Simulation for Integrated Systems of Typical Coal-to-liquids Processes and Waste Energy Exploitation Based on Different Gasification Processes

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Abstract—Integrated systems of FT liquids processes and waste energy utilization based on Shell, GSP and GE gasification are designed and simulated. The results show that under the condition of 1 000 t/hr coal feedstock, the yields of the liquids, including diesel, naphtha and LPG, are 205.2t/hr, 73.2t/hr and 40.1t/hr, respectively based on shell; 205.1t/hr, 73.2t/hr and 40.1t/hr, respectively based on GSP; 183.8t/hr, 65.6t/hr and 35.9t/hr respectively based on GE. However, the electricity generation equivalent to about 2% of coal thermal value cannot meet the power needs of the three systems. Based on LHV, the highest system thermal efficiency of 47.7% comes from the system based on Shell. The lowest system thermal efficiency, resulting from the system based on GE, has decreased 7.1% compared with that of the system based Shell. The proportion of carbon capture to the total carbon entering the systems is 58.7% (for the system based on Shell), 58.6% (for the system based on GSP) and 59.5% (for the system based on GE), respectively.

Keywords — polygeneration; gasification; syngas; WGS; FT synthesis; combined cycle

I. INTRODUCTION

Considering the higher energy consumption and environmental pollution caused by fossil energy industries has become bottlenecks for the sustainable economic development, the exploration of efficient and clean utilization has become more and more significant. From a perspective of feasibility option, polygeneration systems based on gasification may present an opportunity to overcome energy and environment problems caused by conventional coal technologies [1-4]. The concepts of polygeneration and energy integration has been discussed and various examples of polygeneration systems has been investigated. The result is evident that polygeneration systems which include appropriate process integration significantly increase the efficient utilization of natural resources [5]. Some researchers has designed and simulated polygeneration of alternative fuel and electricity from coal and natural gas. In this study, two related processes were compared with a comprehensive sustainability assessment. Scores were given to each process with regard to their performance in four categories: economic, safety, environmental and efficiency. The study has proved the sustainability assessment methodology is quite convenient in the selection or modification of processes [6]. In a research performances of H2/electricity co-production systems with CO2 capture are compared with those of the systems venting CO2. The result has been obtained that a loss of 6%-8% points of electricity conversion is entailed when capturing CO2 as an alternative to venting it. And CO2 capture for H2 production causes an energy loss about 2% points of export electricity [7]. Recently, many researchers pay their close attention to the polygenerations feeding biomass. A study presents preliminary feasibility and performance estimation using thermodynamic model in Aspen Plus for agricultural waste based polygeneration with electricity, refrigeration, utility heat and ethanol as outputs. Results have shown that such polygeneration is highly promising as decentralized efficient option, specifically for rural people [8]. Polygeneration has been reviewed about the technical feasibility and economics of biomass integrated gasification and FT synthesis processes in general. The research suggests that the aim should be the development of large-scale (pressurized) biomass gasification-based systems and special attention must be given to the gas cleaning section [9]. Some researchers have investigated new possibilities and synergy effects for an oxy-fuel fired polygeneration scheme (transportation fuel and electricity) with carbon capture and co-firing of biomass. They conclude that the proposed oxygen lean combustion process constitutes a way to improve the oxy-fuel carbon capture processes with an efficient production of dimethyl ether (DME) in the polygeneration process [10].

Nowadays some countries are abundant in coal but are short of domestic oil and natural gas resources. And, compared with biomass, coal has larger energy density and related process is mature. So the people are likely to turn to coal as a basis for providing synthetic liquid fuels for transportation and other applications [11]. FT synthesis can be applied to convert the syngas derived from various non-petroleum resources, such as coal, natural gas, biomass or other carbon containing materials to liquid fuels. FT liquids are beneficial to environmental protection because of almost free of sulfur and aromatics. FT synthesis technology has been run successfully on commercial scale [12, 13]. The growing market for this technology also drives further technological development of FT related processes. Some recent studies focus on new types of cheap Fe-based catalysts and slurry reactor [14, 15]. These studies have further improved FT synthesis technology. Potential co-products may also be realized by utilizing material and
energy that is not directly associated with FT hydrocarbons. For example, waste heat may be converted to electrical power for sale. Pressured entrained flow gasifiers have higher gasification efficiency (for example, Shell and GSP, 80%-83%, GE, over 70%) and have been widely served for single chemical industries or single electricity generation [16, 17]. However, how to judge which gasification process is optimum depends on what kind of production they manufacture.

