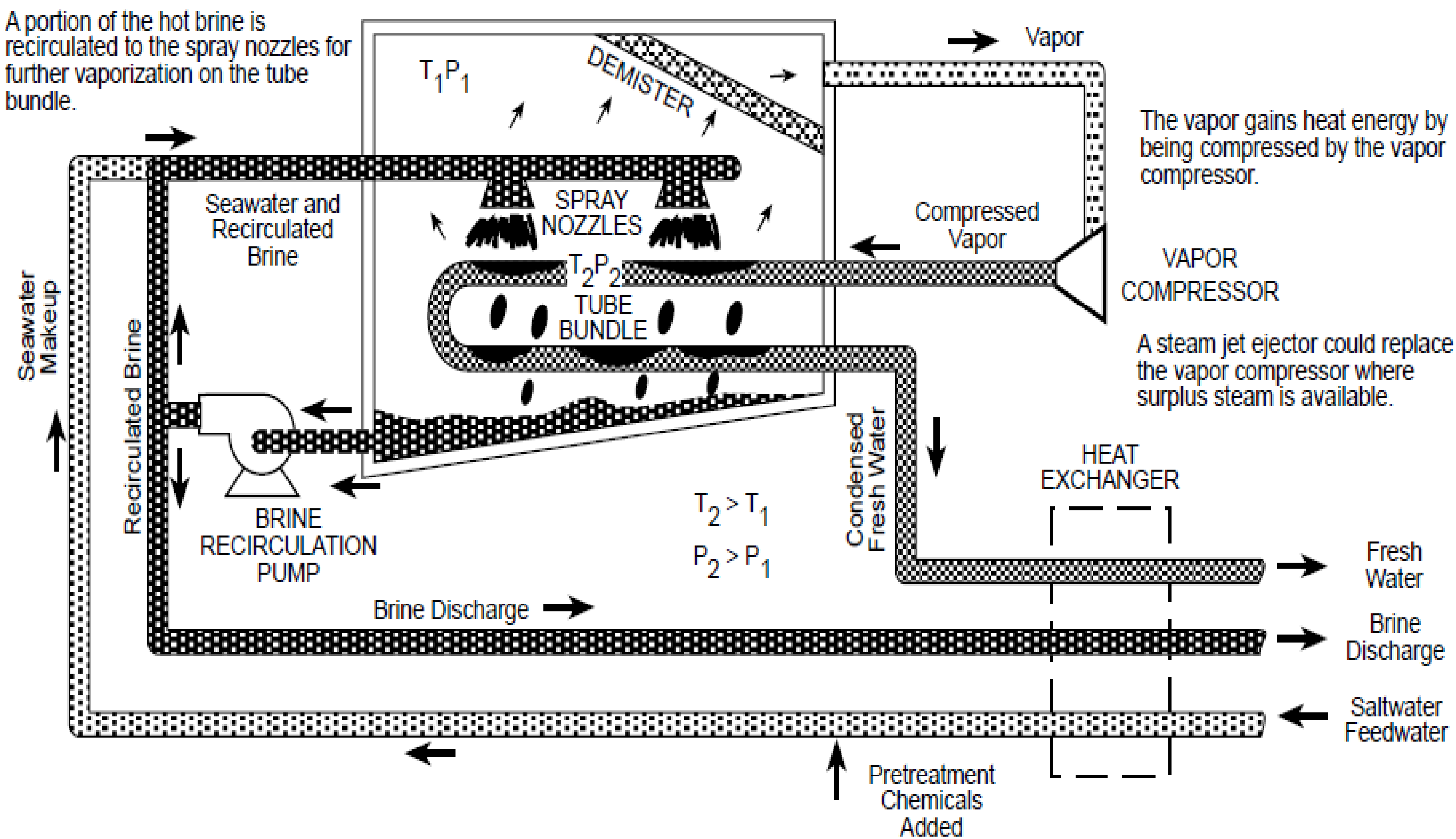
Vapor Compression Distillation (VCD)

Lecture 3

Vapor Compression Distillation (VCD)

- It is generally used for small- and medium-scale sea water desalting units.
- The heat for evaporating the water comes from the **compression of vapor** rather than the direct exchange of heat from steam produced in the boiler.
- The plants which use this process are generally designed to take advantage of the principle of reducing the boiling point temperature by reducing the pressure.

