



**Asia-Pacific
Economic Cooperation**

**Best Practices and Perspectives of
Energy-Efficiency Technologies for
Utilization of Low Rank Coal within APEC
Economies**

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Abstract

The current status of energy-efficiency technologies for utilization of LRC within APEC economies especially in China was analyzed, and general guidelines recommendations for the technological development were put forth based on the concept of circular economy, advocating large scale utilization of LRC through upgrading and integrated functional unit operations and processes. Four guidelines were draw. First, upgrading and classified utilization of LRC should be highly purposive and focus on a comprehensive utilization of LRC, and thereafter critical technologies and processes could be properly selected. Second, such mature theories and unit operations as drying, carbonization, pyrolysis, burning, gasification, reaction, rectification and separation, should be optimally integrated to form innovating integrated circular economic systems. Thirdly, a combined technological innovation should be implemented to products demanded in the market such as gaseous energy, liquid energy, solid energy and high-value-added chemicals. Lastly, key processes and products should be clearly identified to fulfill the comprehensive utilization of LRC in an optimized fashion. Under the guidelines, four technological solution schemes (recommendations) for LRC utilization were proposed and critical technologies and processes used in the four schemes were evaluated.

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Foreword

In many economies of APEC area, coal is a fundamental fuel source for power enterprise; especially in the different kinds of coals, the Low Rank Coal is a principal source of energy. Clean, high-efficient, circular and sustaining development and utilization of Lignite (Low Rank Coal is called as lignite hereinafter) is an important strategic study subject. Taking high carbon energy as foundation, low carbon recycle utilization as purpose, assimilation integrated innovation as instrument, the study of comprehensive utilization of lignite is fully understood by various economic bodies in the APEC area. It is introduced that ash content in Chinese coal is normally around 15-25%. Coal resource with ash content over 30% occupies around 10% of the total coal resource, which is about 100 billion tons, and ash content less than 10% occupies around 15% of the total, which is about 150 billion tons. Average content of total sulfur in the retained reserves and the reserves of coal is 1.32%, in which the main quantity is low sulfur coal and special low sulfur coal and occupies 50.3%, middle and low sulfur coal occupies 34.2%, and middle-and-high and special-high sulfur coal occupies 15-45%. Especially the retained reserves of lignite occupies a big percentage, which is around 10% of the total coal reserves with moisture content of 15-45% and quantity of 200 billion tons. Therefore it is very important to have a study on present technical situation and comprehensive utilization of lignite.

By means of analysis and study of the present situation and the existing problems of lignite application process in APEC economic bodies, the purpose of this Report is to improve further lignite industrialization and technical transfer in APEC area, and to realize maximum energy efficiency and clean utilization of lignite. Meanwhile, as China possesses a large amount of lignite reserves, this Study Report can also be as reference for improving win-win cooperation of lignite utilization between China and the other countries in APEC area^[1-4].

1 General Introduction

1.1 Definition and Character of Low Rank Coal

Low Rank Coal is a kind of coal with low coalification, which refers to young coal mainly including long flame coal in lignite and soft coal. Due to the low coalification, main characteristics of Low Rank Coal are high volatilization, high moisture content, and high oxygen content and high H/C in element analysis point of view. As the characteristics of coal quality, energy density of Low Rank Coal is low, which is normally around half of that of the soft coal in account of receiving basis.

In accordance with international standard ISO / DIS 11760 for definition of coalification, Low Rank Coal is defined by two indexes: R_r (Random Reflectance of vitrinite) and Bed Moisture. In fact, R_r (Random Reflectance of vitrinite) indirectly shows volatilization and coal contents in coal, as R_r rises, carbon content rises and volatilization decreases. Relation between R_r and V_{maf} is shown in figure 1-1. Bed moisture possesses a great impact on energy density of coal counted receiving basis as bench mark, which definition is as follows:

Low Rank Coal: $R_r < 0.5\%$, bed moisture $\leq 75\%$.

Low Rank Coal is classified into three grades:

Low Rank C: $R_r < 0.4\%$, bed moisture $> 35 \sim 75\%$

Low Rank B: $R_r < 0.4\%$, bed moisture $\leq 35\%$

Low Rank A: $R_r \geq 0.4\% \sim < 0.5\%$, Sub-bituminous coal

As $R_r < 0.5\%$, $V_{maf} \geq 50\%$.

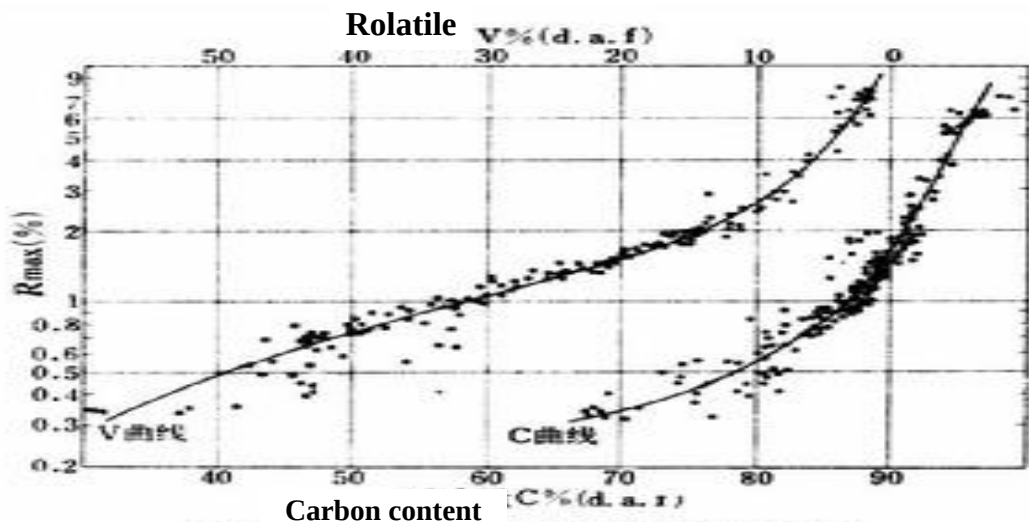


Figure 1-1: Relationship between R_r and V_{maf} ^[5]

Taking R_r (Random Reflectance of vitrinite) as basis, in accordance with

relationship between the value and volatilization and carbon content in coal, as well as Chinese National Standard GB/T17607, coal can be classified. Low Rank Coal consists of lignite and long flame coal. V_{maf} in lignite is 45~65%, characteristic of element analysis is: C: 60~75%, H: 6.0~5.8, O: 34~17%. Normally, Low Rank Coal mainly means lignite with high volatilization content and high moisture content. Coal quality indexes of typical lignite are shown in Table 1-1.

Table 1-1 Coal quality indexes list of typical lignite^[6]

Lignite production area	Mt, %	Ad, %	St, d%	Q _{net} , grMJ/kg
East Inner Mongolia, China	33~35	17~25	0.5~1.5	13~15
Yunnan, China	50~65	5~15	0.3~0.5	8~10
Indonesia	30~33	3~6	0.2~0.5	16~18
Australia	50~65	1~4	<0.5	7~10

As a result of short time of lignite formation, low coalification, rich oxygen function lump, large spacing ratio and high moisture content, from an application analysis point of view, the lignite is of easy weathering and broken, easy self-igniting, difficult for storage and low energy density. Taking as fuel, the energy application efficiency is lower than that of High Rank Coal, and long distance transportation can further decrease economic efficiency. On the other hand, the lignite possesses high volatilization and active chemical property, which can produce value-added efficiency in comprehensive application of classification.

1.2 Lignite Resource and Lignite Development

There are abundant lignite resources in various economies of APEC area. Up to the year of 2008, the explored coal resource for mining in the world is 860.9 billion tons, among which lignite is 195.4 billion tons and is around 22.7% of the total. Top ten economies of the lignite mining capacity are as follows: 40.6 billions in Germany, 37.2 billions in Australia, 30.2 billion tons in the United States, 18.6 billion tons in China, 13.4 billion tons in Serbia, 12.1 billion tons in Kazakhstan, 10.5 billion tons in Russia, 2.4 billion tons in Bosnia and 2.2 billion tons in Canada. The total lignite mining resource of the above ten economies occupies 87.1% of the total resource in the world. The global coal mining resource is shown in Table 1-2.

Table 1-2 Proved recoverable coal reserves at end-2008 (million tons)^[7]

Economies	Bituminous & Anthracite	Sub-Bituminous	Lignite	TOTAL	Percentage of World Total
United States	108,501	98,618	30,176	237,295	22.6

Russia	49,088	97,472	10,450	157,010	14.4
China	62,200	33,700	18,600	114,500	12.6
Australia	37,100	2,100	37,200	76,500	8.9
India	56,100	0	4,500	60,600	7
Germany	99	0	40,600	40,699	4.7
Ukraine	15,351	16,577	1,945	33,873	3.9
Kazakhstan	21,500	0	12,100	33,600	3.9
South Africa	30,156	0	0	30,156	3.5
Serbia	9	361	13,400	13,770	1.6
Colombia	6,366	380	0	6,746	0.8
Canada	3,474	872	2,236	6,528	0.8
Poland	4,338	0	1,371	5,709	0.7
Indonesia	1,520	2,904	1,105	5,529	0.6
Brazil	0	4,559	0	4,559	0.5
Greece	0	0	3,020	3,020	0.4
Bosnia and Herzegovina	484	0	2,369	2,853	0.3
Mongolia	1,170	0	1,350	2,520	0.3
Bulgaria	2	190	2,174	2,366	0.3
Pakistan	0	166	1,904	2,070	0.3
Turkey	529	0	1,814	2,343	0.3
Uzbekistan	47	0	1,853	1,900	0.2
Hungary	13	439	1,208	1,660	0.2
Thailand	0	0	1,239	1,239	0.1
Mexico	860	300	51	1,211	0.1
Iran	1,203	0	0	1,203	0.1
Czech Republic	192	0	908	1,100	0.1
Kyrgyzstan	0	0	812	812	0.1
Albania	0	0	794	794	0.1
North Korea	300	300	0	600	0.1
New Zealand	33	205	333-7,000	571-15,000	0.1
Spain	200	300	30	530	0.1
Laos	4	0	499	503	0.1
Zimbabwe	502	0	0	502	0.1
Argentina	0	0	500	500	0.1
All others	3,421	1,346	846	5,613	0.7
Total world	404,762	260,789	195,387	860,938	100

In 2010, the global coal yield is 7.265 billion tons, in which lignite is 1.338 billion tons. Lignite occupies 19% of the total coal yield. Compared with the total mining resource share of 22.7%, it shows that the lignite development and application is relative insufficient. The world top 10 coal mining production economies and their lignite yields in 2010 are shown in table 1-3.

Table 1-3 The world top 10 coal mining production economies and their lignite yield in 2010 (unit: 100,000,000 tons)^[7]

No.	Economies	Total coal yield	Lignite yield	Yield percentage of lignite %
1	China	32.36	3.36	10.4
2	US	9.81	0.65	6.6
3	India	5.78	0.40	6.9
4	Australia	4.20	0.67	16.0
5	Indonesia	3.36	1.63	48.5
6	Russia	3.24	0.76	23.5
7	South Africa	2.51	1.63	65.0
8	Germany	1.83	1.69	92.3
9	Poland	1.33	0.56	42.1
10	Kazakhstan	1.05	0	0.0

Total coal yield and lignite yield in the world top ten economies in 2010 are shown in table 1-4.

Table 1-4 Total coal yield and lignite yield in the world top ten economies in 2010 (unit: 100,000,000 tons)^[7]

No.	Economies	Total coal yield	Lignite yield	Yield percentage of lignite %
1	China	32.36	3.36 ⁽¹⁾	10.4
2	Germany	1.83	1.69	92.3
3	South Africa	2.51	1.63	65.0
4	Turkey	0.79	0.69	87.5
5	Australia	4.20	0.67	16.0
6	us	9.81	0.65	6.6
7	Poland	1.33	0.56	42.1
8	Greece	0.56	0.56	100.0
9	Czech Republic	0.56	0.44	79.2
10	Serbia	0.37	0.37	100.0

Remarks: These figures are estimated based on yield from Jan. to May 2010.

1.3 Present Utilization Situation of Lignite

As lignite is of high moisture content, low energy density, easily pulverized and self-ignited, and is poor for storage and transportation. Presently, industrial application method of lignite is local processing, in which main process production methods are as follows:

(1) Lignite gasification (fluid bed gasification) + Syngas chemical process;

- + Industrial fired gas process;
- (2) Lignite gasification (broken coal pressurization gasification) + Town gas;
 - + Artificial synthesis natural gas;
 - + Synthesis liquid fuel (FT);
 - + Syngas chemical process;
- (3) Lignite gasification (liquid slag discharge broken coal pressurization gasification, namely BGL)
 - + Artificial synthesis natural gas;
 - + Synthesis liquid fuel (FT);
 - + Syngas chemical process;
- (4) Lignite gasification (dry pulverized coal gasification)
 - + Artificial synthesis natural gas;
 - + Synthesis liquid fuel (FT);
 - + Syngas chemical process;
- (5) Lignite direct liquefaction to oil process;
- (6) Comprehensive utilization process of lignite low temperature pyrogenation classification;
- (7) Lignite drying & dehydration and shaped coal upgrading process;
- (8) Lignite low temperature pyrogenation chemical upgrading process;
- (9) Lignite fired power generation route

The critical technology related to the abovementioned lignite comprehensive utilization processes is mature and widely applied, in which lignite is taken as fired boiler coal to produce steam for heat supply or power generation. It is mature for lignite taken in ambient atmosphere fluidized bed gasification, in which syngas produced in the gasification is utilized in production of chemical products such as ammonia and methanol etc. or is used as industrial fired gas. It is also mature for lignite gasification by means of broken coal pressurization, BGL gasification or dry pulverized coal gasification for preparation of syngas, which is also applied in production of many basic chemical raw materials such as ammonia, methanol, synthesis liquid fuel, gas fuel, natural gas and town gas. Lignite direct liquefaction process is almost mature, by which lignite is directly liquefied to produce engine fuel. By means of drying pyrogenation, then classification and comprehensive utilization of lignite, high-value-added pyrogenated coal gas and liquid fuel, chemical and solid material with high

energy density can be produced.

2 Lignite Utilization for Power Generation

2.1 General

Establishment of pithead fired coal power generation plant is currently a major conversion method for lignite to power in the world, over 90% of lignite is converted into power by this method. In APEC's economies, there are pithead coal power plants established at most lignite mining sites, by which lignite resource is converted into electric power energy. Germany is the first country taking lignite for power generation, who possesses the most advance process and the largest capacity of generation unit. 155,000,000 tons of lignite was used for power generation in 2010 which occupies 24% of the total power generation capacity in Germany. Although lignite is considered as poor-quality boiler fuel, by technical improvement and renovation, RWE lignite power plant with capacity of 1000MW was put into operation in 2003, which power generation efficiency reaches 43%. Thanks to abundant resources of petroleum and natural gas, and hard coal as well in the United States and Canada, the importance and imminence of lignite for power generation is not high. Although petroleum and natural gas resources are abundant in Canada, situation in Saskatchewan province is special, in which there is a huge amount of lignite resource for mining with low mining cost, hence lignite for power generation plays an important role. Its capacity of power generation unit with lignite is 1800MW and occupies 46% of the capacity of this province. In Australia, lignite resource is abundant and its mining cost is extremely low. 80% of the total power generation capacity is produced from power plant with coal, in which the lignite power plant occupies one third of the total. Lignite for power generation plays an important role in Australia. Compared with the developed economies, lignite for power generation in China is started later, however its development is fast. Now China is one of the largest economies of taking lignite for power generation. The imported 300MW generation unit was put into operation in 1978. The imported 600MW generation unit was put into operation in 1985. Localized 300MW generation unit was put into operation in 1994 and another localized 600MW unit was put into service in 1998. The total power generation capacity with lignite in 2010 was 13GW, which occupied 1.4% of the total capacity of power generation unit assembled. Its total capacity of power generation unit assembled still ranks at top line in the world, so do machinery fabrication capacity.

2.2 Lignite for Power Generation

Due to 15wt%-50wt% moisture content, as lignite is directly fed into boiler for combustion and power generation, a great deal of energy needs to be consumed during ignition on the one hand, the lignite is of high volatilization and is easily

exploded on the other hand. Moreover, a large quantity of heat energy is taken away during moisture evaporation, which increases fume heat loss of combustion and decreases heat efficiency of power generation, which results a great discharge of greenhouse gas, hence the lignite with rich moisture content faces a special challenge. As the lignite with high moisture content is directly used in combustion, the boiler combustion cannot be stable and efficiency is low. The lignite with high moisture content can only be used locally instead of long-distance transportation. The reason why the lignite can be taken as fuel for power generation is only because huge lignite resource exists in a specific area with thick bed and shallow deposit, and low mining cost as well. Taking Latrobe Valley area in Victoria, Australia as an example, the lignite resource quantity in this area is 200 billion tons, lignite bed thickness is 300 meters and stored only from 2 to 5 meters underground. Hence, cost of large scale of open pit is very low and its power generation cost is lower than that of soft coal power plant. Commercial and mature conventional power generation technologies consist of sub-critical pulverized coal boiler combustion technology, sub-critical recycle fluidized-bed boiler combustion technology and super-critical pulverized coal boiler combustion technology. Non-commercial and mature power generation technologies consist of IGCC technology, in which suitable coal gasification process is applied and power is generated by IGCC fired gas steam. Due to high investment and facing challenge of the conventional power generation technologies in economic point of view, IGCC technology is difficult to be popularized. Power generation technologies under development include pressurized fluidized -combined cycle PFBC-CC and the advanced pressurized fluidized bed combustion combined cycle (APFBC CC). The power generation efficiencies of these two kinds of technology are higher than those of the conventional ones, however, they haven't been industrialized yet. Contrast of power generation efficiency of the lignite with 62% moisture content and high rank coal is shown in figure 2-1.

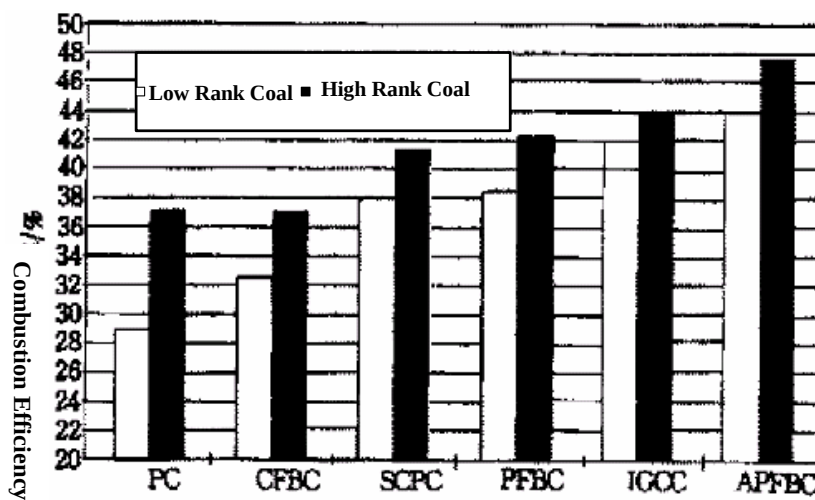


Figure 2-1 Contrast of power generation efficiency of the lignite with 62%

moisture content and high rank coal^[8]

In sub-critical power generation (PC) with pulverized coal combustion boiler technology, the power generation efficiency with lignite of 62% moisture content is 29% and the efficiency with high rank coal is 37%, which efficiency is decreased by 21.6% and carbon discharge strength is increased by 21.6%. In sub-critical power generation (CFBC) with recycle fluidized bed combustion boiler technology, the power generation efficiency with lignite of 62% moisture content is 32.5% and the efficiency with high rank coal is 37%, which efficiency is decreased by 12.2% and carbon discharge strength is increased by 12.2%. In super-critical power generation (SCPC) with pulverized coal combustion boiler technology, the power generation efficiency with lignite of 62% moisture content is 38% and the efficiency with high rank coal is 41%, which efficiency is decreased by 7.9% and carbon discharge strength is increased by 7.9%. Carbon discharge strengths of different power generation technologies are shown in figure 2-2.

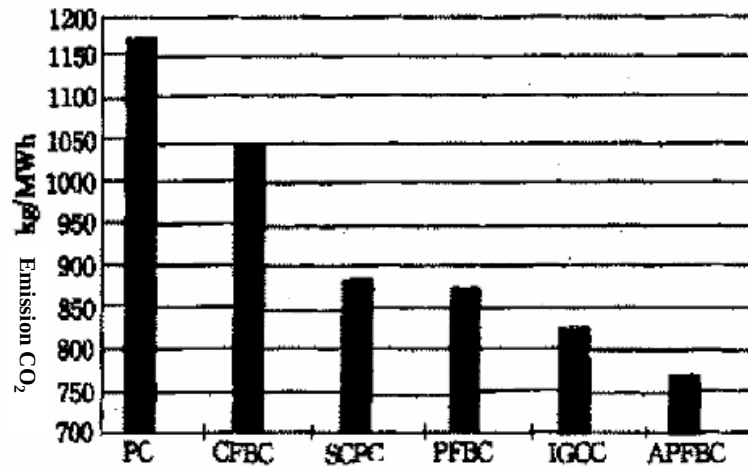


Figure 2-2: Carbon discharge strengths of different power generation technologies with the lignite of 62% moisture content^[8]

In order to increase power generation efficiency and decrease carbon discharge strength of the lignite, currently the most practical and significant technology is to integrate lignite drying process into the lignite the power generation process based on the conventional technologies, and optimize process parameters of the power plant so as to realize the purpose of high efficiency. The lignite of 34% moisture content and 15.31MJ/Kg heat value ($Q_{net,gr}$) is dried to reach 12% moisture content and 20.41MJ/Kg heat value, during this process energy consumption for heating of moisture and evaporation equals to 3.7% of heat value of lignite. As moisture content of lignite is high, in order to control discharge fume temperature higher than that of dew point of acid, the discharge fume temperature shall be higher than that of soft coal combustion, as a result the fume energy cannot be sufficiently recovered. Energy consumption of lignite pulverizing system is about double of normal soft coal capacity and energy

consumption. In order to increase energy application efficiency of lignite power plant with the conventional power generation technologies, moisture content in the lignite shall be maximum decreased and then fed into the pulverization system so as to improve the process and increase conventional power generation efficiency of lignite.

3 Low Rank Coal (Lignite) Drying & Upgrading Process

3.1 General

China, Europe, the U.S., Australia and other economies have abundant lignite resources. In order to improve the market competitiveness and comprehensive utilization efficiency of lignite, these economies have done a lot of research into lignite drying technologies. For instance, Europe has taken lignite drying as an important part of the clean coal technology; the US has carried out a study on coal drying and coal quality upgrading based on the lignite in the Powder River Basin; *Low rank coal R&D in Australia is currently funded through Brown Coal Innovation Australia. There were two earlier joint research centers established in Australia to study lignite utilization technology; the CRC for Clean Power from Lignite and the CRC for Power Generation from Low Rank Coals.*

Up to the present, the successfully-commercialized lignite drying processes have resulted in a huge amount of energy consumption. Just taking the tube drier indirect steam drying process which is used to remove the surface moisture for example, 1.42~1.8 tons of low-pressure steam is consumed when removing 1-ton moisture, which means over 4% of the heat value in raw material lignite is used to remove the moisture contained in itself. On the other hand, lignite drying is more complicated than that of general materials. According to its existence forms, moisture contained is divided into bound moisture (crystal moisture), inherent moisture (capillary moisture) and surface moisture, with bound moisture and inherent moisture much harder to remove whilst re-absorption frequently occurs when only removing surface moisture. Thus there are different kinds of drying processes, which can be grouped into evaporation drying, non-evaporation drying and mechanical dehydration based on their distinct physical principles.

As for mechanical dehydration, the moisture in lignite is completed with its solid-liquid separation by means of screening, centrifugal separation and filtration, etc. This process draws on the experience of the cleaned coal dehydration technology adopted in coal washing, which can only remove part of the surface moisture. Hence, it is not the mainstream technology adopted for the study and application of lignite drying technologies.

Evaporation drying is a process directly or indirectly heating lignite to evaporate the moisture it contains, thus the lignite is eventually dried. Part of the evaporation drying processes have been successfully commercialized, but other part of the processes are still in a demonstrative verification on a commercial scale. According to the dehydration level, lignite evaporation drying can be divided into mild dehydration and deep dehydration. Mild dehydration generally removes part or all of the surface moisture and the drying temperature is less than 200°C. Deep dehydration removes the surface moisture and part of the inherent moisture, with the hydrophilic oxygen-containing function groups partly removed

at the same time. In this case, lignite is slightly modified and the drying temperature is less than 200~300°C. The dried products are weak in re-absorption.

As for non-evaporation drying, it is to change the internal composition and structure of lignite by making steam, hot oil or DME directly contacting lignite in high-temperature and high-pressure conditions without oxygen. Being dehydrated and mildly pyrolyzed, lignite is converted to product similar to bitumastic coal fuels. The non-evaporation drying process is one in which dehydration and mild pyrolysis are completed at the same time. As no moisture is evaporated and alkali metal ions are partly removed at the same time, it thus can modify the ash deposition performance of coal ash and also can partly remove mercury. Hence, it is expected to be one of the new approaches for lignite dehydration. The technology is currently under study and improvement and has not been commercialized yet.

3.2 Lignite Evaporation, Dehydration & Upgrading

3.2.1 Drum-Type Direct Flue Gas Heating Process

The lignite dried by the drum type direct flue gas heating drying process is applied to produce ammonia, methanol and industry gas. Some coal and power enterprises also have begun to use this technology to construct lignite drying units and remove surface moisture, adopting it for the conversion projects around lignite pitheads, for instance, Datang International's 5-million t/a production line in Xilin Gol League, and the Sunite-ZuoQi Xiaobaiyang Mining Co.'s 4.5-million t/a production line in Xilin Gol League.

Lignite is liable to spontaneous combustion due to its low ignition point and active chemical properties. It is dehydrated when the temperature is lower than 120°C and is degassed when the temperature is around 200°C. It then desorbs the adsorbed gases such as methane, nitrogen and CO₂, etc. and begins the decarboxylation reaction. Therefore, it is quite important to control the temperature and oxygen content of flue gas that is used as drying medium, design a rational internal drum drier structure and prevent the materials from local superheating and spontaneous combustion. The heat source for process is the high-temperature flue gas generated from coal-burning. The temperature of the flue gas entering the drum drier is generally under 700°C, with the exhaust temperature of 120~140°C. The main equipment includes coal-fired hot air furnace, drum drier, cyclone and bag-type precipitator or wet-type precipitator and induced draft fan. The drum drier arrangement forms a certain angle with the horizontal line. Lignite (particle size <30mm) is fed into the drum from an upper end of the chute, with the hot flue gas entering the drum in a cocurrent flow or a countercurrent flow. With the rotation of the drum and under gravity, lignite moves from the feed inlet to the discharge outlet. Lignite directly contacts the hot flue gas when it moves in the drum. Heat and mass transfer occurs, moisture in lignite is evaporated and lignite is thus dried. A shoveling plate is provided in the drum, which raises and sprays down the wet materials, to increase the contact surface between the wet materials and the dry flue gas and help to move the materials from the inlet to the outlet. The dried tail gas is vented after dust

precipitation. See Figure 3-1 for the drum drier direct flue gas heating drying process^[9].

