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Energy efficiency improvement in oil refineries through flare gas recovery technique to meet the emission trading targets

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ABSTRACT

Flare gas recovery is one of the most attractive methods to improve energy efficiency in oil refineries to decrease greenhouse gas emissions. The recovered gas is used to feed refinery processes, granting advantages in terms of fuel economy and flare stress. This paper presents the results obtained by a feasibility study of a flare gas recovery system in a real refinery; the work focused on: i) the choice and the design of the flare gas recovery system; ii) the gas treatment and reuse; iii) the economic feasibility, and the payback period. An experimental campaign has been performed to evaluate both the composition and the flow rate of the flare gas. Results showed that the flare gas had a strongly variable flow rate and composition due to the different gas species processed in refinery. A methodology for the system selection is presented: a 400 kg/h liquid ring compression device is chosen; its basic design is described as well as the chemical treatments of inert gases and hydrogen sulphide (H_2S). The yearly energy recovery was estimated to be 2900 TOE, corresponding to 6600 tons of CDE (Carbon Dioxide Equivalent). Finally, an economic evaluation was carried out, showing a payback period of about 2.5 years.

1. Introduction

The global warming issue is mainly driven by a strong increase in the carbon dioxide and other greenhouse gases released in the atmosphere by the human activities.

Oil refineries are energy intensive plants that are responsible of a significant amount of greenhouse gas emissions. In this context, Gielen et al. [1] analysed different types of approaches to reduce the emissions of Japanese petrochemical industries. Due to their contribution to the emission of greenhouse gases, oil refineries are among the energy intensive sectors included in the EU Emission Trading System [2,3]. The production process of refineries has a strong environmental impact due to the significant amount of co-produced gas that is flared as a by-product and large supplies of gas have emerged. Moreover, flare gas has high concentration of H_2S and other harmful by-products species are the most important elements to process. A suggested method to control the environmental impact of oil refineries is the prevention of gas flaring. Gas flaring is a safety practice that consists on burning off the disposed gases lost through the safety valves of the plant and on the gas discharged in the blowdown system during unsteady running conditions, like the shutdowns of the refinery plants. Given the CO_2 reduction targets suggested by the Kyoto Protocol, gas flaring in refineries will be probably forbidden or strongly limited. Therefore, this operation will be analysed and improved in the future oil refineries processes by studying different methods, including the GTL (Gas-to-Liquid) production that is deeply investigated by Bjorndalen et al. [4] and it is considered a suitable alternative to conventional gas flaring. Mourad et al. [5] investigated on burned gas recovery in order to run the petrochemical industry or, otherwise, to maintain the rate of oil production. Anomohanran [6] showed the results of the greenhouse gases emissions produced by gas flaring activities in Nigeria with the purpose to warn the government in order to carry on several activities for their reduction. Xu et al. [7] investigated on the minimization of flare stack to allow chemical plant start-up operations in order to decrease the energy loss caused by the amounts of VOCs (volatile organic compounds) and highly reactive VOCs released by the flare. Zadakbar et al. [8] showed a method which consisted in compressing flare gas and sending it to the fuel gas header for immediate use as fuel gas. Several authors discussed the advantages of flare gas recovery and

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Nomenclature

LHV	Low Heating Value [kJ/kg]
β	Compression ratio
c	Specific heat [kJ/(molK)]
T	Temperature [K]
$\dot{m}$	Flare gas mass flow rate [kg/h]
$\dot{V}$	Flare gas volumetric flow rate [m^3/h]
ρ	Flare gas density [kg/m^3]
p	Pressure [bar]
W_{sp}	Specific work [kJ/kg]
η	Efficiency
P	Power [kW]

