MATERIAL BALANCE

GIVEN:

TO DESIGN A 1000TPD CAPACITY H_2SO_4 ACID PLANT

BASIS:

1 HOUR OF OPERATION.

PURITY:

PRODUCT WHICH IS TO BE MANUFACTURED IS ASSUMED TO HAVE STRENGTH OF 98% ACID.

1000TPD implies that we have $1000 \times 10^3 / 24 = 41666.67$ Kg/Hr of Acid

With 98% purity, the acid that is produced per hour $= (98 \times 41666.67) / 100$
$= 40833.34$ Kg/Hr

Kmoles of Sulfuric acid to be produced $= 40833.34 / 98$
$= 416.667$ Kmoles/Hr

It's assumed that overall absorption of the acid is 100 %

Then, SO_3 required $= 416.667 / 1.0$
$= 416.67$ Kmoles/Hr

Also its assumed that the overall conversion of SO_2 to SO_3 in the reactor is 99.8%

Then SO_2 required $= 416.67 / 0.998$
$= 417.51$Kmoles/Hr

Assuming 100% combustion of Sulfur,

Then S required $= 417.5$ Kmoles/Hr
$= 13360.3$ Kgs

Amount of oxygen required to convert 1Kmole of S to SO_3 = 1.5 Kmoles

Then, amount of Oxygen required $= 417.51 \times 1.5$
$= 626.26$ Kmoles

As cited in the literature that some amount of excess oxygen must be used,

Using 40% excess,

O_2 required = 626.26 x 1.4
= 876.76 Kmoles

From this the total dry air that is coming in can be calculated as.

Dry air in = (876.76 x 100)/ 21
= 4175 Kmoles/Hr

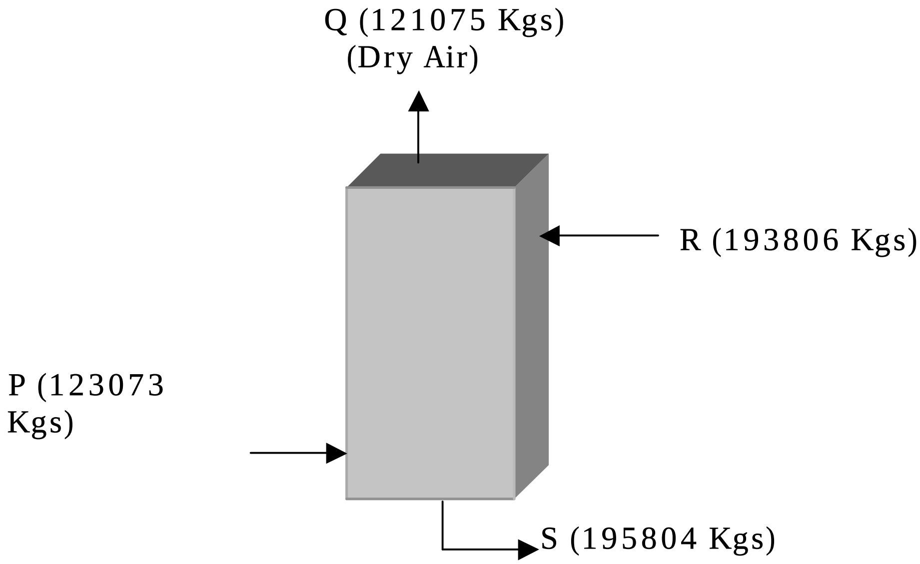
At 30°C, assuming 65% Relative Humidity,

Humidity as calculated from the psychometric chart is,
Humidity = 0.0165 Kg water/ Kg dry air

Then, water entering with dry air = 4175 x 29 x 0.0165
= 1997.73 Kg/Hr
= 110.980 Kmoles/Hr

Total weight of entering air = 4175 x 29 + 110.980 x 18
= 123073 Kgs

DRYING TOWER:



Making a Mass balance around the Drying Tower

$P + R = Q + S$

As water is being removed from the incoming air to make it dry, the 98% acid that is being recycled to the tower, decreases in concentration and let this concentration be assumed as 97%, then we can write,

$0.02 \times R + 1998 = S \times 0.03$ ——— (1)