For example, GSP gasification is proved to use very well for Coal to Ammonia [18]. Some studies give advice that Shell gasification process is optimum to the chemical synthesis [19]. Some reviews recommend that GE gasifier is more suitable for Coal to Liquids than other gasification processes [20, 21]. Furthermore, how gasification processes affect the polygeneration system performance is not very clear. A previous research, which studies the polygeneration systems of FT liquids-power based on Shell gasification process, has shown that system of series connection type has higher energy efficiency than those of parallel connection type [22]. This aim of paper is to evaluate performances, energy efficiency and CO2 capture of polygeneration systems based on different gasification processes.

The main research objectives are: _To explore the technical feasibility of polygeneration systems of FT liquids and power in general._

_To identify the most promising system configurations based on different gasification processes._

a. The detailed material and energy balance calculation for the overall systems.

b. The transition and distribution of coal energy in sub-systems such as gasification process, water-gas shift (WGS) and purification process, FT synthesis and upgrading process, and combined cycle process.

to explain the decrease of CO2 vent of different cases. Above purposes will be achieved through three cases.

Case 1: the integrated system of FT liquids-electricity based on Shell gasification process.

Case 2: the integrated system of FT liquids-electricity based on GSP gasification process.

Case 3: the integrated system of FT liquids-electricity based on GE gasification process.

II. DESIGN

Process configurations for the systems are based on the commercially available technologies. These configurations include: air separation unit (ASU), entrained flow gasification (Shell, GSP and GE technology), WGS process, low temperature physical absorption (Rectisol process), slurry FT synthesis, syncrude upgrading process, pressure swing adsorption (PSA) for H2 separation and combined cycle for electricity generation. Fig. 1 shows the flow schemes for the three cases.

III. METHODOLOGY

In this paper, the integrated systems based on three gasification processes are designed and simulated and their mass conversion and energy transition are analyzed. All the cases are evaluated by Excel-Aspen Plus models, which take trade-off between flexibility and accuracy into consideration. Generally, the detailed processes are simulated by Aspen Plus to get key parameters and the simple input-outputs are calculated by Excel models.

RGibbs model, which performs chemical and phase equilibrium by Gibbs energy minimization, is used to simulate gasifier. Coal is indirectly simulated by Aspen. An efficient solution is that the reaction is divided into two steps: Firstly the coal is broken up into the components including C, H2, O2, N2, S, H2O and ash. And then they interact to reach chemical equilibrium [23]. Defined components of raw syngas include: CO, H2, CO2, H2O, CH4, O2, N2, Ar, H2S, COS, and else trace components (NH3, HCN, S, et al.). A Requil model is applied for WGS reactor is modeled to simulate chemical equilibrium and phase equilibrium. Sulfur-tolerant shift which directly proceed after the gasification and washing can reasonably exploit the utility of the gasification heat. At the same time, the saturated syngas reacting under a higher temperature can reduce the consumption of the injected steam because it contains more water vapor and therefore a reasonable flow matching can be obtained.

Net energy efficiency (EFF) and carbon capture ratio (ηc) are defined:

\[
EFF = \frac{\sum \phi_{\text{useful products}}}{\sum \phi_{\text{feedstock}} + \sum \phi_{\text{utilities}}} \quad (1)
\]

\[
\eta_c = \frac{M_{cc}}{M_{tc}} \times 100\% \quad (2)
\]

Formula (1): The units of all \( \phi \) are converted to tce (ton coal equivalent) units. In numerator the term \( \sum \phi_{\text{useful products}} \) includes synfuel products, sulfur element and net electricity output, which is the generated electricity subtracts the consumed electricity. In denominator \( \sum \phi_{\text{feedstock}} \) is input coal and \( \sum \phi_{\text{utilities}} \) includes consumed electricity, steam and water.

Formula (2): Mcc is carbon captured (t/hr). Mtc is total carbon in the whole system (t/hr).

