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Deaerator Design Aspects and Troubleshooting

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BACKGROUND:

Steam is one of the most useful and vital utilities in many chemical process industries. It is the favored heating medium in process plants for several reasons:

- High content of latent heat associated with condensation.
- It is non-explosive.
- Given that it is generated from water, it is cheap.

Steam applications can be divided into the following categories:

- Recoverable usage:
  - Heating medium in heat exchangers to heat process fluid to desired temperature.
  - To spin turbines to generate power or drive rotating equipment.
  - Steam tracing to maintain the process the temperature at desired temperature or prevent freezing
- Non-recoverable usage:
  - Steam purging to avoid plugging in some services in relief valves
  - Steam stripping, such as in a distillation column, to reduce the partial pressure of the hydrocarbons as per Dalton's Law.
  - Addition of steam to the relief valve outlet piping to improve dispersion and reduce the flammability of certain chemicals, such as ethylene oxide.
  - Steam injection in flare for smokeless operation.
  - Steam ejectors
  - Steam reforming to produce Syngas.

Can steam be produced straight from raw water? is a possible query.

Of course, the response would be negative! We all know that the source of the water affects its quality. Water typically contains the following contaminants, for example

- Sand and silt.
- Iron
- Copper
- Silica
- Aluminum
- Calcium
- Magnesium
- Hardness
- Total dissolved solids
- Suspended solids and organic material
- Dissolved gasses

Some contaminants, such silicates, which have a tendency to deposit on the steam turbines' rotor blades, can lead to scaling. Such deposits will throw off the rotor's balance, which will create vibration, which will eventually harm seals and shaft bearings. Additionally, additional pollutants like oxygen and carbon dioxide, which are present, promote corrosion. So generally, the raw water first needs to have primary treatment through filters to remove sand and silt. Then, this water can be sent to secondary treatment such as demineralization or hot lime softening to remove dissolved solids.

Selecting technology for boiler feed water treatment is a complex activity and that's based on the feed water source and boiler speciation. Hence, such activities shall be conducted by a water treatment expert.

Here are some common treatment processes:

- Reverse Osmosis (RO)
- Softening.
- Chemical precipitation
- Deaeration

Before steam is produced in the boiler, dissolved gases (such as oxygen and carbon dioxide) must also be eliminated. This process is termed ((deaeration)) and it happens in an integral devise called a deaerator. (For a typical Steam plant, see Figure 1)

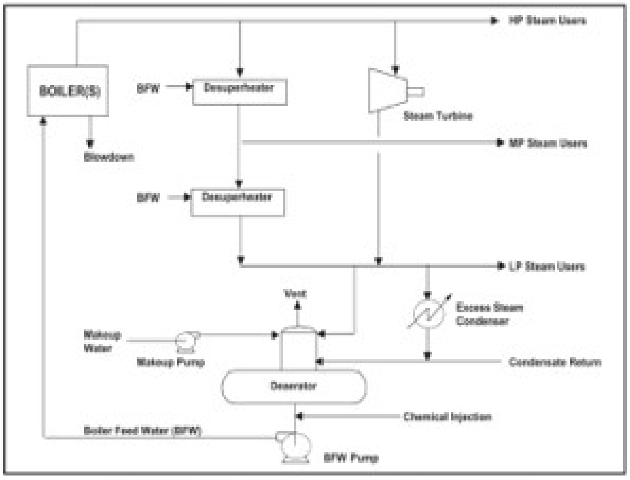


Figure 1- Typical Steam plant

This article will focus on deaeration principles, design aspects of deaerator system and common deaerator malfunction.

DEAERATION PRINCIPLE

Industrial steam boilers are a huge investment and are considered as long lead items. As such, it is required to extend their life and keep their efficiency for as long as possible. The existence of oxygen in the boiler system can be a substantial problem due to its corrosivity at high temperature. Also, carbon dioxide which is produced from dissolved solids could lead to serious corrosion into downstream heat exchangers. That happens as carbon dioxide dissolves in condensed steam and produces formic acid.

The purpose of the deaerator is to remove dissolved gases from boiler feed water oxygen and carbon dioxide). Deaeration is The purpose of the deaerator is to remove dissolved gases from boiler feed water oxygen and carbon dioxide). Deaeration is built on two scientific concepts. The first scientific concept can be defined by Henry's Law.

