A GUIDEBOOK ON PERFORMANCE MONITORING OF SCRUBBER

ENVIRONMENT INSTITUTE OF MALAYSIA (EiMAS)
DEPARTMENT OF ENVIRONMENT

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FOREWORD

Performance monitoring (PM) on air pollution control system (APCS) is a legal requirement under Regulation 9(b), of the Clean Air Regulations 2014 or in short, CAR. The PM is intended to ensure that the APCS are monitored in a systematic manner so that its function is always effective. In this regards, emphasis on preventive and corrective action of the APCS hardware will warrant the emission from APCS comply with emission standards of the regulations on a continuous basis.

The practices of performance monitoring by industry will mainstream environmental agenda into day to day tasks of the industry management and instil self-regulation culture and pride of environmental excellence and subsequently improves the industry's corporate image.

Thus, it is important for industry to have a good understanding on the overall processes of the APCS. With this understanding, the industry will also inculcate a sense of ownership and "do it right" in maintaining the APCS operation by conducting monitoring of process parameters at appropriate sampling locations and frequency. Hence, this guidebook is useful as quick reference guide for conducting **performance monitoring of scrubber**.

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Director General
Department of Environment, Malaysia
October 2015

IMPORTANT NOTICE

This document is intended only as a **quick reference/guide** for conducting performance monitoring of scrubbers by the industries. The Department of Environment assumes no responsibility for the accuracy, adequacy, or completeness of the concepts, methodologies, or protocols described in **this quick reference/guide book.** Compliance with the regulatory requirements and standards is solely the responsibility of the industries

CHAPTER 1 - INTRODUCTION

1. PURPOSE OF GUIDEBOOK

The main objectives of this guide book are:

a) As a quick reference/guide to interested parties/industries **in carrying out requirements of conducting** performance monitoring and preventive maintenance requirement of a pollution control system (scrubber). **under the Environmental Quality (Clean Air)** Regulations 2014 (CAR 2014); and

b) To standardize **procedures of performance** monitoring and preventive maintenance requirement of a pollution control system (scrubber) for easy inspection and reporting.

2. ADVANTAGES OF PERFORMANCE MONITORING (PM)

a. Helps detect early onset of deteriorating performance of the control system hence avoids unnecessary **plant shutdowns** and costly **enforcement penalties**;
b. Preventive maintenance procedure can specify action levels at which corrective actions are to be initiated; and
c. Act as acceptable surrogate to **stack emission testing** to gage compliance with emission standards.

2.1 Why PM?

a. Required by Regulation 9(b), of CAR (2014); and
b. All records shall be documented in standard format and kept for inspection for 3 years.

2.2 PM on Packed Tower

a. For this guidance, discussion would focus more on **scrubber type of packed tower**.
b. For other type scrubber the operator/owner of the industries is responsible to develop their own PM procedures with reference to:
    i. Key performance monitoring parameter for the types of scrubbers
    ii. Sampling and monitoring frequency and location of performance parameter.
    iii. Acceptable range of values for the parameter for optimal scrubber operation.

3 WHO IS RESPONSIBLE FOR CONDUCTING PM IN INDUSTRIES

a. Each factories/premises is required under Section 49AA, the Environmental Quality Act, 1974 to have a competent person in charge of each air pollution control system. The responsibilities of a competent person is given as below:

i. Conduct and submit timely reports to DOE and PMC as schedule/planned on:
    - performance monitoring (PM);
    - preventive inspections; and
    - changes to systems,

ii. Maintain records of activities as above for a minimum period of 3 years.

iii. Activate and supervise the running of Performance Monitoring Committee (PMS).

iv. Maintaining good working ethics and yearly status level of Continuous Professional Development (CDP).

CHAPTER 2 – SCRUBBER

4 WHAT IS SCRUBBER?

It is used to remove dust particles and gaseous contaminants from industrial exhaust streams either by acting as absorber (for gases removal) and/or wet collector (for particulate control)

4.1 Advantages of (Wet) Scrubber

- ✓ Small space requirements hence less capital cost;
- ✓ No secondary dust sources are required;
- ✓ Able to handle high-temperature, high-humidity gas streams;
- ✓ Minimal fire and explosion hazards; and
- ✓ Ability to collect both gases and particulate.

4.2 Disadvantages of (Wet) Scrubber

- ✓ Corrosion problems;
- ✓ High pressure drop and horsepower requirements
- ✓ Water-disposal problem
- ✓ Difficult product recovery
- ✓ Meteorological problems

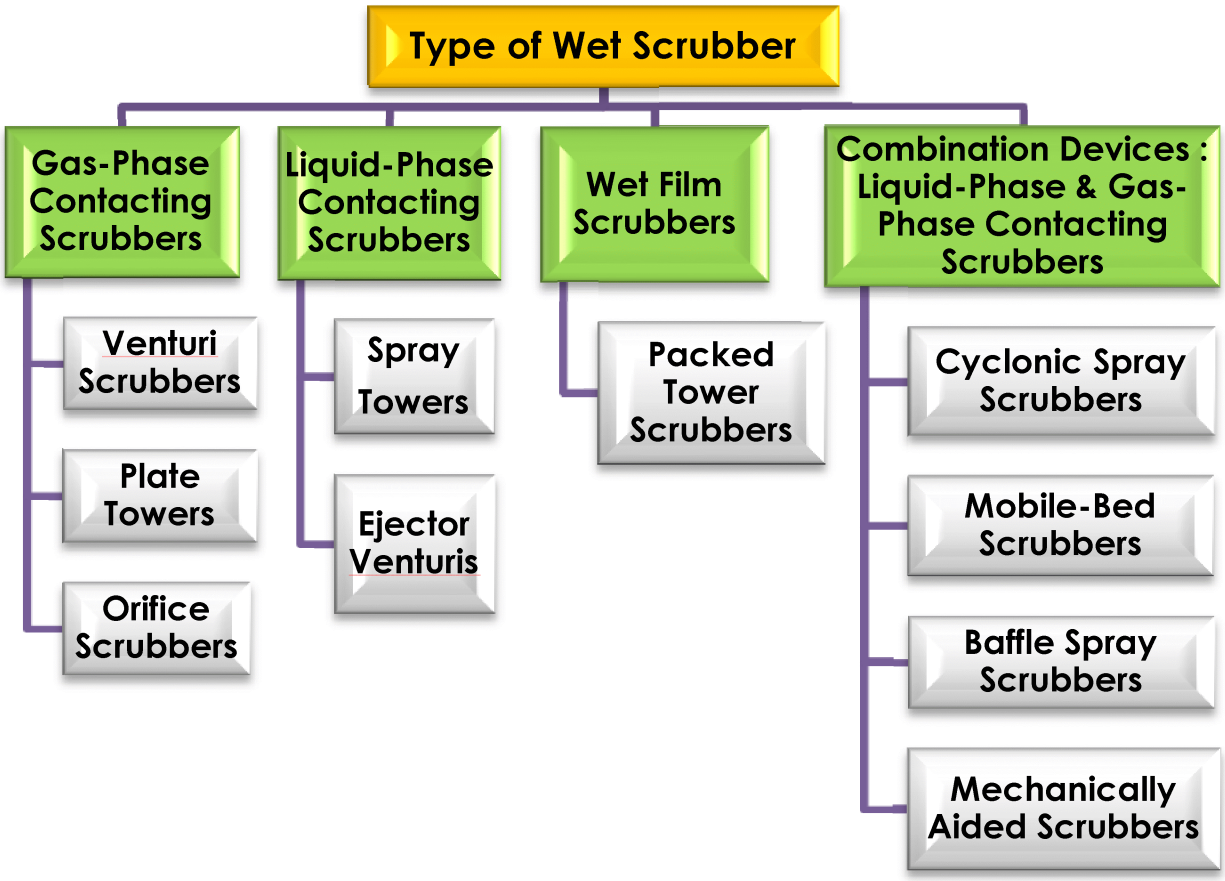
4.3 Types of Wet Scrubbers

a. Scrubbers can be classified by pressure drop as follows[1]:

- **Low energy scrubbers** (pressure drops: 0.5 – 2.5 in of water. (eg gravity spray tower)
- **Low-to-medium-energy scrubbers (**pressure drops: 2.5 – 6 in of water. (eg wet cyclonic)
- **Medium-to-high energy scrubbers** (pressure drops: 6 – 15 of water. (eg packed bed)
- **High-energy scrubbers** (pressure drops: >15 in of water. (eg venturi scrubbers)

b. Scrubber can also be categorized by energy source used for contact as **Figure 1** below. Details of each type of scrubber are as in **Appendix 1**[1 3]

Figure 1 : Type of Wet Scrubber (categorized by energy source used for contact)

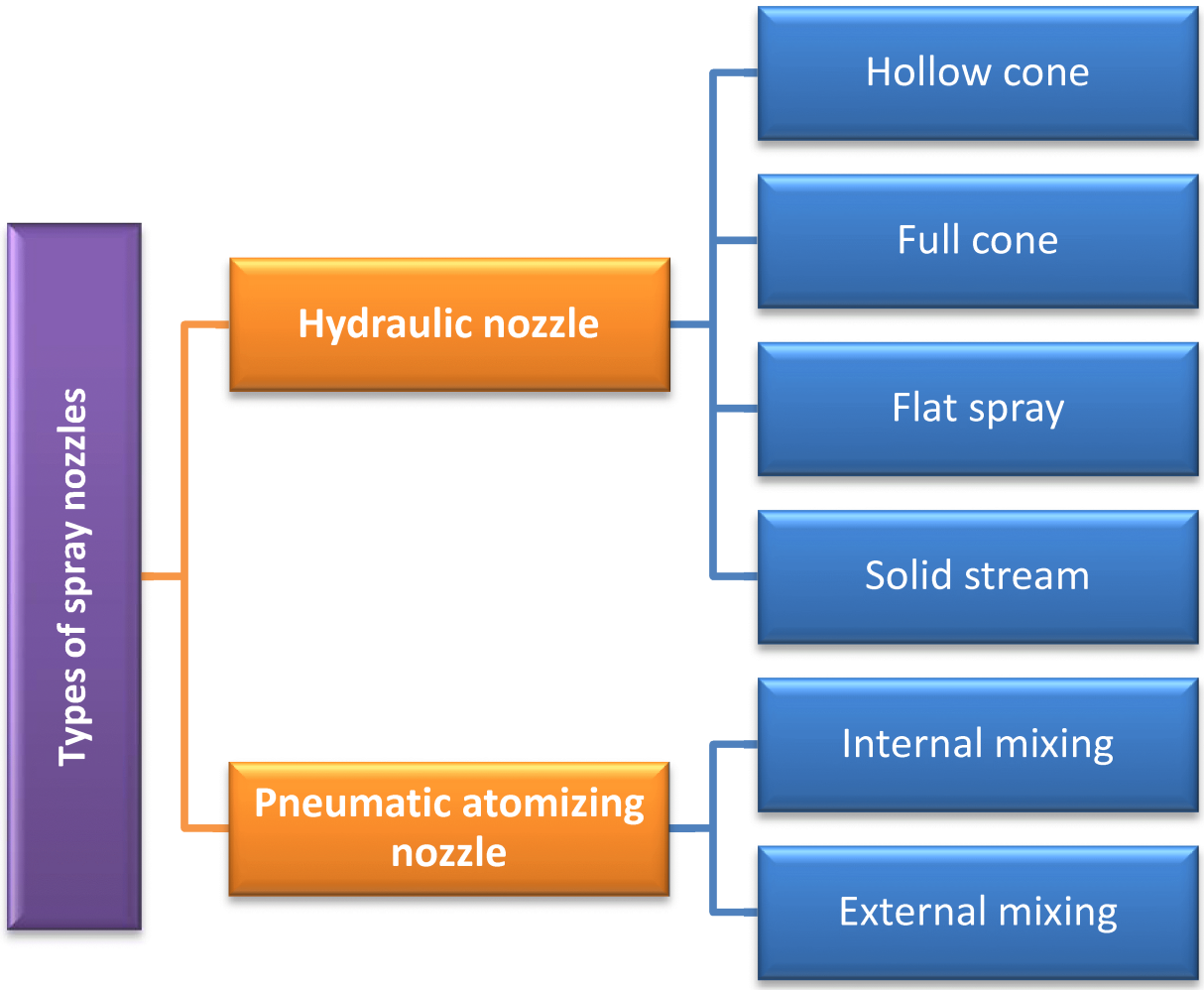


5 EQUIPMENTS ASSOCIATED WITH SCRUBBER SYSTEM

5.1 Spray Nozzle

- ✓ Generally, spray nozzles are used in scrubbing system to maximize the use of liquid by increasing the total surface area for better dispersion.
- ✓ Spray nozzles can be classified as **Figure 2** below. List of spray nozzles and the details as per **Appendix 2**

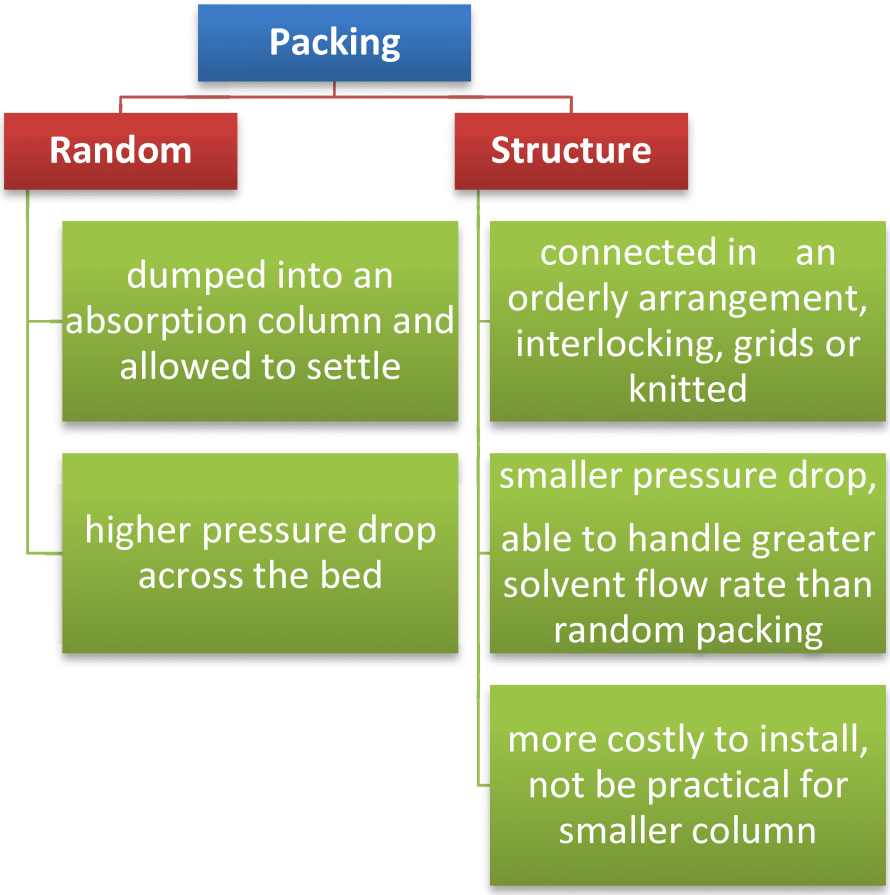
Figure 2 : Types of Spray Nozzles



5.2 Packing

- ✓ Provides the surface over which the scrubbing liquid flows, presenting a large area for mass transfer to occur.
- ✓ Packing can be classified as **Figure 3** below. Some of the various packing and application, the details as per **Appendix 3**.

