

EXERGETIC ANALYSIS APPLIED IN THE PRIMARY PROCESSING IN OFFSHORE PLATFORMS

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Abstract. *In the petroleum production is extracted a mixture of water, gas, oil and also impurities; so it is necessary the product processing to remove all the economically attractive phases, such as oil and gas, extracting water and impurities. This three-phase separation process of oil and gas takes place in offshore fields with the use of various equipment such as biphasic separator, three-phase separators, hydrocyclones, electrostatics separators and centrifuges. This separation, besides having an economic interest in oil phase, has a concern and also a great interest with gas, since its combination with water creates hydrates, which can hinder its transport through the ducts, and difficult the posterior refining of oil remaining. To have knowledge of energy degradation points, the exergetic analyses formulates concepts in order to make visible points of lower efficiency, allowing the search of a possible improvement or process changing. The primary processing requires units with a large number of equipment with high energy consumption, and that still generate large amounts of water for disposal depending on the characteristics of the well. This water to be discarded have to be within quality standards pre-defined by environmental issues, so, its treatment represents an important step in the primary processing due to the high levels of oil and impurities on it. Aiming to analyze the problem of high consumption of energy, to optimize the utilized equipment and their layout, can be used the exergetic analysis theory, that permit quantify the process lost, their economic costs and also, the generation of irreversibility that impacts the environment. With this concept it is possible to analyze the behavior of each stage of primary processing, pointing out its efficiency with respect to plants in general and, through an arrangement of these data, find a better arrangement or advanced technologies with respect to the effectiveness of processing. The exergetic analysis developed for the offshore field calculates the exergetic efficiency and the destroyed exergy in each set of equipment. The importance of each of these sets in the whole process efficiency is qualified by the ratio between consumed exergy in a particular set by consumed exergy in the whole field. Thus, due to the use of various equipment in the primary processing of petroleum in offshore fields, it is necessary to study the various streams of fluids and the verification of the efficiency of each set due to limited space and weight on the fields, requiring an efficient disposition that reduces the energy consumption and increase productivity.*

Keywords: *primary processing, oil, exergy, exergetic analyses.*

1. INTRODUCTION

Oil is a complex mixture of hydrocarbons, also featuring other elements such as oxygen, sulfur, nitrogen and metals, whose concentrations vary from one oil field to another (Santos, 2007). The contaminants that are considered impurities, can be found throughout the distillation range of oil, tending to concentrate in heavy fractions. During the process of oil production, gas and water are associated. In the primary processing, due to the different densities between the liquid and the gaseous phases, gas can be separated under controlled conditions. The water produced, salts and sediments should be removed, which would reduce pumping and transportation expenses, and help to avoid or minimize corrosion problems and the accumulation of solids in the pipeline and equipment used for the oil passage.

With the increasing age of an oil well, the quantity of water produced tend to be higher, and several factors must be taken into account in its management. This water may be the one in the tank since its formation, or that resulting from water injection. The primary processing of oil is meant to separate the economically attractive plots, such as oil and gas, from the water and impurities that can damage the process systems and the petroleum refining.

There are two basic types of produced oil: one is called the conventional or light oil, and the other is known as the non-conventional or heavy oil. In recent years, the participation of heavy oil in the world's production showed a massive increase, while the share of medium and light oil suffered a significant decline.

This way, refiners are being forced to process heavier crude oil, which hinder the extraction from the production well, causing problems in pipelines transport, requiring new equipments and arrangements for the process of water-oil separation. Moreover, heavy oils produce more than 50% of residual fractions, creating problems for conventional refineries (Zhao et al, 2004), which need to modify the oil process or work with blends of oil.

1.1 Conventional Oil and Non-conventional Oil

Conventional oils have minimum API gravity of 22 and minimum viscosity, in the temperature of the reservoir, up to 100 cP (centipoise), according to USGS (2003).

According to Mandil (2002), non-conventional oils are all crude with API gravity below 20. Heavy oils have API gravity between 10 and 20. Extra heavy oil and bitumen have API gravity below 10 and the difference between them relies on their viscosities at reservoir temperature: greater than 10,000 cP for bitumen and less than 10,000 cP for extra heavy oils. Non-conventional oils often result from bacterial oxidation of conventional oils, inside the reservoir rock, influencing the physical and chemical properties, which are generally degraded, reducing the API gravity, increasing the viscosity and making higher levels of heavy metals, sulfur and nitrogen. These properties requires specific solutions for the production, transportation and refining. Such solutions already exist but they need more technological innovations to become economically attractive, the exploitation of these unconventional oils and substantially reduce the environmental problems associated. Heavy oils are widely distributed throughout the world. Half of the world's oil reserves are represented by heavy oils and bituminous materials.

Heavy oil exploration is still growing. About 40% of all world oil has an API gravity lower than 20° (Schlumberger, 2007). Besides, most of the oil produced in Brazil is considered heavy or ultra-heavy.

