Optimization and Modeling of combustion air in Sulfur recovery unit and its effect on productivity and environment

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ABSTRACT

Sulfur recovery unit is one of the basic units of gas plants, it is very important in economic and environmental issues because it converts the H_2S into stable and environmentally neutral elemental sulfur. This work is to study the effect of combustion air used in Claus thermal reactor on performance efficiency of SRU and to find its optimality. SRU at Mellitah complex is used as a case study. Set of live tests (Experiments) on distribution control system (DCS) were done to investigate the effect of combustion air on H_2S conversion, depending on operation parameters (Field data) gathering by using instruments analyzer and transmitter. On the other hand PROMAX® software is used as a tool to simulate and predict the optimal tail gas ratio (H_2S/SO_2) that gets the maximum sulfur recovery efficiency. Results shown excess air forms unwanted SO_2 in tail gases and on contradict lack of air cannot completely oxidize H_2S, The optimal combustion air that get (H_2S/SO_2=2), because this ratio provides the maximum sulphur recovery efficiency. Mathematical correlations were created for the relation between acid gas and combustion air as a function of H_2S concentration in acid gases. The majority of field data were fit to new mathematical models.

Keywords: Combustion air, Sulfur Recovery Unit, Gas Plant, Environment, Mellitah Complex.

1. Introduction

The air pollution is to cause adverse effect on crops, trees, lakes, animals, natural environment, building, monuments and statues. It has been estimated that large amount of premature deaths and adverse health effects are linked to air pollution[1]. Oil and gas exploration and production is source of pollution which are associated with many environmental and socio-economic impacts [2].Environmental legislations imposes limits on the total quantity of sulphur compounds, such as hydrogen sulphide (H_2S) and sulphur dioxide (SO_2), which can be expelled from the plant. Typically each oil refinery operates with a license that specifies the permitted sulphur emission limits[3].

Sulphur recovery is an integral part of the oil refining and natural gas treatment process to recover (H_2S) from various waste gas streams, which are by products of plant operation using Sulphur Recovery Units (SRUs). Environmental legislations imposes limits on the total quantity of sulphur compounds, such as hydrogen sulphide (H_2S) and sulphur dioxide (SO_2), which can be expelled from the plant.

In the widely-used multistage Claus sulphur-recovery process Figure (1), a portion of the H_2S in the feed gas is oxidized to sulphur dioxide (SO_2) and water in a reaction furnace with air or enriched oxygen figure, normally two or more stages are used to achieve up to 97% overall sulphur recovery [4]. The reactions involved in the process are shown as follows:

$$H_2S + 1/2O_2 \rightarrow S + H_2O \quad (1)$$
$$H_2S + 2/3O_2 \rightarrow SO_2 + H_2O \quad (2)$$
$$2H_2S + SO_2 \rightarrow 3S + 2H_2O \quad (3)$$

H_2S is partially oxidized with air (one-third of H_2S is converted into SO_2) in the Claus furnace. The acid gas/air mixture is passed into a furnace operating at temperatures from 1300-1700 K; where the reactions are allowed sufficient time to reach equilibrium. The products from this step are: sulfur dioxide, water and unreacted hydrogen sulfide. Tail gas from the final unit contains a variety of sulphur compounds and normally requires further tail gas cleanup to obtain higher recovery.

