Opposed Multi-Burner (OMB) Coal-Water Slurry 
Gasification Technology and 
its Industrial Applications

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Abstract

Opposed multi-burner (OMB) coal-water slurry (CWS) gasification technology is a representative entrained flow coal gasification technology that has been developed by East China University of Science and Technology (ECUST) and Yankuang Group. This gasification process adopts an entrained flow OMB gasifier in order to produce syngas, which primarily consists of carbon monoxide and hydrogen using a CWS and pure oxygen under high pressure and high temperature operating conditions. With many technical advantages, the gasification efficiency of the OMB CWS gasification is very high, and the carbon conversion is normally higher than 98.5%. Up to now, OMB CWS gasification technology has been licensed in 40 projects for a total of 112 gasifiers for locations both in China and the United States. The design has a coal capacity range from 750 to 3250 t/d for a single gasifier and a pressure range from 1.5 MPa to 6.5 MPa. There are 54 gasifiers in 20 different projects that are currently running smoothly in China with the largest one having a 3,000 t/d coal capacity. According to the industrial application experience, OMB CWS gasification is superior in many aspects, such as gasification performance, process indexes, stability, and reliability. Especially in large-scale gasification applications, OMB CWS gasification technology has obvious advantages.

Introduction

Coal gasification technology is the key technology for the clean and efficient utilization of coal. It is also a basic technology for developing coal-based chemistry products (such as methanol, ammonia, olefins, oils, etc.), advanced IGCC power generation, polygeneration system, hydrogen production, fuel cells, direct-reduction iron-making, and other process industries. It is greatly significant to develop large-scale coal gasification technology for promoting similar industries, boosting the clean and efficient utilization of coal, pushing forward energy conservation and emission reduction, guaranteeing national energy security, etc. The main industrial coal gasification technologies worldwide include fixed bed, fluidized bed, and entrained flow [1]. Fixed bed is represented by Lurgi technology. Fluidized bed is represented by HTW, KBR, and U-Gas. Entrained flow gasification technologies mainly include Opposed Multi-burner (OMB), GE (Texaco) [2], E-Gas [3], which use coal-water-slurry (CWS) as the feeding material, and Shell [4], Sinopet-ECUST (SE), Siemens (GSP), Prenflo [5], etc. which use pulverized coal as the feeding material. The entrained flow CWS gasification technology, in particular, is developing rapidly [6].

East China University of Science and Technology (ECUST) is a research institute that has owned both CWS gasification technology and pulverized coal gasification technology. OMB CWS technology had finished the pilot-scale research during "the 9th Five-Year Plan" in China since 1995, and consequently supported by the National High Technology Research and Development Program of China ("863" Program) and the National Basic Research Program of China ("973" Program) during "the 10th Five-Year Plan", "the 11th Five-Year Plan", and "the 12th Five-Year Plan" since 2005. After years of optimized development and industrial application, the OMB CWS technology is mature and stable. Up to now, there are 112 OMB CWS gasifiers employed by 40 enterprises in China and overseas. The largest designed capacity of single gasifier reaches 3,250 ton coal per day (TPD). 54 CWS gasifiers are now in operation with the largest operation capacity of single gasifier 3,000 TPD. Compared with other CWS gasification technologies, OMB gasification technology has obvious advantages on a large scale for single gasifier, system running performance, stability, reliability, and other aspects. So far, ECUST's OMB CWS gasification technology has become one of the leading technologies in the world gasification market.

OMB Gasification Technology

The OMB CWS coal gasification process uses an entrained flow gasifier to produce syngas consisting mainly of carbon monoxide and hydrogen from CWS and pure oxygen under high pressure and high temperature, which are approx. 1.0~8.7 MPa and 1200~1400 °C, respectively [7]. Under such conditions, the chemical reaction rate is relatively high, and the process is controlled by the transfer process. Based on the above understanding, this process provides a special configuration of the burners, structure, and size of the gasifier to form an impinging flow pattern to enhance the mixing and mass transfer process. Meanwhile, the flow pattern inside the gasifier is optimized to achieve a good result with both process and engineering issues – high content of carbon monoxide and hydrogen in syngas, high carbon conversion, and the long service life of the refractory wall.
OMB CWS Gasification process diagram

The innovative aspects of OMB CWS gasification include: entrained flow gasification with opposed multi-burner, scrubbing-water distributor of crossflow, new-style quenching and scrubbing equipment for high-temperature syngas, pre-film gasification burner for long-life, “step by step” primary syngas purification process, and the slag water treatment process using direct heat-exchange. The process of OMB gasification is shown in figure 1, including the CWS preparation section, OMB gasification and primary syngas purification section, and slag water treatment section of direct heat exchange.

