Aspenplus Simulation Studies to Improve On the Control Systems of Sulphur Recovering Unit (SRU) Of Modern Refinery Plant

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ABSTRACT

Sulphur recovery unit (SRU) is one amongst the most important units of a modern refinery due to its functional peculiarity and economies. Nigerian crude oil is rich in sulphur content when compared with e.g. Arabian light crude. In this study, numerical design of SRU was carried out with the primal emphasis on its control systems and its analysis on the sulphur reheater unit. In this unit, it is required to maintain the outlet temperature of the reheater at about 320^0C *fed into the catalytic equilibrium reactor. The results of the simulation gives a steady outlet temperature of* 319.7^0C *for the PID (proportional, integral and differential) control integration and* 319.6^0C *for PI control integration after a simulation pace of 2.5 secs respectively. The rise time and settling time for the PID control integration of the jacket was recorded at 0.105 sec and 0.814 sec respectively, while the tank was at 0.567 sec and 2.88 secs respectively. In addition, step tests analysis for the transmitter was investigated for both the tank and jacket, and at 2.0 secs was optimally achieved for both cases.*

Keywords: Control systems, simulation, and SRU

1.0 INTRODUCTION

Control systems are designed to ensure product quality as well as process efficiency and in considerations of both economic and environmental sustainability. In real life, there are no industrial processes that functionally exist without quality control systems. Obviously, it is a credit to the use of control systems in the production and manufacturing units which has become more efficient and less hazardous. The new trends and innovations in the control of process systems has not only made control substantially and increasingly efficient and safe, but has made the design and analysis of control systems faster and time effectiveness. These trends include the distributed control systems (DCS), which incorporate all control lines in a single computer where the controller are directly connected to all the field devices. The operators are only being informed of the changes in the controls of the process. The DCS has made control monitoring easier and robust in operations. Other automatic control innovations are the supervisory control and data acquisition (SCADA) and programmable logic control (PLC) etc., (Seal, 1998).

In the chemical and petrochemical industry, productions basics are made with respect to chemical materials, chemicals manufactured in the industries can be categorized based on their nature and uses. Such chemicals can either be a commodity chemical, fine chemical etc. Sulphur is a fine chemical materials used to produce other related chemicals. Sulphur is used in the production of chemical fertilizers, dyes etc., its demand is of high consideration in the market.

Sulphur is recovered from the SRU after all chemical process and unit operations have taken place. In addition, sulphur can be recovered from natural gas or crude hydrocarbons. It is mostly recovered in the natural gas since it is found excess. Its presence in natural gas causes corrosion to gas pipelines and other plant facilities (Angelo et al; 2012).

In the control design of sulphur, it is mandatory to put into consideration control design strategies that will meet design requirement for a better sulphur recovery. Most sulphur recovered in the recovery units are elemental sulphur.

In this work, a steady state recovery unit of sulphur was considered by putting in place all representative units, which were designed and simulated using the ASPEN 8.1 Plus software. Adequate assumptions were made to place the design analysis to a more predictable constraint. A representative model of the controlled unit was considered, putting in place all controlled; measured and manipulated parameters into considerations. For the purpose of theoretical analysis, some few units were considered for the control design of the SRU. Further analysis was carried out to depict the control state as regards to the steady state results.

1.1 Statement of Problem

- The basic problem of this studies is not limited to questions such as:
- What are the processes involved in the recovery of sulphur?
- What are the units involved in the design of the recovery unit?
- What units and variables are controlled?
- What is the control strategy and logic that is applicable to the process?
- What efficacy does the control mechanism have on the units under considerations?
- Does the complete design meet the requirement of the sulphur recovery?

The *aims* of this paper are to design the control systems of SRU, which will efficiently and economically produce 5.0 metric tons per day of sulphur. The *objectives* are to: (i) review previous control designs and their significance, (ii) modify and design a process Flowsheet that depict a typical SRU, (iii) state and specify all unit operating conditions and streams, (iv) model and simulate the units in steady state using the ASPEN Plus software, (v) model and design the control system of the Sulphur recovery unit using MATLAB/Simulink, and (vi) analyse and infer the control design with respect to set point.

1.2 Significance of the Studies

The purpose of this study is to enable proper and intuitive theoretical understanding of control design and analysis, equally to help in discretizing and applying control strategies which will ensure better and extensive reasoning in choosing an exact control technique that will be applicable to the process systems. Furthermore, the new trends are fast evolving; it is of paramount importance to know how this innovation will make impact on existing and new process plants. Hence, the study will also help in improvising ideas that will be beneficial to the real life applications.

2.0 LITERATURE REVIEW

The word ‘petroleum’ means ‘rock oil’ which is derived from the Latin Petra (rock) and oleum (oil) and it refers to crude oil and natural gas (OPEC, 2013). Crude oil consists of approximately 10-14 wt % hydrogen and 83 - 87 wt. % of carbon. Oxygen (0.05 - 1.5 wt. %), sulphur (0.05 - 6 wt. %), nitrogen (0.1 - 2 wt. %), and metals such as vanadium, nickel, iron, and copper (nickel and vanadium < 1000 ppm) may be found as impurities in crude oil. Crude oil is not a uniform material and its exact molecular and fractional composition varies widely with formation of oil, location, age of the oil field, and the depth of the individual well. Crude oils obtained from different oil reservoirs have widely different characteristics (Speight, 2006). An oil well produces predominantly crude oil, with some natural gas dissolved in it. But, a gas well produces predominantly natural gas. Natural gas consists of approximately 65 - 80% carbon, 1 - 25% hydrogen, 0 - 0.2% sulphur, and 1 - 15% nitrogen. Hydrocarbon molecules of natural gas generally are paraffin type that range from one to four carbon atoms in length, but up to six carbon atoms may also be found in small quantities.

A typical natural gas hydrocarbon composition is 70 - 98% methane, 1 - 10% ethane, trace to 5% propane, trace to 2% butane, and trace to 5% pentane and higher molecular weight hydrocarbons, including benzene and toluene. In addition, water vapour, hydrogen sulphide (H_2S), carbon dioxide, helium, nitrogen, and other compounds in the minority may be found in raw natural gas. Gaseous impurities in natural gas that don't burn are called inert (non-combustible). Carbon dioxide, water vapour, helium and nitrogen are the major inert components in natural gas (Speight, 2006; Jafarinejad, 2016).

