



Exergy analysis and energy improvement of a Brazilian floating oil platform using Organic Rankine Cycles



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ABSTRACT

This paper focuses on the exergy performance analysis of the processes on board of a Brazilian FPSO (Floating Production, Storage and Offloading unit) and the integration of an ORC (Organic Rankine Cycle) for improving its efficiency. Based on the exergy analysis of the plant, the integration of an ORC to the existing heat recovery system was modeled. Cyclopentane was chosen as the working fluid and the best configuration of the cycle was determined according to its vapor saturation curve. The improvement was quantified using the plant exergy efficiency and an energy-consumption indicator, assuming a distributed part-load operation of two gas turbines. The study was carried out along an arbitrary profile, at which five of the main production parameters were analyzed separately. According to the results, it appears that the ORC integration has a great potential for generating useful work from the exergy of the exhaust gases, representing savings along the production profile of about 15% based on fuel consumption. On the other hand, the overall exergy efficiency and the ORC power output are strongly influenced by the amounts of gas and water injected back to the reservoir.

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1. Introduction

Recently, the improvement of the energy efficiency in the oil industry has been subject of various publications, showing an increasing interest up in this concern. For example, the analysis made by Nguyen et al. [1] was focused on the exergy life performance of a Norwegian oil and gas platform considering three different stages and examined the integration of different Rankine cycles. Analogously, a comparative exergy study of four North Sea offshore platforms conducted by Voldsund et al. [2] pinpointed the major sources of exergy destruction in each case. By other side, Nur and Shuhaimi [3] carried out an exergy-based performance benchmark applied to a crude distillation unit aiming at the highest fuel reduction. Adopting the notions exposed by Buller [4] regarding the oil sector, this tendency can be explained by the necessity of addressing three current challenges: (i) a growing oil and gas demand, (ii) the necessity of reducing CO₂ and other greenhouse emissions and (iii) the increasing oil and gas production costs. Particularly, the offshore production has been an

important part of the oil industry development, about 33% of world oil production is obtained from offshore platforms and their projected contribution is relatively stable until 2020 [5]. Considering that over 45% of currently known oil resources are located under the sea and about a quarter of these resources corresponds to deepwater (water with a depth of 400 m or above), a remarkable production growth of 81% is estimated only for this type of fields, according to data reported by IEA [6].

Diverse types of offshore installations have been spread around the world, of which the floating platforms are the most suitable for deepwater production [7,8]. Among them, the FPSO (Floating Production, Storage and Offloading) units present technical advantages, especially in the development of short-lived and marginal fields in remote locations where fixed platforms were impractical and uneconomical [9,10]. A recent FPSO survey [11] has reported Petrobras as the operator with the second largest number of FPSO units (about 12 owned and 14 operated), representing over 15% of existing worldwide.

These installations include the production of the energy required by their own processes, using a part of the oil (or gas) produced in the plant as fuel for the generation of power, cold and heat. Improving the use of this energy through the plant will reduce the fuel consumption, which has important benefits like the

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abatement of pollutant emissions and the reduction of operating costs. In that direction, IEA [12] has shown the CHP (combined heat and power) as a good alternative to increase the energy efficiency in various industrial sectors in the short term. By other side, the DOE (Department of Energy of United States) [13] has presented the main opportunities, challenges and barriers to the RD&D (research, development and demonstration) for the development of technology related with WHR (waste heat recovery) in some industries. Within this context, numerous investigations have been focused on the utilization of the waste heat to activate thermodynamic cycles supplying power, cold or upgraded heating [14,15]. Among these systems, the ORC (Organic Rankine Cycle) is a recognized technology for power generation that already has been used to improve the efficiency in many industrial operations and processes [16,17].

The implementation of this technology is especially suitable for WHR with heat sources with low temperature level (up to 230 °C, following the classification adopted by BCS [13]), where few systems can be activated at such temperatures. In the case of the offshore platforms, the waste heat is commonly available at medium level temperatures (up to 650 °C) that also make the conventional Rankine cycle theoretically suitable as the bottoming cycle of gas turbines. However, considering the current status of many platforms, there are space and weight restrictions that limit the applicability of this type of systems. Recent studies have dealt with these restrictions, highlighting the need of minimizing the weight-to-power ratio of the steam cycle [18], and the integration of steam networks into the platform [19]. By other side, Pierobon et al. [20] compared three different bottoming technologies for applying in an offshore platform, resulting in larger performances for the ORC technology when compared with steam cycle units and air bottoming cycles. Accordingly, the ORC systems appear as the most promising alternative for WHR in existing FPSOs, where significant modifications are not permitted.

