jeong, Jihong Moon, Taeyoung Mun, Sungho Job, Jaegoo Lee, Uendo Lee</i> Korea Institute of Industrial Technology	Keynote Lecture: Looping Cycles for Low Carbon Technologies A. Coppola, O. Senneca, F. Scala, F. Montagnaro, P. Salatino Università degli Studi di Napoli Federico II	5.1 Formation of SO ₃ in Flue Gas under SNCR Conditions <i>Kang Wang, Wenfeng Shen, Yang Zhang, Yu Peng, Hai Zhang, Hairui Yang, Junfu Lyu</i> Tsinghua University	6.1 Modeling the Ash Buildup Layer on Steam Tubes and Effects on Radiation Heat Transfer <i>Terry A. Ring, John Camilo Parra Alvarez and Phillip J. Smith</i> Institute of Clean and Secure Energy University of Utah
14:20	1.2 On the plastic behavior of carbonaceous fuels in Fluidized Beds <i>M. Urciuolo, R. Solimene, S. Krusch, V. Scherer, P. Salatino, R.</i>	2.2 A Laboratory study on the spontaneous combustion tendency of blended coal between anthracite and sub-bituminous pulverized coals	3.2 Sodium transformation simulation with a 2-D CFD model during circulating fluidized bed combustion <i>Jieqiang Ji, Leming Cheng, Li Nie, Liyao Li, Yangjun Wei</i> Zhejiang University		5.2 The zeolite-containing rocks use as sorbents for the absorption of sulfur oxide emissions at energy companies <i>A.G. Batukhtin, M.V. Kobytkin, Yu.O. Rikker, S.G.</i>	6.2 Study on Modeling and Control Strategy for Combustion Optimization of Pulverized coal Boiler <i>Miao Liu, Gengda Li, Xin Wang, Baowei Chen</i> Guodian New Energy

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	<i>Chirona, O. Senneca</i> Istituto di Ricerche sulla Combustione	<i>Thieu Trinh Viet, Dung Le Duc, Linh Nguyen Huu, Takahiro Kozaki, Emi Oono</i> Hanoi University of Science and Technology			<i>Batukhtin</i> Transbaikal State University	Technology Research Institute Co., Ltd
14:40	1.3 Validation of a comprehensive kinetic mechanism for sulfur release during pyrolysis of solid fuels <i>P. Debiagi, C. Yildiz, J. Ströhle, B. Epple, T. Faravelli, C. Hasse</i> TU Darmstadt	2.3 A review of ash slagging mechanisms, slag viscosity measurement methodologies and their applications to low-rank coal and biomass slags <i>Md Tanvir Alam, Baiqian Dai, Xiaojiang Wu, Andrew Hoadley, Lian Zhang</i> Monash University	3.3 Cold-experimental Study about Pressure Resistance of CFB Wind Caps <i>Tong Boheng, Zeng Hongyu, Zhang Qingfeng, Lyu Junfu</i> North China Electric Power Research Institute	4.1 Flame Pattern Analysis for 60 kWth Flames under Conventional Air-Fired and Oxy-Fuel Conditions for Two Different Types of Coal <i>A. Maßmeyer, D. Zabrodiec, J. Hees, T. Kreitzberg, O. Hatzfeld, R. Kneer</i> RWTH Aachen University	5.3 Experimental Research on NOx Emission Characteristics Based on Combined Removal Technology of Multi-Pollutant with Ash Calcium Recycling <i>Ting Li, Naji Wang, Shi Yang</i> Coal Science and Technology Research Institute	6.3 The synergistic performance of heat and electricity was studied from the heating demand side and the supply side <i>Pan Zhang, Weiliang Wang, Junfu Lyu</i> Tsinghua University
15:00	1.4 Study on Characteristics and Influencing Factors of Coal-water Slurry Pyrolysis <i>Fan FENG, Boyang LI, Juan YU, Yao ZHANG, Chen LIN, Zhongxiao ZHANG</i> Shanghai Jiao Tong University	2.4 Influence of mass-flow ratio of secondary and tertiary air on gas-particle flow characteristics of a swirl burner in 29MW pulverized coal industrial boiler <i>Rong Yan, Zhichao Chen, Zhengqi Li</i> Harbin Institute of Technology	3.4 Ignition and combustion of a single coal particle in a fluidized bed in O ₂ /N ₂ and O ₂ /CO ₂ atmospheres <i>Xiehe Yang, Zhining Wang, Yang Zhang, Daoyin Liu, Jiansheng Zhang, Hai Zhang, Junfu Lyu</i> Tsinghua University	4.2 Nitrogen-doped microporous carbon material decorated with metal nanoparticles derived from solid Zn/Co zeolitic imidazolate framework with high selectivity for CO ₂ separation <i>Jun Cheng, Niu Liu, Yali Wang, Xiaoxu Xuan, Xiao Yang, Junhu Zhou</i> Zhejiang University	5.4 Effects of the tertiary air injection port on semi-coke flameless combustion with coal self-preheating technology <i>Wen Liu, Ziqu Ouyang, Yongjie Na, Xiaoyang Cao</i> Chinese Academy of Sciences	6.4 Effect of pine pyrolysis in presence of CaO on simultaneous CO ₂ /NO removal by CaO/pine char at calcium looping conditions <i>Yuqi Qian, Yingjie Li, Wan Zhang</i> Shandong University

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15:20	BREAK					
15:40	<p>Keynote Lecture: Advances in Two-Fluid LES of Two-Phase Combustion L.X. Zhou Tsinghua University</p>	<p>2.5 Early stage sub-micron particle formation during pulverized coal combustion in a two-stage flat flame burner <i>Dishant Khatri, Zhiwei Yang, Adewale Adeosun, Richard Axelbaum</i> Washington University in St. Louis</p>	<p>3.5 Experimental Research of Primary Fragmentation of Wood Biomass Particles in Fast Pyrolysis Process <i>D. S. Litun, G. A. Ryabov</i> All-Russia Thermal Engineering Institute</p>	<p>4.3 Potassium-catalyzed Petroleum Coke for Chemical Looping <i>Wang Lulu, Shen Laihong, Yan Jingchun</i> Southeast University</p>	<p>5.5 Experimental research on the combustion and the NO_x emissions characteristics of the preheated semi-coke <i>Ouyang Ziqu, Liu Wen, Liu Jingzhang, Zhu Jianguo, Li Shiyuan</i> Chinese Academy of Sciences</p>	<p>6.5 Effect of Recirculated Flue Gas on 660 MW Double Rheated Boiler <i>H. Xiao, Y.X. Wu, L.L. Feng, C.W.Meng, H.Zhang, M.Zhang, Z Chai</i> Tsinghua University</p>
16:00		<p>2.6 Effect of Na and Fe on Soot Formation during Pulverized Coal Combustion Using a Two-stage Hencken Burner <i>Peng Ma, Qi Gao, Shuiqing Li</i> Tsinghua University</p>	<p>3.6 Emission characteristic of NO_x in CFB boiler at low load <i>Lujian Chen, Xin Tao, Shouyu Zhang, Hairui Yang, Junfu Lyu</i> University of Shanghai for Science and Technology</p>	<p>4.4 CO₂ adsorption performance of Na/K-impregnated MgO <i>Jie Zou, Ning Ding, Cong Luo</i> Huazhong University of Science and Technology</p>	<p>5.6 Removal of NO and SO₂ using TiO₂ supported iron catalysts with vaporized H₂O₂ in a catalytic oxidation process <i>Zijian Song, Ben Wang, Jie Yu, Chuan Ma, Lushi Sun</i> Huazhong University of Science and Technology</p>	<p>6.6 Experimental Study of Temperature Distribution in 0.3MWth Coal-fired Combustion and Hydrodynamic Coupling Test Facility Under Advanced Ultra-Supercritical Condition <i>Jian Zhang, Xueli Ge, Zhongxiao Zhang, Haojie Fan, Jiancong Dong, Wei Xu</i> Shanghai Jiao Tong University</p>
16:20	<p>1.5 Particle History from Massively Parallel Large Eddy Simulations of</p>	<p>2.7 2D temperature comparison by CT-TDLAS measurement and CFD</p>	<p>3.7 Characterization of the sulfation reactivity of limestones with different</p>	<p>4.5 Allam cycle coal - a novel clean coal suercritical CO₂ power cycle</p>	<p>5.7 Formation of N₂O from NO reduction by NH₃ over MnOx/TiO₂</p>	<p>6.7 Large Eddy Simulation of a 660 MW Ultra-Supercritical Boiler</p>

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	Pulverised Coal Combustion in a Large-Scale Laboratory Furnace <i>Miriam Rabaçal, Mário Costa, Martin Rieth, Andreas M Kemp</i> University of Lisbon	simulation <i>Zhenzhen Wang, Wangzheng Zhou, Kazuma Tsujimoto, Takahiro Kamimoto, Yoshihiro Deguchi, Junjie Yan</i> Xi'an Jiaotong University	particle size in a large-capacity TGA <i>Yiran Li, Runxia Cai, Man Zhang, Hairui Yang, Junfu Lyu</i> Tsinghua University	<i>Xijia Lvu</i> 8 Rivers Capital, LLC	<i>D.H. Wang, Q. Yao, S.E. Hui, Y.Q. Niu</i> Xi'an Jiaotong University	under Variable Loads <i>Haoshu Shen, Yuxin Wu, Minmin Zhou, Hai Zhang, Guangxi Yue, Junfu Lyu</i> Tsinghua University
16:40	1.6 In-situ decoupling mechanism of H ₂ O on the whole process of raw coal-H ₂ O gasification reaction for O ₂ /H ₂ O oxy-fuel combustion <i>Dongdong Feng, Dawei Guo, Yijun Zhao, Yu Zhang, Heping Tan, Shaozeng Sun</i> Harbin Institute of Technology	2.8 The sulfur migration during co-pyrolysis of high-sulfur coking coal and high-volatile bituminous coal <i>Jinling Zhang, Dapeng Bi, Jiansheng Zhang</i> Tsinghua University	3.8 Effect of Atmosphere on Lignite Char Structure and Gasification Reactivity in a Fluidized Bed Reactor <i>Shuai Tong, Lin Li, Lunbo Duan, Changsui Zhao, Zhipeng Shi</i> Southeast University	4.6 A Characteristic Chemical Time Scale and Combustion Regime Analysis of Natural Gas MILD Combustion <i>Tingyao Zhang, Yuegui Zhou</i> Shanghai Jiao Tong University	5.8 Effects of high temperature on NH ₃ /NO reactions in the absence of oxygen <i>Degui Bi, Zhixiang Zhu, Juan Yu, Zhongxiao Zhang, Chen Lin</i> Shanghai Jiao Tong University	6.8 The Process of Self-heating Sludge Incineration based on Granular Heat Carrier <i>KONG Hao, MIAO Miao, YANG Hairui, ZHANG Xuyi, ZHANG Man</i> Tsinghua University
17:00	1.7 Hg ⁰ Catalytic Oxidation by HBr over Ce-modified Regenerated SCR Catalyst <i>Duanle LI, Qiyu WENG, Yadi QIN, Li ZHONG, Zhiyong YU, Pengbo HU, Yuqun ZHUO</i>	2.9 Investigation on NO _x Formation Characteristics During Semi-coke Airstaged Combustion <i>Hui Li, Shi Yang, Jianming Zhou</i> China Coal Research Institute Company of Energy Conservation	3.9 Ash Deposition and Heat Transfer Deterioration in the Convection Heating Region of CFB Boiler Burning High Na and Cl Coal <i>Jiaye Zhang, Daoyang Ma, Jingbin Zi, Yongbing Wang, Peng Li, Xuebin Wang</i> Xi'an Jiaotong University	4.7 Hierarchical porous carbon based on biomass in-built nano-CaCO ₃ template for elemental mercury removal <i>Qiqi Shi, Boxiong Shen, Xiao Zhang</i> Hebei University of Technology	5.9 Evaluation of New Kind Wet FGD Effluent Zero-Emission Technology by Waste Heat from Flue Gas <i>Yao, Xuan; Zhang, Man; Hao, Kong; Yang, Hairuia; Lyu, Junfu; Chen, Ou; Chu, Yue</i>	6.9 Industrial-scale investigations on the effects of the tertiary air declination angle on the coal combustion and steam temperature characteristics in a 350-MW supercritical down-fired boiler at

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	Tsinghua University	Corporation Ltd			Tsinghua University	medium and high load <i>Xiaoguang Li, Lingyan Zeng, Hongye Liu, Yao Li, Yifu Li, Yunlong Zhao, Bo Jiao, et al.</i> Harbin Institute of Technology
17:20	Poster Presentation					

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**The 9th International Symposium on Coal Combustion (ISCC-9)
DoubleTree by Hilton Qingdao Oriental Movie Metropolis
Tuesday, July 23 2019**

	Plenary Lecture series, Chair: Prof. Changsui Zhao and Prof. Sankar Bhattacharya Grand Ballroom
08:00 – 08:40	Plenary Lecture 6: Formation and control of fine particulates and trace elements from coal and biomass combustion Prof. Minghou Xu
08:40 – 09:20	Plenary Lecture 7: Characterization of pressurized oxy-coal combustion at 100 kWt and 15 bar Prof. Richard L. Axelbaum
09:20 – 10:00	Plenary Lecture 8: Flexible operation of high efficiency coal power plants to ensure grid stability when intermittent renewables are included Dr. Andrew Minchener
10:00 – 10:20	Break

Room	Room 5#	Room 1#	Room 2#	Grand Ballroom	Room 3#	Room 4#
	Basic Coal Quality & Combustion 2 Chairs: Dunxi Yu	Pulverized Coal Combustion 2 Chairs: Yoshihiro Deguchi	Fluidized Bed Combustion 2 Chairs: Jing Liu	Low Carbon Energy 2 Chairs: Haibo Zhao	Emission Controls 2 Chairs: Terry Ring	Design and Operating Experiences 2 Chairs: Paulo Debiagi

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10:20	<p>1.8 Characteristics of Iron and Sulphur in High-Ash Pakistani Lignite and their Influence on Long-Term T23 Tube Corrosion under Supercritical Coal-fired Boiler Conditions <i>Baiqian Dai, Xiaojiang Wu, Jianwen Zhang, Yoshihiko Ninomiy, Dunxi Yu, Lian Zhang</i> Monash University</p>	<p>2.10 Measurement of Ash Film Fraction from Cenospheres Properties during Pulverized Coal Combustion <i>Siqi Liu, Yanqing Niu, Liping Wen, Yang Liang, Bokang Yan, Denghui Wang, Shi'en Hui</i> Xi'an Jiaotong University</p>	<p>3.10 Experimental Study on Agglomeration Characteristics of CFB Combustion of Furfural Residue <i>Lu Cheng, Yangxin Zhang, Yan Jin, Hairui Yang, Man Zhang</i> Taiyuan University of Technology</p>	<p>Keynote Lecture: Chemical Looping – beyond CO₂ capture to energy storage and chemicals production Sankar Bhattacharya Monash University</p>	<p>5.10 Experimental Study on the Combustion and NOx Emission Characteristics of Shenmu Semi-coke in a Circulating Fluidized Bed Boiler with Post-combustion <i>Yuan Xiao, Guoliang Song, Shaobo Yang, Zhao Yang, Qinggang Lyu</i> Chinese Academy of Sciences</p>	<p>6.10 Investigation of air-blown two-stage entrained-flow gasification of mechanoactivated coal <i>N.A. Abaimov, E.B. Butakov, A.P. Burdukov, P.V. Osipov, A.F. Ryzhkov</i> Ural Federal University</p>
10:40	<p>1.9 A study of the oxy-fuel combustion of Zhundong coal char using ReaxFF MD simulation <i>Dikun Hong, Zheng Cao, Xin Guo</i> Huazhong University of Science and Technology</p>	<p>2.11 Experimental Investigation of Methane Assisted Pulverized Coal Flames using an Optical Accessible Combustion Chamber <i>C. Axt, D. Zabrodiec, S. Pielsticker, T. Kreitzberg, O. Hatzfeld, R. Kneer</i> RWTH Aachen University</p>	<p>3.11 Ignition Characteristics of Coal/Air Jets from Rectangular Nozzles <i>Lilin Hu, Pengyuan Liu, Yang Zhang*, Lele Feng, Yuxin Wu, Junfu Lyu, Hai Zhang</i> Tsinghua University</p>		<p>5.11 Study on Kinetic Model of NOx Reduction Overall Reaction of Fluidized-bed Flue Gas <i>Yao ZHANG, Chen LIN, Juan YU, Jindong JIANG, Fan FENG, Zhongxiao ZHANG</i> Shanghai Jiao Tong University</p>	<p>6.11 Numerical Simulation of Pulverized Coal Furnace with High-Speed Air Jet <i>Wenzhao Xing, Shi Yang, Xiaolei Cheng, Xin Zhang</i> China Coal Research Institute Company of Energy Conservation</p>
11:00	<p>1.10 Effect of K₂CO₃ addition on CO₂ gasification characteristics and ash sintering behaviour of a Chinese lignite at different temperatures and</p>	<p>2.12 Numerical optimization of the influence of multiple deep air-staged combustion on the NOx emission in an opposed firing utility boiler using lean coal <i>Yongqiang Wang, Yuegui</i></p>	<p>3.12 Occurrence Mode of Iron and Its Migration in Bed Material of a Coal-fired Circulating Fluidized Bed Boiler <i>Jiayu Lyu, Yang Zhang, Lilin Hu, Yu Zhang,</i></p>		<p>4.8 The intrinsic reactivity of coal char conversion compared 1 under conditions of O₂/CO₂, O₂/H₂O and air atmospheres <i>Yang Liu, Peifang Fu, Kang Bie, Yusen Gong</i></p>	<p>5.12 Study of the concentration of mercury in coal used in combustion, in an area of Boyacá, Colombia, South America <i>Sonia Guerra L, Manuel Romero, Daniel Ballen</i></p>

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	<p>pressures as examined using a High-Pressure Thermogravimetric Analyser</p> <p><i>Jianbo Li, Zhezi Zhang, Jian Hao, Jiguang Zhang, Mingming Zhu, and Dongke Zhang</i> Chongqing University</p>	<p><i>Zhou</i> Shanghai Jiao Tong University</p>	<p><i>Tianxing Song, Suxia Ma, Hai Zhang</i> Taiyuan University of Technology</p>	<p>Huazhong University of Science and Technology</p>	<p><i>Servicio Geológico Colombiano</i></p>	<p>MW FW down-fired boiler with “Vent-to OFA technology” and “Fuel Preheat Nozzle”</p> <p><i>He Du, Lingyan Zeng, Hui Han, Wenjie Liu, Zhichao Chen, Zhengqi Li</i> Harbin Institute of Technology</p>
11:20	<p>1.11 Development of fast-heating macro-TGA for biomass pyrolysis</p> <p><i>Zhenshan Li, Zehang Zha, Sanjun Wu, Ye Li, Denggao Chen, Lei Liu</i> Tsinghua University</p>	<p>2.13 Distribution of Temperature and Characteristics of Soot Volume Fraction in MILD-OCC Flame</p> <p><i>Jingwen Lu, Shuwei Zhang, Longhui Tan, Jianyi Lu</i> North China Electric Power University</p>	<p>3.13 A Method to Measure the Solid Circulation Rate in CFB Boilers</p> <p><i>Yangxin Zhang, Lu Cheng, Yang Zhang, Baoguo Fan, Hai Zhang, Junfu Lyu</i> Tsinghua University</p>	<p>4.9 Thermodynamic Study on the Utility Oxy-fuel Boiler with Different Oxygen Volume Fractions</p> <p><i>Kai Li, Enlu Wang, Deli Li, Lifan Wang, Naveed Husnain, Qi Wang</i> Shanghai Jiao Tong University</p>	<p>5.13 Study on mercury emission and mercury adsorption characteristics of fly ash in pc and CFB boilers</p> <p><i>Li Jia, Bao-guo Fan, Xian-rong Zheng, Xiao-lei Qiao, Yu-xing Yao, Rui Zhao, Jin-rong Guo, Yan Jin</i> Taiyuan University of Technology</p>	<p>6.13 Study on the Stability of High Pressure Pneumatic Transport of the Mixture of Pulverized Coal and Extraction Residue from Direct Coal Liquefaction Residue</p> <p><i>B. Z. Peng, X. H. Fang, H. Q. An, Z. Liu, Y. Li, Z. Y. Feng</i> National Institute of Clean and Low Carbon Energy</p>
11:40	<p>1.12 Comparability and validity range of pyrolysis kinetics from Chinese coals obtained with different experimental setups</p> <p><i>Stefan Pielsticker, Osvalda Senneca, Thobias</i></p>	<p>2.14 Experimental study on co-combustion characteristics of semi-coke and coal under high-temperature and deep-air-staging conditions</p> <p><i>Pengqian Wang, Chang'an Wang, Chaowei Wang,</i></p>	<p>3.14 Effect of Exit Configuration on the Two-Phase Fluid Dynamics in a 2-D Circulating Fluidized Bed</p> <p><i>Jieqiang Ji, Leming Cheng, Yanquan Liu, Yangjun Wei, Li Nie</i></p>	<p>4.10 Effect of sulfation on N₂O and NO emission during oxy-fuel circulating fluidized bed combustion</p> <p><i>Dianbin Liu, Wei Li, Shiyuan Li, Runjuan Kong</i> Institute of Engineering Thermophysics, Chinese</p>	<p>5.14 Preparation of fly ash adsorbents utilizing non-thermal plasma to add S active sites for Hg⁰ removal from flue gas</p> <p><i>Ruize Sun, Hailu Zhu, Mengting Shi, Guangqian Luo, Yang Xu, Xian Li,</i></p>	<p>6.14 Experimental investigation of coal gasification with plasma for the reburning to reduce NO_x in a pulverized coal fired furnace</p> <p><i>Z.R.Gong, P.Zou, Y.L.Zheng, L.B.Song,</i></p>

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	<i>Kreitzberg, Francesca Cerciello, Oliver Hatzfeld, Reinhold Kneer RWTH Aachen University</i>	<i>Maobo Yuan, Zichen Tao, Jinping Zhang, Chengchang Liu, Defu Che Xi'an Jiaotong University</i>	Taiyuan University of Technology	Academy of Sciences	<i>Hong Yao Huazhong University of Science and Technology</i>	<i>J.J. Yang, J.F. Lyu Tsinghua University</i>
12:00	Lunch					
Room	Room 5#	Room 1#	Junior Ballroom	Room 2#	Room 3#	Room 4#
	Basic Coal Quality & Combustion 3 Chairs: Lian Zhang Hong Yao	Pulverized Coal Combustion 3 Chairs: Thomas H. Fletcher Xuebin Wang	Fluidized Coal Combustion 3 Chairs: Viktor Scherer Hairui Yang	Low Carbon Energy 3 Chairs: Antonio Coppola Cuiping Wang	Emission Controls 3 Chairs: Anna Massmeyer Jun Cheng	Design and Operating Experiences 3 Chairs: Changfu You Zhengqi Li
14:00	1.13 Experimental Investigation on Sodium Migration and Mineral Transformation in Ash Deposit during Gasification of Zhundong Coal using a Drop Tube Furnace <i>Chengchang Liu, Chang'an Wang, Chaowei Wang, Yongbo Du, Guantao Tang, Guangyu Li, Defu Che Xi'an Jiaotong University</i>	2.15 Numerical investigation of fly ash deposition onto tube bundles inside coal-fired boilers <i>Qian Huang, Yipeng Li, Shuiqing Li Tsinghua University</i>	Keynote Lecture: A Characteristic Particle Tracked Modeling for CFB Boiler Coal Combustion and Ultra-low NOx Emission <i>Mingchuan Zhang Shanghai Jiao Tong University</i>	4.11 Effect of O ₂ /CO ₂ atmospheres on coal fragmentation <i>P. Bareschino, M. Urciuolo, V. Scherer, R. Chirone, O. Senneca Università degli Studi del Sannio</i>	5.15 Characteristics of Hg ⁰ Re-emission Caused by Sulfite in Wet Flue Gas Desulfurization System <i>Jialing Xu, Jingjing Bao, Jiguo Tang, Min Du, Zhengyu Mo, Licheng Sun Sichuan University</i>	6.15 Research on Dense Phase Pneumatic Conveying of the Mixture of Pulverized Coal and Extract Residue of Coal Liquefaction Residue at High Pressure <i>X. H. Fang, Z. Liu, H. Q. An, Z. Y. Feng, B. Z. Peng, Y. Li, Y. G. Wang China University of Mining & Technology</i>

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14:20	<p>1.14 Ash Deposition and slagging behavior of Xinjiang High-alkali coal in a 20MWth Cyclone Combustion Test Facility <i>Xiaojiang Wu, Zhongxiao Zhang, Mingqiang Li, Xiang Zhang, Kai Yan, Yuehua Li, Nan Chen, Yanchi Jiang, Xinglei Hu</i> Shanghai Jiaotong University</p>	<p>2.16 Application of Computed Tomography - Tunable Diode Laser Absorption Spectroscopy(CT-TDLAS) to Coal Combustion Analysis <i>Yoshihiro Deguchi, Takahiro Kamimoto, Zhenzhen Wang, KazukiTainaka, Kenji Tanno</i> Tokushima University</p>		<p>4.12 Study on Multi-cycle Reaction Performance of Fe/Al Compound Oxygen Carriers in Chemical-Looping Pyrolysis of Coal Tar <i>Jinyu Wang, Jian Gong, Weiwei Cui, Fengyin Wang, Yanhui Li, Cuiqing Wang</i> Qingdao University</p>	<p>5.16 Adsorption characteristics of floating beads on the fine particulate matter during Zhundong coal combustion <i>Jing Zhao, Yufeng Zhang, Xiaolin Wei, Teng Li</i> Chinese Academy of Sciences</p>	<p>6.16 Effect of Support Material on the CO₂ Capture Performance of K₂CO₃-based Pellets <i>Chuanwen Zhao, Peng Wang, Jian Sun, Yafei Guo, Ping Lu</i> Nanjing Normal University</p>
14:40	<p>1.15 Experimental and Numerical Studies of the Ignition and Combustion of Mechanically Activated Pulverized Coal <i>E.B Butakov, A.P. Burdukov, S.V. Alekseenko</i> Kutateladze Institute of Thermophysics SB RAS</p>	<p>2.17 Effect of particle distance on combustion behaviors through 1-D model with Neumann boundary condition <i>L. Feng, Y. Wu, K. Xu, H. Zhang, Y. Zhang</i> Tsinghua University</p>	<p>3.15 Safety evaluation of the immersed tube in an external heat exchanger of a circulating fluidized bed boiler in case of electricity supply failure <i>Ling Jiang, Yuge Yao, Boyu Deng, Hairui Yang, Lyu Junfu, Man Zhang</i> Tsinghua University</p>	<p>4.13 Evaluation of NO_x emissions and conversion in Chemical Looping Combustion <i>J.C. Ma, C.Q. Wang, X. Tian, Z.H. Liu, H.B. Zhao</i> Huazhong University of Science and Technology</p>	<p>5.17 The Effect of Oxygen-coal Equivalent Ratio on the Rapid Preparation of Powdered activated coke in Low Oxygen Atmosphere <i>Binxuan Zhou, Yuan Zhao, Cheng Li, Tao Wang, Ping Zhou, Zhanlong Song, Chunyuan Ma</i> Shandong University</p>	<p>6.17 Gas/Solid Flow Characteristics and Combustion Performance of an Improved 300-MW Down-Fired Utility Boiler <i>Qingxiang Wang, Zhichao Chen, Lingyan Zeng, Zhengqi Li</i> Harbin Institute of Technology</p>
15:00	<p>1.16 Effect of Oil Shale Semi-coke Addition on Ash Deposit Mineralogy and Morphology on Probes in the Flue Path of a Circulating Fluidized Bed</p>	<p>2.18 Low Temperature Vortex Fuel Combustion: Experience and Possibilities <i>K.A. Grigoryev, V.E. Skuditskii</i> I.I. Polzunov Scientific and</p>	<p>3.16 Combustion of coal and oil processing waste and biomass in the composition of water-containing fuel mixtures</p>	<p>4.14 Comprehensive analyses on activation agents of amines and nanoparticles for TETA-based CO₂ capture absorbents</p>	<p>5.18 Effects of Acid Gases on Elemental Mercury Removal over Magnetic Biochar in Oxyfuel Combustion Flue Gas</p>	<p>6.18 Experimental Study of the Flat-Flame Pulverized Coal Gasification Technology <i>H. Q. An, Z. Liu, X. H. Fang, Z. Y. Feng, B. Z.</i></p>

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	Burning Zhundong lignite <i>Zhuo Liu, Jianbo Li, Mingming Zhu, Xiaofeng Lu, Zhezi Zhang, and Dongke Zhang</i> Chongqing University	Development Association on Research and Design of Power Equipment (NPO CKTI, JSC)	<i>P.A. Strizhak, D.O. Glushkov, G.S. Nyashina, K.Yu. Vershinina</i> National Research Tomsk Polytechnic University	<i>JIANG Yanchi, ZHANG Zhongxiao, YU Juan, ZHAO Ziqi, Fan Junjie, LI Boyang, JIA Mengchuan, MU Aiwei</i> Shanghai Jiao Tong University	<i>Yang, Yongchun Zhao, Junying Zhang and Chuguang Zheng</i> Huazhong University of Science and Technology	<i>Peng, Y. Li, W. H. Li</i> National Institute of Clean and Low Carbon Energy
15:20	Break					
15:40	1.17 Effect of refractory lining thickness on slag layer behavior in cyclone barrel <i>Chunli Tang, Yueyi Hu, Tao Zhu, Limin Wang, Yanhua Liu, Defu Che</i> Xi'an Jiaotong University	2.19 Formation mechanisms of PM from Combustion of Lignite with High Contents of Na, Mg, Ca, S, Fe: the Effect of Furnace Temperature <i>Renhui Ruan, Houzhang Tan, Yan Li, Zhongfa Hu, Xuebin Wang, Zijun Ren</i> Xi'an Jiaotong University	Keynote Lecture: <i>The Change in Bed Materials Size Distribution and its Effect on CFB Boiler Operation</i> <i>G. A. Ryabov, O. M. Folomeev</i> <i>All-Russia Thermal Engineering Institute</i>	4.15 CaO/Ca(OH) ₂ thermochemical heat storage performance of synthetic calcium-based material from CO ₂ capture cycles <i>Zhiguo Bian, Yingjie Li, Chaoying Sun, Jianli Zhao</i> Shandong University	5.19 Self-sustained combustion of CO with transient changes over powdered CuCe _{0.75} Zr _{0.25} O _δ for honeycomb ceramics catalyst <i>Running Kang, Xiaolin Wei, Feng Bin, Junyao He, Pandong Ma, Qinglan, Hao, Baojuan Dou</i> Chinese Academy of Sciences	6.19 Study of Coal Gasification in a Pilot Plant with a Flow-Type Reactor <i>V.E. Mikhaylov, V.I. Breus, A.E. Leykam, N.S. Shestakov, K.A. Grigoryev, A.I. Koryabkin</i> Polzunov Scientific and Development Association on Research and Design of Power Equipment
16:00	1.18 Experimental Study on the Influence of Slagging and Fouling for Wall Temperature Distribution <i>Deli Li, Enlu Wang, Jinda Mao, Wei Wu, Kai Li, and Qi Wang</i> Shanghai Jiao Tong	2.20 Laboratory and industrial studies of gas coal ignition and combustion using high-voltage AC plasmatron <i>E.B Butakov, A.P. Burdukov</i> Kutateladze Institute of Thermophysics SB RAS		4.16 Hierarchical porous carbon derived from wood tar using crab as the template: Performance on supercapacitor <i>Jing wu, Mingwei Xia, Xiong Zhang, Yingquan Chen, Fei Sun, Xianhua Wang, Haiping Yang, Hanping Chen</i>	5.20 Partitioning behavior of arsenic in an ultra-supercritical coal-fired power plant equipped with APCDs for ultra-low emission <i>Zhipeng Shi, Zhijun Huang, Wei Hua, Lunbo Duan</i> Southeast University	6.20 Comparative Study of Properties of Xinjiang Coals and International Low-rank Coals <i>F. Liu, D. Yu, X. Yu, J. Wu, G. Yu, M. Xu</i> Huazhong University of Science and Technology

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	University			Huazhong University of Science and Technology		
16:20	1.19 Effect of temperature on bituminous char structure evolution during pyrolysis and combustion <i>Yandi Zhang, Yinhe LIU, Xiaoli Duan, Yao Zhou, Xiaoqian Liu, Shijin Xu</i> Xi'an Jiaotong University	2.21 Research on the recirculating and combustion characteristics in a reverse-jet swirl pulverized-coal burner <i>Minhang Song, Fang Niu, Shuiqing Li</i> Tsinghua University	3.17 The Technology and Application of a New Type of Coal Water Slurry-fired CFB with High Efficiency and Clean Combustion <i>Yuping Hao, Ruiguo Li, Yujiao Chen</i> Qingdao Clear Environmental Group co. LTD	4.17 Experimental study on carbon capture performance of polyimide hollow fiber membrane in post-combustion process <i>Liu Yang, Yanchi Jiang, Juan Yu, Ziqi Zhao, Mengchuan Jia, Aiwei Mu</i> Shanghai Jiao Tong University	5.21 A New Scheme for Synergetic Removal of NH ₃ and SO ₃ and Particulate Matter in the Flue Gas of Coal-fired Boiler <i>Limin Wang, Dechao Li, Yan Yu, Chunli Tang, Lei Deng, Defu Che</i> Xi'an Jiaotong University	6.21 Research on the preparation of bimetal material PCN-6(M) by steam-assisted method and their CH ₄ adsorption performance <i>Yuan Ning, Bi Dapeng, Zhang Jiansheng</i> Tsinghua University
16:40	1.20 DFT study of the effect of Ca on NO heterogeneous reduction by char <i>ZHANG Xiu-xia, XIE.Miao</i> China University of Petroleum	2.22 Effects of pyrolyzed semi-char blend ratio on coal combustion and pollution emission on a 0.35 MW pulverized coal-fired furnace <i>Yonghong YAN, Liutao SUN, Zhengkang PENG, Hongliang QI, Li LIU, Rui SUN</i> Harbin Institute of Technology	3.18 Overview and Applications of Coal Fluidized Bed Gasification in China <i>Dapeng Bi, Zhenzhong Hu, Jiansheng Zhang</i> Tsinghua University	4.18 Preparation of Nitrogen-doped Porous Carbon Material Based on Oil Sludge and Its Adsorption Performance of CO ₂ <i>Meng Fanzhi, Gong Zhiqiang, Wang Zhenbo, Wang Zhentong, Fang Peiwen</i> China University of Petroleum (East China)	5.22 The release and conversion equilibrium of K during the wheat straw pyrolysis <i>Yufeng Zhang, Xingyun Xie, Jing Zhao, Xiaolin Wei</i> Institute of Mechanics, Chinese Academy of Sciences	6.22 Distribution and Speciation of Mercury in Chemical Looping Combustion of in-situ pyrolysis and char gasification products <i>J.C. Ma, X. Tian, G.P. Chen, C.Q. Wang, H.B. Zhao, Y.C. Zhao</i> Huazhong University of Science and Technology
17:00	Poster Presentation					
18:30	Banquet (Haiyue Ballroom of the Hong Kong Liyumen Seafood Hotel)					

Wednesday, July 24, 2019

Schedule of Papers -- Wednesday, July 24, 2019

<p align="center">The 9th International Symposium on Coal Combustion DoubleTree by Hilton Qingdao Oriental Movie Metropolis Wednesday, July 24 2019</p>	
	<p>Plenary Lecture series Chair: Prof. Mingchuan Zhang and Prof. Reinhold Kneer Grand Ballroom</p>
8:00 – 8:40	<p>Plenary Lecture 9: China's Clean and Efficient Coal Strategy and Practices</p> <p align="center">Dr. Pisi Lu</p>
8:40 – 9:20	<p>Plenary Lecture 10: Advances in Modeling Coal Pyrolysis, Char Combustion, and Soot Formation from Coal Tar</p> <p align="center">Prof. Thomas H. Fletcher</p>
9:20 – 10:00	<p>Plenary Lecture 11: Towards predictive CFD simulations of coal combustion - using Machine Learning for efficient representation of solid fuel kinetics</p> <p align="center">Prof. Christian Hasse</p>
10:00 – 10:20	<p>Break</p>

Room	Room 5#	Room 1#	Room 4#	Room 2#	Room 3#	Grand Ballroom
	<p>Basic Coal Quality & Combustion 4</p> <p>Chairs: Xin Guo</p>	<p>Pulverized Coal Combustion 4</p> <p>Chairs: Yinhe Liu</p>	<p>Basic Coal Quality & Combustion 5</p> <p>Chairs: Yijun Zhao</p>	<p>Low Carbon Energy 4</p> <p>Chairs: Zhenshan Li</p>	<p>Emission Controls 4</p> <p>Chairs: Qiang Song</p>	<p>Keynote & NSF-NSFC/ DFG-NSFC Panel</p> <p>Chairs: Christian Hasse</p>