Vapor Compression Distillation (VCD)



Vapor Compression Distillation (VCD)

Vapor Compression Distillation (VCD)

- Two primary methods are used to condense vapor so as to produce enough heat to evaporate incoming sea water: a **mechanical compressor** or a **steam jet**.
- The **mechanical compressor** is usually **electrically driven**, allowing the **sole use** of electric power to produce water by distillation.

Vapor Compression Distillation (VCD)

- **Mechanical Compression:**
- VCD units have been built in a variety of configuration to promote the exchange of heat to evaporate the sea water.
- The diagram illustrates a simplified method in which a **mechanical compressor** is used to **generate** the **heat for evaporation**.

Vapor Compression Distillation (VCD)

- Vapor compression (VC) involves

1. Evaporating the feed water,
2. Compressing the resulting vapor, and then
3. Using the pressurized vapor as a heat source to evaporate additional feed water.

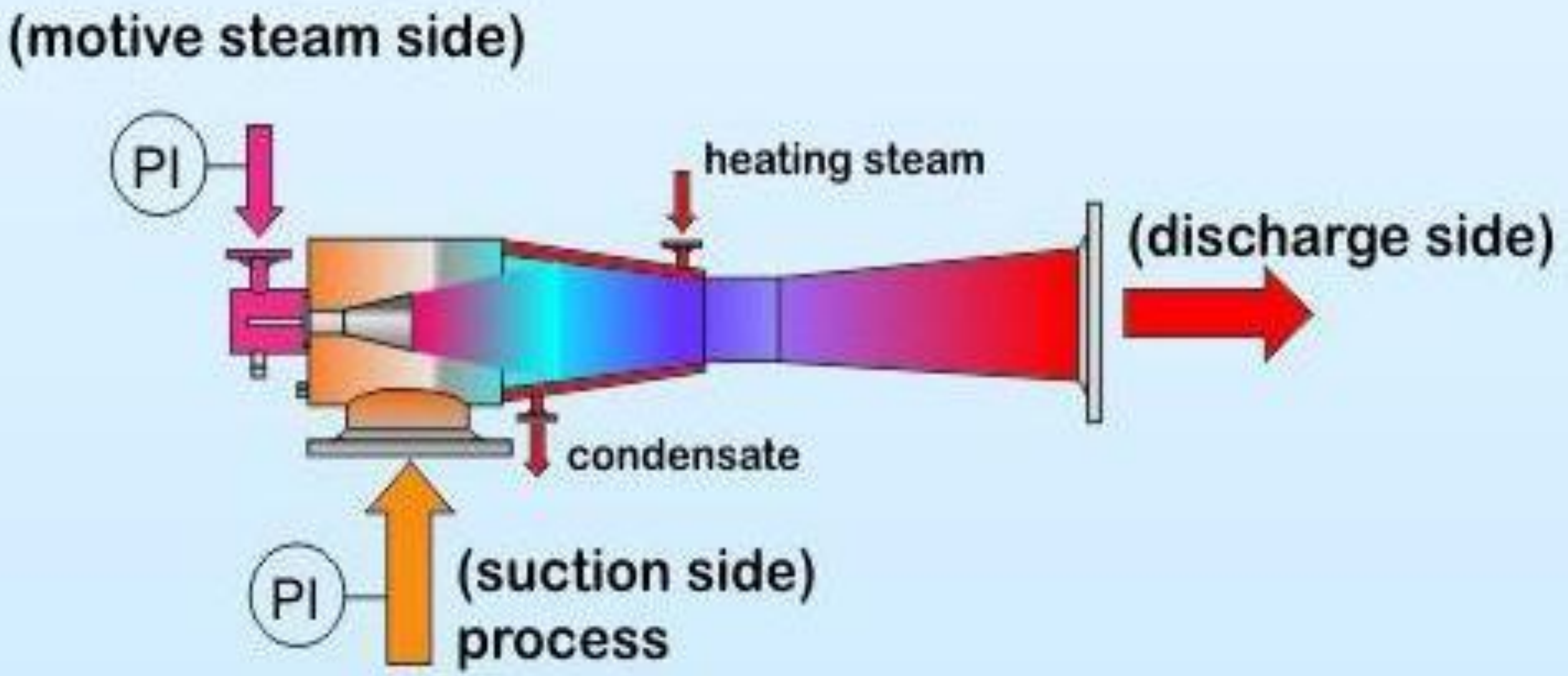
Vapor Compression Distillation (VCD)

