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Produced by the NASA Center for Aerospace Information (CASI)
INSTITUTE OF GAS TECHNOLOGY

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

3424 SOUTH STATE STREET
CHICAGO, ILLINOIS 60616
AFFILIATED WITH ILLINOIS INSTITUTE OF TECHNOLOGY
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>100.0</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>100.0</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 SO₂/million Btu.
GASIFICATION

COAL + WATER $\longrightarrow$ HYDROGEN + CARBON DIOXIDE

$\text{CH}_0.8 + 2\text{H}_2\text{O} \longrightarrow 2.4\text{H}_2 + \text{CO}_2 + \text{HEAT}$

$\text{CH}_0.8 + 1.2\text{O}_2 \longrightarrow 0.4\text{H}_2\text{O} + \text{CO}_2 + \text{HEAT}$

SHIFT

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

METHANATION

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

A75040754
GASIFICATION REACTIONS

- Most of H₂ produced comes from H₂O
- C of coal used to remove the O of H₂O as CO₂
- H₂ production requires heat
- Heat required comes from burning coal
  O₂ for combustion from air
  N₂ from air cannot be tolerated in product H₂
- CO formed along with CO₂
  Shift converts CO to H₂ and CO₂
- Methanation removes CO to safe level
TYPES OF GASIFIERS

- SUSPENSION (Entrained) COMBUSTION
  KOPPERS-TOTZEK

- FLUIDIZED BED
  U-GAS™

- MOVING BED
  LURGI

A75040756
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

ASH

GASIFIER

2730°F

WASTE-HEAT RECOVERY

WATER SCRUBBER

ELECTROSTATIC PRECIPITATOR

H₂S REMOVAL

SHIFT

CO₂ REMOVAL

METHANATION

DRYER

STEAM
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

ASH

STEAM

OXYGEN
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

ATM

CLOSED

OPEN

350 psi

OPEN

CLOSED

350 psi
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: $\text{C} + \text{H}_2\text{O} \rightarrow \text{CO} + \text{H}_2$ – HEAT

$\text{C} + \text{O}_2 + \text{N}_2 \rightarrow \text{CO} + \text{N}_2$ – HEAT

AIR

A75040755
STEAM-IRON REACTIONS

- Makes very pure $H_2$
- No need for separating $N_2$ from $O_2$
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&lt;sup&gt;TM&lt;/sup&gt;</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>CO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>10.0</td>
<td>11.5</td>
<td>0.2</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;</td>
<td>30.4</td>
<td>35.3</td>
<td>95.9</td>
</tr>
<tr>
<td>CH&lt;sub&gt;4&lt;/sub&gt;</td>
<td>—</td>
<td>2.1</td>
<td>—</td>
</tr>
<tr>
<td>N&lt;sub&gt;2&lt;/sub&gt; + Ar</td>
<td>1.0</td>
<td>0.7</td>
<td>2.5</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;S + COS</td>
<td>0.3</td>
<td>0.3</td>
<td>—</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
<td><strong>100.0</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

**PRESSURE, psia**

<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>15</td>
<td>350</td>
<td>350</td>
<td></td>
</tr>
</tbody>
</table>

*Note: The table above represents the raw gas compositions in mol% for K-T, U-GAS<sup>TM</sup>, and STEAM-IRON conditions.*
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™</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>CO₂</td>
<td>&lt;50 ppm</td>
<td>&lt;50 ppm</td>
<td>0.1</td>
</tr>
<tr>
<td>H₂</td>
<td>93.1</td>
<td>94.3</td>
<td>95.7</td>
</tr>
<tr>
<td>CH₄</td>
<td>5.5</td>
<td>4.8</td>
<td>1.5</td>
</tr>
<tr>
<td>N₂ + 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>
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

| lb/hr | 80,585 | 790,758 | —         |

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, 10⁶ Btu/hr*</td>
<td>18,253</td>
<td>15,736</td>
<td>23,375</td>
</tr>
<tr>
<td>HHV PRODUCT GAS, 10⁶ 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\textsuperscript{TM}</th>
<th>STEAM-IRON</th>
<th>METHANE BY HYGAS</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>
<td>1,108,198</td>
</tr>
<tr>
<td>BOILER COAL, lb/hr (Dry Basis)</td>
<td>340,314</td>
<td>269,634</td>
<td>—</td>
<td>206,407</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>
<td>1,314,605</td>
</tr>
<tr>
<td>HHV TOTAL COAL, $10^6$ Btu/hr*</td>
<td>18,253</td>
<td>15,736</td>
<td>23,375</td>
<td>14,942</td>
</tr>
<tr>
<td>HHV PRODUCT GAS, $10^6$ Btu/hr\†</td>
<td>10,416</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>
<td>70.2</td>
</tr>
<tr>
<td>BY-PRODUCT POWER, kW</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

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>BY-PRODUCT POWER, kW</td>
<td>980,000</td>
</tr>
<tr>
<td>EQUIVALENT Btu AT 7300 Btu/kWh, $10^6$ Btu/hr</td>
<td>7154</td>
</tr>
<tr>
<td>HHV PRODUCT GAS, $10^6$ Btu/hr</td>
<td>10416</td>
</tr>
<tr>
<td>TOTAL</td>
<td>17,570</td>
</tr>
<tr>
<td>HHV COAL, $10^6$ 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%
<table>
<thead>
<tr>
<th>QUANTITY OF HYDROGEN</th>
<th>POWER REQUIRED FOR LIQUEFACTION at 5 kWhr/lb</th>
<th>POWER TO COMPRESS H₂ at 1 atm to 800 psi</th>
<th>NET TO LIQUEFY 600 psi GAS</th>
<th>BY-PRODUCT POWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>733 x 10⁸ SCF/day</td>
<td>805,000 kW</td>
<td>220,000</td>
<td>585,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>980,000 kW</td>
</tr>
</tbody>
</table>

*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