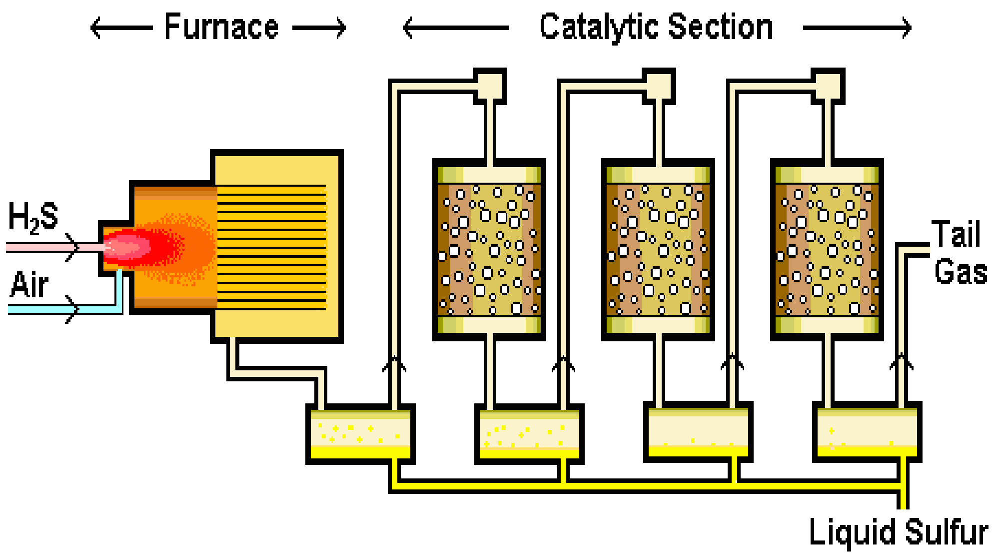

Figure 1: Typical arrangement of a Claus unit

2. Material and Method

2.1. Experimental work (DCS)

This work is to investigate the effect of combustion air on the performance of SRU which based on real tests on operation condition of Distribution control system (DCS) at Mellitah complex from 7-9-2018 to 10-9-2018 at different flow rate of combustion air at two operation live mode (lack of air and excess air) for two running identical sulfur recovery unit called (J_2 area) and (K_2 area). This live mode tests was done at different flow rate of combustion air on Friday (7-9-2018) Table (1), in case of lake of air and another test was on Saturday (9-9-2018), the analyzers and transmitters used in this test as show in Table (2).

Table 1: *Describe of Test runs for SRU trains at Mellitah Control Room*

No	Test Status	Area	Date	Duration	Location	mode
1	Lack of air	J_2	9-Sep-2018.	9:30 PM-12:00 PM	DCS	online
2	Excess air	J_2	9-Sep-2018.	3:30 PM-6:00 PM	DCS	online
3	Lackof air	K_2	7-Sep-2018	10:00 PM-12:00 PM	DCS	online
4	Excess air	K_2	9-Sep-2018.	2:00 AM- 4:00 AM	DCS	online

Table 2: *Analyzers and transmitters used in online test runs.*

No	Process variable	Instrument Tag	Unit	Loc
1	H_2S in process gas to 583HA001	582-AI-001A	vol%	DCS
2	SO_2in process gas to 583HA001	582-AI-001B	vol%	DCS
3	VZ001 process gas to 583HA001	582-AIC-001	vol%	DCS
4	H2S in acid gas to 582HA002	582-AI-002	vol%	DCS
5	Comb air from HA001 to FX001	582-FI-008	Nm3/h	DCS

6	amine acid gas total	582-FI-030	Sm3/h	DCS
7	Thermal reactor VF001	582-TI-011	deg C	DCS
8	Process gas from VF001 to HA005	582-TI-015	deg C	DCS
9	Comb air from HA001 toFX001	582-FIC-010	Nm3/h	DCS
10	Comb air from HA001 to FX001	582-FIC-011	Nm3/h	DCS

The gathering data from the mode live test was from the combustion flow rate change as in 52-582-FI008 and 52-582-FIC011 and for the test output was gathered from 52-582-AI001A and 52-582-AI001B for H_2S and SO_2 in tail gas respectively. The test operation conditions in live mode was changed by 200 nm3/hr per 15 minutes as showing in figure (2),(3) in J_2, and (4),(5) in K_2 for lack and excess air respectively.

