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Integration of flare gas with fuel gas network in refineries

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A R T I C L E I N F O

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The high price of crude oil, strict environmental regulations and ever-increasing demand for energy have made refineries adopt a more holistic approach to integrating energy, economics and environment in their design and operation. Gas flaring is a major factor for the wastage of energy in oil and gas industries that could be better utilized and even generates revenue. Integration and use of wasted and flared gases with fuel gas network (FGN) is an effective approach for reducing GHG emissions as well as conserving energy in refineries. In this paper, current FGN model introduced by Hassan et al. was modified and also a novel methodology was presented for grass-root and retrofit design of FGNs using integration of flare gas streams. GHG emission concept is added to the base model as new constraint to control and minimize the flaring. A FGN proposed for a refinery case study with integration of flare gas streams indicated a 12% reduction in natural gas consumption compared to the non-integrated flare gas stream case and a 27.7% reduction compared to the base case with no FGN. In the retrofit case, results suggested that the maximum utilization of flare gas streams can be the most profitable solution.

1. Introduction

Flaring of waste and unwanted gases to the atmosphere is a major concern in whole petroleum industry. According to the recent data, 139 billion cubic meters of gas are flared annually [1], which is equal to 4.6% of world natural gas consumption of total 3011 billion cubic meters in 2008 [2]. This results in about 281 millions of tons of CO_2 emissions per year [3]. Flaring emissions also lead to warming of the earth and intensify the natural greenhouse effect on atmosphere and hence to climate changes over the coming century [4]. Many developing oil producing countries flare and ventilate large amounts of unwanted, waste or purge hydrocarbon gases with high heating value and make huge losses to energy and economic resources [5].

Global energy demand due to high economic growth has continuously reached new peaks and is predicted to increase by 57% from 2004 to 2030 [6,7]. This concern in addition to successive reduction of hydrocarbon fuel reserves has provided new advanced concepts for energy management in oil and gas industries [8]. Different approaches to increasing energy efficiencies by reducing unnecessary wasting, purging, and energy recovering from waste streams were reported in many researches. These can be reached by investing on improving equipment efficiencies and applying research on new energy resources to replace the fossil fuels and hence reduce fuel consumption and pollution emissions [9]. Alsalem presented the main sources of flaring in Kuwait's petroleum refineries. Better utilization of recovered heat through units and carbon capture projects were suggested [10]. Voldsund et al. analyzed the exergy destruction for on four North Sea offshore platforms and indicated that exergy losses with gas flaring can be significant. A survey was conducted to investigate the installation of flare gas recovery systems for supplying heat demand by waste heat recovery from the exhaust gases and by heat integration with other process streams. Gas filed and gas injection was used as recovery strategies [11]. Morrow III et al. developed energy-usage reduction curves for the United States petroleum refining. The results can estimate the potentials for energy savings and CO_2 emission reductions for refining technologies like refinery gas processing and flare systems [12]. Jou et al. indicated that recovering and reusing waste tail gas emitted from petrochemical industries is a great method for saving energy and reducing the environmental impacts [13]. Liu et al. investigated the key energy-saving technologies in Chinese refineries. They implemented flare gas recovery for fluid catalytic cracking and coker processes, as large values of hot flare gas are generated in these units. Also, the liquid fuel replacing with natural gas was suggested to reduce energy consumptions [14]. Ptasinski et al. applied the Extended Exergy Accounting (EEA) indicator to performance analysis of

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Dutch chemical and energy transformations [15]. Persson et al. considered the influence of seasonal variations on energy-saving opportunities in a kraft process using process integration techniques [16]. Worrell et al. identified the energy savings and CO_2 abatement potentials in the United State iron and steel industry by examining several specific energy efficiency technologies [17].

Over 40% of the operating cost of a chemical plant is contributed from energy [18], which is a main component of daily operating costs in plants such as refineries. Thus, a systematic network utilizing waste and flare gases as the fuel to be consumed in the fuel gas sinks such as turbines, furnaces, and boilers, is an efficient tool to save energy and reduce GHG emissions. A FGN collects various waste gases, flare gases, and fuel gases as source streams and passes them through pipelines, valves, heaters, coolers, and compressors to mix them in an efficient manner and supply them to various fuel sinks [19].

A new management and control strategy to improve the performance of FGN without changing the existing superstructure in a petroleum refinery has already been studied [20]. Wicaksono et al. proposed a mixed-integer nonlinear programming (MINLP) model in an LNG plant for integration of various fuel gas sources [21]. Wicaksono et al. further extended this practice by integrating jetty boil-off gas as an additional source [22]. Afterwards, Hasan et al. addressed the optimal synthesis of a FGN with different practical features such as auxiliary equipment (pipelines, valves, heaters, coolers, compressors, etc), non-isothermal and non-isobaric operation, non-linear mixing, non-isothermal mixing, non-linear fuel quality specifications, treatment costs, and fuel and utility costs. They proposed a FGN superstructure that installs possible alternatives for moving, mixing, heating, cooling, and splitting and also developed a non-linear programming (NLP) model.