A wide variety of air pollutants such as nitrogen oxides (NOx), sulphur oxides (SOx), carbon monoxide (CO), volatile organic compounds (VOCs), dust or particulates, etc. are generated and emitted from operations in the petroleum industry (ECJRC, 2013; Jafarinejad, 2016). Intensification of the greenhouse effect associated with the global warming and climate change, acid rain, photochemical smog, reduced atmospheric visibility, death of forests, ozone depletion (from 7 fire fighting agents), soot/heavy metals deposition, poorer water quality, surface water/groundwater contamination, soil contamination, disturbance of communities/flora/fauna, and destruction of ecosystem can be the environmental impacts of the petroleum industry (E&P Forum/UNEP, 1997; Speight, 2006; Jafarinejad, 2016). As sulphur compounds such as sulphur oxides (SOx) are generated and emitted from operations in the petroleum industry and have negative effects on environment; in this study, the control and treatment methods of these emissions from the petroleum industry have been reviewed. The petroleum industry includes the global processes of exploration, extraction, refining, transporting (pipeline, oil tanker/barge, truck, and rail), and marketing petroleum products. The industry is usually divided into three major components: upstream, midstream, and downstream. Upstream usually includes exploration, development, and production of crude oil and natural gas. Midstream segment, as its name implies, encompasses facilities and processes that sit between upstream and downstream segments. Midstream activities can include processing, storage and transportation of crude oils and natural gas. Transportation is a big part of midstream activities and can include using pipelines, trucking fleets, tanker ships, and rail cars. Downstream usually includes refining/hydrocarbon processing, marketing, and distribution. In another classification, the petroleum industry is divided into five segments upstream, downstream, pipeline, marine, and service and supply (EPA, 2000).

2.1 Overview of control and treatment of sulphur oxides (SOx) emissions

There are a variety of techniques for minimizing, controlling, preventing and treating sulphur oxides (SOx) emissions to air that are listed below:

• Use of low-sulfur crude.

• Liquid fuel desulfurization (hydrogenation reactions are taken place by hydrotreatment process and lead to reducing sulphur content).

• Treatment of refinery fuel gas (RFG), e.g. by acid gas removal to remove H_2S.

• Use of gas such as on-site liquefied petroleum gas (LPG) or RFG or externally supplied gaseous fuel (e.g. natural gas) with a low level of sulphur and other undesirable substances to replace liquid fuel.

• Use of SOx reducing catalysts additives (note that SOx reducing catalysts additives might have a detrimental effect on dust emissions by increasing catalyst losses due to attrition, and on NOx emissions by participating in CO promotion, together with the oxidation of SO_2 to SO_3).

• Use of hydrotreatment process that reduces sulphur, nitrogen and metal content of the feed.
• Acid gas (mainly H_2S) removal from the fuel gases, e.g. by amine treating (absorption).
• Use of sulphur recovery unit (SRU).
• Use of tail gas treatment unit (TGTU).
• Use of flue-gas desulfurization (FGD) (European Commission and Joint Research Centre, 2013); and
• Use of scrubbing systems (wet scrubbing, and dry or semi-dry scrubbing in combination with a filtration system (ECJRC, 2013).

2.2 Adaptive Control

Adaptive control schemes provide the opportunity to achieve improved control performance by basing the control action on a mathematical model of the process, including time delay, that is used to forecast process response and subsequently calculate the actual control action required to obtain set point. The mathematical model is adjusted automatically to compensate for changes in the process characteristics so that the controller can maintain control under various operating conditions. Commercially produced controllers of this type have commonly been called "model based" adaptive controllers.

3.0 RESEARCH METHODOLOGY

3.1 Process Description

The modified clause used for the process is the 'Straight Through Process (STP)', due to its capacity to generate up to 98% of elemental sulphur. The process entails a situation whereby a reaction furnace is used to increase the yield of sulphur ahead of a two or three stage catalytic reaction (Laurence, 998). The amount of heat generated by the reaction is dependent on the supply of compressed and enriched air (O_2) and likewise the supply of H_2S (Goar, 1986).
An enriched gas will increase the amount of heat high which in turn keep the temperature inside the burner above 980°C. One way to mitigate heat depletion in the burner is to preheat the acid gas and enriched air before it goes into the reaction furnace. Steady state assumptions where made to justify the design of the process. The assumptions are given as follows:
• The acid gas is enriched to about 95% by contacting it with some selective absorption solvents like carbon(IV)oxide. This will help increase the concentration of the acid gas.
• The air is also enriched to about 99%. This enrichment is due to the prevalent amount of Nitrogen which is about 79% of composition in air. The presence of Nitrogen reduces the adiabatic temperature of the flame present in the reaction furnace.
• No initial preheating process was considered since the reaction furnace temperature was utilized efficiently and economically.
• No side reactions were considered from the steady state design.
Air and Hydrogen Sulphide is fed into the reaction furnace which initiates a very high reaction heat with a temperature of about 1000°C. Since the furnace reaction requires a very high temperature to promote the reaction, surplus amount of the inlet component is needed to sustain the reaction temperature. The reaction occurring in the reaction furnace is:

$$2H_2S+3O_2 \rightarrow 2SO_2+2H_2O \qquad \Delta H \tag{1}$$

$$2H_2S+SO_2 \leftrightarrow 3S+2H_2O \qquad \Delta H \tag{2}$$

The product from the reacting furnace was fed to a condenser which operates at a temperature of 80°C to recover about 60% of the liquid Sulphur. The rest of the product goes directly into a Steam jacketed Re-heater which increase the liquid to a temperature of 320°C by means of direct steam from a heating source. This temperature increment was required to meet up with the temperature in the catalytic reactor, this is because the reactor operates at a suitably high temperature. The catalytic reactor operates at equilibrium as shown from the reaction below:

$$2H_2S+SO_2 \leftrightarrow 3S+2H_2O \qquad \Delta H \tag{3}$$

Single catalytic reactor won't be enough to convert all the remaining sulphur because it is an equilibrium reaction. A second catalytic reactor was added in order to convert the rest of the unreacted hydrogen sulphide. About 20% of hydrogen sulphide was converted in the first catalytic reactor pass.
The product from the first catalytic reactor was sent to a condenser which condenses the converted sulphur. The sulphur was recovered and the unreacted components goes directly into a second Steam Jacketed Re-heater which analogously increased the temperature to the reactor's operating temperature. The components were sent to a second catalytic reactor which converts the remaining hydrogen sulphide to elemental sulphur, Water and heat as shown in the reaction as shown in Equation (3).
Other unreacted components were also recovered from the second catalytic reactor. The final product was sent to a condenser which condenses the sulphur vapour into liquid.
The liquid sulphur was recovered leaving the tail gas. The tail gas consists of other components like the unreacted hydrogen sulphide, oxygen, hydrogen, sulphur and other contaminants. This tail gas may require clean up and further treatments.
The basic design studies carried out for the sulphur recovery unit is categorized into two: SRU Steady state modelling and SRU Process Control design.