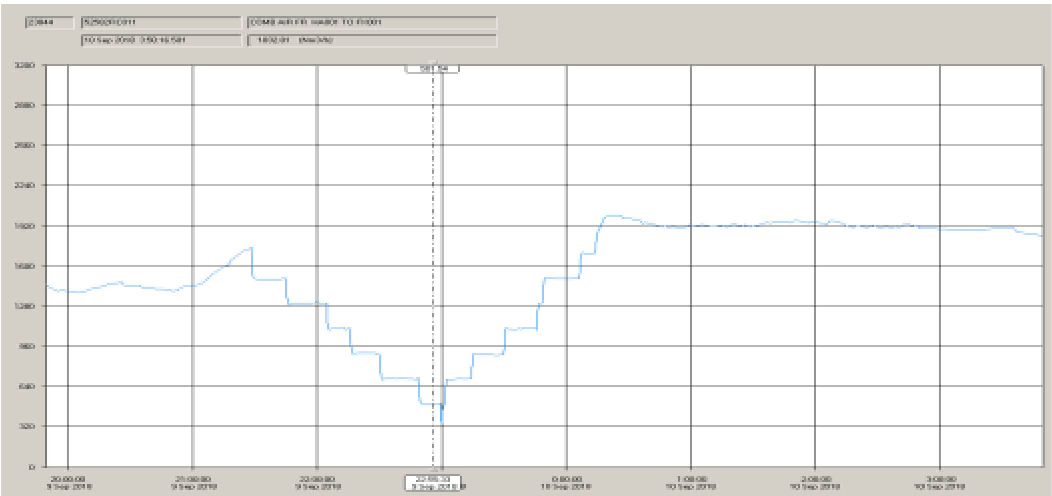

Figure2: Air flow rate In case of lack air for J2 in 9/9/2018. Live mode testone.

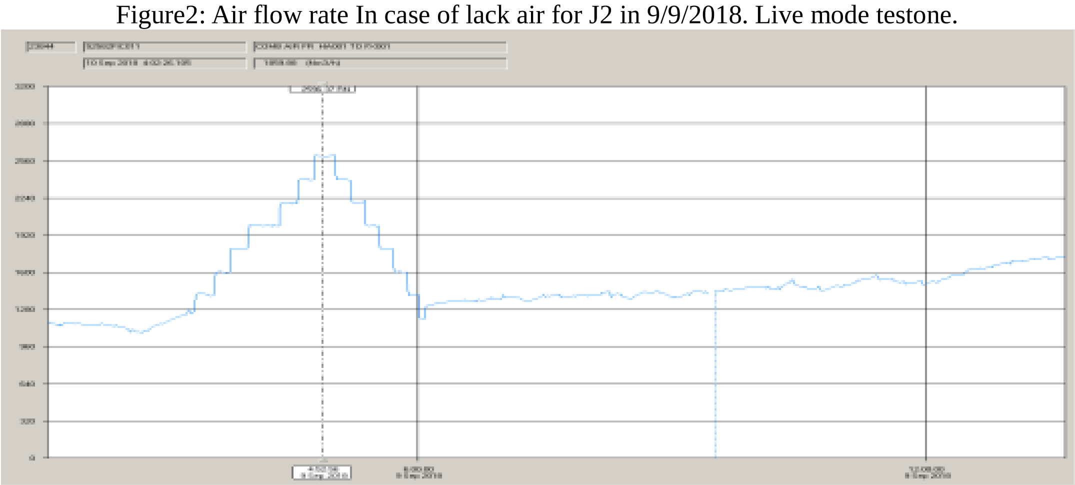

Figure3:Air flow rate in case of excess air for J_2 in 9/9/2018. Live mode testtwo.