However, Hasan et al. did not consider the environmental issues on their proposed model. In this study, the model proposed by him is used as a base model, and new constraints for flaring emissions-mostly for CO_2 emissions-are then developed. Also, their approach is only valid for grass-root design of FGNs, which is extended here to propose our novel profit-based retrofit NLP model.

2. Problem statement

A typical FGN superstructure introduced by Hasan et al. consists of three main nodes (Fig. 1). The first node consists of all available fuel gas sources ($i = 1, 2, \ldots, I$). A source is a kind of gas stream which has a non-zero heating value and potential for mass balance. The waste/purge gas streams from different units in refineries (such as crude distillation unit, amine unit, or visbreaker unit), feed/byproduct/product gas streams (such as LPG in refineries), and external fuel gasses (such as natural gas which are purchased), are some examples of source streams [23].

The second node consists of J pools that are used as mixing headers ($j = 1, 2, \ldots, J$). These pools are used to receive and mix fuel gas streams from different sources and send them to different sinks to satisfy their requirements. Although different source streams that enter into these pools can have different temperatures; however, they should be of the same pressure.

The third node consists of K sinks where fuel gas streams are used ($k = 1, 2, \ldots, K$). A sink is any equipment or plant which needs fuel gas stream to produce heat or work. There are different kinds of sinks such as turbines, furnaces, boilers, and flares. Some sinks such as gas turbine drivers are defined as fixed sinks, since they need a constant value of energy. By contrast, sinks that can consume fuel gas more than their energy need for producing power/heat are defined as flexible sinks such as steam generating boilers [23].

As illustrated in Fig. 1, source stream i entering into the network will be divided by splitters. Each sub-stream passes through auxiliary equipment (cooler, heater, compressor, and valve) and connects to header k. Each header transmits the mixture of sub-streams to the sink k.

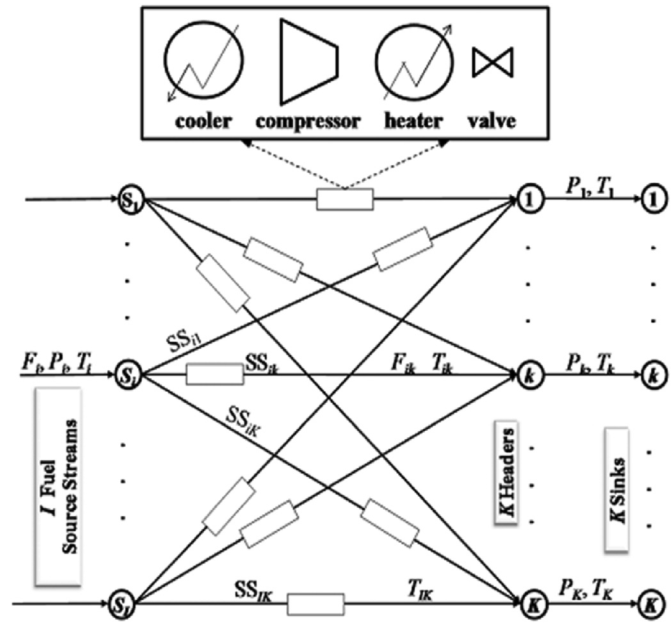

Fig. 1. Schematic superstructure of a fuel gas network [23].

The problem is formulated with the following data:

(1) A set of source streams with known characteristics such as compositions, temperatures, pressures, etc,
(2) A set of fuel sinks with known energy requirements and acceptable ranges for different specifications such as flows, compositions, pressures, temperatures, lower heating value (LHV), Wobbe Index (WI).
(3) Operating and capital cost parameters for equipment used in the FGN.

We make the following assumptions:

(1) Plant operates in the steady state condition with no chemical reaction;
(2) No temperature dependency for lower heating value of fuel gases is considered;
(3) Only valves are used for expansions and all expansions comply with Joule-Thompson expansion theory;
(4) Gas compressions are adiabatic and single stage;
(5) No pressure drop in equipment and pipes are assumed;
(6) There is unlimited utility operation at any temperature;
(7) Reference temperature and pressure are 68 °F and 14.7 Psia.

It is desirable to design a network distributing fuel gas source streams to fuel gas sinks with known characteristics through auxiliary equipment with known duties. All stream specifications such as pressure, temperature, and flow must be calculated. The objective function of total annualized cost (TAC) of FGN should be minimized. The capital costs of the network equipment, operating costs of the fuels and environmental costs due to flaring are included in TAC.

3. Model formulation

Now we can formulate the FGN model with the following