Gasification of ORIMULSION®: Synergism of the Two Technologies

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ABSTRACT
ORIMULSION® is a registered name for an emulsified fuel constituted by 70% bitumen, 30% water and less than 1% of surfactants. The new generation of the fuel was commercially released in 1999 and it has had an excellent acceptance between current users.

ORIMULSION® is produced and marketed by Bitumenes Orinoco, S.A. (BITOR) a subsidiary of Petróleos de Venezuela (PDVSA). With more than 6 million tons of the fuel being fired annually and plans to triplicate this amount in the next four years BITOR, is a solid company with global commercial presence.

Currently, most of the fuel is being used in conventional thermal power stations where it has demonstrated to be a good substitute to Fuel Oil and Coal, with combustion advantages that allow to optimize certain parameters in plant operations such as O₂ excess and CO emissions.

This paper will discuss the potential that ORIMULSION® as fuel offers to gasification processes and the possible synergism between both technologies.

ORIMULSION® has been used in the past in gasification processes, at laboratory and pilot plant scales, always with encouraging results. Texaco tested it in 1989 in their facility at Motebello, California. The pilot test verified performance and design assumptions used for power generation projects. The test concluded that ORIMULSION® is an excellent feedstock for the Texaco Gasification Power System. In 1995 Chubu Electric Power Co., the Central Research Institute of Electric Power Industry (CRIEPI) and Mitsubishi Heavy Industries, conducted a set of tests to gasified ORIMULSION® in their facility. During the tests basic operational conditions were revised and optimized and the materials endurance evaluated. Results obtained demonstrated a great deal of similarities in gasifying ORIMULSION® in comparison with others liquid hydrocarbons.

Fuel prices dynamic and the initially identified market niches have kept these two technologies: Gasification and ORIMULSION®, apart during the last ten years. In one side, gasifiers manufactures have been targeting mainly low cost refinery residuals or solid fuels as Pet-Coke trying to get better economies for their projects, and in the other side BITOR has center its efforts in consolidating the place of ORIMULSION® in the international energy arena.

Today both technologies have reached a satisfactory degree of maturity. They have achieved better public acceptance, decreasing the risk perception and therefore improving the feasibility of developing joint projects. The target now is the power sector, ORIMULSION® can turn IGCC’s in a competitive option against conventional cycles in places where no refineries are present. This paper will compare under theoretical basis different scenarios, evaluating their economies using different fuels. It will be discussed
how liquid fuels, and in particular ORIMULSION®, can improve plant’s availability and generation cost versus all solid options. It is undoubtedly that gasification cycles have a major role to play in the world energy production in the years to come and ORIMULSION® could be an excellent ally, for those places where up to now no competitive positioning was envisaged.

**INTRODUCTION**

Since early 1980's Petroleos de Venezuela S.A. (PDVSA) through its affiliates Bitumenes Orinoco (BITOR) and INTEVEP has been working on the technique for dispersing natural bitumen in water in order to commercialize the vast reserves existing in the Orinoco Belt. The Orinoco Belt is approximately 52,000 square miles and has proven economically recoverable reserves, currently estimated to be 270 billions barrels or 42 x 10^9 tons (Figure N°1).

![Figure 1. Geo-spatial location of Orinoco Belt](image.png)

For practical purposes these reserves are inexhaustible. This reservoir will play an important role in the world energy scenario in the years to come.
Figure N°2. Production capacity of Orinoco Belt reservoir.

Figure N°2 shows the duration of the reserves for different production rates. As can be seen it is practically impossible to deplete them in a rational period of time. For example for a production rate of 5 million BPD there will be reserves for 140 years. Much more of what has been estimated the humankind hydrocarbon era would last.

