TRAINING
Module: Boilers

Purpose

- To provide training on Boilers

Contents

- General description of Boilers
- Types of Boilers
- Basic Construction (Boiler Parts)
- Air pollution control
- Material technology
- Operational monitoring
- Operational Maintenance
- Shutdown Maintenance

Boiler

An Enclosed Pressure Vessel

Heat by Combustion of Fuel transferred to water to generate steam

Process : Evaporation

Steam volume increase to 1,600 times from water and produces tremendous force

Boiler is an extremely dangerous equipment.

Care is must to avoid explosion.

Various heating surfaces in a boiler

Heating surface is expressed in square feet or in square meter

1. Radiant Heating Surfaces (direct or primary) → includes all water – backed surfaces that are directly exposed to the radiant heat of the combustion flame.

2. Convective Heating Surfaces (indirect or secondary) → includes all those water-backed surfaces exposed only to hot combustion gases.

3. Extended Heating Surfaces → refers to the surface of economizers and super heaters used in certain types of water tube boilers.

Typical Boiler Specification

Boiler Make & Year	:	XYZ & 2003
MCR (Maximum Continuous Rating)	:	10TPH (F & A 100°C)
Rated Working Pressure	:	10.54 KG/CM2(G)
Type of Boiler	:	3 Pass, Fire tube, packaged
Fuel Fired	:	Fuel Oil
Total Heating Surface	:	310 M2

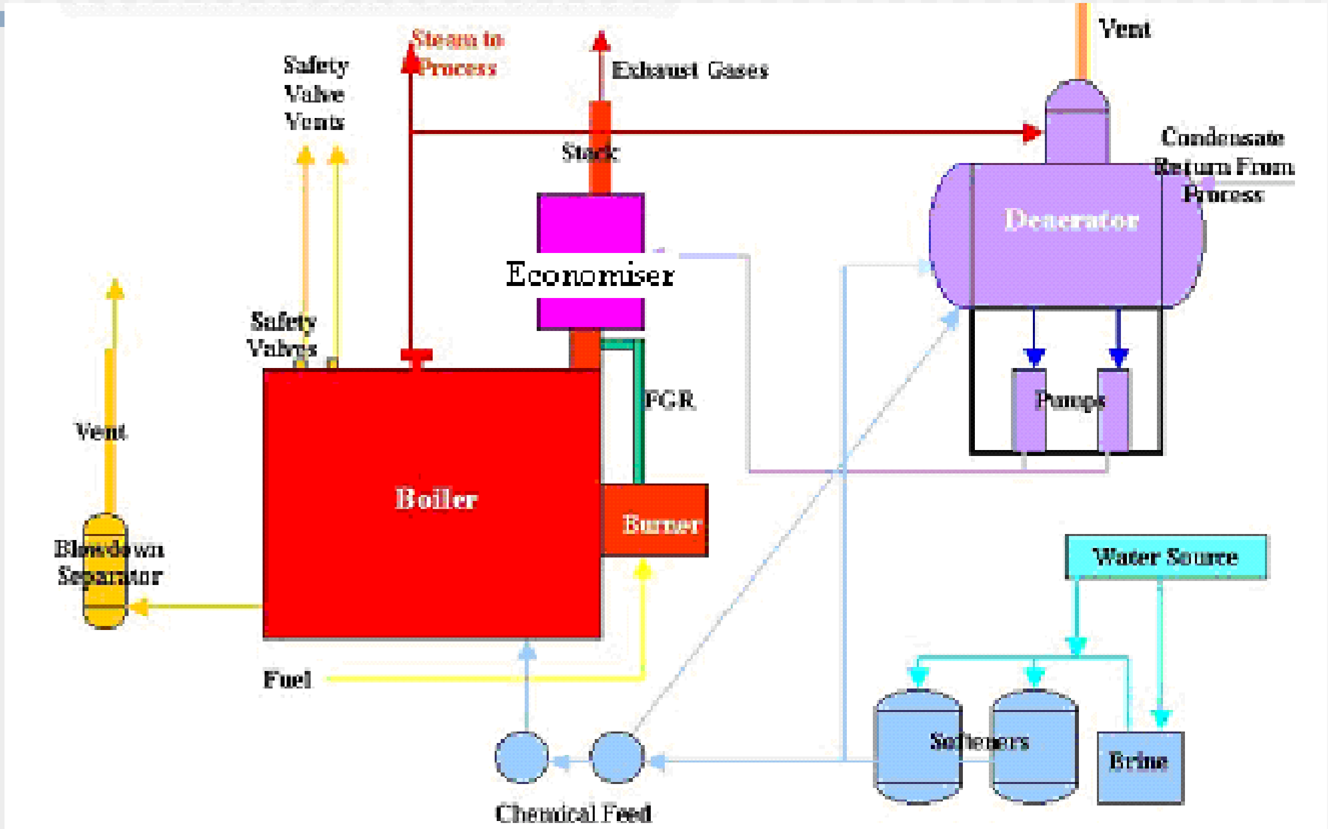
Boiler Systems

Water treatment system

Feed water system

Steam system

Blow down system



Fuel supply system

Air supply system

Flue gas system

Boiler Types and classifications

Fire Tube Boilers

Fire in tube or Hot gas through tubes and boiler feed water in shell side
Fire Tubes submerged in water

Water Tube Boilers

Water in tube or water passing through the tubes and hot gases passing outside the tubes

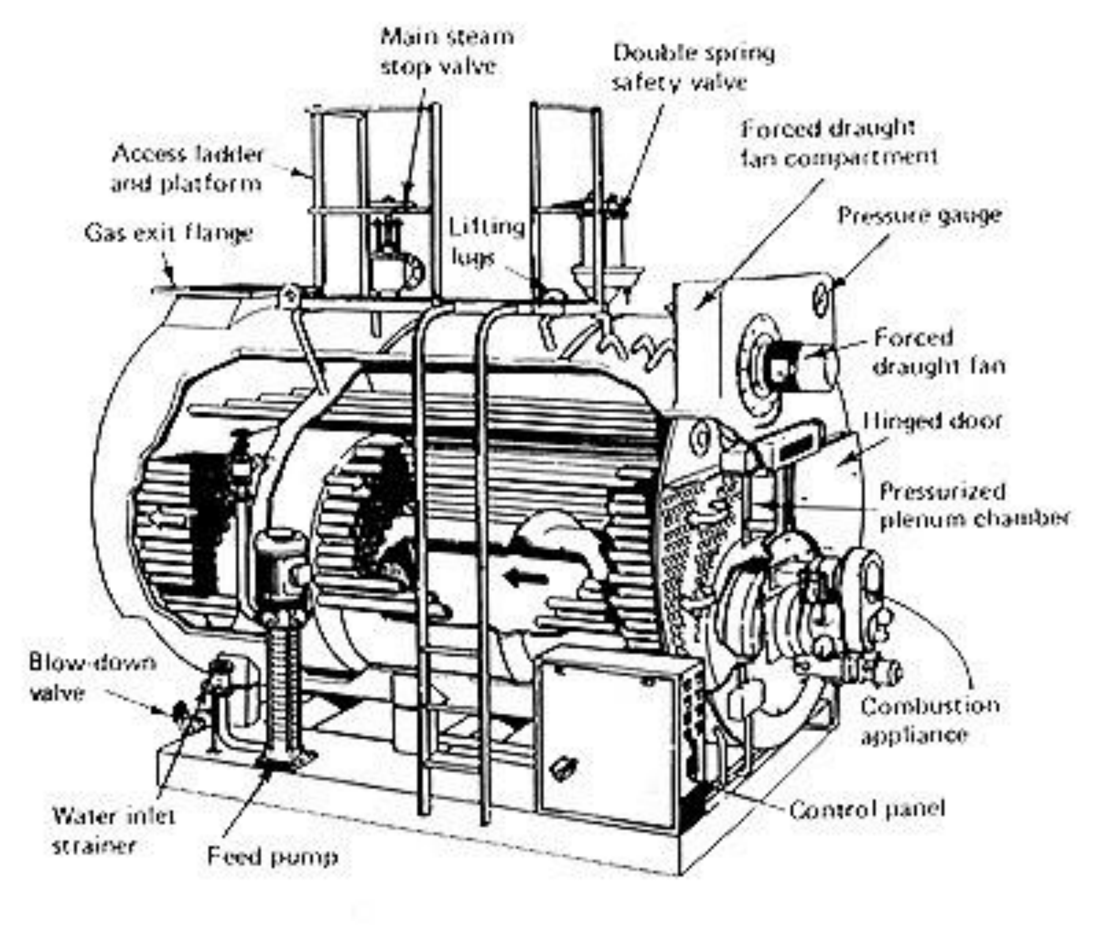
Packaged Boilers

Comes as a complete package and generally of shell type with fire tube design so as to Achieve high heat transfer rates by both radiation and convection

Fire Tube Boilers

Application

Used for small steam capacities (Up to 12000 kg/hr and 17,5 kg/cm2)

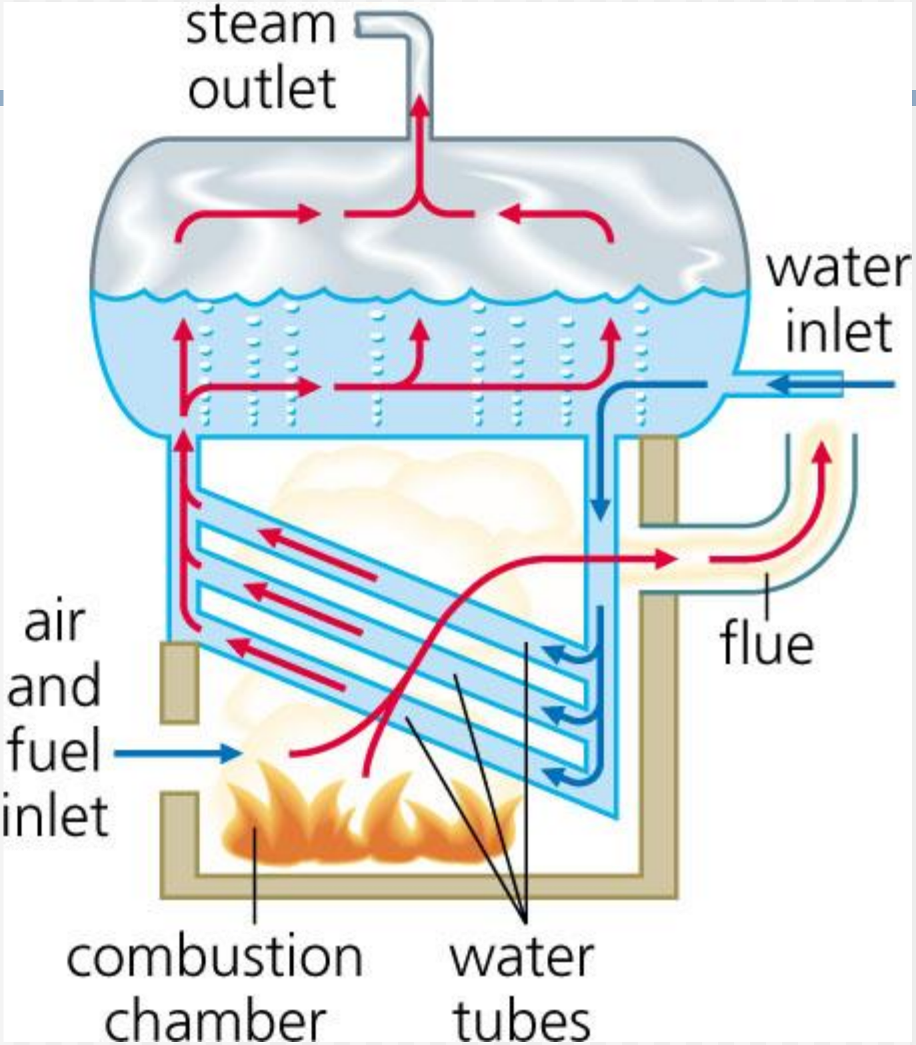


Characteristics

- Low Capital Cost
- Fuel Efficient (82%)
- Easier to operate
- Accepts wide & load fluctuations
- Steam pressure variation is less (Large volume of water)