Henry's Law states that gas solubility in a solution decrease as the gas partial pressure above the solution decreases.

Figure 2- O_2 Impact (Taken from Stork Vendor)

The second scientific concept that explain deaeration further is the relationship between gas solubility and temperature. Simply, gas solubility in a solution decreases as the temperature of the solution increases and approaches saturation temperature. (See Figure 3)

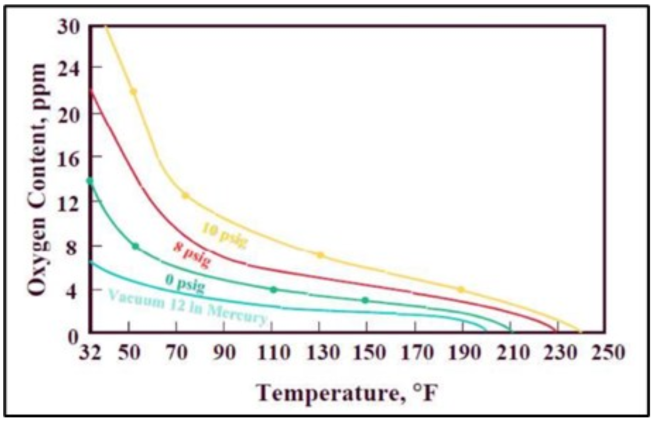
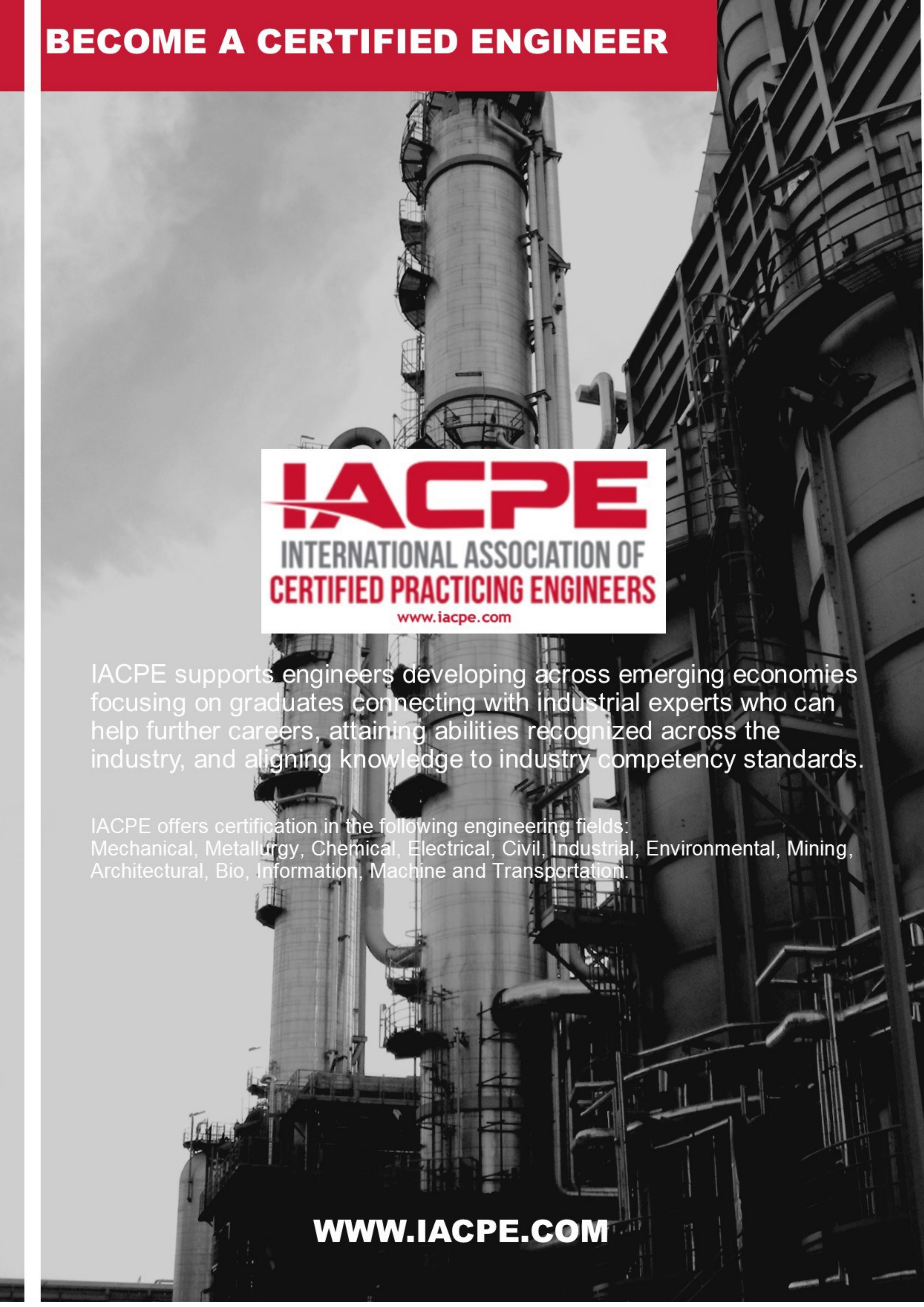