H_2SO_4 Balance will give,

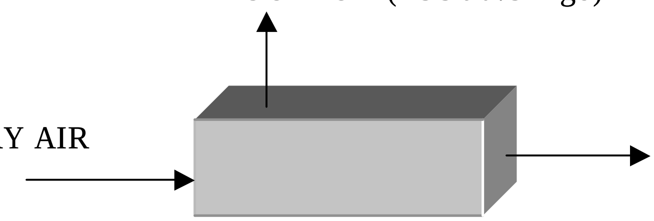
$R \times 0.98 = S \times 0.97$ ——— (2)

Solving the above equations

R = 193806 Kgs
S = 195804 Kgs

SULFUR BURNER:

SULFUR (13360.3 Kgs)



DRY AIR (121075Kgs)

SO_2 (26720.6 Kgs)
O_2 (14696 Kgs)
N_2 (92352.4 Kgs)

The combustion reaction takes place inside the burner where Sulphur is oxidized to Sulphur Dioxide

Moles of Sulfur coming in = 417.51 Kmoles
Moles of Oxygen coming in = 876.76 Kmoles

As mentioned before we have assumed 100% combustion of sulphur,

Sulfur Dioxide Formed = 417.51 Kmoles
Oxygen leaving = 876.76 – 417.51
= 459.25 Kmoles
Nitrogen leaving = (876.76 x 79)/ 21
= 3298.3 Kmoles

REACTOR:

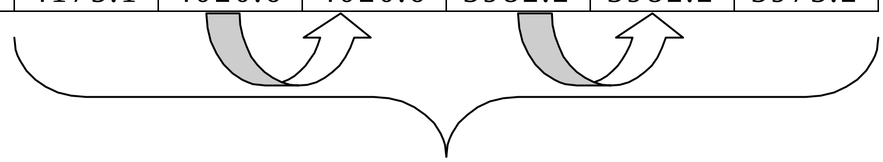
As cited in the reference by author **NORMAN SHREVE et al** Pg 337, the temperature and conversions in Each Stage of a Monsanto Converter is given as follows:

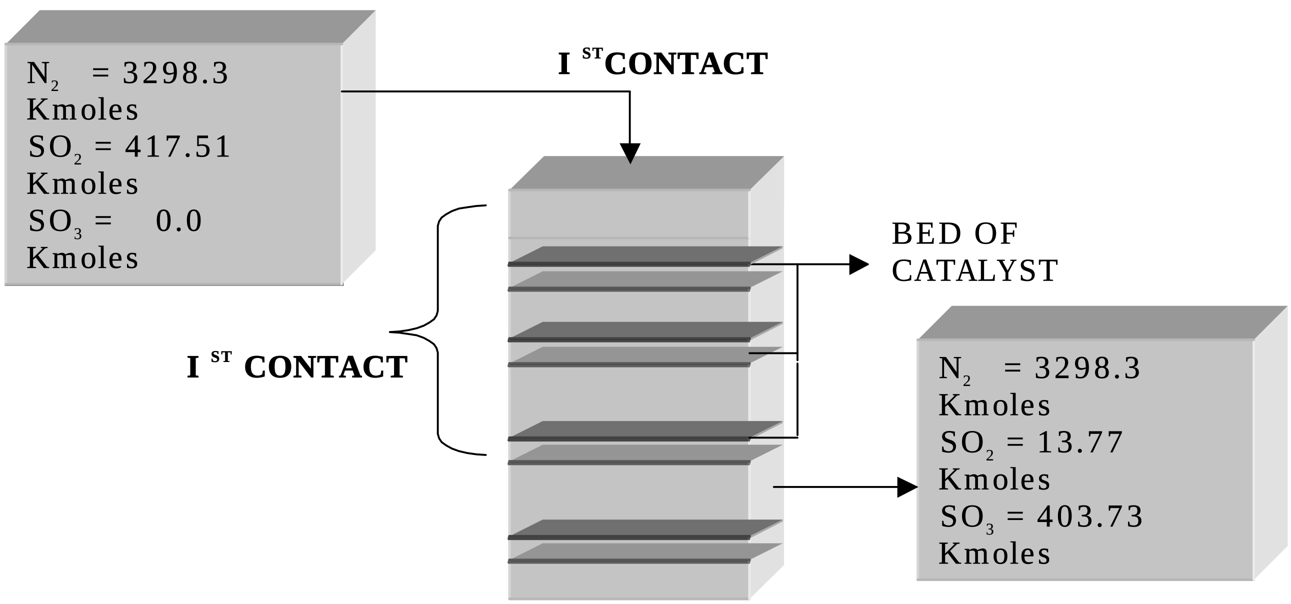
LOCATION	TEMPERATURE (˚C)	EQUIVALENT CONVERSION (%)
Gas entering first pass	410.0	
Gas leaving first pass	601.8	
Rise in temperature	191.8	74.0
Gas entering second pass	438.0	
Gas leaving second pass	485.3	
Rise in temperature	47.30	18.4
Gas entering third pass	432.0	
Gas leaving third pass	444.0	
Rise in temperature	12.00	4.3
Gas entering fourth pass	427.0	
Gas leaving fourth pass	430.3	
Rise in temperature	3.300	1.30
TOTAL RISE	254.4	98.0%