Advanced features

The OMB CWS gasification process has some advanced features compared to other similar entrained flow CWS gasification processes. The details of the OMB gasification process are described below.

OMB gasifier

There are four gasification process burners that are located in opposite directions on the upside of the gasifier, simultaneously feeding CWS and oxygen into the gasifier and thus creating an impinging flow that is favorable for enhancing the material/energy exchange and gasification reaction process, as shown in figure 2. This type of gasifier has reasonable residence time distribution, allowing for the complete burnout of most of the fed coal particles. Due to the unique burner positioning, the mixing process as well as heat and mass transfer are enhanced, the efficiency of gasification process is improved, and the carbon conversion is increased. Due to the proper multi-burner design, the operating flexibility has a wide range from 40% to 120%, and the capacity is easy to change. With the impinging stream principle, CWS flames inside the gasifier are symmetrically confined in the central region of the gasification chamber. The refractory can be protected effectively.

Compared with the single jet burner gasifier, OMB CWS gasification technology has great advantages in processing capacity, gasification efficiency, etc., which is also particularly suitable for large-scale gasification plant.

Process Burner

A gasification process burner is a key piece of equipment for the operation process, which is one of the important factors affecting system long-term operation. By adjusting the burner’s structure to avoid the premix of oxygen and CWS within the burner channel, the pre-film atomization burner structure has been designed. Research studies have shown that a pre-film atomization burner shows excellent performance, simple structure, and low velocity of feeding CWS. The low velocity of slurry that comes out in the burner can also effectively decrease the wear. Industrial performance has proven that this new type of burner enhances the burner’s working life. Up to now, this type of burner has an average working life of 60–90 days, with the longest record at 152 days.

New types of quench and scrubbing equipment and chamber

The quench chamber of the gasifier is combined with the spraying bed and bubbling bed, which helps to reduce the entrainment of water and ash by the syngas leaving the quench chamber.

Raw gas at a higher temperature with the molten ash produced in the gasification chamber is issued into
the quench chamber equipped with a cross-flow spray section and bubble section. The materials and energy diffusion are enforced in the cross-flow spray section by directly spraying quench water into the hot gas flow. The bubbling section equipped with several partition boards is helpful in preventing ash-carrying and water-carrying gas leaving from the gasifier, and its water level is easy to control. Moreover, syngas is completely saturated in the quench chamber to satisfy the requirement of a purification section in the downstream process.

Syngas primary purification section
The syngas primary purification section consists of mixer, cyclone, and water scrubber to achieve high efficiency for the removal of solid particles and fly ash from the syngas. The “step-by-step” concept is introduced in the highly efficient and energy-saving syngas primary purification process consisting of a mixer, cyclone, and water scrubber. Approx. 80–90% of the solid particle and fly ash are removed in the cyclone. Then, the fine particles are removed in the water scrubber, which may greatly reduce the solid concentration (<1 mg/Nm³). Shift condensate and washing water fed into the scrubber are cleaner than the water fed into the mixer to ensure the purification effect.

The industrial application results showed that such a syngas primary purification system has a low pressure drop (≤ 0.1 MPa); after most fractions of the coarse particles separated by the cyclone, the black water quality from the scrubber bottom has improved significantly, in which almost no quench-ring block phenomenon occurs during the system operation process. In this way, the catalyst in the downstream of the shift reactor can be used for many years without the pressure drops increasing.

Slag water treatment section
Slag water from the gasifier and the syngas primary purification unit is introduced into the slag water treatment system separately. The key equipment of the solid water treatment section is the evaporative hot-water tower where steam contacts directly with the recycled gray water to enhance the heat and mass exchange. The slag water enters the evaporation chamber of the evaporative hot-water tower, which is where the slag water evaporates and the desorption of sour gas in water takes place. The vapor evaporated from the evaporating chamber is used to come into direct contact with the ash water in the water-heating chamber. The heat transfer and mass transfer are fulfilled at the same time in the slag water treatment process, which will have a long operation cycle and a good energy recovery result. The slag water from the bottom of the evaporative hot-water tower is flashed in a vacuum flash drum, where the temperature of the slag water is decreased, the concentration of the solid is increased and the sour gas is desorbed completely. The figure of key equipment evaporative hot-water tower is shown in figure 3.

