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Produced by the NASA Center for Aerospace Information (CASI)
HYDROGEN PRODUCTION FROM COAL

Interim Report
Project 8963

Based on
"Study of Conversion of Coal to
Hydrogen, Methane, and Liquid Fuels for Aircraft"

for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
Contract NAS1-13620

Presented at
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Marshall Space Flight Center, Alabama

April 24, 1975
MONTANA SUBBITUMINOUS COAL

**PROXIMATE ANALYSIS**

<table>
<thead>
<tr>
<th>Component</th>
<th>wt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>22.0</td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>29.4</td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>42.6</td>
</tr>
<tr>
<td>Ash</td>
<td>6.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

**ULTIMATE ANALYSIS (Dry)**

<table>
<thead>
<tr>
<th>Component</th>
<th>wt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>67.70</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>4.61</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.85</td>
</tr>
<tr>
<td>Oxygen</td>
<td>18.46</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.66</td>
</tr>
<tr>
<td>Ash</td>
<td>7.72</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

**DRY HEATING VALUE, Btu/lb**

11,290
MONTANA SUBBITUMINOUS COAL

Typical of Western coals (subbituminous and lignite)
In contrast to Eastern bituminous

• High moisture
• Low sulfur
• High oxygen
• Low-heating value

Low sulfur allows burning under boiler without exceeding 1.2 lb $SO_2$/million Btu.
GASIFICATION

COAL + WATER $\longrightarrow$ HYDROGEN + CARBON DIOXIDE

$\text{CH}_{0.8} + 2\text{H}_2\text{O} \longrightarrow 2.4\text{H}_2 + \text{CO}_2$ - HEAT

$\text{CH}_{0.8} + 1.2\text{O}_2 \longrightarrow 0.4\text{H}_2\text{O} + \text{CO}_2$ + HEAT

SHIFT

CO + H$_2$O $\longrightarrow$ H$_2$ + CO$_2$ + HEAT

METHANATION

CO + 3H$_2$ $\longrightarrow$ CH$_4$ + H$_2$O + HEAT
GASIFICATION REACTIONS

- Most of $H_2$ produced comes from $H_2O$
- C of coal used to remove the O of $H_2O$ as $CO_2$
- $H_2$ production requires heat
- Heat required comes from burning coal
  O$_2$ for combustion from air
  N$_2$ from air cannot be tolerated in product $H_2$
- CO formed along with $CO_2$
  Shift converts CO to $H_2$ and $CO_2$
- Methanation removes CO to safe level
TYPES OF GASIFIERS

- SUSPENSION (Entrained) COMBUSTION
  KOPPERS-TOTZEK

- FLUIDIZED BED
  U-GAS™

- MOVING BED
  LURGI
TYPES OF GASIFIERS

- Classify according to method of contacting coal with gasification agent
- Temperature and pressure important
KOPPERS-TOTZEK GASIFICATION FOR HYDROGEN

PULVERIZED COAL

OXYGEN

STEAM

GASIFIER

2730°F

WASTE-HEAT RECOVERY

WATER SCRUBBER

ELECTROSTATIC PRECIPITATOR

ASH

H₂S REMOVAL

SHIFT

CO₂ REMOVAL

METHANATION

DRYER

STEAM

A75040753
KOPPERS-TOTZEK PROCESS

- Coal entrained in oxygen to burner
- Low pressure
- High temperature
- Ash removed as slag
U-GAS™ GASIFIER FOR HYDROGEN

CRUSHED COAL

1900°F

WASTE-HEAT RECOVERY

DUST REMOVAL

H₂S REMOVAL

SHIFT

CO₂ REMOVAL

METHANATION

DRYER

STEAM

ASH

OXYGEN

STEAM
U-GAS™ PROCESS

- Coal fluidized by steam and ox/gen mix
- Medium pressure (350 psig)
- Moderate temperature
- Ash removal as agglomerates
LOCK HOPPER FEED SYSTEM

A75040759
LOCK HOPPER FEED SYSTEM

- Moves coal from low pressure to high pressure
- Not commercialized over 350 psi
- Alternate is pumped slurry feed
STEAM-IRON REACTIONS

OXIDIZER: $3\text{FeO} + \text{H}_2\text{O} \rightarrow \text{Fe}_3\text{O}_4 + \text{H}_2$

REDUCTOR: $\text{Fe}_3\text{O}_4 + \text{H}_2 \rightarrow 3\text{FeO} + \text{H}_2\text{O}$