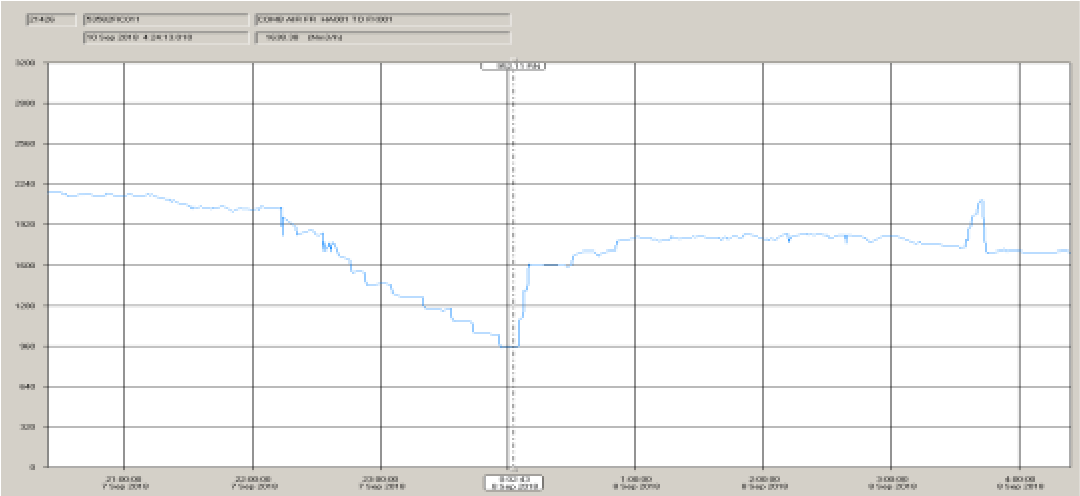

Figure4:Air flow rate In case of lack air for K_2 in 7/9/2018. Live mode test three.

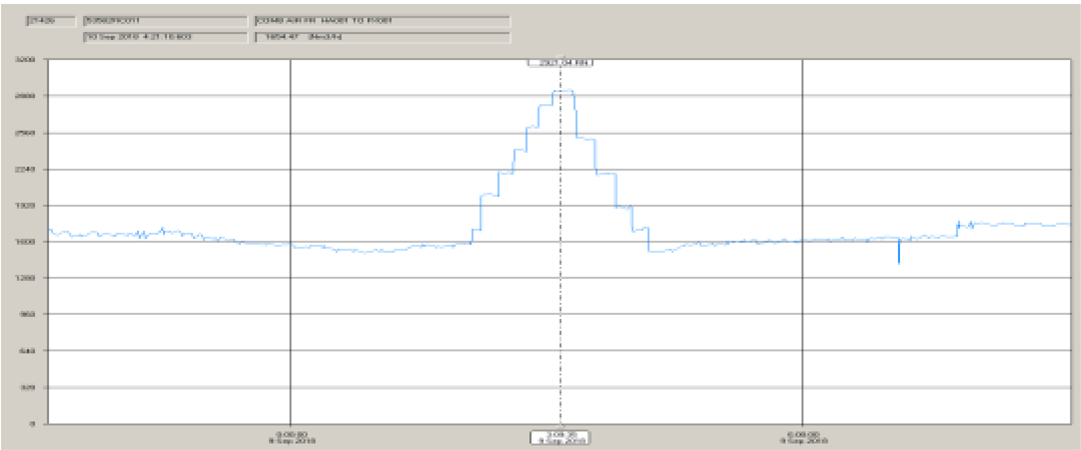

Figure5: Air flow rate In case of excess air for K_2 in 9/9/2018. Live mode test four.

2.2. Operating parameters Simulations

In order to investigate the effect of combustion air on the conversion of H_2S in SRU, a simulation of typical exist industrial Claus recovery unit is studied as show in figure(6). The specifications of the amine acid gas, and combustion air which are considered as unit feed, are given in tables (3) and (4). The ProMax software is used in this study as a simulator of different parameters effects on the H_2S conversion especially combustion air to get the optimal ratio between the acid gas and combustion air at different H_2S concentration.