3.1.1 SRU Steady State Modelling

A process flow sheet was designed to depict a typical Sulphur Recovery Unit. The flowsheet in Figure 1 and 2 is primarily intended for comprehensive studies. The process flow sheets indicate all units and streams that are involved in the modelling of the SRU. Microsoft Visio 2016 was used in designing the process flow diagram (PFD) and ASPEN-plus was used as a modelling and simulation tool for the design. ASPEN stands for *'Advanced System for Process Engineering'*. Figure 1 is the process flow sheet which gives a comprehensive detail of all unit specification, total feed flowrate and the component individual flowrate. While Figure 2 represent the process flowsheet indicating unit specs and feed flowrate based on the material balance from the process capacity.

3.1.2 SRU Process Control Design

3.1.2.1 Modelling of Steam Jacketed Re-heater

Control modelling was carried on the Steam Jacketed Re-heater. In order to improve the efficiency of the reaction, it is imperative to maintain the inlet temperature of the reactor. This is because the reactor operates significantly at a higher temperature, and the primitive temperature of the reactor is not enough to expedite the reaction process.

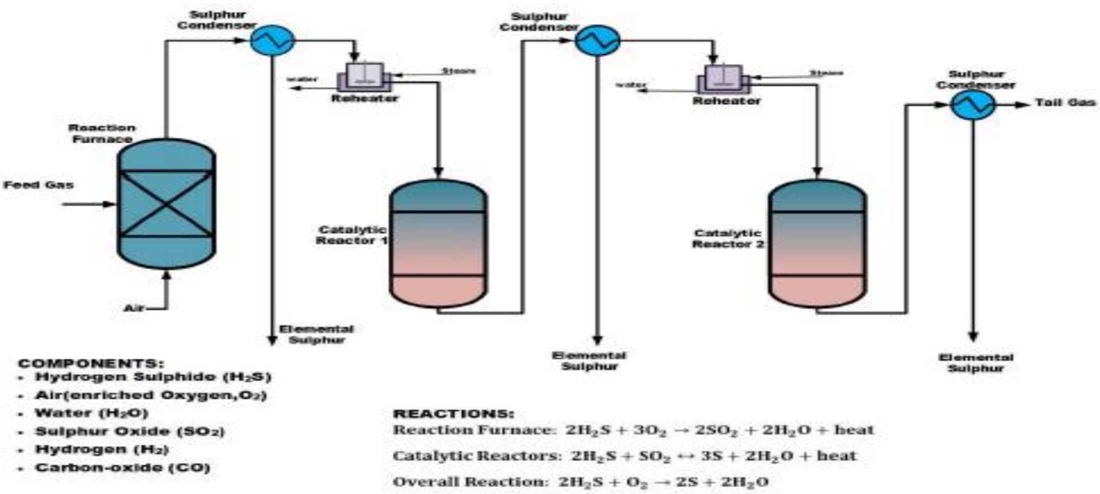


Figure 1: Process flowsheet for Sulphur Recovery Unit

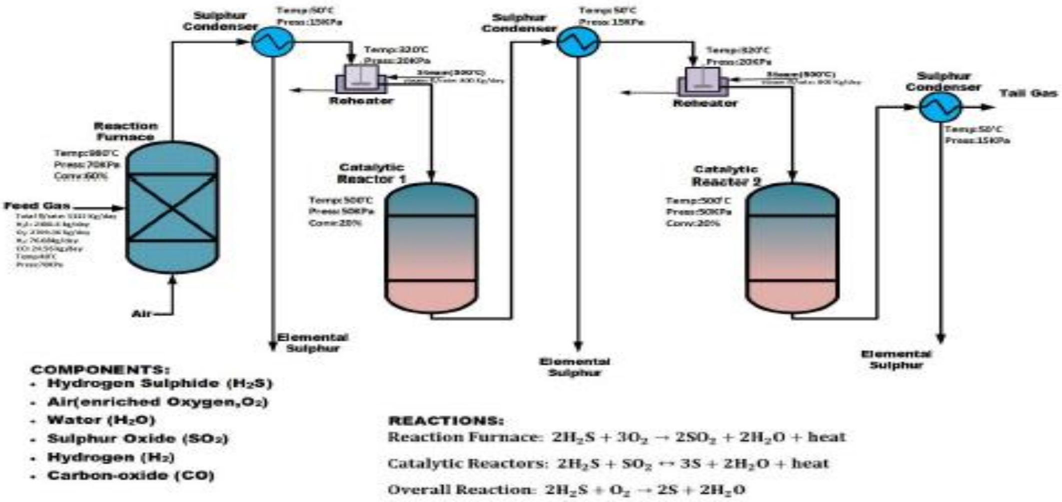


Figure 2: Process flowsheet indicating unit specs and feed flowrate

This can be done only by controlling and maintaining the heating temperature of the steam jacketed temperature. Assumptions implemented for the modelling of the Re-heater is as shown below:

- Jacket flowrate is constant.
- The volume and density of the jacket and tank is kept constant.
- There is a perfect mixing in both the tank and jacket.
- The heat transfer rate from the jacket to the tank is given by: $Q = U(Tj - T)$ where U is the overall heat transfer coefficient, A is the cross sectional area for heat transfer, Tj is the jacket temperature, T is the tank temperature.
- The heat transfer rate is influenced by the jacket inlet temperature.
- The tank outlet temperature is influenced by the heat transfer rate from the jacket to the tank.

Figure 3 depicts the process heat jacket to the tank.