IV. TECHNOLOGY DESCRIPTION AND SUB-SYSTEM CALCULATION

A. Coal Preparation

The properties of the coal (bituminous) used for the study is shown in table 1.
**TABLE I. PROPERTIES OF COAL**

<table>
<thead>
<tr>
<th></th>
<th>Ultimate (dry basis)</th>
<th>Proximate (dry basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon (wt%)</td>
<td>74.71</td>
<td>72.32</td>
</tr>
<tr>
<td>Hydrogen (wt%)</td>
<td>3.40</td>
<td>11.65</td>
</tr>
<tr>
<td>Oxygen (wt%)</td>
<td>4.66</td>
<td>16.02</td>
</tr>
<tr>
<td>Nitrogen (wt%)</td>
<td>0.96</td>
<td>1.19</td>
</tr>
<tr>
<td>Sulfur (wt%)</td>
<td>0.24</td>
<td>28707</td>
</tr>
</tbody>
</table>

**B. Gasification Process**

Both Shell and GSP employ dry pulverized coal feeding system and GE employs coal slurry feeding system. The operation parameters such as temperature and pressure are assumed based on the actual processes which are detailed presented in researches [24, 25].

![Diagram](https://via.placeholder.com/150)

**Figure 1. The systems of FT liquids-electricity based on different gasification.**

1) **Shell gasification process**

Mixture of pulverized coal (with water no more than 2% by weight), additive limestone, pure oxygen and steam are fed into gasifier. The operating pressure and temperature are 4.0MPa and 1400°C. Liquid slag flows down the wall and discharge from the bottom, raw syngas lets out from the top and is quenched by cycled cooled-gas to 900°C to avoid sticking of fly ash in boiler. The raw syngas is cooled down to 350°C in the boiler and enters wet scrubbing system (washing tower), where a majority of fly ash and water-soluble contaminants (primarily HCN, NH3, and chlorides) are removed. In the gasification unit, 5.2MPa steam is generated, partial of which is used for WGS unit.

2) **GSP gasification process**

Similar to Shell technology, GSP process operates under the condition of 4.0 MPa, 1400°C -1600°C. Coal powder is also fed into the gasifier using CO2 as the carrier. The one of differences between the two processes is GSP adopts chilled water to cool the hot syngas and Shell adopts cycled cooled-gas. The chilled water is injected into a venturi to make the hot syngas temperature decrease to about 210 °C. At the same time, the water vapor is saturated in the raw syngas. And then the saturated syngas enters the washing tower scrubber to get rid of the remaining fly ash and the temperature drops to about 200 °C.

3) **GE gasification process**

For GE gasifier, the coal slurry and oxygen are injected from the top of the gasifier. The operating temperature and pressure are 1360°C and 5.0MPa. The hot raw syngas is firstly cooled down to 720°C in a radiant cooler where 4.0MPa steam is generated, and then enters the water scrubber. By carefully adjusting the washing water amount, the syngas temperature maintains about 200°C to meet the requirement of the starting temperature of the WGS reaction. The slag settles in the quench water at the bottom of the radiant cooler and is removed by the slag removal system. All particulate and most water-soluble contaminant are removed in the water scrubber just like Shell process.

Gibbs models are employed to simulate the gasifiers for Aspen Plus. The results of simulation are shown in Table 2.
C. Water-gas Shift Process

WGS process is applied to increase the H2/CO ratio to meet the need of FT synthesis. The main reaction in WGS reactor is:
\[ \text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2 \quad \Delta H = -41.09 \text{ kJ/mol (298.15K)}. \]

Different catalysts have been developed for WGS reactions, including Fe-Cr based high temperature catalysts, Cu-Zn-Al based low temperature catalysts and Co-Mo based sulfur-tolerant catalysts [26, 27]. Co-Mo catalyst can be used in a wide range of temperature. Moreover, the organic sulfur compounds can be hydrolyzed on Co-Mo catalyst and become easier to be removed from the raw syngas [28]. So Co-Mo catalyst is selected for WGS reaction.

Multistage adiabatic fixed bed reactors are employed in WGS section. In Aspen Plus, two REquil model series run to realize appropriate H2/CO ratio about 1.5 for FT synthesis.

To meet the requirement of catalyst, the temperature is controlled within 200°C–455°C and the pressure is 3.5MPa. The extra water vapor need to be injected because there is no enough water vapor amount satisfy WGS reaction in the Shell’s syngas. Saturated vapor (5.2MPa) produced in Shell gasification process can be used to supplement the shortage of water vapor from the perspective of the system optimization. Calculation shows molar ratio of the injected water vapor to the syngas is 0.15:1, while GSP and GE synthesis gas contains enough water vapor and there is no need to add extra water vapor.

A series of heat exchangers and boilers are connected to control reaction temperature and generate the saturated steam of 3.5MPa and 0.6MPa. The shifted syngas is finally cooled down to 15°C, and then is sent to acid gas removal process.

