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Exergy analysis for fuel reduction strategies in crude distillation unit

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ABSTRACT

Inefficient furnaces and heat exchangers contribute to the depletion of fossil fuel problem due to higher fuel demand and higher carbon emission. The method of exergy analysis is applied to the furnace and crude preheat train (CPT) in a crude distillation unit (CDU) to determine performance benchmark of the system. This paper presents exergy analysis and strategies to reduce exergy loss through process modification. The highest exergy loss was found to be located at the inlet furnace. The proposed options for fuel reduction strategies are reduction of heat loss from furnace stack and overall cleaning schedule of CPT. The feasibility and economic analysis for both options are investigated. From the results, overall cleaning schedule of CPT contributes to the highest energy saving of 5.6%. However, reduction of heat loss from furnace stack is the highest cost saving by about 6.4%.

1. Introduction

The exergy of the system is defined as the ability to do work or the work potential of a great variety of streams such as mass, heat and work that flow through a system at a specified reference temperature [1]. Exergy analysis is an effective method based on the second law of thermodynamic which can be used to systematically locate and quantify the inefficiency of a process system. Once the locations of the system's inefficiencies are identified, improvement can be made to reduce exergy loss of the system. Many researches and engineers conduct exergy analysis as a method for analyzing, designing and improving systems and processes. Some of the previous works done on the application of exergy analysis in industrial processes has been reported on crude distillation unit, power plant, cogeneration plant, cooling system and fuel cell system [2–6]. Doldersum [7] applied exergy analysis on distillation process. The author found that the exergy loss occurred in the furnace and distillation column. Several process modifications to reduce exergy loss were proposed. After the process modification, the total exergy loss was able to reduce by 70% that directly related in a reduction of fuel for almost 40%. Rivero et al. [8] studied exergy analysis on crude oil combined distillation unit. The economic improvement potential was analyzed for the process streams. The authors found that the highest cost of exergy loss is the atmospheric fired heater which about 45% of the total cost of exergy loss.

While there are many published approaches on determination of location and magnitude of exergy loss in distillation column [7–11], the strategies to achieve operational improvement is usually uncertain. This paper presents fuel reduction strategies in CDU by applying the concept of exergy analysis to determine location and quantity of exergy loss as well as to generate possible fuel reduction strategies through process modification.

2. Methodology

2.1. Establishment of base case data

The crude distillation unit (CDU) is the first step in a refinery complex to separate crude oil into different fractions. In a typical CDU, crude oil feed stream is preheated in a crude preheat train (CPT). CPT utilizes high temperatures of the distillation column product streams. The relevant process data are extracted from a typical refinery in Malaysia. The selected data has been agreed and validated by a local oil refinery's engineers after careful consideration. Fig. 1 shows a simplified process flow scheme of CDU crude preheat train. The crude oil is heated up to 112 °C before entering the desalter. The hot streams are the hot product streams coming out from crude tower. After desalter, the crude oil stream is further heated up using heat recovered from the process streams. At this end, the crude oil starts to vaporize at 203 °C. Then, the crude oil enters a pre-flash column to remove light naphtha, mixed naphtha

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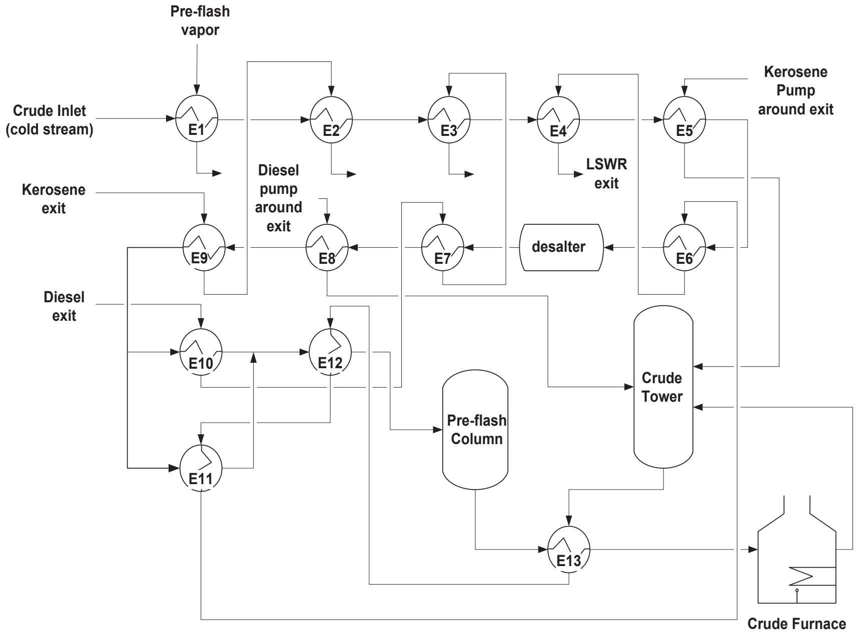