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10:20	<p>1.21 Precipitation Characteristics of Alkali/Alkaline Earth Metal in High Alkali Coal <i>SHI Hang, WU Yuxin, LYU Junfu, ZHANG Man, ZHANG Hai</i> Tsinghua University</p>	<p>2.23 Numerical Simulation of the Effect of Grading size on Coal Water Slurry Gasification <i>Zhenzhong Hu, Dapeng Bi, Yang Zhang, Jiansheng Zhang</i> Tsinghua University</p>	<p>1.27 Investigation of Arsenates Particles Capture from Coal-fired Power Plant Flue Gas by Electrostatic Precipitator <i>Hongyu Gong, Yongda Huang, Hongyun Hu, Shuai Li, Guangqian Luo, Hong Yao</i> Huazhong University of Science and Technology</p>	<p>4.19 Microstructure evolution of the calcium-based sorbent during the self-activation process in environment <i>Rongyue Sun, Yingjie Li, Jiangming Ye</i> Nanjing Institute of Technology</p>	<p>5.23 The mechanisms and applications of NO_x reduction by low-NO_x burner coupling deep air-staging technology in pulverized coal <i>CHENG Xiaolei, WANG Naij, ZHANG Xin, WANG Yongying, CHEN Long</i> China Coal Research Institute Company of Energy Conservation</p>	<p>Keynote Lecture: <i>Insights on Coal Combustion from High-Fidelity Simulations</i> <i>Hang Zhou, Joshua McConnell, Terry A. Ring, James C. Sutherland</i> <i>The University of Utah</i></p>
10:40	<p>1.22 Study on mineral phase transformation and ash melting mechanism of Zhundong coal and blended coal <i>Yang Liu, Shi Tang, Peifang Fu, Kang Bie, Yusen Gong</i> Huazhong University of Science and Technology</p>	<p>2.24 Increasing the S active sites of activated carbon with non-thermal plasma for elemental mercury removal <i>Mengting Shi, Yang Xu, Hailu Zhu, Renjie Zou, Guangqian Luo, Xian Li, Hong Yao</i> Huazhong University of Science and Technology</p>	<p>1.28 The Role of CaO/Fe₂O₃ Ratio on Coal Ash Viscosity Temperature Properties <i>Ping Yuan, Dapeng Bi, Jiansheng Zhang</i> Tsinghua University</p>	<p>4.20 Novel low-cost Li₄SiO₄-based adsorbent with naturally occurring wollastonite as Si-source for cyclic CO₂ capture <i>Yuandong Yang, Wenqiang Liu, Yingchao Hu, Jian Sun, Minghou Xu</i> Huazhong University of Science and Technology</p>	<p>5.24 Selective catalytic reduction of NO_x with NH₃ using coal ash catalyst <i>Shagufta Fareed, Enlu Wang, Naveed Husnain, Kai Li, Deli Li</i> Shanghai Jiao Tong University</p>	
11:00	<p>1.23 Effect of iron content and atmosphere on melt structure and viscosity <i>Haonan Wang, Weiwei Xuan, Dehong Xia</i> University of Science and Technology Beijing</p>	<p>2.25 Experimental Study on Coal Water Slurry Pyrolysis in Flue Gas Recirculation Transport Bed <i>Xinwei Guo, Hao Bai, Zhongxiao Zhang, Jian Zhang, Degui Bi, Zhixiang Zhu</i></p>	<p>1.29 Experimental study on removal of low concentration coal tar in coal gas Mg-Ca composite catalyst <i>Yan Hao, Gong Mingxin, Gong Jian, Chen Qiang, Li Yanhui, Cui Weiwei, Cong Xiaochun, Wang Cuiping</i></p>	<p>4.21 Investigation the Transformation Behaviors of Fe-containing Mineral Matters in Coal during O₂/CO₂ with H₂O-containing Combustion Atmosphere <i>Fang Huang, Liqi Zhang,</i></p>	<p>5.25 Effects of different precipitants on the de-NO performance of the Fe₂O₃ catalyst prepared by co-precipitation method <i>Naveed Husnain, Enlu Wang, Shagufta Fareed, Kai Li, Deli Li, Qi Wang</i></p>	

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		University of Shanghai for Science and Technology	Qingdao University	Shanzhi Xin, Tie Mi Jiangnan University	Shanghai Jiao Tong University	NSF-NSFC/DFG-NSFC Panel Future Science and Technologies of Clean Coal Utilization Chaired by: Yuxin Wu Panel Discussion follows Keynote Panelists: Richard L. Axelbaum Christian Hasse Reinhold Kneer Shuiqing Li Viktor Scherer James Sutherland Minghou Xu Changfu You
11:20	1.24 Roles of Water-soluble Inorganics in Modifying the Properties of Ash from Zhundong Coal Combustion <i>G. Yu, X. Zeng, D. Yu, J. Wang, F. Liu, Z. Wang, M. Xu</i> Huahzong University of Science and Technology	2.26 Studies on Effects of Swirl Burner Arrangement on the Operating Performances of 116MW Pulverized Coal Industrial Boiler <i>Pengtao Wang, Fang Niu, Nan Jia, Pengzhong Liu, Xuewen Wang, Naiji Wang</i> China Coal Research Institute Company of Energy Conservation	1.30 An Experimental Study on Ignition of Single Coal Particles at Low Oxygen Concentrations <i>Wantao Yang, Yang Zhang, Lilin Hu, Junfu Lyu, Hai Zhang</i> Tsinghua University	4.22 Experimental Study on Slagging and Fouling Behaviors during Oxy-fuel Combustion of Zhundong Coal Using a Drop Tube Furnace <i>Lei Zhao, Chang'an Wang, Yueyi Hu, Ruijin Sun, Guantao Tang, Jin Guo, Zhiming Jiang, Yongbo Du, Defu Che</i> Xi'an Jiaotong University	5.26 A population balance model of fine particle removal inside electrostatic precipitators <i>Lu Duan, Qian Huang, Shuiqing Li</i> Tsinghua University	
11:40	1.25 Soot Formation in High-Temperature Pyrolysis of Various Coals <i>Shengjie Bai, Yongbing Wang, Gaofeng Dai, Peng Li, Xuebin Wang</i> Xi'an Jiaotong University	2.27 Numerical Study on Combustion and NOx Emission Characteristics of Co-firing Semi-coke and Coal in a Tangentially-Fired Utility Boiler <i>Qiniqin Feng, Chang'an Wang, Pengqian Wang, Zhichao Wang, Wei Yao, Lei Zhao, Yongbo Du, Defu Che</i> Xi'an Jiaotong University	1.31 Insight of selenium distribution in coal combustion fly ash <i>Tongtong Ma, Yongda Huang, Shuang Deng, Huasheng Wang, Guangqian Luo, Jinggang Wang, Hongyun Hu, Hong Yao</i> Beijing University of Chemical Technology	4.23 Enhanced hydrogen production by biomass pyrolysis based on calcium oxide sorbent absorption of carbon dioxide <i>Jianqiao Wang, Boxiong Shen, Peng Zhao, Dongrui Kang, Chunfei Wu</i> Hebei University of Technology	5.27 A dataset analysis of particulate matter removal techniques in China's coal-fired power plants <i>Xiaoyu Li, Yu Ni, Hui Long</i> China Power Engineering Consulting Group	

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12:00	<p>1.26 Evolution characteristics of char structure during Zhundong coal pyrolysis: further insights from first- and second-order Raman spectrum</p> <p><i>Jun Xu, Kai Xu, Limo He, Hengda Han, Sheng Su, Yi Wang, Song Hu, Jun Xiang</i></p> <p>Huazhong University of Science and Technology</p>	<p>2.28 Theoretical analyses on isolated particle ignition of coal and biomass</p> <p><i>Ye Yuan, Yang Xu, Hongpei Gao, Zhenghai Shi, Xianbin Sun, Ping Xiao, Shuiqing Li</i></p> <p>Huaneng Clean Energy Research Institute</p>	<p>1.32 Gasification kinetics and structure characteristics of petroleum coke and coal chars</p> <p><i>Daqian Wang, Haiping Yang, Chuang Zhao, Yang Wu, and Hanping Chen</i></p> <p>Huazhong University of Science and Technology</p>			<p>NSF-NSFC/ DFG-NSFC Panel</p> <p>Future Science and Technologies of Clean Coal Utilization</p> <p>Chaired by: Yuxin Wu</p>
12:20	Farewell					
12:40	Lunch					
14:00	Technical tour to Huangdao Coal Power Plant					

Abstracts

Basic Coal Quality & Combustion

Oral Session

Basic Coal Quality & Combustion 1

Monday, July 22, 2019

Index No: 1.1

**EXPERIMENT OF BLENDED COALS STAGED
COMBUSTION IN DROP TUBE FURNACE***Jinzhi Cai, Dan Li, Denggao Chen, Zhenshan Li
Tsinghua University, China*

Blended coals are widely used nowadays, while their combustion properties are big different from single coals. In order to design and evaluate the boiler, it is of vital importance to study the characteristic of blended coal combustion. In this study, one lignite is blended with one bituminous coal with different ratio and air- staged combustion experiments are conducted in a drop tube furnace. The combustion characteristic, reductive gases CO and H₂, and pollutants of NO_x and H₂S are studied. Through the air-staged combustion experiments of two kinds of coals which conducted in an electric heated down-fired furnace (DFF), the relationship between NO_x and H₂S reduction with CO generation in the fuel-rich zone was identified. Based on this observation, a modeling strategy was proposed: instead of CH_i which is difficult to calculate, the concentration of CO is used to quantify NO and H₂S homogeneous reduction.

Index No: 1.2

**ON THE PLASTIC BEHAVIOR OF CARBONACEOUS
FUELS IN FLUIDIZED BEDS***M. Urciuolo, R. Solimene, S. Krusch, V. Scherer, P.
Salatino, R. Chirone, O. Senneca
Istituto di Ricerche sulla Combustione, Italy*

During heating and pyrolysis, the morphology and size of incipient char particles can be affected by softening, swelling, fragmentation. While fragmentation of non-swelling coal is well addressed in the literature, effects associated with swelling and softening are still scarcely understood and modeled. Under pulverized fuel-fired (PF) conditions, softening and swelling of fuel particles result in the formation of spherical and often hollow char particles. In fluidized bed conditions the presence of sand in proximity of the particles may lead to more complex phenomena. The present work attempts to investigate the behavior of different carbon rich fuels in Fluidized Bed: 1. Auguste Victoria bituminous coal (Coal); 2. a bitumen used in the cement industry (Bit); 3. a solid waste coming from the refinery industry with high metal content (RW). Tests have been carried out in a laboratory scale Fluidized Bed Reactor (40 mm id) at temperatures of 600-850 °C. Quartz sand of 200-300 µm has been used for the bed, fluidized by a gas flow of N₂ or N₂/air with a superficial velocity of 0.4 m/s. The reactor was equipped by on line gas analysers. Single particles were fed from the top of the reactor and residues were collected by a basket. Coal particles had irregular shape and size of 2-4 mm. Bitumen particles were spheres of d=4-10 mm. RW particles were 10 x 10 mm squares.

In the case of coal, the heavy/tarry species formed in the early pyrolysis stages entrap sand particles and lead to the formation of hollow aggregates. The size of the cavity is comparable with the initial particle diameter. The outer shell is larger than the original particle. Char combustion rate is slowed down by mass transfer of oxygen through the sand-enriched shell. Upon heating Bit particles undergo fast pyrolysis and the small char residue (20 %w), in presence of oxygen burns simultaneously to volatiles. RW upon pyrolysis generates large round particles, which enclose quartz sand and large cavities. Combustion of such

agglomerates requires again much longer time than volatiles release due to mass transfer effects. The properties of the fuel which may be at the origin of the observed behavior are discussed.

Index No: 1.3

VALIDATION OF A COMPREHENSIVE KINETIC MECHANISM FOR SULFUR RELEASE DURING PYROLYSIS OF SOLID FUELS

*P. Debiagi, C. Yildiz, J. Ströhle, B. Epple, T. Faravelli, C. Hasse
TU Darmstadt, Germany*

Coal combustion releases elevated amounts of pollutants to the atmosphere including SO_x. During the pyrolysis step, sulfur present in the coal is released to the gas phase as many different chemical species such as H₂S, COS, SO₂, CS₂, thiols and larger tars. These species are called SO_x precursors, as they are further oxidized in the gas-phase generating SO_x, which is the main agent of acid rain and also contributes to respiratory illnesses, foliage damage and decreased plant growth. Understanding the chemical processes taking place in the release of sulfur is crucial to the development of reliable kinetic models, which support the design of improved reactors for cleaner coal conversion processes. Two bituminous coals, Colombian hard coal (K1) and American high sulfur coal were studied in the present work. Similar content of carbon, volatile matter and ashes was found for both coals, whilst sulfur was three times higher in the second fuel. Low heating rate experiments (20 K/min, reaching max temperature of 1000 K) were performed in a TG-MS, using a N₂ flow of 70 mL/min, allowing to track the mass loss and the evolution of many gas species (CO, CO₂, CH₄, SO₂, H₂S, HCl and H₂O). A kinetic model of coal pyrolysis is proposed, consisting in an updated version of the POLIMI model, and the changes refer to the full integration of the sulfur sub-mechanism into the hydrocarbon sub-mechanism. The originally proposed models were standalone and needed to be processes separately, in sequence. To this aim, sulfur is accounted in five different functionalities: aliphatic, aromatic, thiophenic, pyritic and sulphatic – to each one, a molecular structure is assigned. By assigning molecular structures, not only the sulfur fate

is accounted for in the sub-mechanism, but also the remaining atoms present in every species. This resulted in a comprehensive and general kinetic model that accounts for all the C/H/O/S present in the coal. These new features required the model to be recalibrated, aiming to maintain the same results as the original separated models. The experiments were used to further validate this kinetic model. The new model has the advantage of being fully consistent and coupled, allowing the models to run in parallel instead of sequentially. It also reflects on an easier coupling of the kinetic model with CFD simulations, which is within the objectives of the SFB/TRR 129 “Oxyflame” project.

Index No: 1.4

STUDY ON CHARACTERISTICS AND INFLUENCING FACTORS OF COAL-WATER SLURRY PYROLYSIS

*Fan FENG, Boyang LI, Juan YU, Yao ZHANG, Chen LIN, Zhongxiao ZHANG
Shanghai Jiao Tong University, China*

The distribution, composition and yield of coal-water slurry pyrolysis products have an important impact on the efficient combustion/gasification of coal-water slurry. In this paper, the coal-water slurry made of Shenmu coal (bituminous coal) is rapidly pyrolyzed by a high-frequency heating furnace, and the yield, composition and composition of pyrolysis gas were measured and analyzed. The effects of pyrolysis temperature, heating rate and residence time on the pyrolysis characteristics of coal-water slurry were studied. The results have shown that as the temperature increases, the yields of volatile matters and pyrolysis gas continue to increase. The compositions of pyrolysis gas are mainly H₂, CO, CH₄ and CO₂. With the increase of temperature, the yields of H₂, CO and CH₄ increase first and then decrease, and peaks appear at around 1100 °C. The CO yield continues to increase with increasing temperature. The rate of temperature increase affects the yield of volatiles. The research results provide a reference for understanding and mastering the formation characteristics of primary pyrolysis products of coal-water slurry.

Keynote Lecture:

ADVANCES IN TWO-FLUID LES OF TWO-PHASE COMBUSTION

L.X. Zhou

Tsinghua University

Recently, large-eddy simulation (LES) was used to study spray-air and coal-air two-phase combustion. Most LES of two-phase combustion takes Eulerian-Lagrangian approach, which needs much more computational time than the Eulerian-Eulerian (E-E) or two-fluid approach. A few studies on E-E LES of two-phase combustion were reported in the literature. In this paper at first previous studies are reviewed. Then, the mathematical models for two-fluid LES of two-phase combustion, proposed by the present author are presented, including filtered controlling equations, specific for full two-fluid and two-fluid-Lagrangian approach, a two-phase sub-grid scale (SGS) stress model and a SGS combustion model. For the SGS stress model, the present author proposes a two-phase SGS energy equation model, accounting for the interaction between two phases. For the gas-phase combustion model, a second-order moment SGS (SOM-SGS) turbulence-chemistry model, proposed by the present author, is suggested to simulate gas-phase (liquid-fuel vapor or CO and coal-volatile) combustion. Also, for coal combustion, the coal pyrolyzation and char combustion models are used. These sub-models are separately assessed by comparison with experiments.

Index No: 1.5

PARTICLE HISTORY FROM MASSIVELY PARALLEL LARGE EDDY SIMULATIONS OF PULVERISED COAL COMBUSTION IN A LARGE-SCALE LABORATORY FURNACE

Miriam Rabaçal, Mário Costa, Martin Rieth, Andreas M Kemp

University of Lisbon

A study on the coal particle history during combustion in a large-scale furnace using large eddy simulation is presented. The massively parallel execution produces a high-resolution representation of the fluid mixing and particle dispersion throughout the whole computational domain. The coal combustion is modelled using well

established, cost-effective, combustion models. A specific feature of the devolatilization model is the optimisation of the kinetic constants for the furnace operating condition, which were obtained through an iterative procedure between particle heating rates from full large eddy simulation runs and the advanced model Chemical Percolation Devolatilization. In a previous work, we showed that the classical coal combustion models, when used in a high resolution massively parallel large eddy simulation, lead to satisfactory predictions of the in-flame gas properties, namely gas temperature and gas species concentrations. In this work, we intend to go beyond the comparisons between gas phase measurements and predictions. Single particles were tracked over time and instantaneous ensembles were collected to obtain a better understanding of the conditions that coal particles are subjected to in the investigated test case. The particles trajectory, combustion history and instantaneous state distribution were analysed. The volatile flame features were related with the characteristic trajectory of different sized particles. The combustion history revealed that particles are subjected to large variations of heating rates, including very short sequential periods alternating between heating and cooling during early stage combustion, due to the high turbulence intensity in the near burner region. Finally, the state distribution of the ensemble provided a global picture of the instantaneous coal combustion process.

Index No: 1.6

IN-SITU DECOUPLING MECHANISM OF H₂O ON THE WHOLE PROCESS OF RAW COAL-H₂O GASIFICATION REACTION FOR O₂/H₂O OXY-FUEL COMBUSTION

Dongdong Feng, Dawei Guo, Yijun Zhao, Yu Zhang, Heping Tan, Shaozeng Sun

Harbin Institute of Technology, China

O₂/H₂O oxy-fuel combustion technology, as one of the most promising new combustion technologies for CO₂ emission reduction, has become a hot spot for researchers around the world. This paper uses Shenhua coal as material to decouple the mechanism of H₂O on the whole process of

raw coal-H₂O gasification reaction. At 800°C in 15 vol.% H₂O, the changes of gas-liquid-solid phase product concentration and the development of char structure in the coal-H₂O gasification were investigated. The micro fluidized bed reaction analyzer for multistage gas-solid reactions (MFBRA-MR) was used to analysis the rapid gasification reaction of single-particle coal, and the slow-heating gasification reaction of coal was carried out by Thermogravimetric-Fourier Transformed Infrared Spectroscopy-Mass Spectrometry (TG-FTIR-MS), so as to explore the in-situ decoupling mechanism of H₂O on the whole process of raw coal-H₂O gasification reaction. The results of MFBRA-MR experiments show that: (1) In the rapid single-particle reaction at 800°C, H₂O promotes the whole devolatilization process of coal particles, while it has a certain inhibitory effect on the secondary gas-phase reaction of volatile, especially the release of the H₂. (2) The H₂O gasification increases the content of oxygen-containing functional groups on the char surface and increases the number of structural defects in char. (3) During devolatilization, H₂O will increase the -COO-functional group on the surface of coal particles, reduce the content of -COO-functional group and promotes the consumption of C=C bonds. (4) H₂O has an obvious etching effect on the surface of char. For the slow-heating gasification of the raw coal, it shows that: (1) The coal gasification reaction has obvious secondary weightlessness, and H₂O promotes the initial devolatilization stage, but has an inhibitory effect on the secondary reaction. (2) When the temperatures is above 700 °C, the gasification of H₂O is more pronounced than that of a single particle rapid reaction. (3) H₂O reduces the activation energy of the initial stage of pulverized coal devolatilization, and increases the reaction activation energy of the secondary reaction of the pulverized coal devolatilization stage. (4) H₂O can promote the consumption of aromatic liquid phase products such as toluene and phenol in the devolatilization process of pulverized coal under a slow heating condition. This experiment provides a theoretical basis for the practical application of coal-H₂O gasification technology and the promotion of the third generation of oxy-fuel combustion

technology.

Index No: 1.7

Hg⁰ CATALYTIC OXIDATION BY HBR OVER CE-MODIFIED REGENERATED SCR CATALYST

*Duanle LI, Qiyu WENG, Yadi QIN, Li ZHONG, Zhiyong YU, Pengbo HU, Yuqun ZHUO
Tsinghua University, China*

A method of spent catalyst (V-Mo/TiO₂) regeneration with simultaneous Ce-modification was designed in this research. Pore structure characterization, denitrification activity and elemental mercury (Hg⁰) oxidation ability were studied to select the most effective procedure and Ce content (1 wt.%). Compared to the ordinarily regenerated SCR catalyst, the Ce-modified regenerated SCR catalyst showed higher catalytic activity for Hg⁰ oxidation. As for the influence of the flue gas conditions, HBr showed a strong promotion for the Hg⁰ oxidation on Ce-modified regenerated catalyst, and with the increase of HBr concentration, the catalytic oxidation abilities of both catalysts exhibited an increasing trend. In contrast, NH₃ suppressed the catalytic oxidation abilities of both catalysts, particularly the Ce-modified catalyst.

Oral Session

Basic Coal Quality & Combustion 2

Tuesday, July 23, 2019

Index No: 1.8

CHARACTERISTICS OF IRON AND SULPHUR IN HIGH-ASH PAKISTANI LIGNITE AND THEIR INFLUENCE ON LONG-TERM T23 TUBE CORROSION UNDER SUPERCRITICAL COAL-FIRED BOILER CONDITIONS

*Baiqian Dai, Xiaojiang Wu, Jianwen Zhang, Yoshihiko Ninomiya, Dunxi Yu, Lian Zhang
Monash University, Australia*

The lignitic coal in Pakistan is ranked 7th internationally in terms of reserves and plays an

important role in the energy market. Compared to other lignites, the Pakistani lignite is notorious for its extraordinarily high content of moisture and ash. To date, the properties of ash within this lignite and its influence on pulverized coal (PC) fired boiler remain blank. The investigations of this study start from the coal and ash properties for a typical Pakistan Thar coal seam, where the coal/ash geological distributions are explored. The synchrotron-based XANES was employed to clarify the existence of Fe-bearing and S-bearing species for five typical Thar coal samples extracted from the same seam. Subsequently, the high-temperature tube corrosion tests on T23 alloy coated with the ashes from these five coal samples were conducted in an electrically heated furnace under an air-firing atmosphere at 650 °C with an exposure duration up to 200 hr. For comparison, four super-heater ash deposits from a 30 MWth PC boiler burning Xinjiang (XJ) lignite were selected and coated on the tube surface for the corrosion test under the identical exposure conditions. The results show that, Pakistan Thar lignite has high Fe₂O₃ content (up to ~28 wt%) and high SO₃ (up to ~43 wt%) content in its ash, where most of the iron and sulphur are organically bound in the parent coal samples. For the long-term corrosion tests using the ashes derived from medium-temperature ashing at 575 °C, the Pakistani ash deposits cause a less mass gain per unit area of the T23 specimen compared to that from XJ ash deposits. The mass gain increases as the ash shrinking rate increases, confirming the importance of the formation of trisulfate eutectics. Compared to the abundant SO₃ content, the contents of alkalis (sodium and potassium) are more influential on the tube mass gain. With regarding the tube thickness growth, it increases linearly as the mass gain increases, but at different proportions for the two different set of ashes, Pakistani ash versus Xinjiang ash. Apart from the traditional kinetics based on oxide scale thickness, another approach based on tube mass gain was also applied to the ash-induced corrosion. However, regardless of the approaches used (i.e. thickness versus mass), the entire corrosion process is controlled by both phase boundary reaction and diffusion, where the

ash-induced corrosion starts with a phase boundary control in the interface at the initial stage. The presence of the ash deposits on the tube surface promotes the diffusion when a parabolic law applies subsequently. The Pakistani ash is less corrosive with relatively lower oxidation kinetic rate constants than the XJ ash deposits. Additionally, with regarding the ash deposit induced corrosion kinetic constants, their magnitude is in proportion to the content of sulfur with XJ ash deposits, further substantiating the pre-dominant role of this element. In contrast, the oxidation rate constants for Pakistani ash deposits are more proportional to the Fe₂O₃ content, demonstrating that the effect of iron in Pakistani ashes overweighs that of sulfur. The abundant iron oxide could even catalyse the oxidation of SO₂ (in flue gas) into SO₃ which is apparently more corrosive than the solid sulfates within XJ ash deposits.

Index No: 1.9

A STUDY OF THE OXY-FUEL COMBUSTION OF ZHUNDONG COAL CHAR USING REAXFF MD SIMULATION

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CO₂ gasification reaction has great effect on the overall combustion rates of char during oxy-fuel combustion. The net contribution of CO₂ gasification on the consumption rate of char has not been clearly understood. In this paper, reactive molecular dynamic (ReaxFF-MD) method was used to study the effect of CO₂ gasification on the oxy-fuel combustion rate of Zhundong coal char. The structural representation of Zhundong coal char was constructed based on experimental analysis. A series of ReaxFF simulations were performed at heating rate of 1.5 K/ps (from 2000 to 3500 K) in 5%, 10% and 20% O₂ concentrations for both O₂/N₂ and O₂/CO₂ combustion to investigate the effect of CO₂ on the overall consumption of char. Results indicated that CO₂ reduced the diffusion rate of O₂, thus inhibited the oxidation rate of char. However, the effect of CO₂ gasification reactions is to

increase the total carbon consumption rate, especially at low O_2 concentration at high temperatures. The net contributions of CO_2 gasification to the total carbon consumption of char at 3500 K were 51.38%, 34.74% and 19.88% in 5%, 10% and 20% O_2 concentrations, respectively. The activation energy of CO_2 gasification was determined as 250 kJ/mol at 3000-3500 K. The oxidation of char was kinetically controlled at 3000-3300 K (174 kJ/mol), while was mainly controlled by O_2 diffusion in the regime of 3300-3500 K (101 kJ/mol). The detailed and dynamical description of CO_2 gasification reaction pathways were revealed in atomic scale. CO_2 molecule was initially adsorbed on active carbon site, followed by the cleavage of C-O bond leading to the formation of CO.

Index No: 1.10

EFFECT OF K_2CO_3 ADDITION ON CO_2 GASIFICATION CHARACTERISTICS AND ASH SINTERING BEHAVIOUR OF A CHINESE LIGNITE AT DIFFERENT TEMPERATURES AND PRESSURES AS EXAMINED USING A HIGH-PRESSURE THERMOGRAVIMETRIC ANALYSER

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The gasification characteristics and the morphology of the residue ash from pressurised K_2CO_3 -catalysed gasification of a Chinese lignite in CO_2 was investigated using a High-Pressure Thermogravimetric Analyser operating at pressure of 2.0MPa or 3.5MPa and temperature between 750 and 900 °C for at least 2 hours, after being heated from room temperature at 10 °C/min. The K_2CO_3 addition was varied from 0 to 10% w/w. Gasification characteristics of the K_2CO_3 -doped lignite was determined by analysing the weight loss and conversion rate as a function of time whereas the ash morphology was analysed by using SEM-EDS. Results showed that at 3.5 MPa the in-situ weight loss of the lignite increased as K_2CO_3 addition ratio increased, suggesting that K_2CO_3 addition promoted lignite gasification. The conversion rate of the lignite correspondingly increased from 61% to 92% as the temperature elevated to 750 °C. An increase in the

final temperature to 900 °C significantly promoted lignite gasification when K_2CO_3 was less than 5%, however this was not obvious for lignite with 10% K_2CO_3 addition. This is because the conversion rate of the lignite with 10% K_2CO_3 addition had exceeded 90% before the final temperature of 900 °C was reached. Furthermore, as pressure decreased from 3.5MPa to 2.0MPa, the lignite gasification rate slowed down, with or without K_2CO_3 addition. Conversion rate of the lignite decreased from 61% to 42% while the temperature initially elevated to 750 °C. SEM-EDS analysis revealed that sintering of the lignite ash was not observed at 750 °C, but became apparent at 1% K_2CO_3 addition. The degree of ash sintering further aggravated at 5 and 10% K_2CO_3 addition. As the temperature increased from 750 °C to 900 °C, the ashes of the raw lignite and 1% K_2CO_3 doped-lignite remained largely similar, whereas the sizes of the 10% K_2CO_3 -doped lignite ash was increased and the particle surfaces became smooth, suggesting an enhanced sintering of the ash. The formation of Kaluminosilicate and Ca-aluminosilicate of low-melting points in the ash was responsible for possible deactivation of the doped catalyst K_2CO_3 and the observed ash behaviour.

Index No: 1.11

DEVELOPMENT OF FAST-HEATING MACRO-TGA FOR BIOMASS PYROLYSIS

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Pyrolysis kinetics play vital roles in thermal chemical conversion processes of biomass and serve as the most important targets in industrial design. A key task in studying biomass pyrolysis is to measure the pyrolysis kinetics under real operational conditions. However, this has been a long-standing challenge because one must perform the measurement in a fast heating environment to maintain the biomass sample as a large size. Here, we report a new macro-TGA to measure pyrolysis kinetics of big size of biomass particle with fast heating rate. The mass of each sample in macro-TGA experiments can reach 50 g with size of 40 mm, the heating rate of our newly

developed macro-TGA can go up 3000 °C /min. The experimental conditions in this new setup is very similar to that occurring in actual stoker furnace, and therefore the obtained experimental data can be used as a reference of actual furnace design, operation and optimization.

Index No: 1.12

COMPARABILITY AND VALIDITY RANGE OF PYROLYSIS KINETICS FROM CHINESE COALS OBTAINED WITH DIFFERENT EXPERIMENTAL SETUPS

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Detailed knowledge of devolatilization behavior of solid fuels is required for CFD simulations of burners and boilers as the pyrolysis step affects a lot of subsequent processes like ignition, char burnout and pollutant formation. The experimental determination of pyrolysis kinetics can be achieved with different reactors, while thermogravimetric analyzers are the most common devices. In this study, the impact of the experimental setup and the related boundary conditions is evaluated for two setups: a standard thermogravimetric analyzer and a small scale fluidized bed reactor (FBR) designed for the determination of kinetic parameters of gas-solid reactions. During thermogravimetric analysis (TGA), particle heating rate is low and precisely controlled. In the FBR the heating rate is several orders of magnitude higher which leads to almost isothermal reaction conditions. Both setups have in common that they can capture the entire pyrolysis process and are not limited in residence time. The Chinese Zhundong lignite with a particle size range of 60–70 µm is used as fuel. For each setup the range of operating conditions which ensure kinetic control is identified and kinetic parameters are evaluated for two different empirical devolatilization models. Afterwards, the model performances outside their calibration ranges are investigated for three test cases approximating reaction conditions in a thermogravimetric analyzer, a fluidized bed and an

entrained flow reactor. Additionally, the results are compared with predictions of the sophisticated Chemical Percolation and Devolatilization (CPD) network model. The results reveal that kinetic extrapolations of the empirical models outside their calibration ranges can generate significantly different devolatilization characteristics. The fundamental-based CPD model instead is capable to capture the relevant time-scales at all boundary conditions but fails in the prediction of final volatile yields

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Index No: 1.13

EXPERIMENTAL INVESTIGATION ON SODIUM MIGRATION AND MINERAL TRANSFORMATION IN ASH DEPOSIT DURING GASIFICATION OF ZHUNDONG COAL USING A DROP TUBE FURNACE

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Zhundong coal has attracted an ever-increasing concern due to its super-huge reserve but high content of alkali metals. Volatilized into the gaseous phase during the gasification process, alkali metals are extremely unfavorable for coal utilization. Gasification technology can promote the large-scale utilization of high-alkali coal. However, few efforts, if any, have been conducted on gasification of Zhundong coal. The present study aimed to elucidate the sodium migration and mineral transformation characteristics in coal ash deposition process under different gasification conditions, while the behavior of sodium migration and mineral transformation were further analyzed using Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-OES), X-ray diffraction (XRD) and X-ray fluorescence (XRF) techniques. In this

paper, the sodium migration characteristics in gasification process under different conditions were investigated by adding three sodium salts (NaCl , Na_2CO_3 and Na_2SO_4), kaolin and diatomite into coal, respectively. The effects of ash deposition time on sodium migration and mineral transformation characteristics in ash were also explored. The experimental results showed that the addition of sodium salt could increase the sodium content in the ash to a large extent. Kaolin and diatomite could solidify alkali metals in the gaseous phase during gasification process. As the ash accumulation time increased, the minerals such as chlorine, sulphur, and iron in the gaseous phase were easily bonded to the surface of the ash and reacted to form other crystal phases. The present study can provide guidance for the utilization of Zhundong coal and benefit the development of clean coal technology.

Index No: 1.14

ASH DEPOSITION AND SLAGGING BEHAVIOR OF XINJIANG HIGH-ALKALI COAL IN A 20MWTH CYCLONE COMBUSTION TEST FACILITY

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The high content of AAEMs (alkali and alkaline earth metals) in ash as well as its relating serious ash fouling slagging problems are the main reason for the unit boiler, which cannot absolutely fully use high-alkali coal at full generating capacity. In order to fully use those kinds of coal, the cyclone-fired boiler with slagging tap is induced in this paper. The ash melting behavior as well as the migration and transformation characteristics of AAEMs during cyclone-fired process were performed in a 20MWth cyclone combustion test facility. A number of slagging and deposit samples at different locations of boiler were selected and analyzed by using XRF, XRD and SEM-EDX analysis. The experimental results showed that the slag in cyclone burner contains higher content of Fe_2O_3 , around 37.5~52.6wt%, which is about 2.4 and 3.5 times than that of their parent coal ash. The content of Na_2O in slag is

around 2.3~8.6 wt%, especially for the slag at location C, D and E, where can provide sufficient reaction time and contact area between flue gas and slag. The main existence form of sodium is Na-Al-Si eutectic compounds and being completely melted in cyclone with smooth surface. For the deposit ash on convective tubes, some Na-Al-Si and Ca-Mg-Si low melting eutectic compounds have a rounded boundary in the main particles due to the low melting temperature and low viscosity, which can adhere to the surface of other ash particles to agglomerate each other.

Index No: 1.15

EXPERIMENTAL AND NUMERICAL STUDIES OF THE IGNITION AND COMBUSTION OF MECHANICALLY ACTIVATED PULVERIZED COAL

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This work presents experimental studies and industrial applications of new technology of gas and fuel oil replacement by mechanically activated micronized coal in power engineering: ignition and stabilization of pulverized coal flame combustion, as well as gasification of micronized coal in the flow.

The fact of an increase in the chemical activity of coals at their grinding in highly stressed disintegrator mills have been established at the Institute of Thermophysics of the SB RAS. Based on data obtained, a new technology is proposed to replace high-reaction gases and fuel oil by fine coal at the power plants.

The benefits from coal micronization on combustion are generally well known and manifest among others in compact flames with faster ignition and more complete char burnout requiring less excess air. The origin of these benefits is commonly attributed to the increase in the surface-to-volume ratio due to a decrease in the particle size, but also due to a more extended external surface of irregularly shaped particles and in some cases increased porosity, all depending on the type of mills used. Less is known about the change of the coal kinetic properties, especially the enhancement of coal reactivity due to mechanical activation, which greatly depends on the

method of coal grinding.

On laboratory size installations experimental research conducted of local ignition and flame stabilization conditions, propagation of IR radiation, turbulent flow structure, temperature distribution, concentration of dispersed phase and gas components in a flame with a variation in the size (10-100 μm) of coal particles, gas composition (air / methane / synthesis gas) and temperature of the jet.

When studying the combustion of mechanochemically treated coal samples, it was found that, other things being equal, the parameters of the flame, namely, the size and distribution of the temperature zones, strongly depend on what type of mills was used for grinding.

Special attention paid to the theoretical investigation of the mutual influence of the turbulence of the gas phase, the clustering of coal particles and the chemical reaction in the combustion of particles. As a result, it is obtained extensive data on the features of gasification and combustion of pulverized-coal fuel and the rate of formation of harmful emissions in a gas stream of varying reactivity.

Index No: 1.16

EFFECT OF OIL SHALE SEMI-COKE ADDITION ON ASH DEPOSIT MINERALOGY AND MORPHOLOGY ON PROBES IN THE FLUE PATH OF A CIRCULATING FLUIDIZED BED BURNING ZHUNDONG LIGNITE

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The effect of oil shale semi-coke addition on the mineralogy and morphology of the deposits formed on probes in the flue path of a 0.2 t d⁻¹ circulating fluidized bed (CFB) combustor burning Zhundong lignite was investigated. 10 or 20 wt% (w/w) semi-coke (SC, <3 mm) of high aluminosilicate was added to Zhundong lignite (ZD) and the blend was then combusted in the CFB furnace at 950 °C. Two probes (P1 and P2) with vertical and horizontal orientations installed in the flue duct to simulate ash deposition where the surface temperatures were

maintained at 550 °C and 400 °C, respectively. Both windward and leeward ash deposits on these probes (denoted as P1W, P1L, P2W and P2L) were collected and analysed by using SEM-EDX, XRD, ICP-OES and a laser particle size analyser. The Results show that the P1W ash deposit during ZD combustion comprised agglomerated particles less than 30 μm and in the mineral forms of CaSO_4 , Na_2SiO_3 and Na_2SO_4 , indicating the occurrence of ash sintering due to Na- and Ca-bearing minerals. The P1L ash deposit, however, was of both discrete and agglomerated particles in similar mineral phases but with coarser sizes ($D_{50}=37 \mu\text{m}$). The P2W deposit was of discrete particles and agglomerates with even larger sizes ($D_{50}=140 \mu\text{m}$), where SiO_2 and $\text{NaAlSi}_3\text{O}_8$ were dominated. The P2L deposit was however mainly fine ash particles ($D_{50}=37 \mu\text{m}$), among which $\text{K}_{0.42}\text{Na}_{0.58}\text{Ca}_{0.03}\text{AlSi}_3\text{O}_8$ was formed while Na_2SiO_3 and Na_2SO_4 were absent. As SC was added, the agglomerates in both P1W and P1L decreased meanwhile Na_2SiO_3 and Na_2SO_4 were not identified. Instead, SiO_2 and Ca/Na aluminosilicates of high melting points were presented as the dominant mineral phases, indicating the deposits being more refractory. Likewise, the P2W deposit was found less spread on the probe surface, showing a decrease in the deposit viscosity. Na-bearing mineral phases turned into $(\text{Na},\text{K})(\text{Si}_3\text{Al})\text{O}_8$ and $(\text{Ca},\text{Na})(\text{Si},\text{Al})_4\text{O}_8$, instead of being $\text{Na}_2\text{Si}_2\text{O}_5$ and $\text{NaAlSi}_3\text{O}_8$ when ZD was burned alone. In addition, Na contents within these deposits decreased from more than 32 mg g⁻¹ to less than 15 mg g⁻¹ as 10% or 20% SC presented. The addition of SC addition would thus help alleviating the propensity of ash deposition on the heat transfer surfaces within flue path.