Figure 3 : Types of Packing



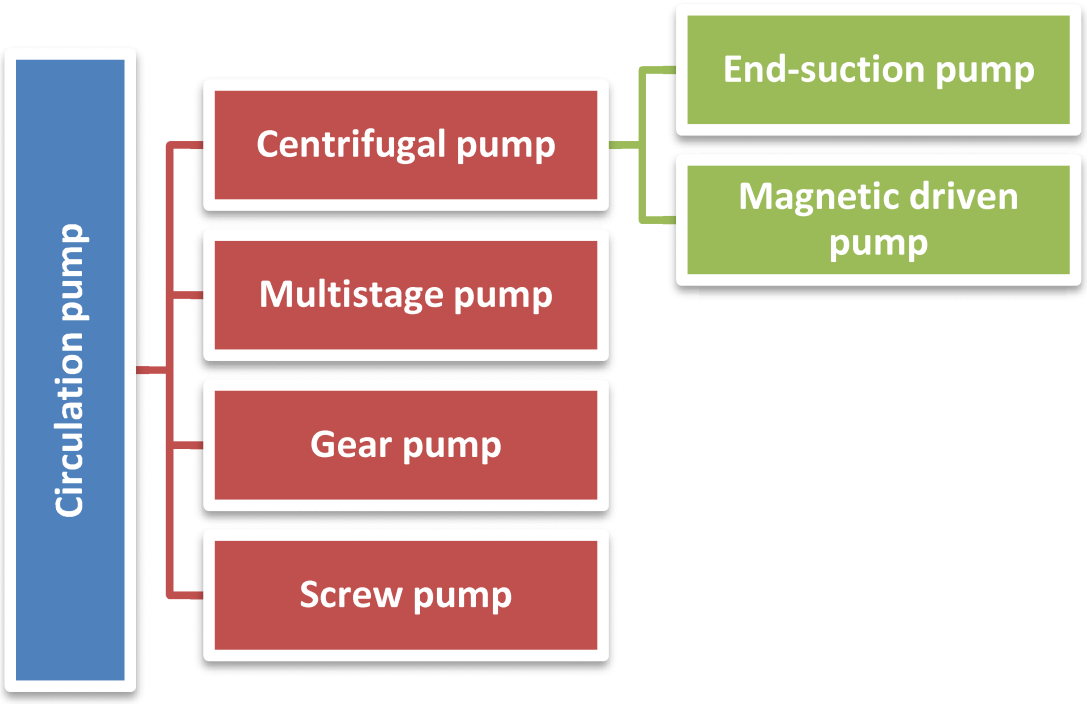
5.3 Water Circulation Pump

✓ Water circulation pump is used to transport either the water or scrubbing liquid and to be recycling back to the scrubber to continue the spraying process.

✓ Types of circulation pump as **Figure 4**. The details of each pumps as per **Appendix 4**

Figure 4 :

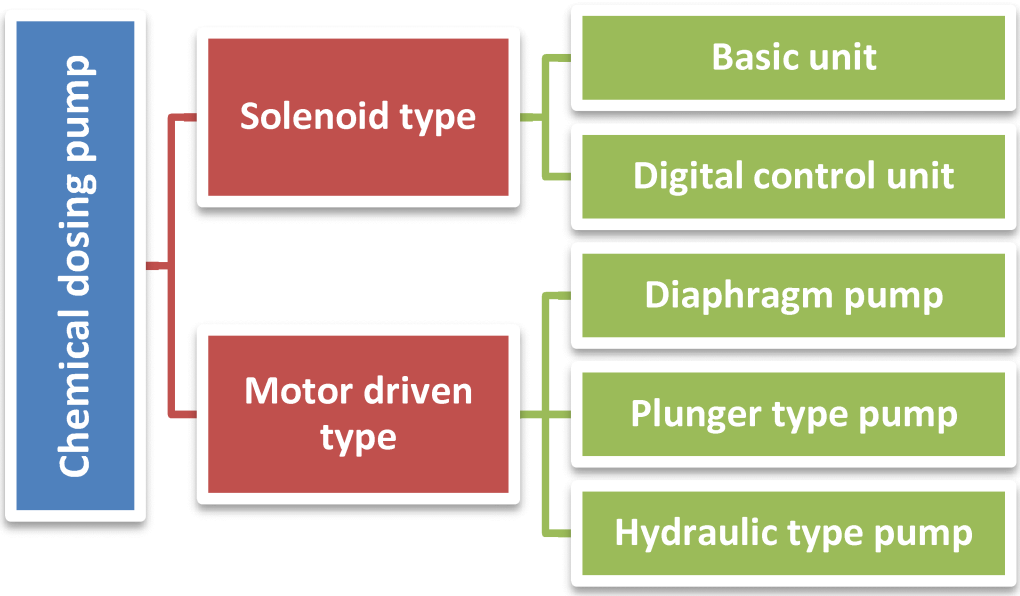
Types of circulation pumps



5.4 Chemical Dosing Pump

- ✓ Used to pump liquids at adjustable flow rates which are precise when averaged over time. Also known as metering pump
- ✓ Chemical dosing pump can be divided into two major types: solenoid type and motor drive type as **Figure 5.** The detail of each type as per **Appendix 5**

Figure 5 : Types of chemical dosing pump



5.5 Mist Eliminator

- ✓ Also known as entrainment separators and demisters.
- ✓ To remove the liquid droplets from the exit gas stream whether the droplets are present because of entrainment, re-entrainment, condensation or any other mechanism.
- ✓ Three (3) most common types of mist eliminator are
    - Mesh type
    - Vane type
    - Fiber type
- ✓ The detail of each types of mist eliminator as per **Appendix 6**

5.6 pH Sensor & Controller

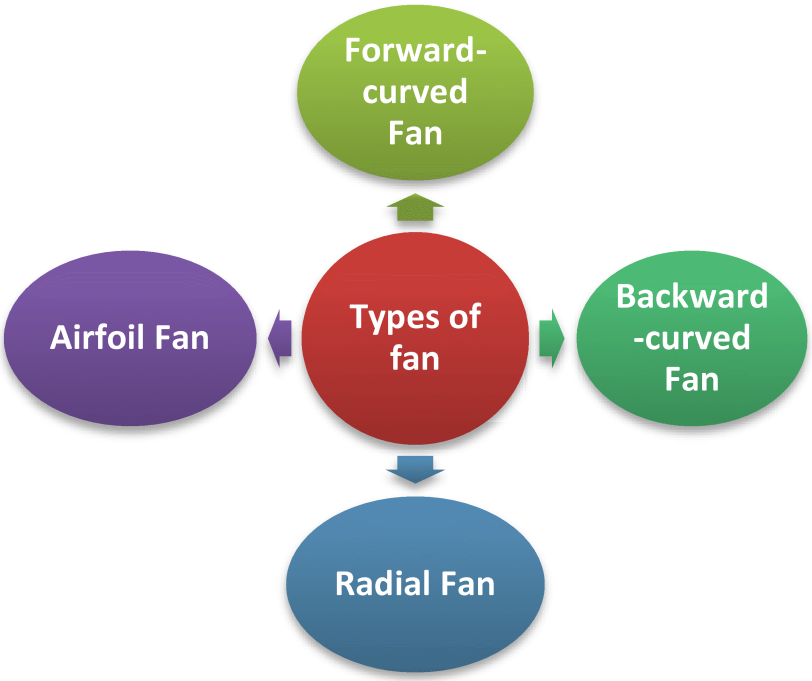
- ✓ The use of pH sensor in a scrubber system is to measure the water pH to prevent the water pH too high (too alkali) or too low (too acid). If the water is too acidic or too alkaline the scrubbing system will not work properly due to the absorption fail to occur.

5.7 Centrifugal Fan

✓ Fans in scrubbing system can be located before (also known as force-draft, positive-pressure, or dirty-side fans) or after the scrubber (also known as induced-draft, negative-pressure, or clean-side fans).

✓ Types of fan as per **Figure 6.** The detail of each types of fan as per **Appendix 7**

Figure 6 : Types of fan



5.8 Water Piping & Valve

- ✓ Pipes transport liquid to and from the scrubber.
- ✓ Valve is a device that regulates the flow of substances (either gases, fluidized solids, slurries, or liquids) by opening, closing, or partially obstructing various passageways.
- ✓ To prevent solids from building up in or plugging the pipe, a liquid slurry velocity in the scrubbing system of **1.2 to 2.1 m/s (4 to 7 ft/sec)** is recommended as a reasonable compromise.

5.9 Chemical Tank & Stirrer

- ✓ A chemical tank in a scrubbing system is used to store the circulating liquid and the use of stirrer is to make sure that the liquid inside the tank is balance.

5.10 Other Accessories

- ✓ **Table 1** summaries accessories equipment for wet scrubber

Table 1 : Other accessories for scrubber

Accessories	Notes
1 - Level Sensor 	✓ The used of the level sensor in the scrubbing system is to measure the level of the water in the water reservoirs and also the level of the chemical in the chemical storage tank.
2 – Pressure Gauge 	✓ A valve pressure gauge shall be provided within the scrubber recirculation plumbing between the pump discharge & the spray of each recirculation pump. ✓ Each gauge will be conveniently located to facilitate viewing from floor level. ✓ Pump discharge pressure at design operating parameters shall be displayed at mid-range of the gauge.

Accessories	Notes
3 – Flow meter 	✓ Each spray header shall include a rate indicating flow meter rated to operate at the mid-range of capability during design operating conditions. Each flow meter shall be independent. ✓ Each flow sensor will be constructed of a material capable of withstanding process chemicals and shall be of paddlewheel design. ✓ The flow meter display shall be mounted on the side of the scrubber with sufficient access to make conduit connections and repairs.

Accessories	Notes
4- Access Panels 	✓ Removable access panels for packing removal and spray nozzle maintenance shall be furnished. ✓ Transparent view ports to allow for inspection of packing and spray nozzles are also standard.
5 - Side View Windows 	✓ Viewing windows shall be supplied in each transition for visual inspection of the packing and the entrainment separator, between the packing and entrainment separator, between each spray header, and at each end of the spray chamber

Accessories	Notes
6 – Basket Strainer 	✓ A basket strainer shall be provided between the recirculation pump discharge and spray headers. ✓ The strainer will have a minimum 6 to1 ratio of open area through the strainer basket to the corresponding pipe cross-section. ✓ The basket strainer will include a threaded top for easy access, and a bottom clean-out plug. ✓ The cover-to-body seal will be an o-ring of material resistant to system present chemicals.

6 GENERAL OPERATIONAL PROCEDURE

A typical checklist procedure format before **start up**, **during start up** and for **shutdown** procedure of scrubber system is given in **Appendix 8.**

CHAPTER 3 – PERFORMANCE MONITORING

7 PERFORMANCE MONITORING OF SCRUBBERS

7.1 Preventive Maintenance Of Scrubber

i. **Table 2** summarizes preventive maintenance of wet scrubber (packed tower).

ii. **Appendix 9** summaries typical forms to record preventive maintenance on wet scrubber

Table 2 : Preventive maintenance of wet scrubber

Frequency	Procedure
Daily	• Check recycle water flow rate • Check scrubbing liquid pH value • Check discharge wastewater flow rate • Check discharge wastewater pH value • Check scrubber overall pressure drop • Check pressure drop across mist eliminator • Check pressure drop across packing • Check inlet & outlet temperature of gas stream • Check air flow rate • Check visually stack emission condition
Weekly	• Check recirculation pump discharge pressure • Check fan motor operating current • Check circulation pump motor operating current

Frequency	Procedure
Monthly	• Check fan vibration • Check pump vibration • Check pump / piping leakages • Check fan motor temperature • Check spray nozzles plugging or leaks • Check pump motor temperature
Semi-annually	• Inspect fan on material build-up
Half Yearly	• Inspect fan drive mechanisms, i.e. bearings, belt tensioning, grease level, etc. • Inspect mist eliminator for any solid build-up • Inspect packing for any fouling • Pump servicing – replace bearing, grease & mechanical seal (for end suction centrifugal pump).

Frequency	Procedure
Annually	➢ Verify accuracy of monitoring instruments and calibrate ➢ Inspect physical conditions of scrubber, i.e. housing, ductwork, etc. ➢ Overall system cleaning

7.2 Performance Monitoring Of Scrubber

At the minimum the parameter stated in **Table 3** must be monitored and kept in log book and made available to the DOE officers for inspection. Typical forms to record performance data on wet scrubber are depicted in **Appendix 10.**

Table 3 : Records of Performance Data

Performance Data	Notes
Pressure drop	To provide the most useful information, the pressure drop Should be monitored across **specific scrubber components** i.e. scrubber chamber and mist eliminator instead of across the entire scrubber body.
Temperature	The scrubber **inlet temperature** is monitored to prevent high inlet gas temperature. Inlet gas temperature higher than the design value could lead to excessive liquid evaporation resulting in damage to scrubber components. The scrubber **outlet temperature** is monitored to evaluate scrubber operation and to protect downstream equipment from excessive temperature. High outlet temperature may be indicative of poor liquid distribution or plugging of liquid inlet

Performance Data	Notes
Liquid flow rate	To ensure effective scrubbing, the **liquor feed rate** as well as the **water make up rate** should be monitored.
pH	Also for ensuring effective scrubbing, the pH of the chemical and scrubbing liquid **feed streams** and the **recycle liquor** systems should be monitored.
Stack emission condition	Visual observation on the stack emission condition should be recorded. The cause of abnormal change in emission condition should be pursued and understood.
Air flow rate	Pressure drop information cannot be interpreted properly unless flowrate information is known. The measurement of air flow rate is useful in identifying a developing leak in the ducting or in the scrubber itself.

* *There are also other monitored data should be considered to ensure effective scrubbing system such as fan current, fan rpm and chemical addition rate.*

8 MEASURING INSTRUMENTS USED TO MONITOR SCRUBBER PERFORMANCE

A monitoring system must be properly installed and maintained to provide reliable data. **Figure 7** illustrates the location of measuring instruments to monitor wet scrubber performance.

In the majority of scrubber operation, measuring instruments is installed directly on the air pollution control equipment, and there are also a premise had installing and connecting directly to a programmable logic controller (PLC). However there is a need to provide portable measuring instruments for the purpose of verifying the data recorded by automatic system.