Diverse publications have demonstrated the usefulness of ORCs for energy efficiency improvement in offshore platforms. Particularly [21], reports an energy efficiency increase of 12.9% in a gas turbine used in a platform by the incorporation of an ORC recovering part of the waste heat associated with its exhaust gases. Furthermore [22,23], have proposed different optimization algorithms in order to maximize the power generated by analyzed ORCs. In spite of that, an important aspect when assessing the suitability of a modification/upgrade of a platform is that the physical and chemical characteristics of the well fluid – hence the operating conditions of the plant, can vary with time following the production profile of the field until its depletion. It makes each platform unique and consequently, the impact of an ORC would be different in each case. Most of the previous works that addressed the exergy analysis and improvement in offshore platforms using ORCs considered constant operation conditions, generally based on the nominal capacity of the plants. By other side, the few works that deal with variable conditions simulate hypothetical operation stages varying different parameters simultaneously. Therefore, these approaches do not enable the identification of the most influencing production variables on the exergy efficiency of a given platform. In that way, this paper presents an evaluation of the impact of an ORC over the exergy efficiency of a typical FPSO, considering the variation of five relevant production parameters independently. The development of the model was based on the current configuration of an existing Brazilian FPSO and the efficiency improvement was calculated using an exergy-related indicator and another indicator representing the energy consumed per each volumetric unit of oil produced.

2. Methodology

2.1. Process description and operation parameters

The considered production plant corresponds to an FPSO located at the Santos basin (Brazil). The main purpose of the process is to separate the well fluid into oil, gas and water meeting the specifications for their export/further treatment. Fig. 1 presents its scheme of operation, where the main products of the plant are shown together with its mass and energy balances.

In the same way, Fig. 2 presents a simplified PFD (Process Flow Diagram) of the plant. The well fluid is throttled through a choke (valve L-B00) to meet the pressure level of the first separation stage, which is formed by the heat exchanger E-B01, in which the well fluid is preheated with the exported oil stream (B09) and the separator V-B01, wherein the most of the gas (B11) and water (B21) are removed from the main stream (B03).

Next, the oil stream is throttled through valve L-B01 and heated in the heat exchanger E-B02 for promoting a further separation of gas and water in the separator V-B02 (streams B12 and B23 respectively). The heat is supplied by means of the circulation of a heat transfer fluid (Dowtherm®A), which withdraws heat from the exhaust gases coming from the power generation subsystem through the heat exchanger E-E01. The separation is accomplished with an electrostatic separator for meeting the final specifications of the oil stream (not shown) and a further separation in separator V-B03 at lower pressure. Then, the oil is pumped (P-B01) through E-B01 and dispatched to the tankers (stream OIL), previous cooling with seawater in the cooler E-B02. By the other hand, the water separated in V-B02 (B23) is pumped back (P-B02) and mixed with the inlet well fluid in order to promote the phases separation prior to the first separation stage. The main production water stream coming from V-B01 is directed to the water treatment system (not shown) to meet the required conditions for its disposal, then is throttled through valve L-B04 and cooled with seawater in cooler E-B04 before being discharged on board.

The gas separated in V-B01, V-B02 and V-B03 is directed to the gas boost subsystem (BOOST in Fig. 2), where the streams at lower pressures are compressed up to an intermediate pressure level before being compressed for injection/export in the gas injection subsystem (GAS INJ. in Fig. 2). The scheme of the gas boost system is presented in Fig. 3. The gas coming from V-B03 (B14) is compressed by C-C01 up to second separation stage pressure (C03, 312.9 kPa) and mixed with the gas coming from the second stage separator (B12); then, the mixture (C04, 108 °C) is cooled through the cooler E-C01.

The liquids formed by condensation are removed from the gas stream in the separator V-C01 and sent back to V-B03 (B26). Next, the gas stream (C06) is compressed (C-C02) up to an intermediate pressure slightly less than the first separation stage (1350 kPa) and cooled through the cooler E-C02 (inlet temperature 149.5 °C). The condensates separated (V-C02) are returned to V-C01. The boost compression train works recirculating a portion of gas to V-B02 (B29). By other side, the gas coming from V-B01 (B11) is regulated through valve L-C01 and mixed with the boosted gas (C10) to be directed to the main compression trains.

The gas stream coming from boost subsystem (B17) is directed to the gas injection system (GAS INJ. in Fig. 2), the scheme of operation is shown in Fig. 4. In a similar manner to the boost subsystem, the gas injection train consists of four compression stages (C-D01/C-D02/C-D03/C-D04, up to 2575 kPa/5099 kPa/10,100 kPa/20,050 kPa, respectively), each one accomplished with a gas cooling stage (air coolers F-D01/F-D02/F-D03/F-D04 with inlet temperatures 126 °C/110 °C/109 °C/104 °C, respectively) and the subsequent separation of condensates, which are returned back to

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