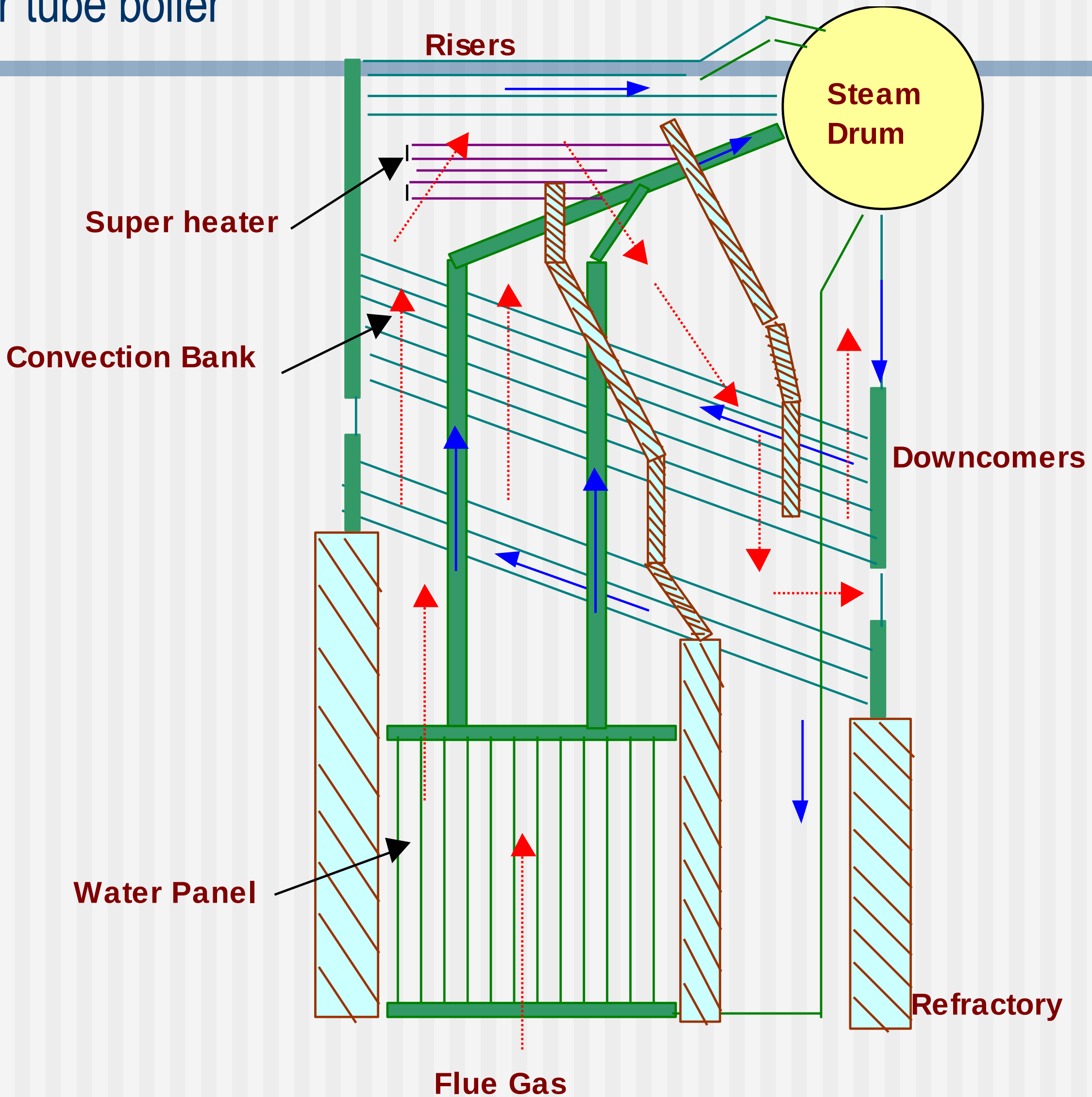
Water Tube Boiler

Application
- Used in Power Plants
- Steam capacities range from 4.5 - 120 t/hr

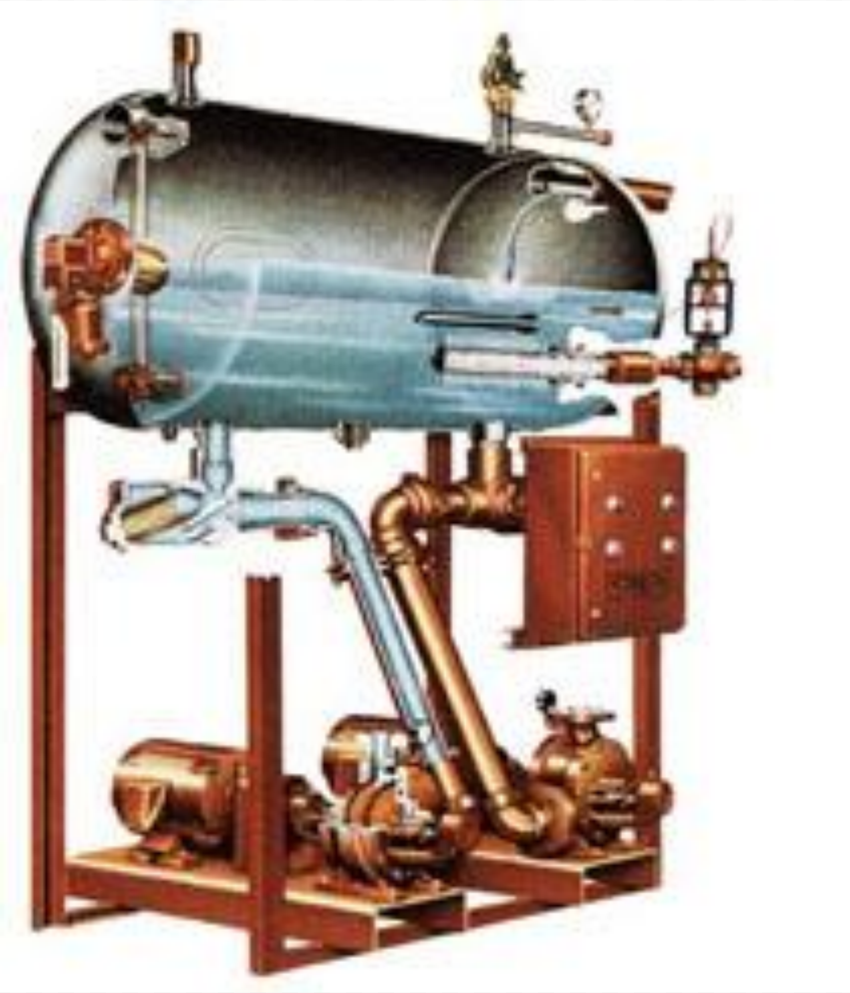


Characteristics
- High Capital Cost
- Used for high pressure high capacity steam boiler
- Demands more controls
- Calls for very stringent water quality

Water tube boiler



Packaged Boiler



Application

Used in smaller applications requiring lower capacity and lower pressure levels

Characteristics

- Small combustion space and high heat release resulting in faster evaporation

- Higher thermal efficiency levels compared with other boilers

BOILER PARTS

- PRESSURE PARTS
- FUEL FEEDING & FIRING EQUIPMENTS
- FEED WATER SYSTEM
- ASH HANDLING SYSTEM
- WASTE HEAT RECOVERY SYSTEM
- AIR POLLUTION CONTROL SYSTEM
- CHIMNEY

PRESSURE PARTS

- BOILER DRUM
- FURNANCE TUBES
- BOILER CONVECTION BANK
- SUPER HEATER

FUEL FEEDING & FIRING EQUIPMENTS

- FUEL STORAGE
- FUEL FILTER MECHANISM
- FUEL CONVEYOR SYSTEM
- FUEL FEEDING MECHANISM
- COMBUSTION CHAMBER
- COMBUSTION AIR CIRCUIT

ASH HANDLING SYSTEM

- ASH DISCHARGE SYSTEM
- ASH CONVEYOR
- ASH TROLLEY

FEED WATER SYSTEM

- WATER TREATMENT SYSTEM
- STORAGE TANK
- FEED WATER PUMP

WASTE HEAT RECOVERY SYSTEM

- ECONOMISER
- AIR PRE - HEATER

AIR POLLUTION CONTROL SYSTEM

- CYCLONE
- SCRUBBER
- ESP
- BAG FILTER

Cyclone

- It is also called a centrifugal separator. It uses centrifugal force to throw solids out of the fluid. It is recommended as a solution to removing solids in the stuffing box that could clog a mechanical seal and open the lapped faces.
- It does not work very well in these slurry applications. To be really effective these units should be used in a bank of several separators, connected in series.
- The normal installation is to have higher pressure discharge fluid connected to the side of the unit with the bottom connected to the suction side of the pump. The clean outlet, on top, is then connected to the stuffing box.