Table 4 List the measuring instruments to monitor wet scrubber performance variables.

Figure 7 : Location Of Measuring Instruments To Monitor Wet Scrubber Performance

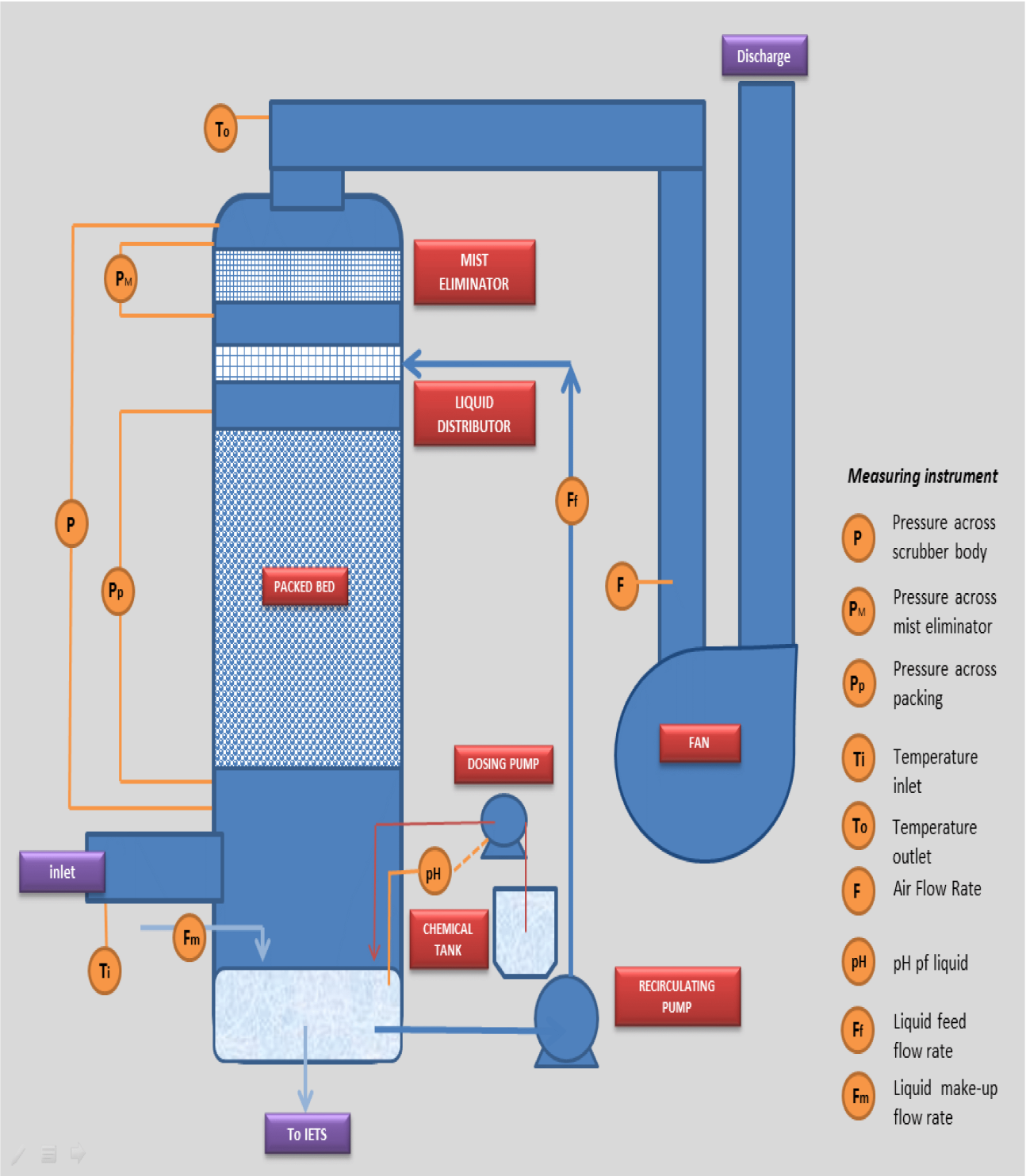
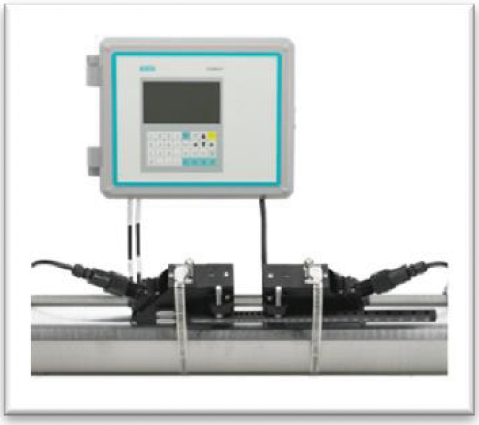


Table 4 : Performance Data and Measuring Instrument

Label (measuring location refer to Figure 7)	Performance Data (Unit)	Example of Measuring Equipment
P	Pressure drop of scrubber body (mm WG or inch WG)	 Magnehelic gauge
Pp	Pressure drop of packing (mm WG or inch WG)	
PM	Pressure drop of mist eliminator (mm WG or inch WG)	 U tube manometer

Label (measuring location refer to Figure 7)	Performance Data (Unit)	Example of Measuring Equipment
F	Gaseous flow rate (m^3/hour)	 Pitot tube and flow meter (portable)  Flow meter

Label (measuring location refer to Figure 7)	Performance Data (Unit)	Example of Measuring Equipment
Ff Fm	Liquid flow rate *(m^3/hour)*	 Rotameter / Water flow meter
Ti To	Temperature of gases (inlet and outlet) (Degree C)	 Thermometer

Label (measuring location refer to Figure 7)	Performance Data (Unit)	Example of Measuring Equipment
pH	pH of liquid	 pH meter (portable)  pH meter

Label (measuring location refer to Figure 7)	Performance Data (Unit)	Example of Measuring Equipment
	Fan Running Ampere (A)	 Clamp meter (portable)  Ammeter for fan at control panel

CHAPTER 4 – MAINSTREAMING OF SCRUBBER PERFORMANCE MONITORING AGENDA

9 RECORD KEEPING REQUIREMENT

Regulation 10, of the Clean Air Regulations (2014) require premises to maintain a record of production process, preventive maintenance and performance monitoring of air pollution control system. A record should be kept at least 3 years and be made available for inspection.

10 PERFORMANCE MONITORING DATA ANALYSIS AND INTERPRETATION

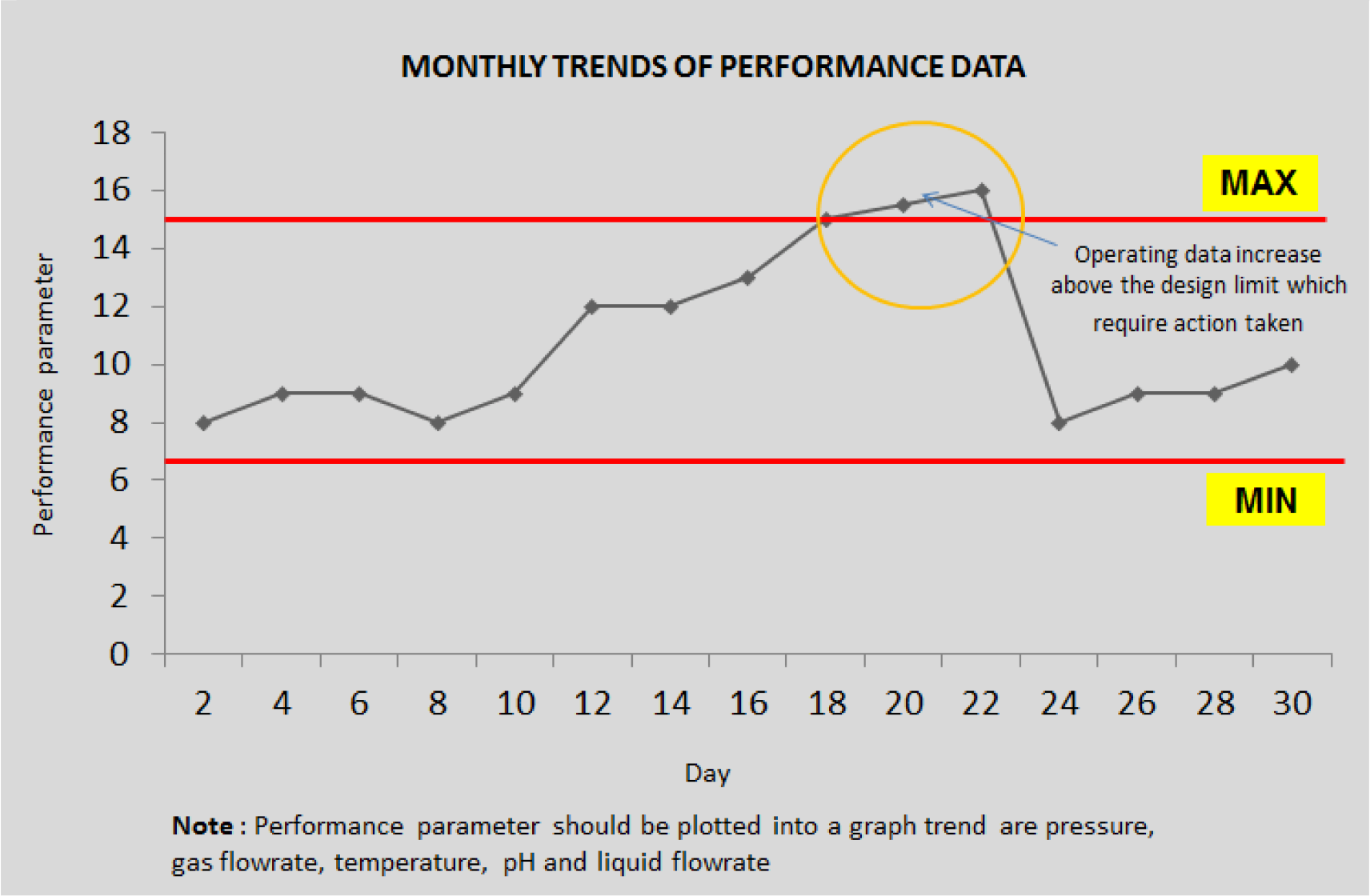
10.1 Advantages of data analysis

- ✓ can provide a very good indication of the performance of a dust collector.
- ✓ can aid in the detection of component deterioration in the bag filter system.

10.2 Performance daily data (pressure, temperature, air flow rate, compressed air pressure, opacity etc.) must be plotted into a graph trends and compare with the maximum and minimum operating limits for dust collector.

10.3 The analysis information must be provided on a monthly basis and reported to the Performance Monitoring Committee.

Figure 8 : Example of Monthly Trends of Performance Data



Note : Performance parameter should be plotted into a graph trend are pressure, gas flowrate, temperature, pH and liquid flowrate

11 ADDRESSING UPSET CONDITIONS

Any upset situation based on the daily performance monitoring data recorded or malfunction of air pollution control system must be attended to immediately. The corrective actions taken should be recorded in the relevant form as illustrated in **Appendix 11.**

For reference **Table 5** indicates the common troubleshooting problem associated with the operation condition of the wet scrubber.

Table 5 : List Of Problems, possible cause and possible solution

Common Cases		
Problem	**Possible Cause**	**Possible Solution**
Static pressure drop increases	Liquid flow rate to liquid distributor has increased and should be check	If the spray nozzle is used, its liquid pressure should be check as well as its condition. If a through-or weir type distributor is used, there should be little restriction on liquid flow rate through the unit.
	Packing in irrigated bed could be partially plugged due to solids deposition, and may require cleaning.	The packing should be clear periodically.

Common Cases		
Problem	**Possible Cause**	**Possible Solution**
	Mist eliminator could be partially plugged and may require cleaning.	Improve mist eliminator, clean mist eliminator and reduced the water flow rate and gas flow rate.
	Packing support plate at bottom of packed section could be plugged, causing increased pressure drop, which will require cleaning.	Required cleaning the packing and addition packing.
	Packing could be settling due to corrosion or solids deposition.	Cleaning or additional packing.

Common Cases		
Problem	**Possible Cause**	**Possible Solution**
	Airflow rate through absorber could have been increased by a change in damper setting, which may need readjustment	Check the damper setting
Pressure drop decreases, slowly, rapidly	Liquid flow rate to distributor has decreased accordingly.	If the spray nozzle is used, its liquid pressure should be check as well as its condition. If a through-or weir type distributor is used, there should be little restriction on liquid flow rate through the unit.

Common Cases		
Problem	**Possible Cause**	**Possible Solution**
	Airflow rate to scrubber has decreased or due to a change in system damper.	Check and adjust the system damper settings.
	Partial plugging of spray or liquid distributor, scrubber, could be occurring. Liquid distributor ensures that it is totally operable.	Liquid distributor should be inspected to ensure that it is totally operable.
	Packing support plate could have been absorbed, allowing packing to fall to bottom drop. This should be checked.	Checked the packing support.

Common Cases		
Problem	**Possible Cause**	**Possible Solution**
Pressure or flow change in recycled liquid causing reduced liquid	Plugged strainer or filter in recycle piping, which may require cleaning.	Require cleaning the plugged strainer or filter in recycle piping.
	Plugged spray nozzles, which may require cleaning.	The spray nozzles should be clear.
	Piping may be become partially plugged with solids and need cleaning.	An increase in the pipe velocity by decrease the diameter and flushed out with clean water on the yearly basis at a minimum.
	Liquid level in sump could have decreased, causing pump cavitation.	Check and make sure the fresh water flow work properly.

Common Cases		
Problem	**Possible Cause**	**Possible Solution**
High liquid flow	Break in the internal distributor piping.	Change the piping or used the high grade alloy.
	Spray nozzle that has been inadvertently "uninstalled".	Check and reinstalled the spray nozzles.
	Spray nozzle that may have come loose or eroded away, creating a low pressure drop.	Change a new spray nozzle.
	Change in throttling valve setting on the discharge side of the pump, allowing larger liquid flow; reset to the proper conditions.	Check the throttling valve settling on the discharge side of pump.

Common Cases		
Problem	**Possible Cause**	**Possible Solution**
Excessive liquid carryover	Partially plugged entrainment separator, causing channeling and re-entrainment of the collected liquid droplets.	Clean mist eliminator and increased the water flow rate and gas flow rate.
	Velocity through scrubber has decreased to a point that absorption does not effectively take place, and low removal is achieved.	Check the spray nozzles, it may be pluggage occur in it.

Common Cases		
Problem	**Possible Cause**	**Possible Solution**
	Airflow rate to scrubber could have increased above the design capability, causing re-entrainment. If a packed demister was used, and a sudden surge of air through the scrubber occurred, this could have caused the packing could be carry out of scrubber, creating an open area "hole" through scrubber.	Check the damper setting which may be adjusted. Check the damper setting which control the air flow rate.

