

Performance Evaluation of a Scrubber for CO₂ Gas Removal

A Case Study from a Pharmaceutical API Manufacturing Plant

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Abstract - Industrial manufacturing process generates gaseous Pollutants that must be Controlled before Discharge into the Atmosphere. For that Industrial Scrubbers Play Critical Role in Controlling gas Emissions. This Study represents a Systemic Approach in to Scrubber Performance Evaluation Through Mole Balance Methodology and focusing on Gas Liberation and Absorption in a Industrial Applications. This Case analysis Demonstrates how Mole Balance Can be applied to Design, Optimize and Troubleshoot the Scrubber. In a Industrial Applications Most of the Chemists and Junior Level People have some Confusion on Gas Liberation and mole Balance but it is a Important Practice For a Industrial Level People. In This paper Represents a Easy and effective Way to practice the Industrial Format to save Our Environmental Surroundings and Useful to all Industrial Formats.

Keywords - Scrubbers, Absorption, Optimize, Mole Balance, Emission

I. INTRODUCTION

Industrial processes often generate gaseous by-products that must be controlled to meet environmental and safety standards. Scrubbers are widely employed as gas treatment units, designed to remove pollutants through absorption, chemical reaction, or neutralization. Accurate calculation of scrubber performance is essential for optimizing design, minimizing emissions, and ensuring compliance with regulatory frameworks.

Traditional approaches to scrubber analysis rely on empirical correlations or pilot-scale testing, which may not fully capture the dynamic behaviour of gas liberation and absorption under varying industrial conditions. In contrast, mole balance provides a rigorous theoretical framework for quantifying the rate of gas liberation and pollutant removal efficiency. By applying mole balance equations, engineers can predict scrubber performance, identify limiting factors, and optimize operating parameters with greater precision. This study focuses on integrating mole balance methodology into scrubber calculations for industrial applications. The aim is to bridge the gap between theoretical modelling and practical operation, demonstrating how mole balance can

serve as a robust tool for design, troubleshooting, and performance evaluation. Through case analysis, the paper highlights the relevance of mole balance in improving emission control strategies, reducing operational costs, and advancing sustainable industrial practices.

II. LITERATURE REVIEW

2.1 Scrubber Design Studies:

A venturi scrubber consists of three sections: a converging section, a throat section, and a diverging section. The inlet gas stream enters the converging section and, as the area decreases, gas velocity increases. Liquid is introduced either at the throat or at the entrance to the converging section. The inlet gas, forced to move at extremely high velocities in the small throat section, turbulently mixes with the liquid, producing an enormous number of very tiny droplets. Particle and gas removal occur in the diverging section as the inlet gas stream mixes with the fog of tiny liquid droplets. The inlet stream then exits through the diverging section, where it is forced to slow down

2.2 Wet Scrubber:

The term wet scrubber describes a variety of devices that remove Pollutants from a Furnace Flue Gas or from other gas streams. In a wet scrubber, the polluted gas stream is brought into contact with the scrubbing liquid, by spraying it with the liquid, by forcing it through a pool of liquid, or by some other contact method, so as to remove the pollutants.

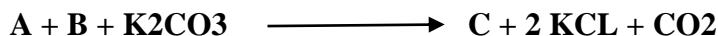
Wet scrubbers capture relatively small dust Particles with the wet scrubber's large liquid droplets. In most wet scrubbing systems, droplets produced are generally larger than 50 micrometres (in the 150 to 500 micrometres range). As a point of reference, human hair ranges in diameter from 50 to 100 micrometres.

2.3 Mole Balance:

While mole balance is a fundamental chemical People tool, its direct application in scrubber calculations is less explored in literature.

III. METHODOLOGY

3.1 Applying Mole Balance:



LHS	
C:	21
O:	4
Cl:	1
H:	28
K:	2

If we Add 2 Moles in KCl then Moles is Balanced

RHS	
C:	21
O:	3
Cl:	1
H:	27
K:	1+1=2

Here mole Balance applying to Gas Phase to determine the liberation Rate. For that I Got 1 mole of KSM Liberates 1 Mole of Co₂.

3.2 Industrial Application Procedure:

Before Getting Into Calculation Firstly we have to Follow up on Piping & Instrumentation Diagram in Our Plant Wet Scrubber made on Packed Bed with "Pall Rings" with MOC PP Rings & Typical Size is 25mm & Packing Height is Considered as 2.5 meters. For any Engineers or production side

Chemists Estimate to Calculate the Gas Velocity & Preferable Scrubber Diameter, Liquid Flow Rate & Finding Re-circulation Capacity. It Helps to Lead troubleshoot at Initial Problems and Helps to Save our Environment. For a Industrial framework I Draw a P&ID Diagram For a Industrial Module.

