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MINIMIZING THERMODYNAMIC LOSSES IN SULFUR RECOVERY UNIT: AN EXERGY ANALYSIS APPROACH

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Abstract

Sulfur Recoveru Unit (SRU) is one the vital units in the treatment of petroelum and natural gas which eliminates sulfur compounds from hydraocarbon products. Since sulfur recovery unit is invovled with high temperature processes, hence it is associated with remarkable potential of thermodynamic losses consequently. In this work, an exergy analysis is performed over the SRU sub-units in order to determine the location of thermodynamic losses. The results show that the exergetic efficiency could be improved and also thermodynamic losses be minimized; so that the exergy efficiency in incinerator and claus reaction furnace could be increased from 9.9% and 11.22% to 12.58 and 14.96% correspondingly.

Keywords: Sulfur Recovery Unit; SRU; Exergy Analysis; Thermodynamic; Debottlenecking.

1. Introduction

Desulfurizing of the hydrocarbon products is one of the most important steps of petroleum and natural gas refining process. The sulfur compound in Sulfur Recovery Unit (SRU) are eliminated and converted to the elemental liquid sulfur. The Claus process is the most significant gas desulfurizing process and has been known as the most common process worldwide for sulfur production in refineries and gas treatment plants. Since the processing of liquid sulfur takes place in high temperature, therefore the operation is associated with considerable amounts of thermodynamic losses.

Exergy analysis is an able tool for evaluating chemical processes in order to minimize thermodynamic losses and energy bottlenecks. Since the exergy analysis is developed based on the concept of the second law of thermodynamics and irriversibility, therefore gives more meaningful and applicable reults about the energy losses in the process. Exergy analysis also can help the engineers to modify the most efficienct method which has the lowest amount of exergy destruction. In the other words, an exergy analysis will give a more realistic and engineering efficiency index as the Exergy Efficiency.

Exergy analysis has been used widely by engineers and researchers to de-bottlenecking the process plants and determining the exergy efficiency of different processes and units. Amir Vosough showed that the efficiency of a steam power plant could be improved using exergy analysis and some changes in the operational conditions considerably [1]. Singh Hada et al. in a similar work minimized the rate of irriversibility generation in a fired boiler within a thermal power plant via exergy analysis [2]. Pal et al. also performed exergy and energy analysis over a coal fired thermal power plant [3] and determined the boiler a energy bottleneck with a 61% loss. Dincer et al. utilized an exergy and exergy analysis on Saudi Arabia utility sector to compare different sub-sectorial efficiencies and determining irriversibility sources in the plant [4]. Change et al. presented a new exergy method for process analysis and optimization based on a two-level idealization concept, involving the definition of intrinsic and extrinsic exergy destruction in a process [5]. Also several studies have been done on the optimization of processes using exergy concept and exergy analysis [6-8].

In this work, exergy analysis is utilized to evaluate a Sulfur Recovery Unit (SRU) thermo-dynamically, and determine irriversibility sources and magnitudes.

2. Methodology

The studied Sulfur Recovery Unit includs two Claus sections, Hydrogenation, Absorbtions, Acid Gas Enrichment (AGE), Regeneration, Incineration and Sulfur Degassification sections. Figure 1 represents the arranegement and connectivity of these sections.