Common Cases		
Problem	**Possible Cause**	**Possible Solution**
Reading indicating low air flow rate	Packing in scrubber may be plugged, causing a restriction to air flow.	Increasing the liquid flow rate which through the column or adding a strainer in the recycle liquid piping.
	Liquid flow rate to scrubber could have been increased inadvertently, again causing greater pressure drop, creating lower gas flow rate.	Check the circulation pump which pumping the liquid flow inside the scrubber.
	Ducting to or from scrubber could be partially plugged with solids.	Clean the ductwork.

Common Cases		
Problem	**Possible Cause**	**Possible Solution**
	Break and leak in duct could have occurred due to corrosion.	Change the duct or lining the duct with a corrosion-resistant liner.
Increased in airflow	Low liquid flow rate to scrubber.	Check the liquid distributor which may have plugged problem and check the bearing lubrication of the circulation pump to make sure the proper of oil is present.
	Packing has suddenly been damaged and has fallen to bottom of scrubber.	Change the packing and the packing support.

Common Cases		
Problem	**Possible Cause**	**Possible Solution**
Sudden decrease in scrubber efficiency	Liquid makeup rate to the scrubber has been inadvertently shut off or throttled to a low level, decreasing scrubber efficiency.	Check the liquid distributor which may have plugage problem and check the bearing lubrication of the circulation pump to make sure the proper of oil is present.
	Set point on pH control may have to be adjusted to allow more chemical feed.	Check the pH controller to make sure the setting of the set point is correct.
	Problem may exist with chemical metering pump, control valve, or line plugage.	Check the bearing lubrication for chemical metering pump.

Associated With The Ancillary Equipment		
Problem	**Possible Cause**	**Possible Solution**
Corrosion (detected at pump system, ductwork, piping, valve and etc)	Corrosive stream flow through the scrubber.	Used the high grade alloy as the material of constructions.
		Increase the amount of the chemical added to a scrubber system can help neutralize the recirculation stream and help preserve the equipment.
		Lining the duct or pipe with a corrosion-resistant liner.

Associated With The Ancillary Equipment		
Problem	**Possible Cause**	**Possible Solution**
Abrasion	Increment of the amount of particulate loading to be collected by the scrubber.	Installed a properly operation mechanical collector preceding the scrubber.
		Reduce the pipe velocity.
Pluggage (always occur on the recirculation system)	the pipe velocity are too low and it will promoting the settling, and may cause by a chemical reaction between the scrubbing liquid and gas pollutant, produce a solid compound.	Raising or lowering the pH. It is because if the pH of recirculation liquid is lower than the required then there may be have acid contaminants which cause pluggage occur in system.
		Increase in the pipe velocity by

Associated With The Ancillary Equipment		
Problem	**Possible Cause**	**Possible Solution**
		decreasing the pipe diameter may help flushed out with the clean water.

Pump		
Problem	**Possible Cause**	**Possible Solution**
Insufficient flow rate or no flow generated	Wrong rotation	Interchange two of the phases of power supply cable.
	Impurities at suction, discharge or impeller	Check strainer/foot valve and suction line for clogging. Check delivery pipe.
	Pipe connection leakage.	Reseal the leaking part.

Pump		
Problem	**Possible Cause**	**Possible Solution**
	Pump or pipe not completely vented or primed.	Vent or prime.
	Air pocket in piping.	Alter piping layout.
		Fit vent valve.
	Defective check valve under parallel operation.	Replace or install check valve.
	Back pressure higher than design.	Replace new pump.
		Fit larger impeller.
	Wear of internal parts	Replace the worn out parts
Pump leaking	Mechanical seal damaged	Replace the mechanical seal.
	Tie bolt / o-ring gasket damaged.	Tighten the bolts / replace o-ring and gasket.

Pump		
Problem	**Possible Cause**	**Possible Solution**
Vibration during operation	Pump or pipe not completely vented or primed	Vent and/ primed.
	Pump back pressure is lower than design	Throttle isolating valve on delivery
		Change new pump of lower pumping head.
	Mist-alignment of pump, motor coupling.	Re-align.
	Possible causes	Possible solution
	Base not firmly fixed.	Check the level and tighten the base screws.
	Defective pump or motor bearing	Fit new bearings.
	Pipe vibration	Check pipeline

Pump		
Problem	**Possible Cause**	**Possible Solution**
		connection and if required, reduce the distance between the pipe clamps.
	Rotor is out of balance.	Clean the impeller.
		Rebalanced the motor.
	Wrong rotation.	Interchange two of the phases of power supply cable.
Motor is overloaded	Back pressure to pump is lower than design.	Reduce impeller size if applicable.
		Adjust isolated valve on delivery-line.
		Change new pump of lower pumping head.

Pump		
Problem	**Possible Cause**	**Possible Solution**
	Wears of internal pumps parts.	Replace the worn out parts.
	Density or viscosity of the pump's liquid than stated.	Check the specific liquid density or viscosity.
		Replace higher kW motor.
	Speed is higher than design	Reduce pump impeller size.
	Motor is running on two phases only.	Replace defective fuse.
		Check electric cable connection.
	Defective pump / motor bearing	Fit new bearings.
	Low input voltage	Check input voltages

Pump		
Problem	**Possible Cause**	**Possible Solution**
Increase in bearing temperature.	Pump-motor assembly is mist-aligned.	Align the pump motor coupling
		Replace higher kW motor.
	Bearing lubricant excess or insufficient.	Reduce, refill or use the adequate lubricant according to specification.
	Incorrect clearance at the coupling sleeve.	Adjust to the correct clearance.
	Defective bearing.	Replace new bearing.
	Increase axial thrust.	Correct rotor adjustment.

Pump		
Problem	**Possible Cause**	**Possible Solution**
Pump does not run smoothly (noise, vibration etc)	Air drawn in at pipe inlet and/or cavitations.	Correct suction condition.
		Reduce flow velocity at suction inlet, increases suction head.
		Check integrity of suction pipe and seal if necessary.
	Shaft is defective.	Replace the shaft.
	Impeller rubs against casing component.	Check rotor.
		Check impeller position
	Back pressure on pump is lower than design.	Throttle isolating valve on deliver line.
		Change new pump of lower pumping head.

Pump		
Problem	**Possible Cause**	**Possible Solution**
Loss of chemical residual	Pump setting too slow.	Adjust higher setting (pump must be operating during the stroke length adjustment).
	Solution container allowed run dry.	Refill the tank with solution and prime.
Too much chemical	Pump setting too high.	Lower pump setting (pump must be operating to adjust stroke length knob).
	Chemical in solution tank too rich.	Dilute chemical solution. (Note: for chemical that reacts with water, it may be necessary to purchase a more dilute grade of chemical from chemical supplier.)

Spray Nozzle		
Problem	**Possible Cause**	**Possible Solution**
Increase in flow rate	Surface of the orifice, internal vane, or core of a nozzle begin to deteriorate.	Inspecting nozzles on a regular basis Installed automatic or manually operated brushes that clean nozzle orifices and headers. Periodic testing of nozzles
Variation in Spray Pattern	Orifice damage or clogging	
Increase in Spray Drop Size	Nozzle orifices wear or corrode	
Changes in Spray Impact	Nozzles with worn orifices	

Fan		
Problem	**Possible Cause**	**Possible Solution**
Airflow rate low, pressure high	System resistance to flow too high	Check to make sure all dampers or inlet vanes in the system are open.
		Check for foreign material in the ductwork or hoods. Is the duct transport velocity high enough ?
		Check to make sure the system was installed as designed. Were extra nonessential duct fittings or ductwork added ?
		Increase the fan speed. Use the fan laws to calculate the new speed and power requirements

Fan		
Problem	**Possible Cause**	**Possible Solution**
Airflow rate low and fluctuating, pressure high or low and fluctuating	System resistance to flow too high – fan install	Check for the cause of the high system resistance per the above (changing fan speed usually will not solve stall problems)
		It may be necessary to use a differently designed impeller – check with the fan manufacturer
		Do not operate axial fans under these conditions for extended periods
Airflow rate low, pressure low	Fan speed too low	Increase the fan speed
	System effects	Redesign the ductwork to eliminate system effects

Fan		
Problem	**Possible Cause**	**Possible Solution**
		Add flow straighteners, turning vanes, or straight sections of duct to minimize the system effect
Airflow rate low, pressure low	Centrifugal fan impeller rotating in the wrong direction	Change the rotation to the proper direction
	Axial fan blade angle too low	If the impeller is an adjustable type, adjust the blades to a higher angle of attack. Keep all the blades set to the same angle
		If the angle is not adjustable, replace the impeller with one with a higher angle

Fan		
Problem	**Possible Cause**	**Possible Solution**
Airflow rate high, pressure low	System resistance to flow too low	Check for access or cleanout doors that are left open
		Check for missing or broken filters
		If the filters are new, the flow may be correct once the filters become seasoned, but the filters may become blinded if the flow rate is excessive
Airflow rate high, pressure high	Fan speed too high	Reduce the fan speed
	Actual air density higher than design air density	Select a new fan speed based on the actual air density

Fan		
Problem	**Possible Cause**	**Possible Solution**
Airflow in the wrong direction	Axial fan impeller rotating in the wrong direction	Change the rotation to the proper direction
Power consumption high	Fan speed high	Reduce the fan speed
	System resistance too low – centrifugal fan impeller with radial or forward-curved blades	Increase the resistance to flow or reduce the fan speed
	Inlet duct configuration cause the air entering the fan to spin in direction	Redesign the ductwork to eliminate system effects

Fan		
Problem	**Possible Cause**	**Possible Solution**
	opposite of impeller rotation	
Motor overload, protection trips before the fan reaches full speed	Inertia (WR2) of the impeller at or above the motor's inertia load capacity	Use time delay or slow trip motor protection. It is not uncommon for fans with across the line starts to take 20s to get to full speed
		Use a soft starting method (auto-transformer, wye-delta, etc.) to bring the motor up to speed more slowly
		If a variable frequency drive is being used, adjust the drive to a longer acceleration time

Fan		
Problem	**Possible Cause**	**Possible Solution**
Excessive vibration levels	Fan not adequately supported	Make sure all bearing bolts, motor bolts, and fan mounting bolts are tight
		Make sure the structure supporting the fan is rigid
		Stiffen the support structure if necessary
Excessive vibration levels	Impeller out of balance	Clean off the buildup of foreign materials
		Check for cracked welds. Repair the welds or replace the impeller
		Check for excessive wear or other damage on the impeller.

Fan		
Problem	**Possible Cause**	**Possible Solution**
Excessive noise	Impeller or shaft rubbing against the fan housing	Adjust the position of the impeller in the housing by moving or shimming the bearings
		Adjust the position of the inlet
	Defective bearings	Replace the bearings

12 PERFORMANCE MONITORING COMMITTEE (PMC)

a. There must be a formal and permanent committee established within the industry to monitor the scrubber performance on a continuous basis. This committee is commonly known as the performance monitoring committee (PMC). The members of PMC should comprise senior management personnel of the industry from various relevant departments.

b. Through this committee the results of the performance monitoring activities are presented, reviewed and discussed. Monthly trends of performance data plotted in graph and corrective action taken should be presented to committee for improvement discussion.

c. Key industrial personnel from relevant departments are directly involved in scrubber operation issues are jointly responsible for ensuring regulatory compliance so that the company business plans can progress without hitches due to noncompliance issue.

d. The record date of the meeting and the reports presented to the committee **shall be kept** for inspection by DOE. The conduct of PMC meetings is mandatory for CePSO to maintain their registration with the DOE in the National Registry of Certified Environmental Professionals (NRCEP).

e. Example of monthly status report of scrubber performance monitoring for PMC meeting is given in **Appendix 12.**

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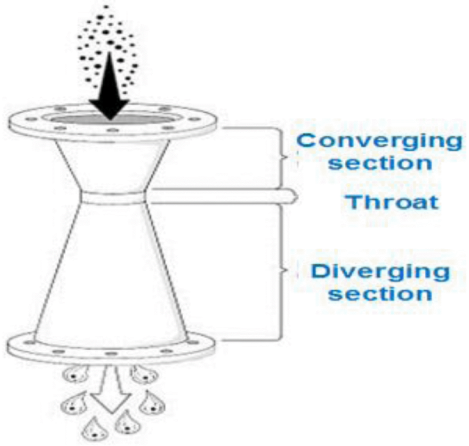
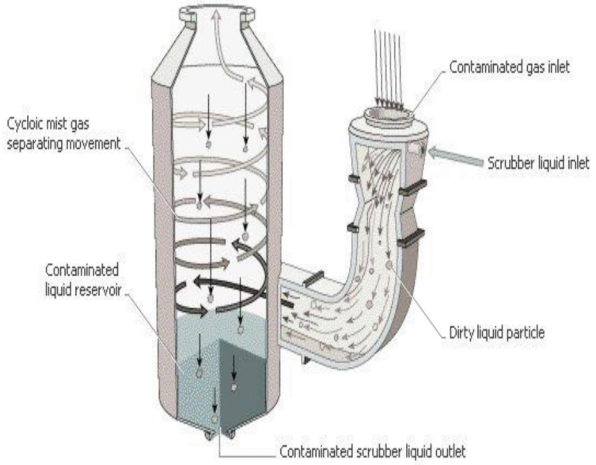
2. American Conference of Governmental Hygienists. 1992. *Industrial Ventilation A Manual of Recommended Practice*. 21st Ed. Cincinnati, OH; American Conference of Governmental Hygienists Inc.
3. C. David Cooper & F.C Alley. 2011. Air Pollution Control – A Design Approach. 4th Ed. Long Grove, Illinois; Waveland Press Inc.
4. Gerald T. Joseph & David S. Beachler. 1998. *Scrubber System Operation Review – APTI Course SI:412C*. 2nd Ed. Raleigh, NC; North Carolina State University
5. Department of Environment Malaysia. 2006. Technical Guidance On Performance Monitoring Of Air Pollution Control Systems. DOE-APCS-5.
6. Department of Environment Malaysia. 2014. Course Module on Certified Environmental Professional In Scrubber Operation; CePSO, EiMAS

APPENDIX 1

VENTURI SCRUBBER



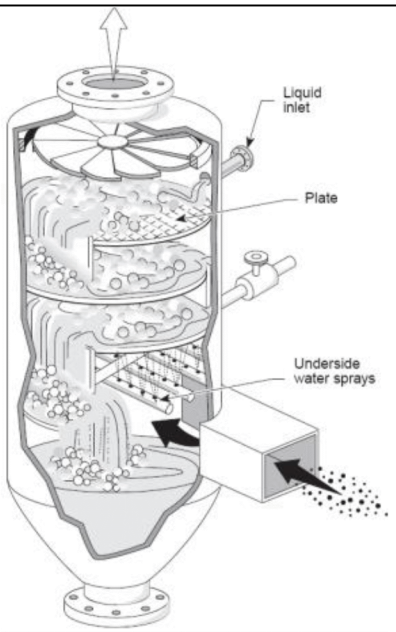


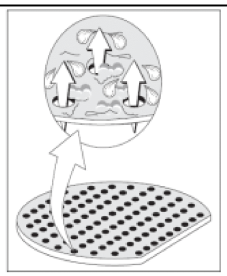
Operating characteristic of venturi scrubbers