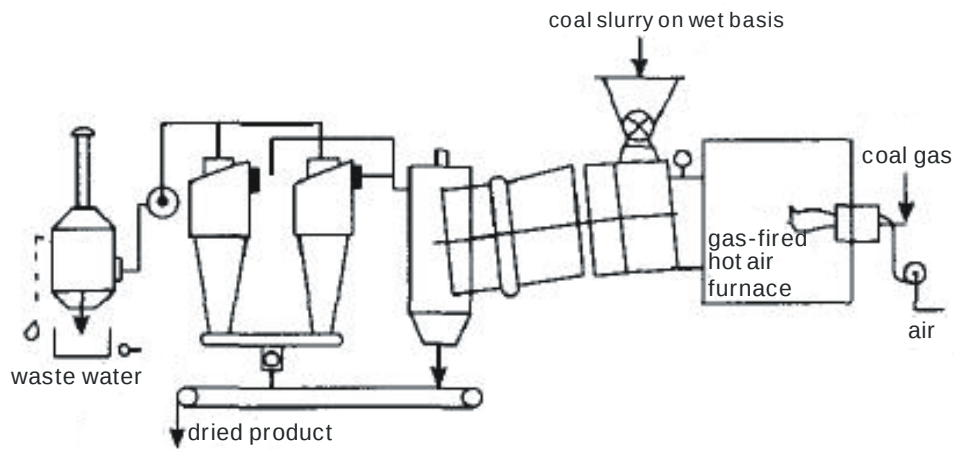


Figure 3-1 Drum Drier Direct Flue Gas Heating Drying Process Flow Diagram

3.2.2 Tube Drier Indirect Steam Drying Process

The tube drier is similar in appearance with the drum drier, but provided with a lot of drying tubes internally and based on an indirect drying principle (coal moves in the tube, steam transfers heat via the tube wall). It is quite safe and reliable, applicable to combustible and explosive young coals (such as lignite, etc.) with a low ignition point. The tube drier is rational in its structural design and of better heat transfer efficiency. The process has decades of application experience in low-rank lignite drying. The tube drier designed is a rotary kiln, with a multi-tube system arranged in the slightly-inclined drum. Lignite is fed into the tube continuously from an inlet above the drier. When rotating the drum, the dried product keeps moving to the outlet under the drier, with the heat energy required for drying provided by low-pressure steam. The air entering the drier together with lignite, is separated in the precipitator after the moisture is absorbed and then vented after treatment. The tube drier technology developed by ZEMAG (Germany) has been widely applied in lignite drying. This drying technology has been adopted in currently-constructed large coal chemical projects taking lignite as raw materials, such as coal-to-olefins and coal-to-ammonia projects. See Figure 3-2 for the tube drier indirect steam drying process^[10-13].

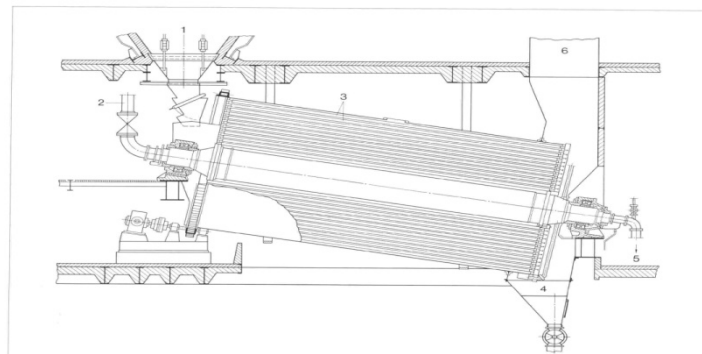


Figure 3-2 Tube Drier Indirect Steam Drying Process Flow Diagram

3.2.3 Fluid-bed Steam Drying Process

The fluid-bed steam drying process is firstly applied for lignite drying in the 70s of the 20th century by Germany and Australia, with Germany more successful. Now, RWE (Germany) has begun to launch its WTA process to the market whilst CHROREN (Germany) has begun to launch its DWT process to the market. Loy Yang Power Plant in Australia has constructed a 55t/h unit in 1991, reducing the moisture content in lignite from 63% to 10%. In 2009, RWE has started up a commercially-demonstrative 110t/h unit in its Coal Innovation Centre, aiming to make an assessment on the technical and economic performance of the process. See Figure 3-3 for the typical fluid-bed steam drying process flow diagram^[5-7].

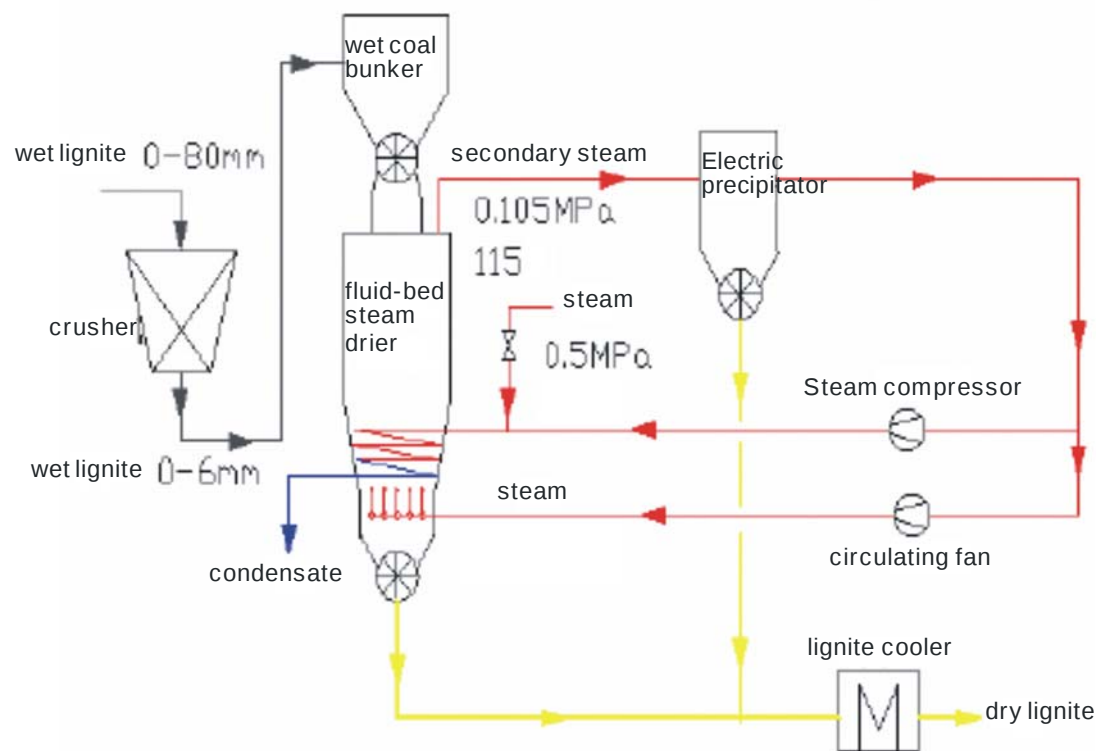


Figure 3-3 Typical Fluid-bed Steam Drying Process Flow Diagram

The fluid-bed steam drying process takes the secondary steam generated from drying as the fluidization medium while taking part of the boosted secondary steam and the low-pressure steam supplied from the outside as the heat sources for lignite drying. In the drier, solid particles are suspended in the drying medium. The contact surface between the fluid and the solid is large and the flow rate is high, which strengthen the heat and mass transfer during the drying process. It is featured with a sound processing capacity and high thermal efficiency. Besides, tube bundles for steam heating are arranged in the fluid-bed, providing heat during the drying process via steam condensation in the tube. As an energy-saving process, the process adopts the energy from the secondary steam for lignite drying.

3.2.4 Internal Heating Fluid-Bed Superheated Steam Drying Process

By absorbing and digesting the RWE technology from Germany, Shandong Tianli Drying Technology and Equipment Co., Ltd. adopts 2-3 layers of built-in heat exchangers, resulting in a drying efficiency 2-3 times of that for the RWE process. The process solves problems such as great investment in foreign technologies and high operational costs, etc. The raw lignite enters the internal heating fluid-bed drier via a sealed feeder. Saturated steam goes into the built-in heat exchanger of the internal heating fluid-bed drier. Lignite exchanges heat fully with the steam in the built-in heat exchanger and in the fluid-bed for drying. The moisture dehydrated from lignite forms the superheated steam, which enters the high-efficiency dust precipitator. After precipitation, some superheated steam enters the internal heating fluid-bed drier again as the fluidization medium after being compressed by the circulating steam compressor, for recycling. The redundant superheated steam enters the waste heat utilization system for recycling. See Figure 3-4 for Internal Heating Fluid-Bed Superheated Steam Drying Process from Shandong Tianli Drying Technology and Equipment Co., Ltd.^[5-7].

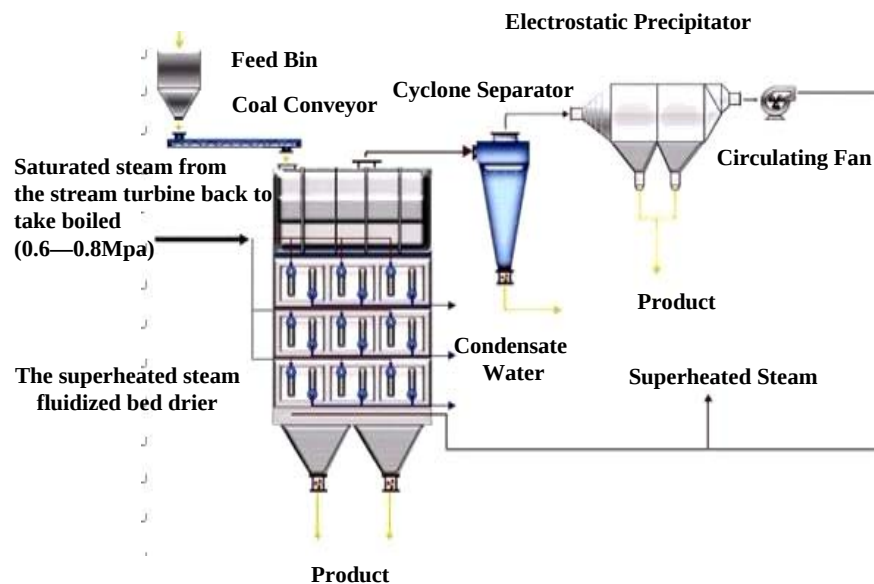


Figure 3-4 Internal Heating Fluid-Bed Superheated Steam Drying Process Flow Diagram

3.2.5 Drum Drier Indirect Steam Heating Drying Process

The drum drier indirect steam heating drying process has been widely applied to the petroleum chemical industry, mainly for drying PTA, CTA and HDPE, and also applied to char coal moisture control projects for the iron and steel industry in recent years. Lignite is fed into the drum drier from the upper end of the chute, the drum drier arrangement forms a certain angle with the horizontal line. With the rotation of the drum and under gravity, lignite moves from the feed inlet to the discharge outlet. Low-pressure steam is introduced into the heat exchange tube via the rotating joint at the end of the drier, and then condensed in the heat exchange tube to supply heat for the drying process. Lignite contacts the outer wall of the heat exchange tube during its moving in the drum. Heat and mass transfer occurs, the moisture in lignite is evaporated and the lignite is thus dried.

The technology has been adopted in the power plants taking lignite as fuels in Indonesia, drying the moisture content from 55.3~61.3% to 33%, with the processing capacity for a single unit of 136t/h. See Figure 3-5 for the domestic rotating drum drier indirect steam heating drying process flow diagram^[5-7].

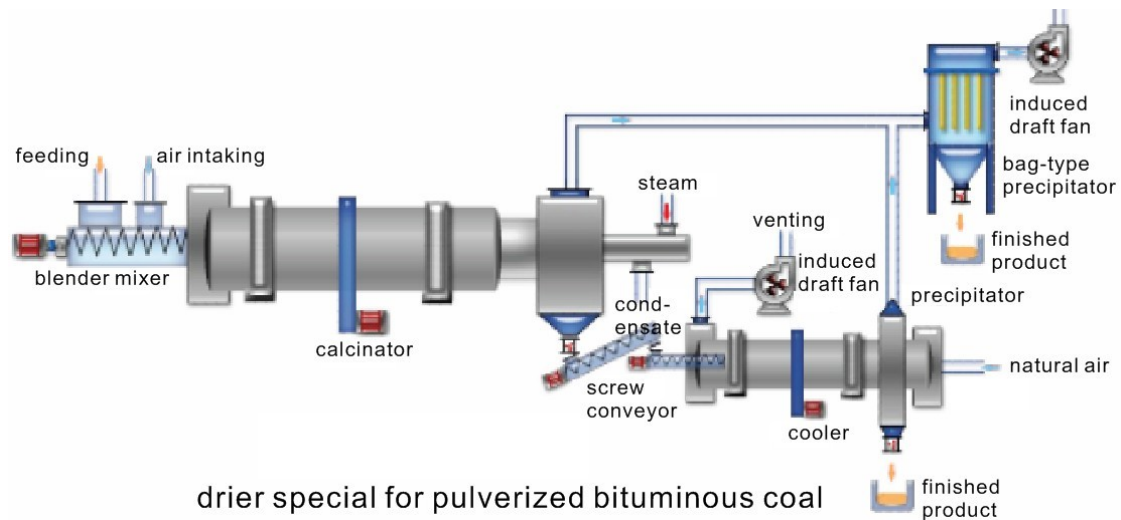


Figure 3-5 Rotating Drum Drier Indirect Steam Heating Drying Process Flow Diagram

3.2.6 Integrated Steam-air Drying Process

The integrated steam-air drying technology is actually an attempt for power plants to use low-rank waste heat. This method adopts a hot water internal heating fluid-bed drier and takes hot air as the fluidization medium, which is of an internal heating fluid-bed drying technology. The air is heated to 110°F by the hot circulating water and becomes the fluidization medium for the fluid-bed drier. It can reduce the relative humidity, improve the driving force for mass transfer and take 120°F hot water as the drying heat source medium for the fluid-bed. The method utilizes the low-rank waste heat from power plants.

Hot water drying is more disadvantaged than steam drying in terms of drying speed and level; besides, such a drier is huge in dimensions. But still, this process is an attempt to effectively utilize the low-rank waste heat for power plants. According to the test results of the power unit in the Power River Basin of the US, the moisture content in coal is reduced from 37.5% to 31.4%, the net efficiency of boilers gets increased by 2.6%, the fuel consumption drops by 10.8% and the flue gas volume decreases by 4%.

3.2.7 Vibration & Mixed Flow Direct Flue Gas Drying Process

The vibration & mixed flow flue gas drying technology is a low-temperature lignite mild-drying process developed by Tangshan Shenzhou Machinery Co., Ltd. (China). Raw coal is crushed to a particle size less than 50mm, entering the SZ-type vibration & mixed flow drier from the top. The drier is provided with a 5~10 vibrating screen, conveying the coal to be dried in a Z-shape manner. The coal rolls and falls down from the vibrating bed, exchanges heat with the heating

medium moving in a bottom-up direction or in a cross-flow direction and finally gets dried. Dried materials are discharged from the bottom of the drier.

The drying medium is the mixture of hot flue gas and air after the coal-fired hot air furnace separates the solid materials, entering the drier at 220~260℃ and with an oxygen content around 18%. Much dust exists in the steam exhaust vented from the top of the drier, which is separated by a bag-type precipitator and briquetted into shaped coal, as part of the product. The tail gas from precipitation is vented by an induced draft fan. See Figure 3-6 for the typical vibration & mixed flow drying process flow diagram^[5-7].

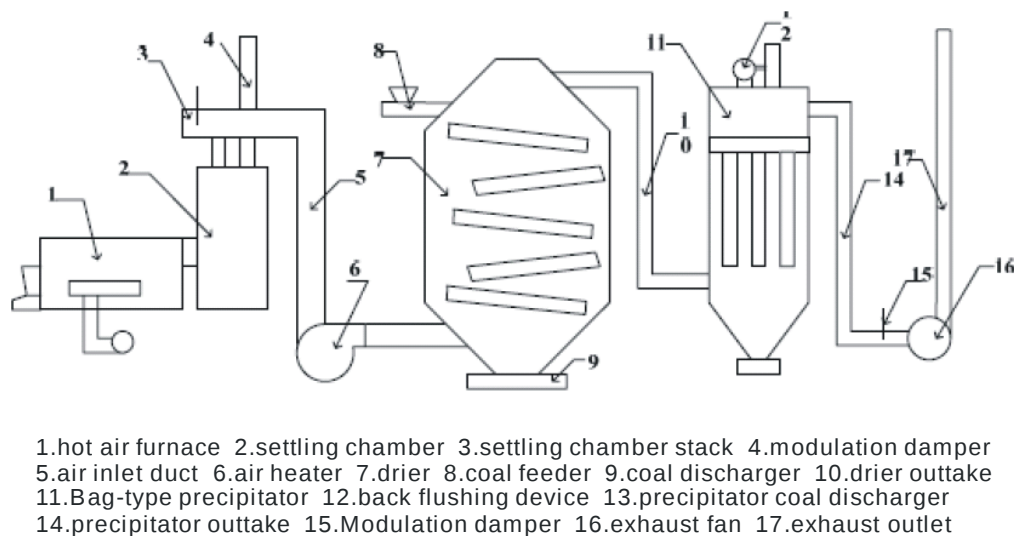


Figure 3-6 Typical Vibration & Mixed Flow Drying Process Flow Diagram

3.2.8 Tube Drier Entrained-bed direct Flue Gas Drying Process

The tube drier entrained-bed direct flue gas drying technology is a lignite drying process of rapid high-temperature flue gas drying and hot-briquetted briquetting, which is developed in recent years. It sells the lignite as fuels after the drying and briquetting. Representative processes include the BCB process developed by White Energy (Australia) and the HPU-06 process jointly-developed by Shenhua International Ltd. and China University of Mining and Technology. The two processes are almost the same, generally divided into the accelerating drying and the cyclone drying stages. The accelerating drying stage is conducted in the tube drier entrained-bed drier, lasting for about 0.5 second. The process is: lignite is crushed to a particle size of 0~3mm and then fed into the tube drier entrained-bed drier via the feeder. The entrained flow drier is of a vertical tube, with 600~700℃ high-temperature flue gas that is generated from coal burning introduced from the bottom. The high-temperature flue gas flows rapidly in the tube, at a speed of about 30m/s. Drastic heat and mass transfer occurs to the wet coal granules under high-temperature and high-speed conditions, the surface moisture is completely vapourized and about 50%~60% of the inherent moisture is removed. With high-temperature flue gas, the structure in the surface of coal granules is

destroyed and part of the crystal moisture is removed. The temperature of the flue gas going out of the tube drier entrained-bed drier is about 300°C, bringing coal granules into the cyclone. In the cyclone, the coal granules get continuously dried after being separated. The flue gas temperature drops to about 150°C, which is vented upon further precipitation. The pulverized coal collected from the precipitator enters an extrusion molding machine and briquetted into shaped coal products without using a binder. See Figure 3-7 for the BCB process developed by White Energy (Australia) ^[5-7].

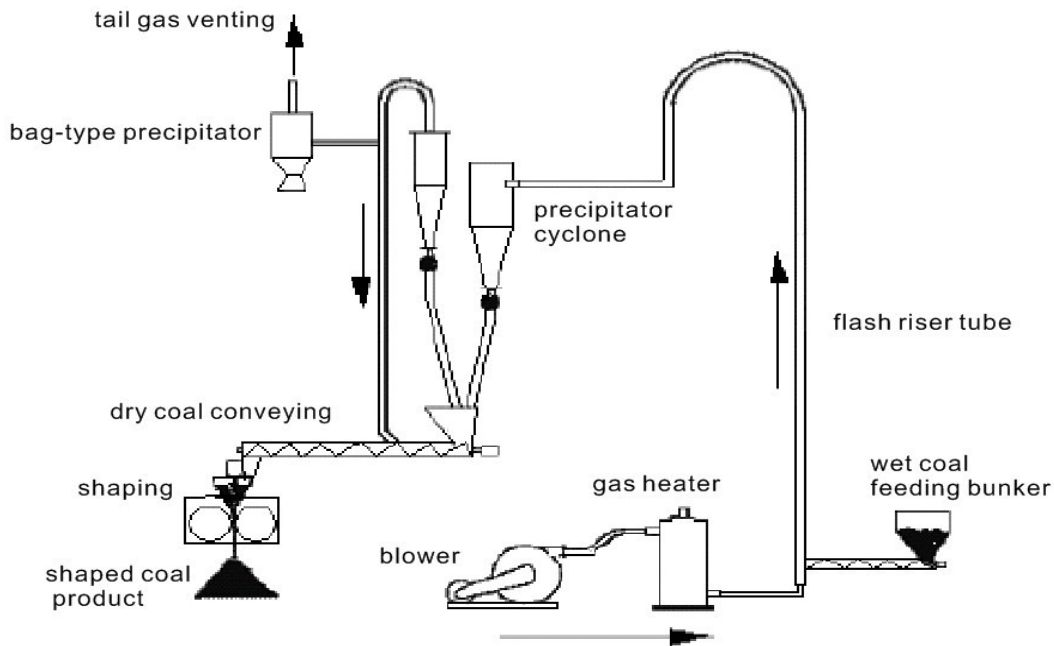


Figure 3-7 BCB (Australia) Lignite Drying Process Flow Diagram

Plants adopting the tube drier entrained-bed direct flue gas drying technology have been constructed on a commercial scale. Bayan Resources (Indonesia) has constructed a 1-million t/a unit in Kalimantan, by adopting the BCB (Australia) lignite drying process for drying and briquetting the soft lignite that is high in moisture and low in ash. China Shenhua has constructed a 1.5-million t/a unit in Hulunbeier League, Inner Mongolia, by adopting the HPU-06 lignite drying process for drying and briquetting the low-rank hard lignite in eastern Inner Mongolia that is high in moisture and moderate in ash. The project is now under rectification.

3.2.9 Bed Mixing Hot Coal Ash Drying Process

The bed mixing hot coal ash drying technology is a lignite drying technology developed by Fortun Power (Finland). The technology is used for the circulating fluid-bed boiler system burning solid fuels with a high moisture content, to improve the energy utilization efficiency. The process takes the secondary steam generated in drying process as the fluidization medium while the hot coal ash generated from the fluid-bed boiler as the drying heat sources. An oxygen-free drying is conducted to lignite in the fluid-bed drier. The dried lignite is directly used as the fuel for fluid-bed boilers. The technology provided another chance to

recover energy from the hot boiler ash. The moisture contained in fuels is removed before entering the boiler, resulting in reduced heat loss on discharged flue from boilers and improved energy utilization efficiency^[5-7].

See Figure 3-8 for the bed mixing hot coal ash drying process flow diagram.

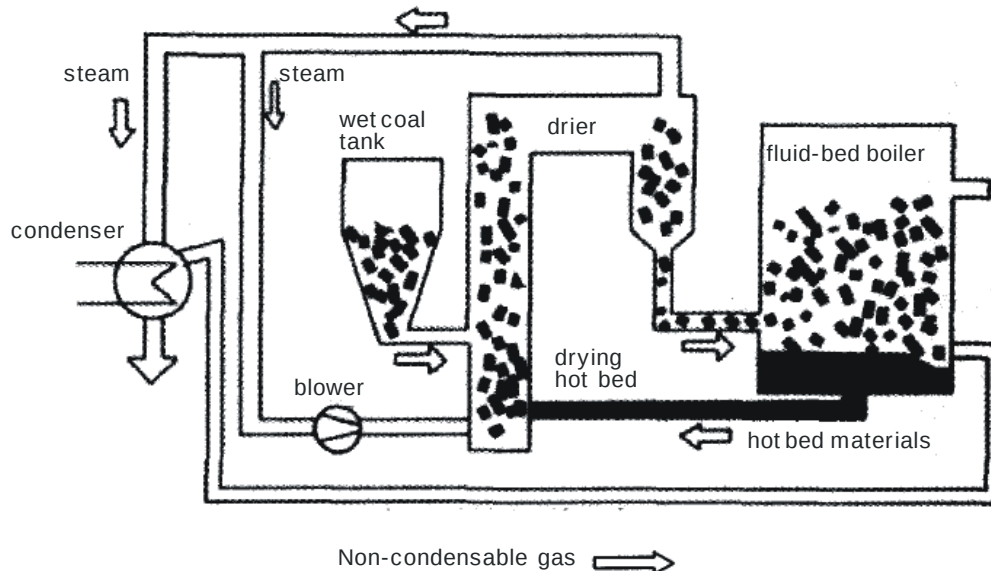


Figure 3-8 Bed Mixing Hot Coal Ash Drying Process Flow Diagram

3.2.10 Beijing Cleanstar Belt Drying Process

The belt drier technology has been successfully applied to foodstuff, pharmacy and other light industries. It is commonly used for applications requiring a lower drying speed and a longer drying time, keeping the operational conditions during the whole drying process constantly. The drying process is done in a fully-enclosed environment. The materials to be dried is placed on the conveying belt for drying in a stationary state, thus the material damage rate is rather low. Beijing Cleanstar Technology Development Co., Ltd. transfers this technology to lignite drying and has successfully started a 300,000 t/a lignite drying unit, in addition of another 3.8-million t/a lignite drying unit under construction in Inner Mongolia, China. The belt lignite drying system developed by Beijing Cleanstar is of a horizontally-arranged continuous lignite drying unit. The furnace is divided into such three sections as drying, deoxidation and cooling. The raw lignite with a particle size of 3~25mm is evenly distributed on the mesh-belt for the drying furnace process from the furnace inlet, forming a 200mm-thick coal bed. As the mesh-belt moves evenly in a horizontal direction, the coal bed is heated through by inert gas with a temperature of around 270°C in the furnace. The coal materials is heated and dried, with surface moisture removed firstly. Then inherent moisture, crystal moisture and part of oxygen-containing function groups are removed as the coal material temperature rises. The coal becomes the "modified lignite" cooled down to 60°C by low-temperature flue gas at the cooling end and discharged out from the furnace as eligible dried products.

3.2.11 Exergen CHTD Process

Exergen has developed Continuous Hydrothermal Dewatering (CHTD) technology for high moisture of subbituminous coal. Brown coal contains up to 70% of moisture by mass. The technology accelerates the efficient use of undeveloped subbituminous coal resources by removing the moisture.

3.2.12 GTLE Process

GTL Energy has successfully transformed samples of high moisture low value coals from around the world into low moisture high value premium fuels. Results include removing up to 80% of the total moisture and increasing the thermal value by 50% to 70%, and 120% for Australian brown coal. GTL Energy has also upgraded a coal and biomass blend. A summary of the results (examples across multiple samples) are as follows in Table 2-1:

Table 2-1 GTLE Process drying results

New Zealand Lignite 1	46%TM to 12.5%TM (73%)	5,500Btu to 9,500Btu (73%)
New Zealand Lignite 2	42.5%TM to 12.5%TM (70%)	6,500Btu to 10,000Btu (54%)
Indonesian Lignite 1	47%TM to 12.5%TM (73%)	6,300Btu to 10,300Btu (64%)
Indonesian Lignite 2	33%TM to 10.0%TM (70%)	8,250Btu to 11,000Btu (33%)
Indonesian Lignite 3	45%TM to 12.0%TM (73%)	6,300Btu to 9,900Btu (57%)
Texas Lignite	35%TM to 12.5%TM (64%)	5,500Btu to 9,200Btu (67%)
North Dakota Lignite 1	42.5%TM to 12.5%TM (71%)	6,000Btu to 9,200Btu (53%)
North Dakota Lignite 2	38%TM to 12.5%TM (67%)	6,600Btu to 9,400Btu (42%)
PRB Sub-bituminous	30%TM to 10%TM (67%)	8,600Btu to 10,800Btu (25%)
PRB & BioMass Blend	35%TM to 4%TM (89%)	7,200Btu to 10,050Btu (40%)
Australian Brown Coal	61%TM to 12.5%TM (80%)	4,700Btu to 10,350Btu (120%)

GTL Energy has blended hard wood biomass and Powder River Basin coal into strong briquettes at its pilot plant at Hazen. This is potentially an exciting new product for use in regions such as the US and Europe that have mandated biomass consumption and will help coal users co-burn biomass and contribute to a reduction in CO₂ and NO_x.

3.3 Non-evaporation Drying & Upgrading Process for Lignite

3.3.1 K-Fuel Drying Process

The basic idea and original process for the K-Fuel process to treat low-rank coals has been brought forward by Edward Koppelman from Stanford University, and then transferred to KFx company that is founded in 1984 for commercialization-oriented research and development. The first 750,000 t/a K-Fuel commercially-demonstrated unit has been completed and put into service in 2005 in Fort Union, Wyoming State, the US and shut down in 2008.

It uses lignite steam for direct drying in a treater for the drying unit. The cold coal is continuously fed into the treater from the coal bunker. The dried hot coal keeps moving to the outlet at the lower part of the treater. Hot energy required for drying is supplied by low-pressure steam, which transfers the latent heat of the steam directly to the coal granules to evaporate the moisture in it. By making steam directly contact coal granules, the treater can increase the contact surface of the heating medium and the heated medium, improve the heat transfer coefficient and shorten the heating time. Dry steam condensate is separated from the moisture at the lower part of the treater. The condensate containing some pulverized coal exchanges heat with the heat sources (or clean high-temperature steam, or high-temperature chemical medium) in the heat exchanger for reboilers after treatment, becoming dry steam and going to the treater for recycling. Water vapor and non-condensable gas evaporated from lignite while containing some dust, are vented and condensed for recycling as recycle water. See Figure 3-9 for K-Fuel process flow diagram^[5-7].