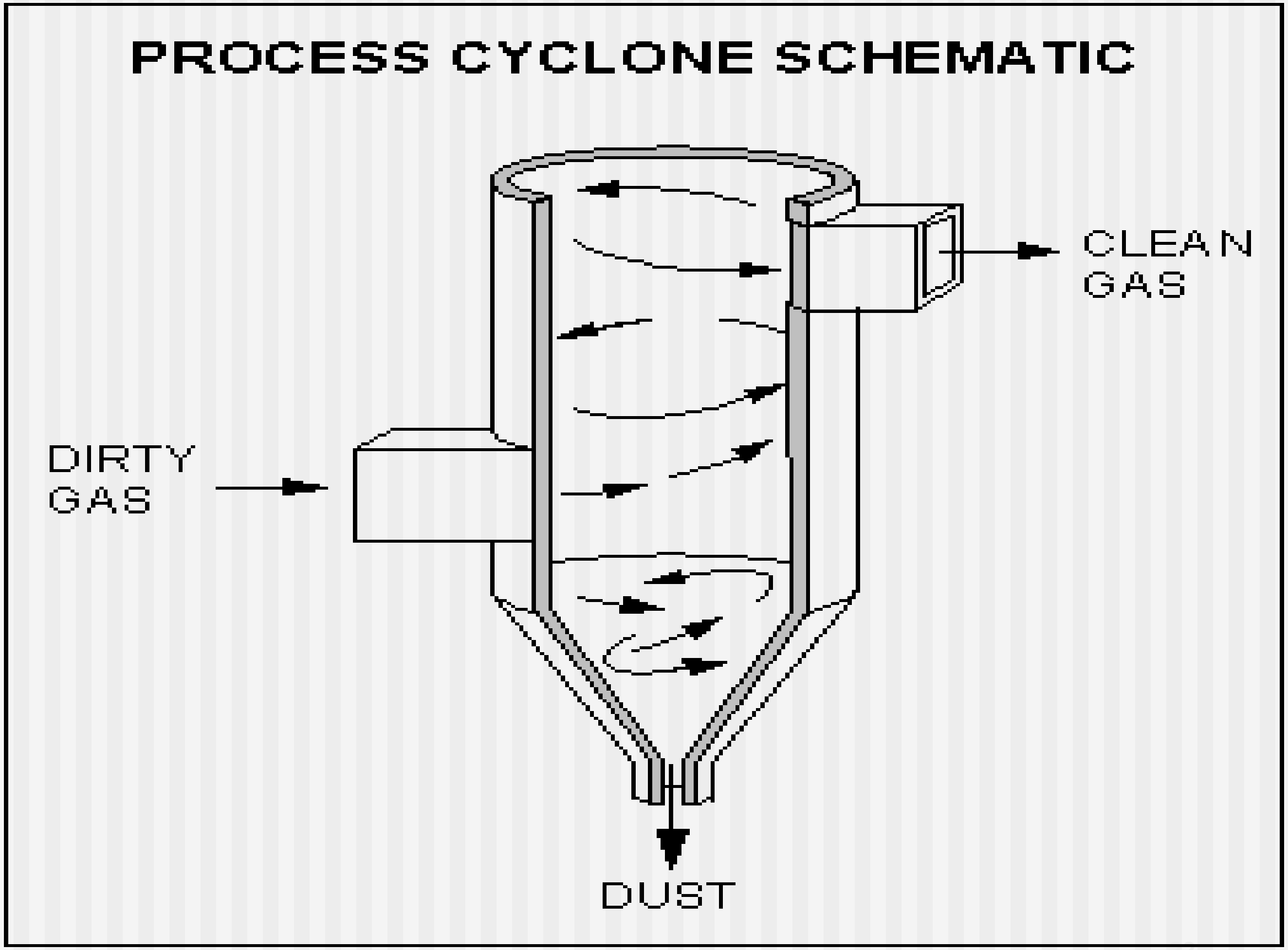
Cyclone

Cyclones operate to collect relatively large size particulate matter from a gaseous stream through the use of centrifugal forces. Dust laden gas is made to rotate in a decreasing diameter pathway forcing solids to the outer edge of the gas stream for deposition into the bottom of the cyclone. Efficiencies of 90% in particle sizes of 10 microns or greater are possible

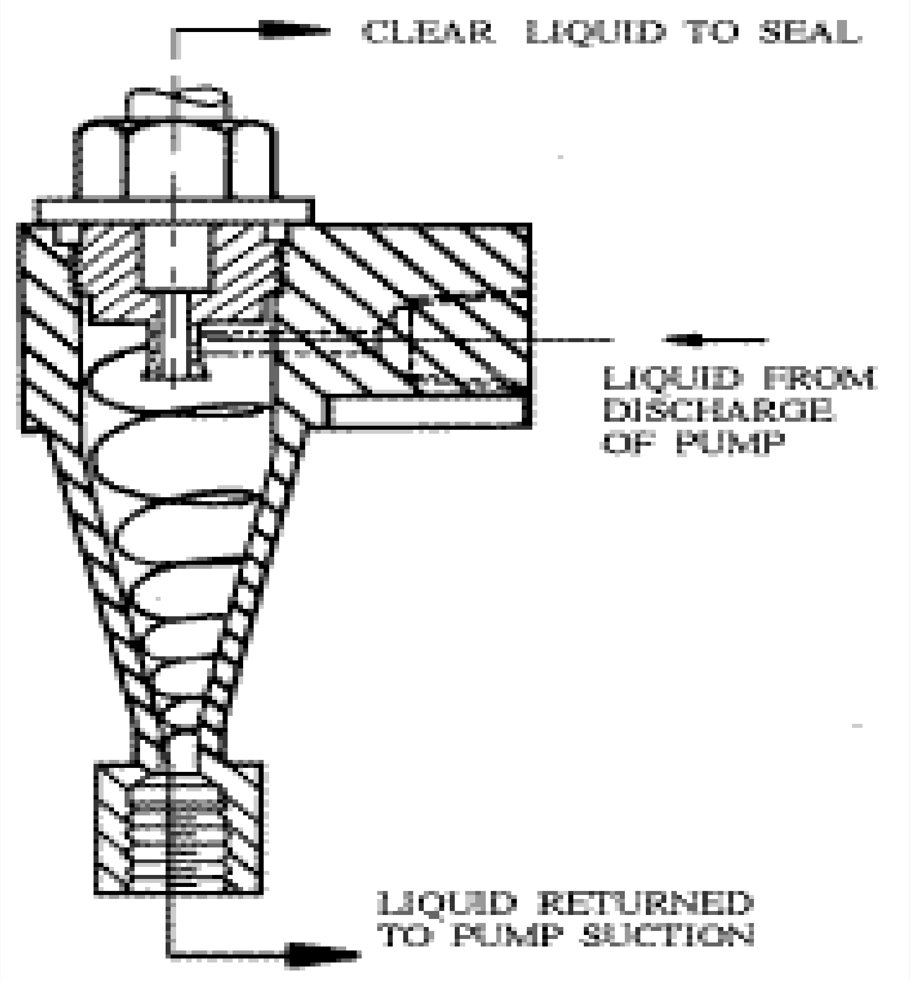
Performance & Collection Efficiency

- Linear increases with: particle density, gas stream velocity, and rotational passes
- Linear decrease with fluid viscosity
- Exponential increase with particle diameter

Cyclone



Cyclone


CLEAR LIQUID TO SEAL
LIQUID FROM DISCHARGE OF PUMP
LIQUID RETURNED TO PUMP SUCTION

Advantages

- Operation at elevated temperatures possible
- Reduces internal access needs
- Few moving parts, few mechanical / electrical ignition sources
- If the solids you are trying to remove float on the liquid (they have a low specific gravity) the separator will remove the clean liquid and put the solids into the stuffing box.

Limitations

- Optimal flow rate difficult to adjust and it is prone to internal erosion / corrosion
- Low efficiency for small diameter material
- Hopper recirculation / flow distribution problems
- High energy costs for volumetric flow requirements
- Dew point agglomeration, bridging, and plugging
- One of the limitations in using this unit in a centrifugal pump application is that often there is very little pressure differential between the stuffing box and the pump suction. In some instances there is no differential at all.

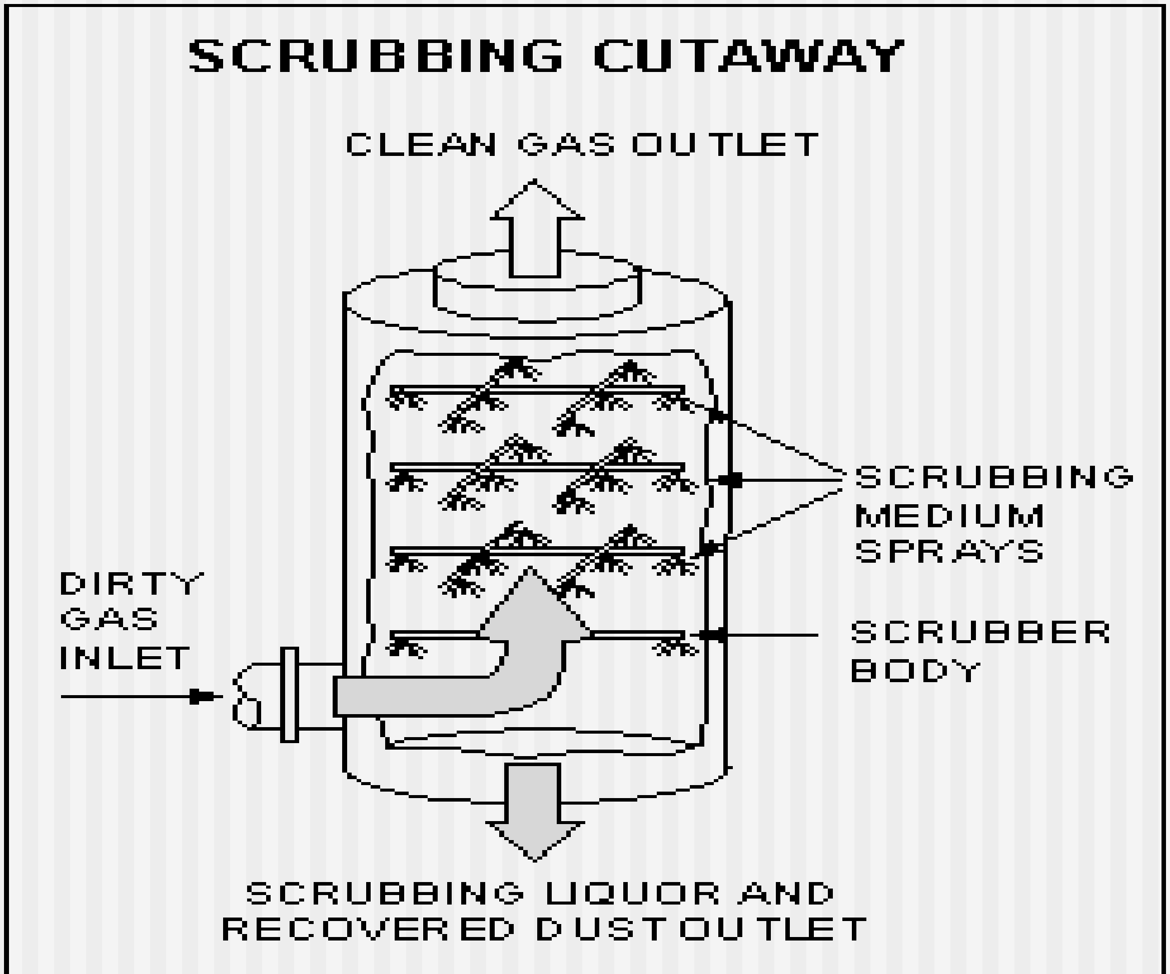
Scrubber

- Scrubbers are air pollution control devices that use a high-energy liquid spray to remove aerosol and gaseous pollutants from air stream.
- The gases are removed either by absorption or chemical reaction.
- In addition to fume and gas abatement, scrubbers may be used for process air cleansing and dust collection.
- Scrubbers are differentiated by the manner in which they remove gases and particulates from the air; either wet or dry.
- Wet scrubbers literally wash dust and particles out of the air. Exhaust air is forced into a spray chamber, where fine water particles cause the dust to drop from the air stream. The dust-laden water is then treated to remove the solid material and is often recirculated.
- Dry scrubbers are used more commonly with acid gases

