

The lean solution out of deacidifier is pumped out with the lean solution pump, part of it is heat exchanged in lean/enriched solution heat exchanger with enriched solution, then cooled with the lean solution cooler and sent to H₂S scrubber in H₂S/NH₃ scrubbing unit. The rest is directly sent to ammonia stripper.

At the upper stage of ammonia stripper, free ammonia in lean solution from deacidifier is further stripped out, and part of stripped water is taken after free ammonia stripped out, the stripped water is first cooled with the cooler and then sent to ammonia scrubber in H₂S/NH₃ scrubbing unit for absorbing ammonia in gas. The rest liquor is reached to the lower stage of ammonia stripper, where soda lye is added for decomposition of fixed ammonia. Ammonia-containing vapor out of ammonia stripper enters into deacidifier for stripping enriched solution. The stripped water out of the sump of ammonia stripper is pumped to the cooler for stripped water for cooling, after that, it is pumped and a small part of it is used for diluting soda lye, the rest, namely waste water is sent to bio-chemical waste water treatment plant. The mixed vapor contained with NH₃, H₂S, HCN and CO₂ discharged from the top of deacidifier is first partially condensed and then sent to the sulfur recovery unit.

The deacidifier and ammonia stripping unit is provided with one enriched solution tank, one lean solution tank and one stripped water tank [2].

Main Technical Parameters [4]

Gas temperature into final cooling stage of H₂S scrubber~45°C
 Gas temperature out of final cooling stage of H₂S scrubber ~22°C
 Gas temperature into ammonia scrubber~23°C

Gas temperature out of ammonia scrubber ~24°C
 Pressure loss of gas in H₂S scrubber <2000Pa
 Pressure loss of gas in H₂S/NH₃ scrubber<2500Pa
 Pressure loss of gas in ammonia scrubber<1750Pa

G. Sulfur Recovery System

1. Feed Gas Composition

Typical feed gas composition					
Component	Mol %	Wt %	Component	Mol %	Wt %
From an amine process:			From a sour water stripper:		
H ₂ S	82.1	80.8	H ₂ S	26.7	40.2
CO ₂	11.9	15.1	CO ₂	2.6	5.1
NH ₃	nil	nil	NH ₃	39.4	29.7
H ₂ O	4.0	2.1	H ₂ O	31.3	25.0
HC	2.0	2.0	HC	nil	nil

Notes: H₂S is hydrogen sulfide, CO₂ is carbon dioxide, NH₃ is ammonia, H₂O is water and HC is an abbreviation for hydrocarbons. Wt % is weight percent.

3. Reactions

Overall Reactions:

$H_2S + 1.5O_2 \rightarrow SO_2 + H_2O$; $\Delta H = -518.4 \text{ KJ/kg } H_2S$ (exothermic Reaction)

$2H_2S + SO_2 \rightarrow 3/X S_x + 2H_2O$ (X=1- 8); $\Delta H = -146.7 \text{ KJ/kg } H_2S$ (at 260°C)

General Reaction:

$3H_2S + 1.5 O_2 = (3/X)S_x + 3H_2O + 664 \text{ KJ}$

$CO_2 + H_2S = COS + H_2O$

$COS + H_2O = H_2S + CO_2$

$2H_2S + CO_2 = CS_2 + 2H_2O$

$CS_2 + 2H_2O = 2H_2S + CO_2$

$NH_3 = 1.5H_2 + 0.5N_2$

$HCN + H_2O = 1.5H_2 + 0.5 N_2 + CO$

$2H_2S + SO_2 = 1.5S_2 + 2H_2O$

Catalyst used in Claus kiln "NICKEL CATALYST" over inert ball. Catalyst used in Claus reactor "ALUMINA CATALYST" over inert ball [2].

The reaction furnace pressure and temperature is maintained at about 1.5 bar gauge (barg) and about 1,000 °C. At those conditions, the Claus reaction occurs thermally in the reaction furnace (i.e., without requiring any catalyst). About 70% of the H₂S in the feed gas is thermally converted into elemental sulfur in the reaction furnace.