In Brazil, there are different kinds heavy oils, such as: the Marlin oil, with low sulfur content (0.78%), is heavy (API gravity 19.2) and acid (1.2 mg KOH/g), and is produced in Campos Basin offshore fields; Jubarte oil with 17 API gravity and viscosity of 12 cP, that is extracted from the northern part of Campos Basin and the Siri oil, with 12.8 API gravity and viscosity of 300 cP at Badejo field and also in the Campos Basin. From the Petrobras' proven reserves, 3 billion barrels are of oil with API density below 19 (Reviewed Petro & Chemistry, 2005). Thus, there is a need to develop.

1.2 World Reserves of Non-conventional Oil

Despite the higher oil production is still of conventional oil, its extraction is decreasing worldwide, which requires investments in research and technologies to extract unconventional oils and a considerable increase in these processing. According to the International Energy Outlook (2010), 11.6% of liquid fuel supplies in 2035 will be of non-conventional sources, so research and development that take into account non-conventional oils and their process are very important to the oil industry.

Due to the decreasing of conventional oil reserves, the extraction and production of heavy oils are becoming increasingly important, especially in Brazil, where most of the Brazilian oil production consists of heavy oil. Thus, the processing of this oil varies in comparison to conventional oils, because it requires some additional processes, such as, preheating the oil in order to reduce its viscosity. Furthermore, a processing platform will have to undergo a rearrangement in their equipment to accommodate the production of heavy oil.

Figure 1 presents the estimates of heavy oil reserves in different countries of the world.

2. EXERGETIC ANALYSIS

Many cases considered by the First Law of Thermodynamics, as the case of analysis of primary processing units of oil, may indicate a large loss of energy, without clearly quantify the energetic content of the processed fluid. Through the analysis using the concepts of the Second Law of Thermodynamics, it is possible to quantify the exergy content, whether in the form of chemical exergy or physical exergy, turning it possible to show the difference of this analysis in the processing facilities in relation to other industrial processes.

According to Sotomonte (2009), the First Law of Thermodynamics enounces that the energy can change from many states to others (mechanical energy, electricity, heat, chemical energy), but always the sum of all the parts of this energy remain the same, i.e., the energy is never lost. But, the Second Law of Thermodynamics imposes some limitations to all energy transformation processes.

To this energy quality was given the name of Exergy, denoted by Rent (1956) apud Sotomonte (2009), measuring the behavior and the quality of the energy in a process.

Unlike the energy, the exergy does not satisfy the conservation law (Szargut, 2005), i.e., all the irreversible process in the nature causes an irrecoverable loss of exergy. This is responsible for the energy degradation in the heat processes, because the energetic flow is converted into heat at room temperature and cannot be used.

So, only an energetic analysis is not enough to identify possible energy loss and the systems efficiencies in study, after all, the first law (energetic analysis) only takes into account the energy quantity, not its quality or capacity to perform work (Sotomonte, 2009).

Therefore, exergy calculus of the flows of a primary processing petroleum plant, can provide an exergetic analysis of the installation, and also identifies losses and exergetic efficiencies.