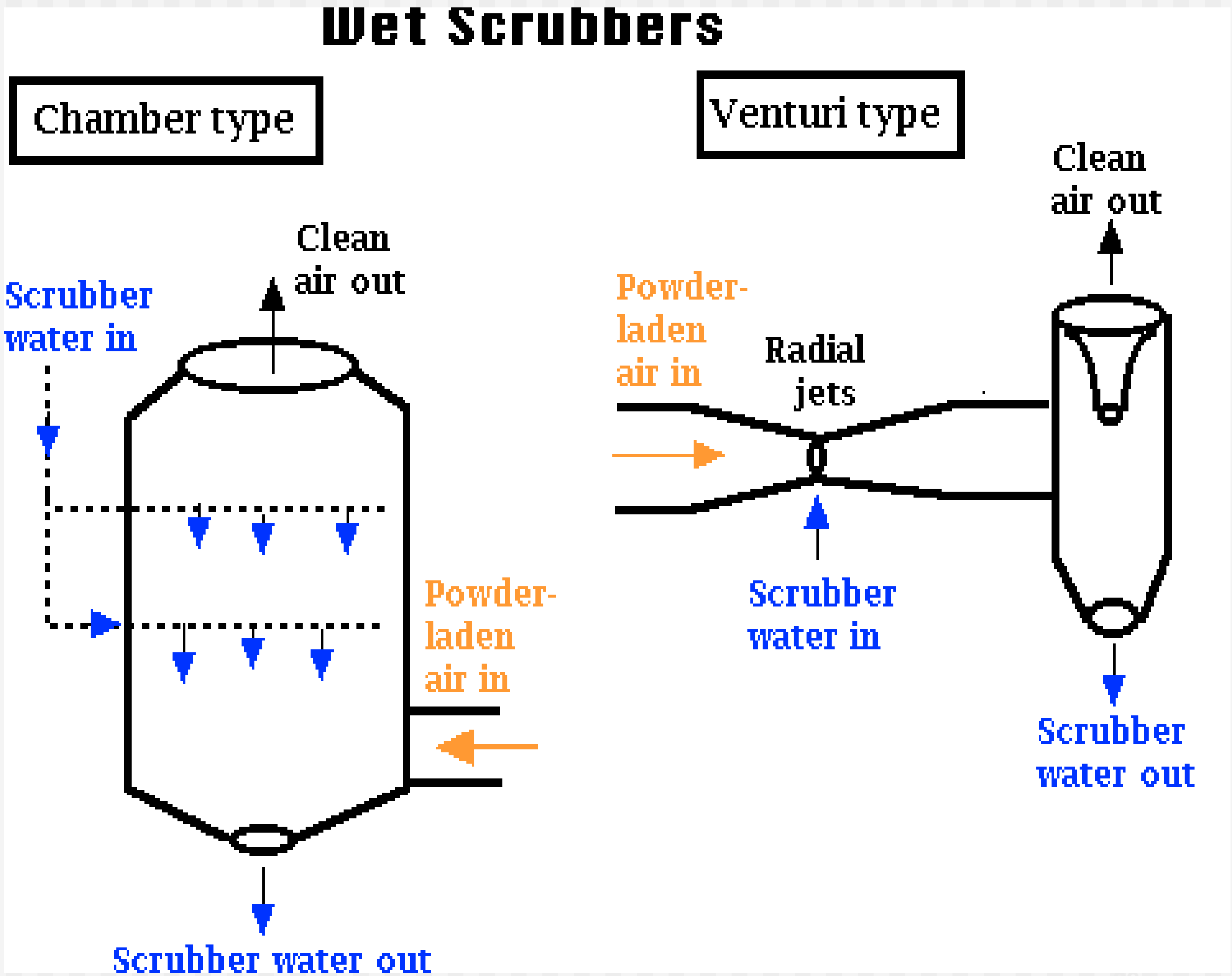
ABSORPTION & WET SCRUBBING EQUIPMENT

- The goal in absorption and wet scrubbing equipment is the removal of gases and particulate matter from an exhaust stream by causing the gaseous contamination to become dissolved into the liquid stream and the solids to be entrained in the liquid.
- The rate of gas transfer into the liquid is dependent upon the solubility, mass transfer mechanism, and equilibrium concentration of the gas in solution.
- Gas collection efficiencies in the range of 99% are possible. The rate of particulate matter collection at constant pressure drops is inversely proportional to the aerodynamic mean diameter of the particulate matter and scrubber droplets.

Scrubber


SCRUBBING CUTAWAY
CLEAN GAS OUTLET
SCRUBBING MEDIUM SPRAYS
DIRTY GAS INLET
SCRUBBER BODY
SCRUBBING LIQUOR AND RECOVERED DUST OUTLET

Wet Scrubber



Performance & Efficiency Parameters

For gas collection, the maximum equilibrium concentration in solution is described by Henry's law:

$[C_{gas}] = (H_k)\ [C_{liquid}]$

where;

(H_k) is Henry's constant

$[C_{gas}]$ is the concentration in the gas stream

$[C_{liquid}]$ is the concentration in the liquid stream

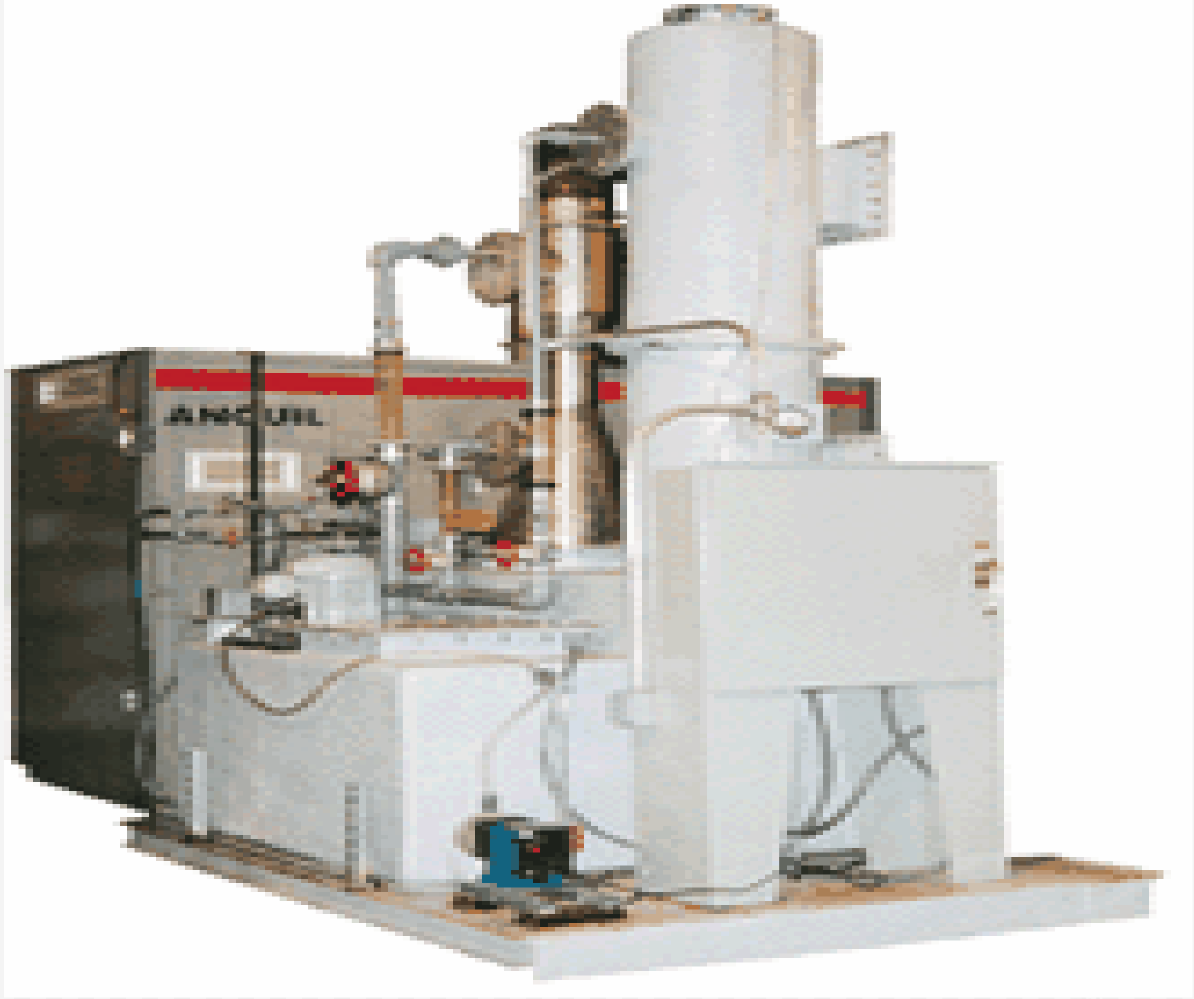
Advantages

- Few internal moving parts
- Reduced opportunity for gas ignition
- Gas and liquid chemistry control important
- Increased relative velocity between scrubbing the fluid and gas stream, increases efficiency for solids

Limitations

- High pressure drops required
- Internal plugging, corrosion, erosion
- Increased need for internal inspection
- Formation / precipitation of solids