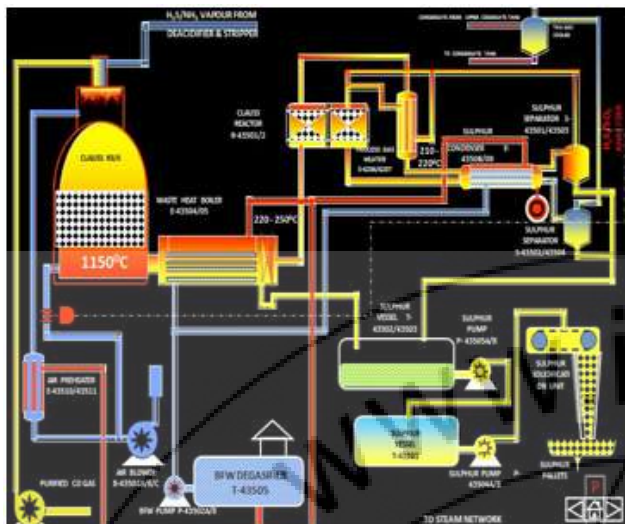
The hot reaction product gas, containing gaseous sulfur, is used to produce steam in a boiler (called a waste heat boiler) which results in cooling the gases. The gas is then further cooled and condensed in a heat exchanger while producing additional steam. The condensed liquid sulfur is separated from the remaining unreacted gas in the outlet end of the condenser and sent to product storage.

The separated gas is then reheated and enters the first catalytic reactor maintained at an average temperature of about 305 °C where about 20% of the H₂S in the feed gas is converted into elemental sulfur. The outlet product gas from the first reactor is cooled in another condenser while also producing steam. Again, the condensed liquid sulfur is separated from the remaining unreacted gas in the outlet end of the condenser and sent to product storage.

The separated gas from the second condenser is sent to another reheater and the sequence of gas reheat, catalytic reaction, condensation and separation of liquid sulfur from unreacted gas is repeated for the second and third reactors at successively lower reactor temperatures.[1] About 5% and 3% of the H₂S in the feed gas is thermally converted into elemental sulfur in the second reactor and third reactors, respectively. For a well-designed and operated Claus sulfur recovery plant having three catalytic reactors (as shown in the flow diagram), an overall conversion of at least 98% can be achieved. In fact, the latest modern designs can achieve up to 99.8% conversion of hydrogen sulfide into product sulfur that is 99+% saleable "bright yellow sulfur" [2].

The remaining gas separated from the last condenser is referred to as "tail gas" and is either burned in an incinerator or further desulfurized in a "tail gas treatment unit" (TGTU).

4. Process Description



Sour vapor containing H_2S/NH_3 from de-acidifier and ammonia stripping unit is first regulated for pressure and then fed into the burner located at upper part of Claus furnace. The partial oxidation is adopted, in which one-third of H_2S is burnt with air to form SO_2 , the rest two-third H_2S is reacted with SO_2 to form elemental sulfur.

The whole reaction is an exothermic reaction. The high temperature in furnace is maintained by chemical reaction. When H_2S in sour vapor is lower, the released heat is not sufficient to keep temperature necessary for reaction, small amount of coke oven gas must be introduced into the furnace so as to maintain heat amount necessary for reaction in furnace.

NH_3 and HCN in sour vapor is decomposed into H_2 , N_2 and CO under

$\sim 1150^\circ C$ catalytic cracking. Hydrocarbon in sour vapor also can be fully decomposed or burnt. Secondary air is introduced into the bottom of Claus furnace; the process gas is further oxidized. The amount of secondary air is controlled with H_2S/SO_2 proportional monitor after sulfur separator. High temperature process gas out of Claus furnace is passed through waste heat boiler for heat recovery, and then continuously passed through two stages of clause reactor to form elemental sulfur, then passed through sulfur condenser and sulfur separator to separate liquid sulfur. The tail gas is sent to the cooler, where it is sprayed and cooled with condensate from upper stage of primary cooler, after cooling it is sent to the gas suction main before downcomer.

Liquid sulfur condensed at waste heat boiler together with liquid sulfur from sulfur separator are merged and then fed into liquid sulfur tank, then sent by pump into sulfur solidification unit, where it forms pellet solid sulfur by cooled, then slide down along chute, packing and finally transported out with truck.