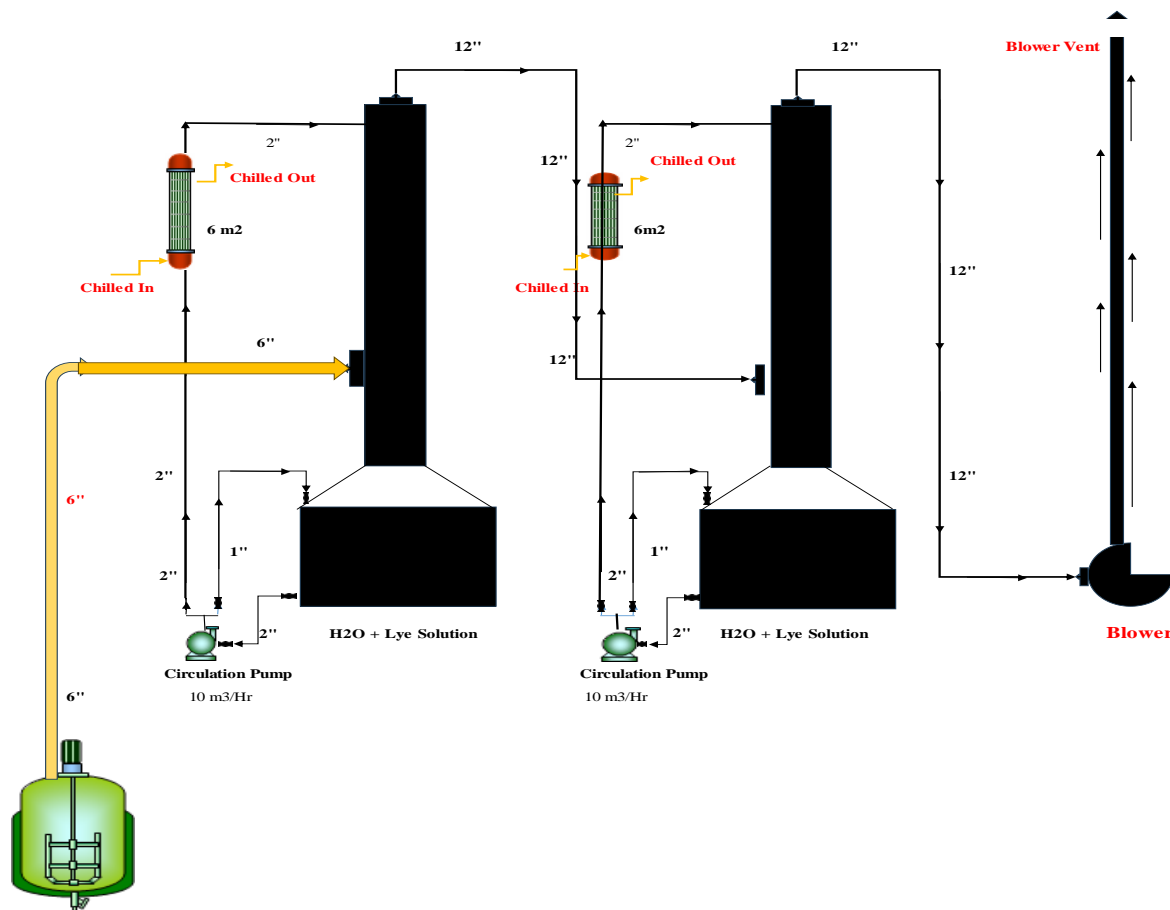


Fig.1 Piping & Instrumentation Diagram in a Industrial Scale

IV. CALCULATION WORK:

4.1 Mole Balance:

Initially we have to Balance the Reaction. The Thing is Separate the L.H.S = R.H.S and Equate the Both Values. Here that in my Balance I Got 2 Moles of Potassium Chloride and 1 Moles of CO₂ Gas then we have to Conclude the reaction Balance.

4.2 Find No, Of Moles in Reactants:

Moles of (A):

$$n = \text{WEIGHT} / \text{MOLECULAR WEIGHT}$$

$$n = 100 \text{ Kg} / 225.33 \text{ Kg/K. mole}$$

$$n = 0.4437 \text{ k. mole.}$$

Moles of (B):

$$n = \text{WEIGHT} / \text{MOLECULAR WEIGHT}$$

$$n = 62 / 108.57$$

$$n = 0.5710 \text{ k. mole}$$

Moles of K₂CO₃:

$$n = \text{WEIGHT} / \text{MOLECULAR WEIGHT}$$

$$n = 113 \text{ Kg} / 138.21 \text{ Kg/K. mole}$$

$$n = 0.8175 \text{ k. mole}$$

4.3 Gas Liberation Calculation:

• 1 K. mole of C₁₆H₁₉N React 1 K. Mole of Co₂

Co₂ Gas Liberation Quantity:

$$0.4437 \text{ K. mole} \times 44.01 \text{ Kg/K. Mole}$$

$$\text{Volume (V)} = 19.527237 \text{ Kg's}$$

$$\text{N (No, of moles)} = 0.4437 \text{ k. mole.}$$

4.4 Total Gas Generated:

Total k. mole of Gas:

$$\text{Moles} = 0.4437 \text{ mole} + 0.4437 \text{ K. Mole}$$

$$\text{Volume (V)} = 0.8874 \text{ k. mole}$$

$$\text{at STP 1 k mole} = 22.4 \text{ Nm}^3/\text{k mole}$$

$$\text{Volume (V)} = 0.8874 \text{ k mole} \times 22.4 \text{ Nm}^3/\text{k mole}$$