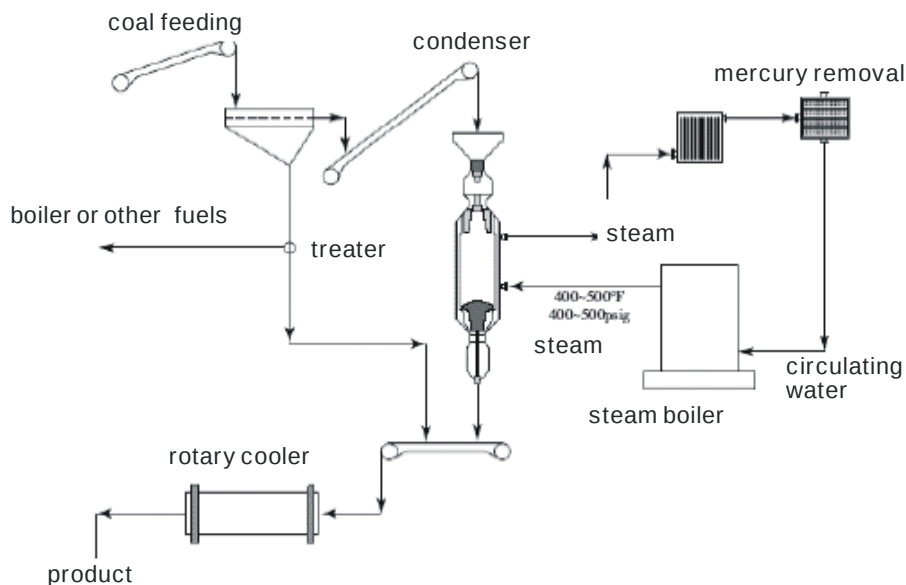


Figure 3-9 K-Fuel Process Flow Diagram

Similar technologies include the hot-press process from Ukraine. The process is to treat lignite with a particle size of 13~100mm for 2~3 hours by using 2.0MPa saturated steam to achieve lignite dehydration and modification.

3.3.2 D-K Drying Process

J-Power and Kawasaki began their study on a process in which the moisture can

be removed in a liquid state by heating lignite while lignite can be modified, in the 70s of last century. The process is called as D-K process. See Figure 3-10 its process flow diagram. A pilot unit is provided with four reaction kettles to realize the recovery of the discharged steam and hot water, capable of semi-continuous operation^[5-7].

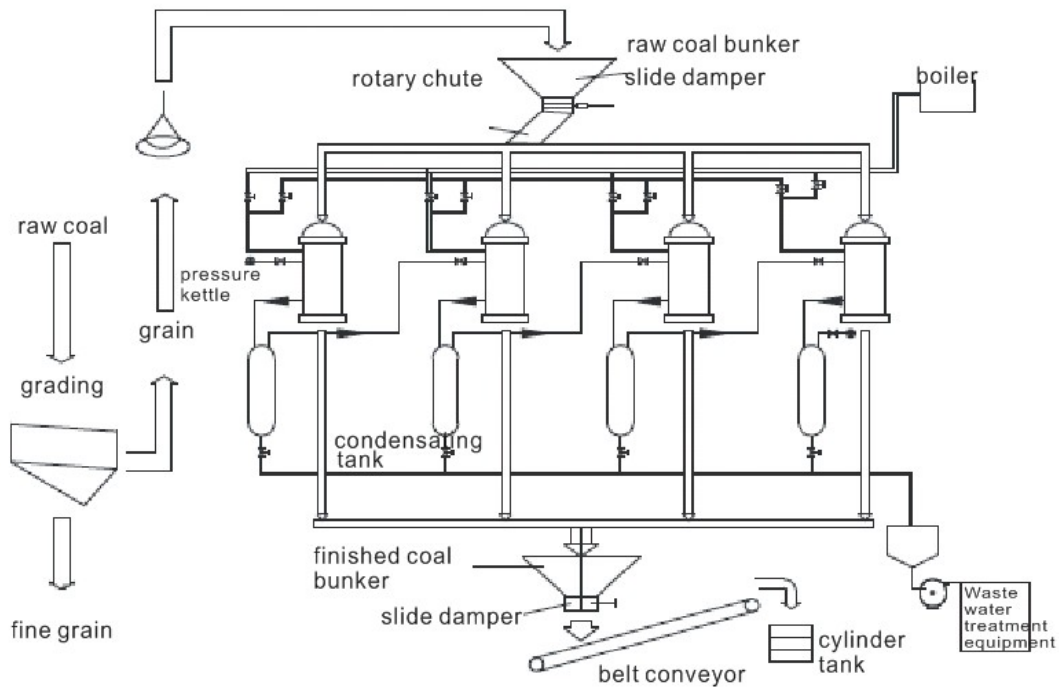


Figure 3-10 D-K Process Flow Diagram

3.3.3 UBC Hot Oil Drying Process

Kobe Steel., Ltd. attempts to use light oil as heating medium to remove hot water in lignite in 1993. The process prepares the coal oil slurry by mixing the pulverized lignite and the light oil mixtures, and then heating the coal oil slurry to remove the moisture in lignite. The slurry oil is recovered for recycling. See Figure 3-11 for its process flow diagram^[5-7].

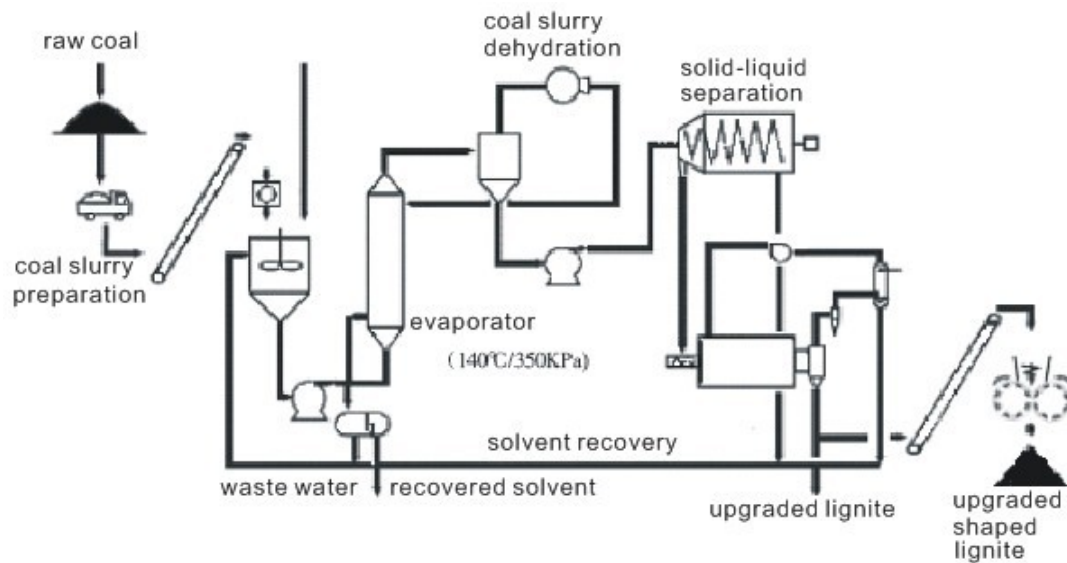


Figure 3-11 UBC Hot Oil Drying Process Flow Diagram

3.3.4 Hot Water Drying Process

The hot water drying process is to load the lignite-water mixture into a high-pressure vessel, heat the vessel after sealing and vacuumizing it. The reaction process simulates the high-temperature and high-pressure metamorphic process of lignite in nature, aiming to modify the coal quality. Moisture contained in lignite that is in hot water of high-temperature and high-pressure is drained in a liquid state, with hydrophilic function groups of longer hydrocarbon side chain, a large number of carboxyl (-COOH), methoxyl (OCH₃) and hydroxyl (-OH), etc. bound via relatively weaker bridging. Pyrolysis removes the side chain on the molecular structure of lignite, reducing re-adsorption for the inherent moisture of lignite. In the meantime, such small molecular gases as CO₂ and SO₂, etc. are drained from the pores in the pyrolysis process. The coal tar generated cannot easily escape from gaps and pores of lignite under relatively higher temperature and pressure. It is solidified in these gaps and pores after being cooled down to seal the gaps and the pores of lignite, thus reducing the surface area and removing the inherent moisture in lignite. After hot water drying, lignite still keeps its reactivity, namely, features such as combustibility and complete combustion, etc.

3.3.5 Colddry Drying Process (Australia)

The Colddry drying process is owned by ECT (Australia). The process converts lignite with a moisture content of over 65% into shape coal with a moisture content of around 10%. By changing the structure of lignite based on a "cutting" principle, it makes structural changes in the coal quality of lignite and then complete the coal-water separation under a temperature of 20~30°C, drying the lignite into shaped coal after being extruded, shaped and hardened. In 2007, a 20,000 t/a test unit has been successfully started up and now completed a processing capacity designed to be 300,000 t/a. See Figure 3-13 its process flow

diagram. Mechanical Thermal Expression was also developed I Australia, where a pilot plant at 15Tp/h was developed in the Latrobe Valley, however difficulties were encountered in scaling up the technology.

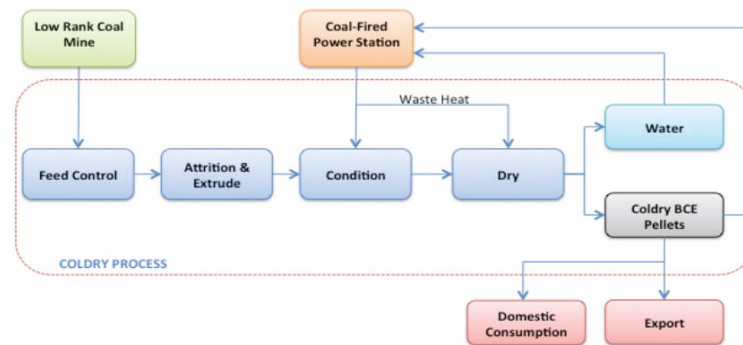


Figure 3-12 Colldry Drying Process Flow Diagram

4 Lignite Drying, Briquetting & Upgrading

4.1 General

Currently, the domestic and foreign lignite briquetting technologies can be divided into two kinds, namely, binder-adopted briquetting and binderless briquetting. The **lignite binder-adopted briquetting process** refers to the process in which pulverized coal fully mixes with the added binders evenly and is briquetted into shaped coal under certain external pressure. Binders mainly include coal tar, tar asphalt, petroleum asphalt or water-soluble binders, etc. Binder-adopted briquetting is mainly based on the soaking and binding of coal granules and binders. According to the research findings, the interaction process between coal granules and binders is quite complicated, including soaking, mass transfer and binding, etc. The binding force between binders and bounded objects is actually an overall result of mechanical binding force and physicochemical binding force. Since coal is a non-polar porous material, mechanical binding force plays a decisive role. Shaped coal strength is resulted from the mechanical bonding that is generated by dehydration and solidification upon binders having penetrated into the gaps of coal granules. The binderless briquetting process refers to a process in which shaped coal is briquetted without using binders but based on its own property and cohesive components while under certain external pressure instead. The existence of "its own binders" is the very basis for lignite binderless briquetting. The lignite binderless briquetting process is that lignite is rolled or stamped under high pressure into shaped coal in certain form. In case of rolling, in order to make granuled lignite material obtain more rolling loads in the double roll meshing area of a high-pressure rolling machine, a preloading device is provided to the granuled lignite material before it enters the high-pressure rolling machine. The feed screw in the preloading device tightly presses the coal granules from the feed inlet by force and transports them to the double roll meshing area for roll briquetting. Under the pressure of the two rolls, the granuled lignite can be compressed and compacted. The volume of the granuled materials drops to 30%~50% of the original volume upon compression, the

density increases to 1.5~3 time of the original density while the heat value gets an increase by 40%~50%^[14].

4.4 Lignite Drying & Briquetting

4.2.1 Tube drier Steam Drying Impact Briquetting Process

The impact briquetting process is a time-honored briquetting process. It is applied to binderless briquetting for low-rank lignite in Germany, Australia, with 70% of the shaped coal product used for civil heat supply. The impact briquetting capacity for a single unit is relatively low. The main steps for such a briquetting process: with a moisture content drops to 12~18% after drying, lignite is cooled down, crushed to a particle size of 0~6mm and then sent to a belt-type coal briquetting machine. In this impact briquetting machine, lignite bears a pressure of 500~2000Bar, with shaped coal produced as per the required shape and particle size. In Germany, this briquetting process is generally integrated with a steam tube drier. See Figure 4-1 for its process flow diagram^[11-12].

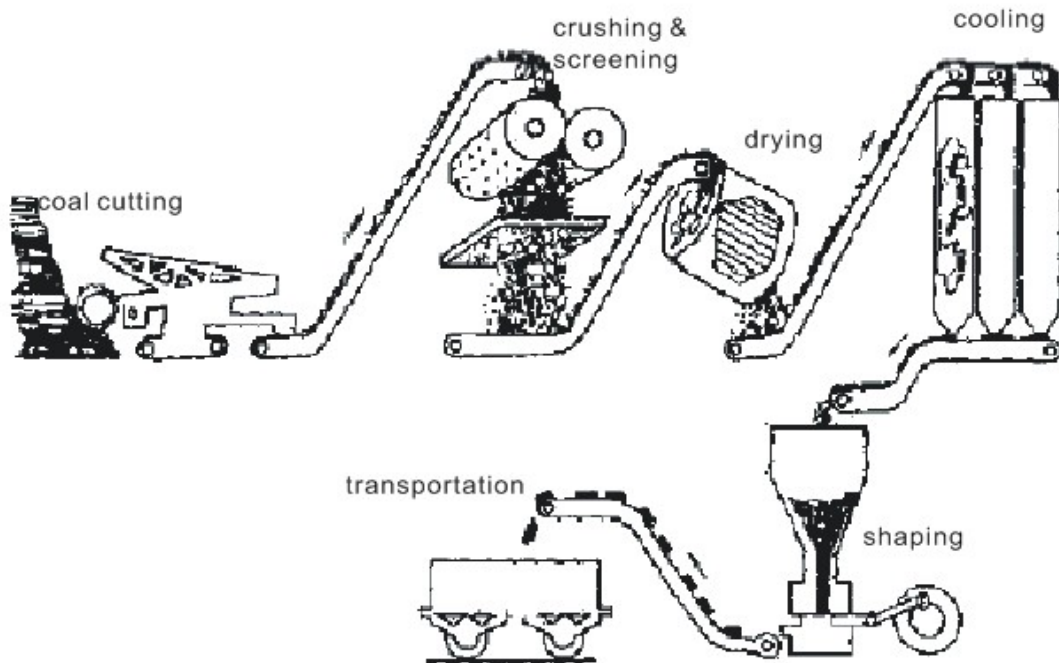


Figure 4-1 ZEMAG (Germany) Lignite Impact briquetting Process Flow Diagram

4.2.2 Tube Drier Direct Steam Drying & Roll Briquetting Process

The tube drier direct steam drying & roll briquetting process as jointly developed by Tianchen (China) and ZEMAG (Germany), is featured with high safety and reliability, especially applicable to combustible and explosive low-rank lignite with a low ignition point. Due to its rational structure and high heat transfer efficiency, the process has achieved sound drying effect when applied to lignite. The tube drier is a rotary kiln, with a multi-tube system arranged in the slightly-inclined drum. Raw coal is continuously fed into the tube of the drier from above. As the drum is inclined, the coal keeps moving to the outlet when the drum is rotating. The heat energy required for drying is supplied by the

low-pressure steam in the multi-tube system. The low-pressure steam enters along the drum in an axial direction and diffuses rapidly to the outer surface of the tube. It absorbs the moisture together with the air entering the drier and is then separated from the dry pulverized coal in the precipitator. Part of the steam goes into the drier again after being compressed, with other part vented into the atmosphere^[14].

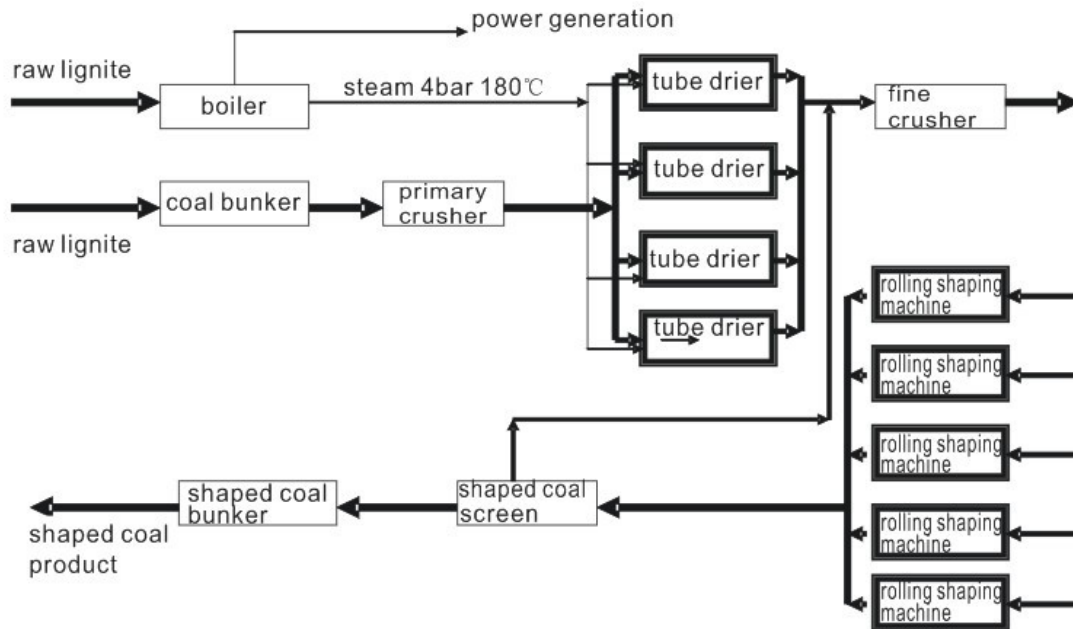


Figure 4-2 Tube Drier Direct Steam Drying & Roll briquetting Process Flow Diagram

See Figure 4-2 for the tube drier direct steam drying & roll briquetting process. The key equipment consists of the high-pressure briquetting machine. Compared to the domestic binder-adopted lignite briquetting, the foreign binderless high-pressure hot-press briquetting has its peculiar advantages. Hot-press briquetting crushes and destroys the pore structure of lignite by force, thus ensuring the drying briquetting effect. Moisture contained in the hot-press shaped lignite is removed with fewer gaps. The strength of the coal briquetting machine is enhanced obviously, providing convenience for comprehensive utilization of lignite.

4.2.3 Fluid-bed Drying & Roll briquetting Process

White Energy (Australia) own the hot flue gas direct drying & briquetting technology (hereinafter referred to as "BCB Process (Australia)"), see Figure 4-3. The 2,000 t/h and 100,000 t/h pilot plants are constructed in Australia separately by using the technology.

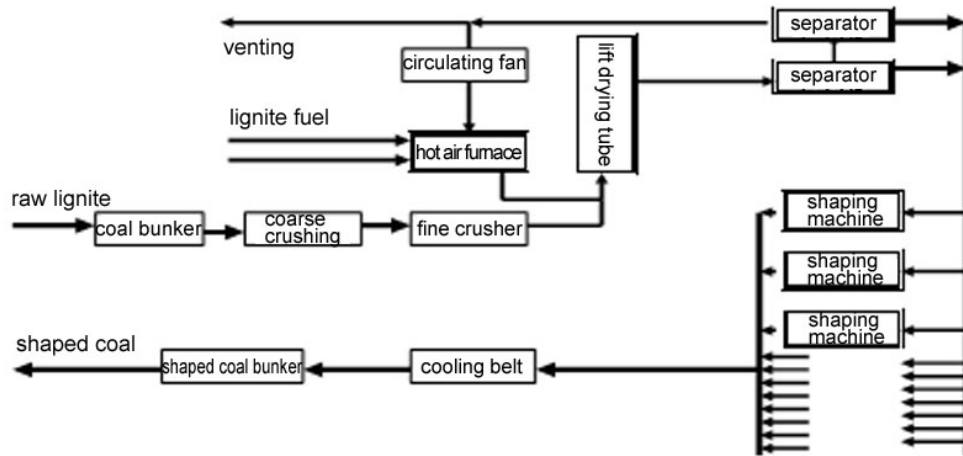


Figure 4-3 Fluid-bed Drying & Roll briquetting Process Flow Diagram

The lignite drying medium adopted is hot flue gas of 800~1000℃, which is generated from the hot air furnace. The hot flue gas is recycled, with the oxygen content in the flue gas controlled no more than 3%, to ensure system safety. The lignite temperature is always controlled no more than 100℃ in the drying process, thus with no loss on volatile constituents in lignite. According to the different moisture contents in lignite, about 1.4-ton raw coal can produce 1-ton shaped coal, wherein: fuel coal takes a proportion of 4~5%. The drying & rising pressure is 5000~7000Pa and the rising height is 20~40m, which is related to the moisture contained in lignite. The fast-heating riser is the key equipment adopting external thermal insulation measures. The dried lignite is shaped by roll briquetting. A 1-million t/a unit are provided with 16 double-roll briquetting machines^[14].

4.2.4 High-temperature Flue Gas Drying & Roll briquetting Process

The low-rank coal high-temperature flue gas briquetting process as jointly developed by Shenghua and China University of Mining and Technology (Beijing), is a high-temperature flue gas drying process, applicable to lignite and other low-rank coal drying. The high-temperature flue gas dries lignite directly, resulting in low exhaust smoke level, high heat efficiency and rapid drying velocity. The moisture contained in coal drops greatly while the thermal value increases. In this process, drying and briquetting relies on each other mutually while running continuously. "Heating" is used for dehydration and removing a smaller part of char tar, providing conditions for binderless briquetting; "pressing" is used for briquetting, which destroys the pore structure of lignite and ensures that no re-absorption occurs in a short time upon dehydration. By controlling drying characteristics and process parameters, it shall on one hand, maintain the dryness, removing part of the char tar as the cohesive constituents, and on the other hand avoiding lignite combustion due to overheating. See Figure 4-4 for the high-temperature flue gas drying & roll briquetting process^[14].

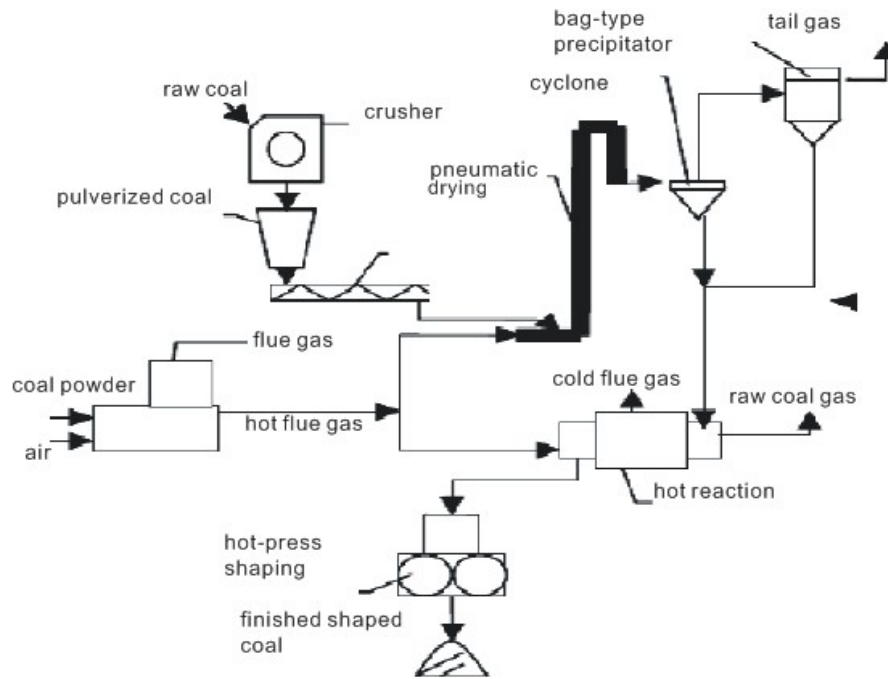


Figure 4-4 High-temperature Flue Gas Drying & Roll briquetting Process Flow Diagram

The roll briquetting pressure is required to be over 1 ton per square centimeter, quite demanding for equipment and materials. The process designs a production line with an annual output of 0.5-million tons. Each production line is designed with a 41.2MW hot flue gas producer, a pneumatic dryer, 4 HPU140-100 double-roll briquetting machines with an output of 7~25t/h. The products are shaped coal in a semi-pillow form. The heat value of lignite after upgrading increases by about 25%, with the heat value up to 4500-5500kcal/kg.

5 Lignite Low-temperature Pyrolysis & Upgrading Technology

5.1 General

In recent years, researches and development on coal pyrolysis processes in China have never ceased, some processes have achieved in a stage of industrial application or industrial demonstration. In order to produce liquid products and aromatic hydrocarbons with a higher yield from high-volatile coal, people refocus on studying the coal pyrolysis process, with some new processes developed one after another. In recent years, new processes are aimed to improve the liquid yield of coal. A widely adopted approach is to speed up the pyrolytic reaction or conduct the pyrolytic reaction in hydrogen environment. In the meantime, new processes put weight on improvement of coal utilization coefficient, enhancement of heat efficiency in process and environmental protection, etc. Pyrolysis technologies typical both at home and abroad include: the external heating vertical furnace process, the internal heating vertical furnace process, the Toscoal process (the US), the fluid-bed fast pyrolysis process (Australia) and other processes, etc. The process is a reaction process in which the material is decomposed when being heated. Decomposition reaction may occur to many inorganic substances and organic substances when they are heated to certain extent.

The principle for coal pyrolysis (retorting) is a process in which coal is heated and decomposed under the condition of air isolation, with such products as char (char), coal tar, crude benzene, coal gas and so on generated. Based on the different ultimate heating temperatures, the process can be divided into kinds: 900~1100°C for high temperature retorting, that is, charring; 700~900°C for intermediate temperature retorting; 500~600°C for low temperature retorting. When the coal temperature is more than 100°C, the moisture in it is evaporated; when the temperature is more than 200°C, the bound moisture in it is released; when the temperature is more than 350°C, the caking coal begins to soften and further forms the sticky plastic mass (this does not occur to peat and lignite, etc.); when the temperature is 400~500°C, most of the coal gases and char tar are precipitated, which is called as the primary thermal decomposed products; when the temperature is 450~550°C, thermal decomposition goes on and the residues gradually become sticky and solidified into char; when the temperature is more than 550°C, the char goes on with its decomposition and precipitates the residual volatiles (mainly including hydrogen). The char is shrank while losing weight, which forms cracks; when the temperature is more than 800°C, the char is reduced in volume and hardened to form porous char. When retorting in the indoor retort furnace, the primary thermal decomposed product contacts the redhot char and the high-temperature furnace wall to form the secondary thermal decomposition and thus generate the secondary thermal decomposed products (char oven gas and other charring chemicals). The products of coal retorting are coal, coal tar and coal gas.

The coal pyrolysis process can be divided into various kinds based on the process conditions such as ultimate heating temperature, heating rate, types of heating, types of heat carriers, atmospheres and pressure, etc. It can be divided into: low temperature (500-600°C), intermediate temperature (700-800°C), high

temperature (950-1050°C) and super-high temperature (>1200°C) coal pyrolysis processes based on ultimate heating temperatures; slow-speed (3-5°C/min), intermediate-speed (5-100°C/s), fast-speed (500-10000°C/s) and flash pyrolysis (>10000°C/s) processes based on heating rates; external heating, internal heating, external & internal heating coal pyrolysis processes based on types of heating; solid heat carrier, gas heat carrier, solid-gas heat carrier coal pyrolysis processes based on types of heat carriers; hydrogen, nitrogen, water vapor, air-isolating coal pyrolysis processes based on atmospheres; atmospheric and pressurized coal pyrolysis processes based on pressures.

5.2 Foreign Gas Heat Carrier Lignite Pyrolysis Upgrading

5.2.1 Lurgi-Spuelags Low-temperature Pyrolysis Process

The Lurgi-Spuelags low-temperature retorting process is the first lignite low-temperature pyrolysis process to be commercialized. By adopting a heat supply mode of internal heating based on gas heat carrier, it integrates lignite drying, retorting and char cooling, realizing a continuous production^[15-16]. See Figure 5-1 for Lurgi-Spuelags low-temperature retorting process flow diagram.