- The compressor creates a vacuum in the vessel and then compresses the vapor taken from the vessel and condenses it inside of a tube bundle also in the same vessel.
- Sea water is sprayed on the outside of the heated tube bundle where it boils and partially evaporates, producing more vapor.
- The **demister** is formed of wire mesh layers and the supporting system.
- The **demister function** is to **remove the entrained brine** droplets from the flashed off vapor.
- This is essential to **prevent increase in the salinity of product water** or **scale formation** on the outer surface of the condenser tubes.

Vapor Compression Distillation (VCD)

- **Steam Jet Compression**
- With the steam jet type of VC unit, also called a thermo-compressor. A venture orifice at the steam jet creates and extracts water vapor from the main vessel, creating a lower ambient pressure in the main vessel.
- The extracted water vapor is compressed by the steam jet.

Vapor Compression Distillation (VCD)



Vapor Compression Distillation (VCD)

- This mixture is condensed on the tube walls to provide the thermal energy (heat of condensation) to evaporate the sea water being applied on the other side of the tube walls in the vessel.
- VC units are usually built in the **20-2,000 m^3/D** range.
- They are often for resorts, industries, and drilling sites where fresh water is not readily available.

Metals used in thermal processes

- Material selection depends on the stage temperature.
- In this regard, **Cu/Ni 70/30** is used in stages with temperatures higher than **80°C.**
- On the other hand, in stages with **lower temperatures** a number of materials can be used, which includes **Cu/Ni 90/10**, **aluminum brass**, **high steel alloys**, and **titanium**.
- The **highest thermal conductivity** among these materials is the **Cu/Ni 90/10**.

Metals used in thermal processes

- On the other hand, **titanium** tube provides the **highest erosion resistance** and the **lowest wall thickness.**
- **Aluminum brass** provides a **cheaper** material, however, its **copper content dissolves in the seawater** and has an adverse impact on the receiving water bodies.
- The same problem is also found in other types of copper based tubes.
- In this regard, **titanium**, although more **expensive** than the copper alloys, it **does not dissolve** in the seawater.

