Assessment of lignite to liquid oil system

1. Background & Target
2. Idea & Scheme
3. Methods
4. Results & Discussions
5. Concluding remarks

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1. Why do we do research on lignite?

- Lignite---an unfully used coal
  - 211.8 billion tonnes, (12.69% of the total reserves); North east Inner Mongolia and Yunnan
  - Mainly used in pithead power plants; Cause environmental problems (SO$_2$, NO$_X$, CO$_2$ etc.)

- Lignite---a low-rank coal

Compared with other high rank coals:

<table>
<thead>
<tr>
<th>Disadvantages:</th>
<th>Advantage:</th>
</tr>
</thead>
<tbody>
<tr>
<td>High moisture content</td>
<td>relatively cheap</td>
</tr>
<tr>
<td>High volatile content</td>
<td></td>
</tr>
<tr>
<td>High ash content</td>
<td></td>
</tr>
<tr>
<td>Low heat value</td>
<td></td>
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<tr>
<td>Low ignition point</td>
<td></td>
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</tbody>
</table>

**Higher cost** to utilize the lignite
*(inevitable, but could take some actions to make it deserving)*

Enhance the added **value** of products and reduce the **production cost**
1. What can we do with lignite

<table>
<thead>
<tr>
<th>Solid</th>
<th>Gas</th>
<th>Liquid</th>
<th>Final product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite</td>
<td>Drying</td>
<td>Steam</td>
<td>Water</td>
</tr>
<tr>
<td></td>
<td>Pyrolysis</td>
<td>Steam &amp; tar &amp;</td>
<td>Tar</td>
</tr>
<tr>
<td></td>
<td>Gasification</td>
<td>combustible gas</td>
<td>Other methods</td>
</tr>
<tr>
<td></td>
<td>Ash</td>
<td>Synthesis</td>
<td>Materials</td>
</tr>
</tbody>
</table>

- to develop a reasonable deep processing technology
- to investigate the key elements in the process
- to investigate the CO₂ emission in the lignite deep processing
1. Background & target---product selection

- Lignite pyrolysis
  - tar
  - char
  - gas
  - Methanol
  - formaldehyde
  - Acetic acid
  - olefins
  - aromatics
  - chemicals
  - Motor fuel
  - DME
  - fuels
  - gas
  - Gasoline cut
  - Diesel cut
  - Paraffin wax
  - A lot of choices

- Lignite gasification
  - syngas
  - Electricity
  - F-T oil

- hydrogenation
  - oil
  - Demand of gasoline and diesel
  - simplifying downstream treating
  - Energy safety strategy

- Complementation
  - Increase oil production
  - Share the same equipments

- Social needs and the market

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Part 1

System integration and assessment
Foundation of the lignite to oil process

Lignite $\rightarrow$ Drying + pyrolysis $\rightarrow$ Tar hydrogenation + gasification + F-T synthesis $\rightarrow$ Separation $\rightarrow$ Products

Process diagram of the new coproduction system
Key variable analysis and evaluation

Lignite to oil production system

Evaluation: Energy, Economy, CO₂ emission

Power demand

Energy available

Moisture of lignite

Net fixed carbon

For burning

Output

Amount of SHC

Reborn and recycle

For gasification

Syngas

F-T synthesis

WGS shift

Energy demand

Drying

Pyrolysis

For burning

Output

Amount of SHC

Reborn and recycle

Power demand

Fixed handling scale
(5 million t/a)

Note:
Output: tar, pyrolysis gas
SHC=solid heat carriers
Power demand: compressor, transportation

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Methods

◆ Energy evaluation

➢ Energy efficiency of lignite to oil = \( \frac{\text{Energy of oil products}}{\text{Energy of lignite}} \)

Based on LHV

➢ The total energy efficiency = \( \frac{\text{The total energy output}}{\text{The total energy input}} \)

◆ Economy evaluation

➢ Investment in unit oil product = \( \frac{\text{The total investment}}{\text{Oil production}} \)

➢ Internal rate of return (IRR) (estimate economic reliability and feasibility)

✔ Two price margins (the most favorable one and the least favorable one) are set to study the economic performance of the system.
Results ---- Energy efficiency

- Effect of different gasifiers and moisture contents on energy utilization under different bases

- F-T synthesis without power generation shows higher total energy efficiency

- Shell gasifier: presenting higher energy efficiency
Results ---- Economic performance

- Effect of different gasifiers and moisture contents on economic performance of the system

- Reducing moisture content can reduce unit investment and improve IRR
- System with Texaco gasifier shows better economic performance

- System with power island is better in economy

Graphs showing the impact of moisture content on total capital investment and IRR for different gasifiers.
Part 2

$\text{CO}_2$ control of the lignite to oil system
Idea & scheme: CO₂ control

◆ General idea :
Control CO₂ emission reduction inside the system based on the features of the system

