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Performance assessment of primary petroleum production cogeneration plants

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ABSTRACT

The cogeneration plant of offshore platforms has to supply utilities following the production of the platform. This production varies yearly and also depends on the mode of operation of the platform, which varies depending on the quantity of oil, gas and water produced. The variable demand for power and heat makes the selection of cogeneration technology for offshore platforms a tricky task. A methodology for this purpose is presented and gas turbines (conventional technology), reciprocating engines, a steam plant and a combined cycle are evaluated. The design point for each cogeneration plant is defined to meet the highest heat and power demands using as much as possible of exhaust gases energy. Load distribution between boilers, internal combustion engines, steam turbines and supplementary firing is optimized for each cogeneration plant yearly. The average exergy efficiency, specific CO_2 emission and the quantity of natural gas saved are evaluated over the lifespan of the oilfield considered. It is showed that the use of reciprocating engines represents a fuel saving of up 308,300 t of natural gas in comparison with gas turbines which represents a reduction in the CO_2 released to atmosphere of about 800,000 t.

1. Introduction

A FPSO (Floating Production Storage and Offloading) is usually an adapted industrial floating plant aimed to maritime fields applications in order to produce and process petroleum [1,2]. An advantage of FPSO is its capacity for temporarily storing treated crude oil together with the possibility to operate in deep and ultra-deep ocean allowing exploration in remote locations [3,4]. Currently, the performance of FPSO is generally assessed by indicators such as specific energy (heat, shaft power and electricity) consumption and quantity of CO_2 produced per unit of oil equivalent [5,6]. However, these indicators are limited to the quantity of energy required regardless its quality. Exergy-based indicators seem to be more suitable since they take into account both, the quality and the quantity of the energy required [7]. In 1997, Oliveira Junior and Van Hombeeck [8] carried out an exergy analysis on separation, compression and pumping modules of a Brazilian offshore platform. Petroleum heating and gas compression were responsible for the major exergy destruction. In 2010, Voldsund at al [9] performed an exergy analysis of a platform located in the North Sea. They focused on the process plant. Results showed irreversibilities were distributed as following: 66% in the gas injection trains, 20% in the separation train, 11% in the gas recompression train and 3% in the gas export section. Furthermore, according to these researchers, the gas injection trains were the most indicated sector to improve efficiency. In 2013, Voldsund et al. [10] performed an exergy analysis on a typical production day of an oil and gas processing plant located on North Sea. Variations in physical exergy were described and analyzed. Authors concluded that most exergy destruction occurs in the recompression and reinjections trains. Nguyen et al. [5] described a generic model of an offshore plant and then made a comparative analysis taking into account 6 different case studies. Similar conditions of operation were considered. However, petroleum production and composition were different for each study case. Authors concluded that major exergy destruction took place in the utilities plants instead process plant. In the utilities plant, major irreversibility occurred in the combustion chamber. In the process plant, major irreversibility occurred in the production manifolds and gas compression trains. Barrera, Sahlit and Bazzo [11] carried out an analysis of exhausted

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gas rejected by an existing platform. Both energy and exergy balances were performed in order to identify the possibility of using the available energy. Three different scenarios were proposed to integrate the heat recovery system on the platform: auxiliary power generation using Organic Rankine Cycle (ORC), absorption chiller to cool gas turbines (GT) intake air in order to increase their power and the combination of both solutions. Authors concluded that the best improvement was found using the combination of both tecnhologies. In 2014, Voldsund et al. [12] identified sources of exergy destructions and losses for platforms with different working conditions. The greatest exergy destructions have taken place in the gas treatment sections followed by gas recompression sections and production manifolds. Although the main sources of exergy destruction vary according to well type, process plant configuration, distance to coast and others, the cogeneration plant is always among them. Nguyen et al. [13] performed an exergy analysis together with the pinch analysis method in order to evaluate the efficiency of an oil and gas platform taking into account 3 different stages of the oil field lifespan. In the early-life production the oil rate increases. In the *plateau* case, the oil rate reaches its maximum. In the end-life case the oil and gas productions decrease significantly. Results showed that the exergy destroyed on the platform was 65, 64 and 58 MW in the early-life, *plateau* and end-life cases, respectively. Sánchez and Oliveira Junior [14,15] compared exergy efficiency of an offshore platform taking into account 2 different configurations: in first case they considered a CO_2 capture system and in second case they did not considered this system. Utilities and process plant were included using data from offshore platform simulation developed by Oliveira Junior e Van Hombeeck [8]. Authors concluded that the CO_2 capture system increased the exergy destruction by 37% while a decrease of 77% in CO2 emissions was noticed. In 2015, Sánchez and Oliveira Junior [4] assessed exergy performance of a FPSO considering 3 operating modes. Results revealed that variations in the oil and gas fraction have significant influence on exergy efficiency. Ortiz and Gallo [16] applied first and second Laws of Thermodynamics to analyse the CO_2 compression system and gas turbine model of a FPSO. Three different petroleum compositions were considered and gas turbines, compressors and heat exchangers irreversibilities were calculated. Results showed that gas turbines were the main exergy destruction source and the compressors exergy efficiency varied significantly for each petroleum composition case. Utilities plant is responsible for providing both thermal and electrical energy to the process plant and since they suffer significantly with changes in production rates, it is important to assess their thermodynamic performance in order to improve the energy efficiency and reduce exergy losses. Although exergy destruction varies according to the characteristics of the offshore platform and properties of the well, a generic model of an overall offshore platform system was described by Nguyen et al. [5]. According to authors, major exergy destruction (around 65%) of an offshore platform occurs in the utilities plant (power generation and waste heat recovery system) and the remaining exergy destruction (around 35%) takes place in the process plant (oil and gas processing).