D. Acid Gas Removal and Sulfur Recovery

Both Rectisol and Selexol are advanced acid gas removing process. However, Rectisol process has more advantages such as less utilities consumption, less operation cost and investment [29]. So it is employed here to remove acid gas including H2S, COS, and CO2 before the shifted syngas goes into FT synthesis reactors and gas turbines [30]. In order to simplify the calculation, it is assumed that 100% of sulfides are removed. Since Fe-based catalysts require the content of CO2 in the syngas is no more than 1% (mol%) to ensure well-balanced FT synthesis reaction, the rest of CO2 must be removed. The previous research showed the high partial pressure of CO2 enhanced the reverse reaction rate of the WGS and decreased the CO2 formation rate [31]. The CO2 selectivity decreased rapidly when a large amount of CO2 is in the feed gas, while the hydrocarbon formation rate decreased slightly and the overall oxygenate formation rate decreased. Absorber for CO2 sequestration operates under 3.0MPa and cryogen of 0.1 MJ/kg syngas is necessary to maintain the methanol temperature under -55 °C [32].

E. Fischer-Tropsch Synthesis

Fischer-Tropsch technology can be briefly defined as the means used to convert syngas containing hydrogen and carbon monoxide to hydrocarbon products. From 1980’s, slurry phase reactors was used to ultimately produce mainly diesel with naphtha as a significant co-product by using a scheme in which the reactor wax is hydrocracked [33]. H2/CO ratio of the feed gas of FT synthesis process varies in a wide range. Dry reported the H2/CO ratio (by moles) into slurry reactor for iron catalyst was 1.7 [34]. But in other studies, the H2/CO ratio seemed in favor of 0.67 [35, 36]. And then, a series of iron based catalysts were improved and ran at the mole ratio from 1.0 to 1.7 in the pilot plant test. The pilot test results showed that the iron based catalysts which acclimatized to the radio of 1.5 is favorable, so in this paper, H2/CO ratio of the shifted syngas is assumed to be 1.5.

Based on the researches of catalysts performance in FT synthesis, Fe based catalyst and slurry reactors are employed for this study [37, 38]. In FT synthesis, CO and H2 react exothermically in the presence of the catalysts to produce hydrocarbons, ranging from methane to high molecular weight hydrocarbons.

### TABLE II. THE RESULTS COMPARISON OF COAL GASIFICATION PROCESSES

<table>
<thead>
<tr>
<th>Components and parameter</th>
<th>Shell</th>
<th>GSP</th>
<th>GE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO (%)</td>
<td>69</td>
<td>69.03</td>
<td>42.4</td>
</tr>
<tr>
<td>H2 (%)</td>
<td>22.88</td>
<td>22.89</td>
<td>25.18</td>
</tr>
<tr>
<td>CO2 (%)</td>
<td>3.43</td>
<td>3.43</td>
<td>13.71</td>
</tr>
<tr>
<td>H2O (%)</td>
<td>3.5</td>
<td>3.5</td>
<td>16.87</td>
</tr>
<tr>
<td>CH4 (%)</td>
<td>0.05</td>
<td>0.04</td>
<td>0.22</td>
</tr>
<tr>
<td>N2 (%)</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
</tr>
<tr>
<td>H2S/COS (%)</td>
<td>0.08</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td>Else (%)</td>
<td>0.69</td>
<td>0.66</td>
<td>1.18</td>
</tr>
<tr>
<td>Average molecular weight</td>
<td>22.2</td>
<td>22.1</td>
<td>21.78</td>
</tr>
<tr>
<td>mole flow rate (kmol/hr)</td>
<td>90343</td>
<td>90349</td>
<td>108838</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>1400</td>
<td>1400</td>
<td>1360</td>
</tr>
<tr>
<td>Pressure (MPa)</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>O2/coal (kg/1000kg)</td>
<td>835.5</td>
<td>835.6</td>
<td>958.5</td>
</tr>
<tr>
<td>Steam/coal (kg/1000kg)</td>
<td>120</td>
<td>120</td>
<td>-</td>
</tr>
<tr>
<td>CO2/coal (kg/1000kg)</td>
<td>157.2</td>
<td>157.2</td>
<td>-</td>
</tr>
<tr>
<td>Coal slurry (wt%)</td>
<td>-</td>
<td>-</td>
<td>65.7</td>
</tr>
<tr>
<td>Steam output (t/hr)</td>
<td>1244.7</td>
<td>-</td>
<td>1484.4</td>
</tr>
<tr>
<td>Cool gas efficiency (%)</td>
<td>80.1</td>
<td>80</td>
<td>70.1</td>
</tr>
</tbody>
</table>
weight wax (>Cn42). The offgas composed of hydrocarbons, CO₂, H₂O, unreacted CO and H₂ is entrained to a series of equipment to get heavy oil (Cn10–Cn20), light oil (Cn5–Cn10), liquid petroleum gas (LPG, Cn3–Cn4), CO₂ and high purity H₂ (99.99%, mol%). The pure H₂, which is separated from the offgas by using the pressure swing adsorption (PSA) process operating at 2.0 MPa, is ready for syncrude upgrading. The final tail gas with low pressure is compressed and fed to the gas turbine system for the electricity generation. Figure 2 is a simple flow sheet of the FT synthesis process and the Tail gas process.