Index No: 1.17

EFFECT OF REFRACTORY LINING THICKNESS ON SLAG LAYER BEHAVIOR IN CYCLONE BARREL

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The cyclone-fired boiler has attracted much attention in recently years. The thickness of the refractory lining is closely related to the slag behavior which is of great

importance for the operation of the cyclone-fired barrel. In this paper, the slag layer behavior in the cyclone barrel is investigated numerically when the refractory lining thickness is constant or varied. The results show that the refractory lining has a great effect on its surface temperature. Besides, the refractory lining should not be too thick to ensure the presence of the solid slag layer at the high temperature zone of the cyclone barrel. Therefore, in the cyclone barrel, the thickness of the refractory lining of the air inlets sections can be increased to reduce the heat dissipation, whereas the thickness of the refractory lining of the outlet section can be reduced to obtain a solid slag layer thick enough to prevent the erosion of the refractory lining. The proposed scheme with variable thickness of the refractory lining is proved effective by the numerical simulation.

Index No: 1.18

EXPERIMENTAL STUDY ON THE INFLUENCE OF SLAGGING AND FOULING FOR WALL TEMPERATURE DISTRIBUTION

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Coal is still the main fossil fuel for power plants in China, and heat resistance ratio of the fly ash slag and fouling layer is the key weight ratio for super-heaters and re-heaters with coal fired boiler. Actually the slagging and fouling layers happened on the fireside surface of tubes are not uniform in the circumferential direction. To explore the influence level of the smoke flow on the slagging and fouling distribution, a tower type furnace facility was established, and the influence of slagging and fouling of a horizontal tube for the wall temperature distribution was studied. Meanwhile, the heat transfer model of clean tube and stained tube was established. A comparative study of clean tube surface and stained tube surface temperature distribution was conducted. The results showed that the wall temperature distribution with slagging and fouling was totally different with the clean condition. And the heat flux distribution of the clean tube was a single-humped

curve, but the stained tube showed the double humped curve in the circumferential direction.

Index No: 1.19

EFFECT OF TEMPERATURE ON BITUMINOUS CHAR STRUCTURE EVOLUTION DURING PYROLYSIS AND COMBUSTION

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Lu'an bituminous chars and ashes were prepared by pyrolysis and combustion processes under the inert N₂ and air atmospheres respectively across ash melting temperature. The scanning electron microscope (SEM) was used to observe the morphology of chars and ashes. The specific surface area analyzer (SSAA) and thermal gravimetric analyzer (TGA) were respectively employed to obtain the pore structure characteristics of the coal chars and their kinetic parameters of the combustion reaction. X-ray diffractometer (XRD) was used to investigate the graphitization degree of coal chars prepared at different pyrolysis temperatures. SEM indicated that the number density and physical dimension of the ashes spheres exuded from the char particles both gradually increased as the pyrolysis temperature increased, thus the coalescence of ash spheres could be observed obviously above 1100 °C. When the pyrolysis temperature rose to 1300 °C, some flocculent materials appeared on the surface of the char particles, and it could be speculated that β-Si₃N₄ was generated during the pyrolysis process in N₂ with the help of energy dispersive spectrometer (EDS). The specific surface area (SSA) of the chars decreased with the increase of pyrolysis temperature. Inside the char particles, the micropore area and its proportion in the SSA also declined as the pyrolysis temperature increases. Furthermore, the constantly increasing pyrolysis temperature also causes the decrease of char reactivity, which is consistent with the results obtained by XRD. The higher combustion temperature resulted in the lower porosity and more fragments of the ash.

Index No: 1.20

DFT STUDY OF THE EFFECT OF CA ON NO HETEROGENEOUS REDUCTION BY CHAR

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The reaction mechanism of Ca on NO-char heterogeneous reaction catalyzed was investigated by simplified coke models and density functional theory. Configuration of reactants, intermediates, transition states and products involved in the reaction process were optimized at b3lyp/6-31g(d) level. The activation energy of each elementary reaction were calculated. The study of NO-char heterogeneous reaction on pristine graphene model showed its activation energy was 88.35kJ/mol, and the activation energy on calcium decorated grapheme model reduced to 49.54kJ/mol. According to the theory of reaction rate determining step, the Arrhenius expressions are $3.95 \times 10^{13} \exp(-51.78/T)$ and $2.07 \times 10^{15} \exp(-94.61/T)$ for zigzag-edge model with Ca and without Ca, respectively. Reaction activation energy is lower and rate constant is faster for Ca-decorated model, which indicates the reaction is more active. The presence of calcium reduces the activation energy of NO-char heterogeneous reaction. Calcium has a significant catalytic effect.

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Index No: 1.21

PRECIPITATION CHARACTERISTICS OF ALKALI/ALKALINE EARTH METAL IN HIGH ALKALI COAL

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Serious problems of fouling and slagging occurred in combustion of high alkali coal. As the physical and

chemical characteristics of coal ash may change at different ashing temperature (AT). The investigation on the precipitation characteristics of alkali/alkaline earth metal (AAEM) in high alkali coal is important for the safety and stable operation of the boilers. To understand the effect of AT on AAEM precipitation characteristics, four different coals were selected as samples. For each coal, three coal ashes were acquired at 200 °C /500 °C /815 °C respectively. X-ray fluorescence spectroscopy (XRF) and Inductively Coupled Plasma Optical Emission (ICP-OES) were applied for the elementary analysis of ash. The test results indicated that ash yields and alkali contents in coal ash decrease while alkaline earth metal content changes little as AT increases. The precipitation temperature of chlorine is lower than 500 °C, and chlorine is substantially completely precipitated before 815 °C. The precipitation characteristic of Na is closely related to the content of chlorine in the coal. Low-temperature ashing will cause carbon burnout problems for high ash coals while the relative error of alkali metal measurement is limited. The test results of ICP-OES on element content in same sample is lower than XRF. However, the elemental content changes with AT are similar between two measurement results. It is recommended to use the ICP-OES test method when measuring AAEM content due to its higher precision.

Index No: 1.22

STUDY ON MINERAL PHASE TRANSFORMATION AND ASH MELTING MECHANISM OF ZHUNDONG COAL AND BLENDED COAL

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Zhundong (ZD) coal is one of the most important coal resources in China. However, its high contents of sodium and calcium induce severe slagging and fouling in boilers. In this paper, by TG- DSC analysis of low ashing temperature samples (500 °C) of ZD coal, XRF, ICP-MS and XRD analysis of mineral identification, FSEM/EDS analysis of morphology and composition of different

ashing temperatures of ZD and blended coal ashes (90% ZD), the mineral phase transformation and ash melting mechanism are obtained. The results show most of sodium minerals in ZD and blended ashes, evaporated before 875 °C, and maintain unchanged after 1000 °C for the production of nepheline (NaAlSiO₄). Blending high contents of Al₂O₃ and SiO₂ coal with ZD coal (mass ratio 1/9) has the ability of increasing sodium retention ratio *R*: *R* in blended ash at 1230 °C (56.59%) is obviously higher (about 1.73 times) than that in ZD ash (32.66%). It indicates this blending method can decrease the effect of Na on fouling. At 1230 °C, the main minerals in ZD ash are Ca-containing minerals (Ca₂SiO₄, Ca₁₄Mg₂(SiO₄)₈, Ca₂Fe₂O₅, CaAl₂Si₂O₈) and NaAlSiO₄. The melting point of these minerals are all above 1450 °C, but the reactions of NaAlSiO₄ and Ca₂SiO₄ (stronger), Ca₂Fe₂O₅ and Ca₂SiO₄ (weaker) to form low melting eutectics lead to the low ash fusion temperatures (AFTs) of ZD ash. New minerals (Ca₂Al₂SiO₇ and CaAl₂Si₂O₈) were found in blended ash. According to the theory of Quantum Chemistry: larger lattice spacing (low *Z* and high lattice size) leads to higher energy states. The energy states of Ca₂Al₂SiO₇ (*Z*=2, lattice size: 5.068–7.686) and CaAl₂Si₂O₈ (*Z*=2, lattice size: 8.176–12.872) are obviously higher than those of NaAlSiO₄ (*Z*=8, lattice size: 8.330–9.978). These minerals are favor to inhibit the reaction of NaAlSiO₄ and Ca₂SiO₄, leading to higher AFTs in blended ash compared with those in ZD ash. This analysis has been verified by FSEM/EDS analysis. As a conclusion, blending high contents of Al₂O₃ and SiO₂ coal with ZD coal decreases the effect of Na on fouling, agglomerate and slagging

Index No: 1.23

EFFECT OF IRON CONTENT AND ATMOSPHERE ON MELT STRUCTURE AND VISCOSITY

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The microstructure of slag, coal gasification slag and geological melt is sensitive to the content of iron and atmosphere, which affect the viscosity. In this paper, the

effects of iron content and atmosphere on melt structure and viscosity were studied by molecular dynamics simulation and thermodynamic calculation methods. In iron-containing silicate melt, Fe³⁺ mainly exists as a network former, and Fe²⁺ mainly exists as a network modifier. With the increase of iron content, the value of Fe³⁺/Fe²⁺ increases, the polymerization degree of the melt decreases first and then increases, the strength of the melt network decreases, the diffusion capacity of ions increases, and the melt viscosity decreases. Based on this, A network strength parameter is proposed to quantify the relationship between network strength and viscosity. When the atmosphere changes between air, weak reducing and strong reducing atmosphere, the oxidation state of iron changes, causing the polymerization degree and network strength of the melt to decrease first and then increase, the ion diffusion capacity to increase first and then decrease, and the melt viscosity to decrease first and then increase. The results reveal the influence mechanism of the melt structure on the viscosity from the microscopic level, and obtain the quantitative relationship between the microstructure and the macroscopic properties.

Index No: 1.24

ROLES OF WATER-SOLUBLE INORGANICS IN MODIFYING THE PROPERTIES OF ASH FROM ZHUNDONG COAL COMBUSTION

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Zhundong coalfield (also known as the Eastern Junggar coalfield) is situated in the east of Junggar Basin, Xinjiang, China. It is a newly discovered superlarge coalfield with reserves estimated to be 164 Gt. Due to their low price and abundance, Zhundong coals are becoming increasingly attractive in the power plants. However, the large-scale utilization of Zhundong coals is largely limited due to their high ash deposition propensities. These issues mainly result from the high contents of alkali and alkaline earth metals (AAEMs) and their unique modes of

occurrence in the coals. The water-soluble AAEMs (especially Na) in Zhundong coals usually account for significant fractions. They have been found to readily vaporize during combustion and form very fine ash particles, which are believed to contribute significantly to the formation of the initial (inside) deposit layer. On the other hand, the fractions of the AAEMs that do not vaporize in combustion may interact extensively with other minerals (especially alumino-silicates), modifying the properties of the ash generated. Therefore, the knowledge of the roles of the water-soluble inorganics (e.g. AAEMs) in ash formation is very helpful to the understanding and prediction of ash deposition during Zhundong coal combustion. Typical Zhundong coals and their water-washed products were used for combustion experiments on a high-temperature drop tube furnace. The generated ash was collected and subject to analyses by laser particle size analyzer, X-ray diffraction (XRD), and scanning electron microscopy with X-ray energy dispersive spectrometry (SEM-EDS). Furthermore, the ash samples were also analyzed by computercontrolled scanning electron microscopy (CCSEM) to obtain the properties of individual ash particles. This information, together with the quantitative data of the modes of occurrence of the AAEMs, was used to examine how the water-soluble inorganics in coal would affect and modify the ash properties. The important ash properties considered included particle size distribution, particle mineralogy, mineral association and chemical composition. Such knowledge can be used for the development of models for the prediction of ash formation during Zhundong coal combustion. The results regarding the effects of different modes of occurrence of AAEMs on the fine ash composition

Index No: 1.25

SOOT FORMATION IN HIGH-TEMPERATURE PYROLYSIS OF VARIOUS COALS

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Soot formed during high temperature pyrolysis or incomplete combustion, has strong effects on human health and the environment, as well as radiation heat transfer during combustion. Most studies on soot formation are focused on gas combustion, while the studies of soot formation during solid fuel combustion are rarely reported. In this study, the formation and properties of soot particles from coal pyrolysis are investigated in a drop tube furnace at 1000-1300 °C. The soot morphology, number size distribution, ignition characteristics, gas composition and soot-ash composition were characterized with transmission electron microscopy, scanning mobility particle sizer, thermogravimetric analyzer, gas chromatography, and energy dispersive spectroscopy. The effect of coal rank on soot formation and yield is mainly discussed. The results show that with the increase of pyrolysis temperature, the soot yield increases. The soot yields show no dependent relationship with the coal ranks. Among the five kinds of coal tested (anthracite, lean coal, bituminous coal, lignite, and high sodium coal), bituminous coal has a much higher soot yield (>7.5%) than that of other coals (0.5%~2%). The oxidation reactivity of soot particles from high sodium coal pyrolysis is much higher than that from other coals, because of the high contents of alkali and alkaline earth metals in soot particles.

Index No: 1.26

EVOLUTION CHARACTERISTICS OF CHAR STRUCTURE DURING ZHUNDONG COAL PYROLYSIS: FURTHER INSIGHTS FROM FIRST- AND SECOND-ORDER RAMAN SPECTRUM

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It is predicted that Zhundong coalfield can meet the coal demand of China for 100 years. Investigating the evolution characteristics of char structures during Zhundong coal pyrolysis can not only reveal the pyrolysis mechanism, but also be meaningful for understanding the char's behavior in subsequent thermal process. Some studies have studied the Zhundong coal pyrolysis kinetic or

char structures under different pyrolysis condition. However, rare studies have revealed the evolution of comprehensive char structures during Zhundong coal pyrolysis and considered the difference of char structures caused by the pyrolysis conditions. In this study, two serious chars were prepared in a fixed-bed reactor: chars under different pyrolysis temperature from 300 °C to 1000 °C with the pyrolysis time of 1800s, and chars under 900 °C with various pyrolysis time from 20s to 1800s. The chemical structures of chars were characterized with micro-Raman spectroscopy. The Raman spectrum parameters $A_{(GR+VL+VR)}/A_D$, A_{GL}/S_1 , A_S/S_1 , $A_{(2D)}/S_2$ can reflect the aromatization degree, the relative amount of C=O functional groups, the cross-linked density and the C-H of alkane.

The results reveal that the aromatization degree is increased slowly and then rapidly, while the relative amount of C-H in alkane rapidly decreases and then mildly decreases with the increase of pyrolysis temperature or pyrolysis time. For C=O functional groups, they nearly unchanged until the char yield is about 75%, and then drastically decreased. It indicates that in the earlier stage of Zhundong coal pyrolysis the C-H of alkane in coal mainly releases and then the small aromatic rings and C=O functional groups start to release and then aromatic rings condensation, resulting in the obvious increase of the aromatization degree. For the effects of pyrolysis condition, it is found that the aromatization degree, relative amount of C-H in alkane, and C=O functional groups is significant different when the char yield is similar for the chars obtained under different pyrolysis temperature and time. This is mainly because that for the coal pyrolysis under 900 °C with different time the pyrolysis is more drastic than that in different temperature. The aromatic rings crosslinked by crosslink structure can firstly opened, forming more small aromatic rings, and partly C-H of alkane can act as the crosslinked roles before its release, increasing the aromatization degree and crosslinked density, and more C-H of alkane is left in the char.

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Monday, July 24, 2019

Index No: 1.27

INVESTIGATION OF ARSENATES PARTICLES CAPTURE FROM COAL-FIRED POWER PLANT FLUE GAS BY ELECTROSTATIC PRECIPITATOR

HONGYU GONG, YONGDA

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Arsenic is easily volatilized as vapors($As_2O_3(g)$) during coal combustion and is predominantly transformed to arsenates particles through the interactions between $As_2O_3(g)$ and coal accessory minerals (mainly Ca, Fe and Al compounds). At present, particulate pollutants are mainly controlled by electrostatic precipitator. To illuminate the capture characteristics of particulate arsenates in electric field, the speciation of the arsenic in different size fly ash was distinguished in this study. The accuracy of the analytical methods was confirmed by measuring the arsenic speciation in pure Ca/Al/Fe-substances after arsenic adsorption. And capture efficiency of arsenates in different size fly ash as well as in the forms within various compounds was further discussed through the experimental and simulation study. The results show that the distribution of arsenic in different size fly ash depends not only on the content of accessory mineral, but also on their occurrence. Experiments conducted with various speciation of arsenic in different size fly ash indicated that arsenic was tended to be enriched in smaller particles. Furthermore, arsenic in coarse particles was more likely combined with calcium while more fraction of arsenic in fine particles was combined with Fe/Al-compounds. Meanwhile, according to the simulation study, when the amount percent of Al atoms rises to that of kaolin, the resistivity will exceed $1011\Omega\cdot cm$ (the most suitable resistivity range is $104\sim 1011\Omega\cdot cm$), which indicates that arsenic combined with Al-compounds is easier to escape from electrostatic

precipitators compared to arsenic combined with Ca/Fe-compounds.

Index No: 1.28

THE ROLE OF CAO/FE₂O₃ RATIO ON COAL ASH VISCOSITY TEMPERATURE PROPERTIES

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Large-scale coal gasification technology is the key foundation to improve the atom economy for coal utilization and realize high efficient and clean coal conversion. The fusibility of coal ash is the critical factor to determine steady operation parameters of gasifier, which is also the significant criterion to selection of coal species for gasification. It is difficult to investigate the structures and properties from tradition experiments. Thus, the relationship between fusibility and microscopic structures is not specific. In this work, The role of CaO/Fe₂O₃ ratio on ash fusibilities and flow properties was investigated by combining the Molecular dynamics (MD) simulation as well as X-ray Diffraction Analysis (XRD) and X-ray Photoelectron Spectroscopy (XPS). It was found that the viscosity and critical viscosity temperature decreased with the increase of CaO/Fe₂O₃ ratio and the ash fusion temperatures (AFTs) varied largely as the ratio of CaO/Fe₂O₃ was lower than two. The viscosity-temperature curves of ash slags were change from the crystalline slag to glassy slag when the CaO/Fe₂O₃ increased above two. Insight from molecular dynamics simulation revealed the effect of CaO/Fe₂O₃ ratio on the structural variation. The radial distribution and oxygen species variation from the simulation results were employed to demonstrate the depolymerization effect of the calcium oxide and ferric oxide. The XRD and XPS analysis were adopted to reveal the oxygen species variation gotten from the simulation results. The combination of the molecular dynamics simulation and experiments can provide new insight into the mechanism of coal ash fusion behavior and viscosity-temperature influenced by CaO/Fe₂O₃ ratio.

Index No: 1.29

EXPERIMENTAL STUDY ON REMOVAL OF LOW CONCENTRATION COAL TAR IN COAL GAS MG-CA COMPOSITE CATALYST

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The catalytic cracking of low concentration coal tar in syngas was studied using Mg-Ca composite catalyst. The reaction was carried out in a two-stage fixed bed reactor. The effects of bed temperature (400–800 °C), catalyst particle size (400–600 μm, 200–400 μm, 100–200 μm, and < 75 μm) and catalyst layer height in bed reactor on tar conversion, pyrolysis gas products (CO, H₂, CO₂, CH₄), and the CO₂ absorption by CaO in catalyst were investigated. The results showed that the cracking rate of coal tar vapor increased with the increasing of bed temperature, till reaching a maximum of 94% at 700°C. The production of H₂ also increased with temperature, and the amount of CO₂ in the gaseous products decreased between 500–700 °C responding to the CO₂ absorption capacity of CaO reaching its peak in this temperature range. The absorbed CO₂ subsequently released at higher temperatures. The catalytic cracking rate was highest when the catalyst particle size was 100–200 μm, and the catalytic cracking efficiency increased with the increasing of catalyst layer height and reaction time. These results demonstrate that when the catalyst particle size is too small (< 75 μm) or the reaction temperature is too high (> 700°C), the catalyst activity for coal tar cracking is reduced.

Index No: 1.30

AN EXPERIMENTAL STUDY ON IGNITION OF SINGLE COAL PARTICLES AT LOW OXYGEN CONCENTRATIONS

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An experimental study on ignition of single coal particles at low oxygen concentrations ($X_{O_2} < 21\%$) was conducted using a tube furnace. The surface temperature

(T_s) and center temperature (T_c) of the coal particles were obtained from the images taken by an infrared camera and thermocouples respectively. The ignition processes were recorded by a high-speed camera at different XO_2 's and furnace temperatures T_w 's. Compared with literature experimental data obtained at a high XO_2 , the ignition delay time τ_i decreases more rapidly as XO_2 increases at low XO_2 region. The responses of T_s and T_c to the variation of XO_2 is different: T_s decreases while T_c keeps nearly constant with increasing XO_2 at a low XO_2 . In addition, τ_i is less sensitive to T_w while T_i is more sensitive to T_w at a low XO_2 than in air. Observations of position of flame front evolution illustrated that the ignition of a coal particle may change from homogeneous mode to heterogeneous or combined ignition mode as XO_2 decreases. At a low XO_2 , buoyancy plays a more significant role in sweeping away the released volatiles during the ignition process.

Index No: 1.31

INSIGHT OF SELENIUM DISTRIBUTION IN COAL COMBUSTION FLY ASH

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Selenium is easily volatilized and is mostly emitted into the flue gas in the form of SeO_2 during coal combustion. Then, part of SeO_2 formed selenite and was enriched in fly ash through the interactions with minerals in fly ash. Also, some SeO_2 might be condensed on the surface of the ash particles. Uncaptured SeO_2 releases into the atmosphere, threatening the environment and human health. Therefore, studying the participation behavior of selenium in fly ash is helpful to understand the transformation of gaseous selenium to particulates and to enhance selenium capture together with the particulate matter emission control.

In this study, we selected the fly ashes from a typical coal-fired power plant (P1.1) and a high-selenium coal-fired power plant (P1.2), respectively. The morphological analysis and thermal desorption

experiments of selenium in different grades of fly ash were performed to illustrate the mechanisms regarding selenium participation in fly ash. The results showed that selenium is mostly tetravalent in the fly ash regardless of the initial concentration and species of selenium in the coal. It was further confirmed that selenium in fly ash mainly exists in the form of selenite. At the same time, a small amount of SeO_2 is accompanied. As the particle size of fly ash decreases, the content of SeO_2 decreases gradually, indicating that SeO_2 is more likely to react with fine particles to form selenite.

Index No: 1.32

GASIFICATION KINETICS AND STRUCTURE CHARACTERISTICS OF PETROLEUM COKE AND COAL CHARs

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Gasification of petroleum coke and coal chars were studied using a drop tube reactor operating at 1100 and 1300 °C. Experiments were conducted to explore the influence of raw materials characteristics and the type of gasification agent on reaction kinetics and char structure evolution. Result showed that no matter CO_2 atmosphere or steam atmosphere, bituminous coal char showed the highest gasification activity, followed by anthracite char and petroleum coke. In addition, compared with the CO_2 atmosphere, the carbon conversion rate of char with steam was improved. The gasification process was well described by the random pore model. Activation energy of bituminous coal char under steam atmosphere was lowest, about 107kJ/mol. The evolution of char physicochemical properties during gasification process indicated that the char gasification reactivity was closely related to the degree of graphitization and pore structure. The order of increasing activation energy for char CO_2 /steam gasification correlated well with the degree of graphitization, but the dominant influence of CO_2 /steam gasification reactivity of three chars seems to be the pore structure. The pore structure of chars after steam

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gasification were more developed, had larger specific surface area, which has a positive influence for gasification reactivity.

Poster Session

Basic Coal Quality & Combustion 6

Frist floor and Second floor

1. Study on Alkali Metal Migration Characteristics in the Pyrolysis of Naomaohu Coal in CO Atmosphere
2. Modeling low NO_x combustion of blended coals in drop tube furnace
3. Effect of microstructures on char combustion reactivity
4. Effect of Mineral Composition on Ash Fusion Temperature and Crystal Composition
5. Release Characteristics of Alkali Metals in Oxygen-enriched Combustion of a Single Char Particle with Random Pore Model
6. Stability of Coal Water Slurry Analyzed Through Interparticle Potential
7. Characteristics of Alkali Metal Migration and Transformation During Pyrolysis of Naomaohu Coal
8. Slagging Behavior and Mechanism of High-Sodium-Chlorine Coal Combustion in a Full-Scale Circulating Fluidized Bed Boiler
9. Numerical analysis on methane steam reforming
10. Experimental and numerical investigations of Coal conversion Kinetics in oxy-fuel atmospheres
11. Co-combustion behaviors of Semi-Coke with bituminous coal in a Tangential Combustion
12. The char reaction behavior during O₂/CO₂ combustion: Exploring difference between for individual gases and their synergy
13. Numerical analysis of multi-objective optimization for coal gasification performance in the drop tube furnace, Part-1 effect of wall temperature and oxygen/coal ratio on coal gasification
14. Homogeneous Ignition Modelling by Different Criteria for Single Coal Particles
15. Experimental study on N transformation during shenhua bituminous coal pressurized pyrolysis
16. Experimental Study on Ignition and Combustion of Pulverized Coal Particles under Laminar and Turbulent Conditions
17. Effect of low ash content on the combustion characteristics of Zhundong coal
18. Full Combustion Process of Single Coal Particles at Microgravity on SJ-10 Satellite Experiments
19. Validation of a comprehensive kinetic mechanism for sulfur release during pyrolysis of solid fuels
20. Development of fast-heating macro-TGA for biomass pyrolysis
21. Comparability and validity range of pyrolysis kinetics from Chinese coals obtained with different experimental setups
22. Study on mineral phase transformation and ash melting mechanism of Zhundong coal and blended coal
23. Characteristics of Iron and Sulphur in High-Ash Pakistani Lignite and their Influence on Long-Term T23 Tube Corrosion under Supercritical Coal-fired Boiler Conditions
24. Numerical investigation of fly ash deposition onto tube bundles inside coal-fired boilers
25. Soot Formation in High-Temperature Pyrolysis of Various Coals
26. An Experimental Study on Ignition of Single Coal Particles at Low Oxygen Concentrations

Oral Session

Pulverized Coal Combustion 1

Monday, July 22, 2019

Index No: 2.1

AN EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER CHARACTERISTIC FOR WATERWALL UNDER ADVANCED ULTRA-SUPERCRITICAL CONDITIONS

Xueli Ge, Zhongxiao Zhang, Yufeng Chu, Haojie Fan, Jiancong Dong, Jian Zhang, Xu Wei
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The design and operation of water wall is crucial for the coming advanced-ultra-supercritical boilers. Heat transfer characteristics for spiral water wall have been conducted from 0.3MWt combustion and hydrodynamics experimental apparatus. The pressure of bulk is from 13.5 MPa to 41.0 MPa, mass flux varies from 124.4 to 557.1 kg/(m²·s), and maximum heat flux is ~448kW/m². The temperature and pressure distributions obtained in the test were exhibited. Obvious enhanced and deteriorative heat transfer performance were observed in the pseudo-critical region during the operating process. The distributed parameters model employed to analyze the heat transfer characteristics with five correlations selected. The comparison of the predicted and experimental temperature demonstrate that existing correlations could better simulate the heat transfer coefficients, such as Swenson et al. correlation for the top, Jackson et al. correlation for the middle and Mokry et al. correlation for the bottom furnace.

Index No: 2.2

A LABORATORY STUDY ON THE SPONTANEOUS COMBUSTION TENDENCY OF BLENDED COAL BETWEEN ANTHRACITE AND SUB-BITUMINOUS PULVERIZED COALS

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The use of coal with high volatile content requires precautions against spontaneous combustion due to low-temperature oxidation. Laboratory tests were carried out to investigate low-temperature oxidation (90 – 200°C) of five blended pulverized-coals with the sub-bituminous ratio of 0, 25, 50, 75 and 100% in anthracite coal filled in the three different sized mesh-cube baskets (30, 60 and 100 mm). In this result, the relation between the volume of coal piles and spontaneous combustion temperature and induction time is obviously seen. The larger stockpile volume, the lower spontaneous combustion temperature, the longer induction time. Moreover, the blending ratio of sub-bituminous coal to anthracite and spontaneous combustion temperature is also obtained. The high blending ratio of sub-bituminous coal shows a tendency for lower spontaneous combustion temperature at the same volume of coal pile. The data in this paper could be helpful for many coal firing power plant using anthracite and sub-bituminous coal to operate stably and safely.

Index No: 2.3

A REVIEW OF ASH SLAGGING MECHANISMS, SLAG VISCOSITY MEASUREMENT METHODOLOGIES AND THEIR APPLICATIONS TO LOW-RANK COAL AND BIOMASS SLAGS

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Gasification or combustion of coal/biomass is still the most important form of power generation today. However, the use of coal/biomass at high temperatures has an inherent problem due to the ash generated. The formation of ash leads to a problematic phenomenon called slagging. Slagging is the accumulation of melted

ash on the walls of the furnace, gasifier, or boiler and is detrimental as it reduces the heat transfer rate, combustion/gasification rate, causes mechanical failure, high-temperature corrosion and on occasions, superheater explosions. To improve the gasifier/combustor facility, it is very important to understand the key ash properties, slag characteristics, viscosity and critical viscosity temperature. This paper reviews the ash content, compositions and melting characteristics of ashes in the differently ranked coal and biomass, and discusses the slag formation mechanism, characteristics and structure of slag. In particular, this paper focuses on low-rank coal and biomass that have been receiving increased attention recently. This paper also reviews the available methodologies and formulae for slag viscosity measurement/prediction and summarises the current limitations and potential applications. Lastly, it discusses the slagging behaviour of the different ranks of coal and biomass by reviewing the viscosity measurement methods, viscosity prediction models and factors that affect the slag viscosity. This review shows that the existing viscosity models and slagging indices can only predict the viscosity and slagging propensity of high-rank coals satisfactorily. Available slagging indices and viscosity models are unable to predict the slagging propensity and slag viscosity of low-rank coal, and especially biomass ashes, and even if they are limited to a particular composition only. Thus, there is a critical need for the development of an index or model, which can predict the slagging propensity and slag viscosity correctly for all biomass ashes.

Index No: 2.4

INFLUENCE OF MASS-FLOW RATIO OF SECONDARY AND TERTIARY AIR ON GAS-PARTICLE FLOW CHARACTERISTICS OF A SWIRL BURNER IN 29MW PULVERIZED COAL INDUSTRIAL BOILER

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On a gas/particle two-phase test facility, a

three-component particle-dynamics anemometer (PDA) is used to measure, in a 29MW pulverized coal industrial boiler equipped with a new type of swirling pulverized coal burner, the characteristics of gas/particle two-phase flows. The distributions of three-dimensional gas/particle velocity, particle volume flux and particle size distribution under different working conditions were obtained. The results show that the mean axial velocity and the particle volume flux in the central region of the burner outlet are negative, which indicates that the central recirculation zone is formed in the central of burner. In the central recirculation zone, the absolute value of the mean axial velocity and the particle volume flux increase when the external secondary air volume increases. However, the size of the central reflux zone is basically unchanged when the air volume ratio is changed. Along the direction of the jet, the peak value formed by the tertiary air gradually moves toward the center of the burner, and is mixed with the peak value formed by the air in the ACC after $x/d=0.7$. Large particle size particles are concentrated in the near wall area, and the particle size of the the recirculation zone is small.

Index No: 2.5

EARLY STAGE SUB-MICRON PARTICLE FORMATION DURING PULVERIZED COAL COMBUSTION IN A TWO-STAGE FLAT FLAME BURNER

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In pulverized coal burners, coal particles transition from a short period of locally reducing environment, caused due to the fast release of volatiles from a dense region of coal particles, to an oxidizing environment. This “reducing-to-oxidizing” transition can influence combustion processes such as ignition, particulate formation, and char burnout. Traditionally, fundamental studies on coal combustion have been conducted in systems that capture neither the “reducing-to-oxidizing” transition nor the high heating rate of practical combustors. In this work the formation and evolution of sub-micron particles is investigated in a novel two-stage flat flame burner that simulates the “reducing-to-oxidizing” transition

and with heating rates on the order of 10^5 K/s. The particle size distribution (PSD) of the sub-micron particles, and their composition are measured using SMPS and SEM-EDX, respectively. Measurements are carried out under both an oxidizing environment (20% oxygen) and a “reducing-to-oxidizing” environment at two different nominal gas temperatures (1500 K and 1800 K), and three residence times. RGB color pyrometry is employed to measure particle temperature under the different environments. To differentiate between soot and mineral matter, the SMPS is operated in a tandem fashion, with a high-temperature furnace located between the two SMPS measurements. The furnace is supplied with sufficient oxygen to oxidize the soot in the sampled aerosol stream. The results, including the difference in the PSD before and after soot removal, will be discussed for both oxidizing and reducing-to-oxidizing environments.

Index No: 2.6

EFFECT OF NA AND FE ON SOOT FORMATION DURING PULVERIZED COAL COMBUSTION USING A TWO-STAGE HENCKEN BURNER

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The formation of fine particles in the initial stage of pulverized coal combustion involves the complex coupling of soot particles with mineral particles. Based on *ex-situ* measurements and *in-situ* optical diagnostics, this study investigated the effect of Na and Fe elements on soot formation during the combustion of pulverized coal particles. First, a two-stage multi-element flat-flame Hencken burner, which could flexibly adjust the atmosphere of the inner and outer flame, was developed. A high-speed thermophoresis sampling method was used to collect ultrafine particles in the pulverized coal flame at different oxygen concentrations. The TEM-EDS results showed that in the initial stage of Zhundong sodium-rich (SR) and iron-rich (IR) coal combustion, soot particles were composed of a carbonaceous component derived from the pyrolysis product, tar, and a mineral component containing Na (Fe). Secondly, the soot concentration in the

initial stage of pulverized coal combustion was measured by laser-induced incandescence (LII). The results showed that the soot formation rate of IR coal at 1500 K was higher than that of the SR coal at different inner flame oxygen concentrations. Moreover, soot from the SR coal samples was more sensitive to changes in oxygen concentration than IR coal soot. This may be due to the catalytic effect of alkali metal elements on soot oxidation. Finally, the Chemical Percolation Model for Coal Devolatilization (CPD) and Molecular Dynamics Simulation were used to theoretically analyze the soot production process of pulverized coal combustion. Under a similar tar yield condition, Fe in the IR coal has stronger promotion effect on the PAH molecule agglomeration process than Na in the SR coal. As a result, the soot in the iron-rich coal combustion has a higher soot formation rate and a lower soot oxidation rate than sodium-rich coal.

Index No: 2.7

2D TEMPERATURE COMPARISON BY CT-TDLAS MEASUREMENT AND CFD SIMULATION

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Gas temperature and species concentrations can be determined by measuring molecular absorbance at multiple wavelengths. Tunable diode laser absorption spectroscopy was used in this research. The principle of TDLAS is based on Lambert Beer's law. 2D distributions of concentration and temperature can be reconstructed by Computed Tomography (CT) using sets of H_2O densities and temperatures when combining CT and TDLAS. The theoretical H_2O absorption spectra near-infrared region calculated by the HITRAN database under one condition of 1000K and 0.1MPa. In this study, 2D temperature was measured using CT-TDLAS, which were compared with CFD simulation and thermocouple measurement. Theoretical H_2O absorption spectra Bunsen burner was employed for the experimental system of temperature measurement and accuracy analysis using the 32-path CT-TDLAS measurement cell with 32 collimators and 32

PD detectors. CT reconstruction accuracy depend on the number of laser beam, laser beam angles and its geometrical configuration. The CT-TDLAS system consists of two DFB diode lasers near 1388nm and 1343nm, lase driver, fiber splitter, amplifier, recorder and other equipment. 2D temperature distribution in CH₄-Air flame was also measured by a platinum-platinum rhodium thermocouple with a diameter of 100 μ m. 2D temperature distribution is reconstructed by CT according to the corrected spectroscopic database. 2D temperature distributions of CT-TDLAS and thermocouple measurement show the consistent results. In order to evaluate the accuracy of CT reconstruction, SSD (sum of squared difference) and ZNCC (zero-mean normalized cross-correlation) are employed to compare the 2D temperature distribution of original CFD and CT reconstruction.

Index No: 2.8

THE SULFUR MIGRATION DURING CO-PYROLYSIS OF HIGH-SULFUR COKING COAL AND HIGH-VOLTILE BITUMINOUS COAL

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With an increasingly huge amount of coal consumption and rapid depletion of the resources of superior coal, it becomes more and more important for the exploitation of inferior or low-grade coals, such as lignite and high-sulfur coal, which are distributed over the world. Coal blending is a useful way for efficient utilization of coal sources. The content of total sulfur in coal, including organic and inorganic sulfur. Inorganic sulfur can be generally removed by flotation or other physical methods. Organic sulfur is very difficult to be removed and have to undergo thermal processing to make the sulfur transform. The sulfur content in coke and the use amount of the coking coal may be reduced by blending coal during pyrolysis of coking coal through regulating the migration behaviors of sulfur according to the interactions existing in different kinds of coal samples. Based on this, some experiments were designed to analyze the influence of

blending coal on the sulfur migration during temperature programmed pyrolysis of high sulfur coking coal.

A coking coal with high organic sulfur (Coal A) and a bituminous coal with low sulfur (Coal B) from China were used as the experimental samples. yrolysis experiment. A novel two-stage fixed-bed reactor was designed to investigate the effect of the reaction between volatiles and volatiles or char on the sulfur transformation during coal pyrolysis. Firstly, the mixing samples containing different propotions of Coal A with Coal B were pyrolyzed, which was denoted as BL. Secondly, the coal B with the same proportions in sample of BL experiment was fed on the upper fixed-bed and Coal A on the lower fixed-bed to be pyrolyzed, which was denoted as BTA. Thirdly, the Coal A with the same proportions in sample of BL experiment was fed on the upper fixed-bed evenly and Coal B on the lower fixed-bed to be pyrolyzed, which was denoted as ATB. Fourthly, the same proportions Coal A and Coal B were fed on the two upper fixed-bed respectively to be pyrolyzed, which was denoted as AAB.

Index No: 2.9

INVESTIGATION ON NO_x FORMATION CHARACTERISTICS DURING SEMI-COKE AIRSTAGED COMBUSTION

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Semi-coke is the product of low-rank coal by pyrolysis at low temperature. If semi-coke could be used as fuel of industrial pulverized coal boilers, it will widen the fuel range of the industrial pulverized coal boilers and effectively promote the coal staged utilization. As the semi-coke need higher temperature than bituminous coal for its ignition and combustion process, the NO_x emission will rapidly increase with the rising of temperature. So, decreasing the NO_x is an important task in its utilization. In this paper, the NO_x emission rules at the higher fuel-rich zone temperature and properties of semi-coke air-staged combustion were explored by two-stage drop-tube furnace. In the air-staged combustion experiments, the influence of fuel-rich zone temperature and the ratio of air on NO_x

emission and combustion behavior were investigated. The results indicate that the NO_x emission concentration of non-staged combustion rises with fuel-rich zone temperature and the excess air coefficient in its combustion process. The air-staged combustion could visibly reduce the NO_x emission in the combustion process. As the Fig1. shows, the optimum ratio of secondary air is 0.56, at which NO_x emission concentration is under 120mg/m³ and the burn-out rates were above 90%. The conclusions of the burn-out rate and the decrease rate of NO_x can be used to guide the industry enlargement experiment in running conditions.