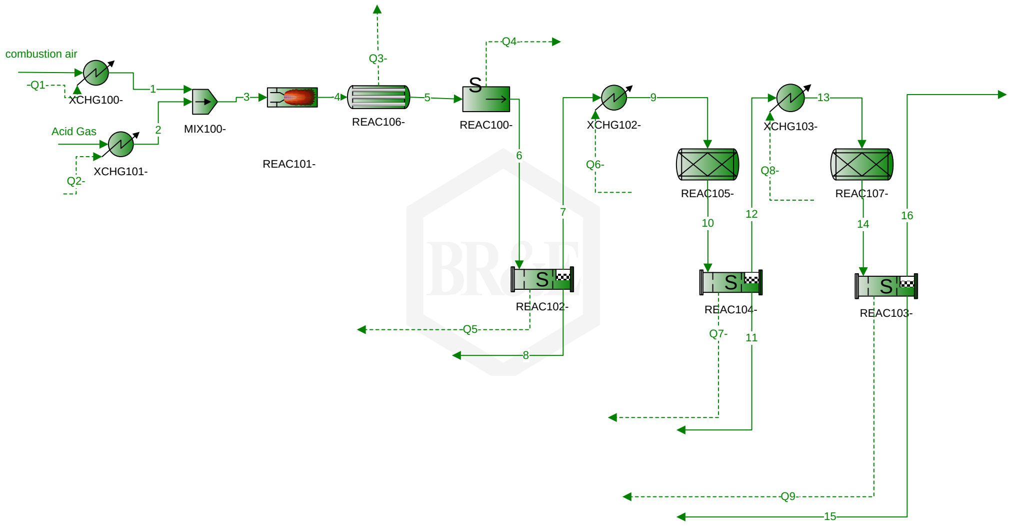

Fig.6: scheme simulation case (SRU).

Table 3: Input data properties and conditions.

Parameter	Temp, OC	Pressure BAR G
Amine acid gas	40	0.1
Combustion air	30	0.01

Table 4: Input data (streams composition).

compounds	Amine acid gas kg/hr	Air (kg/hr)
H2S	9954	
H2O	14	1792
N2	40	503627
CO2	21669	
C1	718	
C2	65	
C3	51	
O2		15291

3. Result and Discussions

The Summary of result online tests table (5, 6, 7, 8) shows that the decrease of combustion air to the Claus unit will lead to increase of the concentration of Hydrogen sulfide in tail gas and then reduce the conversion efficiency. on other hand the increase of combustion air to the Claus unit will led to reduce the concentration of Hydrogen sulfide in tail gas and enhance the conversion efficiency. To find the optimal combustion air for Claus unit is for different H_2S concentration in Amine acid gas, surveys at discreet duration in (September and October 2018) were done for different acid gas and combustion air flow rate at different H_2S concentration in amine acid gas. the optimal ratio between acid gas and combustion air were found a function of H_2S concentration in AAG, and this ratio is increase as H_2S concentration increasing, the correlation for optimal ratio and the relation between each other is show in figure (7). So that led to conclude the primary factor is H_2S concentration.

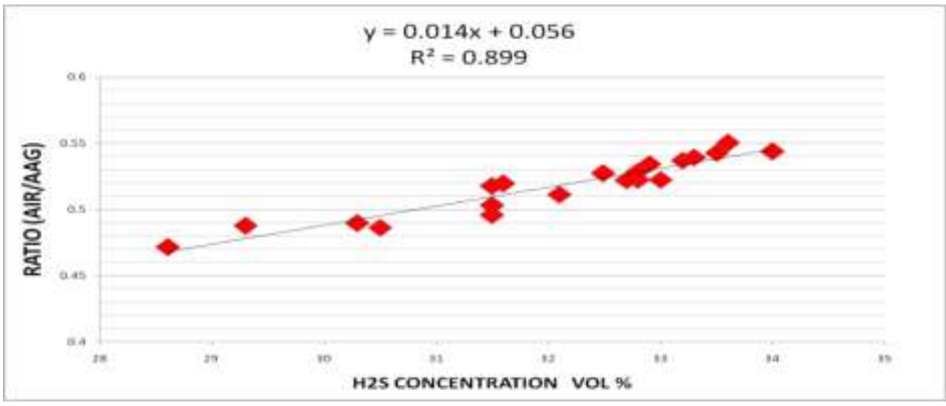

Figure 7: Relation between H_2S concentration and (AIR/AAG) ratio Field data.

