Estimating Required Combustion Air and Fuel Gas in a Sulfur Recovery Unit (SRU) Containing Lean Acid Gas Feed

Hamid Reza Mahdipoor *1a, Saeed Hassan Boroojerdi 2a, Amir Erfani 3b, Hooman Javaherizadeh 4a

a Department of Process Development and Equipment Technology, Research Institute of Petroleum Industry, West Bld. of Azadi Stadium, Tehran, Iran
b School of chemical, gas and petroleum engineering, Semnan university, Semnan, Iran
*1 mahdipoorhr@ripi.ir; 2 hassanboroojerdi@ripi.ir; 3 a.erfani@students.semnan.ac.ir; 4 Javaherizadehh@ripi.ir

Abstract

Modified Claus process is highly applied in oil refining and gas processing for recovery of sulfur from H2S. Estimating the required air and fuel gas in reaction furnace are important in design and operation of sulfur recovery units. In this article based on some industrial SRUs design and operational conditions, variation of air and fuel flow vs. acid gas flow and concentration are investigated. As a result two simple correlations are developed for estimating the air and fuel gas demands.

Keywords

Combustion Air; Fuel Gas; Furnace Temperature; Claus Process; Sulfur Recovery Unit

Introduction

The Claus process continues to be the most widely used process for conversion of H2S to sulfur (Paskall, 1979; Tulsa, 1987; Sames; Baehr, 1938). Sulfur recovery units (SRUs) are necessary to match increasingly stringent emission control regulations (Signor, Manenti, Grottoli, Fabbri and Pierucci, 2010). Multi step Claus process removes sulfur from hydrogen sulfide in natural gas processing, refining crude oil, gasification and synthesis gas processes (Lins, 2007; Rappold, 2010; Maddox, 1974). The modified Claus process consists of a high temperature reaction furnace, followed by catalytic reaction stages. Many researchers had worked on thermodynamic and kinetic modeling of SRUs (Hawboldt, 1999; Monnery, 2001; Nasato, 1994; Dowling, 1990), while many researchers study optimum operation condition of these units (Hawboldt, 1998; ZareNezhad, 2009; Mahdipoor, 2012). Furnace flame temperature is one of the most important criteria’s in SRU operation but accurate prediction of temperature and species concentrations are difficult tasks. Estimation of required combustion air and fuel gas is useful for primary sizing of the air blowers and control valves.

Aim of this research is to introduce two simple correlations for estimation of air and fuel gas flow rates. Although complete sets of data for operating and equipment conditions are not easy to find, we had the opportunity to obtain the plant data for some industrial cases.

SRU Process Design

Figure 1, illustrates process flow of a modified two-stage Claus process. Numerous chemical reactions take place in reaction furnace but the overall reaction characterizing the process is oxidation of hydrogen sulfide as follows:

\[ 2H_2S + O_2 \rightarrow S_2 + 2H_2O \] (1)

At first approximately 1/3 of the acid gas is oxidizes:

\[ H_2S + \frac{3}{2}O_2 \rightarrow SO_2 + H_2O \] (2)

This combustion generates large amount of heat. SO2 also reacts away in subsequent reactions; the most important one is the Claus reaction:

\[ 2H_2S + SO_2 \leftrightarrow S_2 + 2H_2O \] (3)

Reaction (3) is a reversible, exothermic reaction. Principally adiabatic extent of every exothermic
equilibrium reaction increases temperature, which lowers equilibrium conversion. 50-60% of the total sulfur production of the plant is generated in the reaction furnace. Effluent gas from the reaction furnace passes through waste heat boiler (WHB).

In catalytic reaction stages, unreacted H₂S reacts with SO₂, over an activated alumina catalyst to form elemental sulfur. Processing gas with low H₂S content requires some special considerations in burner. Feed containing a relatively low concentration of H₂S has flame stability problems. Also, incomplete combustion of hydrocarbons in the feed can lead to deterioration of the catalyst in the reactors due carbon deposition. Several configurations are applied to treat lean SRU acid gas feed. Most common methods are: acid gas preheating, fuel gas burner, acid gas bypass around the furnace, and oxygen enrichment of the combustion air. Table 1, summarizes design of two SRUs with different H₂S concentrations. In lean feed case, acid gas and combusation air are normally fed to plant.

