Gasification of ORIMULSION®: Synergism of the Two Technologies

Presented in the 2001 Gasification Technologies Conference
San Francisco, October 7-10 2001
**ORIMULSION® compared to other fuels**

ORIMULSION® compares favourably to competing fuels such as Coal or Fuel Oil:
- Liquid fuel handling facilities.
- Optimum combustion conditions.
- Base load operation at high reliability and load factors.
- Modern flue gas cleaning technology:
  - ESP - low PM outlet, ash to metals recovery.
  - deNOx - low NOx burners, OFA or SCR.
  - FGD - wallboard quality gypsum for sale.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Units</th>
<th>ORIMULSION®</th>
<th>Heavy Fuel Oil</th>
<th>Bituminous Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Calorific Value (HHV)</td>
<td>MJ/kg</td>
<td>30.2</td>
<td>43</td>
<td>25 - 28</td>
</tr>
<tr>
<td>Net Calorific Value (LHV)</td>
<td>MJ/kg</td>
<td>27.8</td>
<td>40</td>
<td>23 - 26</td>
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<tr>
<td>Carbon</td>
<td>% (w/w)</td>
<td>61.8</td>
<td>86</td>
<td>60 - 65</td>
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<tr>
<td>Hydrogen</td>
<td>% (w/w)</td>
<td>10.8</td>
<td>11</td>
<td>3 - 5</td>
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<tr>
<td>Sulphur</td>
<td>% (w/w)</td>
<td>2.85</td>
<td>1 - 4</td>
<td>0.4 - 2.5</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>% (w/w)</td>
<td>0.5</td>
<td>0.2 - 0.4</td>
<td>1 - 1.5</td>
</tr>
<tr>
<td>Ash</td>
<td>% (w/w)</td>
<td>0.07</td>
<td>&lt;0.1</td>
<td>5 - 20</td>
</tr>
<tr>
<td>Magnesium</td>
<td>mg/kg</td>
<td>6.0</td>
<td>1 - 3</td>
<td>1 - 50</td>
</tr>
<tr>
<td>Nickel</td>
<td>mg/kg</td>
<td>75</td>
<td>20 - 50</td>
<td>0.5 - 50</td>
</tr>
<tr>
<td>Sodium</td>
<td>mg/kg</td>
<td>12</td>
<td>0 - 30</td>
<td>1 - 30</td>
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<tr>
<td>Vanadium</td>
<td>mg/kg</td>
<td>320</td>
<td>30 - 300</td>
<td>2 - 100</td>
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<tr>
<td>Density at 15 ºC</td>
<td>g/ml</td>
<td>1.0090</td>
<td>0.93 - 1.03</td>
<td>-</td>
</tr>
<tr>
<td>Viscosity at 30 ºC</td>
<td>mPa.s</td>
<td>230</td>
<td>2.400</td>
<td>-</td>
</tr>
<tr>
<td>Water Content</td>
<td>% (w/w)</td>
<td>29.0</td>
<td>&lt;0.5</td>
<td>5 - 20</td>
</tr>
<tr>
<td>Flash Point</td>
<td>ºC</td>
<td>&gt;95</td>
<td>&gt;60</td>
<td>-</td>
</tr>
<tr>
<td>Pour Point</td>
<td>ºC</td>
<td>+3</td>
<td>&lt;30</td>
<td>-</td>
</tr>
</tbody>
</table>
What is ORIMULSION®?

A stable emulsion of bitumen in water with handling properties similar to fuel oil.
VENEZUELA

ORINOCO RIVER

ORINOCO BELT: 54,000 Km²
41 x 10⁹ metric tons

World’s largest bitumen reserves
For practical purposes the Orinoco Belt reserves are inexhaustible...
A general view of the ORIMULSION® chain before export
ORIMULSION® can be used to generate electricity in a number of ways.
**ORIMULSION® experience**

Clients experience can be summarized as follows:

- Lower NOx emissions than Coal and Fuel Oil at the same operating conditions.
- Excellent combustion properties, producing less than 0.2% of unburned carbon.
- CO2 emissions were considerably lower than Coal and similar to those from Fuel Oil.
- SO2 and particulate emissions could be controlled using conventional equipment.