Table 5:*Live mode test for J_2 area (Lack of air).*

Time	com air nm3/hr	H_2S vol%	SO_2 vol%	$2SO_2$-H_2S	Temperature C
9:30 PM	1495.59	0.652	0.181	-0.274	332.5
9:45 PM	1498.28	0.629	0.167	-0.271	332.1
10:00 PM	1309.75	0.757	0.109	-0.5	331.7
10:15 PM	1101.81	0.824	0.102	-0.58	331.4
10:30 PM	760.95	0.97	0.078	-0.776	330.8
10:45 PM	697.03	1.163	0.044	-1.042	330.4
11:00 PM	480.16	1.203	0.037	-1.143	329.9
11:15 PM	898.47	1.016	0.051	-0.985	330.6
11:30 PM	1033.78	0.972	0.075	-0.824	331
11:45 PM	1168.34	0.914	0.094	-0.745	331.8
11:58 PM	1497.56	0.642	0.171	-0.312	332.5

Table 6*: Live mode test for J_2 area (excess air).*

Time	comb air nm3/hr	H_2S vol%	SO_2vol%	$2SO_2$-H_2S	Temperature C
3:30 AM	1406.66	0.518	0.294	0.081	333.7
3:40 AM	1600.94	0.453	0.339	0.23	333.9
3:50 AM	1801.13	0.369	0.408	0.471	334.3
4:45 AM	2394.75	0.284	0.592	0.88	335.7
5:00 AM	2605.81	0.237	0.62	1.015	336.3
5:20 AM	2202.13	0.296	0.506	0.712	335.5
5:30 AM	2002.88	0.348	0.453	0.564	334.9
5:45 AM	1604.22	0.481	0.308	0.149	334.1
6:00 AM	1336.53	0.509	0.299	0.1	333.5

Table 7*: Live mode test for K_2 area (Lack of air).*

Time	comb air nm3/hr	H_2S vol%	SO_2 vol%	$2SO_2$-H_2S	Temperature C
10:00 PM	2033.28	0.714	0.352	0.032	322.1

10:15 PM	**1959.75**	**0.718**	**0.324**	**-0.104**	**322**
10:30 PM	**1826.16**	**0.794**	**0.256**	**-0.29**	**321.4**
10:35 PM	**1735.78**	**0.83**	**0.225**	**-0.338**	**321.2**
10:50 PM	**1554.97**	**0.836**	**0.205**	**-0.402**	**321**
11:00 PM	**1454.38**	**0.888**	**0.188**	**-0.522**	**320.8**
11:15 PM	**1352.06**	**0.95**	**0.137**	**-0.688**	**320.4**
11:30 PM	**1245.41**	**1.033**	**0.121**	**-0.767**	**320.2**
11:45 PM	**1056.69**	**1.113**	**0.095**	**-0.887**	**319.9**
11:56 PM	**943.78**	**1.203**	**0.077**	**-1.024**	**319.6**

Table 8:*Live mode test for K_2 area (excess air)*

Time	comb air nm3/hr	H_2S vol%	SO_2vol%	$2SO_2$-H_2S	Temperature C
2:00 AM	**1581.81**	**0.688**	**0.333**	**-0.033**	**319.7**
2:10 AM	**1707.81**	**0.66**	**0.385**	**0.111**	**319.9**
2:20 AM	**2017.41**	**0.605**	**0.501**	**0.419**	**320.8**
2:40 AM	**2409.31**	**0.557**	**0.724**	**0.84**	**322.1**
3:00 AM	**2799**	**0.557**	**0.91**	**1.265**	**323**
3:15 AM	**2928.75**	**0.536**	**0.993**	**1.451**	**323.3**
3:20 AM	**2630.25**	**0.545**	**0.919**	**1.326**	**323.2**
3:30 AM	**2505.19**	**0.552**	**0.802**	**1.035**	**322.4**
3:40 AM	**2194.31**	**0.554**	**0.616**	**0.712**	**321.6**
3:50 AM	**1909.84**	**0.6**	**0.493**	**0.394**	**321.1**
4:00 AM	**1686.47**	**0.586**	**0.485**	**0.351**	**320.7**

The combustion is the main factor for oxidation of sulfuric compound in Claus unit, so this part of dissertation is going to build mathematical module for air demand to acid gas flow rate based on concentration of hydrogen sulphide. This section will be use PROMAX® software as a simulator to achieve this purpose. The concentration of H_2S in amine acid gas will be ranged from 25% up to 35% as it expected in Mellitah complex for all production lines called K_2, andJ_2area (52/53/582-AI002 DCS). The simulation will be done to achieve two of (H_2S/SO_2 ratio). Ratio (2) is providing the maximum sulfur recovery unit efficiency at different amine acid gas and air demand for different H_2S concentration figure 8. Figure 9 is showing the relation between hydrogen sulfide concentration and the ratio (Air demand/A.G), It is clear that the mathematical correlation is very close with the correlation made by field data as show in table 9, the increasing of acid gas followed by increasing of aid demand to Claus unit.