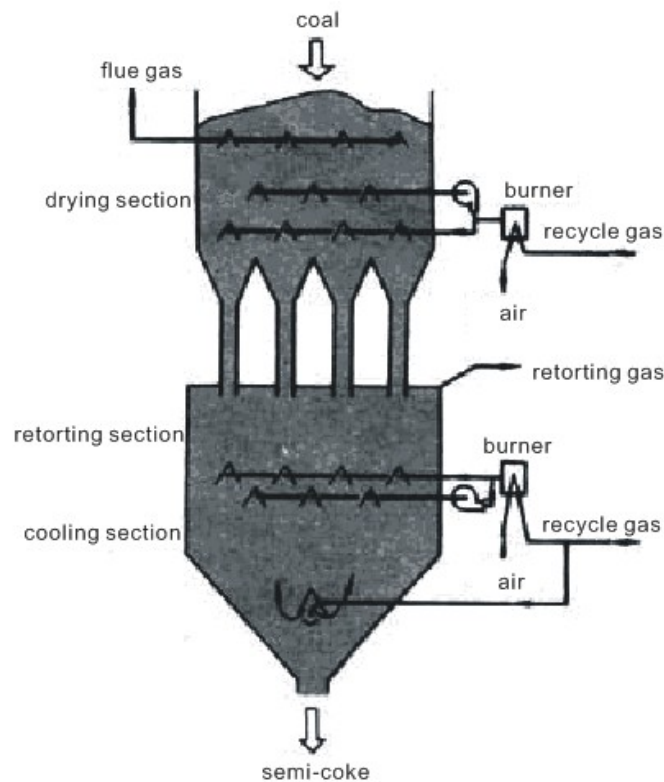


Figure 5-1 Lurgi-Spuelags Low-temperature Carbonization Process Flow Diagram

Lurgi's three-section furnace is of this type, in this case, coal moves downward in the vertical furnace and airflow enters in a reverse direction for pyrolysis. Pulverous lignite and bitumastic coal should be briquetted (shaped) in advance. The coal pyrolysis processes can be divided into the upper, middle and lower sections: coal firstly passes the drying & preheating section, then the retorting

section and finally the char cooling section. In the upper section, the circulating hot airflow dries the coal and preheats it to 150°C. In the middle section, that is, the pyrolysis section, the hot airflow heats the coal to 500-850°C. In the lower section, the char is cooled by the circulating airflow to 100-150°C and discharged. The discharging mechanism controls the productivity of the pyrolyzer. The mixture of recycle gas and pyrolysis gas is exhausted via the pyrolysis section, with the liquid by-products separated out in the following condenser system. Purified gas are mostly sent to the burners in the drying section and the pyrolysis section and partly sent to the char cooling section directly. The surplus coal gas is sent out and used as heating fuels. The condenser system includes pre-coolers, tar separating tanks, aftercoolers, final coolers and benzene-washing towers. It uses the hot water of about 85°C that is generated from pyrolysis for sprinkling and evaporation in the pre-cooler, making the coal gas cool down. It generally uses electrical tar precipitator as the tar separator. After the two steps, the intermediate-temperature char tar is separated out and the residual oil is also eliminated in the aftercooler and final cooler sections, with water condensed. In the benzene-washing tower, it uses the wash oil distilled from char tar to wash benzene. One furnace can process 300-500 tons of coal every day to produce 150-250 tons of char, resulting in 10-60 tons of char tar per day and 180-220m³ of surplus coal gas per ton. The heat value of coal gas is 5880-8820kJ/m³. Domestically various types of gas-fired internal heating vertical pyrolyzers are developed based on Lurgi's three-section furnace, which have now widely been applied to regions such as Northern Shangxi Province, etc. by virtue of the local high-quality long flame coal (or non-caking coal and weakly caking coal) to produce char^[16].

5.2.2 SJ Low-temperature Carbonization Rectangular Retort Furnace Process

The SJ low-temperature retorting rectangular retort furnace is a rectangular retort furnace developed by Shenmu Sanjiang Coal Chemical Liability Co., Ltd. (China), based on the Lurgi-Spuelags process. As for the features of the furnace, materials can fall evenly, the materials and gases can be distributed and heated evenly. In the meantime, it can enlarge the effective volume of the char oven, improve the unit volume as well as the processing capacity in a unit section of the char oven. When bitumastic coal is retorted, the char tar yield of dry-basis raw coal is over 7%, which improves the light components and the economic value of char tar.

The SJ low-temperature retorting rectangular retort furnace can be divided into three parts, namely, the drying section, the retorting section and the cooling section. The main process is: lump coal enters the retorting chamber via the coal bunker distributor, with materials distributed evenly; the cooled coal enters the water seal tank in the bottom of the furnace, to water-seal the discharged char by using a char pushing tray and a scrapper, with materials falling evenly and char discharged evenly; coal gas and air are mixed evenly in the Venturi tube and sprayed into the tracery wall, and then sprayed out via the hole on the wall to burn in the furnace. It mixes with the circulating cooling coal gas and the water vapor generated from water sealing to form the heat carrier used for retorting, heating and retorting the lump coal. Coal gas is introduced into the cooling system via the gas-collecting arrayed umbrella on top of the furnace, realizing

even heating and low-temperature coal retorting.

The SJ low-temperature retorting rectangular retort furnace process provides three types of furnaces with an annual char output of 30,000 tons, 50,000 tons and 100,000 tons separately for a single furnace. A standard unit can form a char production scale of 60,000 t/a, 100,000 t/a and 200,000 t/a. The process has been applied to the 500,000 t/a lignite retorting project in eastern Inner Mongolia, China. The project has not been put into service yet, thus it remains to be verified for whether it can process lignite successfully or not^[15-16].

5.2.3 ENCOAL LFC Pyrolysis Process

ENCOAL LFC lignite upgrading is a development project on clean coal technologies as sponsored by the US Department of Energy in the 90s of the last century. It is firstly developed by Evergreen Energy Inc. (the US) and later further developed by SGI and SHELL. A 1,000t/d demonstrative unit on a commercialized scale has been constructed in Gilett, Ohio, the US. From 1992 to 1997, the unit has been operated for five years, processing 246,900-ton PRB raw coal in total during its operation, producing 114,900-ton PDF and nearly 5-million-gallon CDL. A lot of valuable experience has been obtained during the operation, providing a basis for commercial plants.

The demonstrative unit shut down in 1998. SGI declares bankruptcy in January, 2003. Most of the original patents become invalid around 2008. M&RE (the US) inherits the technical documents and sells both the secondary development right and technical license in China to Datang International Power Co., Ltd. in 2006. In 2011, Datang International Power Co., Ltd. constructs a 1,000t/d production unit to process the lignite from Inner Mongolia. The unit is now under a test run after rectification. The LFC process is a lignite mild pyrolysis process adopting a two-step approach to separate drying from pyrolysis while using low-oxygen gas as the heat carrier. Its target products are high-quality solid fuels and low-temperature char tar. The process is mainly divided into two steps: the first step is drying, removing the equilibrium moisture in lignite, the second step is mild pyrolysis, removing part of the volatile constituents to modify lignite into the high-quality solid fuel--PMC with relatively stable physico-chemical properties. Some liquid fuel--PCT can be by-produced in the mild pyrolysis process. The solid fuel PMC as obtained from lignite upgrading is stable in property, applicable to long-distance transport and standing storage, with the marketing scope greatly increased, the combustion characteristics considerably optimized, the heat value almost doubled and the sulfur content decreased drastically. It is a high-quality environment-friendly solid fuel that can also be used as reductant aggregate for industries such as blast furnace injection and ferroalloy, etc.

The liquid fuel PCT obtained from lignite upgrading and processing is nearly 10% of the PMC yield. PCT is a substitute for petroleum resources and can produce deep processing products from crude oil that is 2-3 times of the crude oil in values by means of simple separation^[16].

See Figure 5-2 for LFC lignite upgrading process flow diagram.



The Beijing Cleanstar belt lignite pyrolysis process is developed from its belt drying process. The technology is a process incorporating high-temperature flue gas with direct drying + high-temperature flue gas heat carrier pyrolysis + cold flue gas deactivation. The advantage lies in the fact that the above three processes are completed in a belt furnace, based on a compact arrangement. After being separated, the pyrolyzed gas tar is consumed by itself due to the low heat value. The unit is easily explosive in case of misoperation, the safety gets worse, and improper drying can result in local overheating and worse coal quality. The direct drying flue gas contains certain volatile constituents and SO₂, which may influence the environment to some extent. As rotating equipment, the belt conveyor may easily fail under high temperature, thus reducing its service life.

By adopting this technology, a commercially-demonstrative 3-million t/a unit was constructed in Inner Mongolia. The lignite pyrolyzer can be divided into such three sections as drying, pyrolysis upgrading and cooling. Same to other drying and pyrolysis processes, the drying temperature is 300°C and the pyrolysis temperature is 500-600°C, which is cooled down to 60°C by low-temperature flue gas at the cooling end and becomes an eligible products^[15-16].

The multi-section rotary furnace low-temperature pyrolysis technology is recently developed by Beijing Research Institute of Coal Chemistry. The process is featured with low (intermediate) -temperature pyrolysis -intermediate-speed heating-external heating-air isolating-atmospheric pressure. When the multi-section rotary furnace is heated by coal gas that is low in heat value, the pyrolysis coal gas of high heat value is purified to civil or industry gas. Since the

coal is dried before pyrolysis, with most of the moisture removed, it thus can reduce the phenolic waste water. A little waste water can be used for quenching char to simplify the waste water treatment system of great investment. The multi-section rotary furnace requires raw coal with a rational particle size of 6-30mm. The pyrolysis heating furnace can not only use solid fuels but also gas fuels, or both at the same time. In the drying rotary furnace, lignite is heated and dried by flue gas with a temperature less than 300°C. The dried lignite is sent to the pyrolysis rotary furnace for pyrolysis and partly used as the fuel for the furnace at the same time, thus providing heat for pyrolysis. The pyrolyzer is of external heating. The coal temperature of the pyrolyzer is controlled at 550-700°C. The heating flue gas from the pyrolyzer is used as the drying heat source for the drying furnace upon temperature regulation. The char discharged from the pyrolyzer is quenched with water in the rotary cooling furnace to get char products. Coal gas and char tar generated from pyrolysis is discharged as the raw materials for downstream deep processing upon purification and precipitation^[17]. See Figure 5-3 for the process flow diagram.

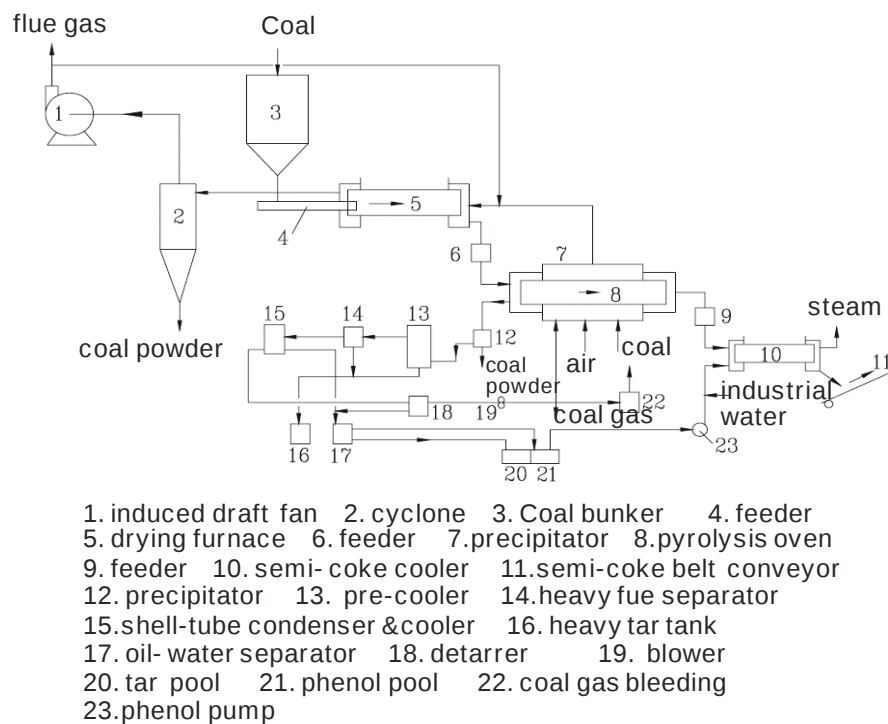


Figure 5-3 Multi-section Rotary Furnace Low-temperature Pyrolysis Process Flow Diagram

5.2.6 IER's Cat-HTR Process

The basic goal of IER's technology is to reduce the oxygen content of lignite, and thereby increase its energy content. Instead of using the more traditional approach to the liquefaction of lignite, namely pyrolysis or gasification, IER uses highly compressed steam (water), in the presence of a catalyst, to selectively remove the chemically-bound oxygen in lignite's polymeric structure. Therefore, IER is able to turn the main disadvantage of lignite – its high water content – into an advantage. See Figure 5-4. By using high-pressure steam, in the presence of a

catalyst, IER's Cat-HTR Process partially liquefies low-energy density lignite, transforming it into an oily coal slurry, which can be simply processed into a high-grade synthetic crude oil (or 'syncrude') and a high-grade micronised coal. Independent analysis has found that:

IER's micronised coal is at least comparable to medium-volatility pulverised coal injection (or 'PCI') coal (a metallurgical coal), and that IER's synthetic crude oil can be processed into various transportation fuels, under near standard refinery conditions.

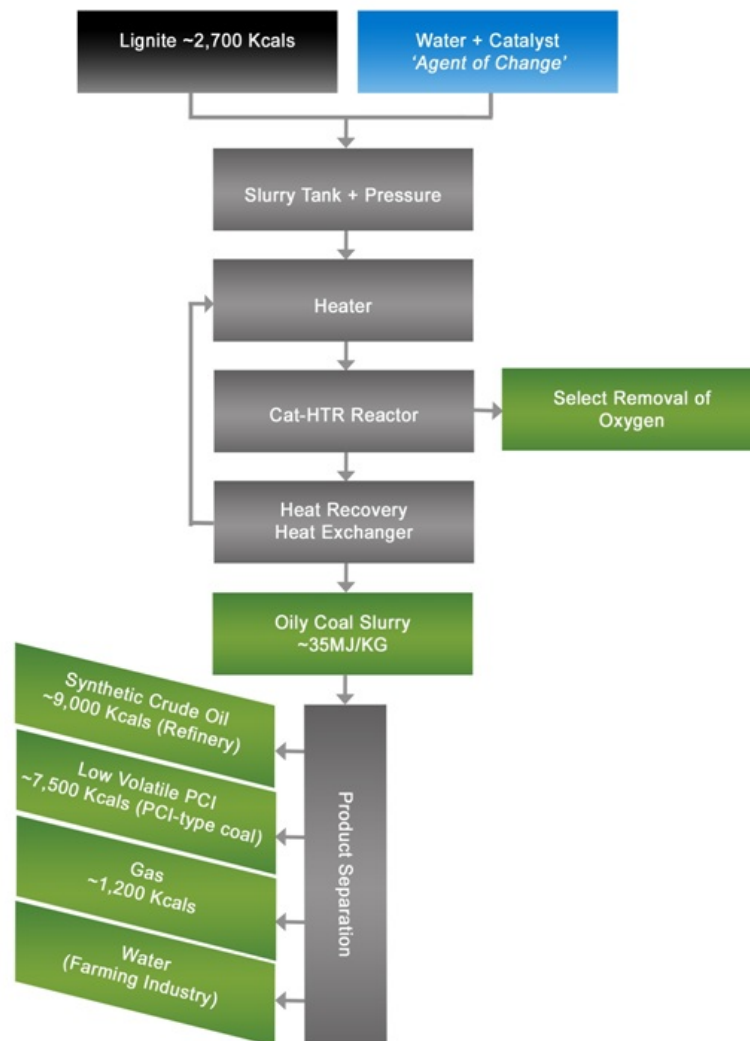


Figure 5-4 IER's Cat-HTR Process Flow Diagram

5.3 Solid Heat Carrier Lignite Pyrolysis Process

5.3.1 Lurgi-Ruhurgas Low-temperature Pyrolysis Process

The LR process is a general-purpose internal heating solid heat carrier fast-pyrolysis process jointly developed by Lurgi (Germany) and Ruhrgas (the US). Raw materials for the LR process include coal, oil shale, oil sand and liquid hydrocarbons. In the 50s of the 20th century, a 10 t/h pilot unit has been

constructed in Dorsten, Federal Republic of Germany. The heat carrier used is of solid particles (small ceramic ball, sand or semi-char). A production unit has been constructed in former Yugoslavia in 1963. The productivity for a single series is 800t/d, with two series in total. The total productivity is 1600t/d. Semi-char, the product, is used as the raw material for charring blend.

In 1974, a 350t/d bitumastic coal pyrolysis unit has been constructed in Prosper Mine, Ruhr, Germany. The produced semi-char from bitumastic coal is hot pressed and shaped for sales. In 1977, a bitumastic coal pyrolysis unit with a processing capacity 600t/d has been constructed in Scuthorpe Factory of British Steel Corporation. The produced char from bitumastic coal is hot-pressed and shaped for sales. The process principle is to use internal heating solid heat carrier for fast pyrolysis. Therefore, the pyrolysis gas does not include the inert gases added for the gas heat carrier process. Equipment for the pyrolysis gas after-treatment system is smaller in dimensions and higher in coal gas heat value, which is up to 20.5~40.6MJ/m³. See Figure 5-5 for the LR process flow diagram.

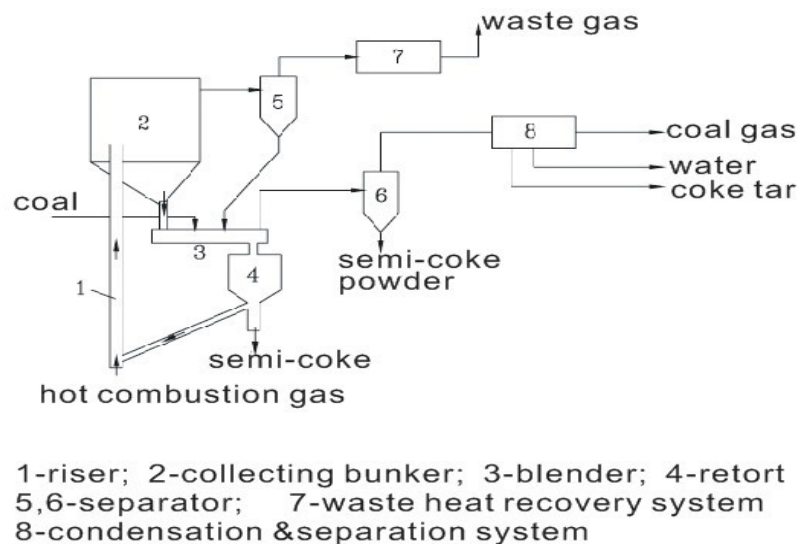


Figure 5-5 Lurgi-Ruhurgas Low-temperature Pyrolysis Process Flow Diagram

The process firstly mixes the pre-heated raw coal in small patches with the hot char from the separator in the blender for pyrolysis. Then the mixture falls into the buffer and stays for a while to complete the pyrolysis. The char from the buffer enters the bottom of the riser and is sent by the hot air. In the meantime, the residual carbon in it is burnt in the riser and the temperature rises. It then enters the separator for solid-gas separation. The char goes back to the blender and the cycle repeats itself. Coal gas high in heat value is obtained after the volatile matters escaping from the blender are treated by precipitation, condensation, cooling and oil recovery. Advantages of the LR process: high oil yield, low energy consumption and simple equipment structure. Problems existed: blocking of the drainage system, dust content in the oil products, poor processing capacity for a single unit, great waste water, and difficulty in processing, bad environmental friendliness^[18].

5.3.2 Garrett Intermediate (Low) -temperature High-pressure Pyrolysis Process

The Garrett process is independently developed by Garrett (the US) R & D Co., Ltd., who later improves and further develops the original process together with Occidental Petroleum Corporation from Los Angeles, California. In 1972, a 3.8t/d pilot unit has been constructed in California. With relatively broader operational conditions, certain test data has been obtained from the unit. The Garrett process is featured with pulverized coal feeding-solid char heat carrier heating-internal heating-fast heating-intermediate (low) -temperature high-pressure pyrolysis. It can heat rapidly in a short time, avoid the secondary pyrolysis of char tar and improve the char tar yield. Besides, it uses part of the char as the heat carrier and downward recycles in the entrained-bed, with high heat efficiency. Taking the bitumastic coal in Western United States as raw material, the coal is crushed to a particle size less than 200 mesh and sent to the reactor with the high-temperature char. The rate of temperature rise is over 278°C/s , with its max. operating pressure of 344KPa (gauge pressure). Pyrolytic reaction occurs within 2s due to a short stay in the furnace. The non-condensed coal gas sends the coal into the furnace for recycling. Char that is partly captured by the cyclone exchanges heat with the burning coal gas, and then heated in a very short time^[15-16].

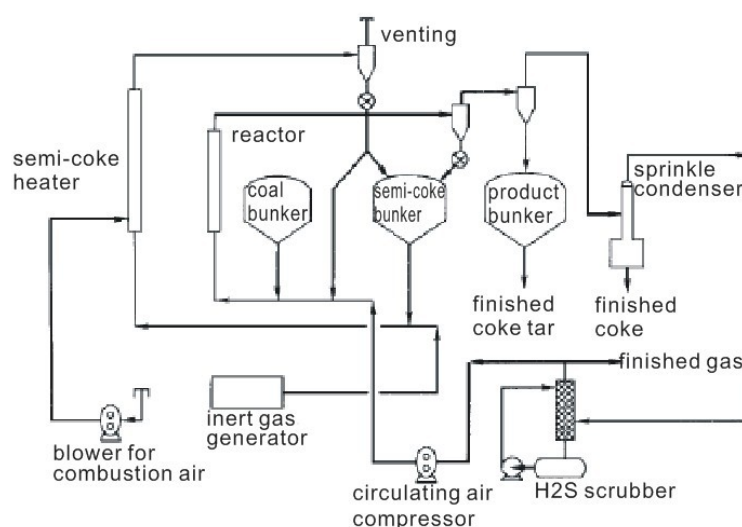


Figure 5-6 Garrett Intermediate (Low) -temperature High-pressure Pyrolysis Process Flow Diagram

The process can maximize its potential to restrain CO generation, which is good for reducing heat loss and realizing heat balance in process. The product, char has a heat value also same to that of raw coal. Being porous, its reactivity is better than that of raw coal and mainly used as fuel for power generation. The coal gas heat value generated is about 25,000KJ/m³ and can be used as pipeline gas and fuel gas. The char tar is low in hydrogen content, so hydrogen is required when producing synthetic crude oil or low-sulfur fuel oil. See Figure 5-5 for the process flow. Major problems existed include that: the char tar, dust and char may be adhered to the inner wall of the cyclone and pipelines, which may block the pipeline in case of long-time operation; contacts between circulating char and the fed coal and full heat exchanges may accelerate the fine grinding of coal and

increase the circulating char, thus an minor increase in the coal processing capacity of the system; when using the eastern coal high in sulfur content, the char is also high in sulfur content and a desulfurization process is required when the char is used as power fuel.

5.3.3 3TX (ETCh-175) Solid Heat Carrier Pulverized Coal Retorting Process

It is a solid heat carrier pulverized coal retorting process developed by former Soviet Union. There is a pilot unit of processing capacities of 4t/h and 6/h in Kalinin. The pilot unit is tested with coal high in dust and sulfur, lignite and peat. The 3TX—175 (i.e. ETCh—175) demonstrative unit on an industrial scale is constructed at No.2 Power Plant, with an hourly processing capacity of 175-ton coal. Lignite from the mine is dried by flue gas after being crushed. The dried pulverized coal is again pre-heated in the pneumatic pre-heater. The pre-heated pulverized coal is mixed with the solid heat carrier and retorted when reaching the retorting temperature. Oil and coal gas precipitated from the pyrolysis chamber are separated upon precipitation and condensation, then resulting in char tar, light oil and coal gas. The surplus char generated from the unit is discharged from the pyrolysis chamber, which is then used as fuel for power stations upon heat recovery. The energy (taking energy consumption of power, steam and production purification into consideration) efficiency of the unit is 83-87%. The retorted products are also used in other applications. 0-0.05mm char fine powder (substituting commercial carbon for the filler applicable to rubber products and thermal plastics); 0.05-0.25mm powdered carbon, with a heat value of 27.24MJ/kg, used as the fuel for power stations, blast furnaces and other furnaces or as reductant admixture for metallurgical industry; fine-grained char with a particle size over 0.25mm, used as the adsorbent to treat oily waste water^[15-16]. See Figure 5-7 for its process flow diagram.

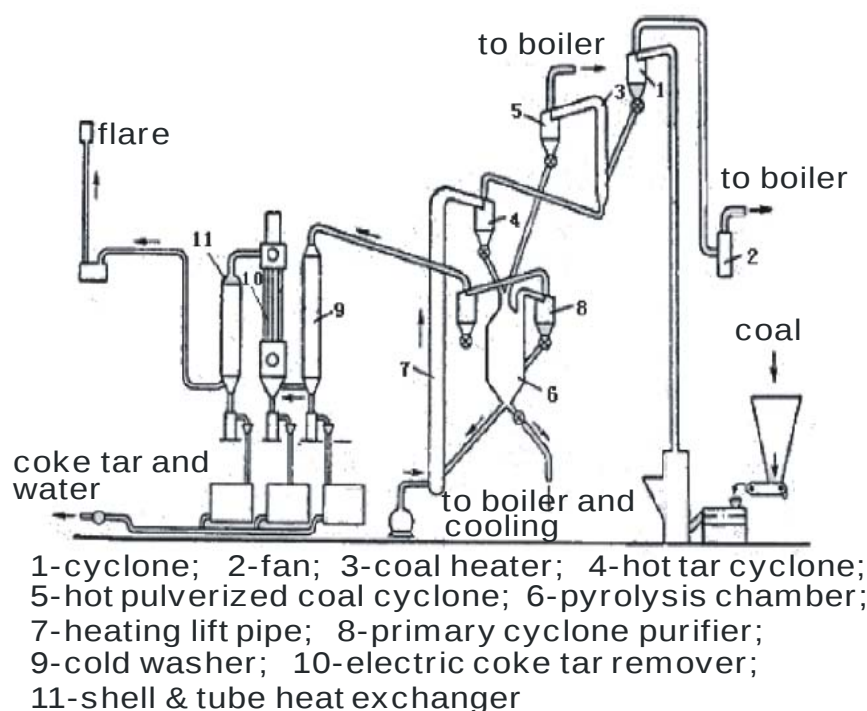


Figure 5-7 Solid Heat Carrier Pulverized Coal Retorting Process Flow Diagram

5.3.4 DG Solid Semi-char Heat Carrier Low-temperature Retorting Process

In the DG semi-char solid heat carrier low-temperature retorting process that is developed by Dalian University of Technology, dry lignite and hot semi-char heat carrier are mixed quickly and heated to make lignite pyrolyzed (retorted) and get low-temperature char tar, coal gas and semi-char. Lignite drying adopts the high-temperature flue gas direct contacting riser entrained-bed drying process. The high-temperature flue gas is generated from the hot air furnace burning char or lignite. First heat char to 800 °C in riser of semi-char pyrolysis and partial combustion as heat source of pyrolysis. After HT gas-solid separation, it is used as heat source of lignite drying riser^[18].

See Figure 5-8 for the process flow.

