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Technical and Economical Evaluation of Using Inline Burners for Reheating of the Process Gas in the Sulfur Recovery Unit

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Abstract

The duty of the sulfur recovery unit in oil and gas refineries is to convert H_2S to elemental sulfur. A proper design and operation of this unit lead to lower SO_2 emissions to the atmosphere. Several configurations can be proposed for a specific acid gas stream and each of them has pros and cons. In this paper, the advantages and disadvantages of using inline burners for reheating the process gas are compared with the conventional reheating method, i.e. the use of steam heat exchangers in terms of technical and economical points of view. The achieved results show that using inline burners will increase the investment costs as well as operational problems and is not recommended to be considered in sulfur plants.

Keywords: *Sulfur recovery; Inline burner; Steam heat exchanger; Tail gas treatment.*

1. Introduction

Crude oils often contain considerable amounts of sulfur compounds which need to be removed as H_2S gas in the refinery units such as gas oil or naphtha hydrotreatment units. Moreover, raw gas coming from the gas reservoir usually contains non-hydrocarbon species such as H_2S [1-4]. The Sulfur Recovery Unit is applied for converting H_2S to elemental sulfur in oil and gas refineries. The modified Claus process is the most common method for this aim. As indicated in Figure 1, this process includes a reaction furnace at the beginning of the unit in which about 60% of H_2S is burned and converted to elemental sulfur at the high temperature of 1000-1400°C, depending on the concentration of the H_2S in the acid gas stream (EQs.1&2).

$$H_2S + {}^3/_2\,O_2 \Rightarrow SO_2 + H_2O \qquad (1)$$

$$2H_2S + SO_2 \Leftrightarrow {}^3/_2\,S_2 + 2H_2O \qquad (2)$$

A waste heat boiler (WHB) exchanged the released combustion heat with water to produce steam (High pressure/Low Pressure/Medium Pressure, depending on the needs of the refinery) as well as cool down the process gas. The temperature of the cooled process gas depends on the pressure and temperature of the saturated steam which is produced in the WHB and usually varies in the range of 200 to 300°C. Therefore, a sulfur condenser may be needed after WHB for more cooling of the process gas and condensing and recovering the produced elemental sulfur in the reaction furnace [5-10].

More recovery of sulfur is achieved in the next catalytic step which involves two or three catalytic converters (reactors) and their down-stream sulfur condensers. Although, equation 2 is an endothermic reaction at high temperatures (above 600°C) and the recovery of sulfur increases with increasing the temperature of the reaction furnace, achieving temperatures as high as the reaction furnace temperature is impossible using the conventional heating methods. Therefore, reaction (2) will be exothermic in the Clause reactors temperature (below 600°C). To increase the rate of reaction (2) in the Clause reactors, using the alumina catalyst is considered which can convert SO_2 to elemental sulfur. Several by-products are produced in the reaction furnace together with elemental sulfur, such as COS and CS_2. These two compounds can be contributed to a high percent of the pollutants in the tail gas. Therefore in addition to the production of elemental sulfur, COS and CS_2 should be hydrolyzed in the first Claus catalytic reactor at a higher temperature than needed for the equilibrium reaction (2) (about 350°C) by the following endothermic reactions [8-16]:

$$COS + H_2O \Rightarrow H_2S + CO_2 \quad (3)$$

$$CS_2 + 2H_2O \Rightarrow 2H_2S + CO_2 \quad (4)$$

Effluent gas from the WHB or sulfur condenser must be reheated to the appropriate temperature for entering the Claus reactors. Generally, the conventional methods for reheating the effluent gas can be divided into two major groups including the direct and indirect methods. In the direct methods, the process gas is mixed with a hot gas stream. For instance, the hot gas bypass method is usually used for reheating the first reactor inlet stream (the hydrolyzing reactor) in which a slip-stream of hot process gases from the WHB is taken and mixed with the first reactor inlet stream. Lower overall sulfur recovery is mentioned as its disadvantage [12].