Oral Session

Pulverized Coal Combustion 2

Tuesday, July 23, 2019

Index No: 2.10

MEASUREMENT OF ASH FILM FRACTION FROM CENOSPHERES PROPERTIES DURING PULVERIZED COAL COMBUSTION

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During the pulverized coal particle combustion, part of the ash forms the ash film and exerts an inhibitory influence on combustion by impeding the diffusion of oxygen to the encapsulated char core, while part ash diffuses back into the char core. Despite the considerable ash effect on combustion, the fraction of ash film is still unclear due to its irregular structure and the difficulty of experimental measurement at high temperatures. However, the research on the properties of cenospheres can be an appropriate choice for the fraction determination, being aware that the formation of cenospheres is based on the model of coal particles with the visco-plastic ash film and a solid core. Therefore, its regular morphological form enables a simple calculation method. The fraction of ash film X is calculated by measuring mass of ash film to the ash content of coal particle according to the proposed

equation. In the present study, the Huangling bituminous coal with different sizes was burnt in a drop-tube furnace at 1273, 1473 and 1673K under air atmosphere. The Scanning Electron Microscope (SEM) and cross-section analysis have been used to study the physical properties of the collected ash cenospheres and the effects of combustion parameters on the fraction of ash film. The results show that the ash film fraction exceeds 0.85 at high temperature, which indicates that the majority of ash is distributed as ash film at char burnout stage. The ash film fraction increases with increasing temperature and carbon conversion ratio, while it decreases with the coal particles with a larger size. The high fraction of ash film provides a reasonable explanation for the extinction event at the late burnout stage. The varied values under different conditions during the dynamic combustion process are necessary for further development of the kinetic models.

Index No: 2.11

EXPERIMENTAL INVESTIGATION OF METHANE ASSISTED PULVERIZED COAL FLAMES USING AN OPTICAL ACCESSIBLE COMBUSTION CHAMBER

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The formation of inhalable fine particles ($d_p \leq 10 \mu\text{m}$) is an undesirable side effect of solid fuel combustion processes. These particles can accumulate in the human respiratory system and thus cause severe lung damage. Therefore, an understanding of the formation of these particles is of crucial importance to avoid or reduce the amount of fine particulate matter released into the atmosphere. For the investigation of particulate matter formation, a swirled methane assisted pulverized coal combustion test rig was developed, which allows intrusive and non-intrusive measurements to be performed during the combustion process.

Within the scope of this work, the developed test rig is described and results of laser Doppler velocimetry (LDV) measurement are presented. The velocity measurements were performed at different height levels of the flame to

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investigate the flame structure. Within this study, it is shown that the experimental setup achieves stable and reproducible combustion conditions to allow de-tailed investigations in further works.

Index No: 2.12

NUMERICAL OPTIMIZATION OF THE INFLUENCE OF MULTIPLE DEEP AIR-STAGED COMBUSTION ON THE NO_x EMISSION IN AN OPPOSED FIRING UTILITY BOILER USING LEAN COAL

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Multiple deep air-staged combustion is a promising technology to significantly reduce NO_x emission and maintains the low level of unburnt carbon in fly ash in opposed firing utility boilers using low volatile coals. The gas-solid two-phase flow, pulverized coal combustion and NO_x emission characteristics of an existing 600MW coal fired boiler was numerically simulated to analyze the influence of varied air distribution and multiple air-staged combustion on the NO_x formation and destruction in furnace. The detailed NO_x formation and reduction model is proposed to take account of the reduction between hydrocarbon species and NO under fuel rich conditions and well validated by the experimental results in one-dimensional coal combustion test furnace. The results show that stoichiometric ratios in the primary combustion region have important influence on the flue gas temperature distributions and the formation of reducing atmosphere in the primary combustion region, which have a significant impact on the NO_x emission. The NO_x concentration at the outlet of furnace is greatly reduced when the deep air-staged combustion with the burner stoichiometric ratio of 0.75 is adopted, and the CO concentration can be maintained at a low level. Compared with the operating mode with balanced air distribution, the pagoda and inverse pagoda type air distributions are found to be irrelevant to enhanced NO_x reduction performance under deep air-staged combustion conditions. By adopting the multiple air-staged combustion, the NO_x emission at furnace outlet will be further reduced because of the wider

reduction zone with high concentration reduction species in burnout region. Numerical calculation results agree well with the measurement data. The results are helpful to the design and operation optimization of similar opposed firing utility boilers using lean coal.

Index No: 2.13

DISTRIBUTION OF TEMPERATURE AND CHARACTERISTICS OF SOOT VOLUME FRACTION IN MILD-OCC FLAME

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Coal and methane were burnt in the MILD-OCC combustion flame under different combustion conditions to study the temperature distribution and characteristics of soot volume fraction. In this experiment, the flame temperature distribution is measured by thermocouple and the volume fraction (fv) of soot at each sampling point is calculated, then combining with the mass concentration of soot by the filter weighing method to obtain the distribution characteristics of soot in the flame. The results of thermocouple particle densitometry (TPD) show that the formation and oxidation of soot at every point in the flame is related closely to its position and temperature in the flame. The fv of soot in the center of the flame is negatively correlated with the temperature of the flame during the MILD-OCC combustion. The lower temperature region of the flame is conducive to the growth of soot, which leads to higher value of fv. The higher temperature in the center of the flame is beneficial to the oxidation of the soot particles, resulting to lower value of fv. The results of the filter membrane weighing method show that the formation of soot mainly occurs in the central region of the flame. When the radial distance increases, the flame temperature rises, and the soot concentration decreases due to oxidation. On the whole, the distribution of soot measured by the filter membrane weighing method is roughly consistent with that calculated by the TPD, which provides a reference for further research on the MILD-OCC combustion.

Index No: 2.14

EXPERIMENTAL STUDY ON CO-COMBUSTION CHARACTERISTICS OF SEMI-COKE AND COAL UNDER HIGH-TEMPERATURE AND DEEP-AIR-STAGING CONDITIONS

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Coal pyrolysis semi-coke is such a solid carbon-based product with ultra-low volatile content, and over-produced in China. Co-combustion of semi-coke and coal is a promising approach to efficiently utilize the excess amount of semi-coke, which can also improve the ignition and burnout characteristics. In the present work, experimental studies on NO_x formation and burnout characteristic under deep-air-staging and high-temperature conditions were conducted on a high-temperature vertical tandem-type drop-tube furnace (DTF) system for co-combustion of semi-coke and bituminous coal. The results indicated that more NO_x and unburned carbon (UBC) in ash was produced during combustion of semi-coke than that of bituminous coal, which can be caused by the relatively high char nitrogen fraction. The maximum of NO_x and UBC of semi-coke was up to 2169.3 mg/m³(at 6% O₂) and 44.38%, in comparison with 1332.1 mg/m³(at 6% O₂) and 11.57% of bituminous coal when T₁= 1500 °C. Due to the interaction, the NO_x formation of semi-coke was inhibited by bituminous coal, while the burnout characteristic was improved by the addition of bituminous coal, the maximum reduction of NO_x and UBC was 624.12 mg/m³ and 22.96% when bituminous coal of 55% fraction was blended. High temperature and strong reducing atmosphere (HT&SRA) was created by the deep air stage, and the NO_x formation of the blended fuel with semi-coke of 45% mass fraction dramatically declined to 284.7 mg/m³ under the condition of T₁=1600 °C and SR₁=0.5. For the blended fuel, the higher temperature favored less NO_x formation in reducing atmosphere, which is opposite in oxidizing atmosphere. The UBC declined with the rising temperature when SR₁ ranged from 0.5 to 1.2. The concentration of CO sharply increased with the decreasing SR₁, while that of CO₂ evidently declined when SR₁ went down. The higher

temperature led to better burnout performance in both primary and burnout zone, and the parameters of T₁=1600 oC and SR₁ ≤ 0.8 were recommended for the application of HT&SRA on co-combustion of semi-coke and bituminous coal.

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Tuesday, July 23, 2019

Index No: 2.15

NUMERICAL INVESTIGATION OF FLY ASH DEPOSITION ONTO TUBE BUNDLES INSIDE COAL-FIRED BOILERS

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Ash-related problems still give rise to technical challenges in the design and operation of coal-fired boilers. Deeper insights into ash deposition dynamics are needed to meet the emerging trends of flexible boiler loads and increasing economical requirements for burning low-rank coal. Different from mechanistic studies of single-probe deposition in lab-scale furnaces, practical boilers are featured with tube bundles in the convection zone and generally more turbulent flows. Thus, quantitative predictions of ash deposition rates for the both cases are beneficial to build the bridge over furnaces of various scales.

This paper numerically investigates ash deposition onto in-line tube bundles in a simulating environment of the reheater zone. The tube diameter is 40 mm and the surface is kept at 873 K. The flue gas is 1300 K and consists of 8 vol% O₂, 15 vol% CO₂, 7 vol% H₂O and N₂. Two inlet gas velocities are used: 10 m/s for practical boilers, whereas 2 m/s for our previous experiments in the 25 kW self-sustained combustor. The 2-D flow field is simulated with *k-ε* model using enhanced wall functions. Particles injected into the known flow field are driven by the drag force and thermophoresis.

A DNS result with similar Re_D is used for a comparison, which validates the accuracy of our simulation. A decrease in s_1/D enhances the impaction efficiency of inertial particles, whereas the increase of flow Reynolds number suppresses the impaction efficiency of thermophoresis-driven fine particles.

It is further revealed that, if all impacting particles stick, few particles can reach the tubes in the second and third rows. Hence the rebound particles from the front tube are expected to contribute remarkably to the deposits formed on the downside tubes. To better characterize this effect, three sticking-rebound criteria for incident particles are incorporated: (i) all sticking; (ii) all rebound and (iii) a criterion based on particle viscosity and kinetic energy. Accordingly, the initial deposition rate and morphology onto the bundle are predicted for a sodium-rich lignite and a common bituminous coal.

Index No: 2.16

APPLICATION OF COMPUTED TOMOGRAPHY - TUNABLE DIODE LASER ABSORPTION SPECTROSCOPY (CT-TDLAS) TO COAL COMBUSTION ANALYSIS

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Two dimensional (2D) temperature and concentration distribution plays an important role for the combustion structure and the combustor efficiency in engines, burners, gas turbines, etc. In this study, the theoretical and experimental research has been conducted to develop the non-contact and fast response 2D temperature and concentration distribution measurement method. The method is based on a computed tomography (CT) using absorption spectra of molecules such as H_2O , CH_4 , NH_3 , CO_2 , etc. CT-TDLAS was applied to CH_4 and 5 kg/h coal combustion fields to demonstrate its applicability to various types of combustor. The time resolved 2D temperature distributions were successfully measured using 32-path CT-TDLAS measurement cell in coal

combustion fields. CT-TDLAS has the kHz response time and the method enables the real-time 2D and 3D species concentration measurement to be applicable for the combustion analysis.

Index No: 2.17

EFFECT OF PARTICLE DISTANCE ON COMBUSTION BEHAVIORS THROUGH 1-D MODEL WITH NEUMANN BOUNDARY CONDITION

*L. Feng, Y. Wu, K. Xu, H. Zhang, Y. Zhang
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Moderate or intense low oxygen dilution (MILD) combustion is a promising technology for coal utilization due to the uniform heat flux and low NO_x emission. In such coal cloud combustion, investigation on the effect of surrounding particles on the single coal combustion behaviors is essential. In this work, the effect of particle distance (d/d_0) on ignition, volatile flame, soot volume fraction (fv) and combustion modes were studied through a 1-D model with Neumann boundary condition. The predicted ignition time (t_i) with homogeneous ignition criterion at different particle number density agrees well with the literature results. The ignition of coal jet is dominated by small particles. When d/d_0 is small, the surrounding gas is not enough to heat up the particle to form a visible volatile flame; and the particle heating rate is slower than that for large d/d_0 , leading to a longer t_i . When d/d_0 increases, the flame temperature increases first and then barely changes, while the position of volatile flame gets closer to particle surface. When the oxygen mole fraction (xO_2) is lower, the flame temperature is lower, and the position of volatile flame is farther away from particle surface. When d/d_0 increases, fv increases dramatically at first and then barely changes. When xO_2 is lower, fv is smaller. As d/d_0 increases, at 5% xO_2 , the soot emission increases dramatically at first and then moderately; meanwhile, at 12% and 21% xO_2 soot emission increases at first and then decreases. At 21% xO_2 , when $d/d_0 < 15$, it is sheath combustion mode; when $15 < d/d_0 < 90$, it is group combustion mode; when $d/d_0 > 90$, it is individual combustion mode.

Index No: 2.18

LOW TEMPERATURE VORTEX FUEL COMBUSTION: EXPERIENCE AND POSSIBILITIES

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Technology of low temperature vortex (LTV) combustion of solid organic fuel is widely used in the Russian energy sector. The peculiarity of LTV technology is on principle of combustion organization of coarse grained fuel in the multiple particle vortex circulation at the active zone of combustion. LTV technology has been extensively verified at modernization of boilers with steam production from 35 to 1600 t/h and has proven its main advantages: a stable ignition and combustion of fuel, an absence of ash slugging and fouling of heating surfaces and low level of harmful emissions into the atmosphere. In order to increase combustion efficiency, reliability and service life time of the equipment, new technological schemes and design of firing systems and burners for furnaces with vortex combustion organization have been developed and applied. Over the years the company "NTV-energo" has successfully carried out a series of projects with the implementation of LTV technology burning peat, lignite and hard coal in the boilers of different steam generating capacity. Modernization of boiler plants performs by applying a complex approach that includes: application membrane-tight semi-open vortex furnace with overlapping of walls in the bottom of the furnace hopper, the new scheme and design of firing system and burners, improved (when necessary) scheme of water-steam system, reconstruction of fuel preparation system (FPS) and other. The main tasks at the execution of boilers modernization were the following: increase of reliability of the FPS, securing of continual fuel supply, spreading of controlling range and increase of FPS capacity; improvement of stability of ignition and cutting of need for firing support with use of the secondary fuel (gas or heavy fuel oil); reduction of slagging and fouling of heating surfaces and increase of steam generating capacity without slagging up to the nominal (and in some cases above it);

provision of high combustion efficiency of solid fuels, even at changing in their thermo technical characteristics in a wide range, as well as the reduction of gaseous pollutants emissions below the required level. The report summarizes the experience of LTV combustion of solid fuels. As an example, the results of successful modernization of the boiler P-49 of 500 MWel unit at TPP "Nazarovskaya" (Russia) are shown. Fuel – heavily slagging lignite. The following results have been obtained:

- operation range of unit electrical load is significantly expanded (from 290 to 500 MWel);
- need for firing support, with heavy fuel oil, on the lowered loadings is excluded;
- gross boiler efficiency is increased (from 86 to 91 %);
- emissions of nitrogen oxides are radically reduced (from 1200 to 400 mg/nm³).

Applied combustion technology with LTV design solutions can be used at the modernization of the existing and construction of new boilers, unified by fuel.

Index No: 2.19

FORMATION MECHANISMS OF PM FROM COMBUSTION OF LIGNITE WITH HIGH CONTENTS OF NA, MG, CA, S, FE: THE EFFECT OF FURNACE TEMPERATURE

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The effect of Na, and Ca in PM formation from zhundong lignite combustion has been widely investigated, while Mg, S, and Fe could also be enriched in PM but the correlate research is not enough. We choose three kinds of zhundong lignite (ZD, YH, and HSY respectively) with different mineral compositions. The air combustion of the three lignite was conducted in an entrained flow reactor. The participation of Na, Mg, Ca, S, and Fe into PM10 are studied under FT (furnace temperature) of 1173-1573K. The PSD (particle size distribution) and elemental composition of PM were obtained through DLPI (Dekati low pressure impactor) and SEM-eds (scanning

electro-microscope equipped with energy dispersive spectrometer). Experiment results show that the yields of PM_{0.1} are generally positively correlated with FT while the yields of PM₁, PM_{2.5}, and PM₁₀ are not monotonic with FT. PM₁ is mainly composed of Ca, Mg, Na, Fe, and S while Ca, Fe, Si, and Al are the main components of PM₁₋₁₀. Enhanced volatilization of Ca, Mg, Fe contribute most to the increase of PM_{0.1} under higher FT although the gasification of Si and Al is also strengthened. The release of Na is highest under 1173K FT and the Na participation in PM₁₀ is inhibited by the capture through coarse particles under higher FT. The formation of PM₁₋₁₀ is governed by the competition between coalescence and fragmentation which can also influence the yield of PM₁. The lowest concentrations of PM₁, PM_{2.5}, and PM₁₀ are found at 1273-1373K FT for YH and HSY while the variation of PM with FT is not obvious for ZD, probably due to the offset effect of coalescence and fragmentation within the experimental FT range.

Index No: 2.20

LABORATORY AND INDUSTRIAL STUDIES OF GAS COAL IGNITION AND COMBUSTION USING HIGH-VOLTAGE AC PLASMATRON

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This work presents experimental studies and industrial applications of a promising method for coal fuel ignition and combustion using a high-voltage AC plasmatron. Experimental studies were carried out on a setup with a thermal capacity of up to 5 MW. As the experimental sample was selected Coal of DG grade, selected after the ball-drum mill with the residue on the sieve $R_{90} = 15\%$ was taken as an experimental sample.

Initially, the electrode unit was turned on; the power spent on plasmatron operation was 5 kW. The experiments were carried out with an air excess factor of 0.4–0.5 and coal consumption of 180 kg/h. After applying the coal dust to the electrode unit, ignition and further combustion were observed in the swirler and combustion chamber.

The main combustion occurred in the initial zone of combustion chamber, the temperature rose to 1200°C within 30 seconds after the beginning of coal supply. The full-scale testing of the high-voltage AC plasmatron was performed by JSC Sibtekhenergo, Novosibirsk, using the single-drum boiler of E-220-100-540 (TP-10) type.

The consumed electric power of plasmatron is 5 kW. The heat power of burners is up to 8 MW. The system provides stable and steady ignition of coal dust when starting the boiler from a cold state. The burner organizes the supply of a burning flame with a temperature of 1250 ... 1350 °C to the combustion chamber. During plasmatron operation, the flame from the muffle burner spreads into the furnace chamber at 5 m. Fuel oil was not fed into the boiler furnace during the whole time of lighting. The temperature of the drum walls before the beginning of lighting was ~ 105 °C. The temperature of gases behind the steam superheater was 70 °C.

Index No: 2.21

RESEARCH ON THE RECIRCULATING AND COMBUSTION CHARACTERISTICS IN A REVERSE-JET SWIRL PULVERIZED-COAL BURNER

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Due to the high combustion efficiency and strong automatic control, the industrial pulverized-coal boiler is receiving increasingly attentions from researchers. The development of industrial pulverized coal combustion technology to reduce the pollutant emissions, stabilize combustion under low boiler loads and achieve good coal adaptability has become a core research content. In this work, employing the numerical simulation and industrial tests, the recirculating and combustion characteristics in a reversejet swirl pulverized-coal burner were examined by incrementally increasing the secondary air velocity and adding the stuff body. The results reveal that the primary coal/air flow has a long reverse-jet trajectory and a stable high-temperature recirculation zone forms inside the burner. On increasing the secondary air velocity, the recirculation area enlarges. Correspondingly, the endothermic length of primary air

prolongs and the pulverized-coal reverse-jet velocity increases, which is conducive to prolong the pulverized-coal trajectory and further increases the area of the reduction zone, the early fuel-NO_x generation is largely restrained. While some unexpected problems appear including too early coal ignition, wall overheating and near-wall particle enrichment. Adding the stuff body also facilitates to form a large recirculating reduction zone. Additionally, the recirculation location is stabilized in the burner central zone, and the near-wall particle mass concentration greatly decreases. The combustion stability improves with the standard deviation of pressure fluctuation at the furnace exit reducing from 173 to 94 Pa, simultaneously, the coal burnout greatly enhances, the carbon in fly ash reduces from 18.63 to 8.55%.

Index No: 2.22

EFFECTS OF PYROLYZED SEMI-CHAR BLEND RATIO ON COAL COMBUSTION AND POLLUTION EMISSION ON A 0.35 MW PULVERIZED COAL-FIRED FURNACE

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Effects of blend ratio on combustion and pollution emission characteristics for co-combustion of shenmu pyrolyzed semi-char (SC), residuals of coal pyrolysis chemical processing instrument, and shenhua bituminous coal (SB) were investigated in a 0.35MW pilot-scale pulverized coal-fired furnace. Gas temperature and concentrations of gaseous species (O₂, CO, CO₂, NO_x and HCN) were measured in the primary combustion zone for different blend ratios. It is found that the stand-off distance of ignition changes monotonically from 132 to 384 mm with the increase of pyrolyzed semi-char blend ratio. Effects on the combustion characteristics may be neglected when blend ratio is less than 30%. Above 30% blend ratio, the increase of blend ratio postpones ignition in the primary stage and lowers burnout rate. With blend ratio increasing, NO_x emission at furnace exit is smallest for 30% blend ratio and highest for 100% SC. So, the blend ratio of

SC no more than 45% can be suitable for the burning of semichar.

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Wednesday, July 24, 2019

Index No: 2.23

NUMERICAL SIMULATION OF THE EFFECT OF GRADING SIZE ON COAL WATER SLURRY GASIFICATION

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Coal gasification is a key process in coal chemical industry. The slurry feed type entrained-flow gasification process has been deeply studied and widely promoted by Shanxi Research Institute for Clean Energy, Tsinghua University in China. Grading size is an important index of coal water slurry (CWS) and it has been proved by industrial operation that grading size can effectively affect the content of effective gas so as to the specific oxygen and coal consumption.

Based on commercial CFD software Fluent, numerical simulation was used to simulate the effect of grading size on the combustion in a GE gasifier as well as the carbon conversion ration during the coal water slurry gasification process. Three different grading size particles were selected for calculation. For double peak grading, the particles were consisted of two size ranges which were coarse and fine respectively. For the narrow grading, the particles were consisted of three size ranges and most particles were in medium size ranging from 80-120um. For the wide grading, the particle were consist of five size ranges and had a more uniform size distribution. The temperature field, flow field, particle concentration field and raw syngas composition were investigated under different grading sizes.

The temperature distribution results showed that, the wide grading size condition get a longer flame length and more combustion intensity compared with the double peak and narrow grading size in the same amount of feeding coal. For the wide grading size condition, the highest temperature in jet region exceed 2000K at position $h/D=1.8$. With the jet steam development, the temperature declined along the axis due to the char gasification and jet entrainment. The double peak and narrow size conditions had the similar changing trend. However, their temperature level was lower than the wide grading size condition so as the highest temperature position was closer to the burner. The wide grading size condition also showed an about 2-4% higher effective gas content than the other two conditions. Coal slurry concentration was confirmed to be the most important reason to cause this difference. For wide grading size, the particles of each grade collocated reasonably, thus increasing the slurry concentration and improving the gasification efficiency. Some other reaction characteristics were also analyzed to compare the gasification performances.

Index No: 2.24

INCREASING THE S ACTIVE SITES OF ACTIVATED CARBON WITH NON-THERMAL PLASMA FOR ELEMENTAL MERCURY REMOVAL

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Elemental mercury (Hg₀) from coal-fired power plants is difficult to be removed due to its low reactivity, low solubility and high volatility. Among Hg₀ removal methods, activated carbon injection technology needs to be improved due to a high C/Hg ratio and a large operating cost.

In this paper, non-thermal plasma (NTP) was applied to modify activated carbon in the sulfur containing gas for improving the elemental mercury (Hg₀) removal performance. The physical and chemical properties of raw and modified AC were characterized by scanning electron

microscopy with energy disperse X-ray spectroscopy (SEM-EDS), Brunauer-Emmett-Teller (BET) and X-ray photoelectron spectroscopy (XPS). The Hg₀ removal performance of modified AC was tested by a bench-scale fixed bed. The results indicated that non-thermal plasma treatment in the sulfur containing gas enhanced S content of raw AC. Moreover, S content and Hg₀ removal efficiency of modified AC increased with the increase of gas concentration. The reason was that higher concentration gas loaded more S active sites on raw AC and S active sites played a significant role during the Hg₀ removal process. Combined the results of temperature programmed desorption and XPS analysis, the mechanism of Hg₀ removal was that Hg₀ reacted with elemental S on the surface of modified AC to form HgS.

To improve the Hg₀ removal efficiency, H₂S was introduced into NTP process as an active gas. Fig. 1 shows instantaneous Hg₀ removal efficiency of different ACs at 140 °C. As seen from Fig.1, raw AC had poor Hg₀ removal performance and its instantaneous Hg₀ removal efficiency was 25%. The instantaneous Hg₀ removal efficiency of modified AC (C5000-t1) was 70% and it is the highest among the above four samples. This may be attributed to the fact that NTP treatment in the presence of H₂S could increase more S active sites on the surface of modified AC.

Index No: 2.25

EXPERIMENTAL STUDY ON COAL WATER SLURRY PYROLYSIS IN FLUE GAS RECIRCULATION TRANSPORT BED

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The use of coal pyrolysis gas can reduce the NO_x produced in combustion process, so as to achieve ultra-low emission. In order to improve the yield of hydrogen, carbon monoxide and methane in pyrolysis gas, 20 kg/h conveyor bed pyrolysis equipment was used to pyrolysis high concentration coal water slurry, and different temperature recycling flue gas was used as pyrolysis carrier to reduce energy consumption. The temperature

programmed pyrolysis reaction shows that under the condition of micro-positive pressure and temperature of pyrolysis flue gas in the furnace at 900-1300 C, the pyrolysis of tar and other heavy hydrocarbons produced by coal-water slurry pyrolysis is complete. The main products of pyrolysis are hydrogen, carbon monoxide and methane, which account for 26.5%, 24.2% and 1.8% respectively. The high temperature flue gas circulating to the conveyor bed is used as heating source for coal water slurry pyrolysis, which does not require high pressure and pure oxygen. The pyrolysis system is simplified and the utilization rate of energy is improved.

Index No: 2.26

STUDIES ON EFFECTS OF SWIRL BURNER ARRANGEMENT ON THE OPERATING PERFORMANCES OF 116MW PULVERIZED COAL INDUSTRIAL BOILER

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In this paper, the effects of the burner arrangement on the performances, i.e. flow and combustion of the 116 MW pulverized coal industrial boiler. Two modes, including offset and tangential arrangements of the reverse-jet swirling burner are involved. The aerodynamic characteristics of the airflow and combustion characteristics of the pulverized coal under different conditions are compared. The results show that the combustion near the exit of the burner can be enhanced under the condition of the offset arrangement, whereas the local high temperature exits and flame full degree is not good. The center of the furnace has a good airflow vortex under burner tangential arrangement. For the case of tangential arrangement, less rigid of the outlet airflow is noticed and it exhibits swirling flow is visible. Burner tangential arrangement is fit for 116MW industrial boiler than opposed arrangement.

Index No: 2.27

NUMERICAL STUDY ON COMBUSTION AND NO_x

EMISSION CHARACTERISTICS OF CO-FIRING SEMI-COKE AND COAL IN A TANGENTIALLY-FIRED UTILITY BOILER

Qiniqin Feng, Chang'an Wang, Pengqian Wang, Zhichao Wang, Wei Yao, Lei Zhao, Yongbo Dua, Defu Che

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With the booming coal industry and the increasing production of semi-coke, a large number of small particles and powder pyrolysis semi-coke are urgent to be exploited. Co-firing semi-coke with coal is a potential approach to achieve clean and efficient utilization of such low-volatile fuel. In this paper, the co-combustion performance of semi-coke and coal in a 135 MW tangentially-fired boiler was investigated by numerical simulation. The influences of semi-coke blending ratio, blending mode and injection position on the combustion efficiency and NO_x generation characteristics of the utility boiler were extensively analyzed. The simulation results indicated that the NO_x emission at the furnace outlet was elevated and the burn-out ratio declined with an increase in semi-coke blending ratio. Different heights of semi-coke injected position could lead to different combustion efficiency and NO_x emissions. The semi-coke was recommended to be injected from the middle layer of burners to obtain low carbon content in fly ash. The blending methods (in-furnace versus out-furnace) had certain impacts on the NO_x emission and carbon content in fly ash. High burn-out ratio could be obtained when the semi-coke and coal were injected from different burners.

Index No: 2.28

THEORETICAL ANALYSES ON ISOLATED PARTICLE IGNITION OF COAL AND BIOMASS

Ye Yuan, Yang Xu, Hongpei Gao, Zhenghai Shi, Xianbin Sun, Ping Xiao, Shuiqing Li

Huaneng Clean Energy Research Institute

In this paper, an improved transient ignition model is used to study the ignition differences between coal and biomass particles, including ignition time and modes. Using the inflection condition for particle temperature, the

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heterogeneous ignition time can be determined. Meanwhile, the spatial gas phase temperature distribution can also indicate the homogeneous ignition time. The calculation has evaluated the particle ignition characteristics, with ambient temperature from 1200 K to 1800 K, particle diameter from 2000 to 40 μm and oxygen mole fractions in the range of 10–30%. It can be found that heterogeneous ignition always occurs first for the range of coal particles from 40 μm to 100 μm with temperature increases from 1200 K to 1800 K. Compared with small coal particles, 500 μm to 2000 μm biomass particle usually ignites homogeneously. The 500 μm biomass particles ignite almost at the same time with coal particles in pc boiler. The changing behavior of ignition temperature is also investigated in this work. The ignition temperatures of small coal particles are all around 1000 K, while ignition temperatures of big biomass particles vary from 650 K to 500 K. In the end, the spatial gas temperature and oxygen species distribution are also used to characterize the particle ignition.

Poster Session

Pulverized Coal Combustion 5

First floor and Second floor

1. Numerical Study on Influence of Platen Super-heaters on Heat Deviation in a 600 MW Tangentially Fired Pulverized-Coal Boiler
2. Simulation of the Release of Coal Volatile Species in a CFB Boiler Based on 1D Modelling
3. Numerical Investigation on Combustion Characteristics and NO_x Emission of Double-Reheat Tower Boiler at Different Loads
4. Numerical Simulation on Combustion Characteristics of Co-firing Biomass Syngas and Coal in a 660 MW Utility Tower Boiler
5. Deactivation of V₂O₅-WO₃-TiO₂ SCR Catalyst by HF during Co-firing Electrolytic Aluminum Waste with Coal
6. Numerical Simulation on Pulverized Coal Combustion Chamber with Air Cooling
7. Numerical Investigation on combustion Stability of coal slurry in the Double Cone Burner
8. The effect of vermiculite on mineral transformation in Zhundong coal combustion
9. Experimental study of NO_x emission and char characteristics
10. Understanding the effect of calcium containing compounds on ash deposition for Zhundong coal combustion: molecular dynamics simulations
11. Effect of inner/outer secondary air mass flow rate on the airflow characteristics of the 14-MW double cone burner
12. Industrial Experimental and Numerical Simulation Study on the Combustion and NO_x Formation Characteristics In a 600MWe Utility Boiler with a Novel Swirl Burner Burning Bituminous Coal
13. Development of Coal Pulverization Equipment for Powerful Thermal Power Units
14. Investigation of Cold-state Flow Characteristics in Horizontal Cyclone Combustor for High-Alkali Coal
15. Effects of pyrolyzed semi-char blend ratio on coal combustion and pollution emission on a 0.35 MW pulverized coal-fired furnace
16. Measurement of Ash Film Fraction from Cenospheres Properties during Pulverized Coal Combustion
17. A review of ash slagging mechanisms, slag viscosity measurement methodologies and their applications to low-rank coal and biomass slags
18. Application of Computed Tomography - Tunable Diode Laser Absorption Spectroscopy(CT-TDLAS) to Coal Combustion Analysis
19. Effect of Na and Fe on Soot Formation during Pulverized Coal Combustion Using a Two-stage Hencken Burner
20. Experimental Investigation of Solid Fuel Endowed Flames using a Highly Optically Accessible Combustion Chamber

Oral Session

Emission Controls 1

Monday, July 22, 2019

Index No: 3.1

DEVELOPMENT OF OXY-CFBC TECHNOLOGY IN FEP CONVERGENCE RESEARCH CENTER

Changwon Yang, Yongdoo Kim, Byungryeul Bang, Soohwa Jeong, Jihong Moon, Taeyoung Mun, Sungho Jo, Jaegoo Lee, Uendo Lee
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Circulating Fluidized Bed (CFB) boiler has been steadily implemented in energy production market because it has many advantages in terms of availability of various low-grade fuels, and capabilities of in-situ DeSO_x and DeNO_x. Recent global warming issue and increase of intermittent power generation have created demands of technology developments for high-efficiency, low-emission (HELE) technology and flexible operation of thermal power plant. To cope with these demands, FEP Convergence Research Center has been developing Oxy-combustion technologies of CFB boiler for medium and large-sized thermal power generation and biomass/waste boilers. The aim of the project is to develop Oxy-CFB system with low-grade fuel (calorific value of less than 5,000 kcal/kg) while maintaining high efficiency and low pollutant emission. Operation technology with rapid load variation, and load ranges are of interest too.

In order to develop the technology, research and development are underway through various approaches with experiments of pilot and demonstration scale facilities, and multi-dimensional numerical simulation of Oxy-CFB system. Research related to material testing for high efficiency boiler and water recovery technologies of exhaust gas are also being studied. In this presentation, the current research activities of FEP convergence research center will be introduced.

Index No: 3.2

SODIUM TRANSFORMATION SIMULATION WITH A 2-D CFD MODEL DURING CIRCULATING FLUIDIZED BED COMBUSTION

Jieqiang Ji, Leming Cheng, Li Nie, Liyao Li, Yangjun Wei
Zhejiang University, China

Studying on the release behaviors of alkali and alkaline earth metals is necessary to understand the mechanisms of ash related problems such as fouling, slagging and corrosion while burning fuel with high alkali contents. Based on the 2-D circulating fluidized bed (CFB) combustion model combined with the sodium migration model, the sodium transformation was predicted in a 30 kW CFB combustor. Simulation results from the 2-D calculation were in agreement with those from the 3-D computation and experiments. Calculation and analysis on the sodium transformation with different parameters including furnace temperature, excess air and secondary air ratio were carried out. Results show that higher furnace temperature leads to more deposited sodium and ash particles on the probe surface. Increasing the excess air or decreasing the secondary air ratio may reduce the contents of deposited sodium and ash particles.

Index No: 3.3

COLD-EXPERIMENTAL STUDY ABOUT PRESSURE RESISTENCE OF CFB WIND CAPS

Tong Boheng, Zeng Hongyu, Zhang Qingfeng, Lyu Junfu
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Air distributor is one of the most important devices to maintain stable and high-efficient operation of circulating fluidized bed boilers. And the pressure drop of the air distributor determine the effect of air distribution and efficiency. The wind caps are the essential parts of air distributors, whose structures determine the pressure drop. Therefore, predicting the resistance of wind caps is one of

3

the most important issues in CFB boiler design. At present, there is little study and theoretical inference about the pressure drop prediction when the diameters of internal structure change. In this study, cold-modelling experiments were made to study the flow characteristics and the resistance regulation as geometry parameters changes qualitatively.

Index No: 3.4

IGNITION AND COMBUSTION OF A SINGLE COAL PARTICLE IN A FLUIDIZED BED IN O₂/N₂ AND O₂/CO₂ ATMOSPHERES

*Xiehe Yang, Zhining Wang, Yang Zhang, Daoyin Liu, Jiansheng Zhang, Hai Zhang, Junfu Lyu
Tsinghua University, China*

To investigate the fuel combustion characteristic under both O₂/N₂ and O₂/CO₂ atmospheres at fluidized bed combustion conditions, a one-dimensional transient single particle combustion model was established from the theoretical point of view. The model accounted for the fuel devolatilization, moisture evaporation, heterogeneous reaction as well as homogeneous reaction integrating with the heat transfer from fluidized bed combustion environment to particles. Validation of the simulation was made by comparing the model prediction and the experimental results in the literature to prove the model reliability. Due to the evaporation of the moisture in the fuel particle, a plateau appeared on the particle center temperature curve during the initial period of the thermal conversion process. Different from the cases in the pulverized coal boiler, particle temperature evolutions under different atmospheres in the fluidized bed were almost the same, indicating that the strong heat and mass transfer controlled the combustion process in fluidized beds. Besides, the carbon conversion rate under O₂/CO₂ condition was greater than that under the O₂/N₂ atmosphere, which was resulted from the gasification reaction between the CO₂ and the fuel particle.

Index No: 3.5

EXPERIMENTAL RESEARCH OF PRIMARY FRAGMENTATION OF WOOD BIOMASS PARTICLES IN

FAST PYROLYSIS PROCESS

D. S. Litun, G. A. Ryabov

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The first results of studies of primary fragmentation of wood biomass particles during fast pyrolysis in an inert medium at different temperatures are presented. Experiments were carried out using a laboratory tube furnace "SNOL" with a chamber diameter of 35mm, equipped with a system of supply and measurement of inert gas flow and scanning electron microscope for SEM analysis. The influence of bed temperature, particle size and shape on the quantitative characteristics and criteria of particle fragmentation, causes and nature of wood particle cracking are considered and analyzed. Increasing the temperature and initial size in the range $t = 800 - 950$ °C increases the probability and intensity of fragmentation in the process of rapid pyrolysis of wood particles. The ratio of longitudinal to transverse size and, more broadly, particle shape, has a significant effect on the fragmentation of wood particles and should be considered as one of the main factors affecting the fragmentation of wood particles, as well as temperature and initial size. Oblong particles are more prone to fragmentation than quasi-circular (cubic) particles with the same equivalent diameter. The critical diameter of fragmentation of spruce wood particles at a process temperature of 950 °C is $d_{v0} = 18-19$ mm for the ratio of longitudinal and transverse size $h/a = 1$ and is in the range of 7 -9 mm for $h/a = 8$. For spruce wood particles in the considered temperatures and equivalent diameters ($t = 800 - 950$ °C and $d_{v0} = 7 - 25$ mm) is characterized by fragmentation due to the volatile release stresses forming large fragments. The role of thermal stresses is negligible, although it increases slightly with increasing temperature. The decay of spruce wood cubic particles into fragments is due to the formation of large cracks arising on the surface and propagating to the center of the particles. The mechanism of fracturing is a consistent, mainly longitudinal rupture of the walls of hollow elements of the wood microstructure (tracheids) due to the volatile release stresses. The irregularities in the places of exit to the outer surface of the particle boundaries of late (autumn) and early (spring) wood gain contribute to the origin of cracks

on the particle surface. Study of microstructure and chemical composition of coke particles (fragments) by microscope with SEM analysis showed existence of thin outer layer (0-15 μm) on the surfaces of particles, containing increased quantity of mineral components. Microspheres with size of 13-23 μm and increased content of sulfur were detected on the surface of particles, resulting at 950°C. Spherical form is possible to be the effect of plastic state. The surface of outer layer including microsphere surface mostly has irregular round –convex inclusions with size of few μm . The surface zones of maximum chlorine content coincide with same of sodium and potassium. It denotes on existence of sodium and potassium chlorides on the surface of coke particles.