Since early 1980's Petroleos de Venezuela S.A. (PDVSA) has been working on the technique for dispersing natural bitumen in water in order to commercialize the vast reserves existing in the Orinoco Belt. An intensive investigation program was carried out in order to develop a transporting mean for the vast reserves of the Orinoco belt as a first approach. PDVSA, Intevep (Research arm of PDVSA), BP and Venezuelan universities were involved. The end product of this research and development effort was ORIMULSION®. The basic idea behind ORIMULSION® is the formation of an emulsion of natural bitumen suspended in water by means of mechanical energy and the addition of surfactants that allows the bitumen droplets to remain suspended in a stable mode. This product can be easily handled at room temperature and with standard equipment. Furthermore, the presence of water improves the combustion characteristics of the natural bitumen. Figure N°3 shows a comparison between bitumen and ORIMULSION® viscosity at room temperature.
ORIMULSION® is currently being manufactured in the Cerro Negro area of the Orinoco Belt. The current commercial ORIMULSION® plant has a name plate capacity of 6.5 million metric tons per year and is producing at full capacity.

Figure N°4 shows the basic manufacturing process for ORIMULSION®. The oil production facilities are arranged in the form of clusters located in a pine-tree forest, using the most advanced drilling technologies in order to minimize environmental impact. Oil from the production facilities undergoes two different separation and one dehydration steps before storage as natural bitumen. Then the ORIMULSION® manufacturing process starts by using the bitumen, water, surfactants and the required energy for the product formation.

Operational conditions in all the steps are key to maintaining a product of consistent quality.

Recognizing its responsibility with ORIMULSION® users, BITOR introduced in 1997 ISO-9002 standards in all the manufacturing process and obtained the certification from Bureau Veritas Quality International in 1999.
BITOR has developed the appropriate infrastructure to manufacture, transport and deliver the fuel to its Clients in a competitive way. The oil production, manufacturing and handling facilities for ORIMULSION® are briefly detailed in Figure N°6. They consist in oil production facilities, ORIMULSION® manufacturing plant, handling facilities, and marine terminal. Oil production facilities and ORIMULSION® manufacturing plant are located in Morichal in southeast Venezuela. After ORIMULSION® is manufactured, it is stored and pumped through a 300km pipeline to the marine terminal located in Jose in the northeast part of Venezuela.

**Figure N°6. ORIMULSION® transport system**
The export terminal has a storage capacity of 2.9 million barrels (460,000 tons). It is able to load up to 300,000 DWT tanker in its single point mooring in 34 hrs.

Figure N°7. ORIMULSION® Jose terminal tanks

ORIMULSION® is marketed geographically by BITOR subsidiaries as follows:

Figure N°8. ORIMULSION® single point mooring

ORIMULSION® is marketed geographically by BITOR subsidiaries as follows:
ORIMULSION® Characteristics and Current Users

ORIMULSION® is a non-Newtonian, shear thinning (pseudo-plastic) fluid. The viscosity of ORIMULSION® is expressed as apparent viscosity (dynamic viscosity of non-Newtonian fluids) and is affected by shear rate and temperature. The apparent viscosity of ORIMULSION® at any shear rate decreases with increasing temperature.

The experience obtained since 1990 by end users of ORIMULSION® in their storage, handling and distribution systems has confirmed that the rheological properties of ORIMULSION® are not affected when processed through screw or centrifugal pumps at low velocity. Likewise, it has been proven that the stability of the product is not affected by standard equipment restrictions in the handling system such as valves, elbows, tees, and reductions or enlargements in the piping.