Figure 3- Solubility of oxygen in water (from Reference #3)

A deaerator uses both concepts to take away dissolved oxygen, carbon dioxide and other non-condensable gases from the boiler feed water. The feedwater is sprayed in thin films though spray nozzles into a steam allowing it to become quickly heated to saturation. Spraying feedwater in thin films rises the surface area of the liquid in contact with the steam, which enhance the mass transfer and results in more quick oxygen elimination and lower gas concentrations. The liberated gases are then vented from the deaeration section.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DESIGN ASPECTS OF DEAERATOR

A typical deaerator consists of two sections, stripping section for deaerating and heating and another section provides storage.

Types

Generally, Deaerators are classified into two types as following:

Spray-Type

A spray-type deaerator is classically a single horizontal vessel which consists of two sections, deaeration section and a preheating section. The two sections are separated by a baffle. Low pressure steam passes into the deaerator through a sparger in the bottom of the deaerator. (See Figure 4)

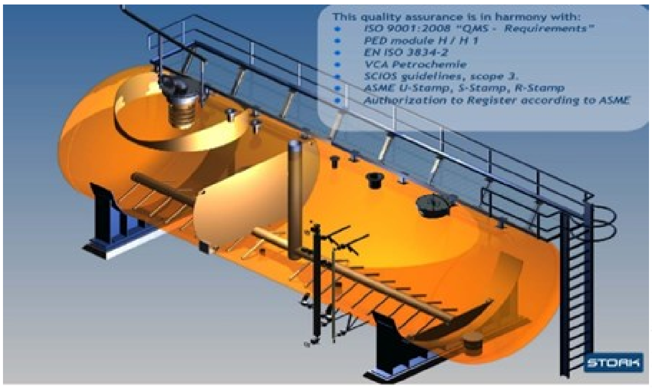

Figure 4- Spray-type deaerator (Taken from Stork Vendor)

The feedwater is sprayed in thin films over spray nozzles into the preheating section (1st section in above photo), where it is heated to saturated temperature to enable stripping out the dissolved gases in the subsequent deaeration section.

Then, the heated feedwater moves to the deaeration section where it is deaerated by the steam rising from the bottom sparger. The stripped-out gases of the water exit via the vent that is mounted on the top of deaerator.

Tray-Type

The typical tray-type deaerator has a vertical domed deaeration section, that may be horizontal in some cases (i.e big deaerator), mounted above a horizontal feedwater hold-up storage vessel.

Make-up feedwater enters the domed deaeration section over spray valves above the perforated trays and then flows downward through the holes in thetrays. Low-pressure steam joins below the perforated trays and flows upward through the perforations. Combined action of spray valves & trays guarantees very high performance because of longer contact time between steam and water.