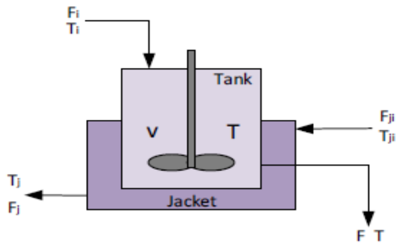


Figure 3: Process heat jacket to the tank

The material and energy balance produced the following set of differential equations:

$$\frac{dT}{dt} = \frac{F}{V}(T_i - T) + \frac{UA(T_j - T)}{V\rho C_p} \qquad (4)$$

$$\frac{dT_j}{dt} = \frac{F_j}{V_j}(T_{ji} - T_j) + \frac{UA(T_j - T)}{V_j \rho_j C_{pj}} \qquad (5)$$

This model applies to both of the re-heater. The first term of the right hand side of Equations 4 and 5 is non-linear because it contains an expression showing the product of flowrate and temperature. It is not possible to obtain transfer function of a nonlinear process directly unless it is linearized. The model is linearized using the Taylor's expansion.

3.1.2.2 Control Design for Steam Jacketed Re-heater

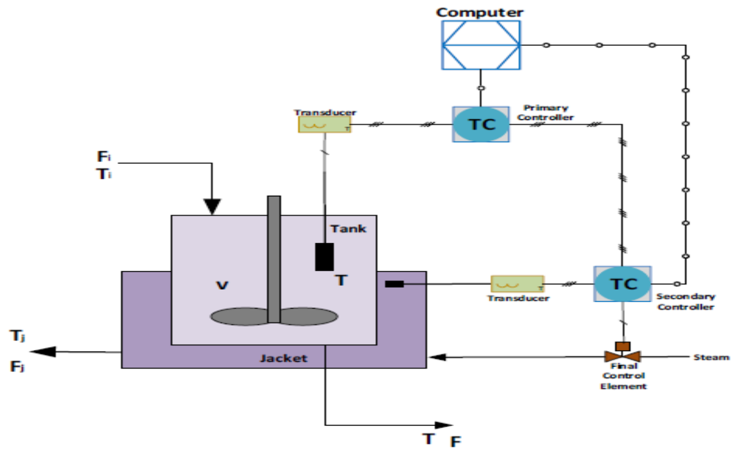


Figure 4: Control Scheme of the Steam Jacketed Re-heater

- The measured and controlled variable is the tank temperature T,
- The manipulated variable is the jacket inlet temperature Tj .
- A Cascade (MISO) control strategy was used for the control design.
- A PID control logic was employed for the control analysis.

According to (Donald et al; 2009), the Transfer Function of the tank and jacket is given respectively:

$$T_0'(s) = \frac{K_1}{\tau_w s+1} T_i'(s) + \frac{K_2}{\tau_w s+1} T_v'(s) - \frac{K_3}{\tau_w+1} w'(s) \tag{6}$$

$$T_v'(s) = \frac{1}{\tau_v s+1} T_0'(s) + \frac{K_2}{\tau_v s+1} w_v'(s) \tag{7}$$

Where:

$$K_1 = \frac{w_s C}{UA+w_s C} \tag{8}$$

$$K_2 = \frac{UA}{UA+w_s C} \tag{9}$$

$$K_3 = \frac{(T_{os}-T_{is})}{UA+w_s C} \tag{10}$$

$$\tau_w = \frac{mC}{UA+w_s C} \tag{11}$$

For the Steam Jacket:

$$T_v' = T_v - T_{vs} \tag{12}$$

$$w_v' = w_v - w_{vs} \quad (13)$$

$$K_s = \frac{H_{vs} - H_{cs}}{UA} \quad (14)$$

$$\tau_v = \frac{(H_{vs} - H_{cs})\alpha V + m_1 c_1}{UA} \quad (15)$$

The basic essence of the transfer function is to enable the design of the block diagram for the Steam Jacketed Re-heater. All related parameters and their meaning are given in the appendix section. It is imperative to note that the control design applies for both re-heaters respectively, but for the purpose of this study, extensive control design analysis will be carried out on just a single re-heater. Figures 5 – 6 respectively represent the block diagram of Steam Jacketed Re-heater, SRU piping and instrumentation flowsheet. And was designed using Microsoft Visio and MATLAB Simulink was used respectively for Figure 7 – 8 Simulink diagram of Steam Jacketed Re-heater and Simulink Diagram of Heater and Jacket Transducers.

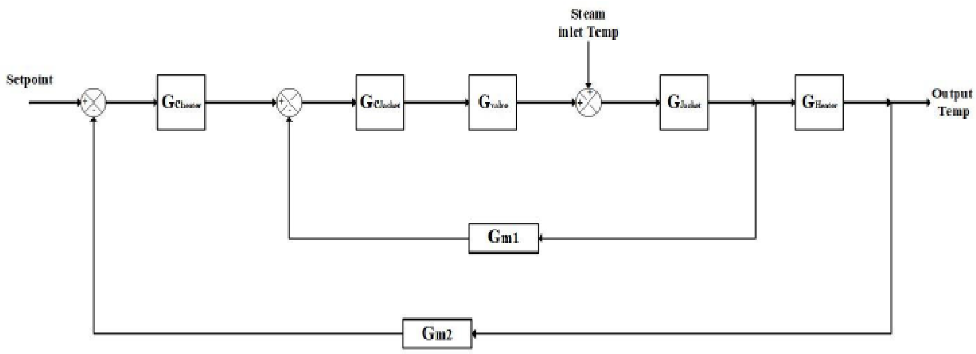


Figure 5: Block Diagram for Control of Steam Jacketed Heater

Where:

G_{Heater}	=	Heater Model
G_{Jacket}	=	Jacket model
G_{m1}	=	Jacket Transducer
G_{m2}	=	Heater Transducer
G_{valve}	=	Control valve
$G_{C_{heater}}$	=	Heater controller
$G_{C_{jacket}}$	=	Jacket controller