<table>
<thead>
<tr>
<th>Characteristics:</th>
<th>Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content, % w/w</td>
<td>29.0</td>
</tr>
<tr>
<td>Density at 15 °C, g/cm³</td>
<td>1.0090</td>
</tr>
<tr>
<td>Apparent Viscosity at 30°C and 20s⁻¹, cP</td>
<td>230</td>
</tr>
<tr>
<td>Apparent Viscosity at 30°C and 100s⁻¹, cP</td>
<td>200</td>
</tr>
<tr>
<td>Apparent Viscosity at 70°C and 100s⁻¹, cP</td>
<td>80</td>
</tr>
<tr>
<td>Gross Calorific Value, MJ/Kg (BTU/lb)</td>
<td>30.20 (12984)</td>
</tr>
<tr>
<td>Net Calorific Value, MJ/Kg (BTU/lb)</td>
<td>27.80 (11952)</td>
</tr>
<tr>
<td>Sulphur, % w/w</td>
<td>2.85</td>
</tr>
<tr>
<td>Carbon, % w/w</td>
<td>61.80</td>
</tr>
<tr>
<td>Hydrogen, % w/w</td>
<td>10.80</td>
</tr>
<tr>
<td>Nitrogen, % w/w</td>
<td>0.5</td>
</tr>
<tr>
<td>Sodium, mg/Kg</td>
<td>12</td>
</tr>
<tr>
<td>Magnesium, ppm w/w</td>
<td>6</td>
</tr>
<tr>
<td>Vanadium, ppm w/w</td>
<td>320</td>
</tr>
<tr>
<td>Nickel, ppm w/w</td>
<td>75</td>
</tr>
<tr>
<td>Iron, ppm w/w</td>
<td>5</td>
</tr>
<tr>
<td>Ash, % w/w</td>
<td>0.07</td>
</tr>
<tr>
<td>Pour Point, °C (°F)</td>
<td>3 (37.4)</td>
</tr>
</tbody>
</table>

Table N°1. Typical ORIMULSION® properties
Current use of ORIMULSION® worldwide is more than 6 million ton per year, following table shows ORIMULSION® users.

<table>
<thead>
<tr>
<th>Utility (Country)</th>
<th>Capacity (MW)</th>
<th>Metric tons/year</th>
<th>Startup Date</th>
<th>PM control</th>
<th>SO₂ control</th>
<th>NOₓ control</th>
<th>Fuel prior to ORIMULSION®</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Brunswick (Canada)</td>
<td>315</td>
<td>750,000</td>
<td>1994</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>Coal &amp; Fuel Oil</td>
</tr>
<tr>
<td>Kashima Kita (Japan)</td>
<td>120 + steam</td>
<td>375,000</td>
<td>1991</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>Fuel Oil</td>
</tr>
<tr>
<td>Kashima Kita (Japan)</td>
<td>120 + steam</td>
<td>375,000</td>
<td>1999</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>New Unit</td>
</tr>
<tr>
<td>Kansai Electric Osaka (Japan)</td>
<td>156</td>
<td>200,000</td>
<td>1994</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>Fuel Oil</td>
</tr>
<tr>
<td>Hokkaido Electric (Japan)</td>
<td>130</td>
<td>120,000</td>
<td>1998</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>New unit</td>
</tr>
<tr>
<td>SK Power (Denmark)</td>
<td>640</td>
<td>1,500,000</td>
<td>1995</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>Coal &amp; Fuel Oil</td>
</tr>
<tr>
<td>Enel Brindisi (Italy)</td>
<td>1,320</td>
<td>1,650,000</td>
<td>1997</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>Coal &amp; Fuel Oil</td>
</tr>
<tr>
<td>Enel Fiume Santo (Italy)</td>
<td>640</td>
<td>1,000,000</td>
<td>1998</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>Coal &amp; Fuel Oil</td>
</tr>
<tr>
<td>Arawak (Barbados)</td>
<td>Cement Plant</td>
<td>40,000</td>
<td>1997</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

Table N°2. Current and near future ORIMULSION® users

**ORIMULSION® in Conventional Power Plants, the Status Quo**

Most of the 6.5 million tons are being used in conventional thermal power stations where ORIMULSION® has demonstrated to be a good substitute to Fuel Oil and Coal, with combustion advantages that allow to optimize certain parameters in plant operations such as O₂ excess (Figures N°9&10).
Part of the fuel success has been the feasibility of using it in compliance with the world's most stringent environmental legislation. As with any other fossil fuel, ORIMULSION® flue gases can be cleaned using conventional technology. Due to its excellent combustion properties, the fuel has reported consistently advantageous in O₂-excess related emissions such as NOₓ, SO₃, and CO with respect to other fuels (Figure N°11).

ORIMULSION® has proven its efficacy as a good power plant fuel during the last ten years. It has demonstrated excellent features in plants all over the world, establishing strong grounds for the future to come.

