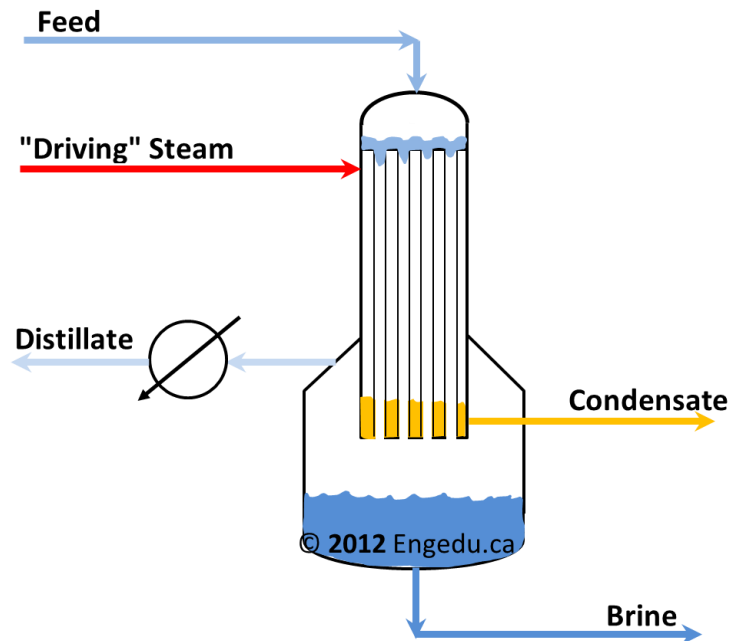


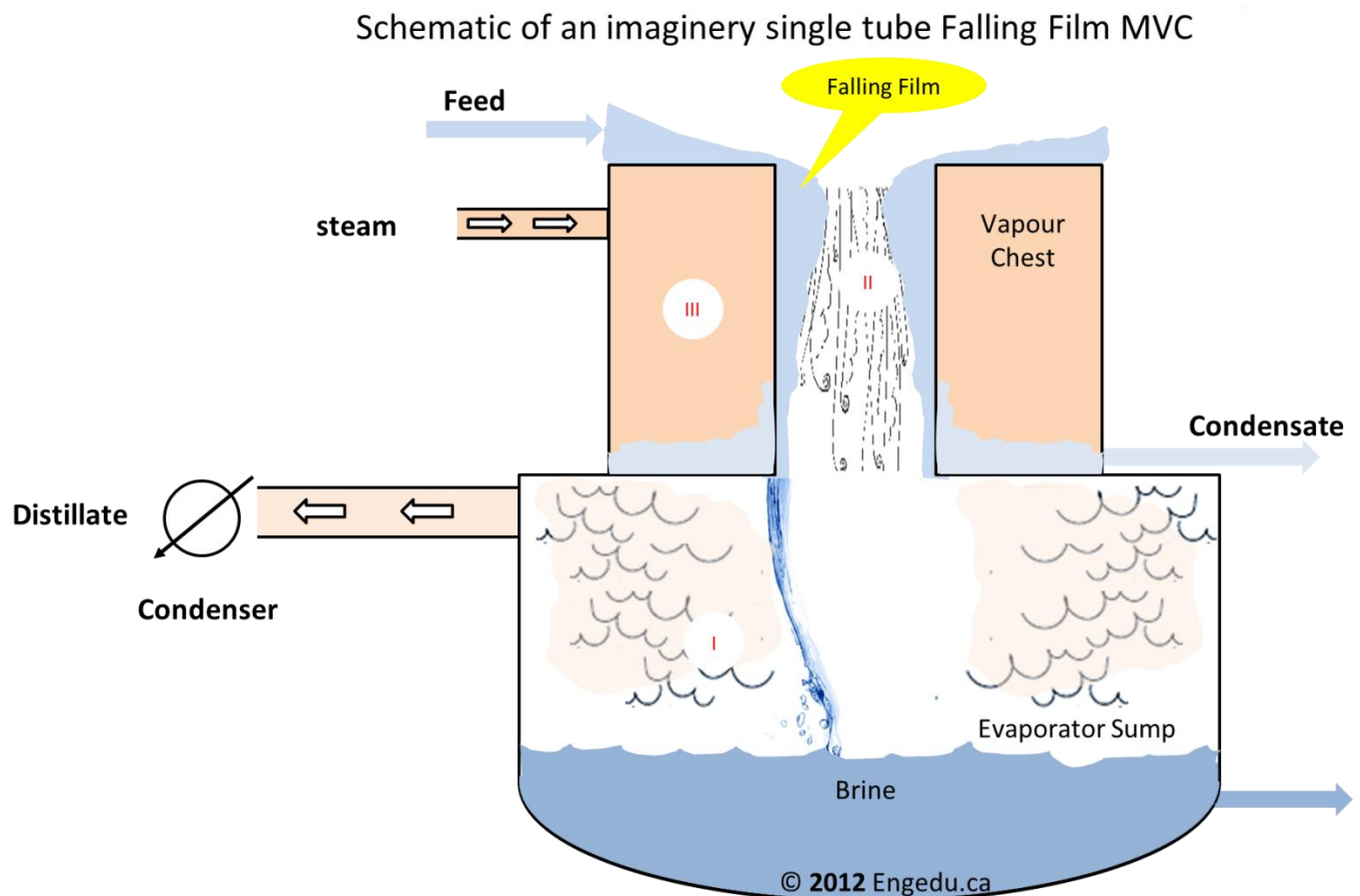
Schematic of a Steam Driven Falling Film Evaporator