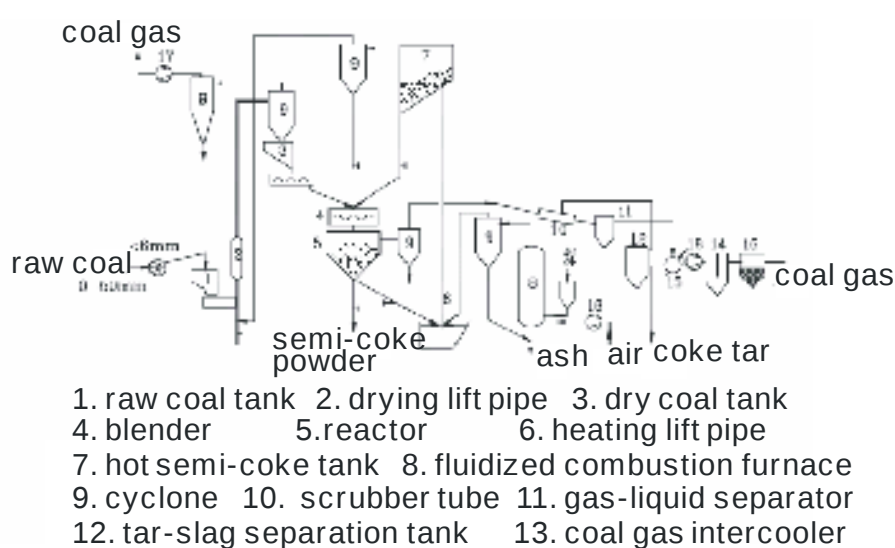


Figure 5-8 Semi-char Solid Heat Carrier Low-temperature Retorting Process Flow Diagram

Dalian University of Technology has set up a continuous hot test device with a processing capacity of 10kg raw materials per hour in the laboratory in 1984. Based on this device, dozens of tests and researches on coal and oil shale have been conducted. A 6t/d lab trial unit is constructed later, based on which the key technical researches on new lignite solid heat carrier retorting technologies are conducted, including the in-depth study on key technologies such as blenders, etc. Based on the above study, a 150t/d industrial test unit adopting the solid heat carrier retorting technology is constructed in Pingzhuang, China, aiming to verify the rationality and feasibility of the process. The technology is finally applied to the Shangxi Shengmu 600,000 t/a Coal Pyrolysis Upgrading Project for commercial scale verification. This commercially demonstrative project is started up in January, 2011, now in the process of rectification and debugging^[19].

5.3.5 Toscoal Low-temperature Retorting Pyrolysis Process

The Toscoal process is a low-temperature coal retorting process developed by Tosco (the US) based on the Tosco—II oil shale retorting process. It adopts

ceramic balls as the heat carrier, with coal retorting conducted in the rotary pyrolysis furnace. The process is an internal heating-low-temperature-intermediate speed-solid heat carrier retorting process. The main purpose to develop this process is to upgrade coal low in heat value, increase its heat value and recover valuable gas and liquid products. The semi-char produced contains enough volatile constituents, can be used in the existing power generation plant without changing equipment or adding auxiliary fuels. See Figure 5-9 for the process.

The Toscoal process starts in 1970, initially selects the Wyodak sub-bituminous coal (the US) as the raw materials, taking a test on a pilot plant with a daily capacity of 25 tons. The test indicates that, the approach can be applied to both the non-caking coal and the weakly caking coal. The significance of the process lies in: reducing coal transportation costs; reducing sulfur emissions from power plants; adopting semi-char as gasification raw material or for formed char production; obtaining high-quality light synthetic crude oil by hydrogenating the crude tar produced. Problems existed: complicated equipment, high investment and great maintenance work^[15-16].

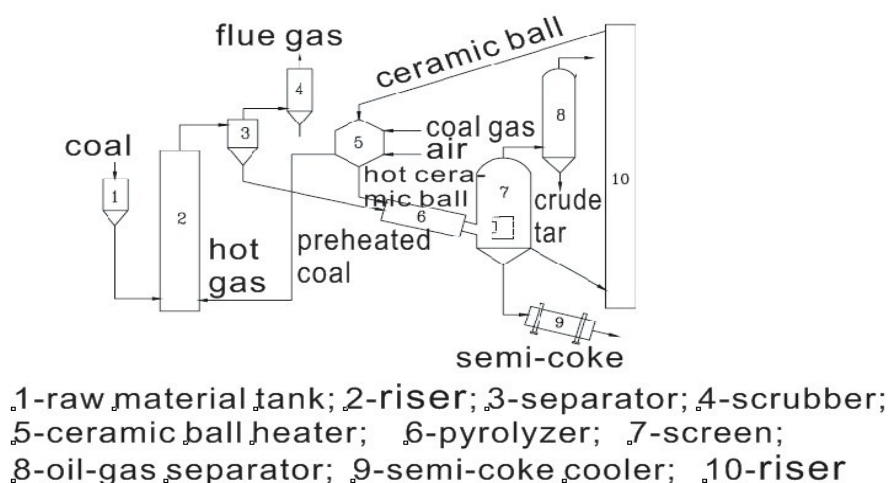


Figure 5-9 Toscoal Low-temperature Retorting Pyrolysis Process Flow Diagram

5.3.6 Solid Ash Heat Carrier Fluid-bed Low-temperature Retorting Process

The solid ash heat carrier fluid-bed low-temperature retorting process is a lignite grading utilization technology developed by Zhejiang University (ZDL process of Zhejiang University) in recent years. See Figure 5-10 for the process flow. Based on the process, a 1MW hot test is conducted and a heat-electricity-gas polygeneration system design based on an hourly capacity of 35 tons, 75 tons and 130 tons separately is completed. The 75t/h polygeneration boiler has been operated successfully in Yangzhou, Jiangsu. The application of the 120MW heat-electricity-gas-tar polygeneration has been completed in Huainan, Anhui.

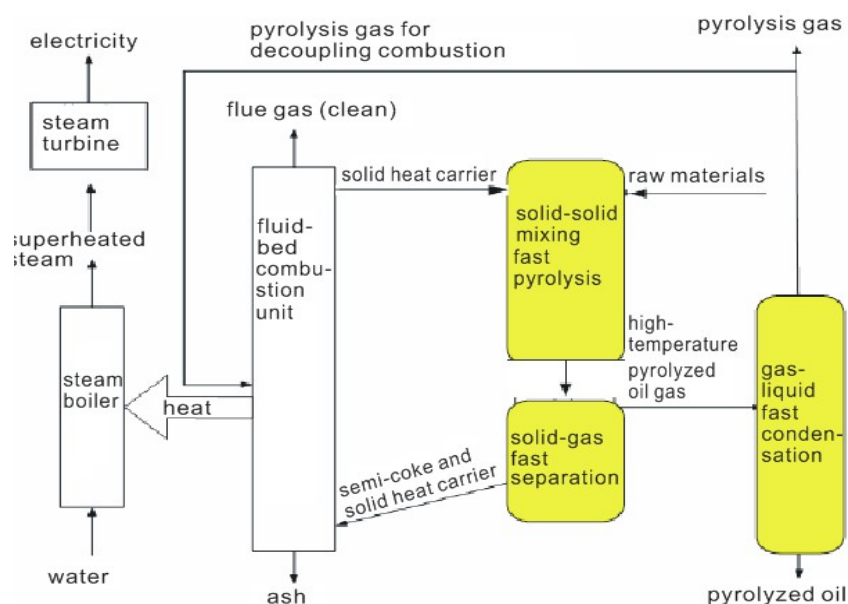


Figure 5-11 Coal Topping Fluid-bed Low-temperature Pyrolysis Process Flow Diagram

The process is realized by coupling the circulating fluid-bed downer and the circulating fluid-bed. Pulverized coal is fed from top of the circulating fluid-bed downer and is strongly mixed with the circulating hot ash from the riser, with the temperature increased. It realizes the fast pyrolysis under atmospheric pressure and low-temperature (550-700°C) environment without hydrogen or catalysts. The generated gas-phase product is separated via the quick separator at the bottom of the downer pipe and quickly cooled down after entering the quench cooler, with the liquid product finally obtained.

Features of the coal topping process: the conditions are mild, the process is simple, to extract coal tar from coal under an atmospheric pressure and an intermediate temperature; the system is integrated, organically combining the fast fluid-bed and the circulating fluid-bed downer; to convert and extract the effective distillate from coal to realize the processing of products with high values. The key technology lies in such three aspects as quick pyrolysis, quick separation and quick cooling, to increase the pyrolysis temperature and the heating rate while reducing the retention time, realizing the conversion to light fraction and quick solid-gas separation of liquid products^[17].

5.3.8 Solid Ash Heat Carrier Moving-bed Low-temperature Retorting Process

The polygeneration process (hereinafter referred to as "BJY Technology") is developed by State Power Economic Research Institute and Jinan Boiler Works. A 150kg/h process unit has been constructed by Jinan Boiler Works in 1992. In 1995, an industrial test has been conducted by making the 35t/h CFB boiler compatible with the pyrolysis reactor, with test data obtained. Jinan Boiler Works has finally completed the design of the 75-ton CFB trigeneration process in Feicheng.

The polygeneration process based on moving-bed pyrolysis is similar to those based on fluid-bed pyrolysis, with main difference lying in the gasification chamber. The gasification chamber based on moving-bed pyrolysis adopts moving-bed gasification. In the BJY process, a moving-bed retort is provided on one side of the CFB boiler, the circulating ash of the fluid-bed is firstly sent into the retort, the circulating hot ash pyrolyzes the coal as the heat carrier, with the volatile constituents precipitated. The semi-char and circulating ash generated from coal pyrolysis are finally sent back to the boiler for cyclic burning. The coal is crushed to a particle size of 0.8mm, with 20% entering the boiler furnace via the coal feeder for boilers and 80% entering the retort together with the hot ash via the coal feeder for retorts. The coal is mixed and pyrolyzed in the retort and the semi-char generated therefrom goes back to the furnace via the refeeder as the fuel for boilers. Combustion flue gas separates the ash via the cyclone at the upper outlet of the furnace and is vented via the cooler, the induced draft fan and the stack. The hot water generated by the boiler is cooled for recycling. The hot ash separated by the cyclone for boilers enters the furnace via the refeeder, forming a standard circulating system consisting of furnaces, separators, retorts and refeeders. The key of the technology is to ensure that the coal fed and the high-temperature blended ash is mixed evenly to avoid coal caking. Tests and analysis have been conducted on such coal types as lignite in Datong, Suzhou and Longkou as well as long flame coal in Meihe, etc., with sound effects.

5.3.9 Shenwu Pyrolysis Process via regenerative heat-carrier-free rotating bed technology

Shenwu Group conducted a lot of researches and experiments aiming at difficult problems like high energy consumption and hard to realize large-scale in the existing pyrolytic technique for lignite and low metamorphic bituminous. Shenwu integrated independent developed regenerative radiant tube combustion technology and rotary bed pyrolysis equipment; innovated radiant tube internal partition arrangement technology, pyrolysis process partitioned and segmented heating control technology, oil and gas multichannel quick export technology; finally developed rotary bed pyrolysis key technology and equipment. Coal experiment equipment with the capacity of 3t/h had been established and it had experimented with about ten kinds of coal such as gas coal of Pingshuo, Shanxi, long flame coal of Erdos, Inner Mongolia, lignite of Xilinguole, Inner Mongolia, lignite of Xinjiang, lignite of Indonesia, lignite of Australia etc. separately in continuous operation large pilot-scale test and it worked stably. Experimental results showed that the high tar yield, high gas calorific value, purer quality, low energy consumption could be realized and megatonnage large-scale could also be realized easily. The technical features:

1. Lignite lays well-distributed on the steel plate of reactor bottom through the feeding device. Coal stays relative static to avoid crushing and chalking phenomenon. empty space below coal makes hot gas circle through the material layer, in order to accelerate the heating speed evenly.
2. Radiation heating mode realizes complete separation of flue gas and furnace circumstance, avoids the mixing of dry distillation gas and flue gas. Effective gas contents are high, such as: H₂: - 45%, CH₄:25-30%, CO: 10-15%.

3. Thermal efficiency of regenerative radiant tube combustion device is 86%, 25-40% higher than ordinary gas retort. Tube's service life can reach more than 8 years; surface temperature difference of effective heating period is less than 20°C; combustion air preheat temperature can reach 800°C. Radiant tube combustion device can use all kinds of low calorific value gas to heat rotating bed retort, so that high quality dry distillation gas can be used as feed material.

4. The method of dry char quenching is helpful to recycle semi-char with low moisture content.

5.4 Lignite Fast Pyrolysis Upgrading Technology

5.4.1 Fluid-bed Fast Pyrolysis Process (Australia)

Common Wealth Science and Industries Research Organization (Australia) has begun to study and develop the fluid-bed fast pyrolysis process since the 70s of the 20th century. It studies various bitumastic coals and lignite on fluid-bed fast pyrolysis, attaching great importance to researches and tests on compositions, properties and reprocessing characteristic of pyrolyzed char tar. The development of the process is aimed to use coals from Australia to produce liquid fuels.

The process is of low-temperature or intermediate-temperature pyrolysis-flash pyrolysis (with the reaction time less than 1s) -internal heating solid-gas heat carrier (sand fluid-bed). The unit is 20kg/h on scale, which is for lab trial. The coals used in the test are all up to 200 mesh in particle sizes. In case of fast pyrolysis, char tar yield of lignite can be 23% (with a max. yield at 580°C), which is 150% of that obtained in the Gray-King assay test on the coal. Char tar is high in viscosity under the ambient temperature and generally in a fluid state at 70°C. Semi-char of lignite is porous and of high-quality. The semi-char produced from lignite at 600°C still contains 30% of the hydrogen in raw coal. The residual volatile constituents existed in the semi-char is good to its stable combustion in the burner. The problem lies in the fact that there is no verification on pilot tests or industrial tests.

5.4.2 Fast Pyrolysis Process (Japan)

Japan develops a fast pyrolysis process, which combines gasification with pyrolysis of lignite, aiming to maximize the output of the gas gaseous (coal gas) and liquid (char tar and benzenes) products. It firstly builds a 7t/d unit for lab trials and then has designed a pilot unit with processing capacity of 100-ton raw coals per day in 1996, which has been constructed and put into service during 1999-2000. It has completed the pilot test in 2001 with test results obtained.

As for the features, the fast pyrolysis process adopts dense-phase pneumatic transportation of pulverized coal that is fed-gas heat carrier fast heating-intermediate (low) -temperature pyrolysis. After drying and grinding, the raw coal is transported by nitrogen and gases generated from pyrolysis based on

dense phase, and sprayed into the pyrolysis section of the reactor via the feeder. Then, it is quickly heated by the high-temperature generated from semi-charing in the lower section and quickly pyrolyzed at 600-950°C and 0.3MPa, resulting in gaseous and liquid products and solid semi-char. In the pyrolysis section, the gaseous and solid products move upward simultaneously. The solid semi-char is separated from the gases via the high-temperature cyclone, part of which returns to the gasification section of the reactor for a gasification reaction at 1500-1650°C and 0.3MPa with oxygen and water vapor while providing heat sources for the pyrolytic reaction in the upper section. The remaining semi-char is recovered by the heat exchanger with its waste heat and becomes the solid semi-char product. The high-temperature gases separated from the high-temperature cyclone contains the gaseous and liquid products. With waste heat recovered by an indirect heat exchanger, the gases become gaseous products upon debenzolization, desulfurization, deamination and other purification treatment. The indirect heat exchanger adopts the heat transfer oil as the heat transfer medium, using the waste heat recovered from coal gas to generate steam. The char tar generated from the coal gas cooling process and the benzenes generated from the purification process are the main liquid products.

6 Clean Gasification Process of Lignite

6.1 General

Coal gasification technology was industrialized in 1950s, however it had been suspended for a period due to great development of natural gas and petroleum. Since international energy crisis appeared in early 1970s and because of worries of insufficient supply of petroleum and natural gas, the developed economies renewedly put highlight on the coal gasification technology as a substitute energy and expedite the study of new coal gasification technology. Numerous foreign companies have conducted huge amounts of research and development for the technology of coal gasification combined cycle power generation in recent years so as to enhance thermal efficiency of coal-fired power plants and reduce environmental pollution to boost rapid development of coal gasification technology. At present, the new coal gasification process, which is characterized by wide coal type adaptability, high gasification pressure, high production capacity, high gasification efficiency and little pollution, has been developed in success. The most representative technologies are Pulverized coal Gasification Process of SHELL, Netherland, Coal Slurry Gasification Process of former TEACO, America, DESTEC Gasification Process of DYNEGY, America, PRENFLO Process (pressurization K-T process) of KRUPP UHDE, Germany, LURGI Process, Germany and GSP Pulverized coal Pressurization Gasification Process of Future Energy Company, Germany. Among them DESTEC Gasification Process is similar to that of TEXACO Process; Process indexes of PRENFLO Process are good, however there is only one demonstration plant at moment with a little operation experience. Although there are many industrial

plants and rich operation experience of LURGI process, treatment of contaminated water is complicated due to high CH₄ content in coal gas, low content of efficient component (CO+H₂) and high contents of tar and phenol in coal gas. GSP process is a kind of fluid-bed pressurization gasification process, which investment is less than that of SHELL coal gasification, cold coal gas efficiency is higher than that of TEXACO coal gasification. However, there isn't sufficient long-term continuous running experience of this process taking coal as raw material. In recent years, some clean coal gasification processes and critical equipment with Chinese own intellectual property rights have been successfully developed in China, such as Four Opposed-Nozzles Coal-Water Slurry Gasification Process developed by East-China University of Science and Technology, Yankuang Lunan Fertilizer Complex and Tiancheng Engineering Company; Multiple Slurry Pressurization Gasification Process developed by Northwest Chemical Research Institute; TPRI gasification process developed by Xi'an Thermal Engineering Institute Co., Ltd., and Hangtian process and Wuhuan process as well. The clean coal gasification is critical process for comprehensive utilization of low rank lignite. Correct selection of coal gasification process is very important, for different coal gasification processes are adaptable for different coals. Type of gasifier shall be chosen by coal variety. That needs to adjust measures to local conditions. Once a coal gasification process is selected, it is very difficult to be changed. Coal gasification process is essential for long-term running of whole system plant, safe and stable operation and product cost, and enterprise benefit as well. Coal gasification process shall be seriously and prudently selected, which shall follow principles of advance, reliability, adaptability, safety and friendly to environment, and clear intellectual property right.

6.2 Main Foreign Clean Coal Gasification Process

6.2.1 GE Coal-Slurry Pressure Gasification Process

GE gasification process, formerly known as TEXACO coal-slurry gasification process, is developed in 1978 and belongs to fluidized-bed pressure gasification process, which consists of raw material coal transportation, coal slurry preparation and gasification sections etc., in which pumping coal slurry to gasifier system is easier and safer than that of feeding dry pulverized coal to gasifier. No superheated steam supply outside and feeding N₂ or CO₂ are required for the gasification system. Production capacity of unit gasifier is large, currently the largest capacity of gasifier put into operation in China is 2000t/d. It can be widely adapted to raw coals, that means gas coal, soft coal, subsidiary soft coal, anthracite, high-sulfur coal and poor-quality coal with low ash fusion point, petrol char etc. can be taken as raw materials for coal slurry gasification. However, there are some certain requirements for ash fusion point and ash content of coal, especially the ash fusion point shall be lower than 1300C.

The content of effective components (CO+H₂) takes up 80vol%, thermal

efficiency reaches around 85%, carbon conversion rate is 96%. Cold coal efficiency is 76% and oxygen consumption is 410. Structure of gasifier with refractory brick lining is simple, which characteristics are convenient fabrication and low cost. Dust removal of coal gas is easy for coal. No high-temperature and high pressure fly-ash filter etc. is required. Quench flow is adopted with single burner and standby gasifier^[20].

6.2.2 E-gas Coal-Water-Slurry Gasification Process

E-gas gasification process is developed from TEXACO coal slurry gasification, which was developed in accordance with two-stage gasification concept by Dow Chemical Company in 1979. An demonstration plant of 550t/d air gasification unit and 1200t/d oxygen unit was built in 1983. In 1985, Dow Chemical built a 1475t/d dry coal gasifier for 160 MW IGCC unit in Louisiana, which is changed as Destec gasification afterword. This process belongs to gas-flow pressurization gasification process.

It has some requirements for raw material and is suitable for petrol char etc. with low ash, its gasification temperature is 1300-1450°C. The process belongs to gas-flow pressurization gasification process. The content of effective components (CO+H₂) takes up 68.47%, and CH₄ reaches 1.72%.

Differences with GE gasifier are as follows: two-stage reaction for classification of gasification is adopted, level installation is for the first stage, partial oxidation reaction is made at 1300-1450°C which is higher than coal ash fusion point. Coal slurry and oxygen are fed simultaneously into the first stage, melted slag is discharged from the bottom after quench pressure release. The coal gas passes through the second stage at central and upper part, which is a gas flow reactor and vertically installed in central of the first stage. 10-20% slurry is injected at inlet, latent heat from the first stage is utilized for gasification of the second coal slurry; Syngas flows upwards, fired boiler flow decreases investment. As the two-stage gasification increases heat value of coal gas, cold coal efficiency is higher than that of TEXACO. Meanwhile, quench coal gas compressor is not required; Semi-char after coal gas separation returns to the first stage, hence carbon conversion rate is increased.

6.2.3 Shell Dry Pulverized Coal Pressure Gasification Process

Shell gasification process had been studied since 1972 and developed in 1993 in Netherland, which is applied in fired gas power generation with coal input of 2000t/d. This process belongs to gas-flow pressure process and consists of sections of raw material coal transportation, pulverized coal preparation, gasification, dust removal and waste heat recovery etc., among which large N₂ or CO₂ unit production capacity is required for dry pulverized coal pressurization and transportation. Currently the largest capacity of unit gasifier put into operation is 2800t/d in China.

It has a wide adaptability to coals, ranging from gas coal, soft coal, subsidiary soft coal, anthracite, high-sulfur coal and poor-quality coal with low ash fusion point, petrol char etc. as raw materials for gasification. Raw coal with 30# ash content can also be gasified, ash melting point can reach 1400-1500°C.

Efficient gas ($\text{CO}+\text{H}_2$) is up to about 90%. Heat efficiency is around 90%. Carbon conversion rate is as high as 98%. Cold coal efficiency is 83%, coal consumption ratio is 0.69 and oxygen consumption ratio is 330. Structure of the gasifier is of water cooling shell without refractory brick lining and standby gasifier.

6.2.4 GSP Dry Pulverized Coal Pressure Gasification Process

GSP process was developed by German Fuel Institute of former German Democratic Republic in 1975. A set of commercialized unit of 130MW was established in Laubag Power Plant in SchwarZePumpe in 1984 for methanol production and IGCC, which coal input is 720/d and belongs to gas fluid bed pressure gasification process. Later GSP process was purchased by SIEMENS and becomes known as SIEMENS Fuel Gasification Technology Company. The process consists of sections of raw material coal transportation, pulverized coal preparation, gasification, dust removal and waste heat recovery etc., in which dry pulverized coal pressurization transportation needs N_2 or CO_2 and goes into integrated burn-nozzle form top of the gasifier.

It has a wide adaptability to coals, ranging from petrol char, gas coal, soft coal, subsidiary soft coal, anthracite, char, soft and hard lignite, and municipal garbage etc. as raw material of gasification. Gasification temperature is 1400°C with quench flow. Efficient gas ($\text{CO}+\text{H}_2$) is up to about 90%. Methane content is low. Structure of the gasifier is of water cooling shell without refractory brick lining and maintenance is simple.

Difference with Shell gasifier is as follows: GSP process has one integrated nozzle, syngas flows downward, water injection quench for temperature decrease, water cooling shell is water input and water output, hot water is exchanged with boiler feed water into low pressure steam in the waste heat boiler. And Shell has saturated water input, after mixture water-steam mixture enters into middle pressure stream drum to separate byproduct MP steam which is 1.0-1.4 MPa higher than that of the gasifier.

6.2.Choren Coal Gasification (CCG) Process

CCG gasification process is originated from a subsidiary fuel research institute of Blackwater Pump Industries Group in former German Democratic Republic. A pilot plant with capacity of 3MW was established in Fredbeck in Germany in 1979. Based on this pilot plant, a industrial gasifier with 720t/d coal input for lignite gasification was built for producing town gas, which process belongs to gas flow bed pressure gasification process. A contract with this process of two sets of gasifier with 1500t/d coal input was signed for 500,000t/a ammonia in Yankuang, Kaiyang, Guizhou in 2007, in which the gasifier was fabricated by Dalian Jinzhong Manufacturer and will be put into operation in 2011.

It has a wide adaptability to coals, ranging from petrol char, soft coal, anthracite, char and lignite etc. as raw material of gasification. Gasification temperature is 1400-1700°C. Design of efficient gas ($\text{CO}+\text{H}_2$) is up to about 93%. Carbon conversion rate is 99%, coal consumption is 0.69, oxygen consumption is 330. Structure of the gasifier is of water cooling shell with quench flow and LP steam as byproduct.

Difference with Shell gasifier is as follows: CCG process has total quench flow, water cooling shell adopts of water input and water output, hot water is exchanged with boiler feed water into low pressure steam in the waste heat boiler. There are not expensive countercurrent waste heat boiler, ceramic filter and recycle gas compressor in this process, so investment is low. Two sets gasifier are in operation. Multiple nozzles on the top eject downward and same-direction arrangement can overcome mutual abrasion caused by opposite arrangement so as to ensure uniform distribution of pulverized coal in the reaction room.

6.2.6 U-gas Dry Pulverized Coal Gasification Process

U-gas process is developed by American Coal Gasification Technology Research Institute, which 25t/d pilot plant was established in Chicago, USA. French Nancy University made trial in 1950s to demonstrate feasibility of this process. Eight (8) sets of U-gas gasifier unit were built by Shanghai Charing Complex in 1995. This process belongs to ash-melting fluidized bed pulverized coal gasification process. Operation is made at temperature of ash-melting point, by which ash can be congregated into ball and ash lump can be removed selectively.

There are certain requirements for raw material coal. As soft coal is adopted, particle size shall be 0-6.35mm, gasification temperature shall be 1000-1100°C. This process belongs to fluidized bed pressure gasification process, in which efficient gas ($\text{CO}+\text{H}_2$) is up to about 37.1%, CH_4 is 3.4%, carbon conversion rate is 96.07%, air consumption is 2.8-3.3kg, steam consumption is 0.4-0.6kg, carbon content in slag is 5-10% and heat value of coal gas is 5860KJ/m³.

Process pulverized coal is fluidized in the gasifier by gasification agent oxygen (or abundant oxygen), air and steam entered with high velocity from the bottom, in which pulverized coal particles are boiled in the bed, and the coal drying, carbonization, burning and pyrogenation are taken place at temperature of 1000°C, then the steam is decomposed and deoxidization reaction of carbon is taken place and finally gasification is realized. Ash congregate congregation separation is installed at lower part of fluidized bed in U-gas gasifier, in which part high temperature zone is formed and ash & slag are mutually felted into balls, then separation of ash ball and coal particle is realized by weight difference so as to decrease carbon content and increase utilization rate of carbon.

6.2.7 SES Fluid-Bed Gasification Process

SES lignite gasification process is invested and developed by American Comprehensive Energy System Co., Ltd., with whom a joint-venture plant was built together with Henan Yima Coal Industry Group Company. This process is

originated from U-gas gasification process of American Fuel Gas Technology Research Institute. The plant is built and put into operation in Zhaozhuang, Shandong, China.

Lignite is adopted for gasification, particle size ranges from 0-6.35mm, gasification temperature shall be 1000-1100°C. This process belongs to fluidized bed gasification process, in which efficient gas ($\text{CO}+\text{H}_2$) is up to about 37.1%, CH_4 is 3.4%, carbon conversion rate is 96%, cold coal efficiency is 83% and localization rate reaches 95%.

Lignite is fluidized in the gasifier by abundant oxygen and steam entered with high velocity from the bottom, in which coal gasification reaction is made at high temperature of 1000°C. There is cyclone recycle system in the unit with multiple-grade cyclone and multiple-class gasification process to increase carbon conversion rate. There are also refractory material structure scheme, bag dust filtration operation system, bottom discharge cooling system, de-dusting with dry method by using syngas, slag discharge with dry method to avoid producing a great deal of waste water. It possesses advantage of producing town gas or natural gas^[21].

6.2.8 Lurgi Fixed-Bed Pressure/Normal atmosphere Gasification Process

Lurgi fixed-bed pulverized coal pressure (atmosphere) gasification process was imported from Lurgi Company, Germany in 1978, which was firstly applied in 1000t/a ammonia unit in Shanxi Tianji Group and ammonia unit in Yunnan. Afterward, this process is also applied in Henan Yima Gas Complex and Harbin Gasification Plant for town gas production. Lignite, non-viscid coal or poor-viscid coal are adapted for this process. It is required that the coal shall be featured excellent heat stability and reactivity, high ash fusion point and mechanical strength.