Index No: 3.6

EMISSION CHARACTERISTIC OF NO_x IN CFB BOILER AT LOW LOAD

Lujian Chen, Xin Tao, Shouyu Zhang, Hairui Yang, Junfu Lyu
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In order to study the NO_x emission of CFB boiler at low load, a bubbling fluidized bed test was established to investigate the effects of bed temperature, excess air ratio and particle size of ZY coal on NO_x emission. A continuous feeder was used to ensure the feeding rate steady, so that the significant parameter excess air ratio can be confirmed. By comparing the NO_x emissions of different conditions, the influence law of three parameters can be obtained.

The results showed that the bed temperature has a two-sided influence on NO_x emission, increasing bed temperature had a negative effect on NO_x emission when temperature was over 750°C, but increasing bed temperature had a promotional effect on NO_x emission when temperature was below 750°C. At a given temperature, the NO_x emission depended mainly on the excess air ratio. In the same condition, the NO_x emission generated in the combustion process of larger particle coal was higher than the value of small particle coal.

Index No: 3.7

CHARACTERIZATION OF THE SULFATION REACTIVITY OF LIMESTONES WITH DIFFERENT PARTICLE SIZE IN A LARGE-CAPACITY TGA

*Yiran Li, Runxia Cai, Man Zhang, Hairui Yang, Junfu Lyu**
Tsinghua University, China

In order to improve the efficiency of CFB desulfurization, the influence factors in the utilization rate of limestone should be thoroughly investigated, however, some factors are still under debate. The mainstream viewed that the limestone with particle size of circulating ash, normally 100-200 μm , behaves best. While limestones of smaller particle, with higher reaction rate and conversion rate, may become sensible for desulfurization with the development of cyclone. So it is necessary to study the effect of limestone particle size on reaction rate and calcium conversion rate.

In this research, the sulfation process of limestone with a broad range of particle sizes was investigated under different SO₂ concentration, CO₂ concentration, and temperatures by using a large-capacity TGA. The experimental results were also compared with those obtained in a fix bed reactor. The result shows that for both two kinds of limestones, conversion rate changes in similar patterns and declines with decreasing SO₂ concentrations. The desulfurization performance of limestone is strongly influenced by its particle size and increases rapidly with the decreasing of particle size. The maximum sulfur efficiency achieved at 850°C ~900°C, which is widely accepted in literature. Besides, the conversion rate and initial reaction rate increase slightly with the increase of CO₂ concentrations, and this phenomena needs further investigation.

Index No: 3.8

EFFECT OF ATMOSPHERE ON LIGNITE CHAR STRUCTURE AND GASIFICATION REACTIVITY IN A FLUIDIZED BED REACTOR

Shuai Tong, Lin Li, Lunbo Duan, Changsui Zhao, Zhipeng Shi
Southeast University, China

Lignite was pyrolysed in pure N₂, 50%N₂/50%CO₂

and 50%N₂/50%H₂O in a fluidized bed (FB) reactor with the temperature of 1160K. Then the raw coal and three kinds of coal char were analyzed by SEM, BET, FTIR and Raman to study the effect of atmospheres on char structure. After, the three different lignite chars were gasified with 50%N₂/50%CO₂ and 50%N₂/50%H₂O in 1160K, aiming to make it clear that the dependence of reactivity with the char structure. Results indicate that after pyrolysis in different atmospheres, the surface roughness of char is obviously improved and the pore structure is developed. The specific surface areas of lignite and three different chars follow the trend: lignite<N₂ char<CO₂ char<H₂O char. The number and intensity of functional groups of three kinds of chars are much lower than that of raw coal, especially those hydroxyl and oxygen- containing. However, there are similar number and intensity of functional groups between three different chars, indicating the effect of different pyrolysis atmospheres on the functional groups of char is not significant. The results of Raman spectral analysis express that the content of disordered and amorphous carbon follows the order: lignite<N₂ char <H₂O char <CO₂ char. The results of gasification experiments reveal that H₂O char has the best gasification reactivity, indicating the char gasification reactivity is much related to its pore structure and surface roughness.

Index No: 3.9

ASH DEPOSITION AND HEAT TRANSFER DETERIORATION IN THE CONVECTION HEATING REGION OF CFB BOILER BURNING HIGH NA AND CL COAL

*Jiaye Zhang, Daoyang Ma, Jingbin Zi, Yongbing Wang, Peng Li, Xuebin Wang
Xi'an Jiaotong University, China*

In China, Shaerhu (SEH) coal is a representative coal of high Cl and Na contents, in which the Cl content in coal and the Na₂O content in coal ash is beyond 1% and 4 %, respectively. High Cl and Na contents result in severe ash deposition and heat transfer deterioration in the convection heating region. However, there is no quantitative data reported evaluating the effect of ash deposition on the heat

transfer in a boiler burning high sodium coal. A quantitative learning on the relation between ash deposition and heat transfer deterioration is essential for the rational design of boilers burning high sodium and chlorine coal.

In this study, high sodium and chlorine coal (1.1% Cl in coal, and 4.7% Na in coal ash) is burned in a 45 t/h Circulating Fluidized Bed (CFB) boiler with three combustion chambers to explore its capability of 100% pure combustion. The heat transfer deterioration is always observed at each start-up of boiler. In 12 h, the outlet temperature increases from 144 °C to 205 °C at a boiler load of ~32 t/h. The gas temperature decrease degree in the economizer region decreases from 85 °C to about 60 °C.

Severe ash deposition was observed in the convection heating region including economizer and air-preheater. The interspace between front and back tubes was full of ash deposit, generating an ash wall. The composition and morphology analyses of ash deposit by XRF/XRD/SEM, show high content of NaCl and agglomerated sticky ash particles.

The coefficient of thermal conductivity of ash layer is measured as 16 W/(m.K) by laser thermal conductance instrument, much lower than that of metal tubes. Using the measured coefficient, we built the geometry and mesh of tube bunch and ash layer, and calculated the heat transfer deterioration in Fluent. The calculated deterioration degree agrees well with the measured one.

Oral Session

Fluidized Bed Combustion 1

Tuesday, July 24, 2019

Index No: 3.10

EXPERIMENTAL STUDY ON AGGLOMERATION CHARACTERISTICS OF CFB COMBUSTION OF FURFURAL RESIDUE

Lu Cheng, Yangxin Zhang, Yan Jin, Hairui Yang, Man Zhang

Taiyuan University of Technology, China

Furfural residue is a kind of biomass waste remaining after the furfural is extracted from corncob. If the furfural residue is directly discharged, it will pollute the atmosphere, soil and river. The yield of furfural residue in China has reached 2.4 million to 3 million tons, so the treatment of furfural residue is an urgent problem to be solved. Thus the furfural residue was tried to be used as a biomass fuel in the boiler to generate steam and electric power and realize the reuse of waste. The boiler is generally circulating fluidized bed (CFB). However, it was found that in the furfural residue fired CFB, the content of alkali metals such as potassium and sodium in the furfural residue is relatively high, resulting in low ash melting point and serious agglomerating problem. Therefore, it is important to understand the agglomeration characteristics of furfural residue in CFB combustion.

This paper focuses on the agglomerating problems in the combustion process of furfural residue in a fluidized bed reactor. In the experimental, the quartz sand were used as blank controls bed material on the small bubbling bed apparatus. The effects of temperature, additive and bed material on the agglomerating characteristics of furfural ash in the fluidized bed reactor were investigated systematically. Then X-ray diffraction (XRD) and scanning electron microscopy (SEM) analysis were performed on the discharged bed materials.

Finally, the influence of temperature, additive and bed material on CFB agglomerating characteristics of furfural ash is obtained, and the optimal conditions for reducing agglomerating are preferred.

Index No: 3.11

IGNITION CHARACTERISTICS OF COAL/AIR JETS FROM RECTANGULAR NOZZLES

*Lilin Hu, Pengyuan Liu, Yang Zhang, Lele Feng, Yuxin Wu, Junfu Lyu, Hai Zhang
Tsinghua University*

The ignition characteristics of pulverized coal-air jets from rectangular nozzles with different aspect ratios (ARs) were studied using a Hencken type entrained flow reactor. High-speed cameras and Mie scattering technique were employed to record the instantaneous flame images and

particle motions under different exit velocities and coal concentrations of the primary air flow. The results revealed that similar to the gas flames, the flame length of the coal-air jet first increases and then decreases with increasing Re and finally barely changes when the flow is fully turbulent. For a coal/air flow from a rectangular nozzle, compared with the one from a round nozzle, the transient Re from laminar to turbulent for the rectangular jets is smaller. In the transient region, the flame length is obviously shorter at the same Re . The dissipation of large eddies is faster on the wide side, and the appearance of large eddy structure is delayed on both sides as the coal concentration increases. The simulation results show that for a rectangular nozzle the ignition of the coal jet begins on the two narrow sides, while for a round nozzle, coal jet ignition starts from the surrounding shear layers uniformly.

Index No: 3.12

OCCURRENCE MODE OF IRON AND ITS MIGRATION IN BED MATERIAL OF A COAL-FIRED CIRCULATING FLUIDIZED BED BOILER

*Jiayu Lyu, Yang Zhang, Lilin Hu, Yu Zhang, Tianxing Song, Suxia Ma, Hai Zhang
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In a coal-fired circulating fluidized bed (CFB) boiler, iron (Fe) could be a rich element in the bed material, mostly existing as iron oxide. Iron oxides usually have two occurrence modes. One is ferrous oxide (FeO), sometimes called as iron monoxide, in which iron is divalent. The other is ferric oxide or called as ionic oxide (Fe_2O_3), in which iron is trivalent. While the mixture of FeO and Fe_2O_3 with 1:1 mole ratio is iron trioxide, or ferroferric oxides, often denoted as Fe_3O_4 . Along the CFB furnace, the redox atmosphere is changing. In the bottom dense bed, the overall atmosphere is reducing, while above the dense bed, especially after the injection level of the secondary air, the atmosphere becomes oxidizing. With the changes of the redox atmosphere, the occurrence modes of Fe element and iron oxides could change as FeO could be oxidized into Fe_2O_3 in oxidizing atmosphere and Fe_2O_3 could be reduced into FeO or even Fe element in reducing atmosphere. Moreover, as coal often contains certain

amount of sulfur, the containing iron could also react with sulfur to form iron sulfide (FeS), ferrous sulfite (FeSO₃), and ferric sulfate (FeSO₄).

In this paper, experiments were first conducted in a thermogravimetry analyzer (TGA) and fixed bed reactor to access the occurrence mode of iron and its migration under different gaseous conditions, residence time, and reaction temperature. The mixture of iron/iron oxides and quartz sand with selected particle size was used as the test sample, and the gas concentration and reaction temperature of the reactor were set to mimic the conditions in a CFB boiler. The reaction products of iron base bed under different conditions were characterized by X-ray diffraction (XRD) and scanning electron microscope (SEM). Through the experiments, the kinetic parameters of iron migration were obtained.

Based on the kinetic experiments, the occurrence mode and its migration in a 3MW test coal-fired CFB boiler were numerically studied by using the Computational Particle Fluid Dynamics (CPFD) method. With the simulated distributions of CO, NO, SO₂, O₂ and residue char, and the temperature field in the furnace, the potential to use the Fe-containing bed material to reduce NO_x emission from a coal-fired CFB boiler was assessed.

Index No: 3.13

A METHOD TO MEASURE THE SOLID CIRCULATION RATE IN CFB BOILERS

*Yangxin Zhang, Lu Cheng, Yang Zhang, Baoguo Fan, Hai Zhang, Junfu Lyu
Taiyuan University of Technology, China*

Circulating fluidized bed (CFB) combustion technology is attracting recently due to its low cost in pollution control. Researches show solid circulation rate (Gs) is an important parameter to CFB boiler design and of great significance in pollution control during the operation of CFB boilers. In view of the complex and rough measuring environments such as high temperature and severe abrasion, the measurement of Gs in a CFB boiler remains an unsolved problem in the literature. Thus, this paper proposes a method to quantitatively measure Gs in CFB boilers based on the heat transfer mechanism. In this

method, the relation of Gs to the heat transfer coefficient between hot solid particles and heat exchange device was established, and thereby this method can overcome the high temperature and the abrasion problems. Experiments in a hot test rig and numerical simulation using the Barracuda package were conducted to obtain quantitative relation between Gs and heat transfer coefficient, as well as the distribution of the solid particle concentration. Finally, a linear relationship between Gs and the heat transfer coefficient/solid concentration of the cross-section in the standpipe were found and fitting functional formulas were presented as well, proving that the heat transfer method was a feasible and potential way to be applied in actual CFB boilers.

Index No: 3.14

EFFECT OF EXIT CONFIGURATION ON THE TWO-PHASE FLUID DYNAMICS IN A 2-D CIRCULATING FLUIDIZED BED

*Tianxing Song, Yang Zhang, Lilin Hu, Runxia Cai, Yi Zhang, Man Zhang, Hairui Yang, Junfu Lyu, Suxia Ma, Hai Zhang
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Two dimensional (2-D) circulating fluidized bed (CFB), due to the convenience in experimental observation and measurement, is a useful tool in laboratory to study the two-phase fluid dynamics in a practical 3-D one. In order to assess the intrinsic characteristics of the two-phase flow, the influence of the exit configuration has to be clarified, and in most cases even to avoid.

In this paper, numerical simulations using the Computational Particle Fluid Dynamics (CPFD) method are conducted on two-phase flow in a rectangular 2-D CFB riser with an inner cross-section dimension of 500 mm (width) x 50 mm (depth) and height of 4000 (mm). Six different type exits are equipped with the riser respectively. The cross-section of exits are rectangular. The riser is connected to a cyclone or and the total cross-section area at the entrance of the cyclone is the same for all types of the exits.

The simulations are conducted at the same ambient temperature and pressure. The bed material is quartz sand

with an average size of 200 μm . The superficial air velocity is set to 3 - 6 m/s. The mass flow rate of the solid phase varies from 3 - 10 $\text{kg}/\text{m}^2\text{s}$. Comparisons are done among the gas and solid velocity field distribution, the axial and radial pressure distribution, and bulk solid density distribution inside the riser. Based on the simulation results, recommendation of the exit configuration for a 2-D CFB with minimum influence on the main upstream two-phase flow is given.

Keynote Lecture:

A CHARACTERISTIC PARTICLE TRACKED MODELING FOR CFB BOILER COAL COMBUSTION AND ULTRA-LOW NOX EMISSION

Ming-Chuan Zhang

Shanghai Jiao Tong University

As a preliminary application of the type-A-choking-oriented unified model for fast fluidization dynamics proposed by the author and coworker previously, characteristic particles tracked modeling for CFB boiler coal combustion and ultra-low NO emission was carried out and reported in this article. One novel feature of the model is that a characteristic cyclone-efficiency-equivalent particle diameter of circulated shrinking chars in the combustion-assisted attrition process was determined statistically, which facilitates greatly modeling of the most complicated process in CFB combustion. The influence of heterogeneous ignition status on CO formation under the combustion condition of CFB boiler and the enhancement effect of CO on carbon surface de-NO were analyzed with emphasis. Demonstration calculations showed that improving the cyclone efficiency with proper matching of feeding coal size, and then increasing the circulated solid flux and consequently the de-NO contribution of falling clusters provide a feasible way to realize the ultra-low NO emission required.

Index No: 3.15

SAFETY EVALUATION OF THE IMMERSED TUBE IN AN EXTERNAL HEAT EXCHANGER OF A CIRCULATING FLUIDIZED BED BOILER IN CASE OF ELECTRICITY SUPPLY FAILURE

*Ling Jiang, Yuge Yao, Boyu Deng, Hairui Yang, Lyu Junfu, Man Zhang**

Tsinghua University, China

External heat exchanger (EHE) is one of the key component of a circulating fluidized bed (CFB) boiler. Generally, the superheater and reheater tubes are arranged in the EHE for the excellence performance of the CFB boiler. The tubes in EHE are immersed in the bubbling fluidized bed, where the bed material is the circulating material. The heat transfer from the bed particle to the immersed is very strong. In case of the electricity supply failure occurs, the fluidizing air of the EHE shut down quickly flowing defluidization of the higher temperature bed material in the EHE while the steam flow rate weakens the heating tubes cooling. The safety of the immersed tube is a concern problem.

In this paper, the safety of the immersed tube in an external heat exchanger of a circulating fluidized bed boiler in case of electricity supply failure is investigated. It is evaluated by the numerically heat transfer. Firstly, the thermal conductivity of the bed material in the EHE is measured. It is found that it is the function of its particle size as well as its chemical composition. Then the heat transfer of the tube from the bed is modeled and simulated with the ANSYS, from which the tube metal temperature is predicted. Finally, the safety of the immersed tube in an external heat exchanger of a 660MW ultra supercritical CFB boiler was evaluated.

Index No: 3.16

COMBUSTION OF COAL AND OIL PROCESSING WASTE AND BIOMASS IN THE COMPOSITION OF WATER-CONTAINING FUEL MIXTURES

P.A. Strizhak, D.O. Glushkov, G.S. Nyashina, K.Yu. Vershinina

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Many countries are faced with the problem of environmental pollution by solid, liquid and gaseous industrial and household waste due to intensive industrial development. The technologies of waste recycling and

extraction of useful substances are quite complex and costly; therefore, they are implemented very limitedly. Direct high-temperature waste combustion is the most accessible utilization method. However many wastes evolve large amounts of hazardous emission during such combustion.

One of the promising directions for the utilization of wastes is their combustion in the composition of the fuel slurries obtained by mixing liquid (water, sewage water or industrial water) and the solid fuel. This allows disposing of several types of waste together and reducing the risk of excessive air pollution due to the presence of water in the fuel.

The aim of the work is to determine experimentally the ignition and combustion characteristics of single droplets of water-containing mixtures based on the coal, plant and oil wastes.

The experimental method is based on heating a fuel single drop (or sample) in a muffle furnace with simultaneous recording ignition and combustion characteristics, including analysis of gaseous emission. The detailed methodology and measuring equipment description are presented in the study [1].

It has been found that plant additives significantly change the ignition and combustion parameters of slurries based on coal processing waste. In particular, rapeseed oil, leaf litter, charcoal, straw are the best additives to reduce the ignition temperatures of coal waste-derived slurries. These additives conduce to reduce the limiting ignition temperatures by 30–40 ° C. The addition of sunflower waste (≈10 wt.%) contributes to reduction in ignition delay time by ≈60%. Oil processing waste, vegetable oils and charcoal are the best additives to increase combustion heat of the fuel slurries. Adding (10–15 wt.%) them into the fuel can increase the specific heat of slurry combustion by 3-4 MJ/kg.

It has been established that the use of plant waste as an additive to coal-water slurries reduces SO_x and NO_x concentrations by 5–91% compared to coal or slurries with waste turbine oil. Even small concentrations of such additives (7–15%) can lead to a reduction of SO_x and NO_x several times. Also it has been found that the higher the

combustion temperature, then the role of the biomass additive is more noticeable. The calculated complex criterion shows that the joint utilization of biomass and industrial wastes improves the fuel slurry efficiency by 1.2–10 times in terms of energy, economic and environmental parameters.

The research has confirmed the feasibility of joint utilization of coal processing and oil refining waste and biomass in the composition of water-containing fuel mixtures. This approach allows not only to utilize waste, but also to reduce the fuel cost, to reduce hazardous emissions and to save non-renewable fuels (coal, oil, gas).

Keynote Lecture:

THE CHANGE IN BED MATERIALS SIZE DISTRIBUTION AND ITS EFFECT ON CFB BOILER OPERATION

G. A. Ryabov, O. M. Folomeev

All-Russia Thermal Engineering Institute

When burning solid fuels in circulating fluidized bed boilers (CFB), it is important to ensure a large multiplicity of particle circulation along the loop of the furnace – cyclone – return system. The high flow rate of circulating particles determines the uniformity of the temperature field along the height of the furnace, ensures temperature equalization along the bed section, which is especially important for large CFB boilers with a furnace section of 200 and more m².

The size of circulating particles is determined by the efficiency of capture in the cyclone, the higher it is, the smaller the average particle size. It is believed that a well-operated CFB boiler has an average size of circulating particles less than 0.2 and even 0.15 mm. Another factor determining the bed material size distribution is the effective removal of bottom ash, which is especially important for high-ash fuels.

The first in Russia large CFB boiler of unit #9 of Novocherkassk TPP has some problems with overly large part of coarse particles in the bed. The report presents the characteristics of the fuel, bed material and circulating ash compositions. The estimate of circulating flow rate was

made. The main characteristics of the boiler, including the temperature field and estimation of circulating flow rate are presented. Special attention is paid to the regimes with the addition of limestone and fly ash. The operating date of changes in the chemical and particle size distribution (PSD) of ash streams is presented. According to results of the study of changes in ash composition, it can be concluded that the composition of fly and circulating ash varies quite rapidly and reaches design values after 10 hours (according to CaO). In bottom ash the PSD varies slowly (the order of magnitude is 50 hours). It is possible that the fractional composition of bed material also varies slowly.

The simplified model for calculation of changes in bed material size distribution after start-up of the boiler is presented. It takes into account the initial composition of sand and coal supplied. The calculation is carried out to determine the specific removal of particles from the bed. The capture efficiency is calculated by dependences of VTI and corrected taking into account published data and results of experiments. According to experimental data, the coefficients of bed material size distribution and the removed bottom ash are introduced. According to the results of calculations, it is shown that for the available fuel fractional composition, the number of large fractions increases over time. The addition of limestone leads to an increase in fractions with sizes of 0.1-0.2 mm. The Best results are obtained when feeding coal with sizes less than 5 mm.

Index No: 3.17

THE TECHNOLOGY AND APPLICATION OF A NEW TYPE OF COAL WATER SLURRY-FIRED CFB WITH HIGH EFFICIENCY AND CLEAN COMBUSTION

*Yuping Hao , Ruiguo Li , Yujiao Chen
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This paper introduces the core technology of coal water slurry-fired CFB with high efficiency and clean combustion, based on flow pattern reconstruction. The design of key boiler components and characteristics of boiler and system are also introduced. This technology realizes high desulfurization efficiency as well as less NOx

emission at the furnace exit that sharply reduce investment and operating cost. In the last part of the paper, it expounds the application references and development prospects.

Index No: 3.18

OVERVIEW AND APPLICATIONS OF COAL FLUIDIZED BED GASIFICATION IN CHINA

*Dapeng Bi, Zhenzhong Hu, Jiansheng Zhang
Tsinghua University*

As a country with coal dominating its energy structure, China attaches great importance on the development of clean coal utilization technology. Coal gasification, which converts solid coal into fuel gas containing CO and H₂ or so-called synthesis gas, has been considered as a promising alternative owing to a number of advantages. Flexible applications of the synthesis gas can be realized including the gas boilers, aluminium oxide kilns, etc., with no or minor modification of the burner. When utilizing the gasification-derived hot synthesis gas as fuel for heat, it can be readily used without prior extensive treatment and its sensible heat can also be beneficial. Apart from gasification for fuel, high quality synthesis gas can also be used for chemical production. Coal chemical products including methyl alcohol, synthesis ammonia, etc. have drawn great attention as a more efficient and economical coal use option compared to via direct combustion for heat.

Many technical routes can be used in coal gasification. The fluidized bed gasification technology has received continuous attention in the field of gasification reaction because of its simple gasifier structure, moderate operation temperature, high processing capacity, products without tar, adaptable feeding coal, etc. Since the first fluidized bed gasifier was put into commercial operation in 1996, the fluidized bed gasification technology developed rapidly in China. So far, there are nearly 10 different types of fluidized bed gasification technology including pure oxygen gasification, pressurized gasification, dual bed gasification etc.

This paper first describes the current fluidized bed gasification technology and its industrial application in China. The results show that the fluidized bed gasification

Abstracts – Fluidized Bed Combustion

technology can be classified according to the operation pressure, oxidant composition and reactor structure. And then, the author analyzes the technical difficulties of fluidized bed gasification technology, finally summarizes the development direction of fluidized bed gasification technology. The author thinks that Although successful industrial applications of fluidized bed gasification have been realized in China, there are still some technical difficulties such as high residual carbon of ash, high ash proportion etc. The author also conclude that high pressure and pure oxygen gasification is the development direction of fluidized bed gasification technology in China.

Poster Session

Fluidized Bed Combustion 2

First floor and Second floor

1. Study on Penetrability of Central Secondary Air Jet in CFB and its Influences on Fluidization Characteristics
2. The fundamental studies on combustion of sintering flue gas in Circulating Fluidized Bed
3. Reliability analysis of 100MW and above circulating fluidized bed boiler units in China in 2017
4. Development of Advanced Ultra Super Critical Circulating Fluidized Bed Technology by DongFang Boiler
5. Effect of Calcination Atmosphere on H₂S Absorption Performance of Mn_xO_y/Al₂O₃ Sorbent in High Temperature synthesis Gas
6. Experimental Study on Peaking Performance of 145MW Circulating Fluidized Bed Boiler Unit with Retrofitting for Low-vacuum Heat Supply
7. Progress and Main Technical Characteristics of Ultra-Supercritical Circulating Fluidized Bed Boiler
8. Combustion uniformity investigation of a 350 MWe supercritical circulating fluidized bed boiler
9. Numerical Simulation of Sludge burning in High and Low Circulating Fluidized Bed Combustion
10. Multifunction firebox with an intensified fluidized bed for burning low-grade solid fuel
11. Study on Pollutants Control of Circulating Fluidized Bed Boiler Burning Low Calorific Value Coal
12. Effect of Atmosphere on Lignite Char Structure and Gasification Reactivity in a Fluidized Bed Reactor
13. Cold-experimental Study about Pressure Resistance of CFB Wind Caps
14. Experimental Research of Primary Fragmentation of Wood Biomass Particles in Fast Pyrolysis Process
15. Emission characteristic of NO_x in CFB boiler at low load

Oral Session

Low Carbon Energy 1

Monday, July 22, 2019

Keynote Lecture:

LOOPING CYCLES FOR LOW CARBON TECHNOLOGIES

A. Coppola, O. Senneca, F. Scala, F. Montagnaro, P. Salatino

Università degli Studi di Napoli Federico II

In the last decades a potpourri of looping processes for clean utilization of fossil sources has been proposed and studied as a transient solution towards zero-emission energy. The present paper examines looping processes recently proposed and developed for both carbon oxidation/gasification and CO₂ capture and transformation. Selected scientific issues associated to dynamic operation are also investigated by means of an innovative experimental technique based on a twin-bed reactor.

Combustion and gasification: Chemical looping with oxygen uncoupling (CLOU) and CarboLoop processes accomplish combustion or gasification of coal and more generally of solid fuels through reiterated alternation of oxidation and desorption steps. The literature on carbon combustion generally refers to continuous operating conditions, whereas dynamical effects have not been deeply investigated. The aim of the present study is to contribute to a better understanding of the mechanism and chemistry of carbon oxidation throughout dynamic oxidizing/reducing cycles.

CO₂ capture: Calcium Looping (CaL) provides a feasible and robust path to accomplish carbon capture from CO₂-bearing exhaust. Efficiency of CaL is affected by sorbent thermal sintering (deactivation) upon iterated looping and by particle attrition/fragmentation. A less scrutinized issue is the concurrent effect of steam and SO₂ in terms of sorbent availability and selective uptake. This

study aims at a deeper investigation of the performance of Ca-based sorbents in ternary CO₂-SO₂-H₂O systems.

CO₂ transformation: In Sorption-Enhanced Methanation the steam generated by methanation is removed from the gas phase in a catalytic bed by adding a sorbent material. CO₂ methanation in combination with chemical storage, solar fuels and CO₂ utilization is particularly interesting. In this work an innovative configuration, based on two interconnected fluidized beds, is investigated.

Index No: 4.1

FLAME PATTERN ANALYSIS FOR 60 KW_{th} FLAMES UNDER CONVENTIONAL AIR-FIRED AND OXY-FUEL CONDITIONS FOR TWO DIFFERENT TYPES OF COAL

A. Maßmeyer, D. Zabrodiec, J. Hees, T. Kreitzberg, O. Hatzfeld, R. Kneer

RWTH Aachen University

The present experimental study aims to evaluate structural features and behavior from a set of 60 kW_{th} pulverized coal flames under conventional air and oxy-fuel combustion conditions. Experiments are conducted in a cylindrical down-fired combustion chamber employing a swirl burner for the aerodynamic stabilization of the flames. The experimental configuration, based on a simplified geometry, provides good optical access to the flame and the capability of close monitoring and control of all relevant operational parameters and boundary conditions. Combined measurements of two detailed optical non-intrusive techniques: laser Doppler anemometry (LDA) and narrow-band flame visualization are employed to characterize major differences in flow field and structural pattern of the reaction zone of each studied flame. The dataset is complemented by flue gas sampling analysis of major species and relative wall-incident radiative heat flux measurements. For this particular study a set of four flames (two different combustion atmospheres for two different coal types) is chosen. All flames have the same thermal

output and fuel to oxidizer ratio. While the first two flames are operated in conventional air, the last two flames are studied in an oxy-fuel mixture with an O₂/CO₂ ratio of 25/75 Vol%. Coals employed are pre-dried Rhenish lignite (HHV: 22.51 MJ/kg) and Prosper-Haniel bituminous coal (HHV: 32.36 MJ/kg). Combined measurements show that structural features such as swirl intensity, vortex expansion and the axial extension of the inner recirculation zone (IRZ) are most likely dominated by the initial inlet velocities, viscosity and momentum of the oxidizer (aerodynamically controlled). On the other hand, heat release and coal particle ignition depends on the chemical composition of the employed coals.

The presented analysis and results are intended to contribute to the general understanding and predictability of pulverized coal combustion processes, in particular for cases where existing conventional facilities are planned to migrate to oxy-fuel combustion. In order to minimize the retrofitting needed, a transition from air to oxy-fuel under analogous firing regimes could be desired. In addition, the detailed data presented in this study can be employed for the validation of complex numerical models of pulverized coal combustion.

Index No: 4.2

NITROGEN-DOPED MICROPOROUS CARBON MATERIAL DECORATED WITH METAL NANOPARTICLES DERIVED FROM SOLID ZN/CO ZEOLITIC IMIDAZOLATE FRAMEWORK WITH HIGH SELECTIVITY FOR CO₂ SEPARATION

Jun Cheng, Niu Liu, Yali Wang, Xiaoxu Xuan, Xiao Yang, Junhu Zhou
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Nitrogen-doped microporous carbon material decorated with metal nanoparticles was synthesized through the pyrolysis of a zeolitic imidazolate framework-solid Zn/Co ZIF at various temperatures for efficient binary mixture separation of CO₂/CH₄ (biogas) and CO₂/N₂ (fuel gas). The composites were characterized on X-ray photoelectron spectroscopy (XPS), thermogravimetric analyses (TGA), Fourier transform infrared spectroscopy (FTIR), Powder X-ray diffraction

(PXRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM) and nitrogen-adsorption porosity analysis. The solid Zn/Co ZIF-pyrolysed carbon material at 725 °C exhibited the highest CO₂ uptake of 2.67 mmol/g, which was 4.05 times higher than the raw solid Zn/Co ZIF. The single adsorption isotherms of CO₂, CH₄ and N₂ fitted well with dual site Langmuir-Freundlich (DSLFF) model. The CO₂/CH₄ and CO₂/N₂ adsorption IAST selectivity (estimated based on ideal adsorbed solution theory) of the solid Zn/Co ZIF-pyrolysed carbon material at 725 °C were 24.3 and 40.2, respectively, which were much higher than that of the raw solid Zn/Co ZIF. The nitrogen functional groups-pyrrolic (N-5) and pyridinic (N-6) along with the unsaturated metal sites (Me-N₂) were proved to act as basic CO₂ adsorption site, that dominated the CO₂ adsorption capacity of nitrogen doped carbon material. This was attributed to the enhanced binding between the CO₂ molecule and nitrogen doped carbon material decorated with metal nanoparticles due to the strong electrostatic interactions between the nitrogen functional groups (pyrrolic and pyridinic nitrogen) or metal atoms (Zn or Co). The potential of industrial feasibility of solid Zn/Co ZIF- pyrolyzed carbon material for CO₂ /CH₄ and CO₂/N₂ separation was confirmed with transient breakthrough tests (40% CO₂ with 60% CH₄, 15% CO₂ with 85% N₂) and moisture stability test was conducted on PXRD analysis. These superior performances suggested that the solid Zn/Co ZIF- pyrolysed carbon material was a promising candidate for industrial CO₂ capture applications.

Index No: 4.3

POTASSIUM-CATALYZED PETROLEUM COKE FOR CHEMICAL LOOPING GASIFICATION

Wang Lulu, Shen Laihong, Yan Jingchun
Southeast University, China

A large amount of petroleum coke (petcoke) is considered as waste with low gasification rate from the petroleum refining process and urgently needs to be exploited in an environmentally friendly and efficient method. Potassium is widely used in the gasification reactivity enhancement of carbon in the varieties of

carbonaceous fuel. The effects of potassium are investigated in order to determine the carbon conversion and gas product distribution via a batch fluidized bed. The results demonstrated the adding of K significantly promoted not only the char gasification but also the water-shift reaction. Especially H₂ yields increased to 2.1 times and 2.9 times with the petcoke modified by 10%KNO₃ in comparison with the non-catalyzed steam gasification and chemical looping gasification (CLG). The optimal adding amount is 10% considering about the syngas quality and the gasification rate. Furthermore, the smaller particles are beneficial to the conversion of petcoke, and its maximum carbon conversion rate obtained 0.0084 mol/min. K₂CO₃ is another source of K⁺, and it has good thermal stability. The yields of H₂ and CO₂ increased dramatically as compared to the case with 10%K⁺ from KNO₃. Although the peak value of carbon conversion rate was lower, the high rate maintained for a long time, so, the carbon conversion efficiency reached 91.58%. The adding of K inhibited the graphitization of petcoke, leading to an increase in the gasification rate. The different potassium salts had weak influence on the gas distribution (about 10% CO, 30% CO₂ and 60% H₂). With respect of sulfur conversion, sulfur released mainly in the form of H₂S in the K-catalyzed CLG, convenient for sulfur recovery. And the effect of K had greater enhancement in carbon conversion than sulfur conversion with the increasing additive amount of K. During the process, the fraction of mercaptan decreased while the inorganic sulfur became dominant composition at the presence of K. In conclusion, K-catalyzed CLG provided a novel approach to effectively solve the problem of utilizing high-sulfur petcoke with low gasification reactivity.

Index No: 4.4

CO₂ ADSORPTION PERFORMANCE OF NA/K-IMPREGNATED MgO

Jie Zou, Ning Ding, Cong Luo

Huazhong University of Science and Technology, China

As a carbon dioxide solid sorbents, magnesium oxide has been widely studied due to its wide distribution and

low price. But pure MgO under intermediate temperature (250-500 °C) showed a poor CO₂ capture capacity. In our study, an effective method for improving the cyclic adsorption stability is to prepare the MgO-based sorbents promoted by sodium/potassium nitrate and citric acid through the mixing-impregnation method. The sorbents were determined by powder X-ray diffraction analyzer(XRD), thermogravimetric analyzer (TGA), and N₂ adsorption and desorption was measured at 77K. The morphology of the sorbents was investigated by field emission scanning electron microscopy (SEM). The results showed that as-prepared composites promoted by sodium nitrate and citric acid exhibited a better adsorption capacity than the sorbents modified by potassium nitrate and citric acid, which was 3.9158 mmol/g during the cyclic CO₂ adsorption reaction of calcination temperature of 450 °C and carbonation temperature of 350 °C. After 30 cycles of adsorption and desorption, the capture capacity of this sorbents was stable at 3.769 mmol/g. The SEM indicated that the pore morphology of this modified sorbents becomes abundant. Overall, the as-prepared Na/K impregnated MgO sorbent was promising for cyclic intermediate temperature CO₂ capture.

Index No: 4.5

ALLAM CYCLE COAL - A NOVEL CLEAN COAL SUPERCRITICAL CO₂ POWER CYCLE

Xijia Lv

8 Rivers Capital, LLC

The Allam Cycle is a novel direct oxy-fuel, semi-closed loop supercritical carbon dioxide (sCO₂) cycle, using natural gas or coal syngas for power generation with inherent carbon capture. Compared to existing power cycle, the Allam Cycle offers significant advantages including high cycle efficiencies, low capital costs, low or no water consumption, and elimination of all air emissions, including full CO₂ capture at purities and pressures necessary for downstream CO₂ reuse and/or sequestration. A 50MWt natural gas-fired demonstration of the core cycle is currently under operation by NET Power, a consortium between 8 Rivers Capital, McDermott, Exelon, and Occidental Petroleum.

There are several specific challenges for the development of coal based Allam cycle, including gasifier selection and integration, materials corrosion, coal derived impurities removal, as well as the design of a high-pressure oxy-fired syngas sCO₂ combustor. 8 Rivers will present background on the general Allam Cycle process, as well as the unique cycle design considerations of the coal based Allam Cycle, and discusses the results of the research and development (R&D) program for addressing and mitigating the additional technical risks associated with the coal based Allam Cycle system.