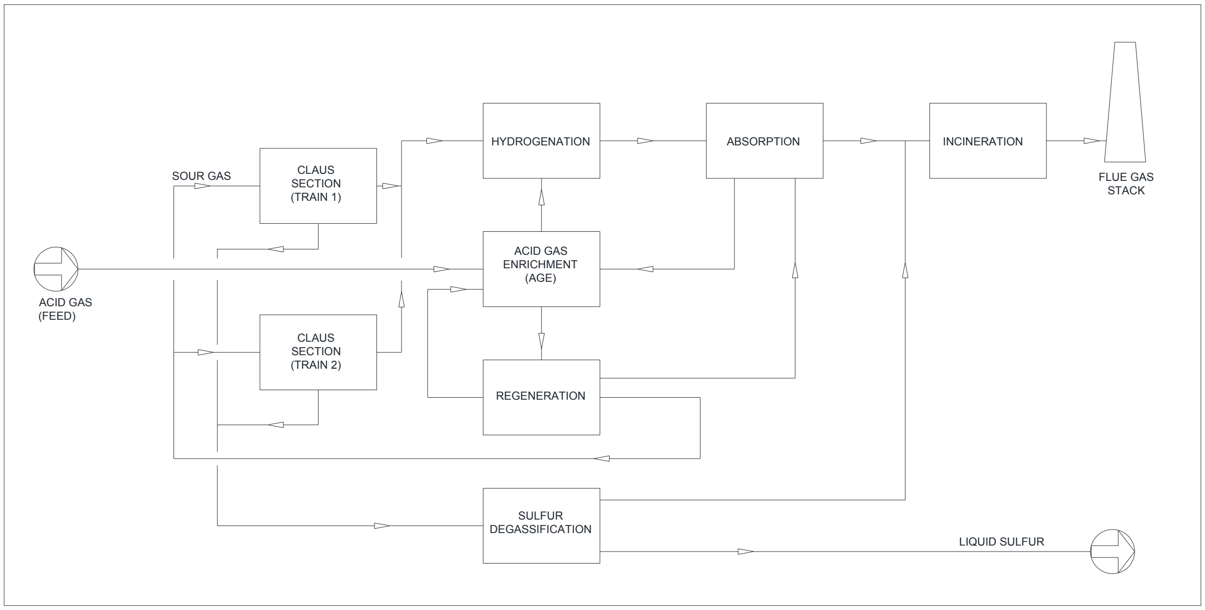

Fig. 1 Block Flow Diagram of Sulfur Recovery Unit

The acid gas from upstream is entered as the unit feed stream and routed to the Acid Gas Enrichment (AGE) in order to increase the concentartion of sour components. The acid component (mainly CO_2 and H_2S) absorbed in the amine solution will be recovered in the Regenerator and then routed back to the Claus sections. In Claus section the sour gas meets a Furnace-Reaction which converts a part of H_2S into SO_2 in order to reach an stoichiometric ratio for further Catalytic Reactors. There are two Catalytic Claus Reactors in which H_2S could be converted to the elemental liquid sulfur. The formed sulfur is removed in each stage using inter-stage condensers and seperation equipments. The unreacted components (such as COS and CS_2) leave the Claus section to Hydrogenation and are converted to H_2S. the off-gases will be burned in Incineration unit which makes the conditions of flue gas suitable for being released into the atmosphere via Stack. The collected liquid sulfur is coveyed to the Degasification in order to eliminate the dissolved H_2S and then sent as the final product to the downstream treatments (i.e. grannulation or storage).

According to the definition, exergy or work potential of the energy contained in a system at a specified state is simply the maximum useful work that can be obtained from the system. In exergy analysis, the initial state is specified and thus the work output is maximized when the process between two specified states is executed in a reversible manner. Disregarding process irreversibility, the system goes to reach the dead state or complete equilibrium state. The irreversibility is equivalent to the exergy destroyed, and in all of real processes the destroyed exergy term is always positive due to entropy generation [9-10].

The second law efficiency or exergy efficiency is intended to serve as a measure of approximation to reversible operation, and thus its value should range from zero in the worst case (complete destruction of exergy) to one in the ideal case. Therefore, the second-law efficiency of a system during a process is defined as below [11].

$$\eta_{Ex} = \frac{\text{Exergy Recovered}}{\text{Exergy Supplied}} = 1 - \frac{\text{Exergy Destroyed}}{\text{Exergy Supplied}} \qquad (1)$$

The exergy methodology consists of four steps. The first step is to establish the system boundaries by developing a flow diagram of the process, determining which inputs/outputs are parts of the system. Secondly, the process is broken down into operation units and nodes to study each one independently. A node or operation unit is defined as a unit of the process with a set of working conditions. Finally the exergy of pure substances, mixtures, heat flows, works and etc is calculated.

In general, the physical exergy is defined by equation (2), where values for specific enthalpies and entropies are obtained from the equations (3) and (4).

$$Ex = (H - H_0) - T_0(S - S_0) \tag{2}$$

$$H = \int_{T_0}^{T} C_p.dT + \Delta H^R \tag{3}$$

$$S = \int_{T_0}^{T} \frac{C_p}{T} .dT - R\ln\frac{P}{P_0} + \Delta S^R - R\sum_{i=1}^{N} x_i \ln x_i \tag{4}$$

After calculation of all of exergy values, a process exergy flow diagram could be developed, which identifies material and energy losses and detecting areas needing technological improvements [11-12].

3. Results

The exergy of all input/output streams have been calculated and all of operational units and sections have been evaluated from exergy point of view. The exergy analysis results are summarized in table 1.