**But...**

A new formula had to be developed mainly because of the two following reasons:

- Environmental concern regarding some detergent agents, specially those composed by nonylphenol ethoxilates, launched a research effort to substitute the surfactant used in ORIMULSION®.
- Some improvements were desirable to adapt the fuel to the growing high requirements of a competitive market.
**Premises for a new formula**

- The new formulation should not have a nonylphenol surfactant to comply with the environmental requirement.
- New formulation should mean improvements in current plants performance in terms of:
  - Environmental emissions.
  - Boiler performance.
  - Minimize de-rate.
  - Lower perceived potential (and real) corrosion.
Droplet size distribution is one of the most important characteristics in ORIMULSION® manufacturing and handling. Typical median droplet size is around 14.5µ.
ORIMULSION® has non-Newtonian behaviour properties. Viscosity depends on shear rate and on temperature. New ORIMULSION® formula has lower viscosity than previous.
### Summary of best operation criteria.

<table>
<thead>
<tr>
<th>Category</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory control</td>
<td>First-in first-out basis.</td>
</tr>
<tr>
<td>Storage period</td>
<td>Maximum recommended period 4 months.</td>
</tr>
<tr>
<td>Temperature</td>
<td>Recommended storage temperature range: 20 ° to 40°C.</td>
</tr>
<tr>
<td>Heating</td>
<td>Maximum wall temperature of heating element: 70°C (158°F).</td>
</tr>
<tr>
<td>Unpumpable volume</td>
<td>Not greater than 1 % of tank capacity.</td>
</tr>
</tbody>
</table>
1. Water in the Emulsion will evaporate.
2. Volatile components of the bitumen will begin to evaporate and ignite.
3. Any water droplets within the bitumen will expand and break-up the droplet even further.
4. The fuel will burn-out leaving only the inorganic ash.

ORIMULSION® combustion

Liquid fuel handling facilities.
Conventional steam boilers (HFO/coal design or new build) and IGCC.
Optimum combustion conditions (low O2 / NOx / PM).
Thermal efficiency similar to HFO operation.
Excellent load following and turn-down capabilities.
Base load operation at high reliability and load factors.
Modern flue gas cleaning technology:
- ESP - low PM outlet, ash to metals recovery.
- deNOx - low NOx burners, OFA or SCR.
- FGD - wallboard quality gypsum for sale.
Low cost, clean electricity.
ORIMULSION® combustion

**ASNAES 5 Corrosion probes under a commercial test**

ORIMULSION® deposits corrosion rate have a parabolic profile. These results are associated with the formation of a protective oxide scale indicating that ORIMULSION® has an acceptable corrosion rate in the long term, without the need to add magnesium in-fuel.
Fouling factors

Asnæs unit 5 - Fouling factors

• From the boiler data compiled during the test in 1998 a boiler modeling was performed to determine fouling factors.

• The one dimensional model estimated that fouling resistances for ORIMULSION®400 should be around half of the values previously gotten when firing ORIMULSION®100.
Lower temperature banks fouling was found to be practically negligible compared to the levels obtained when firing ORIMULSION®100.

Boiler inspection

Asnæs Unit 5 was inspected after 1100 hrs of operation using ORIMULSION®400 as main fuel without magnesium injection, the inspection was carried out during September 26th & 27th.

- Furnace slagging appearance and amount were similar for both formulations. However, ORIMULSION®400 furnace fouling was considerably less.
- No indication of apparent corrosion was found in the high temperature boiler zone, which validates the results obtained from the corrosion probes.
ENEL Brindisi Sud Plant Unit 1 fouling factors

Fouling factors estimated by ENEL using their PROATES® Unit 1 model, indicated (as in Asnæs case) heat resistances of about half when ORIMULSION®400 is compared to its predecessor.

