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Research Paper

Heat exchanger application for environmental problem-reducing in flare systems of an oil refinery and a petrochemical plant: Two case studies

S.M. Jokar *, M.R. Rahimpour, A. Shariati

Department of Chemical Engineering, School of Chemical and Petroleum Engineering, Shiraz University, Shiraz 71345, Iran

HIGHLIGHTS

- Two sever problems were investigated in a domestic oil refinery and an ethylene plant.
- The problems involved in releasing of liquid hazardous waste from flare systems.
- The liquid wastes analyzed and the concerned unit simulated.
- The designed heat exchanger prevents slops formation in flare system of the refinery.
- The heat exchanger prevents emission of 168 kg/h of droplets from the ethylene plant.

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ABSTRACT

In this work, two common problems for refineries and petrochemical plants were investigated, which includes burning of unwanted components in flare systems. Although some heavy components are separated in knock out drums of flare networks, separated liquids or non-separated heavy pollutants cause significant environmental problems. In the domestic refinery, the separated liquids form slops which should be treated in the waste water plant of the refinery. However, the non-separated hydrocarbons generate droplet emissions in the domestic ethylene plant site. To handle mentioned problems, the slops and droplets were analyzed, and the concerned units were simulated. Two heat exchangers were designed to reduce the water carry-over from the waste gas stream of refinery and condense the heavier pollutants of ethylene plant before flaring. The optimum condition of the heat exchangers is obtained by sensitivity analysis and economical optimization. Furthermore, the environmental benefit and cost of the new systems were investigated. The results approved the dramatic impact of the heat exchanger application on reducing the environmental problems of the flare systems. The designed heat exchanger condenses over 60 percent of water from the vapor phase and makes it suitable for introducing to the incinerator. Moreover, preventing the emission of 168 kg/h of droplets is possible by applying the heat exchanger for the domestic ethylene plant.

1. Introduction

1.1. Flare gas and air pollution

Refineries and petrochemical industry flares are major sources of air pollution which have dangerous effects on the ecosystems. In recent years, the reduction of the waste gas emissions and the recovery of the flare gas have been considered in many different processes. Davoudi et al. [1] investigated the major sources of gas flaring in Asalouyeh gas processing plants. Tamba et al. [2] and Al-Salem [3] surveyed the CO_2 emissions in the petroleum refining in Cameroon and Kuwait respectively. Some researchers tried to estimate the CO_2 and NO_x emissions of refinery fired heaters [3–7]. Furthermore, a few studies have been carried out which attempted to prevent the loss of the refinery waste gases. Some refineries planned to construct cogeneration facilities based on gas turbines burning refinery gases [8] or refinery gases and natural gas [9]. Rahimpour et al. [10,11] and Saidi et al. [12] proposed practical methods for recovery of flare gas instead of conventional gas burning in Farashband and Asalouyeh refineries. These methods include (1) gas to liquid (GTL) production, (2) electricity generation with a gas turbine, (3) compression and injection into refinery pipelines and (4) using flare gas as a feed of fuel cell. Abdulrahman et al. [13] investigated the improvement in Egypt's oil and gas industry by implementation of flare gas recovery. Some

* Corresponding author.
E-mail address: s.m.jokar@shirazu.ac.ir (S.M. Jokar).

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studies have been conducted on CO_2 capturing [14–17] and hydrogen production [18–20] by using flue gas as a source in order to save fuel consumption and reduce pollution emissions from furnaces.

1.2. Oil refinery and liquid emissions

Crude oil converted to a large number of products in different processes of oil refineries. The processes require water and also generate a significant amount of wastewaters [21].

Also, the oil refineries could produce oily sludge from different sources including, tank bottoms, slops oil emulsions, oil/water separators, and on-site wastewater treatment pond [22].

Slops have been recognized as a dangerous waste that contain compounds which are hard to break down [23] and should be treated in the wastewater treatment of the refineries [22,24]. Such liquid wastes discharge a toxic pollutant, which is hazardous to any substance or body exposing to these discharges [23].

The major notable content of slops is phenols, ammonia, H_2S and BTEX (benzene, toluene, ethylbenzene and xylenes) [25–28].

Various physical [29,30], chemical [31], and biological [32] methods have been developed for the reduction of chemical oxygen demand (COD) of the waste water which impose extra costs on refineries [33]. Therefore, wastewater management highly affects the economics of a refinery. Besides, the mentioned processes do not completely remove COD, inorganic/organic, and volatile/semi-volatile compounds [23].