Index No: 4.6

A CHARACTERISTIC CHEMICAL TIME SCALE AND COMBUSTION REGIME ANALYSIS OF NATURAL GAS MILD COMBUSTION

Tingyao Zhang, Yuegui Zhou
Shanghai Jiao Tong University, China

Moderate or intense low-oxygen dilution (MILD) combustion is regarded as a novel combustion technology due to its low pollution emissions and high thermal efficiency. Understanding the interaction between turbulent mixing and chemical kinetics can provide a deep insight into MILD chemical reaction zone structure and combustion regime. It is a widespread opinion that the Damköhler number approaches unity for MILD combustion regime. The objective of the present work is to adopt a Jacobian matrix method to calculate the chemical time scales of different species and the Damköhler number with a global reaction mechanism, and subsequently to identify the MILD combustion regime of natural gas. A Jacobian matrix method with simplified chemical time scale selection was used to calculate the chemical timescale according to the inverse of the real part of the eigenvalues from the decomposition of the chemical source term Jacobian matrix. The results show that the chemical time scale is $10^{-6} \sim 10^{-4}$ s in the main combustion zone and 10^{-2} s in the post flame zone. The Damköhler number is calculated to be close to unity with high velocity oxidant jet which reflects the MILD combustion nature. The numerical results confirm that nature gas MILD combustion is in the finite-rate chemistry regime and

disperses throughout the whole furnace volume which is significantly different from the traditional flame combustion mode.

Index No: 4.7

HIERARCHICAL POROUS CARBON BASED ON BIOMASS IN-BUILT NANO-CAC03 TEMPLATE FOR ELEMENTAL MERCURY REMOVAL

Qiqi Shi, Boxiong Shen, Xiao Zhang
Hebei University of Technology

Hierarchical porous carbon materials derived by rice straw based on in-built nano-CaCO₃ have been prepared for elemental mercury removal in flue gas. The effect of different content of nano-CaCO₃ on mercury removal was studied, and removal performance was compared. The results show that 1:2 (rice straw/nano-CaCO₃) provided optimal mass ratio in the preparation conditions for the best pore structure parameters and adsorption property.

The highest SBET and V_t in B₁C₂ reached 742.5 m² g⁻¹ and 0.6972 cm³ g⁻¹, which were far higher than the B₁C₀ without nano-CaCO₃ according to the BET analyzed result. In particular, SEM image Of B₁C₂ indicates the hierarchical porous pore structure. TG and DTG curves demonstrated the combined effect of the template and CO₂ activation from decomposition of nano-CaCO₃. The decreasing surface area and pore volume of B₁C₃ was due to the excessive activation support and over-etching of carbon. The B₁C₂ has the highest elemental removal efficiency. These beneficial elemental removal results were supported by characteristics of porous structure for these samples in above analysis.

Oral Session

Low Carbon Energy 2

Wednesday, July 23, 2019

Keynote Lecture:

CHEMICAL LOOPING – BEYOND CO₂ CAPTURE TO ENERGY STORAGE AND CHEMICALS PRODUCTION

*Sankar Bhattacharya
Monash University*

There is an ongoing strong incentive to develop technologies capable of cleaner power generation from fossil fuels. One such technology which has attracted growing interest in recent years is Chemical Looping Combustion (CLC). CLC is a technology with potential for inherent CO₂ capture for subsequent storage. CLC operates on the principle of oxygen transfer from metallic oxides called oxygen carriers to combust the fuel in the absence of nitrogen, generating a concentrated stream of sequestration-ready CO₂. The oxygen carriers are then separated, re-oxidized in a secondary reactor with air, and reused. When compared to other Carbon Capture technologies, CLC has the perceived advantages of lower cost and lower energy penalty. Additionally, by using oxygen carriers instead of air for the combustion of fuel, CLC eliminates the primary source for the formation of NO_x. Investigations on CLC have focused mainly on gaseous fuels, but over the past decade, interest in the application of solid fuels for CLC has been increasing. Although majority of the work has focused on black coal and petroleum coke as fuel, results from investigations of brown coals and lignites, both locally and globally, have shown that it is a suitable fuel and has several distinct advantages for use in CLC.

Of late, the principle of chemical looping has also been extended to research on air separation, chemicals production, CO₂ splitting, energy storage and mineral processing. This presentation provides a status review of the Chemical Looping research worldwide and that at Monash University in some of these areas. More focus is made on the technical challenges facing practical application of the looping concept and the associated research needs.

Index No: 4.8

**THE INTRINSIC REACTIVITY OF COAL CHAR
CONVERSION COMPARED UNDER CONDITIONS OF
O₂/CO₂, O₂/H₂O AND AIR ATMOSPHERES**

Yang Liu, Peifang Fu, Kang Bie, Yusen Gong

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China*

The reasons of reactivity differences in O₂/H₂O atmosphere compared with in O₂/CO₂ or O₂/N₂ atmosphere in the kinetics-controlled regime (Regime I) have been further investigated. A simple variable activation energy method combined with adsorption/desorption reaction mechanisms were used to study the intrinsic reactivity differences of coal char conversion under O₂/H₂O, O₂/CO₂ and air conditions in a thermogravimetric analyzer. The results show: only CO₂ or H₂O chemisorption but not gasification has happened in the non-isothermal experiments, however, the intrinsic reaction rate of coal char conversion at the same O₂ concentration still increases in the order of O₂/CO₂, O₂/N₂ and O₂/H₂O atmospheres. This is because C(CO) produced from CO₂ chemisorption reaction is likely to occupy some active sites for O₂ chemisorption on the porous surface of particles, which is hard to desorb, leading to a decreased intrinsic reaction rate; while C(OH) and C(H) produced from H₂O chemisorption reaction can promote the increase of surface active sites of coal char, which the C(O) and H₂ desorbed results in an increased intrinsic reaction rate. At the same O₂ concentration, the trends and magnitudes of the variable activation energy for coal char combustion in O₂/CO₂ and O₂/N₂ atmospheres are similar, while they are greatly different from those in O₂/H₂O conditions. Therefore, CO₂ has little influence on the reactivity, while H₂O changes the reactivity. In addition, according to the developed reaction mechanisms, it is concluded that the variable activation energy method is suitable for distinguishing the intrinsic reactivity of coal char conversion in different atmospheres.

Index No: 4.9

**THERMODYNAMIC STUDY ON THE UTILITY
OXY-FUEL BOILER WITH DIFFERENT OXYGEN
VOLUME FRACTIONS**

*Kai Li, Enlu Wang, Deli Li, Lifen Wang, Naveed
Husnain, Qi Wang
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Abstracts – Low Carbon Energy

Oxy-fuel combustion technology is one of the most promising technologies for capturing CO₂ emitted from coal-fired power plants. For the operation of an oxy-fuel combustion utility boiler, its thermodynamic features should be clarified. For this purpose, a calculation model for oxy-fuel combustion boiler was established, and the thermodynamic characteristics of a 2102 t/h oxy-fuel utility boiler were explored. The results show that at a given oxygen volume fraction, the start-up process of an oxy-fuel boiler can be completed in a short time. Along with the increasing of the oxygen volume fraction, from 22% to 29%, it showed a strong effect on furnace radiant surfaces and furnace volumes. And that variation of CO₂ enthalpy played a vital role in the flue gas enthalpy, the oxygen volume fraction was shown to affect the various parts of the furnace differently. The calculations in present research could contribute to the oxy-fuel boiler design and operation.

Index No: 4.10

EFFECT OF SULFATION ON N₂O AND NO EMISSION DURING OXY-FUEL CIRCULATING FLUIDIZED BED COMBUSTION

*Dianbin Liu, Wei Li, Shiyuan Li, Runjuan Kong
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Sulfation of alkali chloride can convert chlorides into less corrosive sulfate and alleviate the ash-related problems. However, the catalytic reduction of alkali metals on N₂O and NO emission might be influenced by sulfation reaction. To disclose the relationship, experiments were carried out in a 50 kW oxy-fuel circulating fluidized bed (CFB) combustor system. Via injecting NaCl and Na₂SO₄ solutions into the combustion of low-sodium coal, it was found that alkali metals can significantly reduce N₂O and CO emission, but slightly increase NO emission. Such results imply that both NaCl and Na₂SO₄ can promote combustion and reduce fuel nitrogen conversion into flue gas. In addition, NaCl outperformed Na₂SO₄ at low Na/coal ratio. Via introducing SO₂ into the combustion of high-sodium and high-chlorine coal, NO emission can be

further reduced and N₂O emission can keep relative low level, which means sulfation reaction have positive effect on inhibiting fuel nitrogen conversion.

Oral Session

Low Carbon Energy 3

Wednesday, July 23, 2019

Index No: 4.11

EFFECT OF O₂/CO₂ ATMOSPHERES ON COAL FRAGMENTATION

*P. Bareschino, M. Urciuolo, V. Scherer, R. Chirone, O. Senneca**

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Several papers addressed changes in particle size distribution both in fluidized bed and in pulverized combustion of coal. Recently, a single particle pyrolysis-combustion fragmentation model has been developed to predict the propensity of coal particles to fragment under a wide range of heating conditions. The model describes heat up and devolatilization of coal and then combustion of the residual char. Fragmentation occurs as a consequence of mechanical failure of the particle. Stress inside the particle arise from thermal shock, associated to particles' heat up, as well as from overpressure generated by volatiles release upon devolatilization. If fragmentation takes place during pyrolysis, it is referred to as primary fragmentation. The model was able to predict nicely the changes in particle size distribution of coal in a laminar flow reactor operated at 1573 K in CO₂ rich atmosphere. Under such conditions, particles fragmentation was mainly due to the heat-up and occurred over timescales comparable with pyrolysis, but much shorter than char gasification with CO₂, which in fact had no effect on fragmentation.

The model has now been used to calculate the propensity of coal particles to undergo fragmentation in the early stages of oxy-combustion, with gaseous atmospheres of 5-30% O₂ in CO₂. In particular, the paper investigates

the possibility that char conversion modifies the particle's porosity, affecting the solid's mechanical strength, volatiles diffusion out of the particle and, ultimately, the fragmentation probability. Reference has been made to both entrained flow and fluidized beds reactors, accordingly particles size of 0.1-10 mm have been assumed, reactor temperatures of 1123 and 2073 K, heating rates of 100 and 10000 K/s.

Results showed that in all the conditions investigated, primary fragmentation occurs over very short timescales compared to char combustion and gasification and that the pattern of primary fragmentation is not influenced by the changes in the gaseous atmospheres. Under entrained flow reactor conditions, the particles break in the first 200 ms, producing relatively coarse fragments. Under fluidized bed conditions, the particles undergo explosive fragmentation after 1-2 s, well before pyrolysis is complete. This produces a multitude of fragments with broad particle size distribution. Reactions of char with oxygen, carbon dioxide and water vapor shall however not be neglected for higher reaction temperatures, more reactive coals, and in the follow up of fragmented particles' conversion over longer residence times.

Index No: 4.12

STUDY ON MULTI-CYCLE REACTION PERFORMANCE OF FE/AL COMPOUND OXYGEN CARRIERS IN CHEMICAL-LOOPING PYROLYSIS OF COAL TAR

*Jinyu Wang, Jian Gong, Weiwei Cui, Fengyin Wang, Yanhui Li, Cuiping Wang
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To ascertain the reaction performance of Fe/Al oxygen carrier (OC) on coal tar pyrolysis, two Fe/Al compound oxygen carriers were prepared by the impregnation method, in which one is CaO-modified, and they were applied in multi-cycle experiments of preparing carbon black (CB) by chemical-looping pyrolysis of coal tar in a small fluidized bed reactor in laboratory. X-ray diffraction (XRD), N₂ adsorption analysis (BET), and scanning electron microscopy (SEM) were employed to analyze the variation of composition, the pore distribution, and the surface morphology of the OCs during the cyclic

reaction. XRD results show that the oxygen-carrying capacity of both two-compound OCs decreases with the increase of the number of cycles, but the CaO-modified OC performs better for carbonation of CaO and then thermal decomposition of CaCO₃ during the cycle reaction. BET and SEM results show that the Fe/Al compound OC can maintain a good porous structure during the first 15 cycles. As the cycle numbers continuously increase, the sintering accumulation appears on the OC surface, resulting in an increase in the tar volatiles' diffusion resistance on the surface of the particles. The CaO-modified compound OC maintained a good porous structure during 20 cycles. It was found that the reaction of chemical-looping pyrolysis between the Fe/Al compound OC and tar volatile gas was controlled by the chemical reaction rate and the diffusion rate at previous cycles. The decrease of the oxygen-carrying capacity and the surface sintering of the OC are the main reasons for the decrease of the reaction activity. The CaO carbonation-decomposition can maintain the porous structure of the compound OC during the multi-cycle reaction and delay the surface sintering effectively, thus improving the reaction performance of the OC.

Index No: 4.13

EVALUATION OF NOX EMISSIONS AND CONVERSION IN CHEMICAL LOOPING COMBUSTION

*J.C. Ma, C.Q. Wang, X. Tian, Z.H. Liu, H.B. Zhao
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China*

Chemical looping combustion (CLC) of coal is a promising way to capture CO₂ at low energy consumption and high efficiency. The evolution of nitrogen contaminants from coal and the subsequent potential interaction with oxygen carrier is nevertheless a big concern in practical operation. In this work, the nitrogen transfer of fuel-N in CLC of *in-situ* coal pyrolysis products and residual char gasification products with a sol-gel prepared Fe₂O₃/Al₂O₃ oxygen carrier was investigated.

This work focused on the evolution and conversion of the coal nitrogen in the *in-situ* gasification chemical looping combustion (*iG*-CLC), using the Fe₂O₃/Al₂O₃

prepared by the sol-gel method as oxygen carrier (OC). The HCN and NO were mainly released within the fast coal pyrolysis process. The HCN was completely oxidized by Fe-based OC and the main product was NO. The nitrogen in tar was also converted by OC along with the conversion of the tar. The highest conversion rate of NO was achieved before the highest carbon conversion rate. While, almost no NO_x was generated within the char gasification process. The typical gas atmosphere of fuel reactor, high concentration of CO₂, showed a positive effect on the release of HCN and inhibition the release of NO. The release fraction of NO per gram coal was the lowest at the oxygen to fuel ratio of 2.0. Moreover, the temperature (900 °C - 990 °C) showed little impact on the amount of NO released. At last, the migration path of coal nitrogen in *i*G-CLC was proposed.

Index No: 4.14

COMPREHENSIVE ANALYSES ON ACTIVATION AGENTS OF AMINES AND NANOPARTICLES FOR TETA-BASED CO₂ CAPTURE ABSORBENTS

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The issue of climate warming and emissions to the core of global public focus. Chemical absorption is the most possible CCS technology for large-scale commercial application, in which the absorbents were the most critical factor to determine the CO₂ capture performance. In this study, TETA-based high-performance absorbents by adding activation agents of nanoparticles and other amines. In this study, TETA-based high-performance absorbents were prepared by adding activation agents with nanoparticles and amines. The ab/desorption performance was tested by a bubble reactor. The critical parameters, such as ab/desorption rate, equilibrium time and CO₂-loading, were comprehensively summarized and learned by AHP method. The results proves that Ab/desorption CO₂-loading occupies the most important part with the value of 30.77% and 24.36%, respectively. The sequences of amine activation agents is 2.5%PZ> 2.5%DEA> 2.5%MDEA> 2.5%AMP> 2.5%TEA and

5.0%PZ> 5.0%AMP> 5.0%DEA> 5.0%MDEA> 5.0%TEA. For amine activation agents, the addition of PZ shows the optimal overall CO₂ capture performance with the value of 0.593 and 0.580. The activation agent of DEA also shows impressive overall CO₂ capture performance. The cheap price of 8k RMB/t gives it the potential for developing high-performance absorbents with the increase of mass fraction, the overall scores of AL₂O₃-TETA nanofluids increase first and then decrease. The Brown motion of nanoparticles can effectively promote the heat/mass transfer performance of the absorbents.

Index No: 4.15

CAO/CA(OH)₂ THERMOCHEMICAL HEAT STORAGE PERFORMANCE OF SYNTHETIC CALCIUM-BASED MATERIAL FROM CO₂ CAPTURE CYCLES

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In this work, the CaO/Ca(OH)₂ thermochemical heat storage performance of synthetic CaO/CeO₂ material from CO₂ capture cycles under the calcium looping conditions was investigated. The effects of mass ratio of CaO to CeO₂, CO₂ capture conditions and number of CO₂ capture cycles and hydration/dehydration cycles on CO₂ capture and heat storage performances of the synthetic material were studied in a four fixed-bed reactor system. The addition of CeO₂ improves the sintering resistance and pore structure of calcium-based material. CaO/CeO₂ material containing the mass ratio of CaO to CeO₂ = 90:10 exhibits highest CO₂ capture and heat storage capacity and best cyclic stability during 10 carbonation/calcination and hydration/dehydration cycles. The heat storage capacity of the synthetic CaO/CeO₂ material experienced 10 carbonation/calcination cycles under severe calcination condition after 10 heat storage cycles is 20% lower than that under mild calcination condition. The steam during carbonation stage has little effect on heat storage performance of synthetic material experienced CO₂ capture cycles. Heat storage process promotes recovery of carbonation reactivity of calcium-based materials experienced multiple CO₂ capture cycles. The synthetic CaO/CeO₂ material experienced 10 CO₂ capture cycles

maybe remains more abundant and stable porous structure than that of original material. The change of pore size caused by fragmentation of particles maybe lead to decrease of heat storage capacity.

Index No: 4.16

HIERARCHICAL POROUS CARBON DERIVED FROM WOOD TAR USING CRAB AS THE TEMPLATE: PERFORMANCE ON SUPERCAPACITOR

Jing Wu, Mingwei Xia, Xiong Zhang, Yingquan Chen, Fei Sun, Xianhua Wang, Haiping Yang, Hanping Chen Huazhong University of Science and Technology, China.

Due to intrinsic structural limitations, biomass has difficulty controlling its pore structure to prepare hierarchical porous carbons (HPCs) with high supercapacitor performance. As an inevitable by-product of thermochemical conversion of biomass, wood tar has the advantages of good thermoplasticity and high carbon content, and can be used as an alternative carbon source for biomass to prepare HPCs. For better utilizing wood tar, a facile synthesis route was proposed to prepare HPCs based on a natural biological template method coupling with KOH activation. The resultant carbon possesses favorable features in terms of high solid carbon yield, high oxygen content (~9 at %), large specific surface areas ($626.43 \text{ m}^2 \text{ g}^{-1}$ ~ $2489.62 \text{ m}^2 \text{ g}^{-1}$) and interconnected hierarchical porous structure, which result in a synergism that enables the construction of high-performance supercapacitor in both aqueous and organic systems. The optimized HPC electrode can exhibit a high specific capacitance of 338.5 F g^{-1} in 6M KOH electrolyte. The constructed symmetric supercapacitors deliver high energy densities up to 9.9 Wh kg^{-1} and 33.87 Wh kg^{-1} in aqueous and organic electrolytes, respectively. This work provided an effective way for the utilization of these wood tar and crab shell waste.

Index No: 4.17

EXPERIMENTAL STUDY ON CARBON CAPTURE PERFORMANCE OF POLYIMIDE HOLLOW FIBER MEMBRANE IN POST-COMBUSTION PROCESS

Liu Yang, Yanchi Jiang, Juan Yu, Ziqi Zhao,

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Carbon capture and storage (CCS) technology is effective in mitigating the negative effect of the greenhouse gases. At the same time, membrane-based technology for the capture of CO_2 has attracted worldwide attention. In this paper, an experimental study on the carbon capture performance of polyimide (PI) hollow fiber membrane in post-combustion process is carried out to analyze the PI membrane system separation performance of single-stage and two-stage membrane separation methods under different pressure, temperature and gas flow rate conditions. For single-stage membrane separation system, increasing feed gas pressure, feed gas temperature and gas flow rate is beneficial to enhance membrane CO_2 permeability. For the two-stage membrane separation system, the feed gas pressure of the first/the second stage pressure, as well as the gas flow rate, can effectively influence the CO_2 concentration on permeate side, which can reach up to 91.01%. Furthermore, the two-stage method has 40%-60% higher CO_2 concentration than single-stage method due to the additional membrane stage

Index No: 4.18

PREPARATION OF NITROGEN-DOPED POROUS CARBON MATERIAL BASED ON OIL SLUDGE AND ITS ADSORPTION PERFORMANCE OF CO_2

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As an adsorbent material, porous carbon (PC) with high specific surface area, renewability and excellent thermal stability has been certified to be an outstanding candidate for carbon dioxide (CO_2) adsorption. However, its high manufacturing cost and insufficient CO_2 adsorption capacity are still significant problems to be solved urgently. The present work reported a nitrogen-doped porous carbon (NPC) synthesized from hazardous waste oil sludge (OS) via a facile and low-cost approach. The NPC possessed favorable features for excellent adsorbent, such as outstanding specific surface area ($1224 \text{ m}^2 \text{ g}^{-1}$), large pore

volume (1.738 cm³ g⁻¹) as well as tunable and large range of pore size distribution, among which the specific surface area and pore volume of porous carbon (PC) were just 632 m² g⁻¹ and 0.826 cm³ g⁻¹, respectively. The carbon material NPC prepared by mixing oil sludge pyrolysis char with KOH and urea at 700 °C achieved the formation of nitrogen-containing functional groups, with CO₂ adsorption capacity as high as 3 mmol/g. Furthermore, NPC possessed excellent renewability and thermal stability, which demonstrated that the NPC synthesized from OS via a facile and low-cost approach was a promising adsorbent material for CO₂ capture. This work provides a new strategy for synergetic processing of hazardous industrial waste and greenhouse gas.

Oral Session

Low Carbon Energy 4

Wednesday, July 24, 2019

Index No: 4.19

MICROSTRUCTURE EVOLUTION OF THE CALCIUM-BASED SORBENT DURING THE SELF-ACTIVATION PROCESS IN ENVIRONMENT

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Calcium looping process is one of the CO₂ capture technologies that achieved in a dual circulating fluidized bed system. Calcium based sorbents such as limestone and carbide slag are used as CO₂ sorbent in this technology. The CO₂ capture capacity of the sorbents decreases sharply with increasing the calcination/carbonation cycles. Dozens of tons of spent calcium based sorbent will be discharged from the reactor per hour, most of which cannot be reused. How to reuse these spent sorbent in an environmentally friendly way has drawn more and more attention.

In this research we found that the spent sorbent can be self-activated in environmental conditions after discharged from the calciner. When put in the environment after discharged from the calciner, the spent sorbent firstly

absorbed the H₂O in the air to form Ca(OH)₂. When all the CaO in the spent sorbent was completely converted to Ca(OH)₂, the spent sorbent go on absorbing H₂O to form Ca(OH)₂·2H₂O until 1.7 mol H₂O were absorbed by 1 mol CaO. φ was defined to describe the degree of the self-activation process and calculated according to Equation (1). The value of φ denotes the molar ratio of the absorbed H₂O to the CaO in the sorbent. The limiting value of φ was 170%. The spent sorbent was again sent back for CO₂ capture test after self-activation process. The results show that the CO₂ capture capacity of the spent sorbent was enhanced by the self-activation process. The CO₂ capture capacity of the sorbent after self-activation process was proportional to the value of φ . Repetitive self-activation can enhance the carbonation conversion of the sorbent once again. The major reason for the decrease of the CO₂ capture capacity of the calcium based sorbent during cyclic reaction is sintering of the sorbent during calcination process at high temperature, which leads to the grain growth and pore blockage. Many new pores especially the pores that distributed in 10-100 nm were again formed on the grain surface of the spent sorbent during the self-activation process, and the values of pore volume and BET surface area increased, which made it easier for the diffusion of CO₂ in the sorbent to react with CaO. That is why self-activation process can enhance the CO₂ capture capacity of the spent sorbent.

Index No: 4.20

NOVEL LOW-COST Li₄SiO₄-BASED ADSORBENT WITH NATURALLY OCCURRING WOLLASTONITE AS Si-SOURCE FOR CYCLIC CO₂ CAPTURE

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Si-source is one of the most important factors in the synthesize process of lithium orthosilicate and it directly determines the CO₂ capture performance of the Li₄SiO₄ adsorbent. In this study, naturally occurring wollastonite was employed as a novel Si-source for the production of Li₄SiO₄-based adsorbent. The as-prepared adsorbent was

primarily composed of Li_4SiO_4 and CaO as detected in XRD test. It is believed that the effect of CaO as well as the occurrence of Li-Ca interactions ($\text{Li}_4\text{SiO}_4 + \text{CaO} + \text{CO}_2 \leftrightarrow \text{Li}_2\text{CaSiO}_4 + \text{Li}_2\text{CO}_3$) could enhance the CO_2 capture performance of adsorbent, which were further experimentally proven by the results of in situ XRD. As a result, the adsorbent possesses a relative high capacity of ~ 0.18 g/g at initial cycles during the cyclic ad-desorption test. However, its capacity is gradually declined owing to the separation and formation of sintered CaO external shell. Moreover, it can be concluded from the cost analysis that the as-prepared $\text{CaO-Li}_4\text{SiO}_4$ adsorbent can effectively decrease the total raw material cost by reducing Li-demand. To sum up, the good comprehensive performance and relative low cost of as-prepared $\text{CaO-Li}_4\text{SiO}_4$ adsorbent make it promising for its practical applications in the future.

Index No: 4.21

INVESTIGATION THE TRANSFORMATION BEHAVIORS OF FE-CONTAINING MINERAL MATTERS IN COAL DURING O_2/CO_2 WITH H_2O -CONTAINING COMBUSTION ATMOSPHERE

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The transformation behaviors of Fe-containing mineral matters in coal was investigated during H_2O -containing oxy-fuel combustion atmosphere in a drop tube furnace (DTF). Two typical Chinese coals (Xinjiang coal (XJC) and Shenhua coal (SHC)) were used in this study. The results show that, the change of the combustion atmosphere do not significantly change Fe-containing mineral main phases of the ashes, but do affect the relative contents of the Fe-containing mineral main phases. The content of Fe-glass phases almost do not changed during XJC combustion in O_2/CO_2 atmosphere, increasing O_2/CO_2 atmosphere O_2 concentration and replacing 10% CO_2 content with H_2O . It mainly due to the presence of pyrite and ankerite in the XJC coal tested mostly excluded mineral in nature, which could transform independently to iron oxides. However, For SHC, O_2/CO_2 combustion resulted in more iron melting into Fe-glass phases and less

iron oxides formation, which is mainly because lower coal char temperature and higher CO concentration. The transformation of intrinsic pyrite and iron dolomite in SHC to iron oxides, meanwhile, were delayed in O_2/CO_2 combustion atmosphere, which is more conducive to the formation of Fe-glass phase. In O_2/CO_2 combustion with the same O_2 level, Replacing 10% CO_2 with H_2O promoted iron oxides formation, mainly due to the reason that O_2 may more easily reach the surface of combustion particles and contact with iron-containing minerals during the short residence time in DTF. It is found that Fe-bearing minerals more easily contact with clays or other silicates formed Fe-glass for Fe-bearing minerals mainly presenting as included. Water vapor addition leads to the ash particle sizes moving to larger particle size regions, which might decrease the deposition and slagging propensity of coal ashes.

Index No: 4.22

EXPERIMENTAL STUDY ON SLAGGING AND FOULING BEHAVIORS DURING OXY-FUEL COMBUSTION OF ZHUNDONG COAL USING A DROP TUBE FURNACE

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Guantao Tang, Jin Guo, Zhiming Jiang, Yongbo Du,
Defu Che
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Zhundong coal featuring high content of alkali metals induces severe slagging and fouling problems during its utilization in utility boilers. Oxy-fuel combustion technology can achieve a large amount of CO_2 capture and reduce the NO_x emission. Unfortunately, in-depth investigation has been seldom carried out on the process of ash deposition and slagging of high-alkali coal during oxy-fuel combustion. In the present study, the oxy-fuel combustion of high-alkali coals were experimentally studied using a non-cooled sampling probe in a drop tube furnace. The fouling and slagging mechanisms were investigated in various atmospheres, temperatures and different O_2 concentrations. In addition, the slag samples were characterized by X-ray diffraction (XRD) and Scanning Electron Microscopy (SEM) coupled with Energy Dispersive X-ray Spectrometer (EDS).

Experimental results indicated that under air and oxy-fuel conditions with the same O₂ content, the types of elements and minerals were almost the same. With the temperature increased, the adhesion between the slag samples was strengthened and the pore structure slag was increased. The degree of slag melting and sintering was aggravated at the temperature of 1200 °C and the slag structure was complicated. As the oxygen concentration was increased, some of the spherical particles had completely melted on the surface of the massive ash, resulting in an uneven surface. The present work can provide new insights into the slagging and ash deposition of Zhundong high-alkali coal during oxy-fuel combustion.

Index No: 4.23

ENHANCED HYDROGEN PRODUCTION BY BIOMASS PYROLYSIS BASED ON CALCIUM OXIDE SORBENT ABSORPTION OF CARBON DIOXIDE

Jianqiao Wang, Boxiong Shen, Peng Zhao, Dongrui Kang, Chunfei Wu

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A bifunctional catalyst using calcium oxide as an absorbent was prepared for enhanced hydrogen production in biomass pyrolysis gasification in a two-stage reactor. The effect of different content of calcium oxide adsorbent on hydrogen production process was studied, and the hydrogen production capacity of Ni/Al₂O₃ catalyst and bifunctional catalyst was compared. The results show that when dual function catalyst (10 wt%) was used instead of Ni/Al₂O₃, more hydrogen and less multi-carbon non-condensable gases are detected at the outlet. Highest surface area was obtained when CaO was loaded 10% Ni (138.34 m²g⁻¹) according to the BET analyzed result, and the decreasing surface area of 20% Ni/CaO is due to the less calcium oxide support. Around 15 vol% to 20 vol% hydrogen was detected when the calcium oxide sorbent utilized better than Ni/Al₂O₃ (around 5 vol%).

Poster Session

Low Carbon Energy 5

First floor and Second floor

1. Simulation Study on Separation of CO₂ from Flue Gas in Coal-fired Power Plant by Membrane Method
2. Routine Investigation in the fabrication of extrusion-spheronized Li₄SiO₄ pellets for high-temperature CO₂ capture
3. Simulation on Supercritical Carbon Dioxide Semi-closed cycle Based on Aspen Plus
4. X-zeolites modified by different alkali impregnating for cyclic CO₂ capture
5. The characteristics and mechanisms of CO and NO formation during pyridine oxidation in O₂/N₂ and O₂/CO₂ atmospheres
6. Impact of oxy-coal combustion on pyrite transformation and its ash slagging behavior
7. Experimental Study on the Interaction of Fe-based Oxygen Carrier with Mineral Matter in CLG
8. Role of Char-CO₂ Reaction in Chemical Looping with Oxygen Uncoupling
9. Comparative study on the performance of different carbon fuels in an MC-DCFC and improvement with a new-structure anode
10. Performance of modified carbide slag from calcium looping cycles during CaO/Ca(OH)₂ thermochemical storage process
11. High specific area activated carbon preparation from degradative solvent extraction residue of peanut shell
12. Combustion behavior of bituminous coal char particle in O₂/CO₂/H₂O in a fluidized bed
13. Nitrogen-doped microporous carbon material decorated with metal nanoparticles derived from solid Zn/Co zeolitic imidazolate framework with high selectivity for CO₂ separation
14. The intrinsic reactivity of coal char conversion compared 1 under conditions of O₂/CO₂, O₂/H₂O and air atmospheres
15. Evaluation of NO_x emissions and conversion in Chemical Looping Combustion
16. Potassium-catalyzed Petroleum Coke for Chemical Looping Gasification

Abstracts – Low Carbon Energy

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| 17. Flame Pattern Analysis for 60 kWth Flames under Conventional Air-Fired and Oxy-Fuel Conditions for Two Different Types of Coal | occurring wollastonite as Si-source for cyclic CO ₂ capture |
| 18. Novel low-cost Li ₄ SiO ₄ -based adsorbent with naturally | 19. Effect of CO ₂ on coal fragmentation |

Oral Session

Emission Controls 2

Monday, July 22, 2019

Index No: 5.1

FORMATION OF SO₃ IN FLUE GAS UNDER SNCR CONDITIONS

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Experimental and numerical studies were conducted to investigate the formation of sulfur trioxide (SO₃) during the selective non-catalytic reduction (SNCR) process. The effects of the inlet NH₃/NO ratio (RAN), reaction temperature, inlet mole fractions of SO₂, O₂, CO and H₂O were assessed. The experiments were conducted using a perfectly stirred reactor (PSR) and SO₃ mole fraction was determined using the sulfur balance method. Corresponding numerical simulation was performed using a detailed chemistry developed by Mueller and coworkers. Both experimental and numerical results revealed that the SO₃ formation was considerably affected by RAN, SO₂ and O₂ mole fractions. The experimental results demonstrated that under typical SNCR conditions, 0.5 % ~1.0 % of SO₂ was converted into SO₃, and SO₃ mole fraction was 5 - 10 ppm. The SO₃ formation was noticeably enhanced by the addition of NH₃ when RAN < 0.5. The conversion rate decreased as the initial SO₂ increased. A small amount of O₂ could promote the SO₃ formation remarkably, but this effect became much weaker as inlet O₂ mole fraction ≥ 1 %. The numerical simulation indicated that the increase of the reaction temperature significantly promoted the SO₃ formation when the temperature was above 1173 K. A small amount of CO could significantly enhance the SO₃ formation. The H₂O addition could inhibit the SO₃ formation. The detailed chemical kinetic analyses showed

that the main reaction paths of the SO₃ formation were the oxidization reaction of SO₂ with O radical via SO₂ + O (+M) → SO₃ (+ M) (R₃) and the one of SO₂ with NO₂ via SO₂ + NO₂ → SO₃ + NO (R₄). The effect of the operational parameters, i.e., RAN, reaction temperature, and SO₂, O₂, CO, H₂O mole fractions, could be well explained by the variation of the reaction rates of R₃ and R₄.

Index No: 5.2

THE ZEOLITE-CONTAINING ROCKS USE AS SORBENTS FOR THE ABSORPTION OF SULFUR OXIDE EMISSIONS AT ENERGY COMPANIES

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This article discusses the method of using zeolite-containing rocks as a sorbent for absorbing sulfur oxide emissions at coals thermal power plants. The high absorptive capacity of zeolites at low concentrations of the adsorbed substance and selectivity with respect to certain components make it possible to effectively use them for industrial separation, purification and drying of gas mixtures. Zeolite use was shown to be highly effective in flue gas desulfurization of TPP. As a principal place of application of zeolite rock in order to suppress sulfur oxide emissions, it is proposed to consider the boilers with fluidized bed combustion (FBC) that is currently widely distributed in Russia and in particular in Transbaikal region. To use zeolites with FBC boilers, a method has been developed for directly feeding zeolite-containing rocks to coal before it is fed into the bed. Industrial tests of fuel combustion with zeolite additive in FBC furnaces were carried out on KE-10/14, KE-10/14 PS boilers installed at the boiler houses of Chita. Many experiments were carried out on the supply of zeolite to the bed during the boiler operation. Changed not only the time of the zeolite, but also the dosage. In this case, the dosage was considered in fractions of the mass of inert material. In this case,

measurements of sulfur dioxide emissions were made. According to the test results, a stable positive effect was obtained. The feasibility study of the dosage of the zeolite in the layer is made taking into account the reduction of emissions charges, additional costs for electricity and fuel costs from reduced efficiency due to deterioration of the combustion mode in the boiler. Preliminary results of technical and economic calculations for current prices for: fuel, fees for emissions and electricity for boiler houses in Chita showed that a dosage of 20% by weight of inert material is reasonable. This indicator should be adjusted when economic indicators change.

Index No: 5.3

EXPERIMENTAL RESEARCH ON NOX EMISSION CHARACTERISTICS BASED ON COMBINED REMOVAL TECHNOLOGY OF MULTI-POLLUTANT WITH ASH CALCIUM RECYCLING

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Coal Science and Technology Research Institute

As one of the feasible technologies suitable for industrial boilers and kilns to reduce pollutant emissions to ultra low emission standards, combined removal technology of multi-pollutant is attracting more attention in recent years. As a combined removal technology of multi-pollutant, a low temperature flue gas deep purification technology based on semi-dry method was proposed by China Coal Research Institute. In this article, NO₂ absorption characteristics of Ca(OH)₂ was investigated in fixed bed and bubbling bed reactor. The composition of reaction products was detected by FTIR method. The result shows that: when the temperature is among 70-80 °C, oxygen content is 5 %, the relative humidity is in the range of 40-60 %, the absorption rate in fixed bed test is in the range of 20-30 %, nitrate and nitrite exist in the reaction products; while in bubbling bed test, the absorption rate is above 90%. Industrial test of this technology was implemented on a 30t/h boiler. The result shows that: at the proper operation condition, the absorption rate is in the range of 81-90%. It is found that the absorption rate of NO₂ by calcium-based absorbent is as

follows: bubbling bed (wet method) \geq airflow bed (semi-dry method) > fixed bed (close to dry method). The results are mainly affected by the humidification mode.

Index No: 5.4

EFFECTS OF THE TERTIARY AIR INJECTION PORT ON SEMI-COKE FLAMELESS COMBUSTION WITH COAL SELF-PREHEATING TECHNOLOGY

Wen Liu, Ziqu Ouyang, Yongjie Na, Xiaoyang Cao
Chinese Academy of Sciences

A novel coal self-preheating combustion technology was adopted to generate high temperature gas-solid two-phase fuel. Experiments on flameless combustion of the two-phase fuel were conducted in a 30 kW coal self-preheating combustion test rig. In flameless mode, effects of the single and the multi levels tertiary air injection ports were discussed, and the flue gas compositions (NO_x and CO) and temperatures along the axis of the down-fired combustor were analyzed. To visualize the combustion process, the flame images were captured. It is confirmed that flameless combustion of high temperature gas-solid two-phase fuel can be easily established, and (1) the temperature profile is uniform and it is transparent in the combustor; (2) NO_x emission can be reduced about a half compared to other combustion modes; (3) for a single level tertiary air, NO_x emission can be minimized by the proper injection port while NO_x emission and CO emission might be increased by an inappropriate port; (4) for the multi levels tertiary air, NO_x emission can be reduced further by the moderate tertiary air injection into the reducing zone, and NO_x might be increased while some of the tertiary air is injected in the burnout zone. It is clear that NO_x and CO emission can be controlled in a low level by rationally arranging two levels of the tertiary air injection ports in flameless combustion.