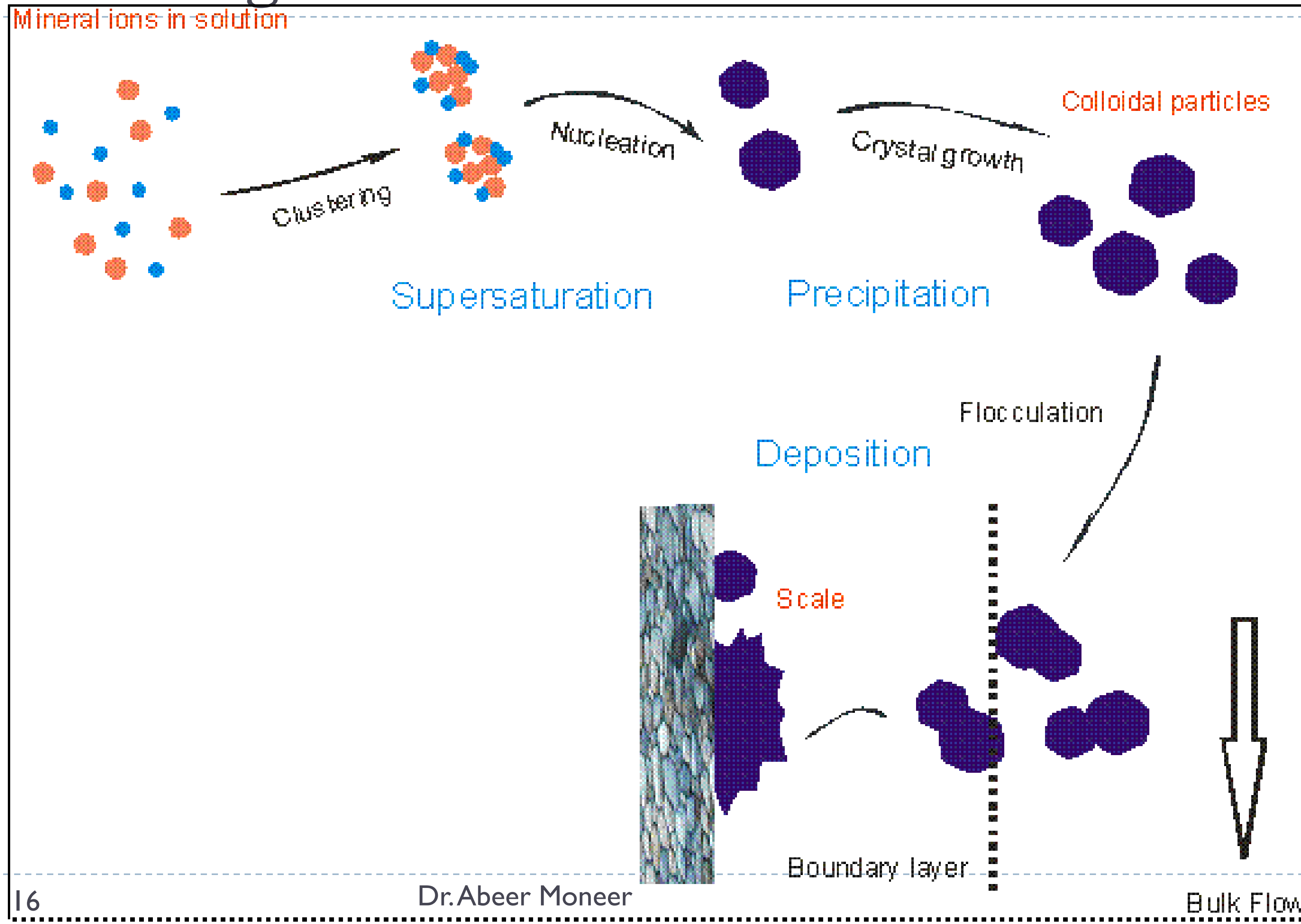
Problems in thermal desalination plants
1. Scaling

- **Scale** is the formation of **salt deposits** on process surfaces.
- Scale forms when a given salt exceeds its **saturation limits**, which depends on both **temperature** and **salinity**.
- Salts of particular concern in seawater desalination are **calcium carbonate ($CaCO_3$)**, **Magnesium hydroxide ($Mg(OH)_2$)** and **calcium sulphate ($CaSO_4$).**
- The **solubility** of these salts **decreases** with **increasing temperature and salinity**, thus limiting the operating range of thermal desalination.

Problems in thermal desalination plants
1. Scaling

- On heating, **bicarbonate will yield carbonate**, which can precipitate **with calcium** if the saturation limit is exceeded.
- **Magnesium hydroxide** will also form.
- **Calcium carbonate** and **magnesium hydroxide** are termed **"alkaline scales"** while **calcium sulfate** is known as **"non-alkaline** scales".
- Alkaline scale formation in condenser tubes is a major problem encountered in the operation of MSF distillers.