Online feeding under operating pressure
The feature of online feeding under operating pressure is a special feature of the OMB gasification process. There are four burners supplied by two CWS pumps, which are located horizontally opposite from one another in the gasification chamber, responsible for injecting the CWS simultaneously with the oxygen. As shown in figure 4, there are two symmetric and identical CWS and O₂ feeding systems. When a failure occurs (except for the burner itself) in one feeding line, such as pump

Fig. 3: Flow diagram of the evaporative hot-water tower

Fig. 4: Mass feeding diagram of online feeding
or valve failure, there is only a need to shut down the corresponding pair of burners and the rest of burners can keep running. Then, the burners that were shutdown can be restarted once the problem is solved. The application of online feeding under operating pressure can ensure the high reliability and availability of the OMB gasification unit.

**OMB CWS Industrial applications**

With the development of Chinese coal chemical industry, the OMB gasification technology has been widely used in China. There are 40 projects (112 gasifiers) licensed in the world, among which 20 projects (54 gasifiers) are now in operation.

Especially in August 2008, the OMB gasification technology has also been licensed to a project in the United States, which is being carried out at the Port Arthur Refinery of North America (Valero Energy Corp.). There are 5 trains in the project and the designed single train capacity is 2200 t pet-coke per day at 6.2 MPa. The total gasifier capacity for all projects is approx. 130,000 TPD, not including the spare gasifiers. This number of all the gasifiers in operation is approx. 60,000 TPD, and the projects’ final products are oil, olefin, methanol, ammonia, urea and hydrogen, etc. 31 out of the 54 operating OMB gasifiers operate at 6.5 MPa while the remaining operate mainly at 4.0 MPa and two pet-coke fired gasifiers operate at 1.5 MPa. For these 54 gasifiers, there are more than 40 gasifiers with a capacity higher than 1500 TPD. OMB CWS gasification technology has obvious advantages and occupies most of the large-scale gasifier market in China.

**Performance of large scale gasifiers**

Since the first pilot scale OMB gasifier operated by Yankuang Group in the year 2000, ECUST and Yankuang Group Co., Ltd. have invested a lot of manpower and great financial support to further develop the OMB gasification technology. The performance results of the first pilot scale plant show that the OMB gasification technology has many advanced features, particularly in the syngas concentration, carbon conversion, coal and oxygen consumption, etc. After that, the gasification plants of single gasifier capacity including 1000 TPD, 1500 TPD, 2000 TPD, and 3000 TPD have been constructed and operated.

**OMB gasifier with 1000 TPD**

Partially funded by the National High Technology Research and Development Program of China ("863" Program), the first 1000 TPD gasification demonstration plant in Yankuang Cathay Coal Co., Ltd. located in Tengzhou, Shandong province was put in operation in 2005. Three 1150 TPD gasifiers were built, and the operation pressure of the gasifier is 4.0 MPa. The syngas from the gasifiers is used to produce 240 kt of methanol annually and 71.8 MW of electricity. The gasifier was first started on July 21, 2005, and then went through the whole process directly. After 80 hours of continuous and stable operation, the gasifier was shut down as planned. The gasi-
Gasiﬁcation commercial operation was started on October 16, 2005 and the product methanol was produced on the next day. The night view of the plant is shown in Figure 5.

The CWS gasiﬁcation online feeding under operating pressure technology was ﬁrst invented by Yankuang Cathay Coal Co., Ltd., which is a major technological breakthrough, greatly reducing the chance of gasiﬁer shutdown, increasing the gasiﬁer’s effective production time. In addition, the gasiﬁers shifting process with no ﬂuctuation during the actual producing period was also implemented. This shifting process can completely eliminate the inﬂuence between the gasiﬁcation unit and downstream devices, and ensure the smooth operation of the whole plant. The OMB CWS gasiﬁcation technology is proven by industrial experience to have a high product yield, low oxygen and coal consumption, and robust and safe operation.

In 2009, there was not a single unplanned shutdown time of the gasiﬁer and the total working time of the two gasiﬁers was approx. 6,533 h including a single gasiﬁer running continuously for 98 days. In 2010, the total working time even increased to 8,057 h; the gasiﬁers performed very well. The average burner working life is 90 days, and the longest working life is 152 days of continuous operation. The dome region refractory wall working life, which is relatively the lowest part inside the gasiﬁer, can reach up to 11,195 h. Compared to other coal gasiﬁcation plants, as summarized in Laugwitz A. et al. [8], the availability of OMB based gasiﬁcation plants is very high.