Subscripts

Stage	Stage
Ovrll	Overall
Inlet	Inlet port
Outlet	Outlet port
Pol	Polytropic transformation
Is	Isentropic transformation
Real	Real transformation
Isobaric	Isobaric transformation
Vol	Volumetric
Tot	Total

the design of the system in order to decrease the amount of CO_2 released in the atmosphere: Abdulrahman et al. [9] analysed the importance of the flare gas recovery through the CDM (Clean Development Mechanism) recognised by KP (Kyoto Protocol). Sterk et al. [10] discussed the subsidising methods granted by the single countries to encourage the local industries to improve their energy efficiency. Saidi et al. [11], after a resume of the flare gas recovery advantages, highlighted three different technologies to recover the flare gas: GTL (gas-to-liquid) technology [12]; gas turbines in order to produce electrical energy [13]; and finally the compression method [14], which consists in compressing the recovered flare gas and injecting it into the fuel gas header. As aforementioned, the flare gas is obtained by mixing all the gases released in the oil refinement processes, so its molecular weight is variable and it depends on the different running plants situations. After an evaluation of the pros and cons of the possible flare gas recovery technologies, Sonawat et al. [15] explained how to recover the flare gas using the ejector; in their paper, they gave detailed information about the design of the recovery system. As regards the liquid ring compressor, Banwarth [16] supplied a detailed description of the design steps required for one-stage and two-stage compressor design. A detailed explanation of the main design points and utilization of the flare gas recovery system and the choice of technology is reported by Zadakbar et al. [17] for a refinery located in Iran, and by Fischer et al. [18], for a refinery located in Arkansas (U.S.A.). In this latter case, liquid ring compressors were used to recover the gas because this type of machine results to be the best-suited solution considering the process requirements, efficiency, maintenance and, finally, the possibility to remove the H_2S contained in the flare gas.

In this paper, technical and economic feasibility of a flare gas recovery system are analysed considering an Italian refinery as a case study. In particular, the flare gas composition and its flow rate will be reported over a wide period of refinery plants operations. In addition, two different technologies for the flare gas recovery are analysed: the first one is the ejector and the second one is the liquid ring compressor. Using the liquid ring compressor technology, it is possible to reduce the percentage of H_2S inside the flare gas and thus to operate a first treatment of the gas itself; downstream the compressor a second process, that consists in an amine washing column, completely removes the H_2S. The cleaned flare gas can be sent to the fuel gas header of the refinery in order to be reused for feeding the refinery processes. The choice of the recovery technology and the energy consumption of the liquid ring compressor are discussed; the work also discusses energetic, environmental and economic considerations of the introduction of a flare gas recovery system; finally, an economic evaluation of the flare gas recovery technology is presented.

The paper is organized as follows: Section 1 describes the two commercial technologies to recover flare gas; Section 2 describes the flare gas system addressed in terms of lay-out, gas analyses (flow rate, chemical composition, LHV (Low Heating Value)) and design of the liquid ring compressor; Section 3 reports the results of the study in terms of energy and economic analyses and emission reduction; finally, conclusions are reported.

2. Technologies for the flare gas recovery

One of the most important topic in the design of a flare gas recovery system is the choice of the most viable technology that can be applied to the refinery plant.

The two most used technologies in petrochemical industries are ejector and liquid ring compressor. Goodyear et al. [19] explained in detail how the ejector works. The ejector is defined as ‘jet pump’ or ‘educator’; for its work, it exploits the Bernoulli's principle: an increase in velocity (kinetic energy) corresponds to a decrease in pressure and vice versa. In this way, the flare gas is catch and, afterwards, compressed at an intermediate pressure between LP (Low process Pressure) and HP (High process Pressure) with the help of HP driving fluid, which can be liquid or gas that supplies the energy required for the final compression. The ejector is very cost effective and it is used in many refinery processes. A single stage ejector consists of driving nozzle, suction nozzle, mixing chamber, throat and diffuser. The driving fluid (HP fluid) goes through the nozzle where its kinetic energy increases in spite of a decrease of pressure energy: this effect carries on a significant pressure drop of the fluid and the generation of a low-pressure region downstream the nozzle that allows the LP fluid to be recalled into the ejector.

The driving and the suction fluid are mixed in the mixing chamber. The driving fluid decelerates while the suction fluid accelerates; indeed, in the throat, the pressure of the mixed gas increases. The mixture goes through the diffuser where its kinetic energy decreases due to a further rise in pressure; thus the pressure of the suction fluid increases to the exit pressure, which reaches a pressure level between the HP and LP, as, reported in Abdelli [20]. Sarshar et al. [21] explained that, if the exit pressure of the mixed gas is lower than that required for the following refinery processes, a higher number of ejectors must be installed in series. The feasibility of this solution requires the characteristics of the elaborated fluid to be almost the same.

In the same way, Banwarth [16] described the second technology, the liquid ring compressor, which is commonly used in