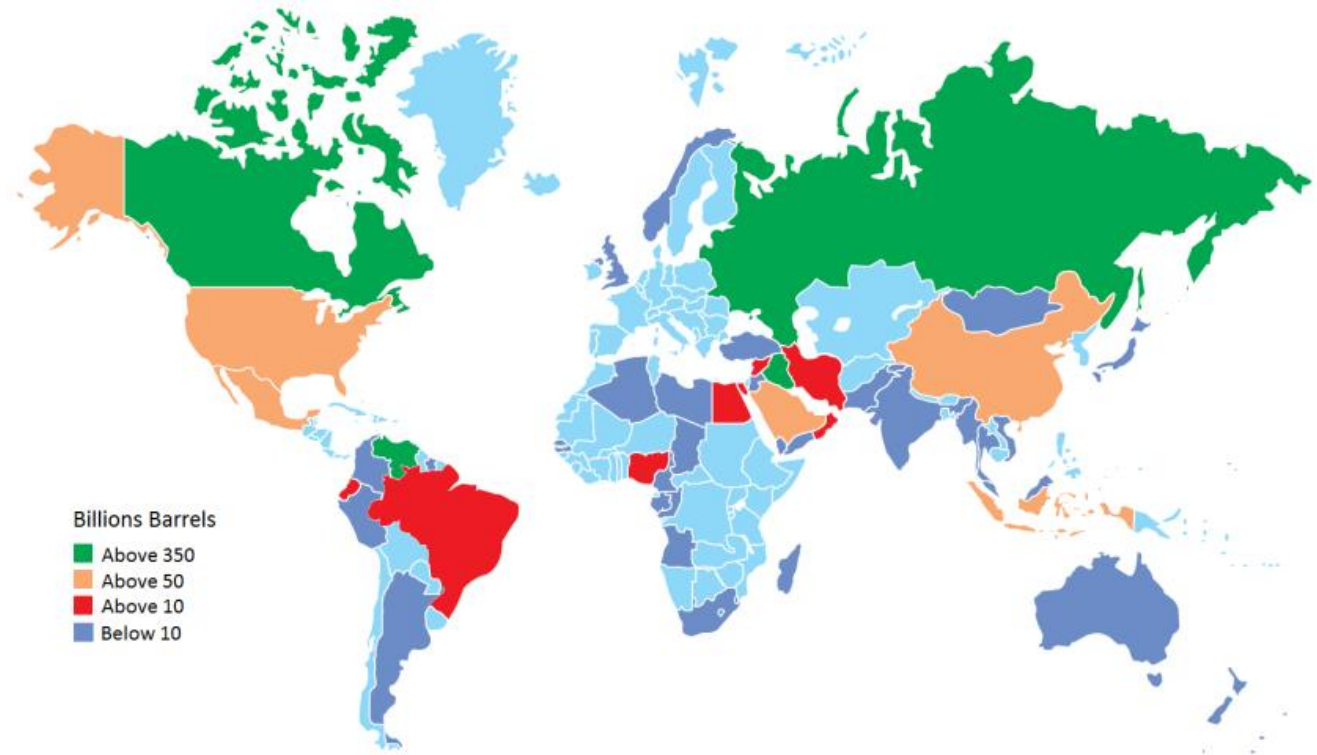


Figure 1: Reserves of heavy oil in the world.
Source: Adapted from Schlumberger (2007).

The energy analysis based on the first law of thermodynamics in industrial processes, such as offshore fields, does not identify and inform about the energy degradation that happens to all processes (Gonzaga, 2009). That is why, an analysis based on the second law of thermodynamics must be made, because it takes into consideration the energy degradation through the exergy concept, making possible to track the energy losses in the process.

The main objective of the exergetic analysis is to find and estimate, quantitatively, the causes of thermodynamics imperfections in thermal and chemical processes, allowing the evaluation of equipment which the design enhancements may be more significant.

According to Kottas (1985), the total exergy can be calculated by the Equation (1):

$$B_g = n_m \cdot b_M^o + (T - T_0) \cdot \sum_k (n_k \cdot C_{P_k}^b) + \nu \cdot m (P - P_0) \quad (1)$$

In which:

B_g - the total exergy (kJ/s); n_m - the moles number of the mixture (kmol/s); b_M^o - the mixture chemical exergy (kJ/kmol) calculated by Equation (2); T - Kelvin temperature (K); T_0 - the reference temperature (298.15K); ν - the substance specific volume (m^3/kg); m - the substance incoming flow (kg/s); P - the local pressure of the process (Pa); P_0 - the reference pressure (101300 Pa); $C_{P_k}^b$ - the heat capacity, considering the enthalpy and entropy variations.

Beneath, the Equation (2) is used to calculate the exergy of a mass mixture, and the Equation (3) to calculate the heat capacity, as follows.

$$b_M^o = \sum_k (y_k \cdot b_k^o) + R \cdot T_0 \cdot \sum_k (y_k \cdot \ln y_k) \quad (2)$$

In which:

y_k - the substance molar fraction (adimensional); b_k^o - standard chemical exergy (kJ/kmol); R - universal gas constant (kJ/kmol.K).

$$C_{P_k}^b = \frac{1}{T - T_0} \left[\int_{T_0}^T C_{P_k} dT - T_0 \int_{T_0}^T C_{P_k} \frac{dT}{T} \right] \quad (3)$$

Enthalpy and entropy variations of the chemical compounds, based on the temperature, are described by Equations (4) and (5), respectively:

$$h - h_o = \int_{T_o}^{T_g} C_{PK} dT \quad (4)$$

$$s - s_o = \int_{T_o}^{T_g} C_{PK} \frac{dT}{T} \quad (5)$$

2.1 Heat Capacity

The Equation (6) presents the heat capacity with the coefficients for the calculus of the enthalpy variation of the compounds with the temperature, which are presented in Table 1.

$$C_p = C_1 + C_2 \cdot T + C_3 \cdot T^2 + C_4 \cdot T^3 + C_5 \cdot T^4 \quad (6)$$

Table 1 - Constants to calculate the heat capacity of each hydrocarbon.