Table 1. Summary of exergy analysis in the studied nodes

#	Operational Unit / Node	Exergy Input (kW)	Exergy Output (kW)	Exergy Destruction (kW)	Exergetic Efficiency (%)
1	Incineration	309138.9	30606.02	278532	9.9
2	Claus Reaction Furnace	72077.5	6135.2	65942.3	11.22
3	Claus Condenser 1	682.9	311.9	371.0	45.7
4	Claus Condenser 2	343.5	163.9	179.6	39.8
5	TGT Reaction Furnace	4985.3	2547.4	2434.9	51.1
6	Regeneration Reboiler	17712.6	16617.9	1092.7	93.8

The results obtained show that furnace units have the least exergy efficiency due to the nature of combustion operation. However, the Claus Condensers have an acceptable efficiency, it could be improve by technical review in design and operating conditions. It must be considered that some part of exergy losses is inevitable because of the process design and operating conditions constraints. Also some weaknesses in the technology used causes exergy losses in the process.

In order to illustrate the magnitude of the losses, assuming that the total exergy desctrutions is corresponding to the exergy losses in the studied nodes, the contribution of each node in exergy loss would be stated as the figure 2.

In order to improve the thermodynamic losses in the process some strategies have been tested which include mainly the thermal integration of possible streams. For example the steam generated in the furnaces is used for warming-up the process streams or even in process heat exchangers. Exergy analysis repeated for the whole studied nodes in the improved conditions. The results are summarized in table 2.

Table 2. Summary of exergy analysis in the improved studied nodes

#	Operational Unit / Node	Exergy Input (kW)	Exergy Output (kW)	Exergy Destruction (kW)	Exergetic Efficiency (%)
1	Incineration	309138.9	38894.7	270244.2	12.58
2	Claus Reaction Furnace	54689.7	8182.0	46507.7	14.96

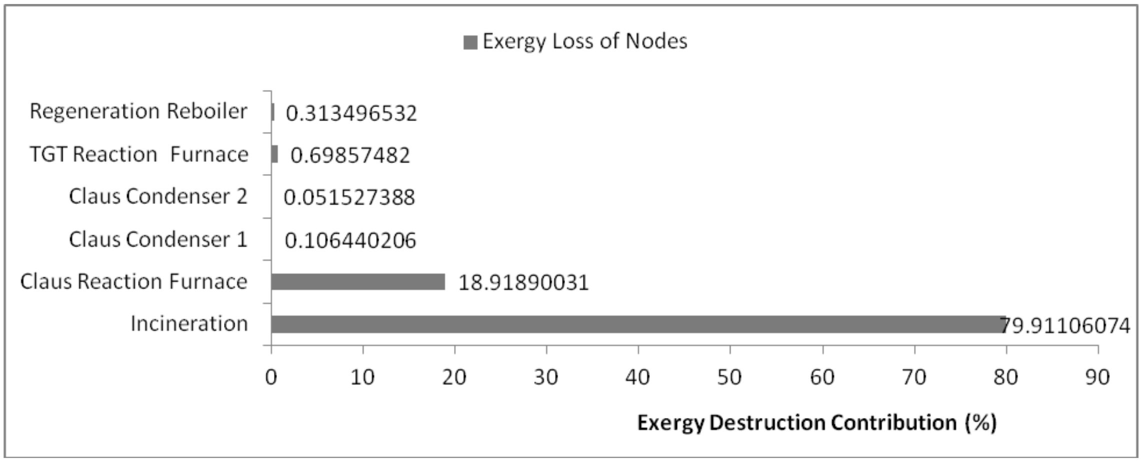

Fig.2 Contribution of the nodes in exergy loss

The considerable changes in exergy efficiency are associated with the thermodynamic bottlenecks in the plant. The increase in exergy efficiency of the other studied nodes was not significant, but the exergy efficiency of Incinerator and Claus Reaction-Furnace enhanced significantly. Figure 3 represents a comparison for exergy efficiencies for the improved conditions.