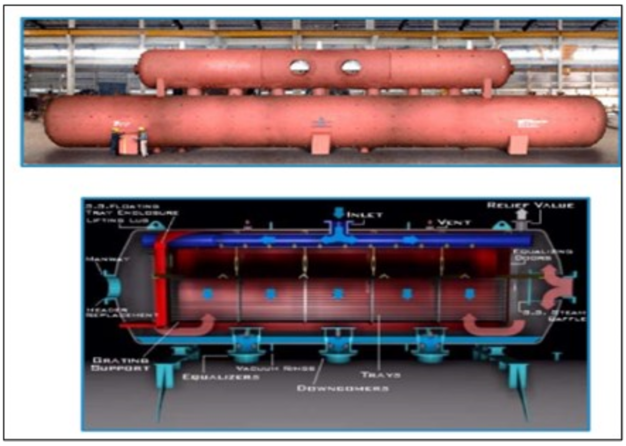

Figure 5- Tray-type deaerator (Taken from Stork Vendor)

The steam strips the dissolved gas from the feedwater and leaves through the vent valve. (See figure #5)

Spray Type Vs Tray Type

	Spray Type	Tray Type
Cost	Lower	Higher
Affected by solids or scale (1)	No	Yes
Load Variation (2)	Can't operate well	Can operate properly

1. Scaling will lead to operating issues in tray type.
2. Tray-type copes well with load variation such as night, summer and with turbines that have extensive range of load. However, some vendors guarantees higher turndown in special spray type such as STORK Spray Deaerator.

Deaerator Performance

Deaerator shall be designed to reduce oxygen to 0.007ppm or less. Deaerators will eliminate free carbon dioxide. Chemical scavenging of oxygen is still enormously significant despite the apparent low levels achieved by physical means.

Steam Consumption:

Steam Consumption could be calculated by means of applying basic form of the first law of thermodynamics:

$$\Delta H+\Delta E_K+\Delta E_P=Q-W_s$$

Equation can be simplified with following:

1- Ws = shaft work =0 (as no moving part in Deaerator system).

2- Kinetic and potential energy (ΔEK,ΔEP)=0

3- Q =0 as deaerator is insulated.

Therefore, Equation will be as following:

$$\Delta H = \sum (H.\ M)_{out} - \sum (H.\ M)\ in$$

H: Specific enthalpy (KJ /Kg)

M: Mass flow rate (Kg/h)

Let's take quick example to estimate Steam requirement for new deaerator with following design data:

Operating Pressure/Temperature: 0.42barg /110℃

Deaerator Sketch

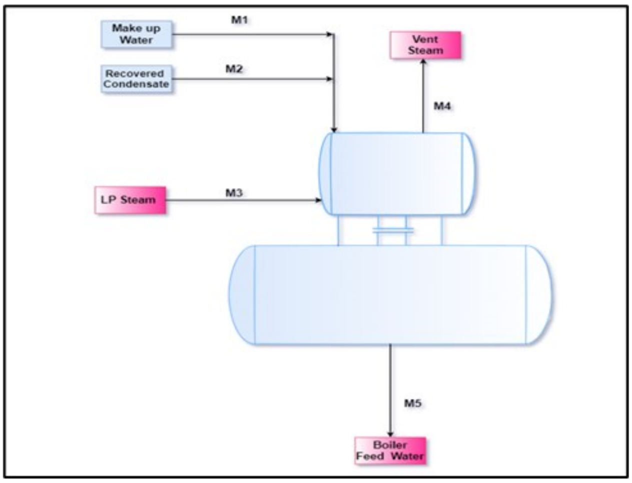

Figure5- Deaerator Sketch

Deaerator Streams Table:

	Pressure	Temperature	Flow	Enthalpy
Stream /Unit	Barg	℃	Kg/h	KJ/Kg
Make up Water	4	30	71319	126.12
Recovered Condensate	4	96.7	618200	405.46
Low Pressure Steam	3.5	165	TBC	2781.43
Boiler Feed Water	0.42	110	TBC	461.32
Vent Steam	0.42	110	200	2691.3

TBC: To be calculated

Please be noted that this vent stream is minor and its value rises with the selected operating pressure and temperature of the deaerator (e.g. 50-200 kg/h at 105 C, 1000kg/h at 150 C).

However, Process engineers sometimes uses other approach to estimate vent steam same as rule of thumb:

The vent stream may be assumed as 2% of the inlet steam to deaerator.

For simplicity in this example, vent steam is assumed as 200 kg/h.