Substance	Formula	C ₁	C ₂	C ₃	C ₄	C ₅
Methane	CH ₄	34.942	- 3.9957.10 ⁻²	1.9184.10 ⁻⁴	- 1.5303.10 ⁻⁷	3.9321.10 ⁻¹¹
Ethane	C ₂ H ₆	28.146	4.3447.10 ⁻²	1.8946.10 ⁻⁴	- 1.9082.10 ⁻⁷	5.3349.10 ⁻¹¹
Propane	C ₃ H ₈	28.277	1.1600.10 ⁻¹	1.9597.10 ⁻⁴	- 2.3271.10 ⁻⁷	6.8669.10 ⁻¹¹
i-Butane	C ₄ H ₁₀	6.772	3.4147.10 ⁻¹	-1.0271.10 ⁻⁴	-3.6849.10 ⁻⁸	2.0429.10 ⁻¹¹
n-Butane	C ₄ H ₁₀	20.056	2.8153.10 ⁻¹	- 1.3143.10 ⁻⁵	- 9.4571.10 ⁻⁸	3.4149.10 ⁻¹¹
i-Pentane	C ₅ H ₁₂	-0.881	4.7498.10 ⁻¹	-2.4797.10 ⁻⁴	6.7512.10 ⁻⁸	-8.5343.10 ⁻¹²
n-Pentane	C ₅ H ₁₂	26.671	3.2324.10 ⁻¹	4.2820.10 ⁻⁵	- 1.6639.10 ⁻⁷	5.6036.10 ⁻¹¹
Hexane	C ₆ H ₁₄	25.924	4.1927.10 ⁻¹	- 1.2491.10 ⁻⁵	- 1.5916.10 ⁻⁷	5.8784.10 ⁻¹¹
Heptane	C ₇ H ₁₆	26.984	5.0387.10 ⁻¹	- 4.4748.10 ⁻⁵	- 1.6835.10 ⁻⁷	6.5183.10 ⁻¹¹
Octane	C ₈ H ₁₈	29.053	5.8016.10 ⁻¹	- 5.7103.10 ⁻⁵	- 1.9548.10 ⁻⁷	7.6614.10 ⁻¹¹
Nonane	C ₉ H ₂₀	29.687	6.6821.10 ⁻¹	- 9.6492.10 ⁻⁵	- 2.0014.10 ⁻⁷	8.2200.10 ⁻¹¹
Decane	C ₁₀ H ₂₂	31.780	7.4489.10 ⁻¹	- 1.0945.10 ⁻⁴	- 2.2668.10 ⁻⁷	9.3458.10 ⁻¹¹
Undecane	C ₁₁ H ₂₄	125.212	3.1401.10 ⁻¹	7.9137.10 ⁻⁴	- 9.1410.10 ⁻⁷	2.7568.10 ⁻¹⁰
Dodecane	C ₁₂ H ₂₆	71.498	7.2559.10 ⁻¹	1.1553.10 ⁻⁴	- 4.1196.10 ⁻⁷	1.4141.10 ⁻¹⁰
Tridecane	C ₁₃ H ₂₈	110.400	5.3321.10 ⁻¹	7.3984.10 ⁻⁴	- 1.0212.10 ⁻⁶	3.2423.10 ⁻¹⁰
Tetradecane	C ₁₄ H ₃₀	115.502	6.0882.10 ⁻¹	6.8043.10 ⁻⁴	- 9.7091.10 ⁻⁷	3.0756.10 ⁻¹⁰
Pentadecane	C ₁₅ H ₃₂	124.647	6.2706.10 ⁻¹	8.3164.10 ⁻⁴	- 1.1689.10 ⁻⁶	3.7326.10 ⁻¹⁰
Hexadecane	C ₁₆ H ₃₄	131.750	6.7397.10 ⁻¹	8.7770.10 ⁻⁴	- 1.2430.10 ⁻⁶	3.9785.10 ⁻¹⁰
Heptadecane	C ₁₇ H ₃₆	111.903	9.5987.10 ⁻¹	2.7901.10 ⁻⁴	-6.7520.10 ⁻⁷	2.2545.10 ⁻¹⁰
Octadecane	C ₁₈ H ₃₈	124.715	9.8653.10 ⁻¹	3.4273.10 ⁻⁴	-7.4838.10 ⁻⁷	2.4804.10 ⁻¹⁰
Nonadecane	C ₁₉ H ₄₀	132.530	1.0358	3.6926.10 ⁻⁴	-7.9581.10 ⁻⁷	2.4804.10 ⁻¹⁰
Eicosane	C ₂₀ H ₄₂	137.730	1.0992	3.6839.10 ⁻⁴	-8.2058.10 ⁻⁷	2.7259.10 ⁻¹⁰
Water	H ₂ O	33.933	- 8.4186.10 ⁻³	2.9906.10 ⁻⁵	- 1.7825.10 ⁻⁸	3.6934.10 ⁻¹²
Nitrogen	N ₂	29.414	- 4.5993.10 ⁻³	1.3004.10 ⁻⁵	- 5.4759.10 ⁻⁹	2.9239.10 ⁻¹³
Carbon Dioxide	CO ₂	27.437	4.2315.10 ⁻²	- 1.9555.10 ⁻⁵	3.9968.10 ⁻⁹	- 2.9872.10 ⁻¹³

Source: Yaws (1996).

3. EXERGETIC ANALYSIS OF THE FPSO OPERATING IN SIRI FIELD

The Siri Member Reservoir, well named as 9-BD-18HP-RJS (PETROBRAS, 2007), situated in Campos Basin, Rio de Janeiro, Brazil, with capacity to produce a 12.5° API heavy oil, requires a special attention for the primary process to separate the phases, which is different if compared to the conventional oil primary process. Figure 2 illustrates the primary processing plant of Siri field.