Note: As we see from the table that the overall conversion in the reactor is 98% but to validate our assumption that was made earlier, we assume that the conversion in the last stage of the reactor is 3.1% instead of 1.3% so that the assumption of 99.8% as overall conversion remains unaffected and thus temperature for the gas leaving the fourth pass is then assumed to be 437˚C.

COMPONENTS	I STAGE 74% CONVERSION	II STAGE 18.4% CONVERSION	III STAGE 4.3% CONVERSION

	I/LET KMOLS	O/LET KMOLS	I/LET KMOLS	O/LET KMOLS	I/LET KMOLS	O/LET KMOLS
N_2	3298.3	3298.3	3298.3	3298.3	3298.3	3298.3
SO_2	417.51	108.55	108.55	31.73	31.73	13.77
SO_3	0.0	308.95	308.95	385.77	385.77	403.73
O_2	459.26	304.7	304.7	266.36	266.36	257.39
TOTAL Kmols	4175.1	4020.6	4020.6	3982.2	3982.2	3973.2





Sample calculation for the 2nd stage is shown as follows:

Components: SO_2 INLET = 108.55 Kmoles
OUTLET = 108.55 – 417.51 x 0.184 Kmoles
= 31.73 Kmoles

N_2 INLET = 3298.3 Kmoles
OUTLET = 3298.3 Kmoles

O_2 INLET = 304.78 Kmoles
OUTLET = 304.78 - 417.5 x 0.5 x 0.184 Kmoles
= 266.4 Kmoles

SO_3 INLET = 308.95 Kmoles

OUTLET = 308.95 + 417.5 x 0.184 Kmoles
= 385.77 Kmoles

The arrow shown indicates that the output from one stage is the input to the other stage.

After the passage from the 3 stages or after the first contact the gases are let into the interpass absorber where the absorption of the SO_3 takes place. After the contact with H_2SO_4 in the tower, the gases are returned back to the 4th stage for the second contact.

We can write from the reaction for sulfur dioxide oxidation to give sulfur trioxide that,

$$K_p = \frac{(P_{SO3})}{(P_{SO2})(P_{O2})^{1/2}} \qquad \text{(A)}$$

And available in the reference by author **NORMAN SHREVE et al** Pg 333, the equilibrium constants for the Sulfur Dioxide Oxidation are given at different temperatures
Now for K_p at the entering temperature of 4th stage i.e. 427°C,

We have K_p = 270.2

INTERPASS ABSORBER:

From the equation (A), SO_3 present are calculated by the following

Let X_1 = Moles of SO_2
X_2 = Initial moles of SO_2 entering the reactor
X_3 = Moles of O_2
X_4 = Moles of SO_3

Then

$$K_p = \frac{(X_4 + 0.031 \times X_2) \times (X_1 + X_3 + X_4)^{0.5}}{(X_1 - 0.031 \times X_2) \times (X_3 - 0.5 \times 0.031 \times X_2)^{0.5}} \qquad \text{(B)}$$

The above equation is once again mentioned in the literature.