Problems in thermal desalination plants
1. Scaling



Problems in thermal desalination plants
1. Scaling

Problems in thermal desalination plants
1. Scaling

- **Scale** formed on heat transfer surfaces **reduces** its **effectiveness** and **increases** the necessary **pumping** water.
- As a result of those solubility problems, thermal desalination operation is limited to a **top brine temperature (TBT)** and a **maximum brine salinity** of effects/stages in order to avoid violation of solubility limits.
- Seawater **pretreatment** additives are utilized in order to **increase the TBT** and thus **decrease** the specific **power consumption** of the process.

Problems in thermal desalination plants
1. Scaling

- **<u>Two methods</u>** are employed to control the formation of alkaline scales.
- **<u>The first</u>** involves the prevention of scale deposition by reaction, hence depletion of carbonate through pH adjustment by **<u>acid addition</u>**.
- **<u>The second</u>** method controls scale precipitation through the **<u>addition of special chemicals</u>**.
- These are **<u>inorganic or organic polymer</u>** compounds which, when adsorbed on a scale crystalline, **<u>interfere</u>** either with the **<u>nucleation</u>** or the **<u>crystal growth</u>** process.

Problems in thermal desalination plants
1. Scaling

- **Sodium tripolyphosphate** dispersing agent has been used to inhibit alkaline scale deposition in seawater evaporators since the 1950s.
- Addition of polyphosphate retards the formation of alkaline scale by preferentially **combining the calcium and magnesium into non-adherent complexes.**
- This treatment is named as **threshold** because of the **small quantities** of chemical used.

Problems in thermal desalination plants
1. Scaling

- Due to **adsorption** of the threshold agent on the scale crystal **nuclei** this results in the formation of **distorted crystal,** and subsequent **inhibition of its growth**.
- The **major problem** with **polyphosphate**-based inhibitors was found to be the **thermal degradation** of polyphosphate at temperatures **above 90°C** and the subsequent loss of threshold effect of the product.
- This restriction in **TBT to 90°C** limited the thermal efficiency of evaporator designed for threshold treatment during the 1950's and 1960's.

Problems in thermal desalination plants
1. Scaling

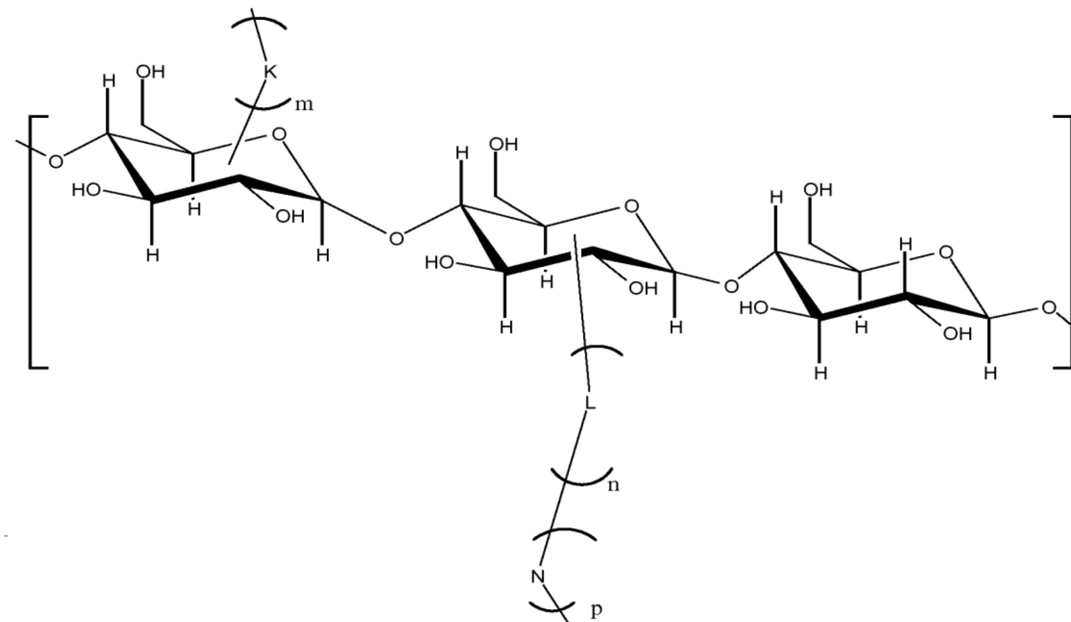
- **Acid dosing** was introduced in the 1960s as a means of **overcoming** the temperature limitations and the **poor performance of polyphosphate**.
- Acid dosing, by **removing the bicarbonate** from the feed water, allowed evaporators to operate at **increased TBT**, close to the **calcium sulfate solubility limits**.
- It was found to have **drawbacks** such as **careful control** and **monitoring of the dose level** was essential to minimize the **risks** of plants **corrosion or scale formation** and ensure a reasonable plant life.