The other conventional direct method uses inline burners to burn either fuel gas or acid gas to produce a hot gas stream (figure 1-a). This hot gas is then mixed with the reactor inlet streams. In addition to the first reactor, this method can be applied for reheating the inlet streams of the second and third reactors too. Controlling the required combustion air is very critical in this method. Any excess oxygen (above 30 ppmv) can lead to the formation of SO_3 and deactivation of the catalyst or increase the corrosion rate in the downstream equipment. Moreover, a shortage of oxygen can lead to the formation of soot in the case of burning the fuel gas which can plug the catalyst pores and deactivate the catalyst.

On the other hand, the indirect reheat methods use direct-fired heaters or steam heat exchangers to reheat the process gases (Figure 1-b). Electrical reheating can also be used in lower capacities (lower than 100 KW). Although applying steam heat exchangers for reheating the Clause reactor inlet streams is considered an expensive alternative, it may be preferred to prevent the above-mentioned operating problems [12].

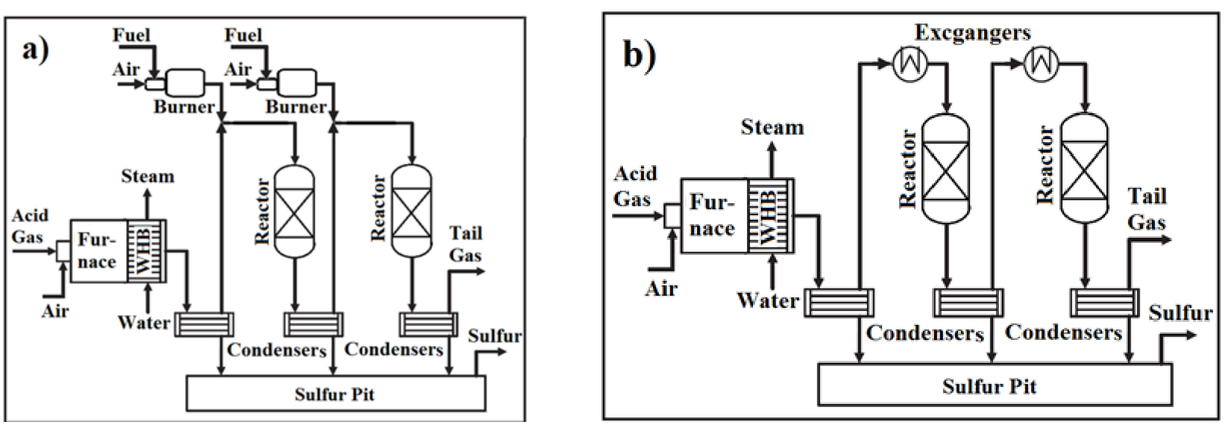

Figure1. A typical Claus process with a) inline burners; b) steam heat exchangers

As mentioned above, because of the presence of the unrecovered sulfur compounds such as elemental sulfur, COS, and CS_2, the overall recovery of sulfur in the modified Claus process is usually limited to 96 to 98 percent, depending on the number of catalytic stages. Therefore, Tail Gas Treatment (TGT) section is applied before the incinerator for achieving more recovery of sulfur and reducing the SO_2 emission under stricter environmental regulations [17-19]. SCOT process (Figure 2) is usually selected for tail gas treatment. In this process, at first, all sulfur compounds are converted to H_2S. Then, H_2S is selectively absorbed in an Amine contactor and desorbed in the regenerator column (stripper). The released H_2S is returned to the input of the Claus where it is mixed with Claus acid gas feed. The stream exiting from the top of the absorber column includes a negligible amount of H_2S and is sent to the incinerator [18-20].