The process gas intermediate heater is provided between Claus reactors. The process gas into second stage Claus reactor is heated with the process gas out first stage Claus reactor, enabling second stage reached to the temperature required by

reaction.

0.4MPa steam produced in waste heat boiler is used for heating of air heater and heating, tracing and purging of equipment and pipe. The surplus one is sent to the 0.4MPa steam net. 0.15MPa steam produced in sulfur condenser is used for degassing of the treatment tank for boiler feed water.

The cleaned gas used for Claus furnace heating comes from downstream of naphthalene scrubber. Gas is boosted to Claus furnace with gas blower. Air for combustion is boosted with air blower and passed through heater to Claus furnace.

Boiler feed water necessary for waste heat boiler and sulfur condenser enters into boiler feed water treatment tank, after degassed with steam, is sent into the waste heat boiler and sulfur condenser by water feed pump.

The blow down water from waste heat boiler and sulfur condenser is mixed with the cooling water from sulfur solidification unit and cooled, then discharged into the water drainage system.

After two batteries put into operation, that is four coke ovens in production, two sets of Clause system can be operated, the actual running capacity of each is $\sim 50\%$, hot standby each other. If only one battery in production, one Clause system will be in operation, the actual running capacity is $\sim 50\%$, the other one serves as clod standby [2].

5. Main Technical Data[4]

Flow rate of sour vapor containing H_2S/NH_3 $\sim 3400Nm^3/h$
 Temperature of catalyst bed in Claus furnace $\sim 1150^\circ C$
 Temperature of process gas out of waste heat boiler: $220\sim 240^\circ C$
 Temperature of process gas into 2nd stage Claus reactor: $210\sim 220^\circ C$
 Temperature of process gas after sulfur condenser $\sim 135^\circ C$
 Tail gas temperature after tail gas cooler $\sim 80^\circ C$
 Resistance of catalyst bed of Claus furnace < 5 KPa
 Resistance of catalyst bed of Claus reactor < 4.5 KPa
 Steam pressure produced by waste heat boiler- 0.4MPa

Steam pressure produced by sulfur condenser- 0.15MPa
 Sulfur purity -99.5% (w/w)

6. Waste Heat Recovery Unit (Waste Heat Boiler)[1]

A waste heat recovery unit (WHRU) is an energy recovery heat exchanger that recovers heat from hot streams with potential high energy content, such as hot flue gases from a diesel generator or steam from cooling towers or even waste water from different cooling processes such as in steel cooling. Waste heat boiler produce steam at a pressure of 0.4 mpa with a capacity of 6 ton/hr.

These systems have many benefits which could be direct or indirect.

- Direct benefits: The recovery process will add to the efficiency of the process and thus decrease the costs of fuel and energy consumption needed for that process.
- Indirect benefits:
 - a. Reduction in Pollution: Thermal and air pollution will dramatically decrease since less flue gases of high temperature are emitted from the plant since most of the energy is recycled.
 - b. Reduction in the equipment sizes: As Fuel consumption reduces so the control and security equipment for handling the fuel decreases. Also, filtering equipment for the gas is no longer needed in large sizes.
 - c. Reduction in auxiliary energy consumption: Reduction in equipment sizes means another reduction in the energy fed to those systems like pumps, filters, fans...etc.

• Disadvantages

- a. Capital cost: The capital cost to implement a waste heat recovery system may outweigh the benefit gained in heat recovered. It is necessary to put a cost to the heat being offset.
- b. Quality of heat: Often waste heat is of low quality (temperature). It can be difficult to efficiently utilize the quantity of low quality heat contained in a waste heat medium. Heat exchangers tend to be larger to recover significant quantities which increases capital cost.

7. Degasifier [3]

Degasification is the removal of dissolved gases from liquids, especially water or aqueous solutions. There are numerous possible methods for such removal of gases from solids.