ORIMULSION® has gained its place in the energy generation international arena as a conventional power plant fuel. The experience compiled has increased new and potential users' confidence in the fuel, which is fomenting a vertiginous increment in BITOR client.
portfolio in the last years. The advantages of this fuel in both combustion and environmental performance and its attractive price formula makes ORIMULSION® a prime fuel for IGCC.

**ORIMULSION® Gasification, the Future Challenge.**

Partial oxidation is beyond any doubt an option with a big potential for increasing future utilization. Although the core of the process, the gasifier, has been largely used for long time, the integrated form of the cycle, the Integrated Gasification Combined Cycle (IGCC) has been recently developed and therefore it is still in the process of gaining adepts. The power sector is an extremely conservative industry, which is justifiable if the capital-intensive investments to build a power plant are properly compensated at the time of evaluating different project options. Normally, power sector takes some time to accept a recent developed technology and this process is mainly based on the generated experience curve. IGCC cycles have taken off and now there are an increasing number of projects worldwide that validate this.

However, IGCC power plants have still a very important issue to solve: the availability of the plants. Although great deal of the research effort in recent years has been directed to improve efficiency and availability in solid fuel feed gasifiers, current results do not allow IGCC to compete with traditional Coal or Fuel Oil power stations. Results of important show case projects such as Tampa IGCC plant with efficiencies in the order of 38% or Washba River with availability in the order of 75%, are not encouraging enough to power a massive use of the technology. On the other hand, liquid feed projects have shown better performance and availability. The data base of one of the most important gasifiers manufacturers Shell-Krupp show availability of more that 98% for the total IGCC, using liquid fuels, and due to the similarities of Shell-Krupp and other technologies (i.e.: Texaco) it would be expectable to have a similar performance in other gasifiers.

One important limitation for the extensive use of liquid fuels as feedstock, is the cost of this type of fuels. Recent liquid fed projects have been mainly located in refineries as a way to add value to the complete refining process. Therefore, seeing the project from the side of the gasifier, the fuel is for all practical purposes free and the availability of the power plant is greatly favored in this way. On the other side, the refinery is transforming a Fuel Oil of difficult commercialization, with a big span in the revenues depending on the crude oil prices, in electricity which at the end will represent an increment in the net profit.

Unfortunately, the above mentioned situation is exclusive of the synergism present in refinery-IGCC projects and for the rest of the cases the IGCC plant would have to pay for the fuel at the market price. This fact has limited the proliferation of liquid fed IGCC projects. Here is where a fuel as ORIMULSION® represents a big advantage. As shown at the beginning of this paper, ORIMULSION® can be handled as any liquid fuel with the additional advantage of having specially designed rheological properties that allow the fuel to be pumped without heating it. Its combustion properties are very similar to Fuel Oil, except by the fact that contains 30% of water, which is ideal for some types of gasifiers because it acts as a temperature moderator eliminating the need of adding more water.

The most important economic characteristic of ORIMULSION® is its competitive and stable price. ORIMULSION® price is fixed following a case-by-case approach. Meaning that depending on the specific necessities of a market the price of the fuel is established (within a pre-fixed limits) to compete against the other available options.
The final objective is to have a liquid fed gasifier with its inherent high availability by using ORIMULSION® and with much better economies than conventional Fuel Oil projects.

**ECONOMIC PREDICTIONS FOR DIFFERENT FUELS**

An analysis was performed to determine the influence of the availability of a plant in the final electricity cost (busbar cost). It is important to point out that the analysis performed does not pretend to be more than an order of magnitude indication of the trend that would be followed by the electricity costs. The availability of the plant was translated as the utilization factor to be able to quantify its effect on the total economy. All the evaluations were done based on a total generation capacity of 500 MWe.