### TABLE 1 DESIGN OF TWO SRUS WITH DIFFERENT H₂S CONCENTRATIONS

<table>
<thead>
<tr>
<th>Feed</th>
<th>Industrial case 1</th>
<th>Industrial case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂S Concentration (molar)</td>
<td>Acid gas from MDEA trains</td>
<td>Sour gas</td>
</tr>
<tr>
<td>Operating Furnace Temperature (°C)</td>
<td>36%</td>
<td>64%</td>
</tr>
<tr>
<td>Design Temperature (°C)</td>
<td>1000</td>
<td>1009</td>
</tr>
<tr>
<td>Pressure (barg)</td>
<td>0.5</td>
<td>0.58</td>
</tr>
<tr>
<td>Preheating</td>
<td>Up to 220 °C</td>
<td>No preheating</td>
</tr>
<tr>
<td>Fuel Gas</td>
<td>Always operational</td>
<td>Only for start-up and shut-down</td>
</tr>
</tbody>
</table>

Estimated the Required Air and Fuel Gas

Conditions of acid gas feed stream demands for a typical SRU is presented in table 2 and combustion air and fuel gas, for industrial cases are summarized in Table 3.

Rigorous modeling of required air and fuel should be based on minimizing Gibbs free energy based of Lagrangian multipliers, which is not in scope of this research. If we assume all furnace reactions, as one simple reaction of H₂S and fuel gas oxidation we have:

(a) H₂S+ (b) Fuel gas+ (AF) Air $\rightarrow$ products

Then we can have:

AF=$(x)$ H₂S+(y) FG

In the other hand: $x=HS*Ag$

AF=a₁*(HS)*(AG)+a₂*(FG)

Which x, y, a, and ai are all constants. Also base on most simple form of energy balance:

AF*(HₐF)+AG*(HₐG)+FG*(HₐF)+Hr(fuel gas) +Hr (Acid gas) -Hproducts = 0

From equation (7), FG can be obtained:

FG=a+a₁(AF)+a₂(AG)+a₃(HS)

Equation 5 and 8 can be solved and reformed for FG and AF, thus:

FG=a+b(HS)(AG)+c(AG)+d(HS)

AF=e+f(HS)(AG)+g(AG)+h(HS)

Utilizing least square method and table 3 data’s, constants in equation 9 and 10 are obtained. Equation 11 and 12 present obtained correlations for air flow and fuel gas flow:

FG=0.7500-0.0024(HS)(AG)+ 0.1190(AG)-0.0206(HS),

r² =0.992

AF=0.9573+0.0024(HS)(AG)+0.9858(AG)-0.0271(HS),

r² =0.995

![FIG. 2 VARIATION OF REQUIRED AIR VS. ACID GAS FLOW RATE AT DIFFERENT H₂S CONCENTRATIONS](image-url)
Summary and Conclusions

Estimating the required air and fuel gas in reaction furnace is important for primary sizing of the air blowers and control valves. In this paper, the variations of the air and fuel gas were illustrated against changes in SRU feed flow rate and Hydrogen Sulfide mole percent. As the result, two correlations were developed for estimating the required air and fuel gas.

Nomenclature

AF: Estimated Air Flow (Kmol/h)
AG: Acid Gas Flow (Kmol/h)
FG: Estimated Fuel Gas Flow (Kmol/h)
Hi: enthalpy of component i
ΔHr: enthalpy of reaction
HS: Hydrogen Sulfide molar percent

REFERENCES


Sames, J., "Sulfur recovery process fundamental", Sulfur experts Inc.


Tulsa, "Gas Processors Suppliers Association (GPSA)”. Engineering Data Book; GPSA; Chapter 22, 1987.

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. 143-147, 15, 2009.