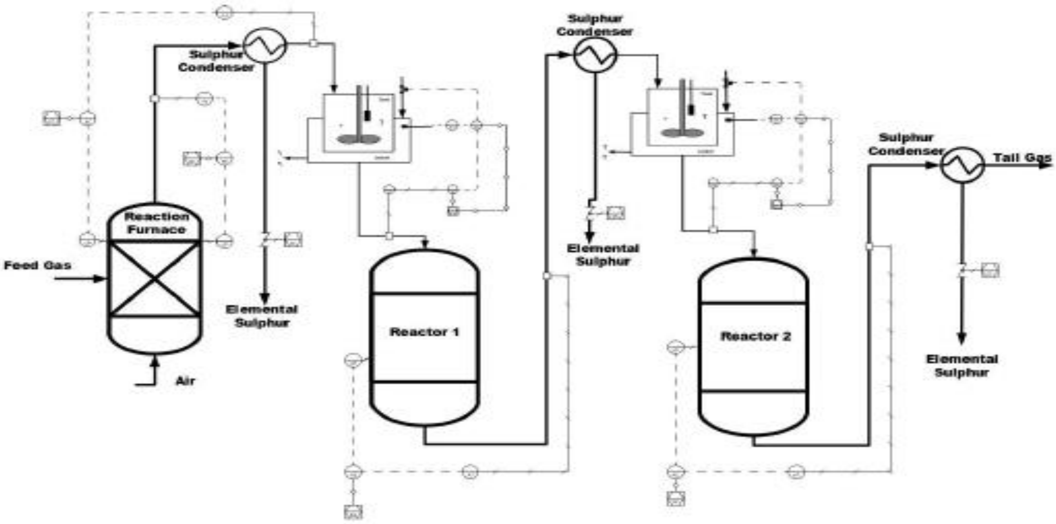


Figure 6: SRU piping and instrumentation flowsheet

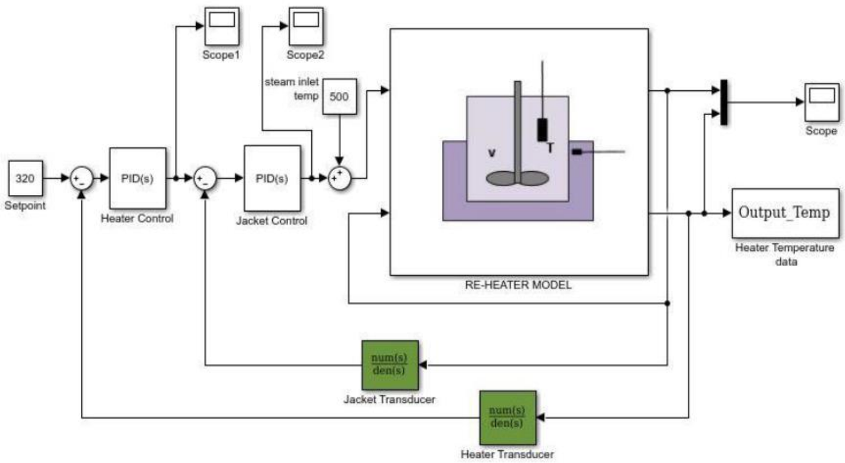


Figure 7: Simulink Diagram of the Steam Jacketed Re-heater

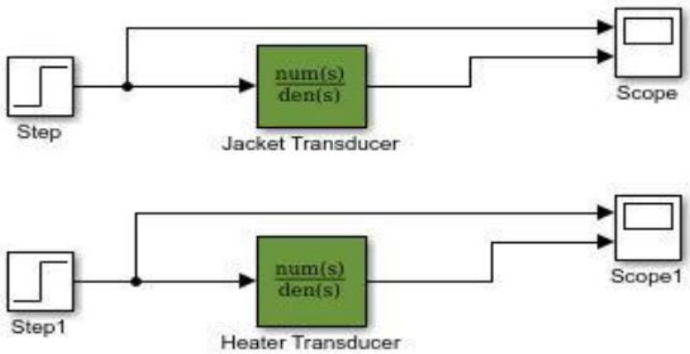


Figure 8: Simulink Diagram of Heater and Jacket Transducers

4.0 DISCUSSION OF RESULTS

4.1 ASPEN Plus Results (Steady State)

The Steady state simulation carried out with ASPEN Plus 8.1 produced the following results as shown in Tables 4.1 – 4.3.

Table 4.1 Simulation Stream Table

Parameters	**Stream Numbers Simulation Data**				
	1	**2**	**3**	**4**	**5**
Temperature (^{0}C)	980	40	50	50	50
Pressure (bar)	0.7	0.7	0.15	0.15	0.15
Vapour Fraction	1	1	0.802	0.939	0
Mole Flow (kmol/hr)	200.887	190.763	200.887	166.194	5.67
Mass Flow (kg/hr)	5111	5111	5111	3357.888	181.804
Volume Flow (m^3/hr)	29900.95	7095.381	28856.13	27966.61	0.086
Enthalpy (Gcal/hr)	0.328	-0.364	-1.388	-3.247	0.358
Volume Flow (m^3/hr)	29900.95	7095.381	28856.13	27966.61	0.086
Mole Flow (kmol/hr)					
HYDRO-01	26.999	67.496	26.999	7.02	0
OXYGE-01	54.297	84.671	54.297	54.297	0
HYDRO-02	38.038	38.038	38.038	38.038	0
CARBO-01	0.558	0.558	0.558	0.558	0
SULFU-01	30.373	0	30.373	5.67	5.67
WATER	40.498	0	40.498	60.477	0
SULFU-02	10.124	0	10.124	0.135	0

Table 4.2 Simulation Stream Table (Cont'd)

Parameters	**Stream Numbers Simulation Data**				
	6	**8**	**11**	**12**	**14**
Temperature (^{0}C)	50	50	320	320	320
Pressure (bar)	0.15	0.15	0.2	0.5	0.2
Vapour Fraction	1	0	1	1	1
Mole Flow (kmol/hr)	160.525	30.373	170.514	186.713	162.415
Mass Flow (kg/hr)	3176.084	973.951	4137.049	4137.049	3357.888
Volume Flow m^3/hr	28752.92	0.463	42045.75	18416.07	40048.54
Enthalpy (Gcal/hr)	-3.56	1.918	-2.845	-1.506	-3.154
Mole Flow (kmol/hr)					
HYDRO-01	7.02	0	26.999	10.799	10.799
OXYGE-01	54.297	0	54.297	54.297	54.297
HYDRO-02	38.038	0	38.038	38.038	38.038
CARBO-01	0.558	0	0.558	0.558	0.558
SULFU-01	0	30.373	0	24.299	0
WATER	60.477	0	40.498	56.697	56.697
SULFU-02	0.135	0	10.124	2.025	2.025

Table 4.3 Simulation Stream Table (Cont'd)