Under the action of the Fe based catalyst, the olefin/paraffin ratio of products from the slurry reactor was significantly greater than that from the fixed bed reactor, attributed at least in part to less secondary hydrogenation of olefins in the slurry reactor because of dilution [39]. A classic kinetics built on the industrial Fe based catalyst is applied for this paper [40]. The detailed hydrocarbon distributions is gotten from the data base which is depended on the tests of demonstration plant so the data is an empirical correlation to a certain extent. The hydrocarbon distributions is as following: CH₄, 4.4% (wt%), C₂H₄, 1.8% (wt%), C₂H₆, 2.7% (wt%), LPG, 11.2% (wt%), light oil, 30.5% (wt%), heavy oil, 16.8% (wt%), wax, 32.7% (wt%). In addition, the overall CO conversion (X_CO) is assumed to be 0.96, CO₂ selectivity (S_CO₂) is 0.21. The other parameters such as temperature and pressures are shown in Fig. 2. The simulation proposes an empirical correlation for more detailed.

F. Upgrading Process

The olefins and oxygenated components in the syncrude are all converted into saturated paraffines in hydrogenation reactors. These paraffins with large molecular weight are further cracked into hydrocarbons with short chain length which fall into the range of the diesel fuels or naphtha. In the distilling tower, the different products are separated according to their different boiling point. The dry gas (including unreacted CO, methane, ethane, excessive H₂ and traces of other components) generated in the course of upgrading processing is also sent to the gas turbine for electricity generation. As the mass flow rate of feedstock (syncrude) is 1 kg/hr, the relative mass flow rates of the main products are 0.25 kg/hr (naphtha), 0.72 kg/hr (diesel). The dry gas of 0.03kg/hr (including unreacted CO, methane, ethane, excessive H₂ and traces of other components) generated in the course of upgrading processing is also sent to the gas turbine for electricity generation.

G. CO₂ Capture

CO₂ is removed in Rectisol process and the carbon removal unit of the FT synthesis process. The simulation shows most of CO₂ (about 97.4% of all CO₂ in the syngas) is removed in Rectisol process and the rest CO₂ about 2.6% is removed in the carbon removal unit. As a result, the content of CO₂ in FT-offgas is maintained about 1% (mol%). The CO₂-rich solution is sent to the regenerator where CO₂ is released and the regenerated solution is recycled to the entrance of absorbers.

H. Combined Cycle Process

The fuel gas is composed of tail gas from PSA and the dry gas from upgrade section. In addition, the net output steams from gasification-FT-liquid process are sent to the heat recovery steam generator (HRSG), where the superheated steam is generated. Then the superheated steam is sent to the steam turbine for electricity production. In Fig. 3, LP means low pressure ranging from 0.1 to 1.5 MPa and MP means middle pressure ranging from 2.5 to 3.5 MPa.
those of Case 3 (based on GE gasification). This is because the quantity of the effective components of CO and H₂ are similar in raw syngas of Case 1 and Case 2. And they are 10% higher than those from Case 3. As to generating capacity of power in the three cases, they are similar when they are generated from gas turbine because FT synthesis processes of the three design options are the same and then combustible components and flow are similar in the tail gas. However, different gasification processes make the steam output quite different, which makes the generating capacity of the steam turbine significantly different. The generating capacity of the byproduct steam of the GSP in Case 2 is remarkably lower than those of the other two systems. Since the syngas are the aimed products and electricity is secondary, valuable syngas is firstly used in the production of the FT liquids. The lower energy of tail gas results in remarkably lower than those of the other two systems. Since the steam turbine is mainly concentrated at the waste heat boiler exit of the combined cycle unit, are 71.6t/hr, 71.5t/hr and 70.1t/hr respectively. Amount of carbon emission occupies 2.5%, 2.5% and 2.6% of the total carbon in the three cases. However, considering the indirect emissions of the compression, the carbon emission is more than these amounts.