Generally speaking, the higher the temperature of a solution becomes, the less a gas dissolves provided it doesn't react with the solvent. Consequently, heating a solution can expel the remaining gas. This method is used in the degasifier, along with chemical dosing. Degasification is done to reduce corrosion and increase heat transfer in the waste heat boiler. A temperature of 104°C is maintained in the degasifier and chemical used are tri sodium phosphate (TSP) and hydrazine hydrate.

8. Material Energy and Product [4]

Crude Coke Oven Gas

- a) Temperature: 82°C (saturated with water).
- b) Content of impurities in crude coke oven gas (excluding tail gas, charging gas and Respiration gas):

H₂S 5~6.5g/Nm³
 NH₃-10~11 g/Nm³
 BTX -30~35 g/Nm³
 Tar -35~45 g/Nm³

C₁₀H₈(naphthalene)- 6~10 g/Nm³

HCN- 1~1.5 g/Nm³

PURIFIED COKE OVEN GAS

a) Pressure (97,000 Nm³/h at battery limit)-3.5kPa (min.)

b) Gas composition (vol %):

CO₂ -3~4

CnHm- 2~2.6

O₂- 0.6

CO - 6~9

H₂- 52~56

CH₄- 24~26

N₂- balance

c) Temperature: ~28°C (saturated with water).

d) Content of impurities (the figures are valid for gas flow 88,000Nm³/h)

H₂S-0.5 g/Nm³

NH₃-0.04 g/Nm³

C₁₀H₈- 0.12 g/Nm³

Tar -0.02 g/Nm³

CRUDE TAR

(After centrifuge)

Specific gravity 1.14~1.22

Moisture3% (W/W)

Solid matters (>100 μm) 0.3% (W/W)

Without Centrifuge

Specific gravity 1.14~1.22

Moisture4% (W/W)

Solid matters (>100 μm) NA

Stripped Waste Water

Total ammonia content: 150mg/l

Quantity: 105m³/h (DN200)

Pressure at T.O.P 0.45MPa

Temperature 40°C

Sulfur

Sulfur purity 99.5% (W/W)

9. Conclusion

The new by product plant established in Tata steel would house two batteries (#10,#11). Each battery is equipped with 44 coke ovens. Approx 44,000 m³/hr coke oven gas will be produced by each battery. Each battery is followed by tar ammonia H₂S and naphthalene removal system. Tar is used within the plant as a fuel. Tar produced is approx 70,610 ton/yr. Ammonia is broken down into n₂ and H₂O in Claus process while sulfur is recovered from H₂S in liquid form. This liquid sulfur is then sent to the pelletization plant where liquid sulfur is converted into solid sulfur pellets by cooling.

The main aim of establishing such a plant was not to attain financial benefits but to keep a check on environmental pollution in Jamshedpur. The SO₂ and NO₂ levels have increased in the city and 2 new batteries producing 44,000 m³/hrcog would have take these gases to extreme levels. Tata

Steel has always been known for uplifting social and environmental causes and keeping this in mind, the new by-product plant came in. Moreover, the sulfur produced has a purity of 99.5%. H₂S concentration is brought down by 87% while ammonia, BTX and HCN are removed entirely from the tail gas.

Heat is recovered from the waste heat boiler as well as the two condensers. Waste heat boiler produces steam at 0.4 mpa and has a capacity of 6 ton/hr while the condenser produces steam at 0.14 mpa and has a capacity of 1 ton/hr.

Sulfur recovery is done by Claus process. Claus process is a two-step process for sulfur recovery. The first step is a thermal step in which the sour gas (mixture of NH₃ and H₂S) is heated to 1150°C where ammonia cracks down to N₂ and H₂O while H₂S breaks down to give liquid sulfur. The second step is a catalytic step in which the exit gas from the first step is treated with a catalyst (Al₂O₃) which breaks the remaining H₂S to give sulfur.

Acknowledgement

First of all, I would like to thank the department of SNTI for giving me the opportunity to visit the plant and attain some industrial experience. Secondly, I would like to thank my guide Mr. Sujit Sinha who has helped me throughout the project and without whom, completion of my project would have been very difficult. Finally, I would like to thank the whole Tata Steel management for rendering such a trainee program through which budding engineers can gain some experience. Without the support of all of them, the project would not have been a success.

Reference

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Author Profile



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