Calculating the value of the unknown X_4, we have, with K_p = 270.2, we get

X_4 = 158.01 Kmoles

Then Moles of SO_3 removed in the interpass absorber is given as = (403.73 – 158.014)

= 245.718 Kmoles

$$SO_3 + H_2O \longrightarrow H_2SO_4$$

As from the stoichiometric coefficients of the reaction given, we can find out the weight of sulfuric acid to be absorbed as = 245.718 x 98

= 24080.4 Kg/Hr

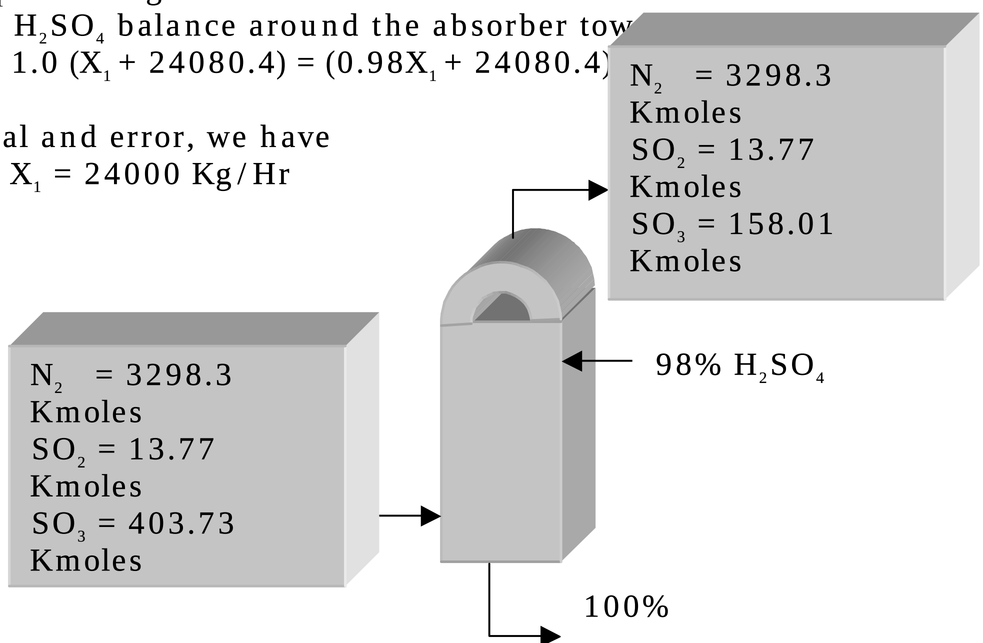
Also mentioned in the literature that “its required to take the strength of the solvent H_2SO_4 for absorption of SO_3 not to increase by more than 1-2%, and the best absorption will occur when the absorbing acid has the strength between the range 97.5 to 99%”.

Let X_1 be the Kgs/hr of the fed to the tower acid
Then, H_2SO_4 balance around the absorber tow