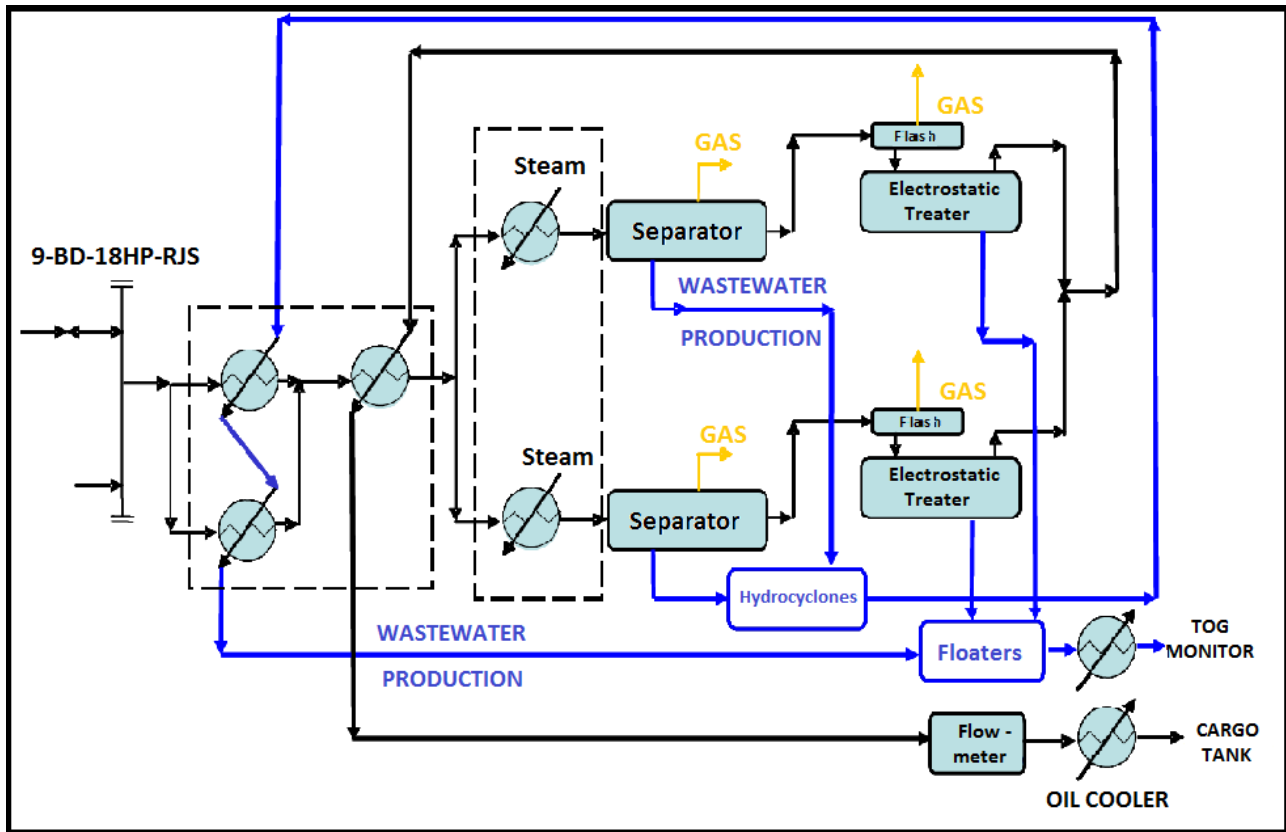


Figure 2: Diagram of the separation and processing of oil.
 Source: PETROBRAS (2007)

However, to calculate the exergy of each equipment in the platform of Siri field, some considerations and simplifications were made. Figure 3 shows the simplifications made, using them as a basis for calculations. The main operation data are shown in Table 2.

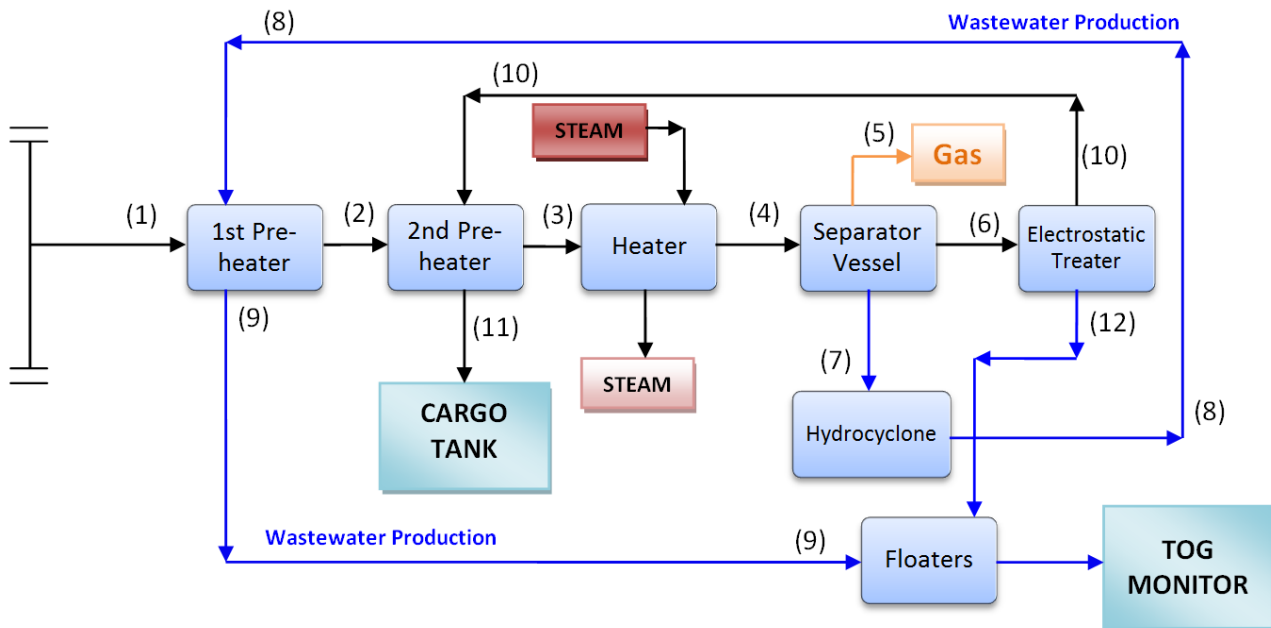


Figure 3: Simplified diagram of the process of separation and treatment of oil from the Siri platform.