After crushing and screening, about 64% of small coal particles are intermittently fed into the gasifier and around 36% of the pulverized coal is taken as boiler fuel. The raw material coal is retained in the gasifier for about 1 hour. Steam and oxygen are fed from the gasifier bottom, passes through grates and is uniformly distributed at the fuel layer; The slag is discharged constantly through the grates to seal hopper discharge system and discharged intermittently. Excessive steam shall be added during operation so as to avoid slag blockage on the grates. Gas out of the top of the gasifier at temperature of 300~600°C enters into quencher, in which the recycle coal gas is quenched and then goes into waste heat boiler and is further cooled down to 180°C.

Design particle size of coal is 8-50mm and gasification temperature is 900-1050°C. The fixed bed is continuously gasified, coarse gas $\text{CO}+\text{H}_2$ is 60-45%, H_2/CO is 2.17, CH_4 is 9%, coarse gas quantity of unit gasifier is as follows: Mark-1 800m³/h, Mark-2 14000m³/h, Mark-3 32000m³/h, Mark-4 35000-55000m³/h and Mark-5 75000m³/h.

6.2.9 BGL Crushed Coal Pressure Gasification Process

BGL process is owned by Lurgi, Germany and British Gas Company, which is improved on the basis of Lurgi gasifier for fuel gas production. Lignite, non-viscid coal or poor-viscid coal are adapted for this process. It is required that the coal shall be molded or pulverized coal from 6-50mm as raw material.

This process is a combination of high temperature fusion slag and Lurgi gasification. Gasification is made at temperature over 1300°C, 99.5% of carbon is gasified. As oxygen consumption is equivalent, steam and oxygen ratio of gasification agent is 1.1 - 1.2, steam consumption is greatly decreased and 90-95% steam is decomposed. The temperature of combustion area shall be controlled by the regulation of steam and oxygen supplied to combustion area in operation to realize liquid slag removal. Pulverized coal or molded coal enters into the gasifier from the top, is heated, dried, distilled and gasified with melting slag in the gasifier, and then is discharged intermittently in form of liquid. Gas out of the top of gasification at temperature of 300~600°C enters into quencher, where the recycle coal gas is quenched by water and then sent into the waste heat boiler.

The gasification temperature is 1100 - 1300°C. Coarse gas CO+H₂ is 80-85%, H₂/CO is 0.5-58, CH₄ is 5-7%, oxygen consumption is 230-330m³/t, coal and steam consumption is 0.22-0.32t/t, oil production rate is 2.14%, coarse gas production of unit gasifier is 58000-68000Nm³/h, waster water is 11t/h and coarse gas production rate is 1600-2000Nm³/t coal.

6.3 Main Domestic Clean Gasification Process

6.3.1 Four Nozzles Coal-Water Slurry Gasification Process

The four-nozzle coal water slurry pressure gasification process is developed by EAST CHINA UNIVERSITY OF SCIENCE AND TECHNOLOGY, YANKUANG LUNAN CHEMICAL FERTILIZER PLANT and CHINA TIANCHEN ENGINEERING CORPORATION in cooperation. This new type of coal slurry gasifier and critical parts were developed in 1996. The process package and basic engineering design were completed in 2000. This process belongs to fluidized-bed pressure gasification process. A plant with capacity of 750t/d 6.5MPa was put into operation in 2005 in Shandong Hualu Hengsheng Complex, Currently the largest gasification capacity of this gasifier in operation is 2000t/d.

The efficient gas (CO+H₂) is up to 84.9%, heat efficiency is around 85%, carbon conversion rate is 98.8%, cold coal efficiency is 76%, oxygen consumption is 309 and coal consumption is 535. Structure of the gasifier is of refractory brick lining with low cost. Quench flow is adopted. Dust removal of coal gas is simple. There are four (multiple)-nozzle and standby.

Its differences with GE gasifier are as follows: multiple-nozzle opposite type of gas flow fluidized bed reactor possesses high load of treatment so as to avoid short circuit. Opposite type of multiple-nozzle makes the gasification area structure multiple and model, in which there are jet flow area, impact area, impact flow area, return flow area, reflux flow area and tube flow area. Effect of

pulverization with impact mixture is good, horizontal-push-flow gasification is carried out completely. The follow-up critical parts of the gasification process have also been greatly improved in combination of injection bed and bubble bed, classification of purification, direct heat exchanging for slag-water treatment, prefiling long-life and high-efficient nozzle etc.

6.3.2 Multiple Slurry Pressurization Gasification Process

Multiple slurry pressurization gasification process is developed by Northwest Chemical Research Institute, which pilot plant was studied and established in 1967 and industrialized application was realized in 1999. This process belongs to gas fluidized bed pressurization gasification process. Currently the largest gasification capacity of this gasifier in operation is 2000t/d.

Slurry concentration is 60-68.5%, the efficient gas ($\text{CO}+\text{H}_2$) is up to 83.4%, heat efficiency is around 85%, carbon conversion rate is 98%, cold coal efficiency is 73%, oxygen consumption is 362 and coal consumption is 575. Structure of the gasifier is of refractory brick lining with low cost. Quench flow is adopted. There is standby gasifier.

Its differences with GE gasifier are as follows: It has a wide adaptability to raw materials, ranging from coal liquefied residue, biological substances, paper pulp waste liquid and organic waste water etc. Slag either in form of liquid or of solid can be removed without corrosion to the refractory materials. Air, rich oxygen or pure oxygen can be taken as gasification agent. There are two kinds of gasifier which are hot shell gasifier and cold shell gasifier for selection. The quench chamber consists of descending tube, ascending tube and overflow quench structure. Nozzle adopts of multicenter configuration, pulverization effect is matched with the gasifier structure. The follow-up critical parts of the gasification process have also been greatly improved.

6.3.3 Non-slag -- slag Gradual Gasification Process

Non-slag -- slag gradual gasification process is developed by Beijing Dalike Company and Heat Energy Research Institute of Tsinghua University. This patent research and heat state test were started in 2001. The process package and basic engineering design were completed in 2006. This process belongs to gas flow bed pressure gasification process. A methanol plant with capacity of 200,000t/a was put into operation in 2005 in Fengxi, Shanxi.

The efficient gas ($\text{CO}+\text{H}_2$) is up to 83.06%, heat efficiency is around 85%, carbon conversion rate is 98.2%, cold coal efficiency is 76%, oxygen consumption is 367.6 and coal consumption is 553.5. Structure of the gasifier is of refractory brick lining with low cost. Quench flow is adopted. There is a standby gasifier.

Its differences with GE gasifier are as follows: Oxygen is fed by classification, by which temperature nearby the main burner is decreased and the burner lifetime is prolonged. The main burner can be free from restriction of equivalent weight ratio of carbon and oxygen required for partial oxidization reaction. Various proportion

of gases with oxygen content can be taken as pre-mixed gas for the main burner. Temperature in the slag removal area is lower than 100°C of the feeding coal ash melting point, that means the ash melting point of coal can be increased by 100°C.

6.3.4 Two-Stage Dry Pulverized coal Pressurization Gasification Process

TPRI gasification process was developed by Xi'an Thermal Engineering Institute in 1990. This process belongs to gas fluidized bed pressurization gasification process. This process pilot plant with capacity of 36t/d was established in 2006. There are waste heat boiler flow and quench flow, the former is applied in 250MW IGCC demonstration power plant in Tianjin Huaneng Company.

It has a wide adaptability to coals, ranging from petrol char, gas coal, soft coal, anthracite and char etc. as raw materials for gasification. The gasification temperature ranges from 1400°C to 1500°C with the waste boiler flow. The process consists of sections of raw material coal transportation, pulverized coal preparation, gasification, dust removal and waste heat recovery etc., among which N₂ or CO₂ is required for dry pulverized coal pressurization transportation. Currently the largest capacity of this gasifier is 2000t/d in China. This process belongs to fluidized bed pressurization gasification process. Efficient gas (CO+H₂) is up to about 91%. Heat efficiency is around 95%. Carbon conversion rate is as high as 98%. Cold coal efficiency is 84%, oxygen consumption is 330. Structure of the gasifier is of water cooling shell with refractory brick lining and simple maintenance etc.

Its differences with Shell gasifier are as follows: there are two-chambers and two-section reaction for gasification in classification. Multiple nozzles are in the two sections, upper section of injection of pulverized coal and steam, lower section of injection of pulverized coal, steam and oxygen. Syngas goes upwards through the waste boiler flow, saturated water enters, after heat absorption, water-steam mixture goes into MP steam drum for separation of MP steam which pressure is higher than that of the gasifier by 1.0-1.4 MPa without cold coal gas for recycle cooling. The waste heat boiler type of gasification unit is suitable for IGCC, which demonstration plant of two-section dry pulverized coal pressurization gasifier (waste heat boiler flow) with coal input of 2000t/d has been applied in "Green Coal Electricity" project of Huaneng Group. Another demonstration plant of two-section of dry pulverized coal pressurization gasifier (quench flow) with coal input of 1000t/d is applied in 300,000t/a methanol project of Inner Mongolia Shilin Chemical Co., Ltd.

6.3.5 HT-L Dry Pulverized coal Pressure Gasification Process (Hangtian Gasifier)

HT-LZ process was developed by The First Research Institute of China Aerospace Science and Technology Group, which demonstration project of 150,000t/a methanol plant was established in 2006 in Linquan, Anhui. The first gasification plant with the waste heat boiler process was put into production in Aug. 2008.

It has a wide adaptability to coals, ranging from petrol char, gas coal, soft coal, anthracite and char etc. as raw materials for gasification. The gasification temperature ranges from 1400°C to 1500°C. The process consists of sections of raw material coal transportation, pulverized coal preparation, gasification, dust removal and waste heat recovery etc., among which N₂ or CO₂ is required for dry pulverized coal pressurization transportation. Currently the largest capacity of this gasifier is 2000t/d in China. This process belongs to gas flow bed pressurization gasification process.

Efficient gas (CO+H₂) is up to about 92%. Heat efficiency is around 95%. Carbon conversion rate is as high as 99%. Cold coal efficiency is 83%, oxygen consumption is 360. Structure of the gasifier is of water cooling shell without refractory brick lining and with simple maintenance etc. Multiple burners, syngas goes upwards through the waste boiler flow, saturated water enters, after heat absorption, water-steam mixture goes into MP steam drum for separation of MP steam which pressure is higher than that of the gasifier by 1.0-1.4 MPa.

6.3.6 Four Opposed-Nozzles Dry Pulverized Coal Gasification Process

The four opposite-nozzle coal water slurry pressure gasification process is jointly developed by East China University of Science and Technology, Yankuang Lunan Chemical Fertilizer Plant (State Engineering Research Center of Coal Water Slurry Gasification and Coal Chemical) and China Tianchen Engineering Corporation in cooperation, which is a coal gasification process with his own Intellectual Property Right. A 1000t/a demonstration unit of pulverized coal gas flow with high ash melting point and pilot plant base of water cooling shell gas flow bed with quench flow were established in 2004. The first plant of 1200t/d was built in Guizhou Kaiyang Chemical Company of Yankuang Group.

It has a wide adaptability to coals, ranging from petrol char, soft coal, anthracite and char etc. as raw materials for gasification. The gasification temperature is 1500°C. The process consists of sections of raw material coal transportation, pulverized coal preparation, gasification, dust removal and waste heat recovery etc., among which N₂ or CO₂ is required for dry pulverized coal pressurization transportation. This process belongs to gas flow bed pressurization gasification process.

The efficient gas (CO+H₂) is up to 89%, heat efficiency is around 95%, carbon conversion rate is 98%, cold coal efficiency is 79%, oxygen consumption is 350. Structure of the gasifier is of opposite water cooling shell without refractory brick lining.

6.3.7 Wuhuan Dry Pulverized Coal Gasification Process

Wuhuan Dry Pulverized Coal Gasification Process was developed by Wuhuan Engineering Co., Ltd. Its demonstration 500,000 t/a methanol plant was contracted with Yongmei Longyu Company in 2010, in which there are two sets of gasifier with daily coal input of 1000t/d with quench flow. This process belongs to gas flow bed pressurization gasification.

The design efficient gas ($\text{CO}+\text{H}_2$) is up to 90%, heat efficiency is around 95%, carbon conversion rate is 98%, cold coal efficiency is 83%, oxygen consumption is 350. Structure of the gasifier is of water cooling shell. As rising to middle section of the gasifier, coarse syngas of $1400\sim 1500^\circ\text{C}$ quenched by mixed mist liquid of water/steam to about 800°C , then is sent by tube into water-bath quencher for dust removal quench to $180\sim 260^\circ\text{C}$, and is sent out of the gasifier.

Its differences with Shell gasifier are as follows: Syngas cooling scrubber is set at outlet of gas duct instead of waste heat boiler and HT and HP fly-ash filter. HT syngas is quenched through water/steam, its temperature out of the gasifier is about 700°C . The syngas and melted slag run) in the opposite direction, in which slag water and ash water are treated simple and the system operation is stable. There are self-washing radial spraying trays, table-flap high-efficient separator and on-line washing unit installed in the syngas cooling scrubber so as to avoid blockage of the sieve pores of the trays, increase the gas scrubbing effect and ensure long-term continuous operation.

6.3.8 Crushed Coal Moving-Bed Pressurization Gasification Process

Crushed coal moving-bed pressurization gasification process was developed and improved by Saining Company, which is based on imported Lurgi's process and combined with innovation and improvement from Shanxi Tianji ammonia plant. This process is applied for town gas production in 2nd phase project of Henan Yima Coal Gasification and Luan Synthesis Oil Plant. This process is especially suitable for lignite gasification to methane gas preparation.

After crushing and screening of lignite, about 70-80% of the small granule coal is intermittently fed into gasifier and about 20-30% of the pulverized coal is taken as boiler fuel. Steam and oxygen are fed from the gasifier bottom through the grates and uniformly distributed into combustion layer. Slag is constantly and intermittently discharged through the grates in form of solid. To avoid blockage of the grates, excess steam is added during operation. Currently there are two types of gasifier: $\varnothing 2800$ and $\varnothing 3500$.

Particle size of coal is 6.36-50mm and gasification temperature is $900\sim 1050^\circ\text{C}$. During fixed-bed pressurization continuous gasification, $\text{CO}+\text{H}_2$ is 49-52%, CH_4 is 12-14% in coarse coal gas. Oxygen consumption is $209\text{m}^3/\text{t}$, steam consumption is $0.859\text{t}/\text{t}$ coal, oil production rate is 2.34%, coarse coal gas of unit gasifier is $40000\text{m}^3/\text{h}$, waste water is $37\text{t}/\text{h}$ and coarse coal gas rate is $962\text{m}^3/\text{t}$ coal.

7 Intensive Processing of Coal Tar

7.1 General

Different from the high-temperature char tar, the deep processing of tar products obtained by low-temperature pyrolysis in lignite is much higher in heavy

components. Coal tar can be processed mainly in two ways. One is for deeply-processed products derived from fine chemicals, dye and medicines, etc., based on the processed products from coal tar; the other is for fuel oil that is refined by taking coal tar as raw material. Developed economies have now taken research & study on components with a lower content as the key for coal tar separation & utilization instead of components with a higher content. Thus they have obtained high value-added components required for fine chemical production and developed a series of advanced new coal tar processing technologies.

China is a economy abundant in coal resources, how to utilize lignite resources to product auto-fuels is of great strategic significance. As the oil price rises, the domestic gasoline and diesel prices also keep increasing. The annual output of coal tar totals millions of tons, but traditional processing methods is relatively low in coal tar utilization coefficient. The hydrofining and hydrocracking approaches that adopt coal tar are used to produce naphtha and diesel products in line with environmental-protection requirements. The approaches can not only improve the coal tar utilization coefficient and ease the tension of auto-fuel supply, but also break a new path for rationally utilizing coal resources.

7.2 Deep Processing Technology for Coal Tar

Many process routes are available for the deep processing of coal tar, which are divided separately into the distillation (combining multiple extraction processes) process, the fixed-bed hydrofining process, the integrated delayed charring-hydrocracking process, the fixed-bed hydrocracking process, the light auto-fuel process, the homogeneous-phase suspension bed hydrocracking process and the heterogeneous suspension bed hydrocracking process.

7.2.1 Coal Tar Distillation Process

Coal tar varies in the property of each component, but with many components of similar properties. The process firstly needs to obtain all the distillates by distillation, making the monocomponent products such as phenol, naphthene and anthracene, etc. that are to be extracted get concentrated into the corresponding distillates. It further uses physical and chemical separation approaches: distillates obtained under 170°C are light oil; distillates obtained at 170~210°C are phenol oil; distillates obtained at 210~230°C are naphthalene oil; distillates obtained at 230~300°C are wash oil; distillates obtained at 280~360°C are anthracene oil I; the initial boiling point for anthracene oil II is 310°C. At present, the deep-processing of coal tar both at home and abroad mainly adopts the distillation process, and many useful chemicals can be extracted by the deep-processing. See Figure 7-1 for the distillation process.

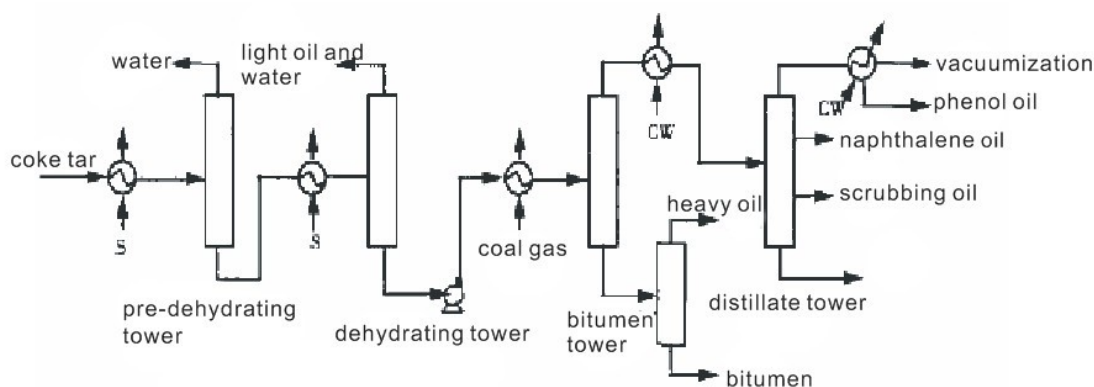


Figure 7-1 Coal Tar Distillation Process Flow Diagram

7.2.2 Fixed-bed Hydrofining Process

The process firstly fractions coal tar, providing hydrotreatment (excluding cracking) to the light distillate of coal tar that is under 350°C and blending the coal pitch component that is over 350°C into ordinary road asphalt. Units adopting the process have been in operation in China, for instance, the 10,000 t/a unit in Kaihua, Yunan, the 40,000 t/a unit of Harbin Gas Works. The advantages of this char tar hydrogenation process include simple in process, low in reaction pressure, less in investment, sound in operability, long in cycle of continuous operation and low in hydrogen consumption (3%); as for the disadvantages, the raw materials for hydrogenation are not pre-treated (without removing the solid impurity), the catalyst bed can be blocked easily (with an operation cycle of 10-12 months), it is demanding in terms of the char tar stability and the scope of raw materials. The fixed-bed hydrofining process has been applied to the oil refining industry maturely.

7.2.3 Deferring Charing Hydrogenation Cracking Process

It processes the distillates heavy in coal tar by delayed charing, converts macromolecular asphaltene, colloid and condensed-nuclei aromatics, etc. that are easily charred into char, thus improving the quality of coal tar. Then it processes the lightly-distilled char tar and the finished oil from delayed charing by means of hydrofining and cracking, to produce naphtha and diesel oil, etc. The products are better in quality and higher in raw material utilization coefficient. The technology organically combines the delayed charing and hydrocracking processes that are applied to oil refining. It better eliminates the adverse impact as exerted by the solid particles and macromolecular colloid asphalt that are contained in the raw oil on the fixed-bed hydrogenation catalyst activity and the production cycle. In the meantime, it can be better applied to the raw oil, capable of processing intermediate and high temperature coal tar, with a good product quality. The process is relatively complicated and the investment increases due to the adopting of delayed charing. In addition, 10%~20% of the coal pyrolyzed oil is converted into char and the yield of the liquid products drops by about 20%. It is known that China PetroChemical East China Design Institute is now designing a 500,000-ton semi-char tar hydrogenation unit for Shangxi Yanchang Petroleum, based on the delayed charing + hydrofining process.

7.2.4 Fixed-bed Hydrogenation Cracking Process

By distillation or extraction or delayed charring, the process removes plenty of colloid asphalt in the coal tar to improve the feeding quality of the hydrocracking unit. It then converts the feedings almost completely into gasoline (or as naphtha) and diesel oil products by means of fixed-bed hydrofining + fixed-bed hydrocracking. The reaction and separation can adopt a cold high-pressure separation process or a hot high-pressure separation process. The product fractionation can adopt a combination of debutanizing tower + atmospheric tower, and also can adopt a combination of stripping tower + atmospheric tower. The technology use the hydrocracking process applied to oil refining for reference, which generally pre-treats the raw materials before hydrocracking. The advantages are that the heavy oil in most of the coal tar is converted into light oil distillate, the oil product yield and the utilization coefficient of coal tar resources are improved, the cetane number in diesel oil products are increased as much as possible (basically over 40%), both the quality and the liquid yield are sound. The disadvantage is that it requires for a corresponding process to remove the asphalt in raw materials in order to meet the feeding quality of hydrocracking, thus decreasing the total light oil product yield of coal tar. Besides, the fixed-bed may be influenced by the property of raw materials, the charring and increase in pressure drop for the catalyst bed may shorten the production cycle, temperature runaway may exist in the cracking bed. It is known that SHCCIG (Shanghai) Spang Chemical Technology Co., Ltd. use the "char tar pre-treatment + hydrofining + hydrocracking + hydro-upgrading" process in most cases.

7.2.5 Process Producing Light Auto-fuel from Coal Tar

The process is developed by Institute of Engineering Thermophysics, Chinese Academy of Sciences. Upon desulfurization and denitrogenation refining, it produces light fuel oil after such processes as extraction, degradation, etherification, polymerization, blending and stabilization. The process is complicated, requiring a lot of light oils such as light hydrocarbon and petroleum, etc, with the mixed refining ratio of coal tar up to 40%. Apart from the above disadvantage, it is more importantly to generate a lot of acid and basic slag devastating the environment during the production process.

7.2.6 Homogeneous Catalysis Suspension Bed Hydrocracking Process

It uses the homogeneous-phase hydrocracking catalyst, with a conversion per pass up to 90% or above. Raw oil, hydrogen and catalysts enter the suspension bed hydrocracking reactor from bottom to top. Thermal cracking and hydrogenation occurs in the reactor, with the thermal cracking reaction as the main one. Due to the high hydrogen partial pressure and catalysts, the process can prevent the oils from vast charring. Due to a higher conversion per pass, it generally selects a process with the raw oil passes at a time. While producing gasoline and diesel oil, it also produces some heavy oil with small granular char. Such a heavy oil yield is generally no more than 10%wt. In addition, as the desulfurization and denitrification percentage is lower for the suspension bed hydrocracking process, the cracked products are still high in sulfur and nitrogen. Therefore, it requires providing a fixed-bed hydrofining process to produce

gasoline and diesel oils that are in line with the environmental protection requirement. The combination of suspension bed hydrocracking + fixed-bed hydrofining processes has become a representative feature of the suspension bed hydrocracking process. In China, SINOPEC Fushun Research Institute of Petroleum and Petrochemicals and China University of Petroleum have studied a lot on homogeneous-phase suspension bed hydrogenation. Besides, a 50,000 t/a demonstrative unit has been constructed in No.3 Fushun Petrochemical Company Refinery of CNPC.

7.2.7 Non-homogeneous-phase Suspension Bed Hydrocracking Process

The BRICC coal tar processing technology is a self-developed proprietary technology of Beijing Research Institute of Coal Chemistry, CCRI, by adopting the design concepts of the direct hydrogenation liquefaction process and the petroleum residual oil hydrogenation process for reference. It is a coal tar suspension bed (or bubbling fluid-bed or slurry bed) hydrogenation process based on heterogeneous catalysts and supporting catalyst technology.

KBR's suspension bed hydrocracking technology originates from the pulverized coal hydrogenation refinery in Germany. Such a technology has been applied to many production units in Germany, with a process concept similar to that of BRICC. It selects fine catalysts (additives) of low costs and uses the heterogeneous-phase suspension bed hydrocracking process to convert over 93% of the coal tar into the light clean products, resulting in high liquid product yield, good product quality and stable operation. Compared to the homogeneous-phase suspension bed hydrocracking process, the catalysts adopted in such a process are moderate in prices; besides, it provides the charring center for solid fine catalysts to prevent the chard substances from sticking to the reactor wall and heat exchange tubes, showing an obvious technical advantage.

8 Lignite Comprehensive Utilization Polygeneration Process

As for lignite, the intermediate products generated upon drying, retorting and briquetting can adopt the advanced gasification technologies based on the entrained-bed (pulverized coal pressurized gasification) and the crushed coal moving-bed (fixed-bed pressurized gasification), etc. for large-scale pressurized gasification. The process is environment-friendly, quite applicable to raw materials, and of high efficiency. The crude syngas $\text{CO}+\text{H}_2+\text{CH}_4$ as obtained after coal gasification, can be used as the raw materials for synthesis ammonia, methanol, methane gas, oils and IGCC.

8.1 General

The low-rank coal gasification comprehensive utilization technology takes low-rank coal as raw materials and is a low-rank coal comprehensive utilization system incorporating such unit processes as low-rank coal pre-treatment, gasification, chemical synthesis, power generation, heat supply and waste recycling, etc. The core process is the drying, retorting, briquetting, gasification and combustion of low-rank coals. As for the process, by pre-treating and upgrading the low-rank coals on a large scale, it sends the upgraded coal in the combustion furnace or gasifier for combustion and gasification; the gasified crude syngas goes into the synthesis reactor via the gas purification unit to generate clean fuels such as synthesis ammonia, methanol, dimethyl ether and synthetic oil or other high value-added chemicals; the reaction tail gas is directly vented for integrated fuel gas-steam cycle power generation or for integrated heating, cooling and power generation. See Figure 8-1.

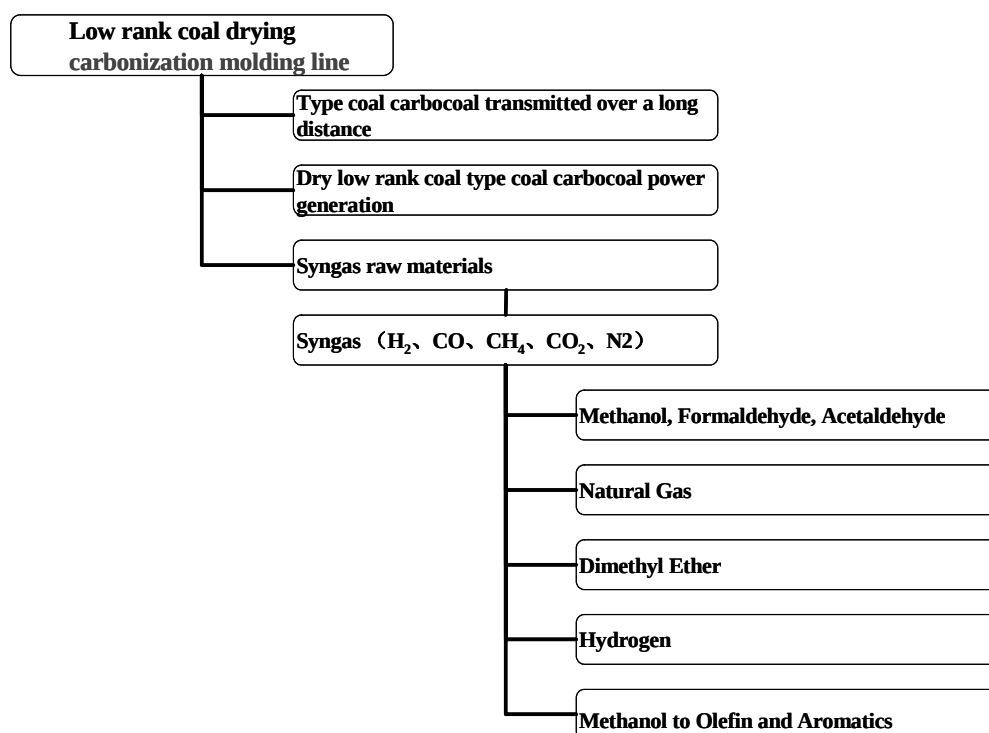


Figure 8-1 Lignite Gasification Comprehensive Utilization Process Flow Diagram

8.2 Lignite Polygeneration Process

The lignite gasification comprehensive utilization technology is featured with flexible product structure, low product costs, high energy conversion efficiency and environment-friendliness, etc. It can maximize the treatment or utilization of the pollutants in coals, demonstrating a concept of circular economy.