Problems in thermal desalination plants
1. Scaling

- As problems associated with acid operation started to become known, the opportunity for high temperature scale control additives to replace acid while giving measurable performance was noted since 1970.
- **Low molecular weight polymeric carboxylic acid and phosphorous base alkaline were developed as high temperature additives.**
- It has become a common belief that these chemicals distort the lattice structure and minimize the rate of growth of the alkaline scales.

Problems in thermal desalination plants
1. Scaling

- **Carboxymethyl inulin (CMI)** is an **environmentally friendly scale inhibitor** (anti-scalant). Carboxymethyl inulin has been successfully applied for many years now as anti-scalant in the following application:
- Anti-scalant in thermal desalination processes
- Drinking water by RO membranes
- Off shore oil industry
- Paper & Pulp industry
- Detergents
- Water treatment



Problems in thermal desalination plants
2. Corrosion

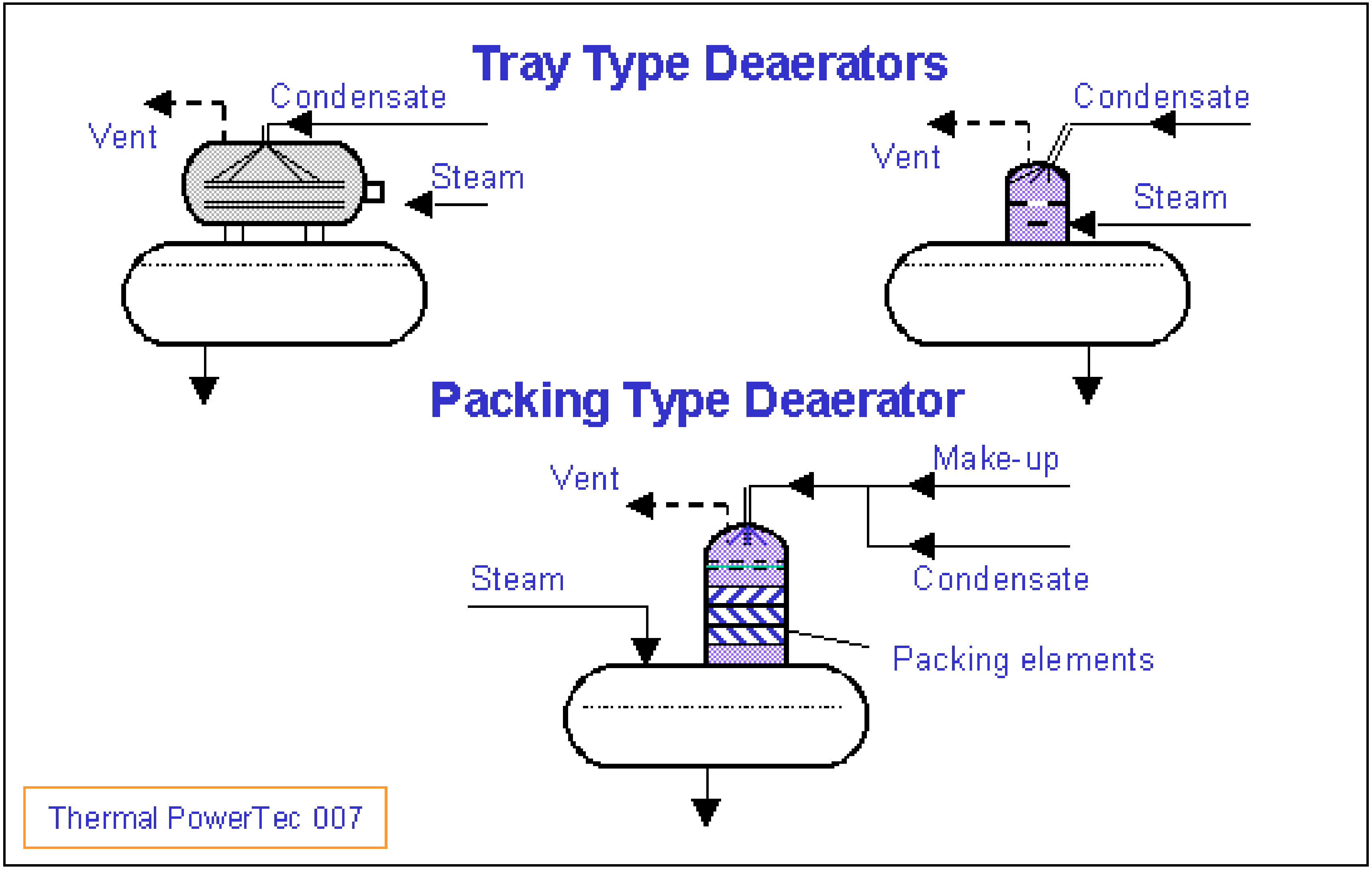
- The presence of dissolved **non-condensable gases (O_2, N_2 and CO_2)** in process water is a serious problem in thermal desalination.
- Even low concentrations can significantly **reduce** the **overall heat transfer coefficient** and hence performance of desalination evaporators.
- In addition, **CO_2** dissolves in the condensate and **lowers** its **pH** which with the **presence of O_2**, may **cause corrosion** of the condenser tubes.