The parameters used in the evaluation are explained as follows:

**General Assumptions**

Technical: All plants must comply with a limit of 400 mg/Nm3 of SO2 emissions

Economical: All plants were evaluated under the following economical parameters

- Projects life: 20 years
- Equity: 30%
- Rate of interest:
  - Equity: 15 %/year
  - Debt: 10 %/year

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

**Coal:**
- Capital cost: 1050 US$/kW
- Fuel cost (delivered): 1.70 US$/MMBTU
- 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$/kW (same as a Fuel Oil Plant)
- Fuel cost (delivered): 1.74 US$/MMBTU
- FGD required
- Fuel Properties
  - HHV: 7218 kcal/kg
  - Ash: 0.07%
  - Sulfur: 2.85 % (w/w)

**Natural Gas Combined Cycle (NGCC):** *(F type gas turbine in a combined cycle with 55% thermal efficiency)*

**Natural Gas:**
- Capital cost: 600 US$/kW
Fuel cost (delivered): 3.80 US$/MMBTU

**Integrated Gasification Combined Cycle (IGCC):** (oxygen-blown type gasifier with 42% thermal efficiency)

**ORIMULSION®:**
- Capital cost: 1080 US$/kW (same as a Fuel Oil plant)
- Fuel cost (delivered): 1.74 US$/MMBTU

Under the assumption explained above, a series of charts were generated. The analysis of the charts includes total plant cost, fuel sensitivity and the availability chart analysis. The results of the analysis are presented below.

![Total Plant Cost Sensitivity Chart](chart.png)

**Figure N° 12. Total plant cost sensitivity chart**

This chart shows that NGCC has the lower busbar cost for any conventional total plant cost evaluated in the sensitivity, which is in line with the literature on this issue.
Figure Nº 13. Fuel cost sensitivity chart

Two important things can be said about Figure 13:

1. Evaluating the vertical line (constant fuel cost fixed at 1,74$/MMBtu) it is seen that an IGCC firing ORIMULSION® produces a marginal lower busbar cost than a conventional plant firing ORIMULSION® at the same fuel price. This makes the development of ORIMULSION® based IGCC projects more attractive than conventional generation, allowing space for further improvements as confidence on ORIMULSION® is gained. It must be said that for the same fuel price, a conventional steam plant firing Coal will produce a much higher busbar cost in the range of 4,45 US Cents/kWh.

2. The horizontal line shows that for the same busbar cost (fixed at 3,87 US Cents/kWh for IGCC firing ORIMULSION® at a fuel price 1,74 US$/MMBTU), a price incentive must be placed on both Coal and ORIMULSION® under a conventional steam generation plant. On the other hand, the price for the gas feeding the NGCC must be in the order of 3,68 US$/MMBTU, which is 0,12 US$/MMBTU lower than the estimation used in this paper as a reference. This can also be considered as a fuel price incentive for NGCC if competing against an IGCC firing ORIMULSION®.
Using the above data, a sensitivity analysis was carried out based on the plant availability. The idea is to use current plant availability in a conventional plant firing ORIMULSION®, to obtain the expected minimum availability for an IGCC firing ORIMULSION®. Figure N°14 shows the result of such analysis.

Figure N° 14. Availability sensitivity chart

Figure N°13 shows that solid fired IGCC are expensive and not very attractive for electricity production. The circle denoting actual availabilities make this option the most unattractive one from the busbar cost point of view.

Conventional power plant firing ORIMULSION® has an availability of about 96%. Note that in this analysis, the NGCC firing natural gas and conventional cycle firing ORIMULSION® have the same busbar cost at this availability. When this point is projected and intercepted with the estimated performance for an IGCC firing ORIMULSION® at the same busbar cost, the resulting minimum required availability obtained is lower than 90%. As stated before, higher availability have already been reached in Shell-Krupp gasifiers using liquid fuels. Due to the similarities of technologies, it is expected that other IGCC manufacturers would show the same performance in their units. Even more, if a higher availability as reached with other liquid fuel applications can be obtained with ORIMULSION®, further improvements can be materialized and a lower
This is the main attraction for using ORIMULSION® in an IGCC based power plant.

CONCLUSIONS

From the above paper it can be concluded that:

- 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.

- An IGCC firing ORIMULSION® produces a marginal 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 of 1,74 US$/MMTU), a price incentive must be placed on both Coal and ORIMULSION® under a conventional steam generation plant and on gas price in one NGCC as well.

- 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.