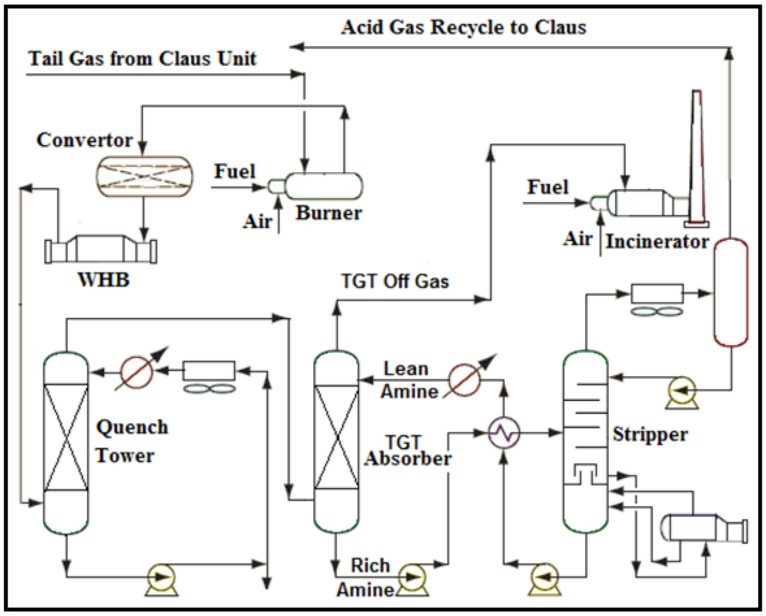

Figure2. Schematic flow diagram of the SCOT process [19]

In the next section, two types of reheating methods, i.e. Case I: using the inline burners (Figure 1-a), and Case II: using the steam heat exchangers (Figure 2-a), are considered in a typical SRU. At first, only the Clause section is simulated to compare these two cases in terms of the technical and economical points of view. Then, the TGT section is added to the simulation and the results are presented for a complete sulfur recovery unit.

2. Case study results

To investigate the effect of the applied reheating method on the performance of SRU, a typical industrial SRU with two catalytic reactors is considered. For this purpose, the commercial simulation software, Promax is applied which is calibrated and verified by several SRU designs and operating data of Iranian refineries to achieve valid and accurate results.

Burning of fuel gas in the inline burners produces H_2O and CO_2. According to eq.2, since H_2O is a product of the Clause equilibrium reaction, increasing the amount of H_2O is expected to shift the reaction toward the left side and reduce the overall recovery of sulfur. Moreover, increasing the CO_2 gas may have a negative effect on the selective absorption of H_2S in the absorber column of the TGT section. Therefore, in addition to a Claus section, the considered SRU contains one TGT section to study the influence of applying inline burners as preheating method on the performance of the TGT section, too. The specification of the acid gas stream which is considered as SRU feed is given in Table 1. As indicated in this table, the feed stream is not so lean and the concentration of H_2S reaches 40-mole percent.

Table1. Specifications of the acid gas feed to SRU

Property	Value
Temperature	60°C
Pressure	1.8 bar
Mole flow	600 kmole/h
Composition (mole%)	
H_2S	40
CO_2	46
CH_4	4
H_2O	10

High-Pressure Steam (HPS) is considered to be generated in the WHB and therefore a sulfur condenser is needed for cooling the process gas down to 180°C and separating the elemental sulfur produced in the reaction furnace. As described before, a high operating temperature of around 250 °C is needed for the first Claus reactor inlet stream to ensure that COS and CS_2 have hydrolyzed appropriately [12]. The second condenser is also responsible for the separation of sulfur produced in the first reactor. Unlike the first reactor, a lower operating temperature is needed in the second Claus reactor to enhance the conversion of the exothermic Claus reaction. But a temperature approach should be considered to prevent sulfur condensation in the catalyst bed. Therefore, the second preheater should rise the temperature of effluent gas from the second condenser, from about 170°C to 200°C.

To investigate the effect of preheating method on the performance of the Claus section, at first, the recycled gas from the TGT section is not considered in the simulations. Table 2 shows the required utility for preheating the inlet streams into the first and second reactors in Cases I and II, i.e. required fuel gas in Case I and required HPS in Case II. In case study II, HPS at 260 ⁰C and 47 bar are used as the heating medium. As presented in this table, the yearly required cost for reheating the process gas in Case I, i.e. using inline burners, is almost similar to the yearly required cost in Case II, i.e. using steam exchangers. However, the initial investment required in Case I will be greater than in Case II due to the need for more complex control systems.