Problems in thermal desalination plants
2. Corrosion

Problems in thermal desalination plants
2. Corrosion

- The release of **CO_2** from the evaporation process considerably influences concentrations of the **carbonate ions** and thus plays an important role in **scale formation**.
- Furthermore, in MSF, the accumulation of non-condensable gases may disturb the brine flow through the flash chambers.
- Therefore, a **deaerator,** and a **decarbonator**, are installed to **avoid** the **accumulation of non-condensable gases** in thermal desalination systems.

Problems in thermal desalination plants
2. Corrosion



Comparison between the 3 thermal processes

	MSF	MED	VCD
Number of stages	4-40	8-16	1
Capacity of each plant (m^3/D)	4,000-30,000	2,000-10,000	20-2,000
Source of heat	Steam from boiler in brine heater	Steam from boiler	Compression of vapor
Top feed temperature (°C)	90-120	About 70	Less than 100
Scale formation and corrosion	High potential	Reduced potential	Same as MED
Thermal efficiency $\alpha(T_{brine\ heater}-T_{condenser})$	Very high	Less	Less than MED
Preheating of sea water	Present	Present	Absent
Direction of sea water and fresh water product	Counter current	Co-current	One cycle
Temperatures and pressure	$T_1>T_2>T_3$...etc $P_1>P_2>P_3$...etc	$T_1>T_2>T_3$...etc $P_1>P_2>P_3$...etc	-

Integrated Thermal Power and Desalination Plant (Co-generation)

Thermal desalination is most widely used in the Arabian Gulf which has led some to presume that only **oil rich nations** can afford a process which appears thermodynamically inefficient.

The reality is that an **integrated power plant and distillation process** (as in the Middle East) has **higher energy efficiency than** achieved when **generating electricity and desalting seawater separately.**

Integrated Thermal Power and Desalination Plant (Co-generation)

In some cases the energy improvement can be **<u>10-20% better</u>**.