Table 2 - Main operating data from the operation plant.

Equipments	Operation Temperature (°C)		Operation Pressure (kgf/cm ²)
	Input	Output	
1° Pre-heater	40	65	12
2° Pre-heater	65	95	11
Heater	95	130	10
Separation Vessel	130	125	10
Electrostatic Treater	125	120	4,5

Source: Adapted from PETROBRAS (2007).

3.1 Primary Processing

The most important equipments present in the platform in which heavy oil is processed are the heaters, gravity separation vessels and electrostatic treaters.

Heavy oil primary processing requires an additional attention if compared to conventional oil primary processing, after all, crude oil must be heated to reduce its viscosity, making possible to process this kind of oil. Consequently, the primary processing of conventional oil in offshore field must be reformulated.

3.2 Separation Process

After going out the well, some chemicals are added to the oil to facilitate the separation process. Then, the oil is heated by the pre-heaters and heaters in order to decrease the viscosity, allowing the separation process (PETROBRAS, 2007).

After heating, the oil is sent to a three-phase horizontal gravitational separator vessel, which separates the gas and much of the water and oil mixture. The water produced is taken to the hydrocyclone to be properly treated, and the oil is carried to an electrostatic treater to remove the remaining water, leaving only a BSW less than 1% (PETROBRAS, 2007). Finally, the oil is cooled and sent to storage tanks. In this analysis it was considered that all gas would be separated in a three-phase separator, when, in fact, one part of the gas is separated in the three-phase separator and the other one in the flash separator.

The gas obtained in the separator vessel is sent to a fuel gas system and submitted to a conditioning in order to analyze its characteristics, and then, become ready for consumption.

In turn, the water is sent to hydrocyclones for treatment and control of the content of Oil and Grease (TOG). Then, it is cooled, losing its energy in pre-heaters and directed to the floaters, where the TOG must be less than 20 mg/L (CONAMA, 2007). Finally, the water is discarded in the sea.

If the water temperature is above 40 °C or the TOG is above 20 mg/L, the current is diverted automatically to a centrifugal separator; if it does not achieve the goal, the water returns to be reprocessed in the centrifugal separator in order to decrease the TOG (PETROBRAS, 2007); when the water achieves a level lower than 20 mg/L, it is discarded on the sea.

3.3. Hydrocyclones

The cargo and space restriction on offshore platforms motivated the development of new processing facilities, once the biphasic and three-phase separators occupy a large space and have a slow speed processing. Considering this, the use of hydrocyclones on the platforms has promoted a rapid processing with compact equipments.

The hydrocyclones use a centrifugal field to produce high accelerations, much higher than gravity. The liquid comes into it with a relatively high speed and is accelerated rapidly, separating oil from water. But a significant disadvantage in this type of process is that it is highly sensitive to fluctuations of load, due to the volume or the ratio of total liquids.

The *deoilers* hydrocyclones are traditionally used for the removal of oil from water that comes from the gravitational vessel, i.e., for the treatment of oily waters which present a low level of oil. But with the growth of technology for hydrocyclones, it will be possible to use them in the treatment of water with even higher oil concentrations, called *dewaterers*.

3.4. Thermo-electrostatic Treater

As seen previously, the water comes with oil, which is a constituent of weight in the three-phase product. Much of the water comes in a free form which greatly facilitates the withdrawal of oil by a simple decantation or dehydration.

However, not all the water comes in a free form, but in a soluble form, creating emulsions with oil droplets. Emulsions are a mixture of two immiscible liquids formed by a dispersed phase in a continuous one, separated by a stable pellicle, and in the primary processing the mixture is not removed with the basic processes, such as, sedimentation, requiring other processes, such as, the addition of chemicals products and using of temperature.

A method capable of breaking the emulsion is the use of a thermo-electrostatic treater or electrostatic coalescers, also capable of creating an electric field perpendicular to the tube through which the stream of oil passes. This field makes the water droplets dispersed to assume an elliptical shape in the direction of the field, creating an attractive force causing coalescence.

3.5. Analysis Procedures

Using Equations (1-6) presented previously, the exergy analysis was performed according to the steps of the work development.

First, it was calculated the enthalpy and entropy of all substances in the oil, making use of the constants for the equation of heat capacity, a constant presented in the Handbook of Thermodynamics (Yaws, 1996). After calculating each enthalpy and entropy, the results were compared with the theoretical values in Sandler (1989), to then conclude that the calculated values were reliable and useful for the analysis. By using this method, we calculated the enthalpies and entropies for all components of the input stream.