Scrubber Module



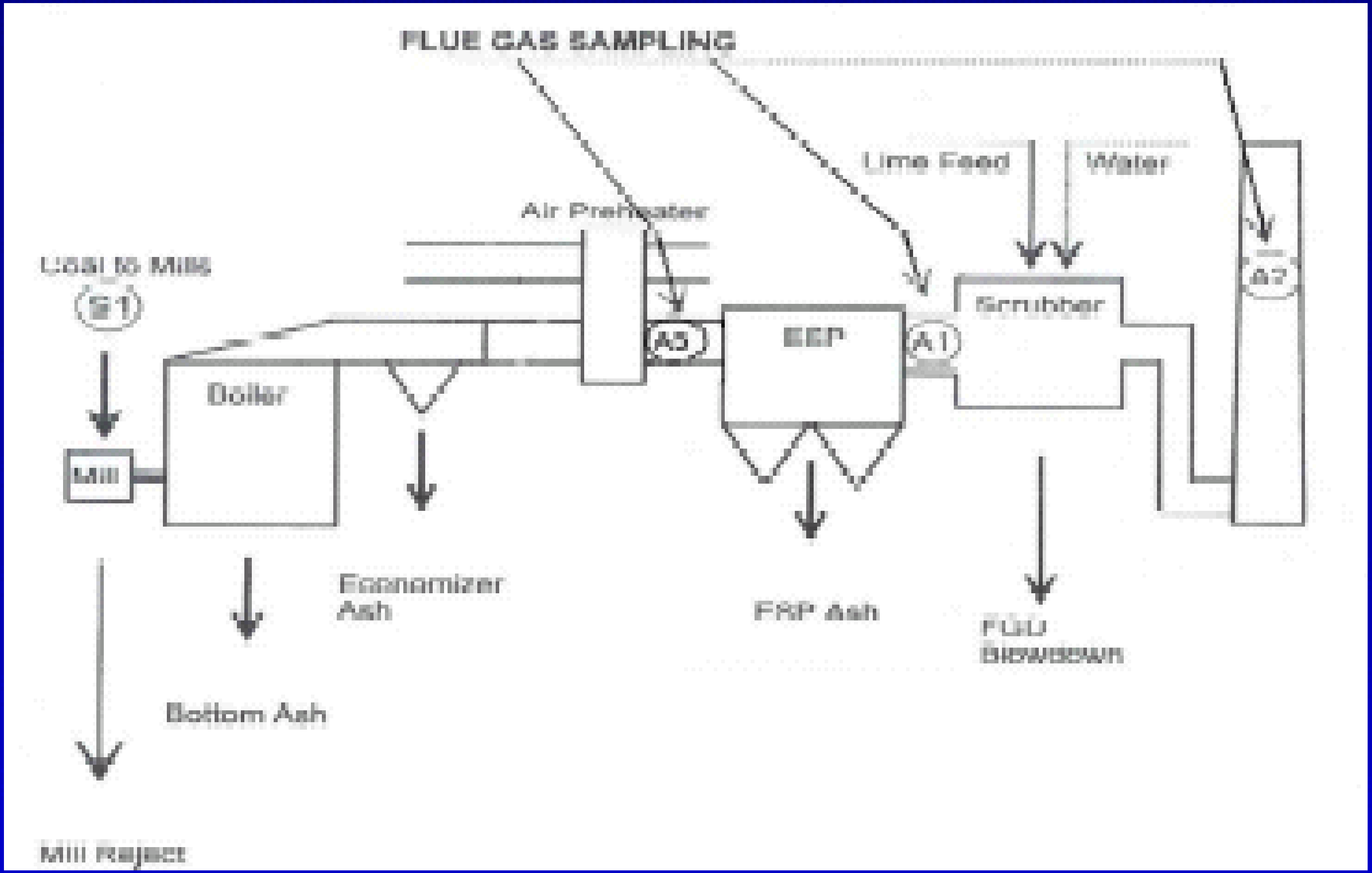
ESP

- A precipitator is used to remove particulate (dust and soot) and prevent it from entering the atmosphere.
- The particulate is removed by passing a gas containing the particulate past a series of high voltage plates. The particulate is attracted to these plates by the high voltage static charge.
- Rappers are used to knock the dust off the plates into the hoppers below for collection and disposal. The high voltage static charge is produced by a transformer rectifier (T.R.). This takes A.C. power from the facility, boosts the voltage and rectifies it to produce D.C. This is used to charge the plates. The plates' potential can be in excess of 50,000 volts.
- For this reason, access must be restricted until safe. The power must be locked off and the plates grounded to remove residual charges.

ESP

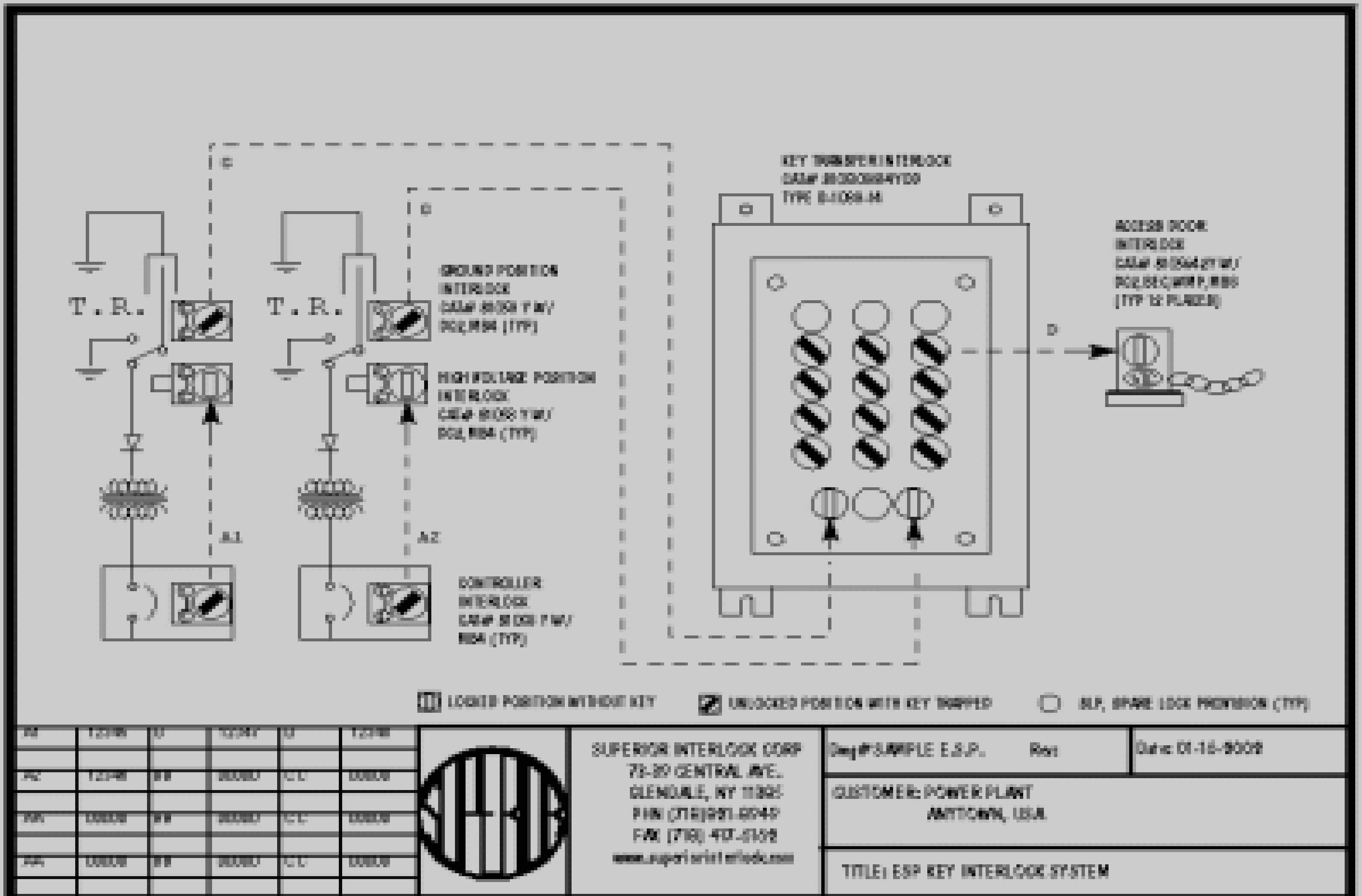
- This control device utilizes gaseous ions to charge particles which are then moved through an electric field to be deposited onto charged collection plates.
- Collected particulate material is then removed by rapping or washing of the plates.
- To produce the free ions and electric field, high internal voltages are required.
- Since the collection process does not rely on mechanical processes such as sieving or impaction, but rather electrostatic forces, the internal gas passages within a precipitator are relatively open with small pressure drops and lower energy costs to move the gas stream.
- High collection efficiencies are possible, but collecting efficiency may drastically change with changes in operating parameters

ESP

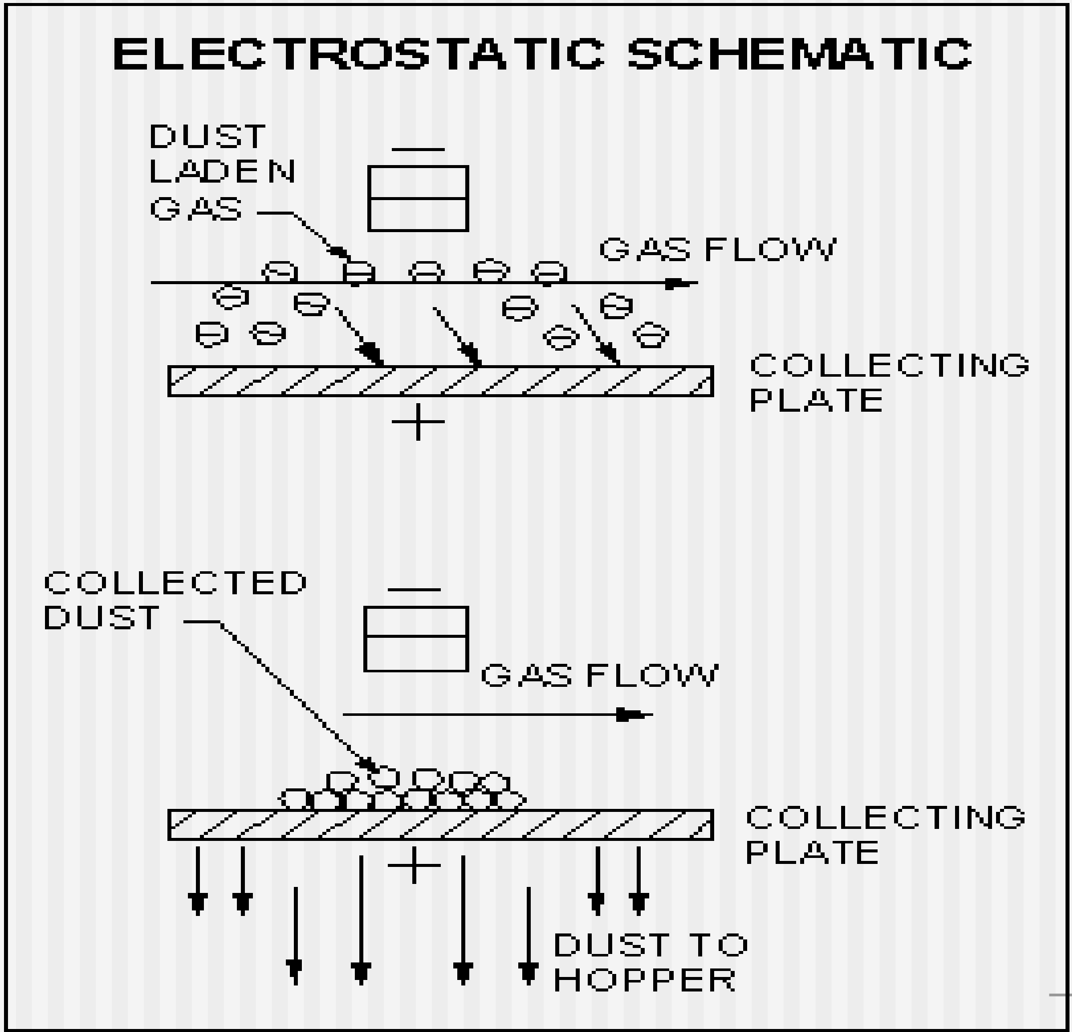


FLUE GAS SAMPLING
Lime Feed
Water
Air Preheater
Coal to Mills
S1
A5
ESP
A1
Scrubber
Boiler
Mill
Economizer
Ash
ESP Ash
FGD
Blowdown
Bottom Ash
Mill Reject