Table 9: *Summery of new mathematical correlations*

No	Correlation	description
1	Y=0.018X+0.077	H_2S concentration VS (AIR/AAG) ratio. Predication
2	Y=0.014X+0.056	H_2S concentration VS (AIR/AAG) ratio. Field data

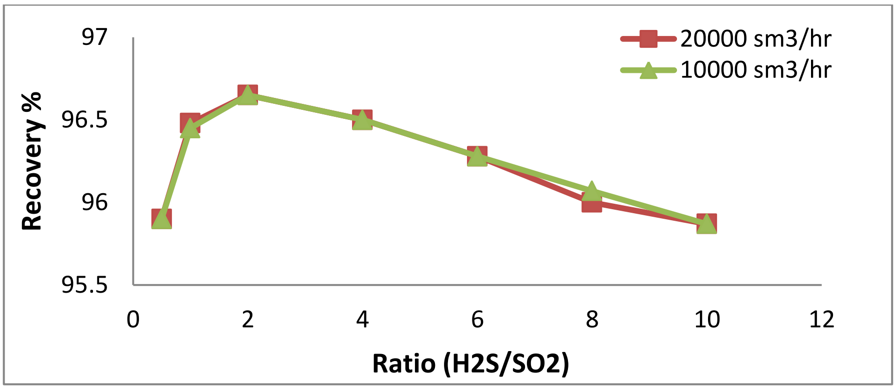

Figure 8: Relation between (H_2S/SO_2) ratio and SRU recovery.

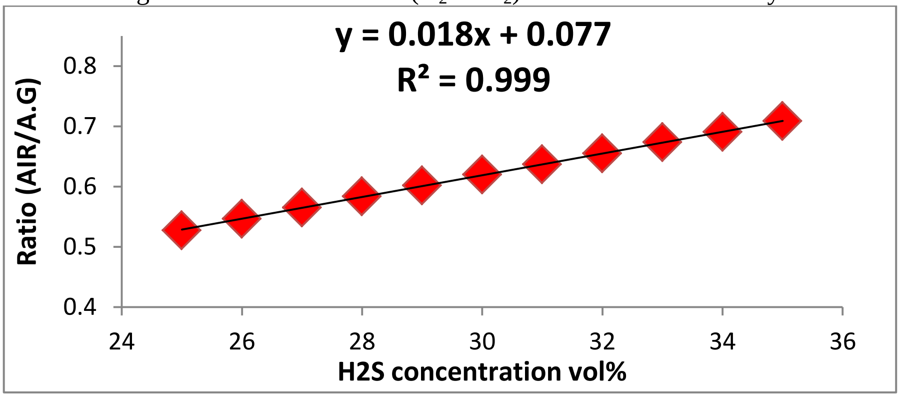

Figure9: Relation between H_2S concentration and (AIR/AAG) ratio predication.

4. Conclusions

Four live tests mode in DCS at Mellitah complex were done to investigate the effect of combustion air on H2S conversion where the excess air forms SO2 in tail gases and on contradict lack of air cannot completely oxidize H2S, The optimal combustion air that get (H_2S/SO_2) ratio in tail gas is 2, this ratio provides the maximum sulphur recovery efficiency. Which in same time reduce the sulfuric emission from Claus unit, finallynew mathematical correlations were created for the relation between acid gas and combustion air as a function of H_2S concentration in acid gases in both field data and simulation case. So these new correlation is going to use in Claus reactions to get the air demand to different acid gas flow rate as a function of hydrogen sulfide concentrations.

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