Parameters	**Stream Numbers Simulation Data**				
	16	**17**	**18**	**19**	**20**
Temperature (^{0}C)	50	50	50	50	320
Pressure (bar)	0.15	0.15	0.15	0.15	0.2
Vapour Fraction	0.799	0	1	1	1
Mole Flow (kmol/hr)	186.713	24.299	162.415	170.514	166.194
Mass Flow (kg/hr)	4137.049	779.161	3357.888	4137.049	3357.888
Volume Flow (m^3/hr)	26706.31	0.37	29091.43	30542.21	40980.57
Enthalpy (Gcal/hr)	-2.096	1.534	-3.494	-3.21	-2.842
Mole Flow (kmol/hr)					
HYDRO-01	10.799	0	10.799	26.999	7.02
OXYGE-01	54.297	0	54.297	54.297	54.297
HYDRO-02	38.038	0	38.038	38.038	38.038
CARBO-01	0.558	0	0.558	0.558	0.558
SULFU-01	24.299	24.299	0	0	5.67
WATER	56.697	0	56.697	40.498	60.477
SULFU-02	2.025	0	2.025	10.124	0.135

The results shown in Table 4.1 - 4.3 depicts the calculations from the flowsheets shown on Figures 6 - 8, our stream of interest for the steady state Sulphur recovery are the streams 5, 8, and 17.

From the flowsheet, the direct oxidation step which consists of the reaction furnace operating at a temperature of about 980°C was able to produce approximately 50% of liquid sulphur.

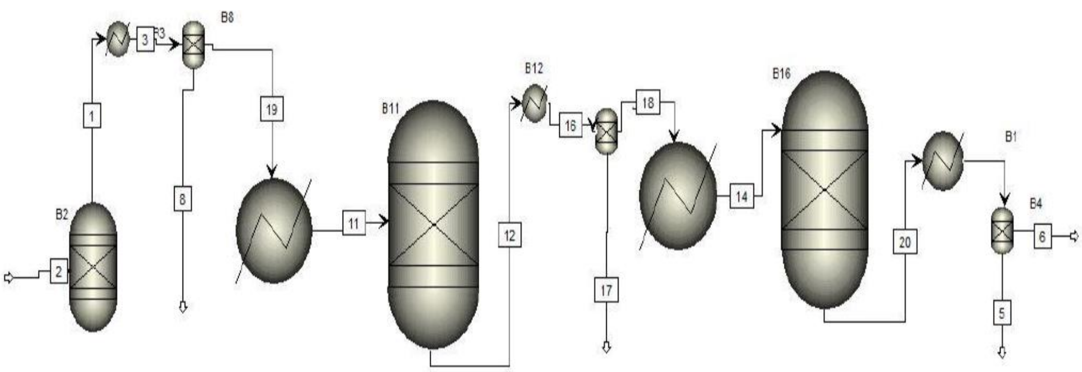


Figure 9: ASPEN Plus Process Flowsheet

4.2 Control Analysis and Results

The control design and analysis carried out with MATLAB/Simulink depicted a typical control mechanism that would enable set point target. A control comparison was carried out by testing the control response of both a PI and PID controller. Two controllers were analysed based on response. The first is the heater controller which is also called the Master or primary controller, and the second is the jacket controller which is also called the Slave or secondary controller. It's apparent to note that, multiple feedback control strategy was employed. This is due to the fact that two controlled variables were indicated. One is the jacket temperature and the other is the heater temperature. From the control analysis, the heater-controlled variable serves as the set point for the jacket control scheme. The system has two input and one output. This type of

control is called a Cascade control. The control simulation of the process was carried out in a continuous time domain.
Figures 10 and 11 shows a graph indicating the response of the Heater and Jacket to a controller response respectively. A simulation pace of 2.5 seconds was used to test the possibility of the set point attainability (Donald et al; 2009).

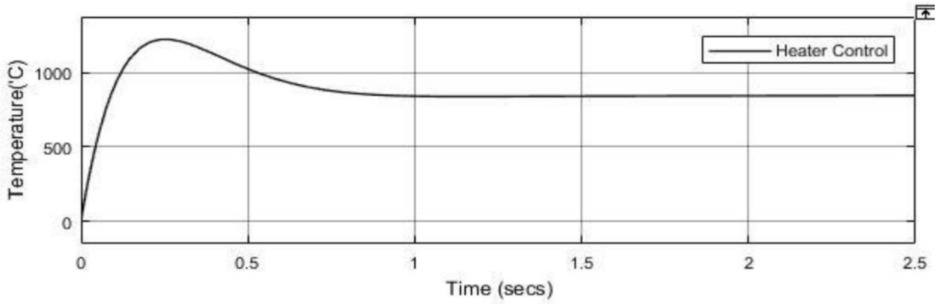


Figure 10: Response of Heater to Controller Response

In Figure 10, it was indicated by the controller that for a controller action, it took about 0.7 seconds (controller response) for the heater to become stable at the required controller setpoint for a simulation pace of 2.5 seconds.
Figure 11 indicated that for a controller action, it took about 0.16 seconds (controller response) for the jacket to become stable at the required controller set point for a simulation pace of about 2.5 seconds. It is important to note that, the controller action/response time for the jacket will be less as compared to the heater. This is because the jacket controller has little control to do since most of the control targets are carried out by the master controller (Angelo et al; 2012).