ESP


T.R.
T.R.
KEY TRANSFER INTERLOCK
GROUND POSITION INTERLOCK
HIGH VOLTAGE POSITION INTERLOCK
CONTROLLER INTERLOCK
ACCESS DOOR INTERLOCK
LOCKED POSITION WITHOUT KEY
UNLOCKED POSITION WITH KEY TRAPPED
SUPERIOR INTERLOCK CORP
CUSTOMER: POWER PLANT
TITLE: ESP KEY INTERLOCK SYSTEM

ESP


ELECTROSTATIC SCHEMATIC
DUST
LADEN
GAS
GAS FLOW
COLLECTING
PLATE
COLLECTED
DUST
GAS FLOW
COLLECTING
PLATE
DUST TO
HOPPER

Performance & Efficiency Parameters

Collection Eff. % = $1 - e^{-WA/Q}$ where; A = collecting electrode area

Q = volumetric gas flow rate

W = particle drift velocity and drift vel. = $W = \frac{E_o E_p aC}{(pi)}$

where;

E_o = charging field

E_p = collecting field

a = particle radius

C = proportionality constant

n = gas viscosity

Limitations

- Large installation space required
- Re-entrainment, spark-over, back corona problems
- Susceptible to changes in moisture and resistivity

Advantages

- High efficiencies for small particles possible
- Low pressure drops and air moving costs
- High potential for ignition sources
- High temperature operation possible

Bag House/Bag Filter

- Bag filter dust precipitator introduces air including dust from lower part of the precipitator into housing by sending pressure or absorbing that air, and makes dust adhere to filter tube surface.
- The filtered air passes through the filter tube and is exhausted from upper exit.
- Dust adhering to the filter tube surface is swept away every fixed time on the pulse jet system with utilizing compressed air.

Bag House/Bag Filter

- Baghouses utilize sieving, impaction, agglomeration, and electrostatic filtration principles to remove solids from a gaseous exhaust stream.
- Baghouses maximize the filtration area by configuring the fabric filter media into a series of long small-diameter fabric tubes referred to as bags.
- They are tightly packed into a housing wherein the dust laden air moves across the bag fabric thereby removing it from the gas stream and building up a filter cake which further enhances air cleaning.
- The filter cake is removed to hoppers by various shaking means. The operating pressure drop across the bags is described by:

Performance & Efficiency Parameters

Pressure drop = dP = $S_e V + KCV^2 t$

where; S_e = drag coefficient

V = velocity

K = filter cake coefficient

C = inlet dust concentration

t = Collection running time

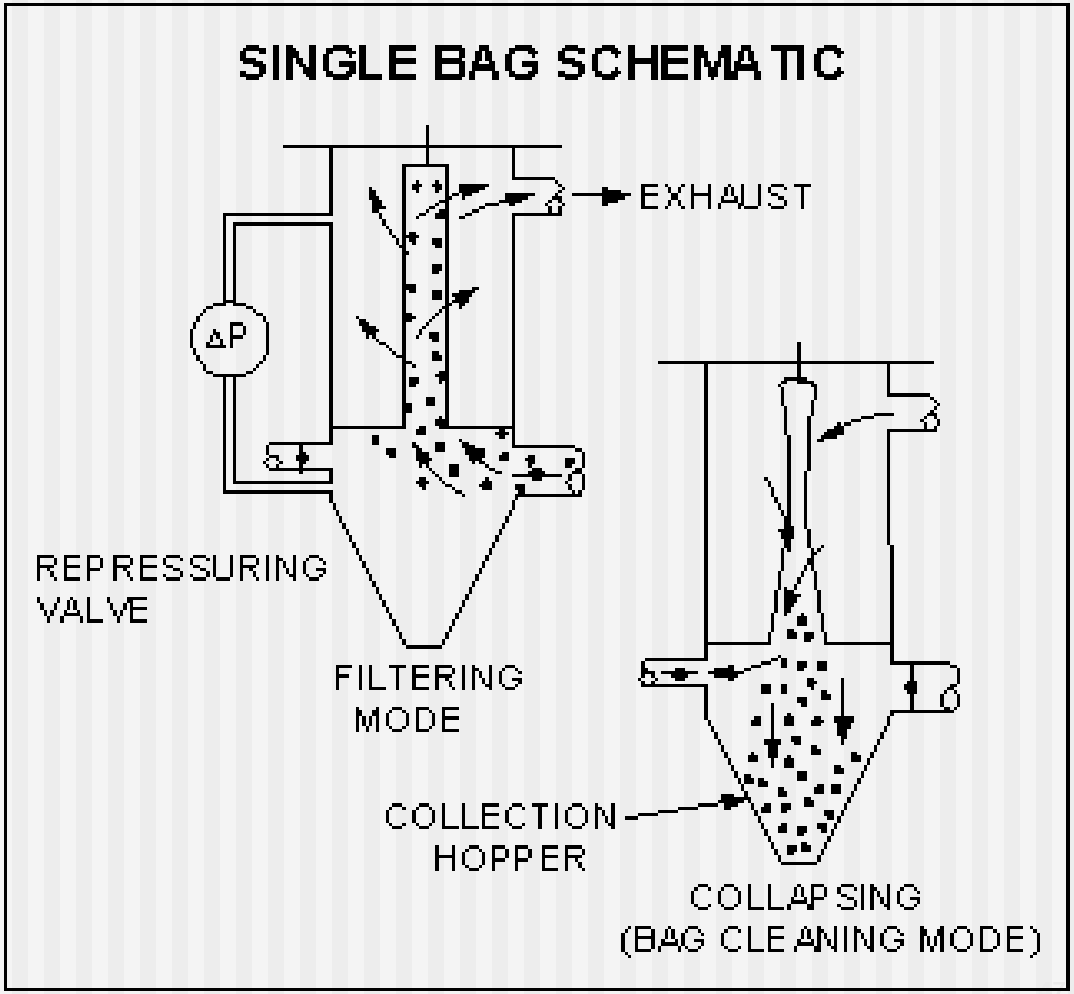
Advantages

- High collection efficiencies
- Possible to have variable flow rates

Limitation

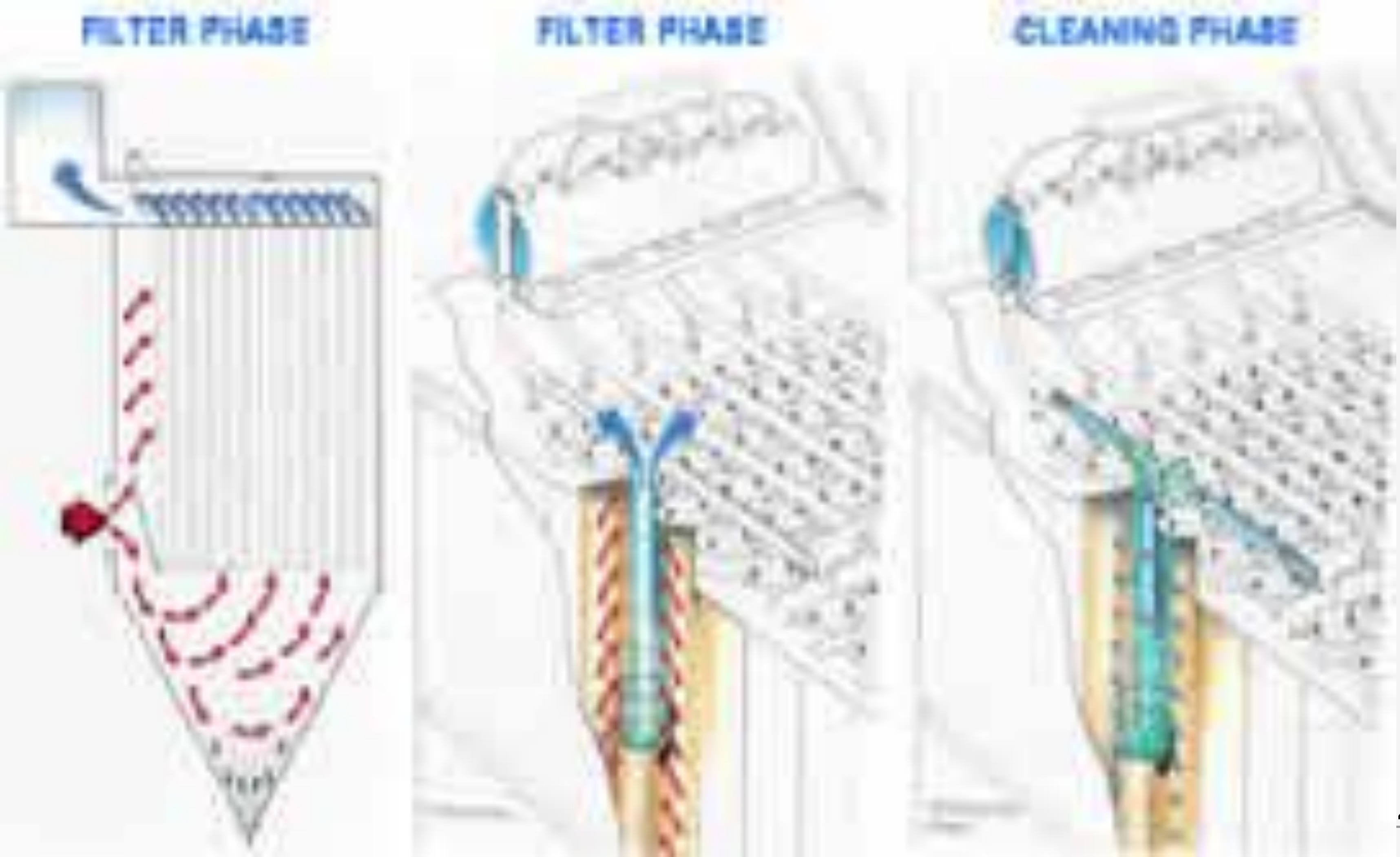
- Internal condensation / corrosion
- Over-temperature limitations
- Need for internal inspection / access
- Plugging / short-circuiting / break-through/ collection media fouling
- Accumulation of flammable gases/ dusts and ignition sources
- Unexpected bag failure due to changes in operating parameters