$1.0 (X_1 + 24080.4) = (0.98X_1 + 24080.4)$

By trial and error, we have

X_1 = 24000 Kg/Hr

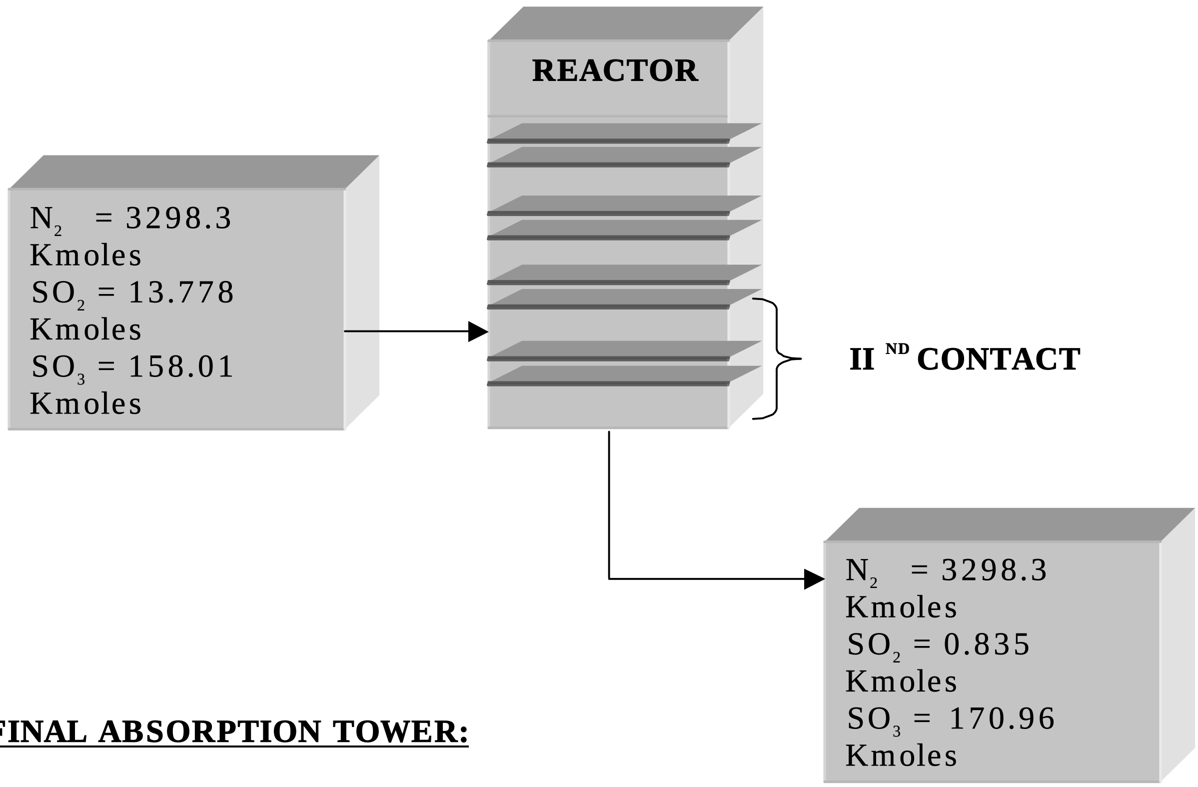


REACTOR:

For the second contact we have the following details,

COMPONENTS	I STAGE 3.1% CONVERSION	
	I/LET KMOLS	O/LET KMOLS
N_2	3298.3	3298.3

SO_2	13.778	0.835
SO_3	158.01	170.96
O_2	257.39	250.92
TOTAL Kmols	3727.5	3721.04



FINAL ABSORPTION TOWER:

Let X_2 be the Kgs/hr of the acid fed in this tower,

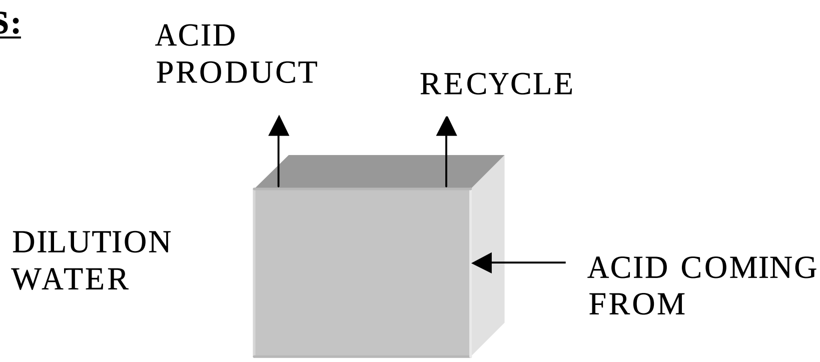
Then,

$$1.0\ (X_2 + 170.96 \times 98) = 0.98 \times X_2 + 170.96 \times 98$$

Again by trial and error, we have

$$X_2 = 16500 \text{ Kgs/Hr}$$

TANKS:



$\longrightarrow$

<u>Tank – 1:</u>

Dilution water is added in the tank to bring down the concentration to the desired 98%, and this is calculated as

= 245.718 x 18 + (24080.4 x 2)/98

= 4915 Kgs/Hr

Material balance around the tank is given as,

Or, 24000 + A_1 – (24000 + 245.718 x 98 – 245.718 x 18) - 4915 = 0

Then,

A_1 = 24572 Kgs/Hr

<u>Tank – 2:</u>

Dilution water is also added in this tank to bring down the concentration to desired 98%,

which is calculated as

= 170.95 x 18 + (16754 x 2)/98

= 3419 Kgs/Hr

Material balance around the tank is given as,

Or, 16500 + A_2 - (16500 + 170.95 x 98 – 170.95 x 18) – 3419 = 0

Then,

A_2 = 17095 Kgs/Hr

Then total amount of acid that is formed is

= 41667 Kgs/Hr

= 41667 x 24

=1000008 Kgs/day

=1000.01 TPD