Pollutant	Pressure Drop (ΔP)	Liquid to gas ratio (L/G)	Liquid inlet pressure (P_L)	Removal effieciency (%)
Gases	5 – 100 in. of water	2.7 – 5.3 L/m^3	<7-100kPA	30-60% per venture depending on pollutant solubility
Particles	20 – 100 in. of water 20 – 60 in. of water is common	0.4 – 2.7 L/m^3		90-99% is typical

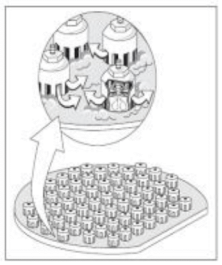
APPENDIX 1

PLATE TOWER SCRUBBER

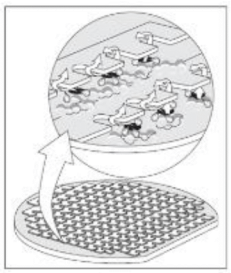




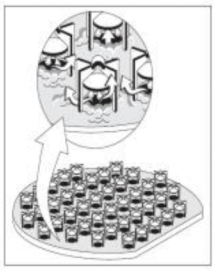
Sieve plate



Impingemet plate



Bubble cap plate



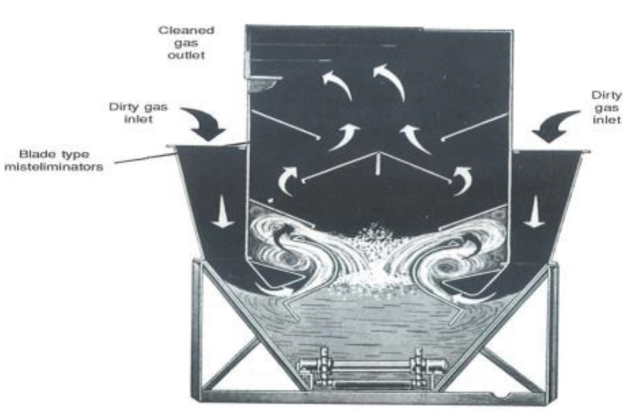
Valve plate

Operating characteristic of plate towers

Pollutant	Pressure Drop (ΔP)	Liquid to gas ratio (L/G)	Liquid inlet pressure (P_L)	Removal effieciency (%)
Gases	1 - 8 in. of water per tray Normal pressure drops 3 in. of water	0.7 – 2.0 L/m^3	<34.5 kPA	Very effective (>98%) depending on the solubility of the gaseous pollutant
Particles		0.3 – 0.7 L/m^3		Particles diameter >1.0 µm

APPENDIX 1

ORIFICE-TYPE SCRUBBER



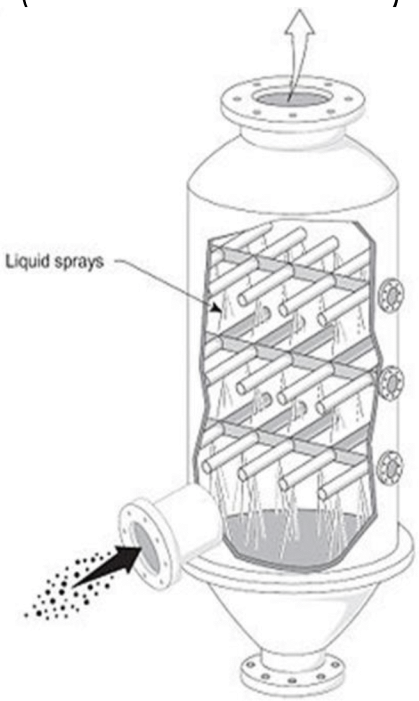
Operating characteristic of orifice scrubbers

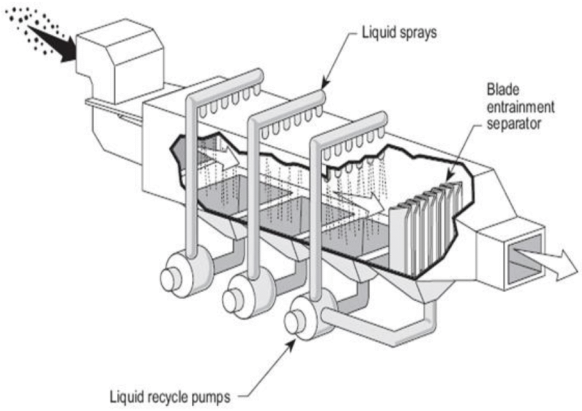
Pollutant	Pressure Drop (ΔP)	Liquid to gas ratio (L/G)	Liquid inlet pressure (P_L)	Removal effieciency (%)
Gases	2 – 10 in. of water	0.07 – 0.7 L/m^3	Not applicable (nozzles are not used)	Limited to very solubale gases or reactive scrubbing
Particles		1.3 – 5.3 L/m^3		Particles diameter 0.8 - 1 µm

APPENDIX 1

SPRAY TOWERS

Spray Tower (countercurrent flow)





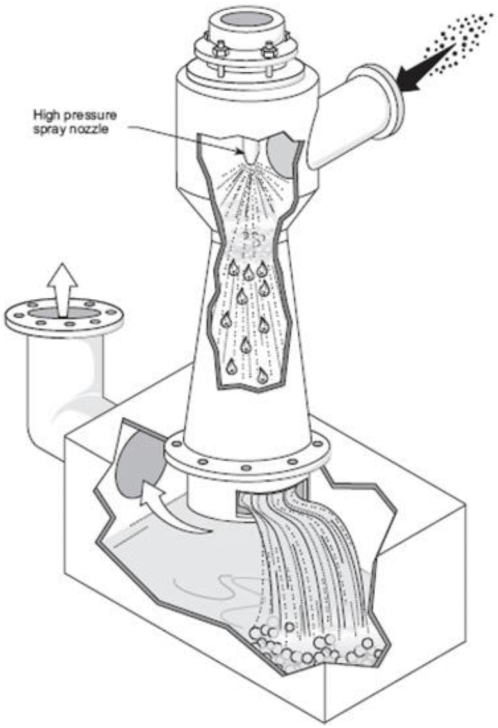
Spray Tower (cross-flow)

Operating characteristic of spray towers

Pollutant	**Pressure Drop (ΔP)**	**Liquid to gas ratio (L/G)**	**Liquid inlet pressure (P_L)**	**Removal effieciency (%)**
Gases	0.5 – 3.0 in. of water	0.07 – 2.7 L/m^3 (0.5-20 $gal/1000ft^3$) (6 $gal/1000ft^3$ is normal; >10 when using spray pressure)	70 – 2800 kPA	50-90% (high efficiency only when the gas is very soluble
Particles				Particles diameter 2.8 µm

APPENDIX 1

EJECTOR VENTURIS

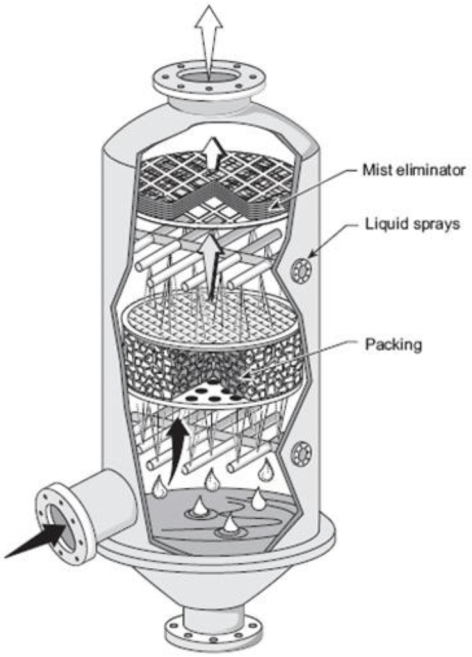


Operating characteristic of ejector venturis

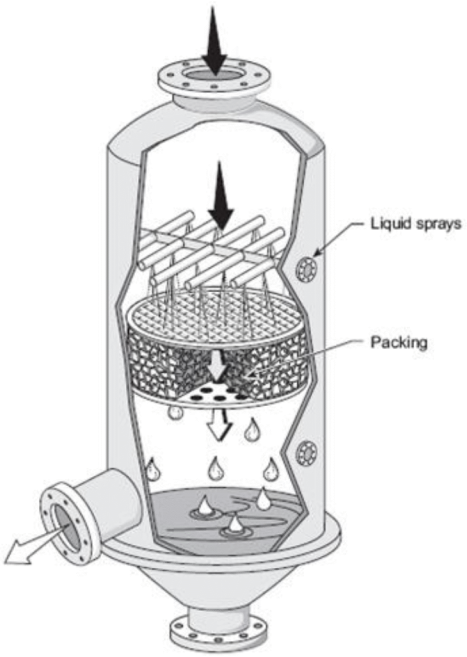
Pollutant	Pressure Drop (ΔP)	Liquid to gas ratio (L/G)	Liquid inlet pressure (P_L)	Removal effieciency (%)
Gases	0.5 - 5 in. of water	7 - 13 L/m^3	100-830 kPA	95% for very soluble gases
Particles				Particles diameter 1 µm

APPENDIX 1

PACKED TOWER SCRUBBERS



Packed Tower (countercurrent flow)



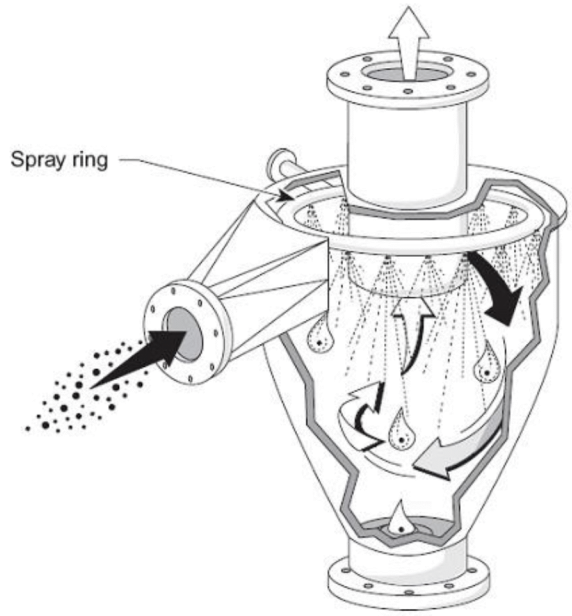
Packed Tower (cocurrent flow)

Operating characteristic of packed column scrubbers

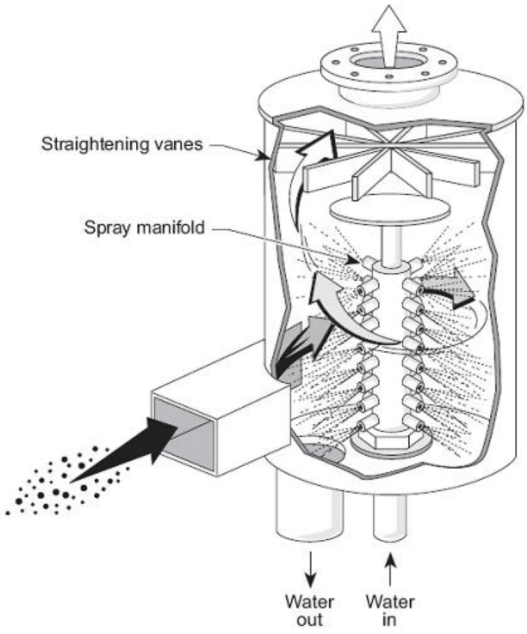
Pollutant	**Pressure Drop (ΔP)**	**Liquid to gas ratio (L/G)**	**Liquid inlet pressure (P_L)**	**Removal effieciency (%)**
Gases	0.25 - 1 in. of water/ft of column packing	0.13 – 2.0 L/m^3	34 - 100 kPA	Very high 99% depending on operating conditions
Particles				Particles diameter 2 µm

APPENDIX 1

CYCLONIC SPRAY SCRUBBER



Irrigated Cyclone Scrubber



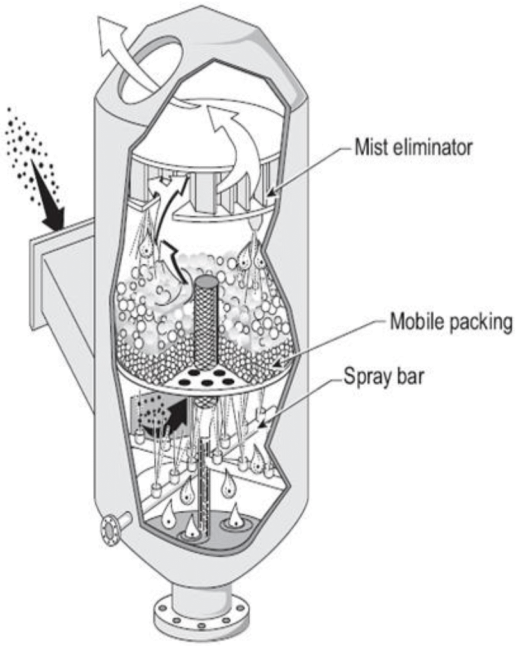
Cyclonic spray scrubber

Operating characteristic of cyclonic spray scrubbers

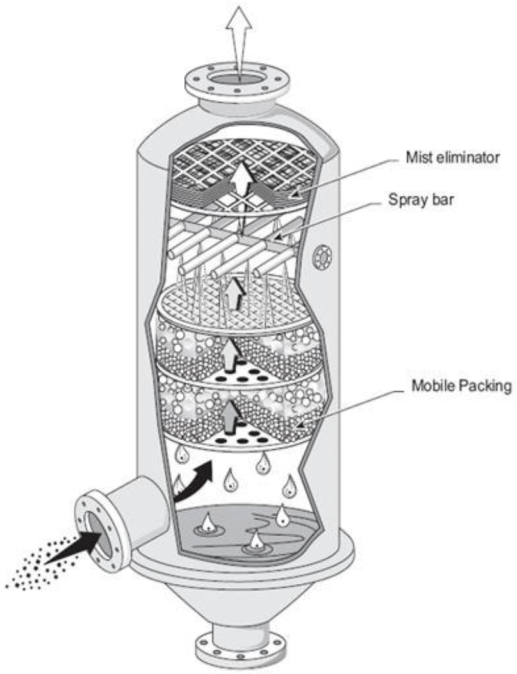
Pollutant	**Pressure Drop (ΔP)**	**Liquid to gas ratio (L/G)**	**Liquid inlet pressure (P_L)**	**Removal effieciency (%)**
Gases	1.5 10 in. of water/ft of column packing	0.3 – 1.3 L/m^3	280 - 2800 kPA	Only effective for very soluble gases
Particles				Particles diameter 2-3 µm