Seawater reverse-osmosis **<u>(SWRO)</u>** is often the **<u>lowest cost</u>** method of desalting seawater in a stand-alone process, especially for low salinity waters.

<u>When thermal processes are integrated with heat from power generation the total water cost can be very low, even lower than SWRO.</u>

Integrated Thermal Power and Desalination Plant (Co-generation)

- Most of the distillation plants installed in the Middle East and North Africa have operated under this principle since 1960s and are known in the field as **dual purpose plants** (**water plus power**).
- These units are built as part of a facility that **produce both electric power and desalted seawater** for use in a particular country.
- The **electricity is produced** with **high-pressure steam** to **run turbines** that in turn power **electric generators.**
- In a typical case, boilers produce **high-pressure steam** at about **540°C.**

Integrated Thermal Power and Desalination Plant (Co-generation)

- As this **steam expands** in the turbine, **its temperature and energy level is reduced.**
- Distillation plants need steam whose temperature is about 120°C or below, and this can be obtained by extracting the **lower temperature steam at the low pressure end of the turbine after much of its energy has been used to generate electricity.**
- This **steam** is then **run through the distillation plant's** brine heater, thereby **increasing the temperature** of the incoming seawater.
- The **condensate** from the steam is then **returned to the boiler** to be reheated for use in the **turbine**.

Integrated Thermal Power and Desalination Plant (Co-generation)

- The main **advantage** of an integrated system is that **it can significantly reduce the consumption of fuel when compared to the fuel needed for two separate plants.**
- Since energy is a major operating cost in any desalination process, this can be an important economic benefit.
- One of the **disadvantages** is that **the units are permanently connected together and, for the desalination plant to operate efficiently, the steam turbine must be operating.**
- This permanent coupling can create a problem with water production when the demand for electricity is reduced or when the turbine or generator is down for repairs.

Integrated Thermal Power and Desalination Plant (Co-generation)

- This type of power and water production installation is commonly referred to as a **dual-purpose plant.**
- Since many of the oil producing countries of the Middle East and North Africa were engaged in building up their total infrastructure, these types of installations fit in well with the overall development program in these countries.
- The dual purpose plant has had a pronounced positive impact on **reducing the cost of power and water**.

Shoaiba power and desalination plant

Questions:

- **Answer with Yes or No and correct the false ones:**

1. VCD process is used for small-and –medium scale sea water desalination unit.
2. In VCD process the heat for evaporating the water comes from the compression of sea water rather than the direct exchange of heat from steam produced in a boiler.
3. VCD process acquires its nature from the compression of vapor to produce heat for evaporating the water.
4. The mechanical compression in a VCD process allows the sole use of thermal power to produce water by distillation.

Questions:

5. In VCD, sea water is sprayed on the outside of the heated tube bundle, where it boils and totally evaporates, producing more vapor.
6. VCD units can not be used for industries but can be only used for resorts and drilling sites where fresh water is not readily available.
7. The materials of the thermal stages are made from Cu/Ni alloys only.
8. Titanium tube provides the lowest erosion resistance and the lowest wall thickness.

Questions:

9. Salts of particular concern in seawater desalination are calcium carbonate ($CaCO_3$), Magnesium hydroxide ($Mg(OH)_2$) and calcium sulphate ($CaSO_4$).
10. Seawater pretreatment additives are utilized in order to decrease the TBT and thus decrease the specific power consumption of the process.
11. Seawater reverse-osmosis (SWRO) is often the highest cost method of desalting seawater.
12. Scale forms when a given salt exceeds its saturation limits, which depends on temperature only.

Questions:

- **<u>Complete the following statements:</u>**

1. Calcium carbonate and magnesium hydroxide are termed -------.
2. ------- dispersing agent have been used to inhibit alkaline scale deposition in seawater evaporators.
3. A -------- and a --------- a re installed to avoid the accumulation of non-condensable gases in thermal desalination systems.

<u>Compare between the three thermal processes for desalination from the different processing parameters.</u>

<u>Mention the advantages and disadvantages of the integrated thermal power and desalination plants.</u>