Burning the fuel gas may increase the volumetric flow rate of streams that enter the first and second reactors as well as the tail gas stream which leaves the Claus section toward the TGT section. Increasing the flow rate of reactor and TGT feeds will increase the size of the equipment and, consequently the investment costs. Standard volumetric flow rates of reactor inlet and tail gas streams are presented in Table 2. As shown in this table, the flow rate of the first rector inlet in Case II is 1204 m^3/h greater than the first rector inlet in Case I (about 4%). This increase for the second reactor inlet and tail gas streams are 1643 m^3/h (about 5.6%) and 1642 m^3/h (about 5.7%), respectively. Therefore, in addition to requiring more investment for using inline burners instead of steam heat exchangers, more costs are needed for reactors and condensers in the Claus section. Moreover, it is expected that a larger TGT section is needed too.

As discussed above, in addition to producing CO_2, burning of fuel gas in the inline burners produces H_2O which shifts the Claus reaction toward the left side and reduces the overall recovery of sulfur. As indicated in Table 2, the overall sulfur recovery in Case I is 95.46 which is just 0.06% less than the recovery in Case II. Therefore, the effect of producing H_2O in the inline burners on the overall sulfur recovery can be neglected.

Moreover as mentioned above, burning the fuel gas will increase the amounts of CO_2 in the tail gas stream which has a negative effect on the selective absorption of H_2S in the absorber column of the TGT section. Although the component molar flow rate of CO_2 is increased in Case I rather than Case II from 268 kmole/h to 274 kmole/h, according to data presented in Table 2 the concentration of CO_2 in the tail gas stream is decreased in Case I rather than Case II which is related to the increasing of N_2 content in the tail gas stream. Therefore, CO_2 concentration is not considered a negative point in Case I rather than in Case II.

Table 2. Comparison of Claus section in Case I and Case II (Without TGT)

Property	Case I	Case II
Required utility, kg/h	110	2407
Utility cost, thousand $/year	154	152
First reactor inlet stream Std Flow, m^3/h	30905	29701
Second reactor inlet stream Std flow, m^3/h	30750	29107
Tail gas std flow, m^3/h	30518	28876
Overall sulfur recovery	95.46	95.52
CO_2 in tail gas, mole%	21.27	22

In the next step, the TGT section is also taken into consideration and the acid gas from the top of the TGT regenerator column (stripper) is recycled to the entrance of the Claus section (see Figure 1 and Figure 2). The same condition is supposed in the TGT section for both cases. For example, the flow rate of the Amine solution is equal to 210 m^3/h, as well as the reboiler duty is set to 10.67 MW. A similar analysis is performed for this case and the results are presented in Table 3. As indicated in this table, the required utility cost is approximately the same yet. The amount of increase in the flow rate of the process gas entering the first reactor, the second reactor, and the output gas from the Claus section, in Case I compared to Case II, is 4.4%, 6%, and 6.1, respectively. These results show that considering inline burners for reheating the process gas will increase the required investment for Claus and TGT sections. Although the Claus section alone has less recovery in Case I compared to Case II, similar recoveries are achieved when the TGT section is applied. Like the previous simulation, in the TGT active mode, the CO_2 concentration of the tail gas stream in Case I is smaller than in Case II.

Table 3. Comparison of SRU (Claus and TGT) in Case I and Case II

Property	Case I	Case II
Required utility, kg/h	124	2689
Utility cost, thousand $/year	174	170
First reactor inlet stream Std flow, m^3/h	34146	32698
Second reactor inlet stream Std Flow, m^3/h	33984	32045
Tail gas Std flow, m^3/h	33729	31791
Overall sulfur recovery	99.93	99.93
CO_2 in tail gas, mole%	25.29	26.11

The achieved results show that the investigated reheating methods have not any effect on the performance of SRU and similar sulfur recoveries are achieved in both cases. Although applying inline burners has benefits such as lower pressure drop and exact control of the temperature, especially for the first reactor, because of the larger amounts of process gas, using inline burners needs more investment rather than using steam heat exchangers. Moreover, the exact controlling of the air in the inline burners is difficult in operation, and severe corrosion is reported in some refineries using inline burners due to oxygen leakage.

3. Conclusions

Reheating of the process gas with inline burners is compared with steam heat exchangers. The achieved results showed that reheating methods do not have any effect on the performance of SRU and the recovery of sulfur. On the other hand, using inline burners need more investment rather than using steam heat exchangers due to burning fuel gas and larger amounts of process gas. Moreover, the exact controlling of air in the inline burners is difficult in operation, and severe corrosion is reported in some refineries using inline burners due to oxygen leakage. As a result, it is advisable to avoid the inline burner method to reheat process gas in the sulfur plant.