PRODUCER: $\begin{align*}
\text{C} + \text{H}_2\text{O} &\rightarrow \text{CO} + \text{H}_2 \quad \text{HEAT} \\
\text{C} + \text{O}_2 + \text{N}_2 &\rightarrow \text{CO} + \text{N}_2 \quad \text{HEAT}
\end{align*}$

\text{AIR}
STEAM-IRON REACTIONS

- Makes very pure $\text{H}_2$
- No need for separating $\text{N}_2$ from $\text{O}_2$
STEAM-IRON PROCESS

- Medium pressure
- Moderate temperature
- Simplified raw gas treating (no shift)
- Spent producer gas utilized for power generation
RAW GAS COMPOSITIONS
mol % (Dry Basis)

<table>
<thead>
<tr>
<th></th>
<th>K-T</th>
<th>U-GAS™</th>
<th>STEAM-IRON</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>58.3</td>
<td>50.1</td>
<td>1.4</td>
</tr>
<tr>
<td>CO₂</td>
<td>10.0</td>
<td>11.5</td>
<td>0.2</td>
</tr>
<tr>
<td>H₂</td>
<td>30.4</td>
<td>35.3</td>
<td>95.9</td>
</tr>
<tr>
<td>CH₄</td>
<td>—</td>
<td>2.1</td>
<td>—</td>
</tr>
<tr>
<td>N₂ + Ar</td>
<td>1.0</td>
<td>0.7</td>
<td>2.5</td>
</tr>
<tr>
<td>H₂S + COS</td>
<td>0.3</td>
<td>0.3</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

PRESSURE, psia
- K-T: 15
- U-GAS™: 350
- STEAM-IRON: 350
RAW GAS COMPOSITIONS

- K-T and U-GAS™ require extensive shift
- Very low sulfur in steam-iron gas
### PRODUCT GAS COMPOSITION

**mol% (Dry Basis)**

<table>
<thead>
<tr>
<th></th>
<th>K-T</th>
<th>U-GAS&lt;sup&gt;TM&lt;/sup&gt;</th>
<th>STEAM-IRON</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>CO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>&lt;50 ppm</td>
<td>&lt;50 ppm</td>
<td>0.1</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;</td>
<td>93.1</td>
<td>94.3</td>
<td>95.7</td>
</tr>
<tr>
<td>CH&lt;sub&gt;4&lt;/sub&gt;</td>
<td>5.5</td>
<td>4.8</td>
<td>1.5</td>
</tr>
<tr>
<td>N&lt;sub&gt;2&lt;/sub&gt; + Ar</td>
<td>1.3</td>
<td>0.8</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

---

A75040760
PRODUCT GAS COMPOSITIONS

- All CO reduced to 0.1%
- CO₂ for K-T and U-GAS™ reduced to <50 ppm during acid-gas removal
- CO₂ for steam-iron reduced to 0.1% by methanation
<table>
<thead>
<tr>
<th></th>
<th>K-T</th>
<th>U-GAS™</th>
<th>STEAM-IRON</th>
</tr>
</thead>
<tbody>
<tr>
<td>COAL, lb/hr (Dry Basis)</td>
<td>1,276,454</td>
<td>1,124,128</td>
<td>2,070,426</td>
</tr>
<tr>
<td>STEAM, lb/hr</td>
<td>270,164</td>
<td>375,776</td>
<td>4,599,209</td>
</tr>
<tr>
<td>OXYGEN, tons/day</td>
<td>12,092</td>
<td>8,631</td>
<td>17,368*</td>
</tr>
</tbody>
</table>

(* in Air)

**STEAM TO SHIFT**

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>lb/hr</td>
<td>86,585</td>
<td>790,758</td>
<td>—</td>
</tr>
</tbody>
</table>

A75040749
GASIFIER FEED QUANTITIES

- Coal, steam, and oxygen to steam-iron higher than to K-T or U-GAS®

- But steam-iron does not require air separation plant. Also no shift steam
PROCESS EFFICIENCY

<table>
<thead>
<tr>
<th></th>
<th>K-T</th>
<th>U-GAS™</th>
<th>STEAM-IRON</th>
</tr>
</thead>
<tbody>
<tr>
<td>REACTOR COAL, lb/hr (Dry Basis)</td>
<td>1,276,454</td>
<td>1,124,128</td>
<td>2,070,426</td>
</tr>
<tr>
<td>BOILER COAL, lb/hr (Dry Basis)</td>
<td>340,314</td>
<td>269,634</td>
<td></td>
</tr>
<tr>
<td>TOTAL COAL, lb/hr (Dry Basis)</td>
<td>1,616,768</td>
<td>1,393,762</td>
<td>2,070,426</td>
</tr>
<tr>
<td>HHV TOTAL COAL, 10^6 Btu/hr*</td>
<td>18,253</td>
<td>15,736</td>
<td>23,375</td>
</tr>
<tr>
<td>HHV PRODUCT GAS, 10^6 Btu/hr†</td>
<td>10,416</td>
<td>10,416</td>
<td>10,416</td>
</tr>
<tr>
<td>% CONVERTED TO PRODUCT GAS</td>
<td>57.1</td>
<td>66.2</td>
<td>44.6</td>
</tr>
<tr>
<td>BY-PRODUCT POWER, kW</td>
<td>—</td>
<td>—</td>
<td>980,000</td>
</tr>
</tbody>
</table>