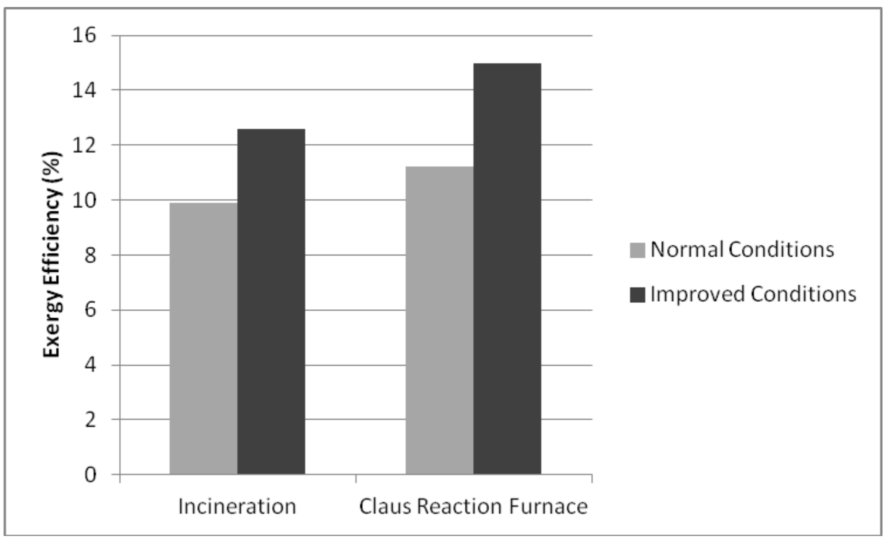

Fig.3 Enhancement of exergy efficiency by improving the conditions

Also, improving the conditions consequently decreases the total exergy losses considerably which could be compared against the normal condition according to figure 4.

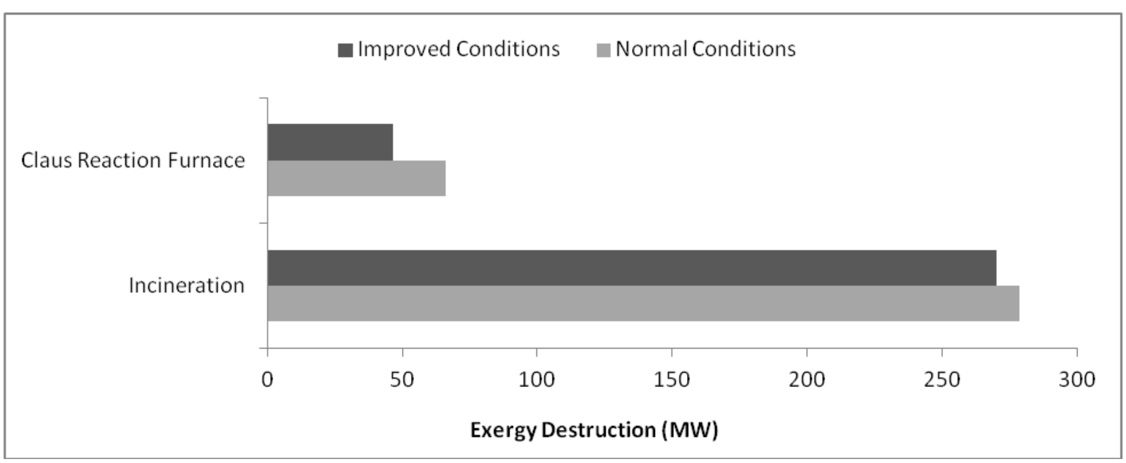

Fig.4 Decrease of exergy destruction rate in the bottlenecks

4. Conclusions

In this paper a Sulfur Recovery Unit (SRU) is evaluated thermodynamically using exergy analysis which as a usefull and able evaluation tool for engineers to determine the thermodynamics bottlenecks in the process plant. The results showed that in the operational unit which is associated with combustion process (mainly Incinerator and Claus Furnace Reactor) the exergy destruction rates are significant. In order to improving the performance of the plant and also enhancing exergy efficiency of the process, some thermal integration strategies applied and the exergy analysis repeated. It showed that although the process design and some operating conditions constrain the reaching to an ideal exergy efficiency, but it could be improved as much as possible by some simple, inexpensive, economic and also environmental changes. Exergy efficiency of the thermodynamic bottlenecks imprved up to 3.74% which considering the magnitude of exergy destruction rates could be a significant save of energy in whole the plant.

List of Symbols and Nomenclature

SRU	*Sulfur Recovery Unit*
TGT	*Tail Gas Treatment*
AGE	*Acid Gas Enrichment*
Ex	*Exergy (kJ/mol)*
H	*Enthalpy (kJ/mol)*
S	*Entropy (kJ/mol/K)*
T	*Temperature (K)*
C_P	*Heat Capacity (kJ/mol/K)*
R	*Universal Gas Constant (Pa . m^3/mol/K)*
x	*mole fraction (-)*
N	*Number of the component in system (-)*

Greek

η Efficiency (-)

Subscripts

Ex Exergetic
O Referece Environment
i Component

Superscript

R : Residual

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