APPENDIX 1

MOBILE BED SCRUBBERS



Flooded mobile bed scrubbers



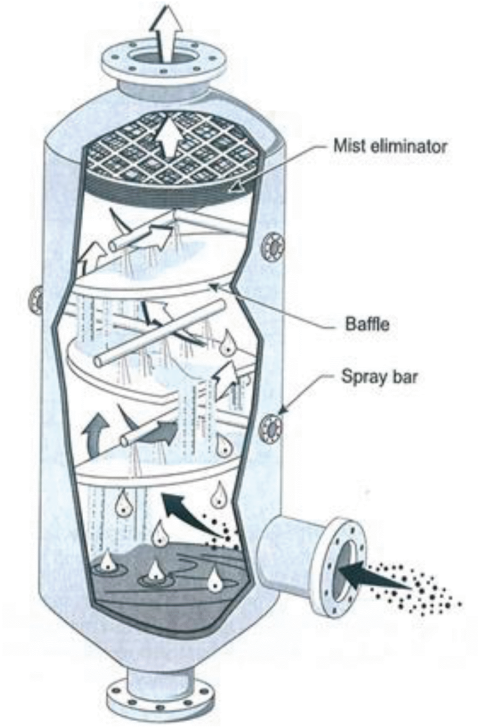
Fluidized bed scrubber

Operating characteristic of mobile bed scrubbers

Pollutant	Pressure Drop (ΔP)	Liquid to gas ratio (L/G)	Liquid inlet pressure (P_L)	Removal effieciency (%)
Gases	2 - 6 in. of water per stage	2.7 – 8.0 L/m^3	-	99% of theoretical
Particles		0.4 – 0.7 L/m^3		Particles diameter 2-3 µm

APPENDIX 1

BAFFLE SPRAY SCRUBBER

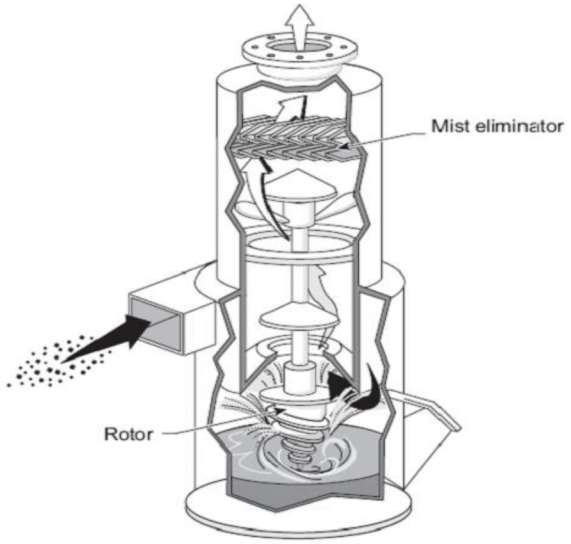


Operating characteristic of baffle spray scrubbers

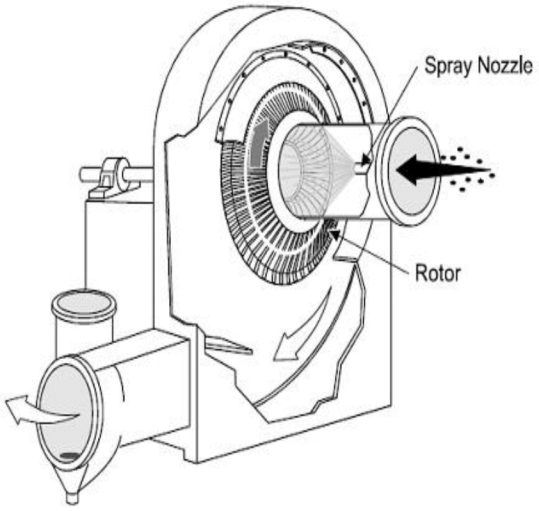
Pollutant	**Pressure Drop (ΔP)**	**Liquid to gas ratio (L/G)**	**Liquid inlet pressure (P_L)**	**Removal effieciency (%)**
Gases	1 – 3 in. of water	0.13 L/m^3	< 100 kPA	Very low
Particles				Particles diameter 10 µm

APPENDIX 1

MECHANICALLY-AIDED SCRUBBERS



Induced spray scrubber



Centrifugal fan scrubber

Operating characteristic of mechanically added scrubbers

Pollutant	**Pressure Drop (ΔP)**	**Liquid to gas ratio (L/G)**	**Liquid inlet pressure (P_L)**	**Removal effieciency (%)**
Particles	4.0 – 8.0 in. of water	0.07 – 0.2 L/m^3 (centrifugal)	20-60 psig (centrifugal)	Particles diameter > 1 µm
		0.5 - 0.7 L/m^3 (spray rotor)		

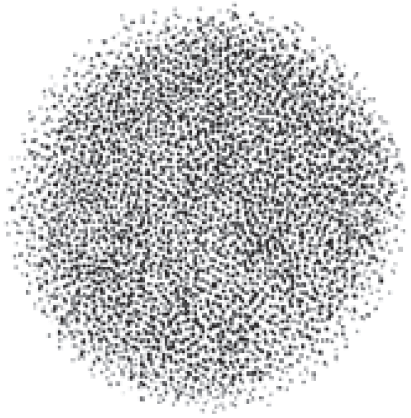
APPENDIX 2

LIST OF SPRAY NOZZLES CLASSIFIED BY PATTERN TYPE

1 - Hollow cone spray patterns

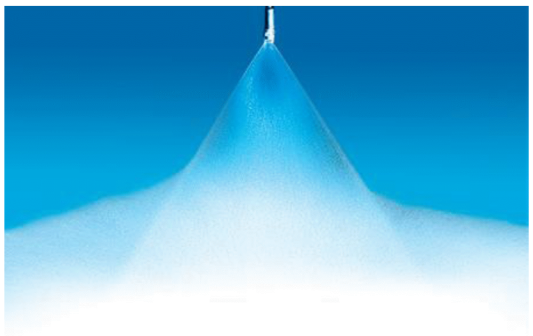
- Most common method is involving a single inlet orifice that exits tangential into a cylindrical swirl chamber that is open at one end with a circular orifice exit having a diameter substantially smaller than the swirl chamber at the other end.
- This simple type of nozzle design has many desirable characteristics; including large free passages for a given nozzle size that result in a relatively high resistance to clogging.
- Tend to provide the smallest drop size distributions obtainable among hydraulic spray styles.
- The relative range of drop sizes tends to be narrower than other hydraulic styles.
- The volume flux resulting from hollow cone sprays is concentrated, as one would expect, in an annular ring.

2 - Full cone nozzle patterns



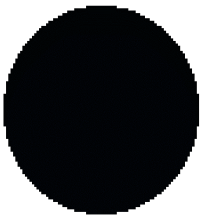
- Liquid is swirled within the nozzle and mixed with non spinning liquid that bypasses the swirl element, or "vane"
- Liquid then exits through an orifice, forming a conical pattern.
- Spray angle and liquid distribution within the cone pattern depend on the vane design, location relative to the exit orifice, the exit orifice design and the relative geometric proportions of all of these elements.
- The free passage through this type of nozzle is limited by the vane element.
- Probably the best overall general-purpose full cone design style because the liquid distribution can be customized through proper design of the components.
- The characteristic drop size distribution for this design is larger than the hollow cone style and the range of drop sizes is the widest of the hydraulic types.
- Most extensively used style in industry.

3 - Hydraulic flat spray



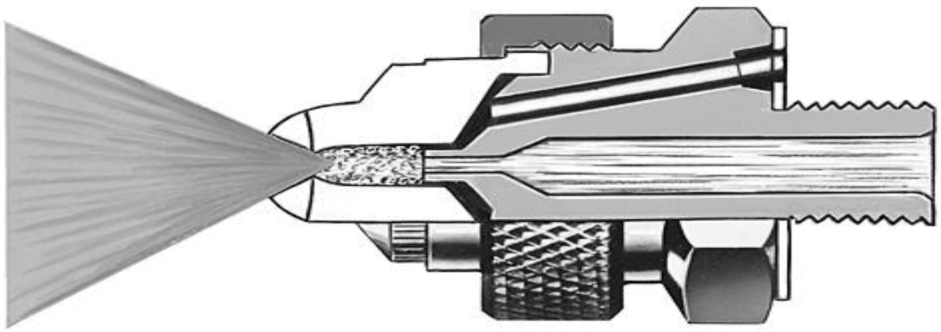
- The most commonly produced by spraying a solid stream onto a profiled deflector surface or by intersecting an angled or profiled external groove with a contoured internal cylindrical radius geometry.
- The later style results in an elliptical ("cat's eye") orifice shape when viewed end-on.
- The elliptic orifice style flat spray nozzles can be designed to provide a wide variety of liquid distribution characteristics and have been successfully applied with or without spray overlap in many applications.
- The use of internal elements such as pre-orifices can be incorporated into the basic elliptical orifice design to provide thicker sprays or to modify the drop size and velocity characteristics.
- Drop size response is between that of hollow cone and full cone hydraulic sprays for a given size nozzle

4 - Hydraulic solid stream spray pattern



- by using proper inlet chamber proportions and contours ahead of the orifice and/or by addition of internal flow stabilizing vanes, these nozzles provide prolonged solid stream integrity and delay breakup and drop formation after leaving the nozzles orifice.

5 - Internal mix pneumatic atomizers



- It is capable of producing fine drop sizes with a very narrow range of sizes.
- Drop size is much smaller than that produced by basic hydraulic atomizers at normal operating pressures.
- The liquid delivery rates and airflow consumption of internal mix nozzles can be quite sensitive to small changes in applied inlet pressures.
- Studies show that process rates for a given amount of liquid are far in excess of those attainable with simple hydraulic nozzles due to small, uniform drop sizes.
- The spray pattern is normally either flat or conical.

6 - External mix pneumatic nozzles

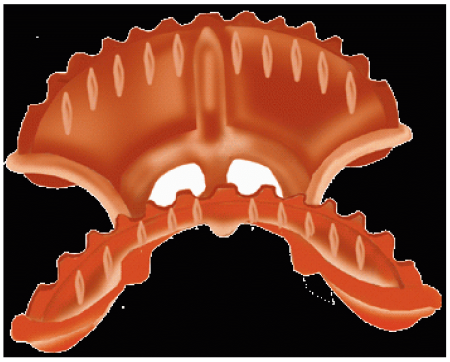
- Function by impacting a stream of liquid with a series of strategically placed air jets that break up the liquid and form a spray pattern that is usually conical or flat.
- Drop sizes and ranges are typically larger than internal mix styles, and they are most often used in situations where the material being sprayed is very thick or would otherwise clog the inside of an internal mix type nozzle.
- Liquid flow is not really affected by changes in gas pressure applied, which could allow for less complex process control systems.
- In this sense, external mix pneumatic nozzle function is much the same as hydraulic nozzles.
- The external mix styles are not often used in continuous caster applications.
- Control systems for air atomizing systems are more complex than those of hydraulic systems.
- Operational costs are higher as well.
- Compressed gas that is used by the nozzles consumes energy at high rates and generally has a high capital cost associated with implementation.
- The nozzles are more expensive than simpler hydraulic types.
- Maintenance and implementation costs for a pneumatic system are typically higher than for hydraulic nozzle systems, as well.

APPENDIX 3

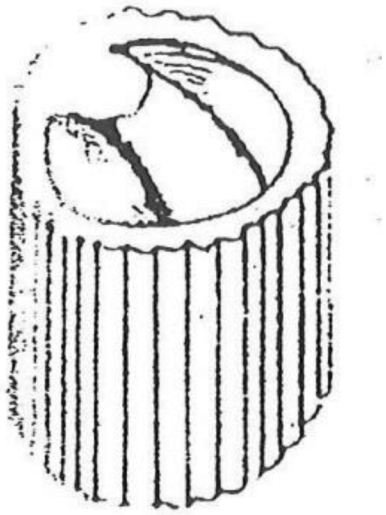
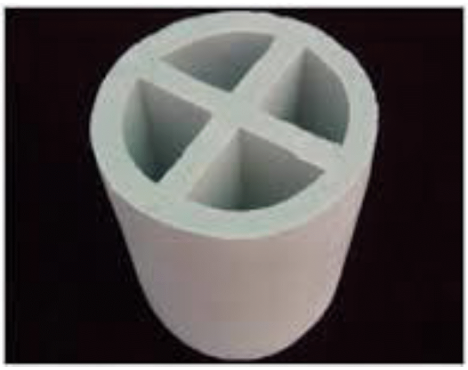
LIST OF PACKING AND APPLICATION

Packing	Application feature
Raschig ring 	✓ Most popular type ✓ cheaper per unit cost but sometime less efficient than others ✓ Available in widest variety of materials to fit service. Very sound structurally. ✓ Usually packing by damping wet or dry, with larger 4 to 6 in. size sometime had stacked. ✓ Usually has more internal liquid channeling and directs more liquid to walls of column.
Berl saddles 	✓ More efficiency than Raschig ring in most application, but more costly. ✓ Packing nests together and creates "tight" spots in bed which promote channeling but not as much Raschig rings. ✓ Do not produce much side hrust and have lower unit pressure drops with highest flooding point than Raschig ring. ✓ Easier to break in bed than Raschig rings.

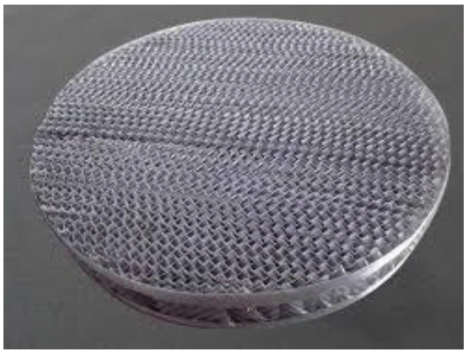
APPENDIX 3

Packing	Application feature
Intalox saddles 	✓ One of the most efficient packing, but more costly. ✓ Very little tendency or ability to nest and block areas of bed. ✓ Gives fairly uniform bed. ✓ Higher flooding limit and lower pressure drop than Raschig rings or berl saddles. ✓ Easier to break in bed than Raschig rings
Pall rings 	✓ Lower pressure drop (less than half) than Raschig rings. ✓ Higher flooding limit. ✓ Good liquid distribution, high capacity. ✓ Considerable side thrust on column wall. ✓ Available in metal, plastic and ceramic.
Teller rossette (tellerette) 	✓ Available in plastic. ✓ lower pressure drop, higher flooding limit than Raschig rings or Berl saddles. ✓ Very low unit weight, low side thrust. ✓ Relatively expensive.