8.2.1 Lignite-to-Ammonia Fertilizer Process

Lignite enters the gasification unit after being dried, retorted or shaped. The CO in the syngas obtained can shift via steam and obtain H_2+CO_2 by means of the catalyst, with CO_2 as the raw material for urea production. The shift gas undergoes ammonia synthesis after the gas purification processes, for instance, low-temperature methanol wash, methanation (or liquid nitrogen wash), nitrogen combination and compression, finally obtaining the product-urea. See Figure 8-2. Hulun Buir Jinxin Chemical Engineering Co., Ltd. (Inner Mongolia) has invested RMB 4.5 billion in a coal chemical project to produce 500,000-ton synthesis ammonia and 800,000-ton urea annually, which adopts the lignite from the Baorixile Coal Mine as the raw materials and the BGL coal gasification process. The unit has been completed and put into service in June, 2011.

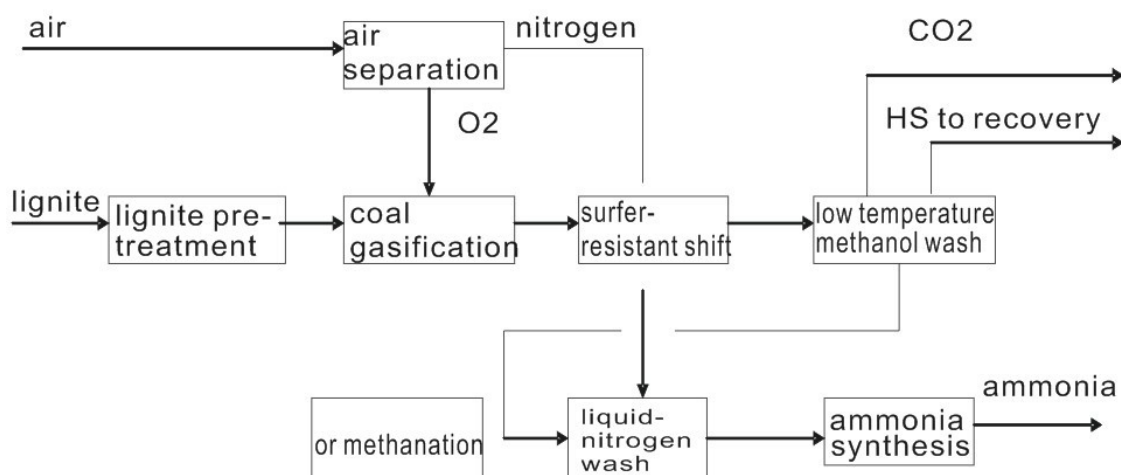


Figure 8-2 Lignite-to-Synthetic-Ammonia Process Flow Diagram

8.2.2 Lignite-to-Methanol & Dimethyl Ether Process

It is a fairly good raw material route to adopt the pre-treated lignite for coal gasification to obtain syngas as the raw material for methanol. Methanol has a very good prospect both as a transitional mixed fuel and as the key raw material for fuel battery. The key lies in the selection of the coal gasification technology and the unit scale. $CO+H_2$ in the crude syngas as obtained from coal gasification are the raw gas to produce methanol. The crude syngas undergoes processes such as low-temperature methanol wash, compression, methanol synthesis and methanol rectification after a pre-shift, finally obtaining methanol. See Figure 8-3. Datang's 1.8-million-ton methanol project in Duolun has been put into service^[22-23].

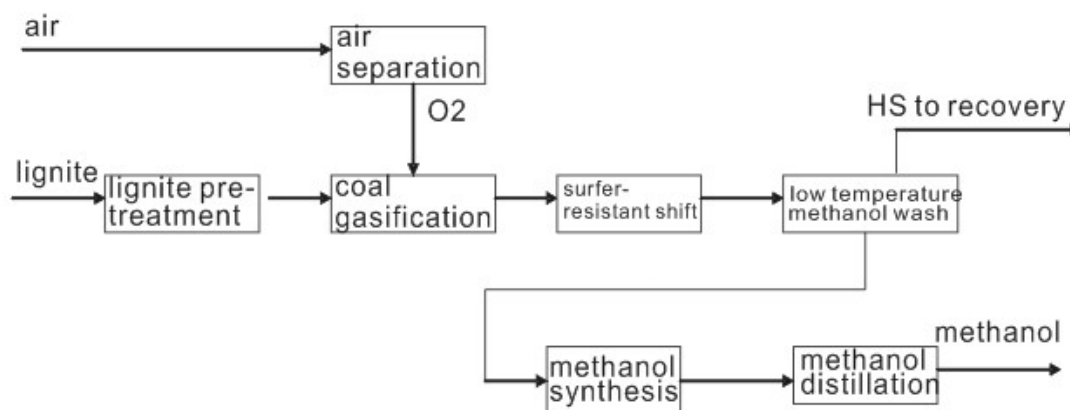


Figure 8-3 Lignite-to-Methanol Process Flow Diagram

8.2.3 Lignite-to-Hydrogen Process

The international oil crisis that occurs at the beginning of 1970s makes people have a profound understanding of the safe supply of petroleum and natural gas, thus promoting the progress in coal gasification technologies.

It alleviates the dependence on petroleum resources by realizing the effective energy conversion via gasification. CO can drop to about 0.2% when crude syngas is shifted. Over 98% of hydrogen is available by further removal of acidic gas. In the direct liquefaction CTL (coal-to-liquids) process, hydrogen is a key raw material and can also be used as the fuel for fuel battery^[24-25]. See Figure 8-4.

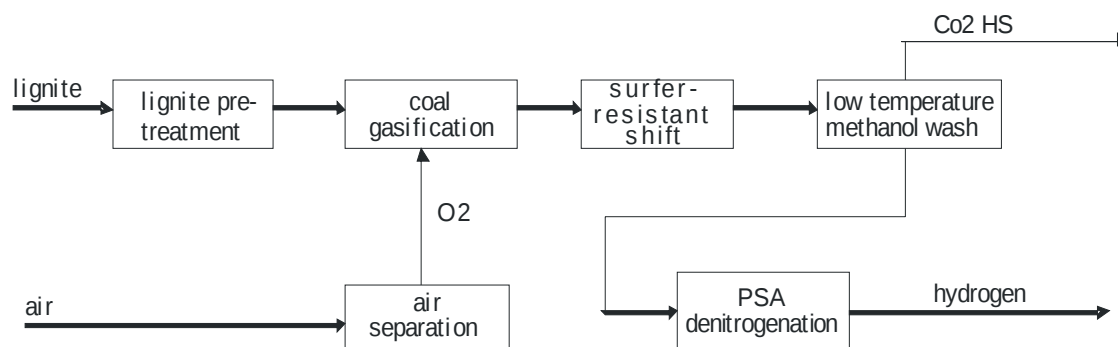


Figure 8-4 Lignite-to-Hydrogen Process Flow Diagram

8.2.4 Lignite-to-Ethylene Glycol Process

The main industrial method to synthesize ethylene glycol is to firstly synthesize ethylene via the petroleum route, then oxidize the oxirane generated from ethylene and finally obtain ethylene glycol by oxirane hydration. The economic profits of the process are greatly influenced by oil prices. As indicated in Figure 8-5, the ethylene glycol production process taking coal-generated syngas as the raw material, is receiving attention due to its multiple advantages such as wide and cheap raw resources, high techno-economics, etc.

The process currently developed in China, firstly obtains dimethyl oxalate via CO

gaseous-phase oxidative coupling, which then made into ethylene glycol by means of hydrogenation. In the ethylene glycol pilot units adopting the technology, the main performance index for the three key catalysts have achieved in advanced international standards. Conversion rate of dimethyl oxalate goes beyond 99%, while selectivity of ethylene glycol is above 98%. Quality of ethylene glycol product meets the national standard with the pollutant emission meeting the national and enterprise standards.

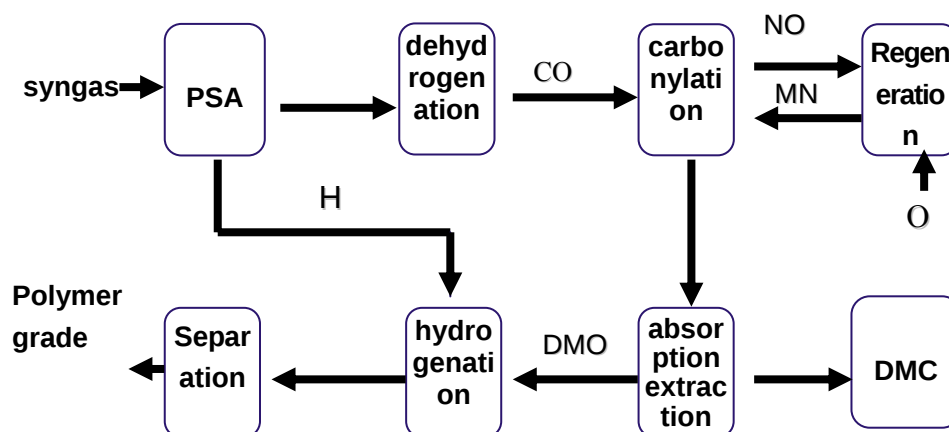


Figure 8-5 Lignite-to-Ethylene Glycol Process Flow Diagram

8.2.5 Lignite-to-Oil Production Process

The lignite indirect liquefaction technology is to firstly produce syngas via coal gasification and then produce liquid hydrocarbons with various distillation ranges via the Fischer Tropsch synthesis process by taking the syngas as raw materials. The coal indirect liquefaction process includes the coal gasification unit, the gas purification unit, the F-T synthesis unit, the separation unit and the post-processing upgrading unit, etc. See Figure 8-6. Indirect liquefaction is not demanding in terms of coal quality. South Africa has begun to construct commercialized plants in the 1950s, and now has formed an annual output of 7-million-ton products. The development of domestic indirect liquefaction technologies has been conducted for 20 years. The low-temperature slurry bed synthetic oil pilot units have been constructed for a long-term test run, achieving in high-quality diesel oil products.

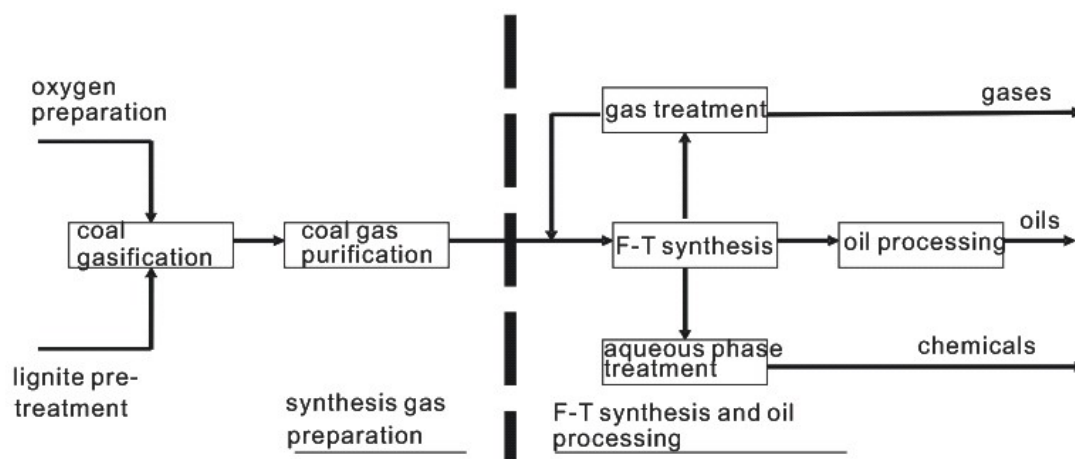


Figure 8-6 Indirect Liquefaction Lignite-to-liquids Process Flow Diagram

In January, 2009, Shenhua Group's Erdos megaton-class direct liquefaction CTL demonstrative unit was successfully commissioned, which verifies the direct liquefaction CTL technology with a proprietary intellectual property right. The unit conducts a test run for the second time in the third quarter. By December, it has produced approximately 100,000-ton gasoline and diesel oil products. The first special train delivers 2,300-ton naphtha to the Tianjin Port on October 18 for export sales. Shenghua Group has acquired a license for refined oil wholesales. See Figure 8-7 for the direct liquefaction CTL process.

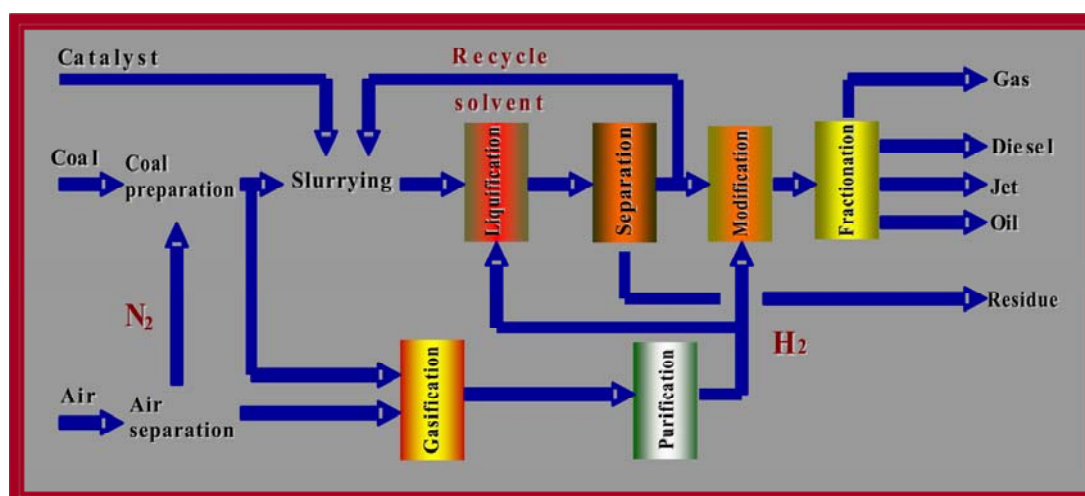


Figure 8-7 Direct Liquefaction Lignite-to-liquids Process Flow Diagram

By the end of 2009, China has achieved a CTL output of 1.68-million tons. Three industrial test units have been put into service successively by using the iron-based slurry-bed indirect liquefaction technology from Synfuels China. The Yitai 160,000 t/a CTL project has been successfully started in March, 2009 and formally put into service in September. By the fourth quarter, the project has accumulatively produced over 120,000-ton oils. Yitai Coal-to-liquids Limited Liability Company (Inner Mongolia) and Inner Mongolia Petrochemical Industry Test Center work out two enterprise standards for F-T synthetic diesel and F-T synthetic naphtha, filling in gaps in China's CTL standards. China's CTL

demonstrative projects completed in 2010 will march toward a commercialized operation one after another. The economical efficiency, product proposal and quality index of the direct liquefaction CTL process and the indirect liquefaction CTL process will by then withstand all the market tests^[26-27].

8.2.6 VI. Lignite-to-Olefins Process

As two important new C1 chemical processes, the Methanol-to-Olefins (MTO) process and the Methanol-to-Propylene process refer to the chemical technologies that take methanol synthesized from coal or natural gas as raw materials to produce low-carbon olefins, by virtue of a fluid-bed reaction formation similar to that of a catalytic cracking unit. Low-carbon olefins are the intermediate products from the MTG reaction, therefore, the successful development of the MTG process promote the development of the MTO process. Some internationally-known petrochemical corporations such as Mobil, BASF, UOP and Norsk Hydro, etc. have invested heavily in the technical development. Mobil is the first to study how to convert methanol into ethylene and other low-carbon olefins, based on its own ZSM-5 catalyst. However, it is UOP and Norsk Hydro that see dramatic breakthroughs by jointly developing the UOP/Hydro MTO process with UOP MTO-100 as the catalyst^[18]. See Figure 8-8.

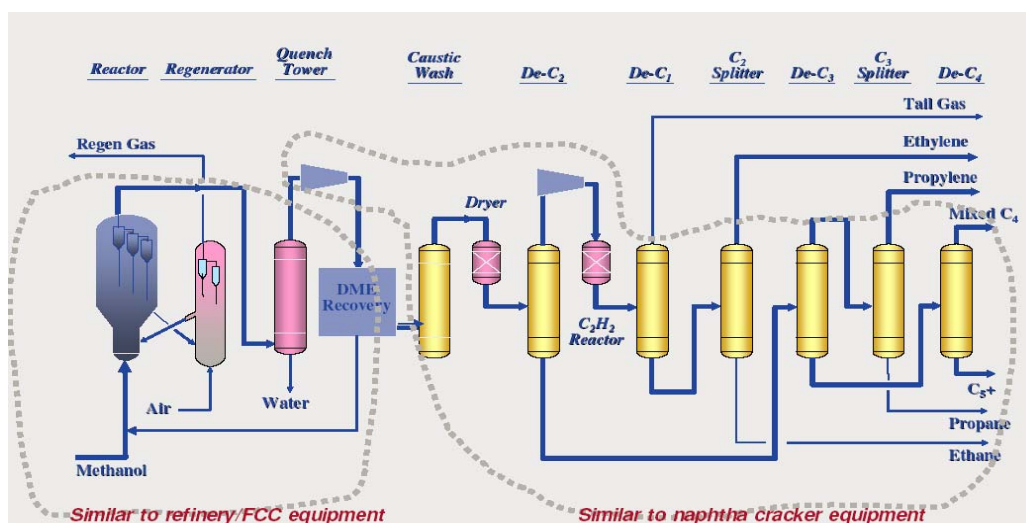


Figure 8-8 Lignite-converted Methanol-to-olefins (UOP/HydroMTO) Process

See Figure 8-9 for the methanol-to-Propylene (MTP) process developed by Lurgi (Germany). The process uses the fixed-bed methanol to produce propylene and adopts the modified ZSM-5 catalyst developed by Snd-Chemie. With a view to its features, methanol goes through two continuous fixed-bed reactors, firstly converted into dimethyl ether in the first reactor and then into propylene in the second reactor. Datang Power has introduced the MTP technology from Lurgi and constructed a 470,000 t/a methanol-to-propylene unit in Inner Mongolia.

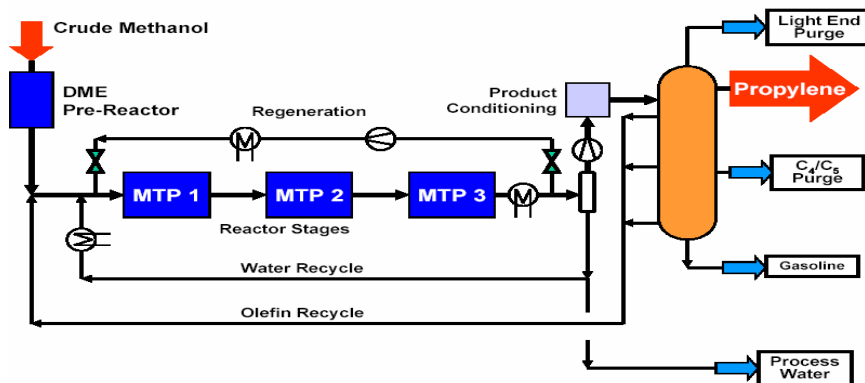


Figure 8-9 Lignite-converted Methanol-to-propylene (Lurgi MTP) Process Flow Diagram

Dalian Institute of Chemical Physics, Chinese Academy of Sciences, China University of Petroleum and SINOPEC CORP. Research Institute of Petroleum Processing, etc. have also conducted similar work. Notably, Dalian Institute of Chemical Physics, Chinese Academy of Sciences has developed a DMTO technology proprietary intellectual property rights based on years of research. A pilot unit was completed in December, 2005 and succeeded in the first start up on 20th February 2006. As compared to the traditional MTO process in which syngas is converted to methanol to produce low-carbon olefins, the original process route (SDTO) is high in CO conversion rate that is over 90%, thus saving 50%~80% of the construction and operation costs.

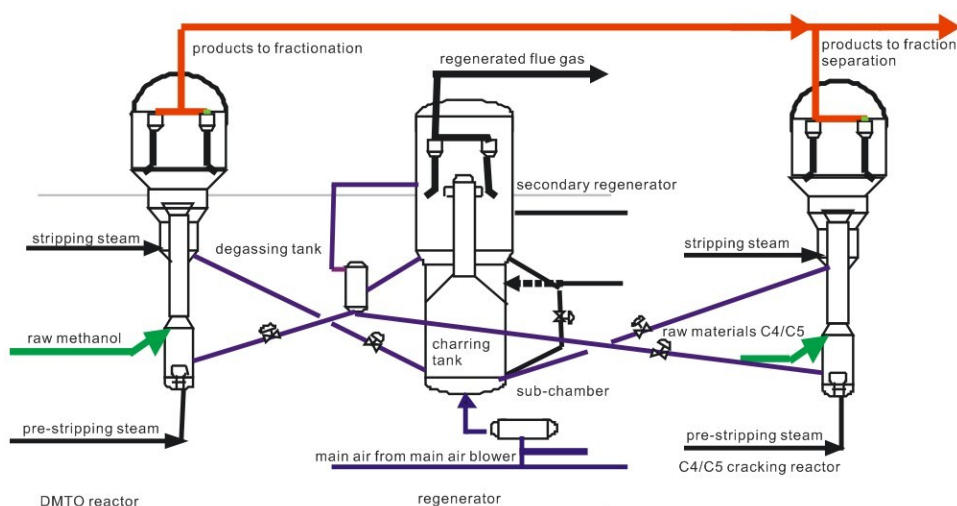


Figure 8-10 Lignite-converted Methanol-to-olefins (DMTO) Process Flow Diagram

China National Chemical Engineering Co., LTD. and Tsinghua University and other units have developed the methanol-to-propylene FMTO industrial test project in joint efforts. See Figure 8-11. The project covers three parts, namely,

basic research, industrial scale-up and commercial test. The test unit succeeds in a test run in October, 2009.

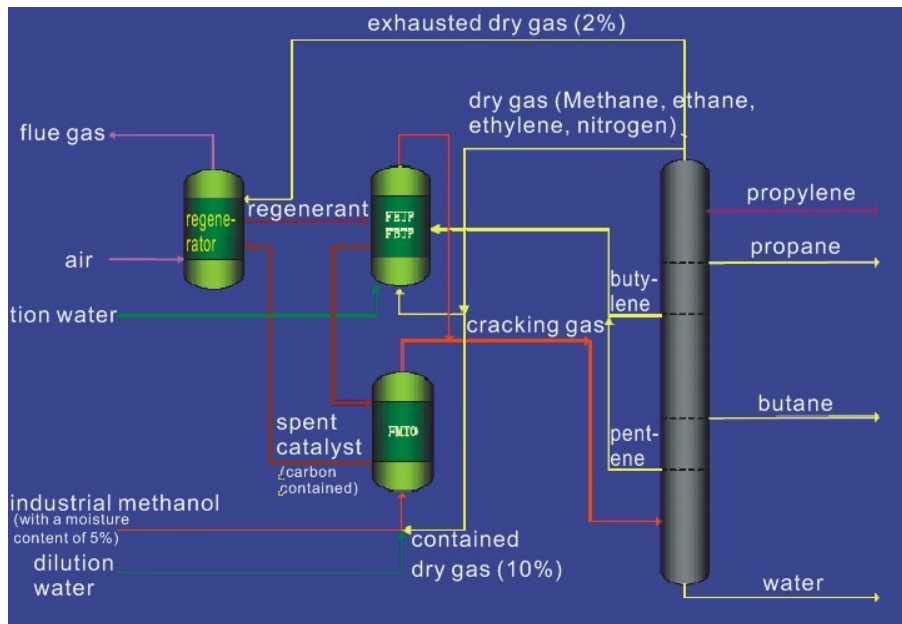


Figure 8-11 Lignite-converted Methanol-to-propylene (FMTP) Process Flow Diagram

8.2.7 Lignite-to-artificial-natural-gas Process

With an analysis on the overall structure of energy and fuels, it is quite promising to use coal, especially the low rank coals, to produce artificial natural gas (syngas high in methane). The technology adopts the gasification processes including Lurgi's pressure gasification process and the BGL process (or the crushed coal moving-bed gasification process), etc. to obtain high-methane crude gas to finally produce high-methane artificial syngas upon conversion, low-temperature methane wash, methanation and refining. See Figure 8-12. Datang International's coal-to-natural-gas project in Chifeng, Inner Mongolia acquires the formal approval from National Development and Reform Committee in August, 2009. The first 1.3-billion m³/a natural gas production line will be completed before 2012, with some other coal-to-natural-gas products to be approved for construction^[6].

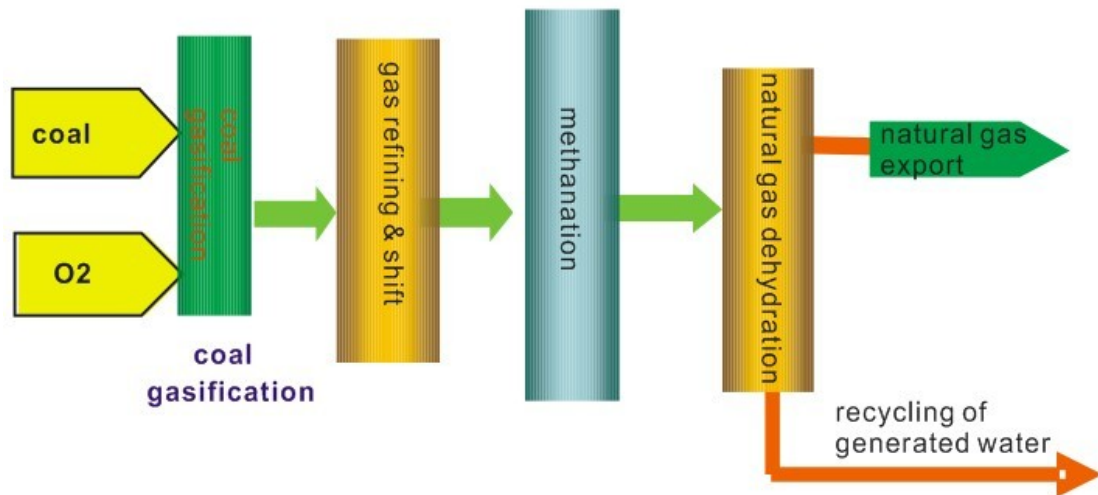


Figure 8-12 Lignite-to-natural-gas Process Flow Diagram

8.2.8 Lignite-gas-steam IGCC Process

The gas-steam IGCC (IGCC-Integrated Gasification Combined Cycle) process is an advanced power generation system combining the efficient integrated energy system with the clean coal technology. See Figure 8-13. It consists of two parts, that is, the coal gasification & purification part and the integrated gas-steam power generation cycle part. Major equipment for the first part includes gasifiers, air-separation units, coal gas purification equipment (including sulfur recovery unit). Major equipment for the second part includes gas turbine power generation systems, waste heat boilers, steam turbine power generation systems. Major features of IGCC clean coal power generation cover:

- (1) High heat efficiency, currently up to 43%~ 46%, aiming for 50% in 2010.
- (2) Good environmental performance. The desulfurization percent is over 98%~ 99%, the NO_x emissions equals to that of natural gas and the CO₂ emissions are also reduced;
- (3) The fuel is quite adaptable, particularly applicable to high-sulfur coal;
- (4) It can be used for the transformation of integrated oil fuel units and old oil fuel power plants, aiming to improve the efficiency and the environment. Lignite is adopted for the gas-steam IGCC process as the raw material.