The feedstock used by Yankuang Cathy Coal Co., Ltd. is Beisu Coal, a local coal in Shandong province. A comparison of the performance indexes between OMB and another CWS gasiﬁcation process fed by the same type of coal is made consequently. The comparison results show that the OMB CWS gasiﬁcation process used by Yankuang Cathy Coal Co. Ltd. had a higher carbon conversion of 3 percent, a lower speciﬁc oxygen consumption of approx. 8 percent, and a lower speciﬁc coal consumption of 2–3 percent than that of another CWS gasiﬁcation at the Lunan Fertilizer Plant.

Fig. 5: 1000 TPD OMB demonstration plant in Yankuang Cathay Coal Co., Ltd.

Fig. 6: OMB gasiﬁcation plant in Jiangsu Linggu Chemicals Co., Ltd.

OMB gasiﬁer with 2000 TPD
First 2000 TPD demonstration OMB gasiﬁcation plant

Funded by the National High Technology Research and Development Program of China (“863” program) in “the 11th Five-Year Plan”, the large-scale capacity (2000 TPD in Single Train) commercial plant of OMB gasiﬁcation was built in Jiangsu Linggu Chemicals Co., Ltd. located in Yixing city of Jiangsu province.

An overview of the plant is shown in Figure 6. Two sets of gasiﬁers, one in operation and one standby, were built with each coal capacity of 2000 TPD. The inner diameter of the gasiﬁer shell is 3880 mm, which is the largest entrained ﬂow CWS gasiﬁer in the world for now. The inner diameter of the refractory wall is 2762 mm, and the operating pressure is 4.0 MPa. Syngas from the gasiﬁer is used to produce 450 kt ammonia per year. The plant was designed by China Tianchen Engineering Corporation Co., Ltd. The plant was ﬁrst started on June 15, 2009. From the beginning of the operation to November 15, 2011, the plant has been operated over 19,000 hours. In the years 2011, 2012, and 2013, the plant was operated with a total of 357, 351, and 355 days, respectively, which shows excellent stability and reliability.

During Nov. 25-28, 2011, the OMB gasiﬁcation technology in this project passed the 72 hours continuous performance test, which is organized by
Table 1: The performance results of 72 hours continuous test of 2000 TPD gasification technology

<table>
<thead>
<tr>
<th>Design indexes</th>
<th>Performance results</th>
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<tbody>
<tr>
<td>Composition of syngas CO+H₂, %(v)</td>
<td>81.0</td>
</tr>
<tr>
<td>Carbon conversation, %</td>
<td>98.0</td>
</tr>
<tr>
<td>Specific oxygen consumption, Nm³ O₂/1000Nm³(CO+H₂)</td>
<td>390.0</td>
</tr>
<tr>
<td>Specific coal consumption , kg coal/1000Nm³(CO+H₂)</td>
<td>590.0</td>
</tr>
<tr>
<td>Cold gas efficiency, %</td>
<td>74.0</td>
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</tbody>
</table>

For several years, as regards the operating experience and results of the 72 hours' test, the conclusion is drawn that the gasification unit in Jiangsu Linggu Chemicals Co., Ltd. runs in a stable manner and the performance achieves a world-advanced level. Compared with the single burner gasification technology in China Shenhua Coal to Liquid and Chemical Co., Ltd. which also uses a similar coal as the feedstock, the typical operation data are listed below:

1. The specific oxygen consumption of OMB gasification unit is 352 Nm³ O₂/1000 Nm³ (CO + H₂), which is 11.4 percent lower than that of single burner CWS gasifier.
2. The specific coal consumption is 568 kg coal/1000 Nm³ (CO + H₂), which is 2.1 percent lower than that of single burner CWS gasifier.
3. The effective gas (CO + H₂) content is 82.9 % (v), which is 3.1 percent higher than that of a single burner CWS gasifier.
4. The residual carbon content in coarse slag is less than 2 % (wt), and the carbon conversion is higher than 99 %.

Most sets of the 2000 TPD OMB gasifier in one plant

According to the successful operation of the 2000 TPD gasification plant, a number of domestic companies have adopted the OMB CWS gasification technology. Shanxi Future Energy Chemical Co., Ltd. is one of these companies that owns 8 sets of 2000 TPD entrained flow CWS gasifiers to support the production of Fischer-Tropsch synthesis with a capacity of 1 million tons per year. This mode of 8 sets entrained flow CWS gasifiers with 6 in operation and 2 on standby is also the first time it has been employed by one plant in CWS gasification history.

The gasifier size and operating pressure are the same as the gasifiers operated in Jiangsu Linggu Chemicals Co., Ltd. Gasifier #1 was first successfully started at 23:08 on Jul. 31, 2015. The photo of this gasification plant is shown in figure 7. This whole plant is running smoothly now.