APPENDIX 3

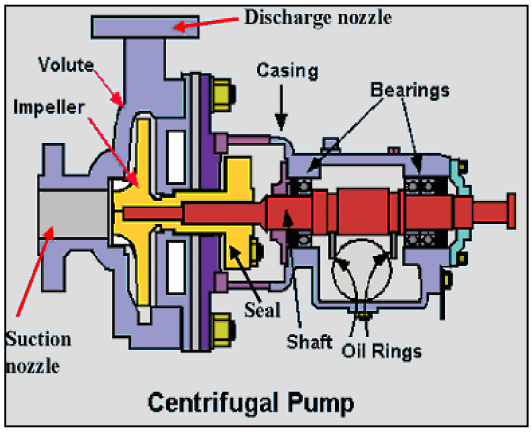
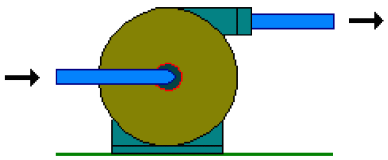
Packing	Application feature
Spiral rings 	✓ Usually installed as stacked, taking advantage of internal whirl of gas-liquid and offering extra contact surface over Raschig rings. ✓ Lessing rings, or cross-partition rings, available in single, double, and triple internal spiral designs, higher pressure drop, wide variety of performance data not available.
Cross-partition rings 	✓ Usually used stacked, and as first layers support grids for smaller packing above ✓ Pressure drop relatively low, channeling reduced for comparative stacks packing ✓ No side wall thrust
Lessing rings 	✓ Not many performance data available, but in general slightly better than Raschig rings ✓ Pressure drop slightly higher; high side wall thrust

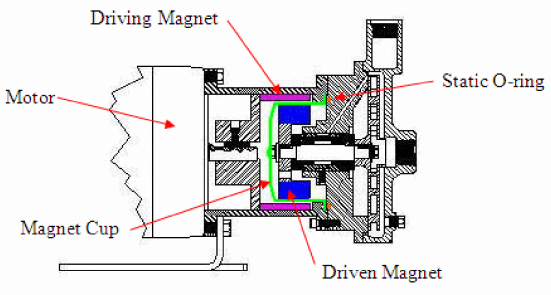
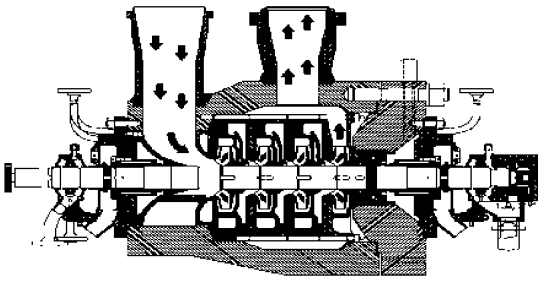
APPENDIX 3

Packing	Application feature
Ceramic balls 	✓ Tend to fluidize in certain operating range ✓ Self-cleaning, uniform and structured ✓ Higher pressure drop, and better contact efficiency than Raschig rings ✓ High side thrust
Goodloe packing and wire mesh packing 	✓ Available in metal only ✓ Used in large and small columns for distillation, absorption, scrubbing, liquid extraction ✓ High efficiency ✓ Low pressure drop

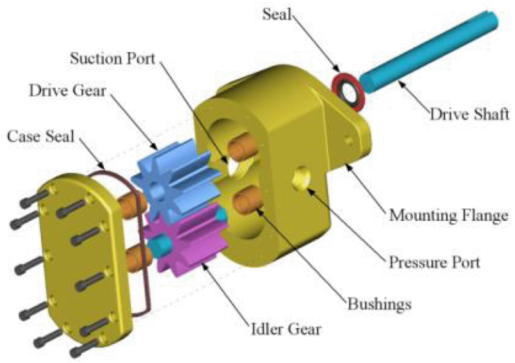
APPENDIX 4

LIST OF CIRCULATION PUMPS

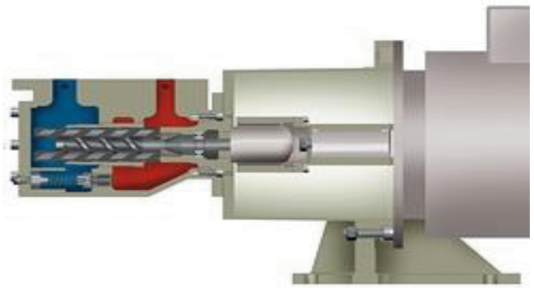
TYPES OF CIRCULATION PUMPS	NOTES
1 – Centrifugal Pump  Centrifugal Pump	✓consists of a set of rotating vanes, enclosed within a housing or casing, used to impart energy to a fluid through centrifugal force. ✓the pump has two main parts: a rotating element which includes an impeller and a shaft, and a stationary element made up of casing (volute or solid), stuffing box, and bearings.
1(a) End suction pump 	✓ The most common centrifugal pump. ✓ Shaft is used to transfer energy from the motor to the impeller. ✓ The most common shaft materials are high carbon steel and stainless steel. ✓ Each shaft is supported by bearings which must support loads along the shaft. ✓ The energy is transferred from the shaft to the impeller and from the impeller to the liquid.

TYPES OF CIRCULATION PUMPS	NOTES
1(b) Magnetic driven pump  	✓ Use a standard electric motor to drive a set of permanent magnets that are mounted on a carrier or drive assembly located outside of the containment shell. ✓ The drive magnet assembly is mounted on a second shaft which is driven by a standard motor. ✓ The external rotating magnetic field drives the inner rotor. ✓ A magnetic force field is established between the north and South Pole magnets in the drive and driven assemblies.
2 – Multi stage pump 	✓ A multistage pump has two or more close impellers housed toget her in one casing. ✓ Each impeller usually acts separately, discharging to the suction of the next-stage impeller. ✓ It can create high pressure to transfer clean liquid.

APPENDIX 4

TYPES OF CIRCULATION PUMPS	NOTES
3 – Gear pump  	✓ Use gear teeth, lobes, or vanes to trap a fixed volume of fluid and carry that fluid via a rotary motion from the inlet to the outlet of the pump. ✓ Two meshing gears rotate in a closed cavity with a close clearance maintained between the gear teeth and the pump casing. ✓ Fluid is captured between each tooth and the casing at the inlet port and carried to the outlet port. ✓ By maintaining very accurate volumes between the teeth and low leakage rates between the tooth and casing, the gear pump can be a very accurate metering pump. ✓ Flow control is easily achieved by controlling the rotational speed of the gears.

APPENDIX 4

TYPES OF CIRCULATION PUMPS	NOTES
4 – Screw pump 	✓ The liquid is carried between the screw threads on one or more rotors. ✓ The liquid is then displaced axially as the screws rotate and mesh. ✓ Applications include utilities fuel oil service, industrial oil burners, lubricating oil service, chemical processes, petroleum and crude oil industries, power hydraulics.

APPENDIX 5

LIST OF CHEMICAL DOSING PUMP

<table>
<tr><th colspan="2">1- Solenoid type metering pump</th></tr>
<tr><td>Basic unit
  </td><td>Digital control unit
  </td></tr>
<tr><td>Consists of an adjusting dial which can be used for manually adjustment for different flow rate required (0-100% of maximum capacity for each pump)</td><td>Consists of a digital panel meter
➢ Injection amount can be enters directly. This eliminates conversions and ensures reliable injection.
➢ There are three types of injections
I. Batch injection
II. Proportional injection
III. On-off injection</td></tr>
</table>

2 – Motor Driven Metering Pump

2(a) Diaphragm pump

- ✓ A rotary drive motor converts the rotary action of the drive shaft into an oscillating movement of a connecting rod, which in turn transmits its motion to the diaphragm. In combination with inlet and exhaust valves, this diaphragm motion produces the pumping or metering action.
- ✓ Commonly used in chemical plants (scrubber), water treatment and sterilization

2 – Motor Driven Metering Pump

2(b) Plunger type pump

- ✓ Reciprocating motion of the plunger coupled to the drive piston by a proprietary universal joint transmits volumetric changes to the inside of the cylinder to suck in and feed liquid.
- ✓ The universal joint drastically extends the service life of seals
- ✓ Create very high pressure (up to 200 bar)
- ✓ High capacity
- ✓ Easy maintains but higher maintenance and grinding machine.

2 – Motor Driven Metering Pump

2(c) Hydraulic type pump

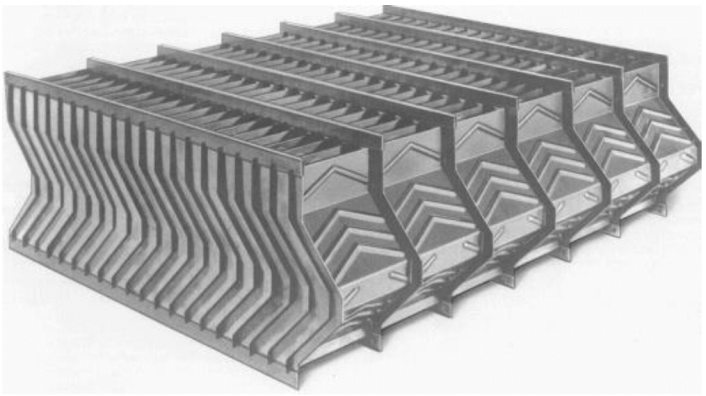
- ✓ Fixed amount of liquids are transferred by hydraulic pressure generated by the piston to cause reciprocal motion of the diaphragm.
- ✓ Create high pressure, high capacity
- ✓ High precision injection achieves stable quality on production.
- ✓ Transfer of liquid containing slurry and hazardous liquid.
- ✓ Cheapest, bigger, but need more maintenance.

APPENDIX 6

LIST OF MIST ELIMINATOR

Mist Eliminator
1 – Mesh type 
✓ In the most familiar application of knitted mesh, the crimped strips are stacked to form a pad with typical thickness of four or six inches. ✓ Rigidity is provided by a frame (usually metal) consisting of a grid on each side and rods passing through the mesh. ✓ Pads larger than about 3 ft across are fabricated in sections narrow enough to pass through a manway for assembly inside a vessel. ✓ Mesh pads can be made in almost any shape, but most are round or rectangular.

APPENDIX 6

Mist Eliminator
2 – Vane type 
✓ Also known as chevron or plate type, vane mist eliminators consist of closely spaced corrugated plates that force mist-laden gas to follow serpentine paths. ✓ Not efficient for mist droplets smaller than about 20 microns, but they are sturdier than mesh pads and impose less pressure drop. ✓ Vane arrays can be mounted horizontally or vertically. ✓ They are preferred in applications involving high vapor velocities, low available pressure drop, viscous or foaming liquids, lodging or caking of solids, slugs of liquid or violent upsets. ✓ Vane units are usually round or rectangular. ✓ They are sometimes used in combination with mesh pads for optimum performance in special situations.

Mist Eliminator

3 – Fiber type

- ✓ Fiber mist eliminators can capture mist droplets so small (below 1 micron) that they appear as smoke or nearly invisible haze.
- ✓ These units employ fine fibers (typically cellulose, glass, or plastic) packed into a mat with thickness of a few inches.
- ✓ Fiber mist eliminators are mostly used in cylindrical form called candles but are also available in flat panels.

APPENDIX 7

LIST OF FAN TYPE

Type	*Description*
1 - *Forward-curved Fan* 	✓ Use blades that are curved towards the direction of the wheel rotation. ✓ Blades smaller ✓ Space closer together ✓ Not usually used if the flue gas contains dust or stick material. ✓ Used for heating, ventilating, and air-conditioning applications ✓
2 - *Backward-curved Fan* 	✓ Use blades that are curved away from the direction of wheel rotation. ✓ Used on the clean-air discharge of air pollution control device or provide clean combustion air for boilers.

APPENDIX 7

Type	*Description*
3 - *Radial Fan* 	✓ Use straight blades that are attached to the wheel of the motor. ✓ Built for high mechanical strength ✓ Easily repaired
4- *Airfoil Fan* 	✓ Use thick tear drop-shaped blades that are curved away from the wheel rotation.

APPENDIX 8

CHECK LIST BEFORE START-UP

Equipment		Remark
Utilities	Incoming power supply	Verify proper power to control panel
	Incoming water supply	Verify proper water supply connection to the scrubber
	Wastewater discharge piping	Verify overflow & drain piped properly
Mist Eliminator	Installation	Inspect mist eliminator for proper installation
Packing	Installation	Verify packing height installed
Spray nozzles	Installation	Verify spray nozzles installed & tightened
Pumps	Pump Rotation	Verify correct rotation of pump
	Installation	Check for leaks, vibration & unusual noise
	Lubrication	Verify pump greased prior to start-up

APPENDIX 8

Equipment		Remark
	Discharge pressure gauge	Verify water pressure gauge properly installed & operational
	Electrical interlock	Verify proper wiring connection to motor
Piping/ fittings	Installation	Verify duct bolts are tightened
	pH sensor / controller	Verify pH sensor properly installed & operational
	Water flow meter	Verify water flow meter properly installed & operational
Fan	Electrical interlock	Verify proper wiring connection to motor
	Installation	Check for vibration & unusual noise
	Fan rotation	Verify correct rotation for fan
	Lubrication	Verify fan motor greased prior to start-up

APPENDIX 8

CHECK LIST DURING START-UP

No	Procedures	Remarks
1	Open the water supply valve and check for leaks. Ensure that the wastewater drain is open.	
2	Fill scrubber sump or remote tank with freshwater until water begins to overflow.	
3	Start pump.	
4	Adjust spray pattern to minimize spray hitting side wall of scrubber.	
5	Immediately check stack discharge. If excessive misting is observed shut system down immediately and consult factory.	
6	Adjust ducting dampers to produce desired flow rate. Begin at suction point furthest from exhaust fan and work towards fan. Measure velocity with Pitot tube and average readings.	
7	Check to see that water flow is set to required value (GPM). Water flows below this rate cause solids break-through in the scrubber exhaust line.	
8	The unit should operate quietly and vibration free. The bearings and shaft should be warm to the touch. If not, see the troubleshooting section.	
9	Be certain that the inlet temperature have reached operating temperature prior to introducing process chemicals to the scrubber. High startup purge rates delay the heating process.	
10	Check to see that all valves are open between the scrubber and the central exhaust.	

APPENDIX 8

CHECKLIST FOR SHUT DOWN PROCEDUCES

No	Procedures	Remarks
1	Switch off the fan and isolate the scrubbing system from operation	
2	Allow the liquid system to operate for as long as practical. This will cool the scrubber and will reduce scrubbing liquid slurry concentrations	
3	Purge scrubber for 10 minutes.	
4	Turn off purge gas.	
5	Close valve between scrubber and central exhaust.	
6	Turn off scrubber power.	
7	Turn off water.	
8	Disconnect power before control box is opened.	