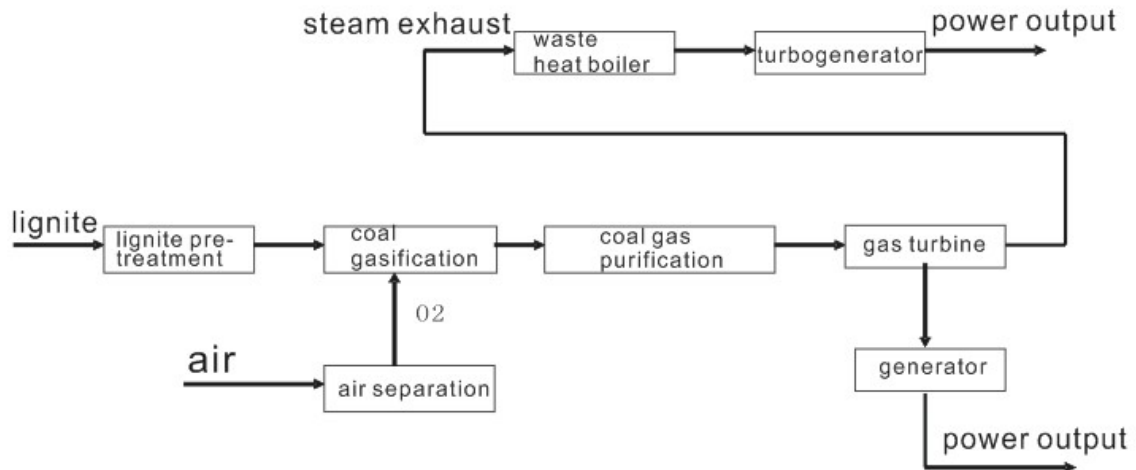


Figure 8-13 Lignite-based gas-steam IGCC process Flow Diagram

The development of IGCC mainly undergoes three stages: the conceptual verification stage, the commercially-demonstrative verification stage and the commercialization stage. At present, it has become a main trend in power generation technologies to improve and develop the second generation of technologies and transit technically to the third generation of technologies while realizing commercial applications. With the operation of the IGCC units from demonstration to commercialization around the world, China has also begun to develop the IGCC technologies. Huaneng Tianjin's IGCC green demonstrative coal power generation project, Huadian (Hangzhou) Banshan Power Generation Co., Ltd.'s IGCC demonstrative project, China Yantai Power Plant's IGCC project, CGN-DGPC Taiyangzhou IGCC demonstrative project, etc, having started or to be started under the guidance of national energy-saving & emission-reduction policies^[28-30].

8.2.9 HRL IDGCC Process

The Integrated Drying and Gasification Combined Cycle (IDGCC) Technology is a process for generating power from low rank brown coal. See Figure 8-14. The brown coal is dried and then converted to gas (otherwise known as synthesis gas or syngas), which is burnt to produce power in a gas turbine. The power station will use a combination of natural gas and syngas as fuel for the gas turbines.

The gasification process occurs in a 'gasifier' which is a vessel containing a fluidized bed of solid (granular) char particles (formed from the dry coal feed) that operates at high temperature and pressure. The bed is fluidized and mixed by bubbles of gas generated from the reaction of coal and char within the bed with the supply of air into the gasifier. This reaction also provides the heat that increases the temperature of the bed.

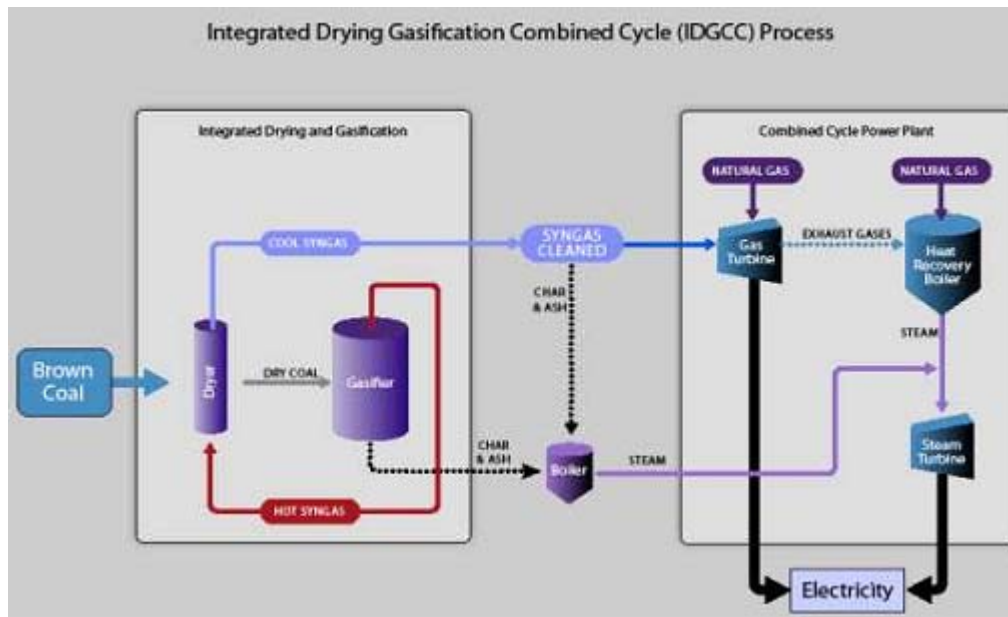


Figure 8-14 IDGCC process Flow Diagram

8.2.10 CO₂ Capture and Storage Process

With the strict environmental regulations, carbon emission reduction pressure of all countries increase, carbon taxes are unavoidable. Meanwhile, low rank coal (LRC) comprehensive utilization projects will get fewer profit and competitiveness for high carbon tax, or shut down with environmental standard not satisfied. CCS technology is a system engineering including CO₂ capture, transport and storage process. The capture and transportation technologies are relative mature with high cost. While geologic storage technology is still in the verification stage, the mechanism and evaluation of geologic storage need to be improved; injection technology needs to be developed. At the same time public awareness should be raised; compensation of emission reduction, cross-industry capture and management of the pipe network should be discussed.

It is well known that natural gas production cause carbon emission, a 2 billion m³/y natural gas project emits nearly 6 million t/y CO₂. CCS plant will certainly increase project investment. Few technologies are available for enterprises to produce chemicals from purified CO₂. Shenhua coal to oil project has started CCS full process, transported byproduct of CO₂ to storage area about 17km away

and 3000m underground after purification, liquefaction etc link. This technique needs further observation to meet requirements. The 100000 t/y CCS pilot plant sends CO₂ into feed gas buffer tank to adjust pressure. Through 4 level compressors, 5.0 MPag is reached. Then sulfur and oil are removed in the desulfurization and deoiling system. The variable temperature adsorption technology is applied to purify CO₂ captured from rectisol process. CO₂ concentration is raised to meet the requirements of CO₂ storage, or produce food grade. Food grade CO₂ can immediately be produced when CO₂ storage test ended to avoid device investment waste.

The 100000 y/t CCS pilot plant will find suitable process and optimum operating parameters for CO₂ purification, liquefaction in direct liquefaction project. Geological and chemical data from underground salt water layer can be got. Seal ability, perfusion requirements, perfusion distribution, testing requirements, geological safety of CCS would be concluded. Influences on coal mining, petroleum and natural gas mining industries can be clear. Therefore massive CO₂ emission reduction through CCS still has a long journey to explore.

9 Recommendations on Technical Development of LRC Utilization in APEC

Based on a comprehensive survey of the current status of lignite industry and a technological analysis of successful experiences and unsuccessful lessons in key technology R & D, long term operation of equipment, and safe and stable operation of lignite utilization systems, the present report propose an overall solution scheme of large scale and circular economic utilization of LRC (lignite) by proper integration of selected processes, which ultimately leads to optimized economic and social benefits for various commercial LRC plants. Four solution schemes for such utilization are proposed and listed below.

● Solution Scheme 1: Integrated Utilization of Lignite Through Upgrading & Staged Conversion

This scheme is shown in Figure 1. The system consists of different functional unit operations and processes, including preliminary dewatering of low rank coal, deep drying of lignite, low temperature rapid pyrolysis of lignite in moving beds with semi-char as heat carrier, pretreatment of carbonized coal gas, hydrotreating of tar, 4.0MPa gasification of semi-char by dry/wet process, oxygen production through air separation in liquid oxygen pump, partial shift anti-sulfur conversion

in wide temperatures, removal of sulfur and carbon by Rectisol, natural gas production through methanation, refrigeration low temperature dewatering, etc. This solution scheme for LRC utilization is typical of advanced constituting processes that are mature and demonstrative in engineering practices and have reliable patent properties. The scheme is also considered to have a flexible product structure, low production cost, high efficiency of energy conversion and environmentally friendly character. Furthermore, in the foreseeable long run, coal remains the main resource in the energy structure of APEC economies, especially in China. Hence, considering that lignite accounts for nearly half of the coal resource, we consider the present upgrading and then staged conversion scheme as a critical step toward the realization of high-efficient, clean and circular utilization of low rank coal (lignite) in APEC^[31].

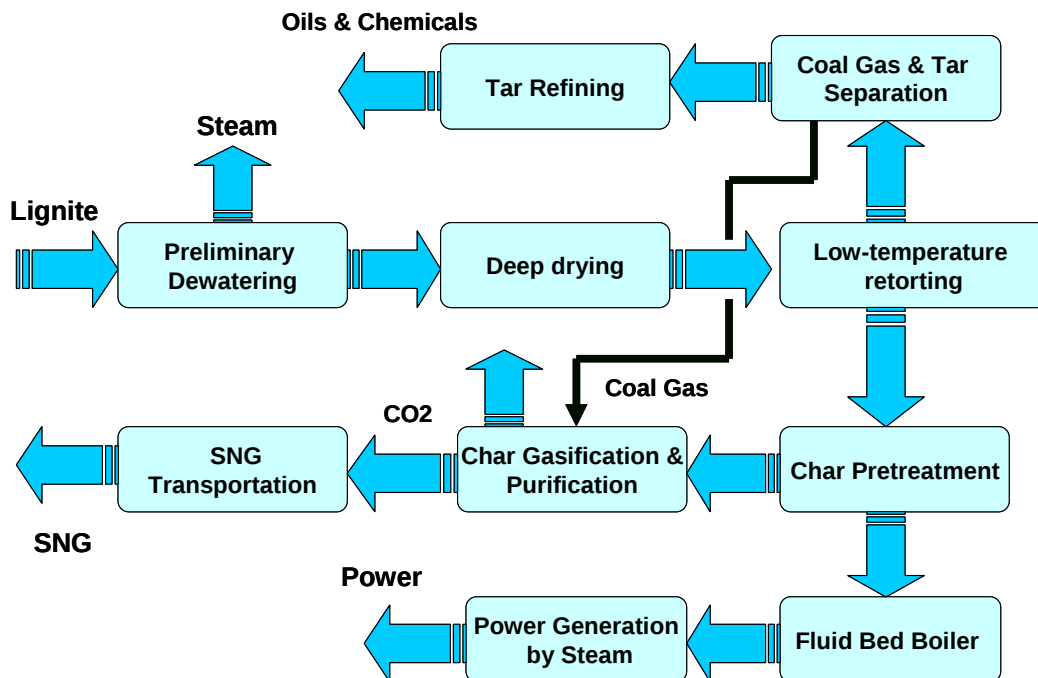


Figure 1 Solution Scheme Through Upgrading & Staged Conversion of LRC

● Solution Scheme 2: Upgrading and Pyrolysis of Lignite Integrated with Power Generation

This scheme is shown in Figure 2, where a CFB fired boiler is integrated with a low temperature pyrolysis reactor, steam turbine power generation unit, lignite drying molding unit and long distance transportation unit of solid fuel. Heat required for the lignite pyrolysis is fed from recycle hot dust of the CFB boiler, in which the lignite enters into the pyrolysis reactor for drying carbonization and reacts with hot steam to produce coal gas, and semi-charing dust mixture goes into CFB boiler as fuel to produce by-product steam for power generation. Part of LP steam is used for drying lignite with specified moisture content. Before molding, the drying coal powder passes through boiler fume for deep drying and is carbonized and partly gasified as raw material of the low temperature fluid bed pyrolysis reactor. Such a closed circulation process is designed to export solid

fuel and power, tar and coal gas in addition to power generation^[32].

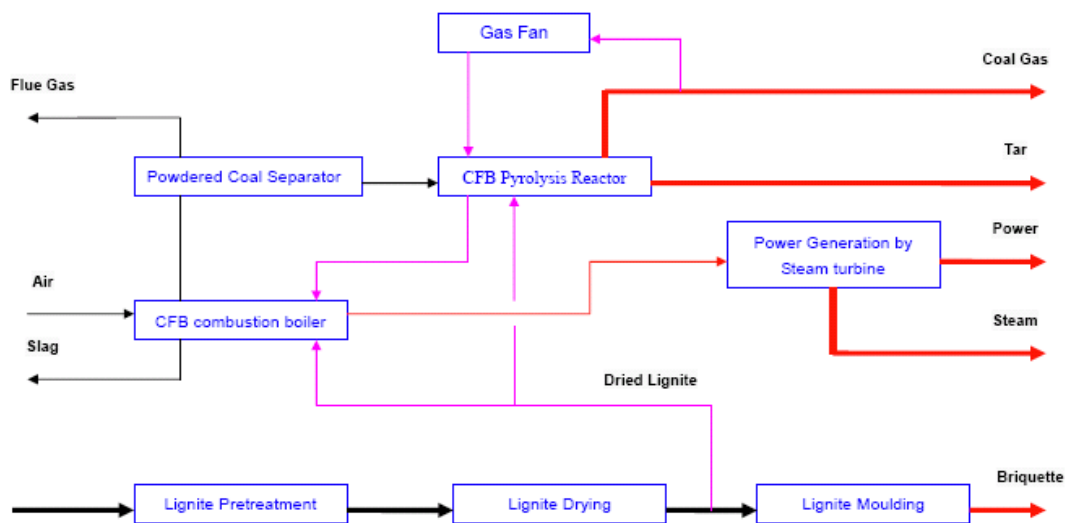


Figure 2 Solution Scheme of Upgrading and Pyrolysis of Lignite Integrated with Power Generation

● Solution Scheme 3: Upgrading and Pyrolysis of Lignite Integrated with Natural Gas Production

In this scheme (Figure 3), mainly a dry carbonization & gasification process with large scale lignite pyrolysis in a low temperature moving bed is adopted; in the process deeply dried lignite is quickly mixed with the semi-char hot carrier from the moving bed, and then partially gasified, producing low temperature tar, coal gas and semi-char. With a small quantity of steam fed to react with semi-char, the low temperature carbonization of coal is merely a hot treatment process at atmosphere pressure, yet coal gas, tar and semi-char are produced and partial gasification and liquefaction of lignite are realized.

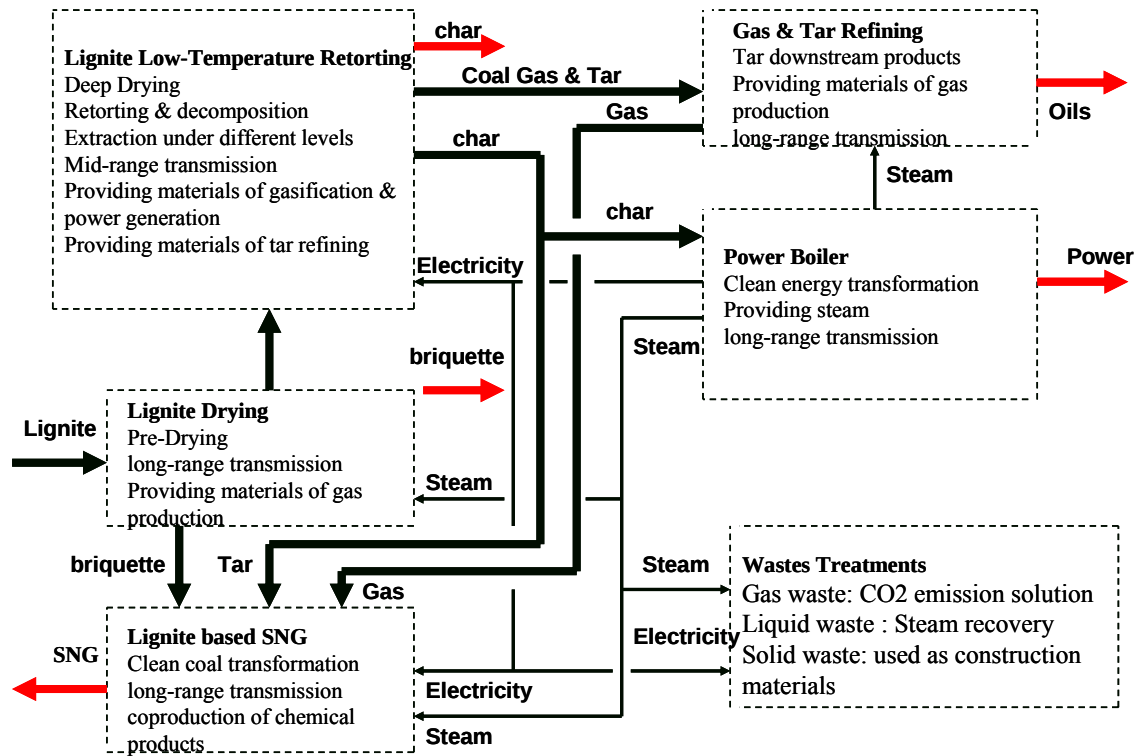


Figure 3 Solution Scheme of Upgrading and Pyrolysis of Lignite Integrated with
Natural Gas Production

Coal with high volatilization and oil content is an ideal feedstock for producing oil through pyrolysis (carbonization). Lignite pyrolysis in the low temperature moving bed uses powder feedstock (less than 6.3mm); compared with the other low temperature carbonization method, this process can produce more tar and oil with a good quality. Fat hydrocarbon, aromatic hydrocarbon and hydroxybenzene compounds can be used to produce chemicals and fuel oil. Heat value of the semi-char is higher than that of raw coal (it is normally higher by 5%-50% depending on coal types), and has high reaction activity. Different semi-chars could be produced with raw coals having different dust contents: semi-char with low dust can be used as char powders such as blasting feedstock and agglomeration powder of a blast furnace, or be processed to clean smokeless fuels, etc; semi-char with high dust content can be used as syngas feedstock or for fired power generation. The coal gas by low temperature lignite pyrolysis carbonization is a medium-heat-value coal gas, which can be used as town supply fuel gas, industrial fuel or feedstock for hydrogen production as well. In accordance with different purposes, integrated production can be realized, in which semi-char gasification can be used as natural gas feedstock or boiler fuel, coal gas can be used to increase inlet temperature of a fired turbine unit so as to enhance efficiency of power generation^[33].

● Solution Scheme 4: Upgrading and Pyrolysis of Lignite Integrated with Chemicals Production

This scheme is shown in Figure 4. In the system, a large scale lignite upgrading/pyrolysis process produces semi-char, low temperature tar and coal gas. This is attained by a solid char hot carrier process at atmosphere to realize partial gasification of lignite for syngas production, and then chemical products can be produced from the syngas^[34].

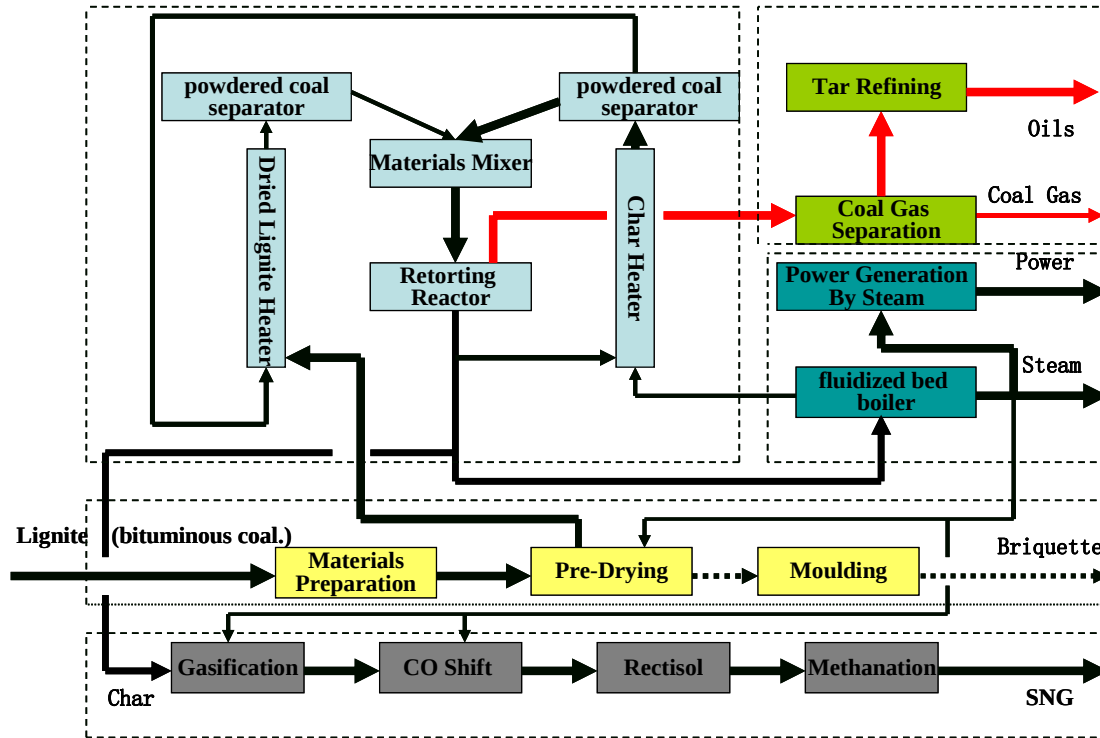


Figure 3 Solution Scheme of Upgrading and Pyrolysis of Lignite Integrated with Chemicals Production

● Other concerns:

As for warm-gas clean up of syngas, rectisol process should be taken in decarburization to raise energy efficiency. In the future, desorption and regeneration parts of rectisol process should be improved. As for shift process, low temperature and sulphur- tolerant catalysts should be applied to adapt more coal types. Catalysts with longer life, higher selectivity and better activity should be developed in the future.

According to the areas and coal types, cinder from supercritical and ultra supercritical power station will be used to produce cement, building materials and other materials achieve comprehensive utilization.

For water saving in lignite efficient utilization, cooling process unit adopts the air-cooler as much as possible; recycling principle should be emphasized in wastewater treatment design to reduce water loss; for the high moisture content in lignite, evaporative water recycling problem is technically to be solved at present.

As for coal water slurry used in diesel engine, the emission aftertreatment equipment size is still to be reduced; mixed fuel injection and combustion studies are needed to reduce water slurry cost; during studies, ash content, spontaneous point, atomization, fuel pumping and storage, emissions and calorific value should all be taken into consideration.

10 Conclusion

The current status of energy-efficiency technologies for utilization of LRC within APEC economies especially in China was analyzed, and general guidelines recommendations for the technological development were put forth based on the concept of circular economy, advocating large scale utilization of LRC through upgrading and integrated functional unit operations and processes.

Four guidelines were draw. First, upgrading and classified utilization of LRC should be highly purposive and focus on a comprehensive utilization of LRC, and thereafter critical technologies and processes could be properly selected. Second, such mature theories and unit operations as drying, carbonization, pyrolysis, burning, gasification, reaction, rectification and separation, should be optimally integrated to form innovating integrated circular economic systems. Thirdly, a combined technological innovation should be implemented to products demanded in the market such as gaseous energy, liquid energy, solid energy and high-value-added chemicals. Lastly, key processes and products should be clearly identified to fulfill the comprehensive utilization of LRC in an optimized fashion.

Under the guidelines, four technological solution schemes (recommendations) for LRC utilization were proposed, including

- Solution Scheme 1: Integrated Utilization of Lignite Through Upgrading & Staged Conversion
- Solution Scheme 2: Upgrading and Pyrolysis of Lignite Integrated with Power Generation
- Solution Scheme 3: Upgrading and Pyrolysis of Lignite Integrated with Natural Gas Production
- Solution Scheme 4: Upgrading and Pyrolysis of Lignite Integrated with Chemicals Production

Critical technologies and processes used in the four schemes were evaluated and the corresponding conclusions are as follows:

Selection of the LRC drying process should be made upon whether the process is safety, friendly to environment and energy effective; these criterion are essential for its applicability, with low energy consumption being the utmost important one in the course of its R&D. Part of evaporative drying processes have been commercialized; for instance the steam tube drier process without direct contacting between heat-transfer-medium and dry lignite, is safe in the drying process because the temperature is lower than those of lignite pyrolysis and ignition, which is devoid of the possible safety problem caused by application of "direct" drying for low ignition point coal, and at the same time makes it possible that redundant LP steam can be efficiently utilized in large coal-based chemical

project and shall be greatly utilized in construction of large scale lignite deep processing unit. Another part of the processes are in the demonstration stage at commercial-scale. Non-evaporative drying processes are characteristic of safety, environmental protection and low energy consumption, however, this kind of processes needs further study and improvement, which shall be evaluated and acknowledged by running in commercial demonstration plants.

The lignite pyrolysis upgrading process, by which gaseous and liquid fuel and solid fuel of high-energy density are produced from cheap lignite resource, shall be widely used in APEC area especially in China. Many pyrolysis processes such as LFC low-temperature pyrolysis upgrading process, semi-char solid hot-carrier pyrolysis upgrading process, hot-dust solid hot-carrier pyrolysis upgrading process have been applied in the construction of commercial lignite pyrolysis plants to produce different target products. All these plants can be taken as commercial demonstration plants, which will provide valuable experiences for a comprehensive utilization of lignite through evaluation of the demonstration plant running results.

Selection of clean gasification processes of lignite shall follow basic requirements in advance, i.e., reliability, adaptability, safety & environmental benignancy, and clear intellectual property (IP) rights. Clean coal gasification processes shall be selected upon a basis of basic data and physical properties from lignite pretreatment. For dry gasification process, gasifiers with water-cooling wall are preferred with gasification temperatures in a range of 1400~1600°C. Wet gasification processes use gasifiers with refractory bricks for inner wall insulation, in which case ash melting point is less than 1400°C. The representative lignite gasification processes are such processes as Shell dry pulverized coal gasification, GSP gasification, Hangtianlu gasification, Lurgi gasification, GE coal slurry gasification and 4-nozzle gasification, etc.

Lignite liquefaction processes such as IGOR, NEDOL and HTI processes have completed their demonstration at industrial trial scale. 1,000,000 t/a oil of commercial demonstration plant with coal direct liquefaction process of China Shenhua has been in operation for several years, by which reliability and advance of the process are demonstrated. Before direct liquefaction and conversion of lignite, Preliminary direct liquefaction tests shall be made for specified coal types so as to estimate energy efficiency of conversion and economics. The present study shows that investment of direct liquefaction is huge with dense technology and capital, in which good economic efficiency can be only obtained from large scale production. Therefore, the direct liquefaction of lignite needs a quite long time for demonstrating its economic efficiency.

At present power/ electricity generation process is the most popular utilization method of lignite in the world; such power plants are set up close to mining sites and convert lignite directly into power/ electricity. Main target of the process improvement in this field is to increase energy conversion efficiency of lignite power plant. To this end, mature and advanced power generation process applied in conventional hard coal power generation plants, e.g., super-critical power generation, ultra-super- critical power generation and IGCC, shall be used; on the other hand, mature drying processes before furnace shall be integrated into the

power generation process so as to enhance the power generation efficiency by over 3%.

Integrated production process of lignite means to convert highly volatile components in lignite into gaseous and liquid products, and the fixed carbon in to fuels or gasification feedstocks for production of electricity, steam or syngas. As the amount of gaseous and liquid products produced from the pyrolysis of lignite is lower than that of solid products, highly efficient deep processing & utilization of gaseous and liquid products are needed, in which especially the gaseous product of these two products needs to reach a certain scale and meanwhile it also needs to match the deep processing capacity. Large scale production is a premise to realize integrated production. Low temperature pyrolysis of lignite using hot gas carrier cannot realize the integrated production, in view of that the drying and pyrolysis systems can not attain a thermal balance under low pyrolysis temperature conditions (below 620°C), and the pyrolysis gas contains a great deal of inert gases and has a low heat value. Another low temperature pyrolysis of lignite using semi-char heat carrier or inert solid medium carrier yields pyrolysis gas having low content of inert gases and high heat value, while the semi-char product could be locally gasified or used for power generation to realize the integrated production. In this way, the low density semi-char is free of problems in storage, loading and transportation, etc. At the same time, reliability, safety and environmental protection of the solid hot carrier operation need further validation. Combination of the low temperature lignite pyrolysis process of a hot ash solid heat carrier and CFB boiler can enhance safety and heat efficiency; production of deep processing gaseous & liquid products integrated with power generation is highly promising. If a CFB boiler with a higher unit boiler capacity can be combined and meanwhile an advanced lignite drying process can be integrated, better energy saving and value-added application results can be obtained.

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