Index No: 5.5

EXPERIMENTAL RESEARCH ON THE COMBUSTION AND THE NOX EMISSIONS CHARACTERISTICS OF THE PREHEATED SEMI-COKE

Ouyang Ziqu, Liu Wen, Liu Jingzhang, Zhu Jianguo, Li

Shiyuan

Chinese Academy of Sciences

In order to investigate the combustion characteristics of the high temperature preheated fuel nozzle and the ultra-low NO_x emissions of the preheated semi-coke, a series of experimental researches were conducted in a 2 MW coal preheating combustion test rig. The effects of the secondary air equivalence ratio, the ratio of the internal and external secondary air and the multi levels tertiary air on the NO_x emissions, combustion temperature distributions, flame characteristics and combustion characteristics of the nozzle organizations, were mainly studied. The 2 MW coal preheating combustion test rig was consisted of a preheating burner, a furnace, a tail flue duct and other auxiliaries. The preheating burner was of 2 m in height and 400 mm in inner diameter, while the furnace was of 15 m in height with the section size of 1 m × 1 m. The flameless combustion of bituminous coal was realized in the tests, and the original NO_x emission was as low as 66.9 mg/Nm³ (6%O₂) and the unburnt carbon content was 2.16% in fly ash and the combustion efficiency was 99.2%. In the case above, the secondary air equivalence ratio was 0.45, the momentum ratio of the internal and external secondary air (MR_{sa}) was 0.69, and the tertiary air injection ports were at 4 m, 6 m and 8.5 m. The high temperature combustion zone was at 1500 mm of Shenmu semi-coke preheating combustion in that case, corresponding to 8 times of the inner diameter of the nozzle. The experimental results showed that with decreasing the secondary air equivalence ratio, adjusting tertiary air multi-level uniform distribution, decreasing the momentum ratio of the internal and external secondary air and strengthening the high temperature gasification reactions, the NO_x emissions were massively reduced.

Index No: 5.6

REMOVAL OF NO AND SO₂ USING TiO₂ SUPPORTED IRON CATALYSTS WITH VAPORIZED H₂O₂ IN A CATALYTIC OXIDATION PROCESS

Zijian Song, Ben Wang, Jie Yu, Chuan Ma, Lushi Sun
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Nitric oxide and sulfur dioxide are the major pollutants emitted from coal-fired power plants and industrial boilers. In this study, simultaneous removal of NO_x and SO₂ from simulated flue gas were carried out by an oxidation-absorption process, which NO oxidized by active hydroxyl radicals (OH) from catalytic decomposition of vaporized H₂O₂ over Fe₃O₄/TiO₂ and then adsorbed with SO₂ by NaOH solution. Fe₃O₄/TiO₂ was prepared by wet impregnation method with an additional reduction under H₂ atmosphere and characterized by X-ray diffraction patterns (XRD), Fourier transform infrared spectroscopy (FTIR), Brunauer–Emmett–Teller (BET) surface area, X-ray photoelectron spectrometer (XPS) and vibrating sample magnetometer (VSM). Effects of important factors on NO and SO₂ removal were investigated, i.e., H₂O₂ concentration, H₂O₂ injection rate, reaction temperature, gas flow rate and flue gas component. The experimental results show that NO can be effectively oxidized by highly reactive ·OH radicals generated from H₂O₂ decomposition over Fe₃O₄/TiO₂ catalyst. Removal efficiencies of 93.31% for NO, 85.90% for NO_x and 100% for SO₂ were obtained under the optimal condition. Density functional theory (DFT) calculations were performed to investigate the H₂O₂ adsorption and dissociation mechanism on catalyst surface. The calculation results demonstrate that H₂O₂ prefer to dissociate on iron containing surface, and ·OH radicals generation follow by Haber-Weiss (H–W) mechanism based on the analysis of Mulliken population, electron density difference and partial density of states (PDOS). The stable oxidative product of HNO₂ and HNO₃ were generated on the Fe₂O₃/TiO₂ (0 0 1) surface through NO/NO₂ and H₂O₂ co-adsorption.

Index No: 5.7

FORMATION OF N₂O FROM NO REDUCTION BY NH₃ OVER MnO_x/TiO₂

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MnO_x/TiO₂ is a promising catalyst used in selective catalytic reduction of NO with NH₃ for its outstanding

DeNO_x performance at low temperatures. However, the formation of undesired by-product N₂O was too noteworthy to be ignored, which has received great concern. Its probable formation pathways were studied by contrastive experiments in this research. In all experiments, N₂O started to significantly arise above 150 °C, while little N₂O was detected below 150 °C. As the temperature increased from 150 °C to 400 °C, the formation amounts of N₂O greatly increased, indicating the promotion effect of high temperature on N₂O formation. Experimental results indicated that two formation pathways finally brought about the generation of N₂O, namely NH₃ oxidation and the non-selective catalytic reduction of NO with NH₃. The latter was the main one. The higher O₂ concentration resulted in the higher N₂O origination. The surface absorbed oxygen on catalysts and O₂ participated in N₂O formation, and in O₂-deficient experiments, surface absorbed oxygen was the O source for N₂O formation. The work helped to better understand the N₂O formation pathways during NH₃ SCR over MnO_x/TiO₂, which benefited to make the N₂O formation mechanism more clear.

Index No: 5.8

EFFECTS OF HIGH TEMPERATURE ON NH₃/NO REACTIONS IN THE ABSENCE OF OXYGEN

Degui Bi, Zhixiang Zhu, Juan Yu, Zhongxiao Zhang, Chen Lin
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The influence of industrial processing parameters, especially high temperature, on NO_x abatement in the absence of oxygen has been experimentally. NO_x reduction efficiency is significantly promoted with increasing residence time and NSR and optimal residence time and NSR are 0.7s and 1.5, respectively, when temperature exceeds 1400°C. NO_x reduction is strongly dependent on temperature. When temperature is lower than 1000°C, NO consumption is hindered due to lack of O radicals. The denitrification efficiency is significantly promoted with the increase of temperature because thermal decomposition of CO₂ and NO is quite sensitive to temperature. However,

NO formation from pyrolysis of HNO begins plays an important role since temperature exceeds 1400°C, which results in decline in NO_x reduction efficiency. And the peak value of NO reduction efficiency can reach almost 100% at temperature range of 1300-1400°C with NSR of 1.5. Four chemistry mechanisms have been adopted to simulate NO_x reduction by ammonia. Validation shows that results calculated by POLIMI chemistry mechanism agrees better with experimental data than other 3 mechanisms.

Index No: 5.9

EVALUATION OF NEW KIND WET FGD EFFLUENT ZERO-EMISSION TECHNOLOGY BY WASTE HEAT FROM FLUE GAS

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Limestone-gypsum wet FGD is widely used in coal-fired plant to control the SO₂ emission. During the scrubbing process in the absorber, chlorine ions is enriched in the slurry. After long term operation, high chlorine ions will decrease SO₂ removal efficiency and cause heavy corrosion. Therefore, waste water should be discharged to maintain the quality of FGD absorber slurry.

The effluent of FGD is variable depends on types of coal and limestone. Traditional methods such as chemical precipitation, ion exchange, activated carbon adsorption cannot fulfill the zero-emission regulation on waste water of China government.

This paper proposed a new kind of technology to deal with WFGD waste water. The waste water is firstly condensed 10~20 times in a condense scrubber by heating with low-temperature flue gas, then the condense slurry is neutralized by lime. After neutralization, amounts of hot second-wind is used to solidify the condensate slurry.

A pilot scale test with a condense scrubber of Φ2.5m×16m was established to verify the process. Using 120°C flue gas, the effluent can be concentrated 10 times into condensate with high acid (PH=1.0), high chlorine content (20g/L). The analysis of slurry before and after the condensate can be shown in table 1. The pilot test verified the reliability of the new technology and provide essential

information to guide the industry engineering design for coal fire plant.

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Index No: 5.10

EXPERIMENTAL STUDY ON THE COMBUSTION AND NOX EMISSION CHARACTERISTICS OF SHENMU SEMI-COKE IN A CIRCULATING FLUIDIZED BED BOILER WITH POST-COMBUSTION

*Yuan Xiao, Guoliang Song, Shaobo Yang, Zhao Yang, Qinggang Lyu
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Nitrogen oxides pollution is a highly concerned environmental issue, semi-coke is the low-grade product of grade utilization of coals. For the purpose of achieving clean and highly-efficiency combustion of semi-coke, the effect of the combustion temperature and excess air ratio on NO_x original emission was investigated on a test platform of a 0.4t/d CFB test rig with a post-combustion chamber. Unlike Shenmu coal, NO_x emission of Shenmu semi-coke decreases with the increase of combustion temperature. When the furnace is in strong reducing atmosphere, NO_x emission is positively related to temperature under the post-combustion conditions. In the case of post-combustion, NO_x emission increases when the excess air ratio in furnace increases. In optimum condition, NO_x original emission can reduce to only 16.1% of conventional combustion. When the temperature decreases and the excess air ratio increases, CO emission and carbon content in fly ash decrease under all the experiment conditions, which means higher combustion efficiency. The post-combustion technology is a very effective method to decrease NO_x original emission and improve the combustion efficiency.

Index No: 5.11

STUDY ON KINETIC MODEL OF NOX REDUCTION OVERALL REACTION OF FLUIDIZED-BED FLUE GAS

*Yao ZHANG, Chen LIN, Juan YU, Jindong JIANG, Fan FENG, Zhongxiao ZHANG
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There have been a great number of investigations on kinetic model of NO_x reduction reaction. However, it was found that it is difficult to apply the reaction model conveniently in the comprehensive numerical simulation of fluidized bed combustion due to the complexity of the kinetic model. Therefore, it is necessary to establish a simplified overall reaction kinetic model to adapt to the complex simulation computation of fluidized bed. In this paper, the Arrhenius coefficients of the overall reaction of NO_x reduction were obtained by comparing with detailed mechanism model and optimized by using a genetic algorithm. The result showed that the overall reaction model can predict the change of NO_x reduction reaction temperature window, the denitrification efficiency and the ammonia slip accurately.

Index No: 5.12

STUDY OF THE CONCENTRATION OF MERCURY IN COAL USED IN COMBUSTION, IN AN AREA OF BOYACÁ, COLOMBIA, SOUTH AMERICA

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According to research of the Colombian Geological Service policies – known as SGC, the Only Plan of mercury and the Strategic Sector Plan for the eliminate the mercury use, a project that studies the occurrence of mercury in the charcoal in an area of Boyacá is developed as an integral part in the generation of geoscientist knowledge of the subsoil of the national territory. In this context, and in order to establish a baseline of the mercury content in the coals of the area Sogamoso - Tunja and its effect on combustion processes, Characterization and Processing of Minerals and Coal group carried out 84 samples in front of mines of 16 municipalities of the area, characterizing samples in 24 parameters, physic-chemical and petrographic, obtaining an important input in aspects

of: classification, research in combustion, mercury in the combustion cycle, evaluation environmental, social and economic. It includes an analysis of mercury and its relations with the other measured parameters, given its importance in the production of coal energy and the associated environmental impact. The average content of mercury in dried base in analyzed samples is 127 µg/kg. 89% of the coals have values less than 300 µg/kg. According to the results, an acceptable significant direct correlation was identified between the mercury content with Ash, sulfur, pyritic sulfur, and no correlation with chlorine content, which reacts in the combustion.

Index No: 5.13

STUDY ON MERCURY EMISSION AND MERCURY ADSORPTION CHARACTERISTICS OF FLY ASH IN PC AND CFB BOILERS

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The mercury emission was obtained by measuring the mercury contents in flue gas and solid samples in PC and CFB utility boilers. The relationship was obtained between the mercury emission and adsorption characteristics of fly ash. The parameters included unburned carbon content, particle size and pore structure of fly ash. The results showed that the majority of mercury released to the atmosphere with the flue gas in PC boiler, while the mercury was enriched in fly ash and captured by the precipitator in CFB boiler. The coal factor was proposed to characterize the impact of coal property on mercury emissions in this paper. The larger the coal factor was, the lower the mercury emission to the atmosphere was. It was also found that the mercury content of fly ash in CFB boiler was ten times higher than that in PC boiler. The more unburned carbon content and thus the more mercury adsorbed. The capacity of adsorbing mercury by fly ash was directly related to the particle size. The particle size corresponding to the highest content of mercury, which was about 560 ng/g, appeared in the range of 77.5 to 106µm. The content of mesoporous (4-6nm) of the fly ash

among the particle size of 77.5-106µm was the highest, which was beneficial to adsorbing the mercury. The specific surface area played a more significant role than specific pore volume in the mercury adsorption process.

Index No: 5.14

PREPARATION OF FLY ASH ADSORBENTS UTILIZING NON-THERMAL PLASMA TO ADD S ACTIVE SITES FOR Hg0 REMOVAL FROM FLUE GAS

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This paper proposed a novel method of preparing efficient, cost-effective and eco-friendly adsorbent utilizing non-thermal plasma technology in H₂S atmosphere. The Hg₀ removal experiments were conducted in a bench-scale fixed-bed reactor. After H₂S plasma treatment, the initial Hg₀ removal efficiency of modified fly ash has increased significantly compared to raw fly ash (2.8-3.6 times). The Hg₀ removal efficiency had a positive correlation with adsorption temperature in the range from 60 °C to 140 °C. HCl, O₂ and NO in the flue gas could promote the removal of Hg₀ whereas SO₂ had an adverse effect. The non-thermal plasma had little effect on porous structure, surface morphology and crystal structure of fly ash samples. The Hg₀ adsorption performance is better with longer treatment time due to more elemental S loaded on the fly ash surface. This is confirmed by XPS results. The loaded elemental S particles could serve as active sites with good Hg₀ oxidation ability. Then, the temperature-programmed decomposition (TPD) experiments further proved existing species of mercury in used modified fly ash was black HgS (mainly) and red HgS, and its desorption peaks are located at 240 °C and 310 °C.

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Index No: 5.15

CHARACTERISTICS OF Hg0 RE-EMISSION CAUSED BY SULFITE IN WET FLUE GAS DESULFURIZATION SYSTEM

*Jialing Xu, Jingjing Bao, Jiguo Tang, Min Du, Zhengyu Mo, Licheng Sun
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Re-emission of Hg0 caused by sulfite and metal ion in wet flue gas desulfurization system was investigated experimentally in this work. Effects of sulfite concentration, slurry temperature, pH value, O₂ concentration and metal ions on mercury reduction and re-emission was studied. The mechanisms of Hg0 re-emission were particularly proposed based on kinetics of mercury reduction and the equilibrium of mercuric-sulfite complex. The results indicate that Hg₂⁺ can be reduced by SO₃²⁻, which would cause a re-emission of Hg0. It is worth mentioning that increasing SO₃²⁻ concentration exhibits inhibition effect on Hg0 re-emission due to the formation of Hg(SO₃)₂²⁻. Mercury reduction is proved to have a positive correlation with slurry temperature. The rate constant of mercury reduction increases by approximately 11 times with temperature rising from 40 °C to 60 °C. A decrease of pH value has an impact on the equilibrium of mercuric-sulfite complex and consequently intensifies Hg0 re-emission. The re-emission amount of Hg0 increases from 0.4μg to 23.8μg as pH value drops from 6.0 to 4.0. The calculation reveals that the stabilities of HgSO₃ and Hg(SO₃)₂²⁻ complexes are weakened at lower pH value, which would promote the decomposition of them into Hg0. Although a secondary release of Hg0 was observed in presence of O₂, Hg0 re-emission is inhibited to a certain extent with increasing O₂ concentration. Besides, the presence of Cu²⁺ or Fe²⁺ ions is also found to lead to Hg0 re-emission because of the reducing ability.

Index No: 5.16

ADSORPTION CHARACTERISTICS OF FLOATING BEADS ON THE FINE PARTICULATE MATTER DURING ZHUNDONG COAL COMBUSTION

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The internal mineral elements, especially Na, Ca and S, etc. result in a large amount of fine particulate matter (PM) formation during Zhundong coal combustion. Floating beads are used as the sorbent for reducing the PM emission in this work and typical kaolin is selected as a reference to evaluate the adsorption characteristics of floating beads on PM. The pulverized coals mixed with floating beads and kaolin are burned in an electrical heated drop-tube furnace at 1573 K. The results indicate that Si-Al sorbents such as floating beads can efficiently reduce the PM formation during pulverized coal combustion. The yield of ultrafine mode particles (PM_{0.5}) reduces by 55.76% during combustion of coal mixed with floating beads and that of central mode particles (PM_{0.5-7}) decreases by 21.7%. The ultrafine mode particles formation is mainly controlled by the homogeneous nucleation/condensation of alkali metals sulfate vapors in the flue gas. The yields of central and coarse mode particles are mainly determined by the char and coarse minerals fragmentation and the concentrations of Ca, Si, etc. are relatively high due to their lower gasification ratio. The surface reaction between mineral vapors and sorbent particles reduces the PM_{0.5} emission, and PM_{0.5+} can be reduced by the particles collide and coalesce with resulting aluminosilicates on the surface of sorbents. In addition, floating beads have more active sites and free silicon dioxides due to the broken of Si-O and Al-O bonds, and thereby promoting the capture mineral vapors such as alkali metals.

Index No: 5.17

THE EFFECT OF OXYGEN-COAL EQUIVALENT RATIO ON THE RAPID PREPARATION OF POWDERED ACTIVATED COKE IN LOW OXYGEN ATMOSPHERE

*Binxuan Zhou, Yuan Zhao, Cheng Li, Tao Wang, Ping Zhou, Zhanlong Song, Chunyuan Ma
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Oxygen is a good activator for the rapid preparation of the powdered activated coke (PAC) in the low oxygen atmosphere, and the oxygen-coal equivalent ratio is an important parameter in the preparation process. In order to

obtain the optimal range of oxygen-coal equivalent ratio, it was adjusted by changing the amount of coal supplied under a certain gas distribution (6% O₂ and 94% N₂). The changes of the SO₂ adsorption capacity of the PACs, the burn-off rate of raw coal and the production rate of gas phase products with the equivalent ratio were studied. In addition, the BET and SEM were used to characterize the pore structure of the PACs. The results showed that with the increase of the equivalent ratio, the SO₂ adsorption capacity of the PACs increases first and then decreases, reaching the maximum at 0.5, which is 102.2 mg/g; the burn-off rate increases as a whole, but the increment is not obvious, which is in the range of 0.2~0.4. Combined with the analysis of gas phase products, BET and SEM, it is concluded that the PACs prepared when the oxygen-coal equivalent ratio is in the range of 0.2~0.5 have relatively developed pore structure. To sum up, the suitable oxygen-coal equivalent ratio range about the preparation of PAC is 0.3~0.5. This conclusion provides reference for future industrial application.

Index No: 5.18

EFFECTS OF ACID GASES ON ELEMENTAL MERCURY REMOVAL OVER MAGNETIC BIOCHAR IN OXYFUEL COMBUSTION FLUE GAS

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The effects of acid gases on elemental mercury (Hg⁰) adsorption and oxidation efficiencies over the magnetic biochar (MBC) were studied at different reaction temperatures. At 150 °C, the low concentration of SO₂ (400 ppm) increased the Hg⁰ adsorption efficiency by producing HgSO₄ but only if the enriched H₂O was present in the atmosphere. Because more C=O groups formed, the oxidation of Hg⁰ was facilitated with the enriched SO₂. With the increase of NO concentration, Hg⁰ adsorption efficiency firstly increased and then decreased. Enriched NO slightly promoted Hg⁰ oxidation. HCl promoted the Hg⁰ adsorption reaction over the Fe₃O₄ and carbonaceous surface of the MBC. When the reaction temperature was up

to 350 °C, the promotion of enriched SO₂ on Hg⁰ oxidation was enhanced. In contrast, the oxidation of Hg⁰ with the present of NO was undetectable.

Index No: 5.19

SELF-SUSTAINED COMBUSTION OF CO WITH TRANSIENT CHANGES OVER POWDERED CUCE0.75ZR0.25Oδ FOR HONEYCOMB CERAMICS CATALYST

*Running Kang, Xiaolin Wei, Feng Bin, Junyao He, Pandong Ma, Qinglan, Hao, Baojuan Dou
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The CuCe_{0.75}Zr_{0.25}O_δ catalyst was prepared by sol-gel method, and then successfully coated on honeycomb ceramics (HC). The activity of CuCe_{0.75}Zr_{0.25}O_δ/HC was carried out by temperature programmed oxidation of CO and an infrared camera (CO-TPO + FLIR), with results demonstrating that the critical condition of CO self-sustained combustion is 3% CO+3% O₂/N₂ at the flow of 0.5 L/min. As the CO concentration increasing from 1 vol% CO to 3 vol% CO, the induction process (<T₁₅) shifts towards slower CO conversion while the light off process (>T₁₅) turns to rapider ignition with transient change for CO oxidation reaction. The ignition temperature for self-sustained combustion of CO is reduced with increasing the CO and O₂ concentrations. Upon increasing CO₂ concentration, however, the furnace temperature is needed to enhance much higher than that under CO₂-free atmosphere in order to realize the complete conversion of CO, and thus it's difficult for the self-combustion reaction of CO. The thermal stability test, combined with SEM+EDS results, indicated that the CuCe_{0.75}Zr_{0.25}O_δ /HC remains high thermal stability after 200 h time-on-stream test and the high temperature region during self-combustion reaction of CO remains at 225±1 °C. The activity of catalysts is reduced after 200 h test because of the carbon deposition on the catalyst surface, but such a deactivation can be eliminated by air oxidation. In situ DRIFT results show that the competitive adsorption of CO/O₂ and CO₂ leads to an inhibiting effect on CO oxidation. As main active sites, the Cu⁺ sites of catalysts tend to absorb CO to form

carbonyls, which interacts with neighboring active oxygen in a strongly exothermic reaction, forming the gaseous CO₂ release.

Index No: 5.20

PARTITIONING BEHAVIOR OF ARSENIC IN AN ULTRA-SUPERCRITICAL COAL-FIRED POWER PLANT EQUIPPED WITH APCDS FOR ULTRA-LOW EMISSION

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To study the partitioning behavior of arsenic (As) in an ultra-supercritical coal-fired power plant equipped with air pollution control devices (APCDs) for ultra-low emission, the US EPA Method 29 was used to simultaneously sample flue gas before and after selective catalytic reduction (SCR), electrostatic precipitator (ESP), and wet flue gas desulfurization (WFGD). The solid and liquid samples including feed coal, bottom ash, ESP ash, limestone slurry, flush water, WFGD gypsum and wastewater were simultaneously collected in step with flue gas sampling. The mass distribution of As was obtained based on mass balance calculation. Results indicate that the mass balance rate of As is in the range of 78.40%~117.68%, which is acceptable. At the outlet of air-preheater, particulate-bound As is the dominant species in the flue gas, which accounts for over 98%. Most of As were migrated to ESP ash and bottom ash, accounting for 95.19% and 4.28%, respectively. Both As⁵⁺ and As³⁺ existed in the feed coal and bottom ash, while As⁵⁺ was found to be the major form in the ESP ash, WFGD gypsum and wastewater. The removal efficiency of As by ESP and WFGD is 99.3%~99.4%, while that by ESP is 99.87%~99.90% and that by WFGD is 26.32%~46.77%. The new APCD (mercury absorption device) can oxidize As³⁺ to As⁵⁺ in the flue gas, but somewhat increase the emission concentration of As. As tends to enrich in ESP ash (relative enrichment index =1.28) but dilute in bottom ash (relative enrichment index =0.23).

Index No: 5.21

A NEW SCHEME FOR SYNERGETIC REMOVAL OF NH₃ AND SO₃ AND PARTICULATE MATTER IN THE FLUE GAS OF COAL-FIRED BOILER

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In China, coal-fired boilers generally utilize the selective catalytic reduction (SCR) denitration technology to achieve low NO_x emission. The SCR catalyst will inevitably convert some of the SO₂ in the flue gas into SO₃. NH₃ escaping from the SCR denitration system can react with SO₃ generated in the flue gas to form (NH₄)₂SO₄ and NH₄HSO₄. NH₄HSO₄ is highly hygroscopic, viscous and corrosive and easy to induce ash deposition on the heat transfer surfaces at the temperature below its dew point. Since the condensation temperature of NH₄HSO₄ is just in the operating temperature range of the rotary air preheater (RAPH), the RAPH suffered more serious sticky ash deposition problems seriously impacting the economical and safe operation of the boiler. In this study, a new scheme was proposed for synergetic removal of NH₃ slipped from SCR, SO₃ and particulate matters in flue gas. The flue gas outlet temperature of the RAPH is raised to the dew point temperature of NH₄HSO₄ by reducing the heat transfer area, and then NH₃ and SO₃ in the flue gas can be used as the flue gas conditioning agent to modify the adhesion property and specific resistance of the particles. Therefore, by using this new scheme, not only the particulate matters but SO₃ and NH₃ escaped from SCR in the flue gas can be removed in the electrostatic precipitator, and the ash deposition corrosion problem on the low temperature heating surface can be greatly alleviated. The key to this new system is the proper parameters design to achieve sufficient adsorption for NH₃ and SO₃ and the appropriate agglomeration of particulate matters. Therefore, the adsorption and agglomeration characteristics of ash particles were experimentally studied. The results showed that the agglomeration of ash particles can be significantly enhanced by the adsorption reaction, which can increase the mean size of particle matters. The molar ratio between the absorbed N and S contents always maintained in the

range of 1.2-1.8. The adsorption of the SO_3 and NH_3 would interact with the ash particles leading to the morphology changes. Besides, the adsorption of NH_3 and SO_3 could strengthen the agglomeration of fine ash particles, and produces highly cohesive and relatively large particles, resulting in high collection efficiency due to the reduced rapping losses and re-entrainment. The experimental results initially proved that the proposed system would be a promising approach for the alleviation of the sticky ash deposition and for the synergetic removal of NH_3 and SO_3 and particulate matters. Further more detailed study would be made to examine the effects of the ratio of NH_3 and SO_3 in the gas, the adsorption temperature and the particle size on the adsorption rates and adsorption ratio of NH_3 and SO_3 , and the specific resistance of the particles, and the particle agglomeration, in order to obtain proper operating parameters for the synergetic removal system.

Index No: 5.22

THE RELEASE AND CONVERSION EQUILIBRIUM OF K DURING THE WHEAT STRAW PYROLYSIS

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Biomass is an abundant and clean energy source with good application value. However, it contains a lot of alkali metal (especially K), which releasing during combustion and pyrolysis causes the boiler's corrosion and slagging. In this paper, the chemical extraction, the microwave digestion, SEM-EDS, XRD and ICP-AES are applied to explore the occurrence, release and conversion characteristics of wheat straw. The occurrence of K, Na is obtained and it is found that NO_3^- content is high. So at low temperatures ($< 400\text{ }^\circ\text{C}$), K will mainly release in the form of KNO_3 and cause more serious corrosion and slagging than fuels with less NO_3^- content. And part of K and Cl enriches on the sample surface due to carrying of decomposed crystal water. When temperatures are higher than $400\text{ }^\circ\text{C}$, K is mainly released in the form of KCl. As KCl on the sample surface is released, K and Cl inside the sample can't reach the sample surface. At $600\text{ }^\circ\text{C}$, the total KCl content increases to the maximum and the surface KCl

content fell to the minimum. It is found that the reaction of organic K (NACS K) converting into water-soluble K (WS K) has equilibrium. When the temperature is raised from 200 to $1000\text{ }^\circ\text{C}$, Water-soluble K releases first. When water-soluble K content lowers to a certain extent, organic K begins to convert to water-soluble K. This reaction proceeds until water-soluble K relative amount rises to a certain value and the reaction reaches equilibrium. This phenomenon appears repeatedly with temperatures increasing.

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Index No: 5.23

THE MECHANISMS AND APPLICATIONS OF NOX REDUCTION BY LOW-NOX BURNER COUPLING DEEP AIR-STAGING TECHNOLOGY IN PULVERIZED COAL

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In order to reduce the original NO_x emission from coal combustion, and lighten the excessive redeucer used in the De- NO_x post-treatment which will lead to the corrosion of steam heat exchanger tube and economical efficiency, a new De- NO_x technology combined with the De- NO_x combustor and the deep air stage combustion was developed, and the technology was testified by theory, numerical simulation, pilot experiment, and industrial experiment. FR/ED (Finite Rate/Eddy Dissipation) model which considering the chemical reactions involved in the gasification process is used in the simulation, and it showed a sufficient accuracy with the experiment results. A strong reductive atmosphere including CO and CH_4 was detected with a low stoichiometric ratio both by numerical simulation and experiment in a 7MW double-cone De- NO_x burner, the CO and H_2 conten could be 15.457% and 0.992

for SR of 0.456, respectively, while no NO_x content was detected at the burner outlet. Method Oxygen-enriched air used in the burner could intensify the reductive atmosphere, and the CO content at the center burner increased from 9.54% to 20.258%, when the oxygen content increased from 21% to 28.3%. For the 7MW pilot boiler system, the initial NO_x emission of the boiler can reach to 159 mg/m³, and the total reduction of NO_x generation was more than 70.9%, when the oxygen content in secondary air was 28.3% and the proportion of staged air in tertiary air was 41.2%. Utilization of De-NO_x technology in long-term industrial experiment for 40t/h steam boiler showed near no influence on the boiler operation, original NO_x of less than 200mg could be reached at the extreme condition. When the original NO_x emission reduced from 697mg/m³ to 300mg/m³, the heat loss was less than 0.5%, and more than 50% of ammonia water was saved for SCR, which leading about 1yuan per ton steam saving of the cost.

Index No: 5.24

SELECTIVE CATALYTIC REDUCTION OF NO_x WITH NH₃ USING COAL ASH CATALYST

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The selective catalytic reduction (SCR) of NO_x with NH₃ has been investigated with coal ash. Coal samples from different regions of the People Republic of China are taken and processed to be used as the SCR catalysts. The influences of different coal ash catalysts, as well as the influences of calcination temperatures on the NO_x conversion of catalysts, are analyzed. The methods of XRF, XRD, and BET are used to characterize the materials. It is found that the calcined sample at 800 °C with Ca: Fe: Al: Si ratio of 0.051: 0.123: 0.511: 1, exhibited good NH₃-SCR activity in a broad temperature range of 200-500 °C. As well, the influences of [NH₃]/[NO] molar ratio and oxygen concentration on the SCR activity are also studied.

Index No: 5.25

EFFECTS OF DIFFERENT PRECIPITANTS ON THE DE-NO PERFORMANCE OF THE Fe₂O₃ CATALYST PREPARED BY CO-PRECIPITATION METHOD

Naveed Husnain, Enlu Wang, Shagufta Fareed, Kai Li, Deli Li, Qi Wang
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Fe₂O₃ catalysts prepared by co-precipitation method with two different precipitants (NH₄OH/Na₂CO₃) were experimentally investigated in the selective catalytic reduction of NO with NH₃. It was found that the catalyst in which NH₄OH was used as precipitant exhibited high NO conversion (above 80% from 250–400 °C). The methods of XRD, BET, EDS, and FT-IR were used to characterize the materials. The catalyst prepared by using NH₄OH precipitant exhibited lower crystallization degree together with better pore structure, and an increase in the O/Fe ratio, which was beneficial for the NH₃-SCR reaction. Also, the SO₂ tolerance of the catalyst was investigated. The results showed that that addition of SO₂ gradually decreased the SCR activity. Fourier transform infrared spectroscopy analysis of the fresh and deactivated catalyst exhibited that after the introduction of SO₂ in the de-NO reaction the formation of ammonium sulfate species on the catalyst's surface caused pore plugging and were responsible for a decrease in the NH₃-SCR activity.

Index No: 5.26

A POPULATION BALANCE MODEL OF FINE PARTICLE REMOVAL INSIDE ELECTROSTATIC PRECIPITATORS

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Electrostatic precipitators (ESPs), as the major dust removal devices, require more advanced designing tools to efficiently reduce fine particulate matter (PM). In this paper a multidimensional population balance model (PBM) is proposed to describe the mechanisms including particle mitigation, coagulation/breakage, nucleation/condensation and deposition/re-suspension inside ESPs. The governing equation is solved after discretizations of space, particle size and velocity. The numerical investigation of a

mechanistic lab-scale ESP at Tsinghua shows reasonably good agreements with experimental measured particle size distribution (PSD) and collection efficiencies. Therefore, the model is able to benefit the state-of-the-art design and retrofit of ESPs.

Index No: 5.27

A DATASET ANALYSIS OF PARTICULATE MATTER REMOVAL TECHNIQUES IN CHINA'S COAL-FIRED POWER PLANTS

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China Power Engineering Consulting Group Co.,Ltd.

The electrostatic precipitator (ESP) is widely used in coal-fired power plants to control particulate matter (PM) emission. With an increasing concern for the environment, China has formulated a much stricter regulation in which the PM emission level is 5 mg/m³. Moreover, modern coal-fired plants are more prone to variations in fuel property and operating conditions. Those factors have a marked impact on the collection efficiency of fine PM inside ESP and are likely to cause a higher actual emission level. Therefore, improved ESP design is needed in either new plants or upgrading of existing ESP's.

For ESP design, the selection of ESP structure, especially the collection surface area, mainly relies on the ash migration velocity empirically determined by design/check coal properties and operating parameters. In most cases these design parameters are quite different from practical ones, leading to deviated actual performance. The resultant ESP efficiency is rarely systematically investigated in literature. Consequently, the power plant designers are unable to provide their clients with effective guidelines to the choice of ESP system for meeting emission standard.

To resolve this issue, in this work we build an ESP database for coal-fired power plants in all regions of China, containing both design/check and actual operating data. The data were collected from leading ESP manufacturers, environmental research institutes, and coal-fired plants. The database is composed of datasets of coal property, flue gas, ESP structure and PM concentrations. At present, 308

kinds of coal samples and operating data from 162 power plants are included, and the database continues to grow and renew.

Using the dataset, the properties of coal samples properties from different coal mines and burnt in different areas of China can be summarized. It is further noted that, in actual operation, the penetration ratio of total inlet PM (ϵ_o) is different from the designed one (ϵ_d) for most plants, as shown in Figure 1. Here the penetration ratio ϵ is defined as

$$\epsilon = 1 - \eta = \frac{\text{outlet PM concentration}}{\text{inlet PM concentration}}$$

where η is the collection efficiency. In most plants the operating collection efficiency did not reach their design values (with $\epsilon_o/\epsilon_d > 1$). The correlation of η with operating parameters is investigated, aiming at reasonable predictions of ESP efficiency for our design of power plants. Multivariate regressions using linear or quadric forms did not strong correlations. Then, a support-vector-machine (SVM-) model is trained based on our current database, exhibiting a predictive capacity. Quantitative effect of each main factor on ESP efficiency is studied. Finally, guidelines to the ESP selection in plant design/retrofit are given for different cases.

Poster Session

Emission Controls 6

First floor and Second floor

1. Experimental study on denitration and Zn reduction of iron complex mixed absorption solutions
2. Effect of Chemical Composition on Adsorption and Agglomeration Characteristics of Ash Particles after Sulfuric Acid Adsorption
3. Experimental study on combustion of pulverized char preheated by a circulating fluidized bed
4. Simulation Investigation on NOx Emission Characteristics and Mechanisms during Co-combustion of Fossil Fuels with Different Fuel-nitrogen

Abstracts – Emission Controls

- Distributions via CHEMKIN
5. Condensation Characteristic of Sulfuric Acid Vapor on Low-temperature Surface of Tube Heat Exchanger
 6. Experimental Study on Synergistic Dust Removal of Desulfurization Tower of Coal-fired Thermal Power Unit
 7. Analysis of Desulphurization Process in Circulating Fluidized Bed Boiler by Calcium and Sulfur Conservation
 8. An Experimental Study on Ash Deposition Problem of Low-low Temperature Flue Gas System
 9. Effect of O₂ concentration on NH₃ oxidation over MnO_x/TiO₂
 10. Study on Desulfurization Mechanism of Adsorbents Prepared by High Ratio Circulating Fly Ash and Lime
 11. Influence of secondary air angle and SOFA ratio on combustion performance and NO_x emissions of a 600 MWe Foster Wheeler (FW) type down-fired boiler
 12. A Novel Study on 2MWth Binary Fuel Combustion Behavior with Pre-heating Gasification Burner
 13. Experimental Study on The Effect of Iodine Additive and Coal Char on The Heterogeneous Decomposition of N₂O under High Temperature
 14. Effect of NaCl on the NO_x emission during Zhundong coal combustion
 15. Distribution of Water-soluble Ions and Hygroscopic Analysis for Filterable Particulate Matter Emitted From A Cement Plant
 16. CO self-sustained combustion induced by CuCe_{0.75}Zr_{0.25}O_y catalysts with different pore-forming ways
 17. Study on Aerosol Formation Characteristics in Reaction System of SO₂, NO₂, NH₃ and H₂O(g)
 18. Mercury Oxidation and NO Reduction over Bifunctional Cu_xFe_{3-x}O₄ Spinel-type Catalysts
 19. Char-Nitrogen Conversion Characteristic of Coal Char Produced with O₂ Exist under Combustion Conditions
 20. Effects of high temperature on NH₃/NO reactions in the absence of oxygen
 21. Effects of the tertiary air injecton port on semi-coke flameless combustion with coal self-preheating technology
 22. Characteristics of Hg₀ Re-emission Caused by Sulfite in Wet Flue Gas Desulfurization System
 23. Self-sustained combustion of CO with transient changes over powdered CuCe_{0.75}Zr_{0.25}O_δ for honeycomb ceramics catalyst
 24. Partitioning behavior of arsenic in an ultra-supercritical coal-fired power plant equipped with APCDs for ultra-low emission
 25. Study of the concentration of mercury in coal used in combustion, in an area of Boyacá Colombia, South America
 26. Evaluation of New Kind Wet FGD Effluent Zero-Emission Technology by Waste Heat from Flue Gas
 27. Investigation of Arsenates Particles Capture from Coal-fired Power Plant Flue Gas by Electrostatic Precipitator

Oral Session

Design and Operating Experiences 1

Monday, July 22, 2019

Index No: 6.1

MODELING THE ASH BUILDUP LAYER ON STEAM TUBES AND EFFECTS ON RADIATION HEAT TRANSFER

Terry A. Ring, John Camilo Parra Alvarez and Phillip J. Smith

Institute of Clean and Secure Energy University of Utah

Fireside heat-transfer characteristics in a pulverized-coal furnace are affected, by the chemistry, physical properties and evolving microstructure of the ash deposit layer as it builds up between ash blowing events. Several complex mechanisms are involved in determining the radiative heat-transfer process at the walls. These include: sintering, radiation scattering and radiation absorption in a porous structure that has steep temperature gradients. These complex mechanisms restrict the absorption of the incident radiation from the flame due to radiating hot coal particles, hot combustion gases and radiating soot. These mechanisms involve dependencies on the radiation spectrum and its interaction with the ash, its physical properties and ash-sintering effects that enhance heat transfer. Each of these phenomena has different time constants that are investigated as well as significant impact on the radiation heat transfer modeled in this paper.