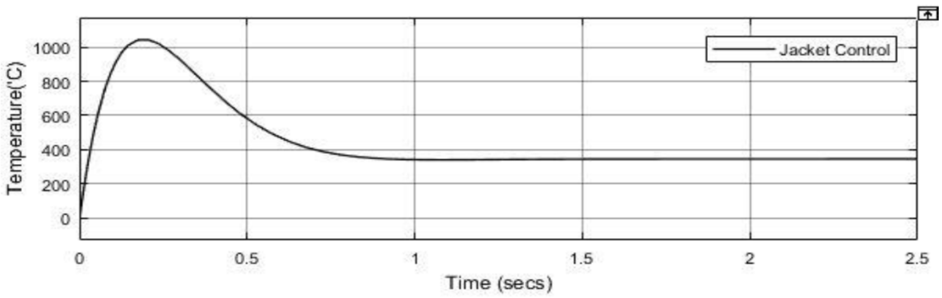


Figure 11: Response of Jacket to a Controller Response

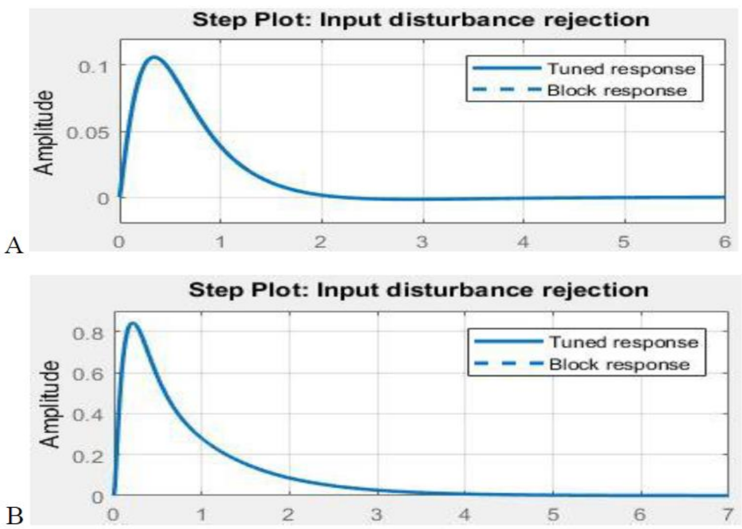


Figure 12: Input Disturbance Rejection A), Heater B) Jacket

Table 4.4 Controller Parameter and Performance for Jacket

Controller Parameter	**Tuned**	**Block**
P	1.1367	1.1367
I	1.3023	1.3023
D	-0.000828	-0.000828
Overshoot	15.6%	15.6%
PERFOMANCE		
Rise time	0.105s	0.105s
Settling time	0.814s	0.814s
Close-loop stability	Stable	Stable

Table 4.5 Controller Parameter and Performance for Heater

Controller Parameter	**Tuned**	**Block**
P	3.16	3.16
I	11.755	11.755
D	-0.321	-0.321
Overshoot	4.87%	4.87%
PERFOMANCE		
Rise time	0.527s	0.527s
Settling time	2.88s	2.88s
Close-loop stability	Stable	Stable

From Figure 12, it is observed that more consideration was given to the master controller in terms of response. The controller response was increased to investigate how the Re-heater was able to attain stability with an optimal set point target. The simulation pace was reduced to 2.5 seconds where which the controller response was likewise dropped down to 1.5 seconds. In Figure 12, the response comparison between the Input Disturbance Rejection (IDR) A, and the heater jacket B, are clearly visualized (Jafarinejad, 2016). Furthermore, data from Table 4.4 and 4.5 shows high performance indicator differences of 10.73% when compared. However, the operations show a total stability (Donald et al; 2009).
The graph of Figure 13 shows how the Re-heater was able to adjust to meet up with the optimal set point target. A temperature of 319.7℃ was recorded for the given controller response which is almost close to the required set point of 320℃ (Donald et al; 2009).

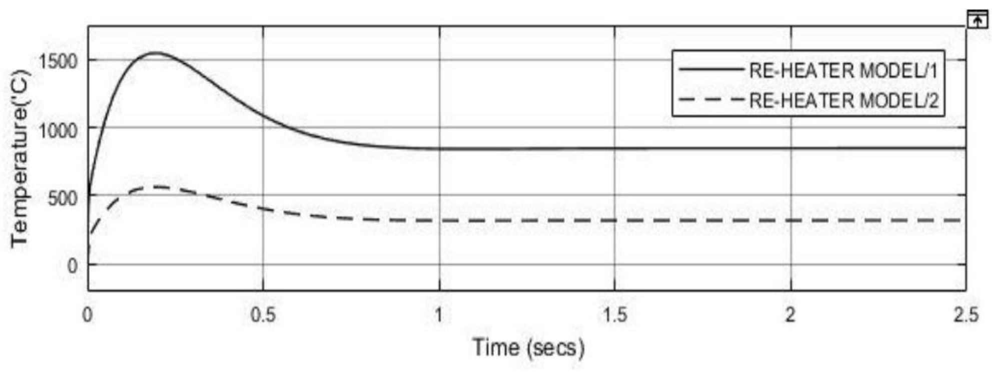
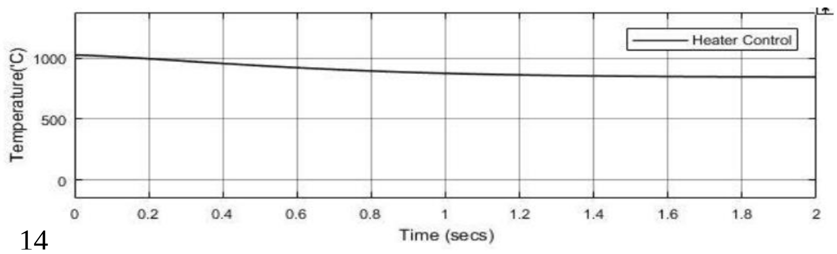


Figure 13: Response of Heater to a Controller Response

It is apparent and conclusive to state that, the heater was able to meet up with the set point at a considerably quicker control response time. It is also noted that the heater was able to reach its set point at a minimal settling time of 0.814 seconds as recorded by Simulink. An overshoot of 15.6% was also recorded. The rise time was also recorded to be 0.527 seconds. A PI controller was incorporated (as shown in Figure 14 - 16).



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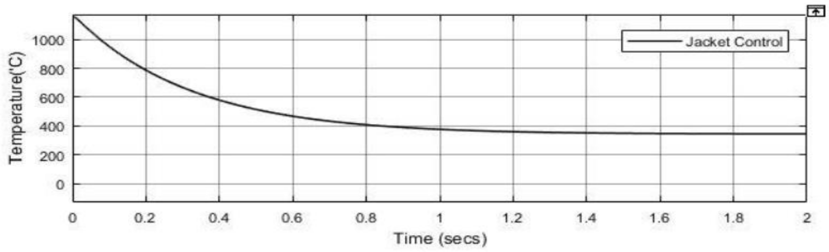