Then, it was considered that the density of the oil was approximately equal to the water, because it is a heavy oil, and from this, we calculated the molar fraction of each component.

For the result, it was needed the standard chemical exergy of each component, and in literature the chemical exergy of C_{16+} are not calculated. Knowing this, it was used a mechanism for calculating the components standard chemical exergy already known and compared with literature values, noting that the standard exergy were very close to the literature (Kotas, 1985 and Szargut, 2005). This procedure was used to calculate the chemical exergy for unknown substances.

To obtain the chemical exergy, it was calculated a β constant, that multiplied by the enthalpy of combustion results in the standard chemical exergy of the substance. The β constant can be calculated by Equation (7).

$$\beta = 1.0412 + 0.1728 \frac{z_{H_2}}{z_C} \quad (7)$$

Which, z_{H_2} and z_C are the mass fraction of H_2 and C, respectively.

Each substance in the feed stream has a β itself, because the mass of Hydrogen and Carbon varies from one to another. Thereafter, this constant was multiplied by the enthalpy of combustion, also characteristic of each component, giving the value of the standard chemical exergy.

It was considered that 35% of the inflow was water. The mass flow of oil, excluding water, was calculated according to the mass fractions taken from PETROBRAS (2007) and the molecular weights of each substance. By proportion, after considering that the total oil corresponds to 65% of the total mass input, the mass of water was obtained. Finally, the total mass of the input stream was found by adding the mass of water to oil.

The oil processing capacity which is 2400 (m^3/day), according to PETROBRAS (2007), was transformed in (kg/s) considering that the density of oil is close to the density of water. The processing capacity in ($kmol/s$) was obtained by dividing that capacity in (kg/s) by the oil total mass. This value, was multiplied by each weight fraction of oil, finding the quantity in ($kmol/s$) of each substance present in the stream.

The mole fraction remains constant from the Flow (1) until Flow (4). After passing the separator, the molar fractions become the followin: Flow (5) - gases mole fraction; Flow (6) - molar fraction with 99.9% of initial oil and 7% of initial water; Flow (7) - molar fraction with 0, 1% of initial oil (2000 ppm) and 93% of initial water; Flow (10) - with 100% of the Flow (6) oil and 0.5% of that water; Flow (12) - 99.5% of the Flow (6) water. These values are presented in Tables (3) and (4).

Considering the reference temperature, T_o , as the room temperature of 25 °C and using the molar fractions and the standard chemical exergy values of each component, it was calculated the chemical exergy of the mixture flows, using the Equation (2).

Adopting the enthalpies and entropies calculated in the beginning for each considered temperature, the Equation (7) was used to calculate the exergy of the mixture flows, which calculated values are presented in Table (5).

After passing through the hydrocyclone, the water flow (8) is used as a heat source to heat the mixture which goes through the first preheater. From the heat balance using the first law of thermodynamics, it was calculated the enthalpy of the water after passing through the first preheater. Thus, the final temperature of the water after passing through this equipment (Flow 9) is about 43°C.

The separated oil in the process, Flow (10), is also used for heating the mixture in the second preheater. Thus, following the same procedure described previously, it was calculated the final temperature after the passage of this oil in the preheater (Flow 11), and it was obtained a value of 72°C. From these temperatures we can calculate the exergy of these two flows, as described in Table 5. However, it was not possible to evaluate the exergy efficiency of the third heat exchanger, which operates with a saturated steam at 184°C and pressure of 11 bar at the entrance, for lack of more data. Due to the same reason, it was not possible to calculate the exergetic efficiency of the electrostatic treater.

The values of the outlet flow minus the inlet flow for the preheaters and the heater, provide the exergy transferred in each heaters, and allow the calculation of exergetic efficiency, as shown in Table 7.

Table 3 - Flow (1) to (6) of the primary processing plant.

Substances	Phase	Flows feed 1-4		Flow feed 5		Flow feed 6	
		Molar fraction	kmol/s	Molar fraction	kmol/s	Molar Fraction	kmol/s
CO ₂	g	0.010133	0.009884683	0.222294	0.009884683	-	-
N ₂	g	0.000148	0.000144513	0.00325	0.000144513	-	-
CH ₄	g	0.034354	0.033512544	0.753656	0.033512544	-	-
C ₂ H ₆	g	0.000474	0.000462441	0.0104	0.000462441	-	-
C ₃ H ₈	g	0.000178	0.000173415	0.0039	0.000173415	-	-
iC ₄ H ₁₀	g	0	0	0	0	-	-
nC ₄ H ₁₀	g	0.000148	0.000144513	0.00325	0.000144513	-	-
iC ₅ H ₁₂	g	0.00003	2.89E-05	0.00065	2.89026E-05	-	-
nC ₅ H ₁₂	g	0.000059	5.78E-05	0.0013	5.78052E-05	-	-
C ₆ H ₁₄	g	0.000059	5.78E-05	0.0013	5.78052E-05	-	-
C ₇ H ₁₆	l	0.000015	1.45E-05	-	-	0.000071	1.44E-05
C ₈ H ₁₈	l	0.000015	1.45E-05	-	-	0.000071	1.44E-05
C ₉ H ₂₀	l	0.00003	2.89E-05	-	-	0.000142	2.89E-05
C ₁₀ H ₂₂	l	0.00043	0.000419087	-	-	0.002053	0.00041868
C ₁₁ H ₂₄	l	0.001081	0.001054944	-	-	0.005168	0.00105391
C ₁₂ H ₂₆	l	0.001555	0.001517386	-	-	0.007433	0.0015159
C ₁₃ H ₂₈	l	0.002548	0.002485622	-	-	0.012176	0.00248319
C ₁₄ H ₃₀	l	0.002963	0.002890258	-	-	0.014158	0.00288743
C ₁₅ H ₃₂	l	0.003911	0.003815141	-	-	0.018689	0.00381141
C ₁₆ H ₃₄	l	0.002904	0.002832453	-	-	0.013875	0.00282968
C ₁₇ H ₃₆	l	0.002696	0.002630135	-	-	0.012884	0.00262756
C ₁₈ H ₃₈	l	0.0032	0.003121479	-	-	0.015291	0.00311843
C ₁₉ H ₄₀	l	0.0024	0.002341109	-	-	0.011468	0.00233882
C ₂₀ H ₄₂	l	0.078841	0.076909771	-	-	0.376747	0.07683455
H ₂ O	l	0.851828	0.830959164	-	-	0.509775	0.10396453