Bag Filter

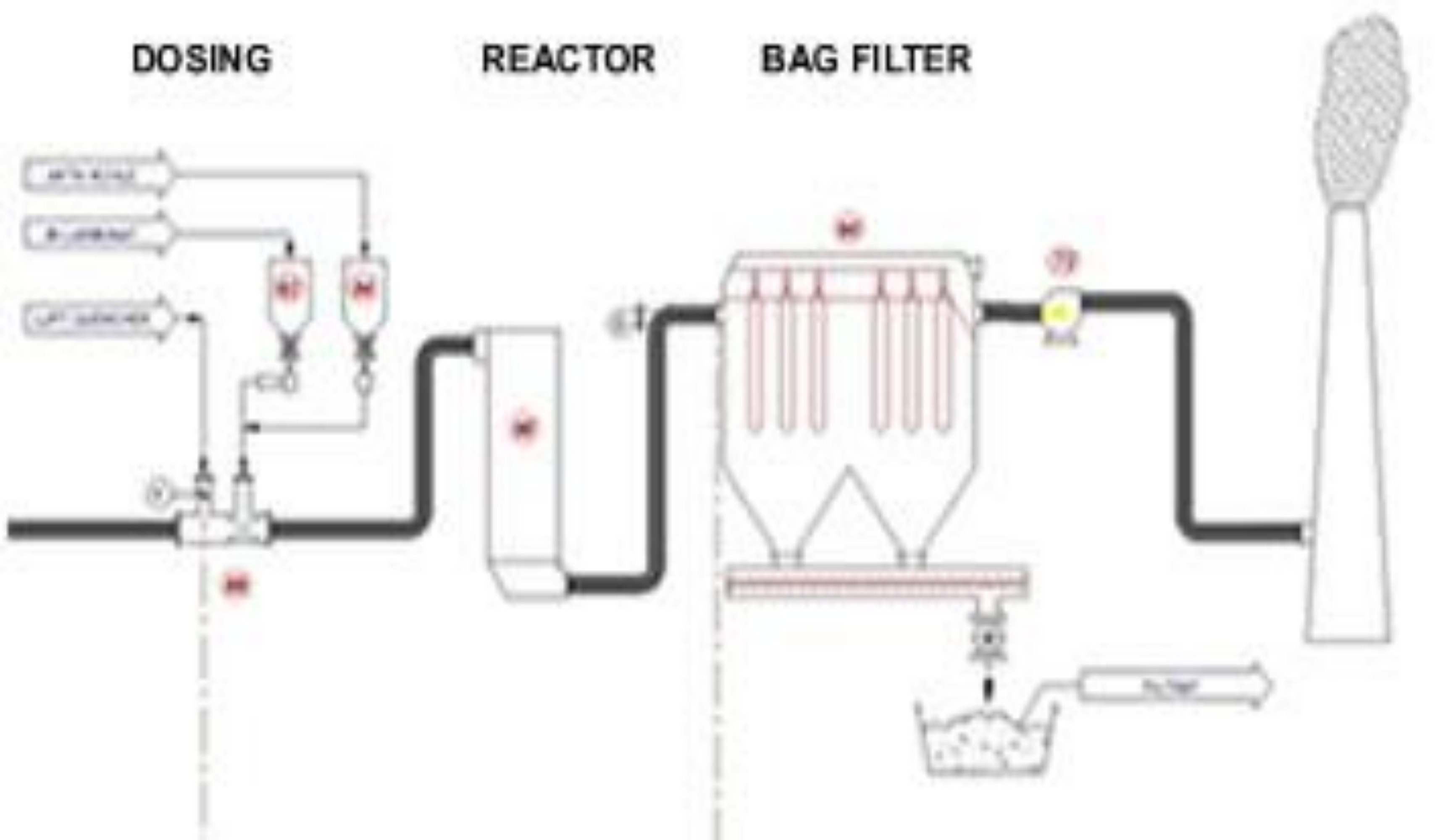

SINGLE BAG SCHEMATIC
EXHAUST
ΔP
REPRESSURING
VALVE
FILTERING
MODE
COLLECTION
HOPPER
COLLAPSING
(BAG CLEANING MODE)

Bag Filter

Bag filter



Bag filter



Performance Evaluation of Boilers

Factors for poor efficiency

Efficiency reduces with time due to
- Poor combustion
- Heat transfer fouling
- Poor operation and maintenance and
- Deterioration of fuel and water quality

Advantages of Efficiency testing

Helps us
- To find out how far the boiler efficiency drifts away from the best efficiency and
- To target problem area for corrective action

Operational Monitoring

- Boiler Blow down
- Feed water quality
- Steam quality
- Fuel/Steam ratio
- Drum water
- Temperature
- Drafts
- Pressure
- Unburnts

Boiler Blow Down

Why?

When water evaporates

- Dissolved solids gets concentrated
- Solids precipitates
- Coating of tubes
- Reduces the heat transfer rate

Benefits of good blow down

- Lower pretreatment costs
- Less make up water consumption
- Reduced maintenance downtime
- Increased boiler life
- Lower consumption of treatment chemicals

Types of blow down

- Intermittent Blow down
- Continuous Blow down

Intermittent Blow Down

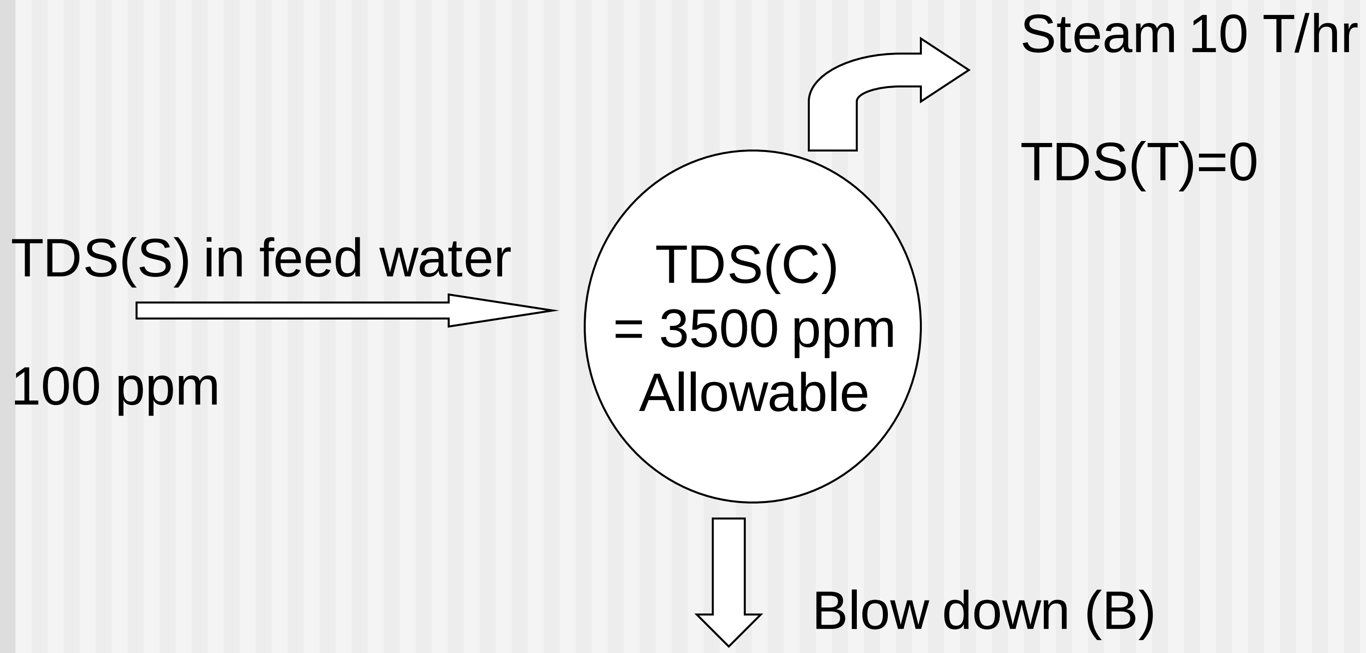
- Intermittent blown down is given by manually operating a valve fitted to discharge pipe at the lowest point of boiler shell to reduce parameters (TDS or conductivity, pH, Silica etc) within prescribed limits so that steam quality is not likely to be affected.
- TDS level keeps varying
- Fluctuations of the water level in the boiler
- Substantial amount of heat energy is lost with intermittent blowdown.

Continuous Blow Down

- A Steady and constant dispatch of small stream of concentrated boiler water, and replacement by steady and constant inflow of feed water.
- Ensures constant TDS and steam purity.
- Once blow down valve is set for a given conditions, there is no need for regular operator intervention.
- Even though large quantities of heat are wasted, opportunity exits for recovering this heat by blowing into a flash tank and generating flash steam.
- This type of blow down is common in high pressure boilers.

Blow Down- Estimation

The quantity of Blow down required to control boiler water solids concentration (continuous Blow down) is calculated by using the following formula:



$$\text{Blowdown \%} = \frac{\text{TDS in FW} \times 100}{\text{Allowable TDS in Boiler drum} - \text{TDS in FW}} = (100 / 3400) \times 100$$

Blow down flow rate = 3% x 10,000kg/hr = 300kg/hr

Automatic Blowdown Control

- Uncontrolled continuous blowdown is very wasteful.