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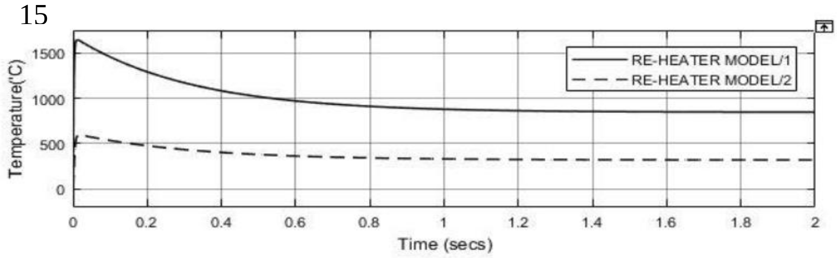
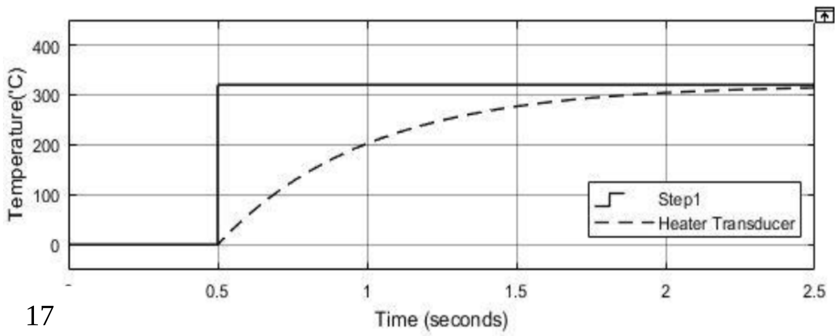


16 Figures 14 – 16: Heater Response for a PI Controller

A temperature of 319.6°C was recorded which has a difference of 0.1°C as compared to when a PID controller is used, heater controller, as shown in Figure 14.

A step test was carried out to investigate the response of the heater and jacket transmitter respectively. A Step time of 0.5 seconds was specified for all step simulation with an initial and final temperature value of 0°C to 320°C respectively, as shown in Figures 15 and 16.

The graph in Figures 17 and 18 indicates how the transducer was able to attain steady state temperature of 320°C at a simulation pace of 2.5 seconds. This indicates the efficacy of the thermometer to measure the output temperature of the heater and jacket respectively.



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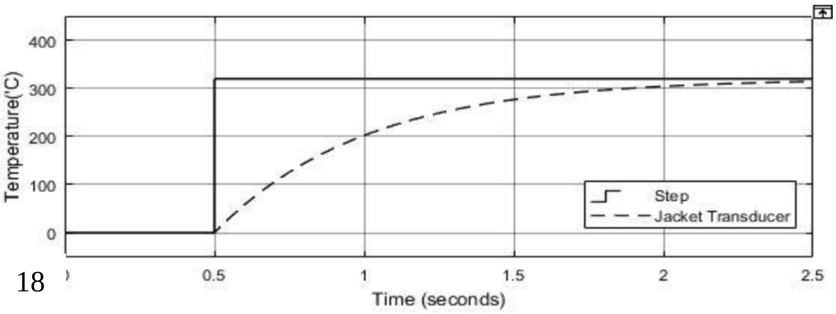
18 

Figures 17 – 18: Step Response of Heater and Jacket transducer respectively

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The design study of the SRU was categorized into steady state study and dynamic study. In the steady state study, the SRU was designed using the ASPEN Pus software. Various units and their specifications were modified based on pertinent assumptions.

The simulation result was efficient enough to meet up with the required production. The steady state results were used as reference to design and control the dynamic model of the system.

Basically, a control design was carried out on the Re-heater, to which it was required to control the output temperature of the product. The heater was studied, modelled in terms of Ordinary Differential Equation and Transfer Functions. Simulink was used in analysing and simulating the design to investigate how effective the control design responded to set point. The controlled variable was the output temperature, the manipulated and measured variable of the re-heater was the controller output temperature and heater output temperature respectively. A temperature of 319.9℃ was obtained after a controller action was incorporated. The rise time and settling time for the PID control integration of the jacket was recorded at 0.105 sec and 0.814 sec respectively, while the tank was at 0.567 sec and 2.88 secs respectively. In addition, step tests analysis for the transmitter was investigated for both the tank and jacket, and at 2.0 secs was optimally achieved for both cases.

5.2 Recommendation

The study of the control was carried out by employing a Multiple Input Single Output (MISO) strategy, which is also called a *cascade control*, where two controllers were used, PI and PID. An alternative strategy might also be used to test the functionality of the process under investigation.

Steam was also used as the heating fluid for the re-heater. Other heating fluid can also be incorporated in place of the steam. A PID control logic was employed to analyse the process under investigation. It is recommendable to investigate the response of the heater by the application of other control logic like the Neural Networks (NN) or the Fuzzy systems.

6.0: REFERENCES

Angelo Raimondi, Antonio Favela, Raul Estrada, Antonio Nevado, & Edgar Gracia. (2012). *'Adaptive predictive control of the sulphur recovery process at Pemex Cadereyta refinery'*. International Journal of Adaptive Control and Signal Processing. https://doi.org/10.1002/acs.2282 Wiley Online Library, pp. 965-971

Donald R. Coughanowr, & Steven E. Leblanc. (2009). *'Process Systems Analysis and Control'* ECJRC, (2013), *'Report on Pollution in the Oil and Gas Industry'*, European Commission and Joint Research Centre, UK. **15**:1202-12

E&P Forum/UNEP (1997); *'Report on Exploration and Production'*. United Nation Environmental Programme, NY, USA. **97**:12082-15.

EPA, (2000). *'Environmental Report, Office of Compliance Sector Notebook Project'*, Environmental Protection Agency, New York: McGraw-Hill companies, NY. 6th ed., pp. 443–452.

Goar, B. et al. (1986). Sulphur Recovery Technology. *Energy Progress*, **6**(2), pp.71–75.

Microsoft Visio (2016), *'MS Visio Design platform'* installed on window 8 version 2016

OPEC (2013): *'Organisation of Petroleum Exporting Countries 2013 Report'*, OPEC HQ.

Reid Laurence (1998), '*Engineering and Geoscience College of Continuing Education'*. (1998, March 1). Fundamental Manual for Sulphur Recovery: Laurence Reid Gas Conditioning Conference. University of Oklahoma, USA. **75**:182-17.

Shahryar Jafarinejad (2016), *'Control and treatment of sulphur compounds specially sulphur oxides (SOx) emissions from the petroleum industry', A review'*, Chemistry International, **2**(4), 12.

Seal A. M (1998), *'Practical process control'*, Elsevier book of company, Amsterdam, Netherland. Pp. 354-73

Speight J. G (2006), *'Petroleum Chemistry and Refining'*, Heinz Heinemann Book Company, pp. 39 – 54.

Hill J, Nelson E, Tilman D, Polasky S, Tiffany D (2006). *Environmental economic and energetic costs and benefits of biodiesel and ethanol biofuels*. Proc Nat'l Acad. Sci. USA. **103**:11206–10.