### TABLE III. SIMULATION RESULTS OF THE INTEGRATED SYSTEMS BASED ON DIFFERENT GASIFICATION PROCESSES

<table>
<thead>
<tr>
<th>Items</th>
<th>Input and output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Case 1</td>
</tr>
<tr>
<td>Feedstocks</td>
<td></td>
</tr>
<tr>
<td>Coal (t/hr/°C)</td>
<td>-1000/80</td>
</tr>
<tr>
<td>Limestone (t/hr/°C)</td>
<td>-107/80</td>
</tr>
</tbody>
</table>

The results also indicate what contributions the cases make to the environment. There are two decarburization segments in the systems. Most CO₂ is generated from the water-gas shift reaction and is captured in Rectisol process. A small amount of CO₂ comes from FT synthesis process, where WGS reaction takes place on Fe based catalysts. It is shown in Table 4, the captured CO₂ in three cases are 1707.4t/hr, 1706.5t/hr and 1644.3t/hr respectively, and are equivalent to 58.2%, 58.6% and 59.5% of the ratio of captured carbon elementals amount to the total carbon elementals respectively. CO₂ emissions, which are mainly concentrated at the waste heat boiler exit of the combined cycle unit, are 71.6t/hr, 71.5t/hr and 70.1t/hr respectively. Amount of carbon emission occupies 2.5%, 2.5% and 2.6% of the total carbon in the three cases. However, considering the indirect emissions of the compression, the carbon emission is more than these amounts.
Energy consumption because higher ratio of H₂/CO in the process. These two processes based on GE have lower 2.6%-4.4% is caused by WGS process and the purification steam. In different gasification processes, energy loss of the latter (f, in Table 4) significantly decrease. The reason is similar syngas composition due to the similar syngas based on Shell and GSP gasification processes have the highest EFF of 47.7%, the system based on GE gasification process has the lowest EFF of 40.6%.

Shell and GSP processes have high cold gas efficiency. Compared with GSP, Shell gasification process can take full advantage of the gas sensible heat. Extra power generation can make the total efficiency increase nearly three percentage points. GE process produces steam of 4.0MPa for electricity generation and needs no steam injection for WGS. However, the coal slurry feed results in the lowest cold gas efficiency (approximately below 10%), which makes this program has no advantages from the view of thermal efficiency.

The systems based on coal gasification imply a good chance for reducing greenhouse gas emission. The calculation results show that the captured CO₂ in three cases are 1707.4t/hr, 1706.5t/hr, and 1644.3 t/hr, respectively. It is equivalent to recycle 58.7%, 58.6% and 59.5% of the total carbon content in the system. Since the indirect emissions of the compression are not considered, the actual captured carbon is lower than the calculated value.

VI. CONCLUSION

This paper investigates the processes based on commercially ready technology to convert coal to liquid fuels and waste energy utilization with CO₂ sequestration. Three cases have been analyzed and the following conclusions can be drawn.

The integrated system based on Shell gasification process has the highest EFF of 47.7%, the system based on GE gasification process has the lowest EFF of 40.6%.

As can be seen from the results in Table 4, the systems based on Shell and GSP gasification processes have the similar energy distribution due to the similar syngas composition. However, steam generating capacity of the latter (f, in Table 4) significantly decrease. The reason is water chilling process sharply reduce the byproduct of the steam. In different gasification processes, energy loss of 2.6%-4.4% is caused by WGS process and the purification process. These two processes based on GE have lower energy consumption because higher ratio of H₂/CO in the raw syngas makes CO conversion lower to meet the need of H₂/CO = 1.5 (molar ratio) for FT synthesis process. To FT synthesis and upgrading process, the purified syngas is made as calculating basis, the same ratio of H₂/CO and the same operating conditions (including temperature, pressure and recycle ratio, etc) result in similar energy efficiency. At the same time, similar tail gas composition and molar flow rate (Based on the GE process, the molar flow rate of the tail gas accounted for about 97% of Shell and GSP) get similar gas-fired power generation efficiency, up to about 56%.

The energy distribution calculated by only considering coal energy transition limitedly reveals the main change trend. However, energy consumption of ASU is important to the overall systems. According to the results of calculation, electricity consumption of ASU is about 357 MW -359MW, which occupies 70%-72% of total electricity consumption. And the total electricity consumption equals to about 6%-7% of total coal energy input.

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