Recently, some researchers tried to increase the efficiency of water treatment units by introducing new methods, such as electrochemical method [34,35], ozonation [36–38], Fenton and photocatalytic oxidation [39,40] and membranes processes [41]. All of the aforesaid processes carry noticeable cost and thus the prevention of liquid wastes production should be of a major concern.

1.3. Ethylene plant and liquid emissions

The petrochemical industry is a fast-growing industry in the world. Ethylene plants are important industrial plants where paraffin feedstocks such as ethane, propane and naphtha are processed and converted into ethylene. The ethylene production is economically important but highly energy-intensive process [42]. Steam cracking of naphtha at high temperatures is the most common method for ethylene production. Impurities such as acetylene are formed in this procedure. The acetylene concentration should be lower than 1 ppmv to avoid the catalysts deactivation [43]. It can be omitted from ethylene through hydrogenation, in which acetylene is selectively hydrogenated in a packed bed catalytic reactor [44].

The following four reactions take place in the hydrogenation of acetylene [45]:

$$C_2H_2 + H_2 \rightarrow C_2H_4 \quad (1)$$

$$C_2H_4 + H_2 \rightarrow C_2H_6 \quad (2)$$

$$2C_2H_2 + H_2 \rightarrow C_4H_8 \quad (3)$$

$$nC_2H_2 + mH_2 \rightarrow \text{green oil and coke} \quad (4)$$

Coke and green oil are formed by side reactions of the hydrogenation reaction (Eq. (4)) and deposited on the catalyst surface leads to catalyst deactivation [46,47]. Consequently, it is essential to regenerate the catalyst for several times during the catalyst lifetime.

Green oil is formed in all types of hydrogenation reactors of ethylene plants and other petrochemical production facilities [48]. It is a mixture of hydrocarbons with composition ranges from C_4 hydrocarbons to paraffins and olefins of high molecular [49].

Yajun et al. devised the general formula for green oil as: $C_nH_{(1.8-1.9)n}$ ($14 < n < 17$) [50]. Typically, 10–20% of the acetylene converted to C_4 and heavier green oil [48,51–53].

The fuel gas used for the regeneration of the catalyst, strips out the deposited green oil and coke on the molecular sieves, contaminating the fuel gas with the green oil [54]. The flue gas from catalyst regeneration discharged directly into the atmosphere or flared.

The green oil droplets in the flare and flue gas cause negative environmental and societal impact and generate large volume of odor. Recently, Rahimpour et al. [54] and Dehghani et al. [55] suggested new configurations to reduce coke and green oil formation during acetylene hydrogenation process. Recently, several studies were conducted on efficient methods for flare gas minimization during ethylene plant start-ups [56–62]. Unfortunately, the problem of flare gas emissions during normal operation is overlooked in these studies. At normal conditions, flare gas from ethylene plants contains green oil, catalyst dust, carbon monoxide and hydrocarbons [63].

2. Objectives

Flaring is an important part of oil refineries and ethylene plants. It could be happened during to the following conditions:

1- Startup and shut down: During the startup and shut down of the plant, a significant amount of hydrocarbon should be flared.
2- Non-continuous flaring (for plant-safety): Flaring will take place due to the deficiencies in compressors, chillers, vessels, etc.
3- Continuous flaring: After initial start-up, continuous flaring occurs when the plant is in the production stage. The flue gas from different processes flared during normal operations.

The most studies undertook to minimize flaring during start-ups and shut downs [56–62]. But it should be taken into account that various types of hydrocarbons are produced during the production. For this reason, the hazardous impact of pollutants in continuous gas flaring could contribute to more serious environmental problems.

2.1. The domestic oil refinery

Huge sums of money are wasted daily in a typical refinery as energy loses. Some of these losses are inevitable while in some cases money is squandered for the sake of consistent non-stop operation. However, there exist cases in which savings in costs can be achieved through logical analysis. This is where a process engineer can make a difference [64].

In a typical sour water treating unit (SWTU), gases rising from the feed surge drum, rich in NH_3 and H_2S, are vented off the system to be burnt up. This is usually carried out in the incinerator furnace of the sulfur recovery unit (SRU). Care must be taken for this gas stream, known as the waste gas or sour gas, to keep the water carry-over as low as possible. This is due to the high energy of vaporization of water which makes it impossible to be destroyed in the downstream furnace [65].

Due to the boosting capacity of the domestic refinery in recent years, the aforementioned issue has risen. All of the units operate at an over design capacity, SWTU is not an exception. The feed of this unit has increased and resulted in an inevitably significant