APPENDIX 9

TYPICAL FORM TO RECORD PERFORMANCE DATA OF SCRUBBER (PREVENTIVE MAINTENANCE)

(B) WEEKLY

Month : _____ Year : _____

Date	Procedure	Notes	Entries by Operator			Checked by Supervisor		
			Name	Sign	Date	Sign	Name	Date
	Check recirculation pump discharge pressure Check fan motor operating current Check circulation pump motor operating current							

APPENDIX 9

(C) MONTHLY

Month : _____ Year : _____

Date	Procedure	Notes	Entries by Operator			Checked by Supervisor		
			Name	Sign	Date	Sign	Name	Date
	Check fan vibration Check pump vibration Check pump/ piping leakages Check fan motor temperature Check pump motor temperature Check spray nozzles plugging or leaks							

(D) SEMI ANNUALLY

Month : _____ Year : _____

Date	Procedure	Notes	Entries by Operator			Checked by Supervisor		
			Name	Sign	Date	Sign	Name	Date
	Inspect fan on material build up.							

(E) HALF YEARLY

Month : _____ Year : _____

Date	Procedure	Notes	Entries by Operator			Checked by Supervisor		
			Name	Sign	Date	Sign	Name	Date
	Inspect fan drive mechanisms, i.e. bearings, belt tensioning, grease level, etc. Inspect mist eliminator for any solid build-up.							

APPENDIX 9

Date	Procedure	Notes	Entries by Operator			Checked by Supervisor		
			Name	Sign	Date	Sign	Name	Date
	Inspect packing for any fouling. Pump servicing – replace bearing, grease & mechanical seal (for end suction centrifugal pump).							

(F) ANUALLY

Month : _____ Year : _____

Date	Procedure	Notes	Entries by Operator			Checked by Supervisor		
			Name	Sign	Date	Sign	Name	Date
	Verify accuracy of monitoring instruments and calibrate Inspect physical conditions of scrubber, ie housing, ductwork, etc Overall system cleaning.							

APPENDIX 10

TYPICAL FORM TO RECORD PERFORMANCE DATA/ACTIVITIES OF SCRUBBERS

Operating Setting	Minimum	Maximum
Pressure Drop - Body - Packing - Demistor		
Temperature		
Gas Flow Rate		
Liquid Flow Rate		
pH		

(A) Daily; Month: ……

Date	Scrubber Pressure drop of scrubber body (mmWG)	Scrubber Pressure drop of packing (mmWG)	Scrubber Pressure drop of mist eliminator (mmWG)	Gaseous flow rate (m^3/*hour*)	Notes on Opacity or Stack emission condition (*visual*)	Temperature of gases(*Deg C*)		pH of liquor (pH)		Liquid flow rate (m^3/*hour*)		Operator's Signature	Supervisor's signature
						Inlet	Outlet	*Feed*	Recycle	Feed	Make-up		
1													
2													
3													
4													
..													
30													

APPENDIX 11

GENERAL FORM TO RECORD CORRECTIVE ACTION FOR UPSET CONDITIONS

(Applicable for all types of control equipment)

Month : _____

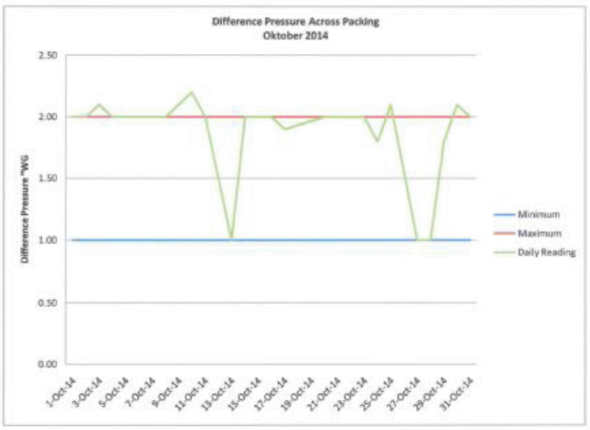
Date	Type of Upset Condition	Diagnosis of Cause of Upset Condition	Any Non Compliance of Discharge Standard Occurred – Give Explanation	Corrective Action Taken	When Condition Returned to Normal	Name and Signature of Reporting Officer	Name and Signature of Supervisor

APPENDIX 12

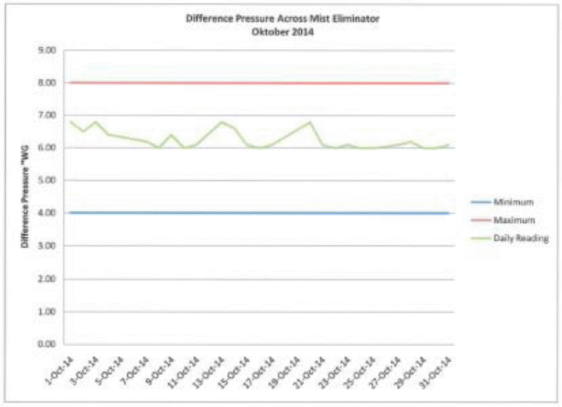
EXAMPLE

SCRUBBER PERFORMANCE MONITORING REPORT

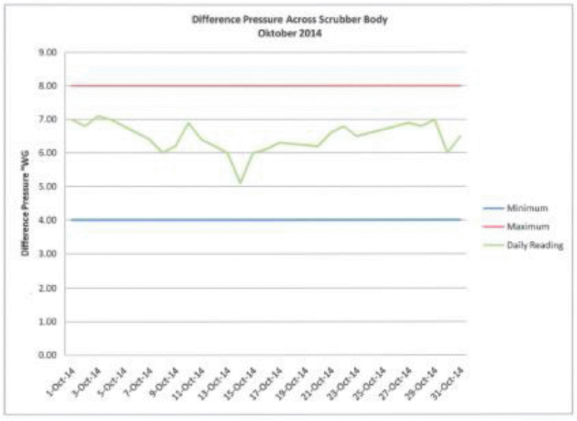
MONTH : OKTOBER 2014



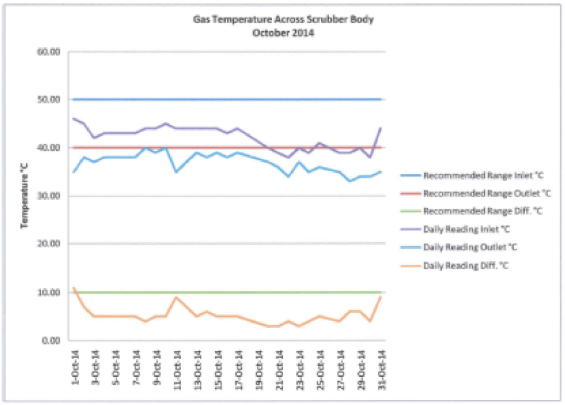
Pressure Drop Across Packing



Pressure Drop Across Mist Eliminator

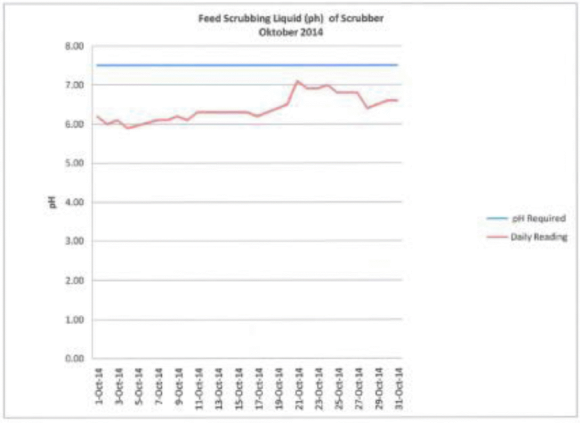


Pressure Drop Across Scrubber Body

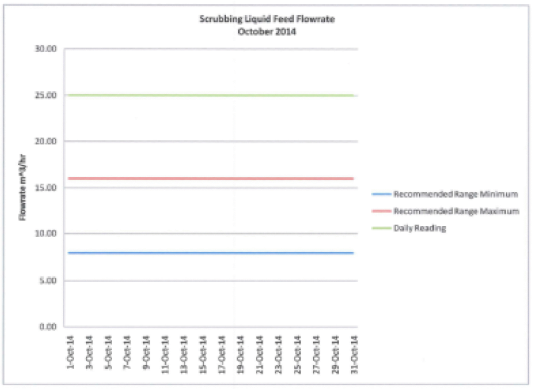


Gas Temperature (Inlet & Outlet)

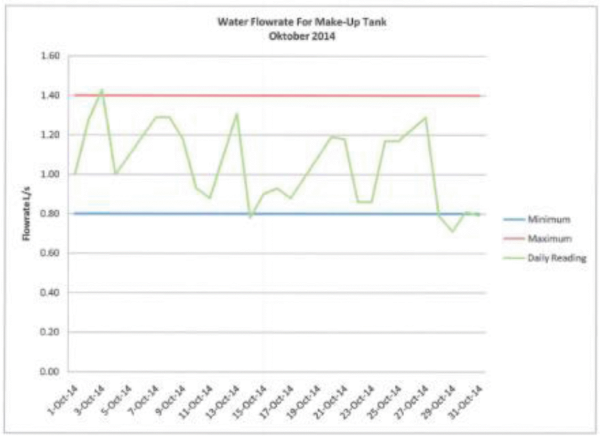
APPENDIX 12



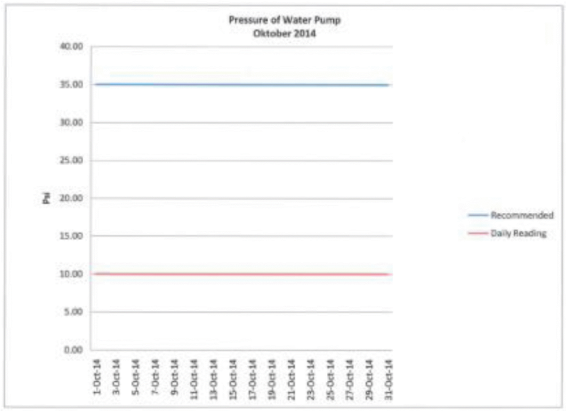
pH feed scrubbing liquid



Scrubbing Liquid Feed Flowrate



Water Flow Rate Make Up Tank



Pressure of Water Pump

Summary

1) All PM parameters were within the acceptable ranges.
2) Corrective action taken for month Oktober as per attached

Report prepared by

Signature :.....

Name of Competent Person : .....

CONVERSION FACTORS

Mass	1 kg	2.205 lb
	1 lb	0.4536 kg
	1 tonne	0.9842 tons
	1 ton	1.016 tonnes
Length	1 mm	0.03937 in
	1 in	25.4 mm
	1 m	3.281 ft
	1 ft	0.3048 m
	1 m	1.094 yd
	1 yd	0.9144 m
Area	1 mm^2	0.00153 in^2
	1 in^2	645.2 mm^2
	1 m^2	10.764 ft^2
	1 ft^2	0.0929 m^2
	1 m^2	1.196 yd^2
	1 yd^2	0.8361 m^2
Volume	1 mm^3	0.000061 in^3
	1 in^3	16 390 mm^3
	1 m^3	35.32 ft^3
	1 ft^3	0.0283 m^3
	1 m^3	1.308 yd^3
	1 yd^3	0.7646 m^3
Density	1 kg/m^3	0.06242 lb/ft^3
	1 lb/ft^3	16.02 kg/m^3
	1 $tonne/m^3$	0.7524 ton/yd^3
	1 ton/yd^3	1.329 $tonne/m^3$

Pressure	1mm WG	9.81 Pascal
	1 inch WG	249.17 Pascal
	1 mbar	100 Pascal
	1mbar	0.1 kPa
	1 mm HG	133.3 Pascal
	1 PSI	6894.75 Pascal

USEFUL FORMULA

1) $Q = A \times V \times 3600$

Where
Q = flow rate (m^3/hour)
A = area (m^2)
V = velocity (m/s)

2) $A = \frac{\pi D^2}{4}$

where
A = area (m^2)
$\pi = 3.142$
D = diameter (m)

3) $P = \pi D$,

where
P = perimeter (m)
$\pi = 3.142$
D = diameter *(m)*

DOE STATES

IBU PEJABAT JABATAN ALAM SEKITAR
KEMENTERIAN SUMBER ASLI DAN ALAM SEKITAR
ARAS 1-4, PODIUM 3, WISMA SUMBER ASLI
NO. 25, PERSIARAN PERDANA, PRESINT 4
62574 PUTRAJAYA

JABATAN ALAM SEKITAR NEGERI MELAKA
ARAS 19 MENARA PERSEKUTUAN
JALAN PERSEKUTUAN
BANDAR MITC HANG TUAH JAYA
75450 AYER KEROH

JABATAN ALAM SEKITAR NEGERI PAHANG
ARAS 1, KOMPLEKS MAHKAMAH KUANTAN
BANDAR INDERA MAHKOTA
25200 KUANTAN

JABATAN ALAM SEKITAR NEGERI SEMBILAN
TINGKAT 5, ARAB MALAYSIAN BUSINESS CENTRE
JALAN PASAR
70200 SEREMBAN

JABATAN ALAM SEKITAR W.P. KUALA LUMPUR
TINGKAT 1 & 2, WISMA SCA
NO.3 BATU 2, JALAN SUNGAI BESI
57100 KUALA LUMPUR

JABATAN ALAM SEKITAR NEGERI PERAK
TINGKAT 7 & 9, BANGUNAN SERI KINTA
JALAN SULTAN IDRIS SHAH
30000 IPOH

JABATAN ALAM SEKITAR NEGERI PULAU PINANG
ARAS BAWAH – ZON B
WISMA PERSEKUTUAN
SEBERANG PERAI UTARA
13200 KEPALA BATAS

JABATAN ALAM SEKITAR NEGERI SELANGOR
TINGKAT 12, 13, & 14 SUNWAYMAS
JALAN TENGKU AMPUAN ZABEDAH C 9/C, SEKSYEN 9
40100 SHAH ALAM

JABATAN ALAM SEKITAR NEGERI KEDAH
ARAS 2, MENARA ZAKAT
JALAN TELOK WAN JAH
05200 ALOR SETAR

JABATAN ALAM SEKITAR NEGERI JOHOR
WISMA JAS JOHOR
NO. 46, JALAN PERTAMA, TOWER 2
PUSAT PERDAGANGAN DANGA UTAMA
81300 JOHOR BAHRU

JABATAN ALAM SEKITAR NEGERI KELANTAN
LOT 322 - 324, SEKSYEN 27
JALAN SRI CEMERLANG
15300 KOTA BHARU

JABATAN ALAM SEKITAR NEGERI TERENGGANU
WISMA ALAM SEKITAR
OFF JALAN SULTAN OMAR
20300 KUALA TERENGGANU

JABATAN ALAM SEKITAR NEGERI PERLIS
TINGKAT 2, BANGUNAN KWSP
JALAN BUKIT LAGI
01000 KANGAR

JABATAN ALAM SEKITAR NEGERI SARAWAK
TINGKAT 7-9, WISMA STA NO. 26,
JALAN DATUK ABANG ABDUL RAHIM
93450 KUCHING

JABATAN ALAM SEKITAR NEGERI SABAH
ARAS 4, BLOK A KOMPLEKS PENTADBIRAN KERAJAAN
PERSEKUTUAN SABAH
JALAN UMS-SULAMAN, LIKAS
88450 KOTA KINABALU

NOTES

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