◆ Main ways :
Converting produced CH₄ and CO₂ to H₂ and CO using CH₄ reforming

◆ Features
  ➢ CH₄ reforming as one of supplementary means in CO₂ emission control
  ➢ lignite to oil system provides a specific platform for CH₄ reforming
  ➢ CH₄ comes from the system itself, no external source
Idea & scheme: CO₂ control

◆ CH₄-CO₂ reforming and CH₄-H₂O reforming

- CH₄-CO₂ reforming: CO₂ control after its generating
  \[ CH_4 + CO_2 = 2CO + 2H_2 \]

- CH₄-H₂O reforming: CO₂ source control before its generating
  \[ CH_4 + H_2O = CO + 3H_2 \]

Reduce CO₂ emission from WGS: CO+H₂O=CO₂+H₂

◆ Sources of CH₄-H₂O-CO₂

- CO₂ sources
  - gasification
  - Solid heat carrier regeneration (char or syngas combustion)
  - WGS

- CH₄ sources
  - F-T synthesis
  - Lignite pyrolysis

- H₂O(steam) sources
  - Drying & pyrolysis
Idea & scheme: CO₂ control

Effects of pyrolysis — Energy demand of pyrolysis process

Advantages:
1. Cleaner than char
2. Without blending and separation (char, solid heat carriers, ash)

Disadvantages:
1. Increases gasification load
2. Some equipments should be improved

The four key variables
1. CH₄ reforming type
2. The source of CH₄
3. The ways of solid heat carriers regeneration
4. Gasifier types

VS
No reforming scenario

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Results

**Comparison of CO apparent conversion efficiency**

\[
\text{CO apparent conversion efficiency} = \frac{\text{The amount of CO converted into oil}}{\text{The amount of CO from gasified gases}}
\]

<table>
<thead>
<tr>
<th></th>
<th>Reforming</th>
<th>No reforming</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syngas not to combust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry-powder</td>
<td>49.4&lt;sup&gt;a&lt;/sup&gt;/50.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>54.9&lt;sup&gt;a&lt;/sup&gt;/56.1&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Coal-water slurry</td>
<td>54.3&lt;sup&gt;a&lt;/sup&gt;/54.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>61.3&lt;sup&gt;a&lt;/sup&gt;/62.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Case 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syngas to combust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry-powder</td>
<td>/37.8&lt;sup&gt;b&lt;/sup&gt;</td>
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</tr>
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<td>/38.9&lt;sup&gt;b&lt;/sup&gt;</td>
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</tr>
</tbody>
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- **Case 1** has more potential in CO<sub>2</sub> emission reduction.
- Using **Dual-CH<sub>4** and CH<sub>4</sub>-H<sub>2</sub>O reforming** has higher CO apparent conversion efficiency.
- Coal water slurry gasification is better for CO<sub>2</sub> control.
Results

**Comparison of CO₂/C_{hydrocarbon}**

From element point of view:

lignite = “feedstock carbon”, CO₂ = “waste carbon”, C_{hydrocarbon} = “product carbon”

\[
\frac{CO_2}{C_{hydrocarbon}} \rightarrow \text{Carbon in raw material} \rightarrow \text{Processing} \rightarrow \text{Waste carbon} \rightarrow \text{Product carbon}
\]

<table>
<thead>
<tr>
<th>CO₂/C_{hydrocarbon}</th>
<th>Reforming</th>
<th>No reforming</th>
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<tbody>
<tr>
<td>Single-CH₄</td>
<td>Dual-CH₄</td>
<td></td>
</tr>
<tr>
<td>Case 1</td>
<td>Syngas not to combust</td>
<td>Dry-powder</td>
</tr>
<tr>
<td></td>
<td>Coal-water slurry</td>
<td>1.65ᵃ/1.6ᵇ</td>
</tr>
<tr>
<td>Case 2</td>
<td>Syngas to combust</td>
<td>Dry-powder</td>
</tr>
<tr>
<td></td>
<td>Coal-water slurry</td>
<td>/3.3ᵇ</td>
</tr>
</tbody>
</table>

a : CH₄-CO₂ reforming; b : CH₄-H₂O reforming ;
Single-CH₄ : CH₄ from F-T products ; Dual-CH₄ : CH₄ from F-T products and pyrolysis products
5. Concluding remarks

Such an lignite based liquid-oil aimed coproduction system is able to:

- provide multiple products (motor fuels, phenols and gases or electricity)
- improve liquid oil yield and reduce a part of fixed investment
- reach a relatively high energy efficiency (~40% LHV), and IRR (~20% for the best case)
- CO₂ emission of unit oil product is 7.5-9.5 t/t

• The system produces insufficient CH₄, so WGS reaction is still necessary to provide H₂

*If external CH₄ is added into the system, WGS can be avoided and more CO₂ emission can be reduced*

• The pyrolysis process provides most of the CH₄, but it also generates a large part of CO₂

*If pyrolysis can be done by non-carbon based energy, CO₂ emission will be much less*
Acknowledgements

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