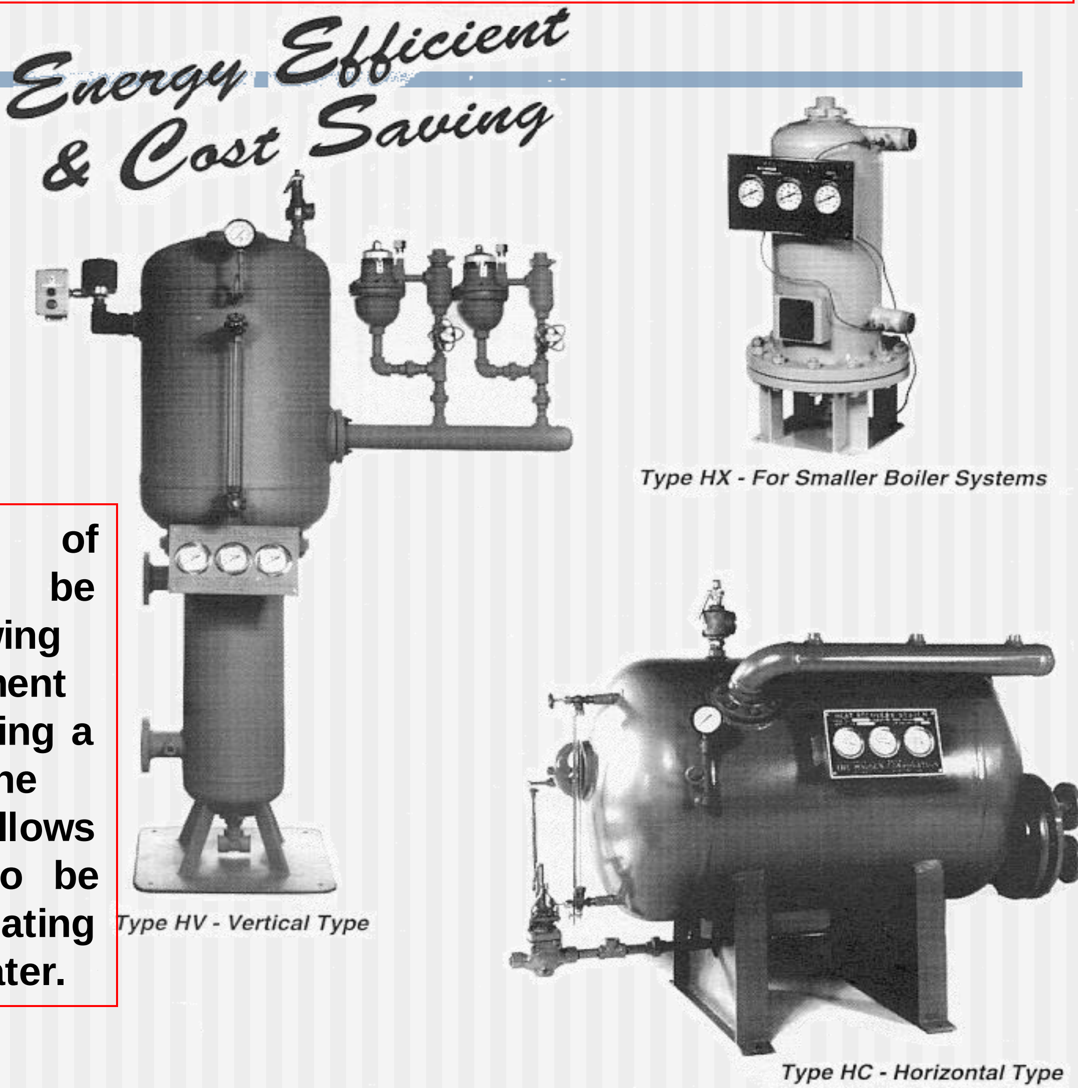
- Automatic blowdown controls can be installed that sense and respond to boiler water conductivity and pH.

A 10% blow down in a 15 kg/cm2 boiler results in 3% efficiency loss.

Blowdown Heat Recovery

Efficiency Improvement – Up to 2 percentage points.

Blowdown of boilers to reduce the sludge and solid content allows heat to go down the drain.



The amount of blowdown should be minimized by following a good water treatment program, but installing a heat exchanger in the blowdown line allows this waste heat to be used in preheating makeup and feedwater.

Heat recovery is most suitable for continuous blowdown operations which in turn provides the best water treatment program.

Boiler water treatment

Boiler water treatment required to

Control steam purity

Control deposits

control corrosion

Soluble components in feed water → *At elevated temp & Pressure* → **Particulate solids**
Some times in crystallized forms and other times as amorphous particles

Solubility of a specific Component in water → *Exceeds certain limit* → **Development of Scale or deposits**

Recommended feed water limits

Recommended Feed Water Limits			
Factor	**Upto 20 Kg/cm^2**	**21 - 40 Kg/cm^2**	**41 - 60 Kg/cm^2**
Total iron (max) ppm	0.05	0.02	0.01
Total copper (max) ppm	0.01	0.01	0.01
Total silica (max) ppm	1.0	0.3	0.1
Oxygen (max) ppm	0.02	0.02	0.01
Hydrazine residual ppm	-	-	-0.02-0.04
pH at 25^{0}C	8.8-9.2	8.8-9.2	8.2-9.2
Hardness	1.0	0.5	-

Recommended Boiler water limits

Recommended Boiler Water Limits			
Factor	**Upto 20 Kg/cm^2**	**21 - 40 Kg/cm^2**	**41 - 60 Kg/cm^2**
TDS	3000-3500	1500-2000	500-750
Total iron dissolved solids ppm	500	200	150
Specific electrical conductivity at 25^{0}C (mho)	1000	400	300
Phosphate residual ppm	20-40	20-40	15-25
pH at 25^{0}C	10-10.5	10-10.5	9.8-10.2
Silica (max) ppm	25	15	10

Reduce Stack Temperature

•Stack temperatures greater than 200°C indicates potential for recovery of waste heat.

•It also indicate the scaling of heat transfer / recovery equipment and hence the urgency of taking an early shut down for water / flue side cleaning.

22° C reduction in flue gas temperature increases boiler efficiency by 1%

Reduce Stack Temperature

Feed Water Preheating using Economiser

For an older shell boiler, with a flue gas exit temperature of 260°C, an economizer could be used to reduce it to 200°C, Increase in overall thermal efficiency would be in the order of 3%.

6°C raise in feed water temperature by economizer / condensate recovery, corresponds to a 1% saving in fuel consumption.

Reduce Stack Temperature

Combustion Air Preheating

- Combustion air preheating is an alternative to feed water heating.

In order to improve thermal efficiency by 1%, the combustion air temperature must be raised by 20°C.

Incomplete Combustion
(C C C C C + CO CO CO CO)

Incomplete combustion can arise from a shortage of air or surplus of fuel or poor distribution of fuel.

In the case of oil and gas fired systems, Co or smoke with normal or high excess air indicates burner system problems.
Example : Poor mixing of fuel and air at the burner. Poor oil fires can result from improper viscosity, worn tips, carbonization on tips and deterioration of diffusers.

With coal firing : Loss occurs as grit carry-over or carbon-in-ash (2% loss).
Example : In chain grate stokers, large lumps will not burn out completely, while small pieces and fines may block the air passage, thus causing poor air distribution.
Increase in the fines in pulverized coal also increases carbon loss.

Control excess air

The optimum excess air level varies with furnace design, type of burner, fuel and process variables.

Excess air levels for different fuels		
Fuel	**Type of Furnace or Burners**	**Excess air, % by wt**
Fuel Oil	Oil Burners, Register type	5-10
	Multi-fuel burners & flat falme	10-30
Pulverised Coal	Completely water cooled furnace for slag - tap dry- ash removel	15-20
	Partially water cooled for dry ash removal	15-40
Coal	Spreader stoker	30-60
	Water cooled vibrating grate stokers	30-60
	Chain grate and travelling grate stokers	15-50
	Underfeed stoker	20-50
Wood	Dutch over (10-23% through grates) and Hofft type	20-25
Bagasse	All furnaces	25-35
Black Liquor	Recovery furnace for draft and soda pulping processes	5-7

Install oxygen trim system

For every 1% reduction in excess air, 0.6% rise in efficiency.

Radiation and Convection Heat Loss

•The surfaces lose heat to the surroundings depending on the surface area and the difference in temperature between the surface and the surroundings.

•The heat loss from the boiler shell is normally a fixed energy loss, irrespective of the boiler output. With modern boiler designs, this may represent only 1.5% on the gross calorific value at full rating, but will increase to around 6%, if the boiler operates at only 25 percent output.

•Repairing or augmenting insulation can reduce heat loss through boiler walls.

Reduction of Scaling and Soot Losses

•In oil and coal-fired boilers, soot buildup on tubes acts as an insulator against heat transfer. Any such deposits should be removed on a regular basis. Elevated stack temperatures may indicate excessive soot buildup. Also same result will occur due to scaling on the water side.

•High exit gas temperatures at normal excess air indicate poor heat transfer performance. This condition can result from a gradual build-up of gas-side or waterside deposits. Waterside deposits require a review of water treatment procedures and tube cleaning to remove deposits.

•Stack temperature should be checked and recorded regularly as an indicator of soot deposits. When the flue gas temperature rises about 20°C above the temperature for a newly cleaned boiler, it is time to remove the soot deposits.

Reduction of Scaling and Soot Losses

- Incorrect water treatment, poor combustion and poor cleaning schedules can easily reduce overall thermal efficiency.
- However, the additional cost of maintenance and cleaning must be taken into consideration when assessing savings.

Every millimeter thickness of soot coating increases the stack temperature by about 55°C. 3 mm of soot can cause an increase in fuel consumption by 2.5%.

A 1mm thick scale (deposit) on the water side could increase fuel consumption by 5 to 8%.

Reduction of Boiler Steam Pressure

- Lower steam pressure gives a lower saturated steam temperature and without stack heat recovery, a similar reduction in the temperature of the flue gas temperature results. Potential 1 to 2% improvement.

- Steam is generated at pressures normally directed by the highest pressure / temperature requirements for a particular process. In some cases, the process does not operate all the time, and there are periods when the boiler pressure could be reduced.

Adverse effects, such as an increase in water carryover from the boiler owing to pressure reduction, may negate any potential savings.

Pressure should be reduced in stages, and no more than a 20 percent reduction should be considered.

Variable Speed Control for Fans, Blowers and Pumps

Generally, combustion air control is effected by throttling dampers fitted at forced and induced draft fans. Though dampers are simple means of control, they lack accuracy, giving poor control characteristics at the top and bottom of the operating range.

If the load characteristic of the boiler is variable,
the possibility of replacing the dampers by a VSD should be evaluated.

Operational Maintenance and Shutdown Maintenance

- Checking of Pressure parts for

Sagging

Distortion

Thickness

- Refractories/Insulation
- Fans/Pumps
- Ducting
- Steam drum

Boiler Replacement

If the existing boiler is :

Old and inefficient, not capable of firing cheaper substitution fuel, over or under-sized for present requirements, not designed for ideal loading conditions replacement option should be explored.

The feasibility study should examine all Implications of long term fuel availability and company growth plans. All financial and engineering factors should be considered. Since boiler plants traditionally have a useful life of well over 25 years, replacement must be carefully studied.