Source: ENEL report “Experience firing Orimulsion® in a 660 MWe Power Plant
Firing ORIMULSION®100 with no additional soot blowing facilities.
Orimulsion®400 Fouling - Summary

• Fouling reduction proofs have been consistently found in all the installation firing Orimulsion®400.
• Estimated fouling factors are in agreement with those measured with a deposition probe.
• The reduction in fouling resistance relative to Orimulsion®100 is around 50%.
• This reduction is due to the morphologic differences found between both formulation ashes.
Background

• Brindisi units are 660 MWe once-through boilers, designed by Franco Tosi SpA.

• The units are fitted with 56 burners in a front/rear arrange.

• Each unit is equipped with over fire air (OFA) ports and selective catalytic reduction (SCR) to control NOx emissions.

• A FGD scrubber tower and a seven-field ESP are installed to control SO$_2$ emissions and PM, respectively.

• Brindisi Sud started operations using ORIMULSION®400 in November 1999.
The lower excess oxygen used for ORIMULSION® firing indicates better combustion properties.
When compared on the same bases Fuel Oil and ORIMULSION® produce the same amount of NOx.

Under the same operating conditions ORIMULSION® produces 40% less NOx than Coal.
More scatter but slightly better particulate collection efficiencies are obtained for ORIMULSION® firing when compared to Fuel Oil.
Brindisi Sud Highlights

When boiler performances are compared using Fuel Oil, Coal and ORIMULSION®, the following facts are the most relevant:

• Lower excess oxygen used for ORIMULSION® firing.
• Similar boiler outlet temperature obtained for ORIMULSION® and Fuel Oil.
• ORIMULSION® and Fuel Oil performances are very similar in NOx and CO emissions. However, particulate levels are slightly lower for ORIMULSION® despite of its relatively higher ash content.
• ORIMULSION® produces about 40% less NOx than Coal and similar values than Fuel Oil.
As derived from the previous presented data, the advantages of the ORIMULSION® fuel in both combustion and environmental performances and its attractive price formula makes ORIMULSION® a prime fuel for IGCC.
Gasification Test In Texaco Montebello Pilot Plant

In 1989, a ORIMULSION® gasification test took place in the Texaco Montebello pilot plant facilities in California.

Approximately 144 tons of ORIMULSION® were gasified in a combined run time of nine days.

A Variable Run Test for investigating different process variables and an Extended Run Test of over four hours were conducted.

The main objectives of the tests were:

• To demonstrate the suitability of ORIMULSION® as feedstock for the Texaco Gasification Power System.
• To demonstrate sustained operation of the power plant using ORIMULSION®.
• To obtain process design and analytical data.
Conclusions From The Texaco Montebello Test

• ORIMULSION® is an attractive feedstock for the Texaco Gasification Power Systems (TGPS) from the efficiency, environmental and economical standpoints.

• The water contained in the ORIMULSION® mixture serves as a temperature moderator for the Texaco Gasification Process (TGP), thus making ORIMULSION® a very desirable feedstock. This minimize the plant's overall water requirements.

• Excellent performance and unit operability were demonstrated during the gasification tests. Data obtained during the tests validated Texaco's performance estimates for commercial design.
Conclusions From the Texaco Montebello Test (Cont)

• ORIMULSION® handling facilities for commercial TGPS units can be readily designed taking into account BITOR's handling guidelines.

• Compared with the gasification of typical coal/water slurries, ORIMULSION® gasification results in better thermal efficiencies and higher yields of product gas per units of dry fuel and oxygen.

• TGPS, plants can be designed with feedstock flexibility to handle ORIMULSION® and/or other materials such as coal/water slurries.
Plant availability for different fuels

The purpose of the study is to determine the influence of the plant availability in the final electricity cost. For this, a number of different comparisons were made, including:

- Conventional cycle (Coal and ORIMULSION® fueled).
- Natural Gas Combined Cycle NGCC.
- Integrated Gasification Combined Cycle IGCC.