Fig. 1. CDU crude preheat train flow scheme.

and light hydrocarbon gases from the crude oil. The vapour is risen up to pre-flash overhead distillate and the liquid flows downward to the bottom. The preflash column bottom is further heated by heat exchanger E13 before entering furnace at design temperature of 215 °C. The preheated crude oil enters furnace at furnace inlet temperature (FIT). In a furnace, the heat source is provided by the burning fuel with air at theoretical flame temperature (TFT). The heat from the burning of fuel with air is transferred to the crude oil [12]. Then, the heated crude oil enters the crude distillation column at tower inlet temperature (TIT). The remaining heat in the furnace leaves through furnace stack at stack temperature (*T* stack).

2.2. Exergy analysis

Fig. 2 shows an exergy composite curve. The upper line is the hot composite curve and the lower line is the cold composite curve. The area under the hot composite curve is the amount of exergy source (ΔE_H) and the area under the cold composite curve is the amount of exergy sink (ΔE_C). Note that ΔE_H is partly covered by ΔE_c in Fig. 2. The gap between hot composite curve and cold composite curve is the exergy loss which is $\Delta \text{Ex}_{\text{loss}} = \Delta E_H - \Delta E_C$ [13].

The exergy source in a system is provided by hot process streams that transfer heat and is calculated as follows:

$$\Delta \text{Ex}_{\text{source}} = (H_{h2} - H_{h1}) - T_o(S_{h2} - S_{h1}) \tag{1}$$

On the other hand, the cold process stream that receives heat is the exergy sink:

$$\Delta \text{Ex}_{\text{sink}} = (H_{c2} - H_{c1}) - T_o(S_{c2} - S_{c1}) \tag{2}$$

Exergy is never conserved in real processes. Exergy will degrade and will be lost. Exergy loss reflects the irreversibility in the heat transfer process. Exergy loss can be calculated from an exergy balance as follows:

$$\Delta \text{Ex}_{\text{loss}} = \sum \Delta \text{Ex}_{\text{sources}} - \sum \Delta \text{Ex}_{\text{sinks}} = T_o(\Delta S_c - \Delta S_h) \tag{3}$$

where ΔS_c is change in entropy for cold streams and ΔS_h is change in entropy for hot streams.

2.3. Generation of possible fuel reduction strategies

Fig. 3 shows a typical exergy composite curve for furnace. *T* stack is located at the initial point of hot composite curve while TFT is located at the end point of hot composite curve. FIT is located at the initial point of cold composite curve while TIT is located at the end point of cold composite curve.

The fuel reduction strategies are generated from exergy composite curve analysis. As shown in Fig. 3, amount of exergy loss is represented by the gap between hot and cold composite curve. Thus, the idea to minimize exergy loss of the system is to obtain closer gap between hot and cold composite curve. The closer gap between hot and cold composite curve can be obtained by:

a) Reducing theoretical flame temperature (TFT)
b) Reducing stack temperature (*T* stack)
c) Increasing tower inlet temperature (TIT)
d) Increasing furnace inlet temperature (FIT)

These four options are the possible fuel reduction strategies for CDU. Two options are chosen to be implemented in this study which are reducing *T* stack and increasing FIT. The proposed options for fuel reduction strategies in this study are reduction of heat loss from furnace stack and overall cleaning schedule of CPT. The first

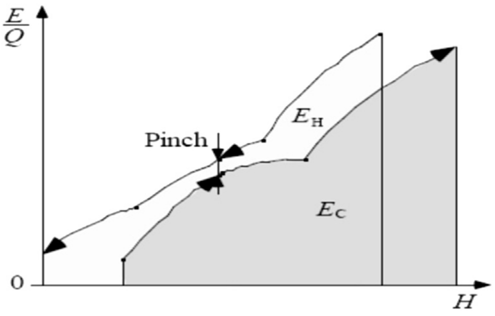

Fig. 2. Exergy composite curve.