* At 11,290 Btu/lb.
† At 250 billion Btu/day.
PROCESS EFFICIENCY

- K-T boiler coal higher than U-GAS® because of higher oxygen, higher gasification temperature, and more shift
- High total coal for steam-iron because of heat in spent reductor gas
## PROCESS EFFICIENCY

<table>
<thead>
<tr>
<th></th>
<th>K-T</th>
<th>U-GAS™</th>
<th>STEAM-IRON</th>
<th>METHANE BY HYGAS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>REACTOR COAL, lb/hr (Dry Basis)</strong></td>
<td>1,276,454</td>
<td>1,124,128</td>
<td>2,070,426</td>
<td>1,108,198</td>
</tr>
<tr>
<td><strong>BOILER COAL, lb/hr (Dry Basis)</strong></td>
<td>340,314</td>
<td>269,634</td>
<td>---</td>
<td>206,407</td>
</tr>
<tr>
<td><strong>TOTAL COAL, lb/hr (Dry Basis)</strong></td>
<td>1,616,768</td>
<td>1,393,762</td>
<td>2,070,426</td>
<td>1,314,605</td>
</tr>
<tr>
<td><strong>HHV TOTAL COAL, 10^6 Btu/hr</strong></td>
<td>18,253</td>
<td>15,736</td>
<td>23,375</td>
<td>14,842</td>
</tr>
<tr>
<td><strong>HHV PRODUCT GAS, 10^6 Btu/hr</strong></td>
<td>10,416</td>
<td>10,416</td>
<td>10,416</td>
<td>10,416</td>
</tr>
<tr>
<td><strong>% CONVERTED TO PRODUCT GAS</strong></td>
<td>57.1</td>
<td>66.2</td>
<td>44.6</td>
<td>70.2</td>
</tr>
<tr>
<td><strong>BY-PRODUCT POWER, kW</strong></td>
<td>---</td>
<td>---</td>
<td>980,000</td>
<td>---</td>
</tr>
</tbody>
</table>

* At 11,290 Btu/lb.
† At 250 billion Btu/day.
PROCESS EFFICIENCY

- Methane production by HYGAS® Process has higher efficiency than hydrogen production processes
STEAM-IRON PROCESS FOR HYDROGEN VALUATION OF BY-PRODUCT POWER

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BY-PRODUCT POWER, kW</td>
<td>980,000</td>
</tr>
<tr>
<td>EQUIVALENT Btu AT 7300 Btu/kWhr, 10⁶ Btu/hr</td>
<td>7154</td>
</tr>
<tr>
<td>HHV PRODUCT GAS, 10⁶ Btu/hr</td>
<td>10416</td>
</tr>
<tr>
<td>TOTAL</td>
<td>17,570</td>
</tr>
<tr>
<td>HHV COAL, 10⁶ Btu/hr</td>
<td>23,375</td>
</tr>
<tr>
<td>OVERALL EFFICIENCY, %</td>
<td>75.2</td>
</tr>
</tbody>
</table>
STEAM-IRON PROCESS -
VALUATION OF BY-PRODUCT POWER

- Power valued at 7300 Btu/kWhr added to gas values raises overall efficiency of steam-iron to 75.2%
### Power for Hydrogen Liquefaction

**Quantity of Hydrogen**

733 x 10^6 SCF/day (161,000 lb/hr)

<table>
<thead>
<tr>
<th>Description</th>
<th>Power Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Required for Liquefaction at 5 kWhr/lb*</td>
<td>805,000 kW</td>
</tr>
<tr>
<td>Power to Compress H₂ 1 atm to 800 psi</td>
<td>220,000</td>
</tr>
<tr>
<td>Net to Liquefy 800 psi Gas</td>
<td>585,000</td>
</tr>
</tbody>
</table>

**By-Product Power**

980,000 kW

*From H₂ at 1 atm.*
POWER FOR HYDROGEN LIQUEFACTION

- By-product power from steam-iron (980,000 kW) is more than enough to liquefy hydrogen produced