References

[1] Mahdipoor HR, Khorsand K, Mohammadi M, Alaei J, Tajerian M, Simulation of Hydrodesulfurization Reactive Column Using the Research Institute of Petroleum Industry Method, Ind. Eng. Chem. Res., 2009; 48: 2049-2055.

[2] Darwish NN, Shareefdeen ZM, Sayed YE, Zubaidy IA, Sara Z, Design and analysis of adsorptive desulphurization of diesel oil, International Journal of Oil, Gas and Coal Technology, 2018; 17(3): 304-320.

[3] Kayukova GP, Petrov SM, Romanov GV, Hydrogenation processes for white-oil production from Ashal'cha heavy crude, Chem Technol Fuels Oils, 2012; 48(4): 48-262.

[4] Zhu GY, Zhang SC, and Liang YB, The controlling factors and distribution prediction of H_2S formation in marine carbonate gas reservoir, China, Chin. Sci. Bull., 2007; 52: 150-163.

[5] Zhang Z, Wood DE, Sour gas reservoirs and sulfur-removal technologies: A collection of published research (2009-2015), Journal of Natural Gas Science and Engineering, 2015; 26: 1485-1490.
[6] Santo S, Rameshni M, The challenges of designing grass root sulphur recovery units with a wide range of H2S concentration from natural gas, Journal of Natural Gas Science and Engineering, 2014; 18: 137-148.
[7] Monnery WD, Hawboldt KA, Pollock AE, Svrcek WY, Ammonia Pyrolysis and Oxidation in the Claus Furnace, Ind. Eng. Chem. Res., 2001; 40: 144-151.
[8] ZareNezhad B, An investigation on the most important influencing parameters regarding the selection of the proper catalysts for Claus SRU converters, J. Ind. Eng. Chem., 2009; 15: 143-147.
[9] Sames J, Sulfur recovery process fundamental, Technical paper, Sulfur experts Inc.
[10] Anonymous, Gas Processors Suppliers Association (GPSA), Engineering Data Book, GPSA Tulsa, 1987; Chapter 22.
[11] Nasato LV, Karan K, Mehrotra AK, and Behie LA, Modeling Reaction Quench Times in the Waste Heat Boiler of a Claus Plant, Ind. Eng. Chem. Res. 1994; 33: 7-13.
[12] Mahdipoor HR, Ganji H, Minabi A, Zareie-Abyane M, Different Options for Reheating of the Claus Hydrolyzing Reactor, Petroleum & Coal, 2014; 56(2): 200-205.
[13] Huisman HM, van der Berg P, Mos R, van Dillen AJ, and Geus JW, Hydrolysis of Carbon Sulfides on Titania and Alumina Catalysts: The Influence of Water, Applied Catalysis A, 1994; 115: 157-172.
[14] Gens TA, Decrease in Carbonyl Sulfide in the Feed to Claus Converters by Shift Catalysts, Ind. Eng. Chem. Res., 1994; 33: 1654-1656.
[15] Puchyr DMJ., Mehrotra AK, Behie LA, and Kalogerakis N, Hydrodynamic and Kinetic Modeling of Circulating Fluidized Bed Reactors Applied to a Modified Claus Plant, Chem. Eng. Sci., 1996; 51: 5251-5262.
[16] Maadah AG, and Maddox RN, Predict Claus Product, Hydrocarbon Processing, 1978; 57: 143-146.
[17] Anonymous, Emission limit values: Combustion plants in EU and USA, Official Journal of the European Communities, 2001: 12-17.
[18] Mahdipoor HR, Kakavand M, The effect of amine concentration on the performance of TGT absorber column, Petroleum & Coal, 2015; 57(1): 56-59.
[19] Mahdipoor HR, Investigating the Effect of Operating Temperature on the Performance of TGT Absorber Column, International Journal of Energy Science (IJES), 2016; 6(1).
[20] Mahdipoor HR, Yousefian H, Naderi H, Kakavand M, The effective parameters at choosing an appropriate tail gas treatment process, chemical technology An Indian Journal, 2012; 7(3): 82-86.

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