- All estimations are based on a 500MW net output power plant size.
- All plants must satisfy environmental regulations, specially the SO2 limit of 400 mg/Nm3.

All projects are based on:

- Projects life: 20 years
- Equity: 30%
  Rate of interest:
  - Equity: 15 %/year.
  - Debt: 10 %/year.
Plant availability for different fuels (cont)

Conventional Cycle drum-type boiler with 38% thermal efficiency:

Coal:
- Capital cost: 1050 US$/kW.
- Flue Gas Desulfurization unit (FGD) no required.

Fuel Properties:
- HHV: 6671 kcal/kg.
- Ash: 14%.
- Sulfur: 0.8 % (w/w).

ORIMULSION®:
- Capital cost: 900 US$/Kw (same as a Fuel Oil Plant).
- FGD required.

Fuel Properties:
- HHV: 7218 kcal/kg.
- Ash: 0.07%.
- Sulfur: 2.85 % (w/w).
Plant availability for different fuels (cont)

Natural Gas Combined Cycle (NGCC) (F type gas turbine in a combined cycle with 55% thermal efficiency)
  Natural Gas:
    Capital cost: 600 US$/kW.

Integrated Gasification Combined Cycle (IGCC) (oxygen-blown type gasifier with 42% thermal efficiency).
  ORIMULSION®:
    Capital cost: 1080 US$/kW (same as a Fuel Oil plant).
This chart shows that NGCC has the lower busbar cost for any conventional total plant cost evaluated in the sensibility, which is in line with the literature on this issue.
An IGCC firing ORIMULSION® produces a marginal lower busbar cost than a conventional plant firing ORIMULSION® at the same fuel price. A conventional steam plant firing Coal at the same fuel price will produce a much higher busbar cost.

For the same busbar cost (fixed at 3,87 US cents/kWh for IGCC firing ORIMULSION® at a fuel price 1,74 US$/MMBtu), a price incentive must be placed on both Coal and ORIMULSION®, under a conventional steam generation plant, and also on gas prices in a NGCC plant.
The minimum required availability for an IGCC project firing ORIMULSION® is lower than 90%. For ORIMULSION(R) further improvements in terms of availability can be obtained, which is the case of a liquid fuel, and a lower busbar cost can be expected.
Conclusions

• Bitumen reserves for manufacturing ORIMULSION® are for practical purposes, inexhaustible. This reservoir will play an important role in the world energy scenario in the years to come.

• ORIMULSION® has several advantages when compared against Coal not only from the handling point of view, but from the combustion and environmental performance as well. ORIMULSION® has an enhanced Fuel Oil like performance, due to the excellent combustion properties linked to both the low excess O2 required for combustion and excellent atomizing properties. ORIMULSION® environmental performance is comparable to Fuel Oil using conventional emission abatement equipment.
Conclusions (cont)

- An IGCC firing ORIMULSION® produces a lower busbar cost than a conventional plant firing ORIMULSION® at the same fuel price, making the development of ORIMULSION® based IGCC projects more attractive than conventional generation, allowing space for further improvements as confidence on ORIMULSION® is gained. On the other hand, a conventional steam plant firing Coal at the same fuel price will produce a much higher busbar cost.

- For the same busbar cost (fixed at 3.87 US cents/kWh for IGCC firing ORIMULSION® at a fuel price 1.74 US$/MMBtu), a price incentive must be placed on both Coal and ORIMULSION® under a conventional steam generation plant and on gas price in a GTCC as well.
Conclusions (cont)

- The minimum required availability for a IGCC project firing ORIMULSION® is lower than 90%, which already has been reported for liquid fuel IGCC. If a higher availability as reached with other liquid fuel applications can be obtained with ORIMULSION®, further improvements can be obtained and a lower busbar cost can be expected.
End of presentation