This work focus on the cogeneration plants for FPSOs and it presents a methodology for assessment of these plants. Load distribution between parallel components is optimized yearly and the off-design operation for the main equipment is considered since the electricity and heat demands vary according to platform production. Gas turbines, reciprocating engines, combined cycle and cogeneration steam plant are evaluated as case studies.

2. Methodology

A typical FPSO configuration is used in this work. The equations used for simulation of off-design behaviour of main cogeneration plant components are indicated. The indicators used to evaluate the cogeneration plants under different demands over the lifespan of the platform are also presented. Fig. 1 indicates the main steps proposed.

2.1. Production prediction

Many techniques are used to predict the decline behaviour of given well such as exponential, hyperbolic and harmonic models. These models are capable to predict the quantity of oil, water and gas production along the years indicating the lifespan that is economically viable for the well. They are very important for equipment sizing and for definition of process plant operation strategy, however these predictions carry significant uncertainties due to geological complexity and uncertainties regarding petroleum composition [17]. The production curves for oil, gas and water used in this work will be presented in the case study section.

2.2. Process plant sizing

The process plants of modern Brazilian FPSOs are usually composed of compressors, pumps, CO_2 separation membranes and oil and water separation/treatment unit (Fig. 2). The expected water, oil and gas mass flow rates for each year are used to determine the utilities demand (heat and electricity) required for the process plant using the process plant model. It is possible to adjust the simplified model used for the process plant to meet detailed models results as the one developed in Carranza Sanchez and Oliveira Junior [15] or in Carranza Sanchez [18] by using calibration factors.

Two operation modes for the process plant are considered: in mode 1 all gas produced is re-injected into the well and only oil is exported; in mode 2 natural gas is separated from CO_2 which is re-injected into the well while the natural gas free of CO_2 is exported to an onshore basis. According to the simplified scheme proposed, the petroleum arrives at the platform through the production manifold and it is directed to the treatment and separation train which is composed of a series of separators, where gas, oil and water are separated by using temperature increase and pressure decrease sequentially. The oil is directed to storage tanks and produced water is re-injected or discharged into the sea after passing through treatment (hydrocyclones and decantation) to eliminate the remaining oil. The gas is directed to the compression trains which are organized in 4 groups. Group A is composed of 3 parallel compressors with a single compression stage and they compress all produced gas leaving separation train. Group B1 is composed of 3 parallel compressors with 2 stages of compression and with inter-cooling between stages. This group is designed to compress all produced gas from group A (mode 1) or natural gas free of CO_2 when CO_2 membranes are in operation (mode 2). Group B2 is composed of 2 parallel compressors with 4 stages of compression and with inter-cooling between stages. This group is designed to compress CO_2 when the CO_2 membranes are in operation (mode 2). Group C is composed of 2 single stage compressors which are designed to compress not only produced gas but also CO_2. Group C is used for injection of produced gas into the well when the CO_2 membranes are not in operation (mode 1); conversely it is used for injection of CO_2 when the CO_2 membranes are used and natural gas free of CO_2 is exported to shore using compression group B1 (mode 2). The main energy requirement for the CO_2 membranes is due to pressure loss, thus it is taken into consideration in compression units. Each group of compressors is sized considering the gas flow rate for the year in which the highest production occurs. For the compressors, the specific work