Boiler feed water and Steam flow rates shall be calculated. We have two equations (mass balance and energy balance) and two unknowns so degree of freedom is zero.

Hence, this example can be solved with following equations:

$$M_1+M_2+M_3=M_4+M_5\ (1)$$

$$M_1 \times H_1 + M_2 \times H_2 + M_3 \times H_3 = M_4 \times H_4 + M_5 \times H_5\ (2)$$

M_1, M_2 and M_3 are knowns from Deaerator Streams Table, so equation (1) would be: $M_5=689319 + M_3$ **(3)**

Then, if we substitute equation (3) in in equation (2), equation (2) would be:

$$M3 = \frac{((M1\,X\,H1) + (M2\,X\,H2) - (M4\,X\,H4) - (689319\,X\,H5))}{(H5 - H3)} \quad (4)$$

Now, M_3 and M_5 can be calculated simply from equation (4).

M_3=25380.17 Kg/h

M_5=714699.17 Kg/h

M_1, H_1: Mass flowrate, Enthalpy of Make-up Water
M_2, H_2: Mass flowrate, Enthalpy of recovered condensate
M_3, H_3: Mass flowrate, Enthalpy of LP steam
M_4, H_4: Mass flowrate, Enthalpy of vent steam
M_5, H_5: Mass flowrate, Enthalpy of boiler feed Water

CASE STUDY

The intention of this case study is to show impact of recovered condensate temperature on low-pressure steam requirement.

Before diving into case study, lets have quick overview of typical condensate system in chemical process industry (CPI).

Recovered condensate usually represent 80% to 90% of total inlet stream to deaerator. Hence, Temperature have more impact on low -pressure steam requirement than make up water.

Recovered condensate can be classified into two into following categories:

Suspected Condensate:

Condensate comes from process heat exchanger where hydrocarbon can leak to condensate system. Such condensate shall be sent to condensate polishing unit where hydrocarbon is adsorbed on activated carbon.

Clean Condensate:

Condensate comes from condensing steam turbine that use water-cooled shell and tube heat exchanger to condense its exhaust steam.

Cooling water leak to condensate system can increase silica that has bad impact on rotor blades of steam turbines as mentioned previously. Such condensate shall be sent to condensate polishing unit where cations /anions limits are restored by means of mixed bed column.

It is typically necessary to cool the condensate to nearby 50 °C to inhibit temperature degradation of the anion resins.

In such case, process engineer shall find a way to raise condensate temperature by means of heat recovery such routing condensate stream through Condensate in waste heat boiler. Such heat recovery will reduce steam requirement, fuel gas and boiler feed water power consumption.

Back to case study, HYSYS was utilized to realize steam requirement to deaerator at various temperatures.

The results are summarized in below table:

	Temperature (°C)	steam requirement (kg/h)
Case 1	50	77638.3
Case 2	55	72067.3
Case 3	60	66493.7
Case 4	65	60917.2
Case 5	70	55337.4
Case 6	75	49753.6
Case 7	80	44165.5
Case 8	85	38572.3
Case 9	90	32973.5
Case 10	95	27368.2
Case 11	100	21755.8

The below plot may demonstrate results in better way than previous table: \

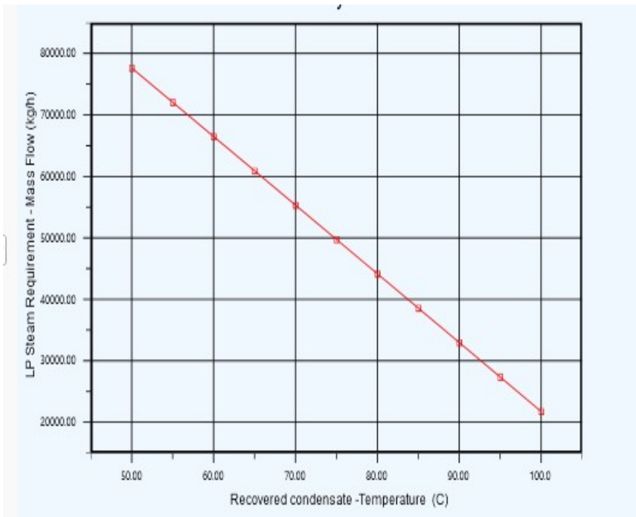

Figure 6- Steam requirements Vs Temperature of Condensate

The below tables show steam requirement reduction % based on temperature rise by 5 ° C:

	Temperature (°C)	steam requirement (kg/h)	Steam Requirement Reduction %
Case 1	50	77638.3	7.2%
Case 2	55	72067.3	7.7%
Case 3	60	66493.7	8.4%
Case 4	65	60917.2	9.2%
Case 5	70	55337.4	10.1%
Case 6	75	49753.6	11.2%
Case 7	80	44165.5	12.7%
Case 8	85	38572.3	14.5%
Case 9	90	32973.5	17.0%
Case 10	95	27368.2	20.5%
Case 11	100	21755.8	

If condensate is heated from 50 °C to 95 °C, steam requirement will reduce by 58%, which will decrease fuel gas and pump power consumption accordingly.

COMMON DEAERATOR MALFUNCTION

Deaerators play a key role in ensuring a long and efficient equipment life. Mechanical deaeration is the primary means of removing dissolved gases from various condensate streams and make-up water streams.

Some of the essential factors required for deaerators to work efficiently are as outlined below:

Temperature:

Ensuring the entire water flow to the reaches the saturation temperature is vital to the performance of the deaerator. Dissolved gases are released from water at the saturation temperature.

Spraying/Mixing:

Good spraying or turbulence increases the contact area and promotes the release of gases.

Venting:

Adequate venting capacity plays a major role in the deaerator performance. The released gases should be continuously vented from the system.

Stable operating conditions:

Wide range of fluctuations in feed water flow rate and temperatures can affect the deaerator performance adversely. By creating, additional demands on steam control systems.

The following table lists some of the common malfunctions encountered in typical deaerators and their possible causes

Malfunction	Possible cause
High dissolved Oxygen in BFW	Inadequate venting Very high delta T between deaerator temperature and BFW outlet Internal channeling or damaged spray nozzles Large variations in incoming water flowrates and temperatures Air leakage through surface condenser for turbine
Pressure fluctuations	Heating steam control valve hunting or incorrectly sized
Excessive vibration of deaerator or tank	Blocked internals or damaged condenser tubes
Low Outlet Temperature	Incorrect Thermometer reading Insufficient steam flow Spray valves or internals malfunction

STORK DEAERATOR

Last but not least, we would like to present a technical comparison between conventional tray-type and STORK- Spray type. The below comparison table is handed by STORK vendor.

ACKNOWLEDGMENT

We are grateful to STORK Company, world-leading designer and manufacturer specialty equipment (e.g. boilers, deaerators and burners, along with complex pipe spools), for providing some pictures and sharing some practical information about deaerators.

	Stork-type	Conventional tray-type
Layout	Low total height, because of the single-vessel design. Easy erection, minimum platforms, insulation, and piping. Since the Stork design requires a specific steam compartment in the vessel above the water level, water levels must be a little lower than in the tray-type design, giving slightly less storage volume at the same geometric vessel volume.	Usually two-vessel design or dome-design. More piping, connection between vessels makes erection more complicated. More insulation and platforms needed.
Operation	During heating-up and filling deaerated water is available, saturation conditions in every part. No thermal stress as there are no temperature differences present. The operating range is approx. 1:30. There is no pressure difference in the steam area.	The operating range is approx. 1:4. Pressure differences top- and bottom section can arise.
Safety	Low susceptibility to earthquakes thanks to the application of internal deaeration instead of a superimposed deaerator dome. Single vessel with a minimum of components gives maximum safety.	Two-vessel design has drawbacks in robustness and earthquake-resistance.
Maintenance & Spares	No maintenance required, only gaskets for manholes and gaskets for sprayers are needed as spare parts to enable inspections.	Trays to be replaced after certain time of operating. In case of unexpected high loads, risk of tray damage exists.
Erection	The erection is extremely easy. The deaerator can be mounted by local personnel, using the accompanying instructions for erection.	Erection more complex. If deaerators are placed inside a building, they are usually located on elevated areas. Because of the dome section, the building's roof must be higher with a tray-type design in such a case.

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