OMB gasifier with 3000 TPD

Yanzhou Coal Mining Inner Mongolia Rongxin Chemical Co., Ltd. adopts three sets of 3000 TPD scale OMB CWS gasifiers, achieving the automation, maximization, and intensification of methanol production. The capacity of this type of gasifier is the largest CWS feeding capacity in the world for now. The final production for this plant is 1.8 million tons of methanol in total Phase I plus Phase II. The gasifier operation pressure is 6.5 MPa. On June 24, 2014, A# gasifier first startup successfully, however, due to the requirement of downstream commissioning, A# gasifier second time formally operated on July 7, 2014. From Aug. 19, 2014, two gasifiers began operating together with another one standby. Since Aug. 16, 2015, the plant is running at full capacity with about 3,200 tons of methanol production per day. Until Sep. 26, 2015, A# gasifier has been running with a total of 7,004 hours, B# gasifier 5,858 hours, and C# gasifier 4,957 hours. The view of this plant is shown in Fig. 8. Now, the gasification plant and the entire production system are very stable, which provides a high economic benefit for the company.

Moreover, this project is also a demonstration project of the national whole process quality management and undertakes the National High Technology
Table 3: Carbon conversion of the OMB gasifier

<table>
<thead>
<tr>
<th>Project name</th>
<th>Carbon conversion</th>
<th>Illustration</th>
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<tbody>
<tr>
<td>Hualu Hengsheng Chemicals Co., Ltd.</td>
<td>98.30%</td>
<td>Reported data</td>
</tr>
<tr>
<td>Yankuang Cathay Coal Chemicals Co., Ltd.</td>
<td>98.80%</td>
<td>11.–18. December 2005 168 hours continuous performance test</td>
</tr>
<tr>
<td>Xinneng Fenghuang (Tengzhou) Energy</td>
<td>99.16%</td>
<td>13.–16. October 2010 72 hours continuous performance test</td>
</tr>
<tr>
<td>Shenhua Ningxia Coal Group</td>
<td>98.90%</td>
<td>24.–27. September 2010 72 hours continuous performance test (two gasifiers)</td>
</tr>
<tr>
<td>Jiangsu Linggu Chemicals Co., Ltd.</td>
<td>99.20%</td>
<td>25.–28. November 2011 72 hours continuous performance test</td>
</tr>
<tr>
<td>Anhui Huayi Chemicals Co., Ltd.</td>
<td>98.94%</td>
<td>20.–24. August 2012 72 hours continuous performance test (two gasifiers)</td>
</tr>
<tr>
<td>Shanghai Coking &amp; Chemical Corporation</td>
<td>98.80%</td>
<td>Reported data</td>
</tr>
<tr>
<td>Yingde Gases in Anyang</td>
<td>99.30%</td>
<td>29.–31. October 2014 72 hours continuous performance test</td>
</tr>
<tr>
<td>Henan Xinlianxin Fertiliser Co., Ltd.</td>
<td>98.70%</td>
<td>12.–14. January 2015 72 hours continuous performance test</td>
</tr>
<tr>
<td>Yantai Wanhua Co., Ltd.</td>
<td>99.38%</td>
<td>17.–19. August 2015 72 hours continuous performance test</td>
</tr>
<tr>
<td>Inner Mongolia Rongxin Chemical Co., Ltd.</td>
<td>99.63%</td>
<td>23.–26. September 2015 72 hours continuous performance test</td>
</tr>
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</table>
heat and mass transfer, and improved the efficiency of the gasification reaction. OMB CWS gasification technology has high carbon conversion and a low consumption of raw materials. The pre-film burner has excellent atomization performance and the abrasion of this burner is significantly reduced compared with the premixed burner, so the working life of the pre-film burner is much longer than the premixed type burner. The flow field structure in the OMB gasifier is reasonable and the refractory wall life is enhanced as well compared to other CWS gasifiers. The syngas washing purification system has obvious advantages in the purifying effect. The energy efficiency of OMB CWS gasification technology, especially the carbon conversion is much higher than that of similar entrained flow CWS technologies. The online feeding under operating pressure technology is a special feature for the OMB gasifier which has ensured the high reliability and availability of the OMB CWS gasification unit.

The completion of the 3000 TPD large scale CWS gasification plant created the milestone of the ultra-large coal gasification technology demonstration, further enhanced the application level of coal gasification technology, and effectively promoted the technological progress in the field of coal chemical industry and coal-based polygeneration in the world.

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