Table 4 - Flows (7), (10) and (12) of the primary processing plant.

Substances	Phase	Flows feed 7		Flows feed 10		Flows feed 12	
		Molar fraction	kmol/s	Molar fraction	kmol/s	Molar fraction	kmol/s
C ₇ H ₁₆	l	< 0.000001	1.41337E-08	0.000144	1.44E-05	-	-
C ₈ H ₁₈	l	< 0.000001	1.41337E-08	0.000144	1.44E-05	-	-
C ₉ H ₂₀	l	< 0.000001	2.82674E-08	0.000287	2.89E-05	-	-
C ₁₀ H ₂₂	l	0.000001	4.09877E-07	0.004166	0.0004187	-	-
C ₁₁ H ₂₄	l	0.000001	1.03176E-06	0.010487	0.0010539	-	-
C ₁₂ H ₂₆	l	0.000002	1.48404E-06	0.015084	0.0015159	-	-
C ₁₃ H ₂₈	l	0.000003	2.43100E-06	0.024709	0.0024832	-	-
C ₁₄ H ₃₀	l	0.000004	2.82674E-06	0.028731	0.0028874	-	-
C ₁₅ H ₃₂	l	0.000005	3.73130E-06	0.037926	0.0038114	-	-
C ₁₆ H ₃₄	l	0.000004	2.77020E-06	0.028157	0.0028297	-	-
C ₁₇ H ₃₆	l	0.000004	2.57233E-06	0.026146	0.0026276	-	-
C ₁₈ H ₃₈	l	0.000004	3.05288E-06	0.03103	0.0031184	-	-
C ₁₉ H ₄₀	l	0.000003	2.28966E-06	0.023272	0.0023388	-	-
C ₂₀ H ₄₂	l	0.000103	7.52195E-05	0.764545	0.0768346	-	-
H ₂ O	l	0.999865	0.72699464	0.005173	0.0005198	0.106043	0.1034447

Table 5 – Exergy Flows (kW)

Flow 1	Flow 2	Flow 3	Flow 4	Flow 5	Flow 6
1288906.0	1289136.6	1289676.0	1290620.8	31674.0	1256930.7
Flow 7	Flow 8	Flow 9	Flow 10	Flow 11	Flow 12
2234.73	1627.4	1299.6	1256988.9	1256263.4	70.1

Table 6 – Transferred exergy to the water-oil mixture in the heaters (kW).

1° Pre-heater	2° Pre-heater	Heater
230.6	539.4	944.8

Table 7 – Exergetic efficiency.

Exergetic efficiency (%)					
1° Pre-heater	2° Pre-heater	Heater	Separator	Hydrocyclone	Electrostatic Treater
70.35	85.0	-	99.9	59.5	-

4. CONCLUSION

In a primary processing facility, the great need of energy in various equipments that composes the plant, when confronted with the values now involved in exergy analysis, reveal many interesting information because of the large chemical exergy of flows present in oil.

The increase of exergy of the separator feed flow in a water-in-oil emulsion with 35% water, necessary to reach the operating temperatures of the three-phase separator (130°C), requires a full transfer of approximately 1715 kW. About 45% of the exergy necessary to the process comes from the heat recovered from water and oil flows, and must have their temperature reduced for disposal in the case of water, either for the oil storage in the cargo tank.

Therefore, the results of the preheater and heater energy consumption demonstrate that the energy required for primary processing to occurs is relevant and that this analysis is extremely important to the company, as well as the exergetic efficiency values of equipment that are able to avoid the excessive cost to this.

It's worth noting that from the exergy viewpoint, the exergy transferred to emulsion feed if compared to the chemical exergy in the gravity separator, represents only 1.3% of this total. It means that, considered the process losses, the energy consumption directly related to the process is small. Thus, because of the costs of the final product on the market, solutions for the exploitation of heavy oil reserves are becoming attractive.

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7. RESPONSIBILITY NOTICE

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