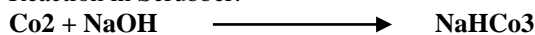
$$\text{Volume(V)} = 19.8901836 \text{ Nm}^3$$

4.5 NaOH Requirement:

Before Getting into this Findings Firstly we Have to Find After CO₂ Gas Inlet into Scrubber the Reaction Carry Forwarded inside Scrubber is must to be Understand. Here the reaction Inside is NaHCO₃

CO₂ Neutralization:

Reaction in Scrubber:



Input Generation of Co₂:

$$\text{Co}_2 = \text{Liberation} / \text{Molecular Weight}$$

$$n = 0.451946912 \text{ k. mole}$$

NaOH Required for Neutralizing of CO₂:

$$\text{Volume (V)} = 0.4437 \text{ K. mol} \times 40 \text{ Kg/K. mole}$$

$$\text{Volume (V)} = 17.748 \text{ Kg}$$

4.6 Calculation of Gas Emission:

$$\text{PPM} = \frac{\text{mg}}{\text{m}^3} \times 24.45$$

$$44.01$$

Input Data:

Blower Capacity = 3000 m³/Hr.

Addition Time = 3 Hours

Finding total Exhaust Gas Volume:

$$\text{Total Gas Volume} = 3000 \text{ m}^3/\text{Hr.} \times 3 \text{ Hours}$$

$$\text{Total Gas Volume} = 9000 \text{ m}^3$$

• Convert CO₂ in Kg's to mg:

$$19.49 \text{ Kg's} = 19490000 \text{ mg}$$

• Calculate mg/m³:

$$\text{CO}_2 \text{ Concentration} = \frac{19490000 \text{ mg/m}^3}{9000 \text{ m}^3}$$

$$\text{CO}_2 \text{ Concentration} = 2165.55 \text{ mg/m}^3$$

Now Calculate PPM:

$$\text{PPM} = \frac{\text{mg}}{\text{m}^3} \times 24.45$$

$$44.01$$

$$= 2165.55 \times 24.45 / 44.01$$

$$= 1203.086 \text{ PPM}$$

4.7 Packed Bed Scrubber Design:

Finding Gas Flowrate:

Blower Flowrate = 2500 m³/Hr.

$$2500 \text{ m}^3/\text{Hr.} \times 1.2 (20\%) = 3000 \text{ m}^3/\text{Hr}$$

*Finding Gas Velocity:

Acid gas Scrubber = 1-2 m/s

I have to Take 1.5 m/s

Solvent Vapor = 1.5-2.5 m/s

4.8 Calculate Diameter:

Formulae:

$$\text{Area} = \frac{Q}{3600 \times \text{Velocity}}$$

$$= \frac{3000 \text{ m}^3/\text{Hr}}{3600 \text{ s} \times 1.5 \text{ m/s}}$$

$$\text{Area} = 0.556 \text{ m}^2$$

Now I Find Diameter:

$$D = \sqrt{4 * 0.556 / \pi}$$

$$D = 0.84 \text{ m}$$

Scrubber Diameter is 850 mm.

4.9 Finding liquid Flowrate & Recirculation pump Capacity

As considered at L/G Ratio CO₂ Gas Having Ratio is 5 L/m³ So, we have Gas Flowrate is 3000 m³/Hr. then the Circulation Flowrate is 3000 m³/hr. × 5 L/m³ = 15,000 Liter/ Hour Finally Flowrate is 15 m³/hr.

Recirculation pump Capacity:

Previously we Got Liquid Flowrate is 15 m³/Hr. so, requirement of Pump is Nearly 15-20 m³/Hr. then Total Dynamic Head is

$$\text{H}(\text{static}) + \text{H}(\text{friction}) + \text{H}(\text{pressure}) + \text{H}(\text{velocity})$$

Flowrate = 20 m³/Hr.

Static Lift = 6 m

Friction Loss = 4 m
Pressure Head = 2 m
Velocity Head = 1 m

Formulae:

$$H(\text{static})+H(\text{friction})+H(\text{pressure})+H(\text{velocity})$$

$$= 6 \text{ m} + 4 \text{ m} + 2 \text{ m} + 1 \text{ m}$$

$$H(\text{m}) = 13 \text{ m}$$

Consideration of Head is Nearly **15 meters**.

V. RESULTS & DISCUSSION:

Parameters	Result
Gas	Co2
Total Moles Generated (k. mole)	0.8874
Total Gas Generated (Kg)	19.890
NaOH Requirement For Neutralize (Kg)	17.48
CO2 Liberation in PPM	1203.086
Scrubber Diameter Required	850 mm
Liquid Flowrate	15 m3/hr.
Requirement of recirculation Pump	20 m3/Hr.
Requirement of Pump Head	15 meters

VI. REFERENCES:

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