Index No: 6.2

STUDY ON MODELING AND CONTROL STRATEGY FOR COMBUSTION OPTIMIZATION OF PULVERIZED COAL BOILER

Miao Liu, Gengda Li, Xin Wang, Baowei Chen
Guodian New Energy Technology Research Institute Co., Ltd

Pulverized coal boilers are often in a state of frequent changes in load, coal type, combustion and other parameters. The generation and removal of nitrogen oxides are closely related to the operating conditions of coal-fired units. Therefore, it is of great economic and environmental significance to study the generation and removal characteristics of nitrogen oxides under full operating conditions of coal-fired units. In this paper, combined with the formation mechanism of nitrogen oxides in coal-fired boilers, the long-term short-term memory neural network model is used to predict the formation of nitrogen oxides in 660 MW front-wall and back-wall pulverized coal fired boilers. Then the optimization of burner switching in variable load process is studied.

Index No: 6.3

THE SYNERGISTIC PERFORMANCE OF HEAT AND ELECTRICITY WAS STUDIED FROM THE HEATING DEMAND SIDE AND THE SUPPLY SIDE

Pan Zhang, Weiliang Wang, Junfu Lyu
Tsinghua University

As the increasingly fast development of cogeneration of heat and power and renewable energy, it is necessary to review the traditional technical route, and develop a more flexible and efficient cogeneration system. The thermal power units on the heating side and the heating users on the thermal demand side, including the whole heat network transmission system, have a great impact on the power grid dispatching. Exploring the regulating potential of the whole heating system can effectively improve the peak regulation of the power grid and the absorption capacity of new energy. Based on the minimum stable combustion load of the boiler, the peak shaving capacity of the cogeneration unit can be increased by 36 million kW compared with the pure condensation operation. In the social energy consumption system, the cogeneration unit can deeply peak-shaving to promote new energy consumption, and save 2.58 million tons of standard coal per year. In addition, different response and delay

characteristics of electricity and heat can be utilized to effectively cooperate with frequency modulation operation of power grid and improve power supply quality and operation stability of power grid. At the same time, on the demand side, the adoption of heat storage method can well adjust the peak and valley difference of the power grid.

Index No: 6.4

EFFECT OF PINE PYROLYSIS IN PRESENCE OF CAO ON SIMULTANEOUS CO₂/NO REMOVAL BY CAO/PINE CHAR AT CALCIUM LOOPING CONDITIONS

*Yuqi Qian, Yingjie Li, Wan Zhang
Shandong University*

Calcium looping is deemed as one of the most promising technologies for large-scale CO₂ capture to restrain CO₂ emissions. It is found that coal char can reduce NO and CaO can catalyze NO reduction with coal char. Based on this finding, a new simultaneous removal of CO₂ and NO at calcium looping conditions for a coal-fired power plant. Biomass is pyrolyzed by utilizing the heat carried by CaO from calciner in the pyrolysis reactor. In this work, the effect of pyrolysis condition and CO₂ capture reaction condition on the simultaneous CO₂/NO removal by CaO/pine char are studied.

Limestone and pine were employed to research the effect of pine pyrolysis in the presence of CaO on simultaneous CO₂/NO removal by CaO/pine char at calcium looping conditions. The pine char pyrolyzed in the presence of CaO achieves NO reduction efficiency of The NO reduction efficiency of pine char pyrolyzed in presence of CaO maintain at 100% before 273s while the NO reduction efficiency of pine char pyrolyzed in presence of CaO is from 83% to 92% before 117s, which prove the biochar pyrolyzed in the presence of CaO possesses higher NO reduction performance than biochar pyrolyzed in absence of CaO. Higher pyrolysis temperature and higher O₂ concentration in simultaneous CO₂/NO removal improve NO reduction, while longer pyrolysis time, higher mass ratio of CaO to pine and longer cycle number decrease NO reduction. The microstructure analysis results show that in presence of CaO, carbon distributed evenly on the surface of CaO and pine char possesses loose structure,

which are constructive for NO reduction. Higher pyrolysis temperature during pyrolysis of the pine in the presence of CaO leads to larger the volume of pores in 3.4-4.4 nm in diameter of pine char. It proves that the pores in the range of 3.4-4.4 nm in diameter of pine char is favorable for NO reduction.

Index No: 6.5

EFFECT OF RECIRCULATED FLUE GAS ON 660 MW DOUBLE REHEATED BOILER

*H. Xiao, Y.X. Wu, L.L. Feng, C.W. Meng, H. Zhang,
M. Zhang, Z. Chai
Tsinghua University*

To investigate effect of recirculated flue gas (RFG) on combustion, heat transfer and pollutant emission of double reheated boiler, a three dimension CFD model was established and a scalar equation of mass fraction of RFG was involved to analyze the dispersion of RFG in the furnace. Realizable k- ϵ model, Euler-Lagrange method, DO model and finite-rate/eddy-dissipation were applied to solve the turbulent flow, dispersion of pulverized coal, radiation and gas-phase turbulent combustion in the furnace. The results show that when the RFG ratio is low, recirculated flue gas was mainly distributed in the central zone of the furnace and spiraled upward in the combustion zone. When the amount of RFG increases, it was diffused around the furnace from the central furnace to the vicinity of the wall, which effectively reduced the temperature. Moreover, NO_x emission decreases with the increase of RFG ratio but the carbon burnout decreases apparently when the RFG ratio is larger than 10%. The results show that a RFG ratio of 6%-10% was the best suitable rate for 50% THA condition.

Index No: 6.6

EXPERIMENTAL STUDY OF TEMPERATURE DISTRIBUTION IN 0.3MWTH COAL-FIRED COMBUSTION AND HYDRODYNAMIC COUPLING TEST FACILITY UNDER ADVANCED ULTRA-SUPERCRITICAL CONDITION

*Jian Zhang, Xueli Ge, Zhongxiao Zhang, Haojie Fan,
Jiancong Dong, Wei Xu*

Shanghai Jiao Tong University

An experiment for the flue gas temperature and wall temperature distribution characteristics was conducted at advanced ultra-supercritical pressure in coal-fired experiment platform. The main purposes is to explore the temperature distribution characteristics in all heating surfaces with the coal feed capacity of 0.3MWth, the uncertainty of all measuring equipment are given in this paper. The flue gas temperature in the main combustion zone in the furnace can reach 1630K, with a measuring uncertainty of 0.75%, when the oxygen concentration is 3.4%(vol) at the exit of flue gas. The flue gas temperature difference during stable experimental process is 33.5K with a relative error of 2.4% which means a steady combustion performance and good repeatability, when the pressure of steam is 41MPa. The maximum wall temperature of waterwall can reach 832.85K, for the superheater, the wall temperature can be heated to 988.42K with a relative fluctuate error of 5.8% when the steam pressure was adjusted. The wall temperature of reheater heating surface was very stable when the combustion and steam condition was not changed.

Index No: 6.7

LARGE EDDY SIMULATION OF A 660 MW ULTRA-SUPERCRITICAL BOILER UNDER VARIABLE LOADS

*Haoshu Shen, Yuxin Wu, Minmin Zhou, Hai Zhang, Guangxi Yue, Junfu Lyu
Tsinghua University*

Large eddy simulation (LES) has become a promising tool for pulverized coal combustion with the development of CFD technologies in recent years. LES can better capture the unsteady features and turbulent structures of coal jet flame than RANS. The coal-fired power plants in China are now required to be operated under a wide load range and quickly response to the electric grid due to the instability of renewable energy. However, the flow, heat transfer and combustion processes should be investigated thoroughly when the utility boilers are not operated in the designed condition. In this paper, LES was applied to study

the performance of a 660 MW ultra-supercritical boiler under BMCR, 75%THA-100 and 50%THA-100 conditions. The predicted gas velocities agree well with the thermal calculation and the temperature errors are less than 127 K. The simulation results show that the operation load has significant effects on the boiler performance. It is proved that LES can provide guidance for the design and operation of the advanced coal-fired boilers.

Index No: 6.8

THE PROCESS OF SELF-HEATING SLUDGE INCINERATION BASED ON GRANULAR HEAT CARRIER

*KONG Hao, MIAO Miao, YANG Hairui, ZHANG Xuyi, ZHANG Man
Tsinghua University*

Among the current sludge treatment methods, drying and incineration is one of the most frequently adopted for sludge processing since it works efficiently and can reduce pollution caused by sludge. However, sludge with high moisture content needs a lot of heat for drying before stable burning in the furnace, which increases its cost and causes the stink.

This paper introduces a novel process of self-heating sludge incineration based on granular heat carrier as shown in figure.1. Self-heat incineration means that the process uses self-generating heat for drying and incineration to reduce heat consumption. Free falling particles curtain is used to quickly cool down the flue gas temperature to below 300 °C, to avoid the temperature 300-800 °C that may cause regeneration of dioxin. The particles heated works as heat carrier to dry the wet sludge with water content over 70% in the fluidized bed dryer. The dried sludge is incinerated in the insulated fluidized bed furnace to provide heat to burn other wet sludge directly injected into the furnace. A 240t/d unit with such process was manufactured and operated in 2017, and the performance is satisfied. SO₂ emission is less than 30 mg/Nm³, NO_x emission is less than 100mg/Nm³, PCDD/Fs emission is less than 0.034ng-TEQ/Nm³ and the investment of this process is less than 250000yuan/t/d.

Index No: 6.9

INDUSTRIAL-SCALE INVESTIGATIONS ON THE EFFECTS OF THE TERTIARY AIR DECLINATION ANGLE ON THE COAL COMBUSTION AND STEAM TEMPERATURE CHARACTERISTICS IN A 350-MW SUPERCRITICAL DOWN-FIRED BOILER AT MEDIUM AND HIGH LOAD

Xiaoguang Li, Lingyan Zeng, Hongye Liu, Yao Li, Yifu Li, Yunlong Zhao, Bo Jiao, Minhong Song, Shaofeng Zhang, Zhichao Chen, Zhengqi Li
Harbin Institute of Technology

Industrial-scale experiments were conducted to study the effects of the tertiary air declination angle (TDA) on the coal combustion and steam temperature characteristics in the first 350-MW supercritical down-fired boiler in China with multiple-injection and multiple-staging combustion (MIMSC) technology at medium and high load. The experimental results indicated that as the TDA increased from 0 ° to 15 °, the overall gas temperature in the lower furnace rose and the symmetry of temperature field was enhanced. The ignition distance of the fuel-rich coal/air flow decreased. In the near-burner region, the O₂ concentration decreased while the CO and NO concentrations increased. The NO concentration decreased in the near tertiary air region. The carbon in fly ash decreased significantly from 8.40 % to 6.45 % at 260-MW load. At the TDA of 15 °, the ignition distance of the fuel-rich flow is the shortest. The ignition distances at 210-MW and 260-MW loads were 2.07 m and 1.73 m, respectively. The main and reheat steam temperatures were the highest (557 °C and 559 °C at 210-MW load, 558 °C and 560 °C at 260-MW load). The carbon in fly ash was the lowest at 4.83 % at 210-MW load. On changing the TDA from 15 ° to 25 °, the flame kernel was found to move downward, the temperature in the hopper region increased, and the main and reheat steam temperatures dropped obviously. During the measurements, the water wall temperature deviations were within permitted under various working conditions, which can meet the requirements of safe operation of the boiler. The NO_x emissions were in the range of 660-681 mg/m³ at 6 % O₂. The change of the TDA has little effect on the NO_x

emissions. In comprehensive consideration of the combustion characteristics of pulverized coal and the economic performance of unit, the optimal TDA of 15 ° is recommended.

Oral Session

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Tuesday, July 23, 2019

Index No: 6.10

INVESTIGATION OF AIR-BLOWN TWO-STAGE ENTRAINED-FLOW GASIFICATION OF MECHANOACTIVATED COAL

N.A. Abaimov, E.B. Butakov, A.P. Burdukov, P.V. Osipov, A.F. Ryzhkov

Ural Federal University named after the first President of Russia B. N. Yeltsin

The aim of this work is to intensify the air conversion of standard coal into the fuel syngas by means of mechanical activation of some part of the coal without the involvement of other methods of conversion intensification (enrichment of blast, heating of blast or fuel, etc.). Experimental studies were carried out at the IT SB RAS setup with the capacity of 5 MW modified for two-stage coal input. We have performed a comprehensive experimental and computational study of air-blown gasification of standard coal by combustion products of mechanoactivated primary coal at the ratio of primary and secondary coal 90/110-90/230 kg/kg (KMAC=0.82-0.39), $\alpha=1.37-0.5$ and the temperature in the core from 1200-1300 to 1500-1600 °C. It has been found that mechanoactivation of primary coal allows maintaining a stable autothermal mode of air-blown gasification of oxidized coal of standard grinding without involving additional methods of conversion intensification at $\alpha=0.5$.

Index No: 6.11

NUMERICAL SIMULATION OF PULVERIZED COAL FURNACE WITH HIGH-SPEED AIR JET

*Wenzhao Xing, Shi Yang, Xiaolei Cheng, Xin Zhang
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Conservation*

Traditional pulverized coal furnace pollutant emissions will be effectively reduced when high-speed air jets are adopted. The high-speed jets entrain the high-temperature flue gas reflux and rapidly blends to form a "high temperature and low oxygen" atmosphere, which creates conditions for the low-nitrogen combustion. Recently, amount of experimental researches on this low N combustion technology have been carried out. However, the mechanism research is not enough. Therefore, it is necessary to study the effect of the furnace structure and intake parameters on the reaction atmosphere formation on the mechanism. In this work, the mechanism of reaction atmosphere formation is studied by numerical simulation, illustrated by the example of a 0.5MW pulverized coal furnace. The calculation model selected in this article includes gas-solid mixing, devolatilization, a detailed reaction mechanism of gas phase hydrocarbon/NO chemistry and gas-solid reaction model. Based on this model, the influence of nozzle position, jet velocity, particle size of coal powder on the flow field in the furnace, the reflux ratio of flue gas, the residence time, the concentration distribution of coal powder was studied. and the effects of operation conditions on temperature field, composition field, carbon burnout rate, pollutant discharge were also discussed. There exists a strong NO-reburning process within the downstream of the reflux zone. In other words, less NO is formed from combustion of volatiles than conventional coal combustion technologies.

Index No: 6.12

NUMERICAL RESEARCH ABOUT THE INFLUENCE OF DECLINATION ANGLE ON CARRYING CAPACITY OF F-LAYER SECONDARY AIR, IGNITION AND COMBUSTION CHARACTERISTICS OF PULVERIZED COAL IN A 670 MW FW DOWN-FIRED BOILER WITH "VENT-TO OFA TECHNOLOGY" AND "FUEL PREHEAT NOZZLE"

He Du, Lingyan Zeng, Hui Han, Wenjie Liu, Zhichao Chen, Zhengqi Li

Harbin Institute of Technology

Numerical simulations are carried out to study the influence of declination angle (viz., 0°, 10°, 20°, 25°, 30° and 40°) on F-layer secondary air carrying capacity, pulverized coal combustion characteristics of a 670 MW FW down-fired boiler adopting "Vent-to OFA Technology" and "Fuel Preheat Nozzle". Air-flow performance, pulverized coal/air flow ignition and combustion characteristics of "Fuel Preheat Nozzle" are studied in this work. Results uncover that compared with ordinary fuel nozzle, "Fuel Preheat Nozzle" can effectively shorten the ignition distance of pulverized coal/air flow from 1.7 to 0.77m. When F-layer secondary air is horizontally arranged, flow field and temperature field are skewed. Pulverized coal/air flow penetrating depth is only about 0.4. The arrangement of small F-layer secondary air declination angle (10~25°) can effectively improve the symmetry of flow field and temperature field in furnace. Vertical dimensionless velocity attenuation curve of pulverized coal/air flow in furnace can always keep smooth. Penetrating depth of pulverized coal/air flow extends to about 0.7. For F-layer second air declination angle of 20 and 25°, highest temperature in upper furnace reduced by 200K. Vertical dimensionless velocity attention between fuel-rich nozzle and F-layer secondary air nozzle are much smaller, which are respectively 46.5 and 47.3m²/s. Carbon content in fly ash, NO_x emissions and O₂ concentration at furnace outlet are relatively lower. For declination angle of 30 and 40°, vertical dimensionless velocity attenuation curve shows large fluctuations at F-layer secondary air entering position. Flow field deflection and combustion disorder in furnace show up. Therefore, F-layer secondary air is recommend to arranged with 20~25° declination angle in industrial application and use vertical dimensionless velocity attenuation curve to optimize the arrangement of F-layer secondary air (staged air).

Index No: 6.13

STUDY ON THE STABILITY OF HIGH PRESSURE PNEUMATIC TRANSPORT OF THE MIXTURE OF PULVERIZED COAL AND EXTRACTION RESIDUE

FROM DIRECT COAL LIQUEFACTION RESIDUE

B. Z. Peng, X. H. Fang, H. Q. An, Z. Liu, Y. Li, Z. Y. Feng

National Institute of Clean and Low Carbon Energy

The utilization of residues from direct coal liquefaction (DCL) process has gradually become the focus of reducing the waste of DCL process. In this article a new approach of using extraction residue (ER) from the residue of DCL process have been proposed, which is considered it as a feedstock mixing with coal powder and injected into a dry-fed entrained flow coal gasifier for gasification. However, the stability of high pressure pneumatic transport of the mixture of pulverized coal and ER is crucial to the safety and the stability for operations of dry-fed entrained flow coal gasifiers. Therefore, In this work a set of high pressure dense phase transport experiments was built with pneumatic pressure up to 6.0 MPag, high pressure pneumatic conveying experiments were carried out using a high-volatile bituminous coal mixing with 20wt% ER of direct coal liquefaction residue (DCLR) in pipes with diameters of 25mm and 15mm, respectively, at back pressures of 2.0~4.0 MPag. By comparing and calculating the relative standard deviations (RSDs) of different signals on the transport stability, the RSD of solid flow rate was selected as an indicator for conveying stability. The result show that the RSDs of both transport stability of coal and its mixture with 20wt% ER from DCLR is less than 4%, which indicated a good stability in both the coal and its mixture with 20wt% ER from DCLR.

Index No: 6.14

EXPERIMENTAL INVESTIGATION OF COAL GASIFICATION WITH PLASMA FOR THE REBURNING TO REDUCE NO_x IN A PULVERIZED COAL FIRED FURNACE

Z.R.Gong, P.Zou, Y.L.Zheng, L.B.Song, J.J.Yang, J.F.Lyu

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Reburning is an effective method to reduce NO_x emission of pulverized coal combustion. Yantai Longyuan

Power Technology Co., Ltd. suggested the novel idea that H₂, CH₄, CO and other reducing gases generated by coal gasification with plasma was used as reburning fuel. These gases were sprayed into the furnace to reduce the generated NO_x emission of a boiler. Based on series of theory and calculation, a 1t/h plasma coal gasification test system was designed and constructed. The influence of excess air coefficient, temperature, pulverized coal concentration, steam concentration as well as coal quality on the coal gasification performance were studied systematically.

The experimental results of Penglai coal showed that the yield of H₂ increased with the increase of excess air coefficient α in the range of 0.24~0.58 and reached 23.84kg/t when α was 0.58; the yield of CH₄ increased first and then decreased with the increase of α , arriving at the maximum of 17.34kg/t when α was 0.36. The H₂ yield increased with the increase of the temperature; the yield of CH₄ increased first and then decreased with the increase of temperature and reached the highest value at 1150 °C. Along with the increase of pulverized coal concentration in the range of 0.22~0.53kg/kg, the CH₄ yield increased while the H₂ yield increased first and then decreased. However, the pulverized coal concentration had little influence on the yield of H₂. Steam had little positive effect on the gasification reaction. If a large amount of steam was added, the overall temperature inside the device drops, which leads to the deterioration of the gasification effect.

The volume fraction of H₂, CH₄ and CO in the gasification product were 8~10%, 0.4~0.8% and 10~12% respectively at the condition of the primary air velocity of 17m/s, the excess air coefficient of 0.4, the pulverized coal concentration of 0.4kg/kg and the exit gas temperature of 1200 °C for Penglai coal. The results for Cangdong coal and Kangping coal were basically closed to that of Penglai coal.

Oral Session

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Tuesday, July 23, 2019

Index No: 6.15

RESEARCH ON DENSE PHASE PNEUMATIC CONVEYING OF THE MIXTURE OF PULVERIZED COAL AND EXTRACT RESIDUE OF COAL LIQUEFACTION RESIDUE AT HIGH PRESSURE

X. H. Fang, Z. Liu, H. Q. An, Z. Y. Feng, B. Z. Peng, Y. Li, Y. G. Wang

China University of Mining & Technology

In order to study on the high pressure dense phase conveying characteristics of extract residue of coal liquefaction residue (hereinafter referred to ER) blending to pulverized coal, the pulverized coal (M1) and the pulverized coal blending 20wt.% extraction residue (M2) were prepared as experimental samples. The conveying experiments were conducted at back pressures (receiver pressure) of 2 and 4Mpag in a pipeline with 25mm inner diameter. The results showed that at the same superficial gas velocity, there is no significant difference in particles velocity when conveying M1 and M2 samples. The increasing of back pressure reduced the velocity difference between local superficial gas velocity and particles velocity. The conveying phenomena showed that both the mass flow rate and the particle concentration of these two samples increased with the increasing of flow rate of the fluidizing gas. When the fluidization number increased to 2.5, the fluidization effect were good enough to keep the mass flow rate of M1 and M2 stable; when back pressure decreased from 4Mpag to 2Mpag, blending ER to pulverized coal will lead to a decrease in mass flow rate of the mixture powder. The effect of the blending ER to pulverized coal on particle concentration was mainly appeared in the low superficial gas velocity region, in the high gas velocity region, the particle concentration of M1 and M2 was similar during the conveying processes.

Index No: 6.16

EFFECT OF SUPPORT MATERIAL ON THE CO₂ CAPTURE PERFORMANCE OF K₂CO₃-BASED PELLETS

Chuanwen Zhao, Peng Wang, Jian Sun, Yafei Guo,

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Application of the K₂CO₃-based sorbents in fluidized-bed demands the material to be in the form of particles or pellets with enough mechanical strength and attrition resistance. In this work, K₂CO₃-based sorbent pellets were prepared via an extrusion-spheronization method. Four types of biomass materials were used as the supports: alumina (Al₂O₃), Bayer aluminum hydroxide (BAh), Kaolin clay (KC), and calcium aluminate cement (CC). The CO₂ capture performances of the pellets were tested under 60 C, 10%CO₂ + 10%H₂O using a self-designed CO₂ absorption system. Further, the microstructure, CO₂ capture performance and mechanical properties of K₂CO₃-based sorbent pellets with different supports and loadings were investigated by means of some relevant characterization tests.

The results show that there are significant differences in the CO₂ capture performance of K₂CO₃-based sorbent pellets with different supports. The Bayer aluminum hydroxide supported sorbent pellet (K₂CO₃/BAh) presents the best CO₂ capture performance, ~1.85mmol/g. The calcium aluminate cement supported sorbent pellets (K₂CO₃/CC) possess the remarkable mechanical properties, while their CO₂ capture performance is inferior. Comprehensively considering the CO₂ capture performance and mechanical properties, K₂CO₃/Al₂O₃ is the most suitable CO₂ sorbent. Moreover, the effect of loading amount of K₂CO₃ on performance of K₂CO₃/Al₂O₃ sorbent pellets was further studied. It is found that the microstructure, CO₂ capture performance and mechanical properties of K₂CO₃/Al₂O₃ sorbent pellets are significantly different with the change of loading amount of K₂CO₃. CO₂ capture capacity of K₂CO₃/Al₂O₃ increases first and then decreases with the increase of K₂CO₃ loading. Sufficient K₂CO₃ loading can provide substantive active sites for enhanced CO₂ chemisorption, whereas excessive loading will cause particle aggregation and pore structure blockage and affect its CO₂ capture capacity adversely. The maximum CO₂ capture capacity of 2.81 mmol CO₂/g is obtained with an K₂CO₃ loading of 50 wt.%. In general,

the K_2CO_3 -based sorbent pellets prepared via extrusion-spheronization method achieve better fluidization characteristics, CO_2 capture performance and mechanical properties, which is suitable for large-scale application in post-combustion flue gas treatment.

Index No: 6.17

GAS/SOLID FLOW CHARACTERISTICS AND COMBUSTION PERFORMANCE OF AN IMPROVED 300-MW DOWN-FIRED UTILITY BOILER

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Deep peak shaving requires extremely high requirements for lowload combustion stability of boilers. In this study, a novel swirl burner (NSB) with an eccentric secondary air arrangement was proposed, and validity and progressiveness of NSB in achieving ultra-low-load combustion stability for down-fired boilers (DFBs) were confirmed from laboratory experiments to industrial applications. Firstly, cold-modeling experiments of gas/particle (GP) two-phase flow characteristics involving two combustion systems (i.e., DFB with traditional swirl burners (TSBs) and DFB with NSBs) were performed at an ultra-low load of 90 MWe. Compared with the original boiler with TSBs, the maximum horizontal recirculation velocity and the area of recirculation zone below arches significantly increase for the improved DFB with NSBs. The particle number concentration near furnace center for the improved DFB with NSBs is much higher than that for the original DFB with TSBs. The downward depth of GP flows and the space utilization ratio of the lower furnace increase. In addition, full-scale industrial-sized measurements aiming at a 300-MWe DFB improved by NSBs were performed at ultra-low loads of 100 and 90 MWe. For the original DFB after improved by NSBs, minimum load for stable combustion without oil support is reduced from 150 to 90 MWe. For the improved DFB with NSBs, ignition distances for operating burners are about 2 and 2.6 m, respectively, and the signal strength of flame detectors for all operating burners is above 95% at 100 and

90 MWe. The flame fullness and combustion stability are good at the initial combustion stage. At ultra-low loads, furnace negative pressure, superheat steam pressure and oxygen concentration at furnace outlet fluctuate slightly. The temperature at air preheater inlet meets the needs of normal operation of denitrification system, and there is no problem of low temperature corrosion on the surface at flue gas side of air preheater. The unburned carbon in fly ash is about 4%. The maximum concentrations of NO_x emission at furnace outlet are 714 and 687 mg/m_3 ($O_2=6\%$) at 100 and 90 MWe, respectively, and ultra-low emission of NO_x after denitrification system is achieved.

Index No: 6.18

EXPERIMENTAL STUDY OF THE FLAT-FLAME PULVERIZED COAL GASIFICATION TECHNOLOGY

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A flat-flame pulverized coal gasification technology is presented and its test results on a 3 t/d gasification test facility are discussed. The test results show that the performance of flat-flame gasification technology is better than the traditional top-placed single-burner technologies, and the test facility is running stably during the test periods. It is revealed that, the flat-flame burner enables higher turbulent intensity and enhances the turbulent mixing between coal particles and oxidant. The overall gasification reaction rate is increased by abovementioned effects. When the mass ratio of O_2 /coal is 0.8, the carbon conversion, volume fraction of efficient syngas and cold gas efficiency of flat-flame burner were respectively 96.7%, 88.6% and 82.1%, which are completely better than single-burner gasification. Preliminary test results and analysis validates the technical feasibility of flat-flame gasification technology and it is ready for scale-up for industry-scale demonstrations.

Index No: 6.19

STUDY OF COAL GASIFICATION IN A PILOT PLANT WITH A FLOW-TYPE REACTOR

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Technologies based on IGCC are a promising direction for the energy use of coal. As part of the program for the creation of a pilot gas combined-cycle plant based on IGCC with a capacity of 250 MW, NPO CKTI in 2013 created a bench unit for studying coal gasification in an oxidant flow under pressure (in a flow reactor). The gasifier is a vessel designed for operation under pressure, 5600 mm high and 720 mm in diameter. In the upper part of the gasifier there is a reaction chamber lined with refractory material, and in the lower part there is an original two-stage cooling system and primary purification of synthesis gas. A combined dust and gas burner and a pilot-stabilizing device are installed in the gasifier cover. The installation is designed to work on coal dust with a maximum particle size not exceeding 120 microns. Maximum coal consumption 100 kg/h. The maximum working pressure in the reaction chamber is 1.6 MPa.

As a gasifying agent, various combinations of air, steam, and oxygen are used, heated to 350–500 °C. The blending of the blast components takes place in the mixer, after which the mixture enters the 10 kW electric heater. The hot mixture flows directly into the burner. The report presents the results of computational studies of the process of gasification of coal in a flow-type chamber (reactor) based on mathematical modeling, as well as the results of experiments on a bench installation.

In the calculations, the composition of the oxidizing agent (air, oxygen, and their mixtures with steam) and operating parameters were varied. The volume fraction of steam in mixtures with air or oxygen varied from 5 to 20%. The oxidizer excess ratio in terms of air varied within 0.3–0.5. The maximum design value of the specific heat of combustion of synthesis gas (2335 kcal/nm³) gave the gasification mode on the steam-oxygen blast with a steam fraction of 10%. The results of experiments conducted on coal dust showed a satisfactory agreement between the experimental data and the calculation (both in terms of the

yield of individual gas components and the value of the specific heat of combustion of synthesis gas). As a result of testing the gasifier, synthesis gas was obtained with a specific heat of combustion of 800–1000 kcal/nm³ with a steam-air blast and 2000–2500 kcal/nm³ with a steam-oxygen blast (results obtained without removing CO₂ from the synthesis gas).

Index No: 6.20

COMPARATIVE STUDY OF PROPERTIES OF XINJIANG COALS AND INTERNATIONAL LOW-RANK COALS

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In the past two decades, a number of superlarge coalfields have been discovered in Xinjiang province, China. Xinjiang coals are mostly sub-bituminous and light coals. They are cheap, of high quality, and are, therefore, being actively investigated for meeting the increasing energy demand. In contrast to their importance in the energy structure, Xinjiang coals are found to be more prone to induce severe ash slagging and fouling problems, compared with conventional utility coals. These ash issues pose a major challenge to sole combustion of Xinjiang coals, and thus restrict their utilization in large scales for power generation. The difficulties encountered in Xinjiang coal combustion are closely associated with their particular properties. Such coal properties have not been systematically investigated or evaluated, and therefore, the mechanisms of ash deposition during Xinjing coal combustion are still little known. A comprehensive survey is conducted in this work. It finds that there exist quite a few international lowrank coals which possess some properties similar to Xinjiang coals. Comparisons of the properties between Xinjiang coals and those international lowrank coals are believed to be very helpful to the understanding their unique features, which largely determine the ash issues occurred during combustion. On the other hand, the measures taken in combustion of the international low-rank coals may enlighten the engineers in

power plants firing Xinjiang coals. This work reports a comparative study of the properties of Xinjiang coals and some typical international low-rank coals. The data were collected from the open literature published by the authors themselves and other international scholars. The emphasis was put on Zhundong coals, which have been extensively exploited and investigated. The coal properties evaluated in this work included proximate analysis, ultimate analysis, ash composition, modes of occurrence of alkali and alkaline earth metals and their abundance in the coals. The established slagging and fouling indices were comprehensively compared to elucidate ash deposition propensities.

Index No: 6.21

RESEARCH ON THE PREPARATION OF BIMETAL MATERIAL PCN-6(M) BY STEAM-ASSISTED METHOD AND THEIR CH₄ ADSORPTION PERFORMANCE

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Methane is the main ingredient of natural gas, biogas and pit gas, which is one of the currently widely used fuels. However, separation of CH₄/CO₂ in natural gas and biogas is difficult, therefore CH₄/CO₂ separation and CH₄ storage are essential research in the low-carbon energy field. Metal-organic frameworks are widely concerned in the field of gas storage and separation due to their large specific surface area, diverse structures. PCN-6 has a huge Langmuir surface area of 3800 m² g⁻¹ and a hydrogen storage capacity of 1.9 wt%, based on its particular properties, this work uses PCN-6 as the modified parent material. A steam-assisted method was introduced to prepare the bimetallic material PCN-6(M) and get five different bimetallic materials.

The specific operation of steam-assisted method: the parent material PCN-6 is grinded in a mortar with a metal salt corresponding to the metal to be exchanged, the mixed samples was transferred into a small beaker and placed in a reaction vessel with a little DMF at the bottom and then to be heated. At high temperature, DMF steam will promote

metal (Co, Fe, Mn, Zn, Ni) partly to exchange with the original metal(Cu) in parent material and finally obtain different bimetallic materials.

In this work, compared with the traditional solvent heat exchange method, the steam-assisted method greatly improves the exchange amount of the second metal. It is a new idea for MOFs materials that are structurally stable and difficult to exchange metals by conventional methods. The CH₄ adsorption of PCN-6(Zn), PCN-6(Co) and PCN-6(Ni) is higher than the parent material PCN-6, the CO₂/CH₄ selectivity of PCN-6(Fe) is higher than PCN-6, this shows that the steam-assisted method can successfully prepare bimetallic MOFs materials, and the obtained bimetallic materials exhibit better performance than the parent materials.

Index No: 6.22

DISTRIBUTION AND SPECIATION OF MERCURY IN CHEMICAL LOOPING COMBUSTION OF IN-SITU PYROLYSIS AND CHAR GASIFICATION PRODUCTS

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Mercury emission is an important issue in in situ gasification chemical-looping combustion (iG-CLC) of coal. This work focused on experimentally “isolating” two elementary subprocesses (coal pyrolysis and char gasification) during iG-CLC of coal, identifying mercury distribution within the two subprocesses, and examining the effects of a hematite oxygen carrier (OC) on the mercury fate. The mercury measurement accuracy was carefully ensured by comparing online measurements (by a VM 3000 instrument) and benchmark measurements (by the standard Ontario Hydro Method, ASTM D6784) as well as repeated tests (10 times for each case). The mercury mass balance was 115% for the entire iG-CLC. A total of 44.7% of the mercury was released as the gas phase form within the coal pyrolysis process at a typical CLC operation temperature (950 °C), while 13.4% was released during the char gasification process. The release rate and amount of mercury were

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minimally affected by the presence of an OC; however, the OC promoted the conversion of $\text{Hg}_0(\text{g})$ to $\text{Hg}_2+(\text{g})$. Only a small amount of mercury was absorbed by the OC and transported into the air reactor along with carbon residue, released as $\text{Hg}_0(\text{g})$ and $\text{Hg}_2+(\text{g})$ or remained in the OC and coal ash as particulate mercury.

Poster Session

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First floor and Second floor

1. Power plant boiler operation optimization system based on co control
2. Characteristics of RB Control Loop of Large Lignite Power Plant Boiler and Analysis and Comparison
3. Furnace outlet temperature prediction model of a 350MW ultra-supercritical boiler
4. Research on Evaluation of Pulverized Coal Flow Stability in Dilute Phase Pneumatic Conveying Based on Pressure Fluctuation of Resistance Components
5. Experimental Study on Optimal Adjustment of SCR Ammonia Injection for 1000MW Coal-fired Unit Based on Multi-field Cooperative Diagnosis
6. Characteristics of RB Control Loop of Large Lignite Power Plant Boiler and Analysis and Comparison
7. Energy-loss mechanism of boilers system in large-scale coal-fired power plants and the corresponding energy-saving approaches
8. Mechanism analysis of pore diffusion on coal char gasification
9. Experimental Study of Temperature Distribution in 0.3 MWth Coal-fired Combustion and Hydrodynamic Coupling Test Facility Under Advanced Ultra-Supercritical Condition
10. Large Eddy Simulation of a 660 MW Ultra-Supercritical Boiler under Variable Loads
11. Gas/Solid Flow Characteristics and Combustion Performance of an Improved 300-MW Down-Fired Utility Boiler
12. Modeling the Ash Buildup Layer on Steam Tubes and

Effects on Radiation Heat Transfer

13. Investigation of air-blown two-stage entrained-flow gasification of mechanoactivated coal
14. Dynamic characteristics of a boiler with low- NO_x Combustion

Oral Session

Keynote & NSF-NSFC/ DFG-NSFC Panel

Wednesday, July 24, 2019

Keynote Lecture:

INSIGHTS ON COAL COMBUSTION FROM HIGH-FIDELITY SIMULATIONS

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Coal combustion remains a challenging topic due to the multiple physical processes involved which span a large range of length and time scales. Although detailed models exist for devolatilization, char oxidation and gas-phase kinetics, most simulation efforts simplify these models considerably to reduce the high cost of simulation. The One-Dimensional Turbulence (ODT) model provides the ability to examine high-fidelity thermochemistry models by instead modeling the details of three-dimensional turbulent mixing by a one-dimensional, stochastic process where the size and frequency of mixing events is determined by the local fluid dynamics. Past results have shown that ODT can capture many salient features observed both experimentally and in Direct Numerical Simulation (DNS) but at significantly lower cost. Here, we consider several simulation techniques including well-stirred reactors and ODT to examine the effect of model fidelity on prediction of key experimental observables such as ignition and flame standoff. We present several examples of situations where high-fidelity models are important to predict experimentally-observed behavior including ignition (flame stand-off), char oxidation and tar/soot oxidation. We also apply these

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modeling techniques to Moderate or Intense Low Oxygen Dilution (MILD) combustion. MILD combustion occurs when the inlet temperature of the reactant mixture is higher than mixture self-ignition temperature whereas the maximum allowable temperature increase with respect to inlet temperature during combustion is lower than mixture self-ignition temperature (in Kelvin) [Cavaliere, 2004]. It has attracted increased attention in recent years for its potential to reduce emissions. A key requirement for MILD combustion is that mixing rates are sufficiently fast that gasphase chemistry occurs nearly volumetrically, eliminating visible flame structures. By simulating MILD combustion with well-stirred reactors, we can examine the effect of recirculation (dilution) rate on the resulting

particle dynamics and gas-phase kinetics. We also examine the effect of particle sizes. The results are compared to the ODT model where effects of finite-rate mixing can be captured. These models are used to gain fundamental insights into MILD coal combustion and to establish guidelines for how to achieve MILD combustion in practice.

Panel Discussion:

NSF-NSFC/ DFG-NSFC Panel

**FUTURE SCIENCE AND TECHNOLOGIES OF CLEAN
COAL UTILAZITION**

Notes