This schematic shows an evaporator with steam-driven film falling from vertical pipes—a very popular arrangement in industrial systems. The feed (water with high dissolved solids) comes on the top of the system then is distributed amongst the tubes. However the liquid doesn't seal whole cross section of each tube. It coats the internal wall of each tube and is drawn down by the force of gravity. Throughout this travel, the high temperature of the tubes walls causes this thin film of liquid (liquid film) to slowly evaporates and make it thinned as it goes to the bottom of the tubes. However, no portion of tubes even at the bottom will be dry at all. This process, then, will result in an increase in the concentration of the liquid film which will eventually spills into the sump. The sump contains high-salinity water or brine. The question will arise; what happens to the vapour that was generated as the film traveled down the tube? Does the vapour move up? Actually, no, though the vapours are light, they still accompany the liquid film down the tube and to the sump, where they are at last removed from the evaporator, condensed, and labelled the "distillate".

Now we will discuss the reason behind the high temperature of the tubes themselves. This is achieved by steam (dubbed "driving steam") in the chamber housing the tubes, and later turning into condensate and emerging from the shell side. The diagram above shows that an evaporator is basically an "evaporator heat exchanger". In the tube side we have feed which will be converted to brine and distillate and in the shell side there is steam which will be converted to condensate.

Why do we call the steam "driving steam"? In the evaporator, the desired result is to evaporate a liquid, meaning we will need a source of energy. Since there is no fire or burner inside of the evaporator, the only source of energy is the hot steam which "drives" all the evaporation function.



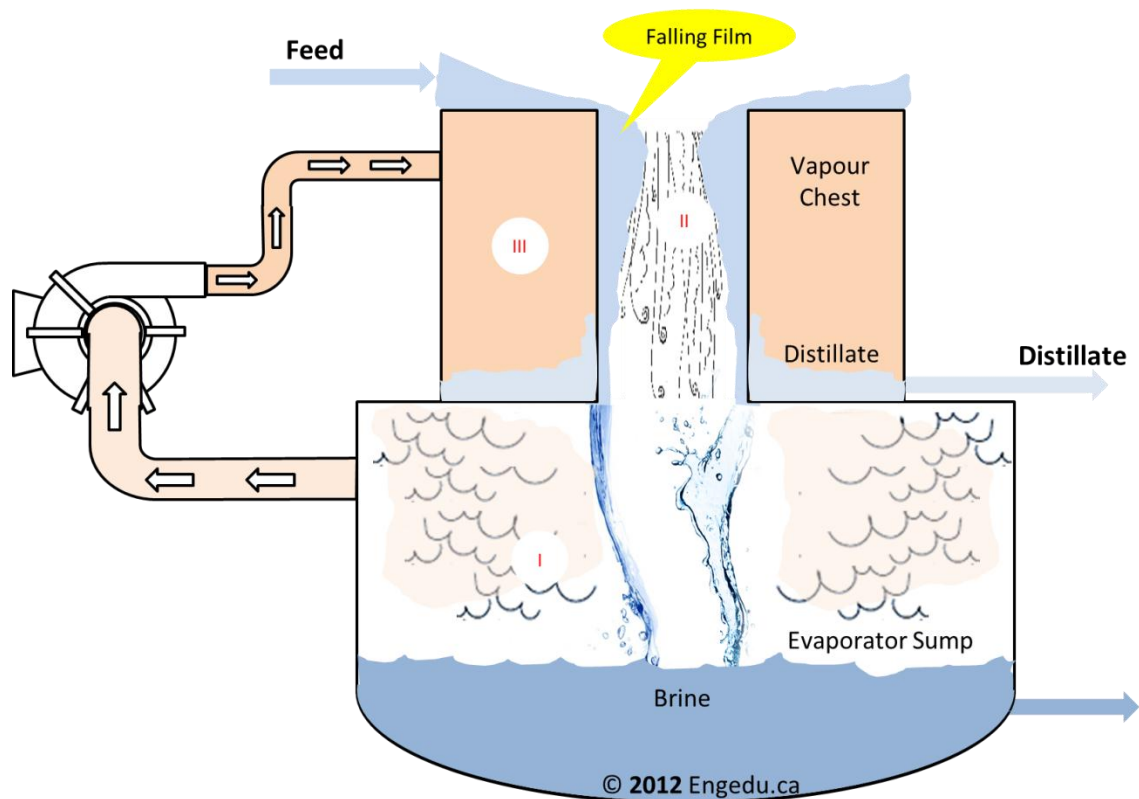
This schematic shows the detailed process inside of evaporator. However for the sake of simplicity only one tube (instead of the bundle of tubes) is shown on the sump.

As it is depicted, the feed is entered at the top of the tube, and a thin layer of it pours down the tube but it does not fill up the tube. It coats the inner surface and creates a thin film which shrinks even thinner as it gradually evaporates by travelling through the heated tubes and leaves a concentrated residue, Brine. The heated tubes result from the steam inside the chamber housing the tubes. The concentrated residues of the thin liquid film are dumped into the sump housing the generated brine. The vapour which resulted from this evaporation will be separated out in the sump.

Therefore each evaporator basically has three areas:

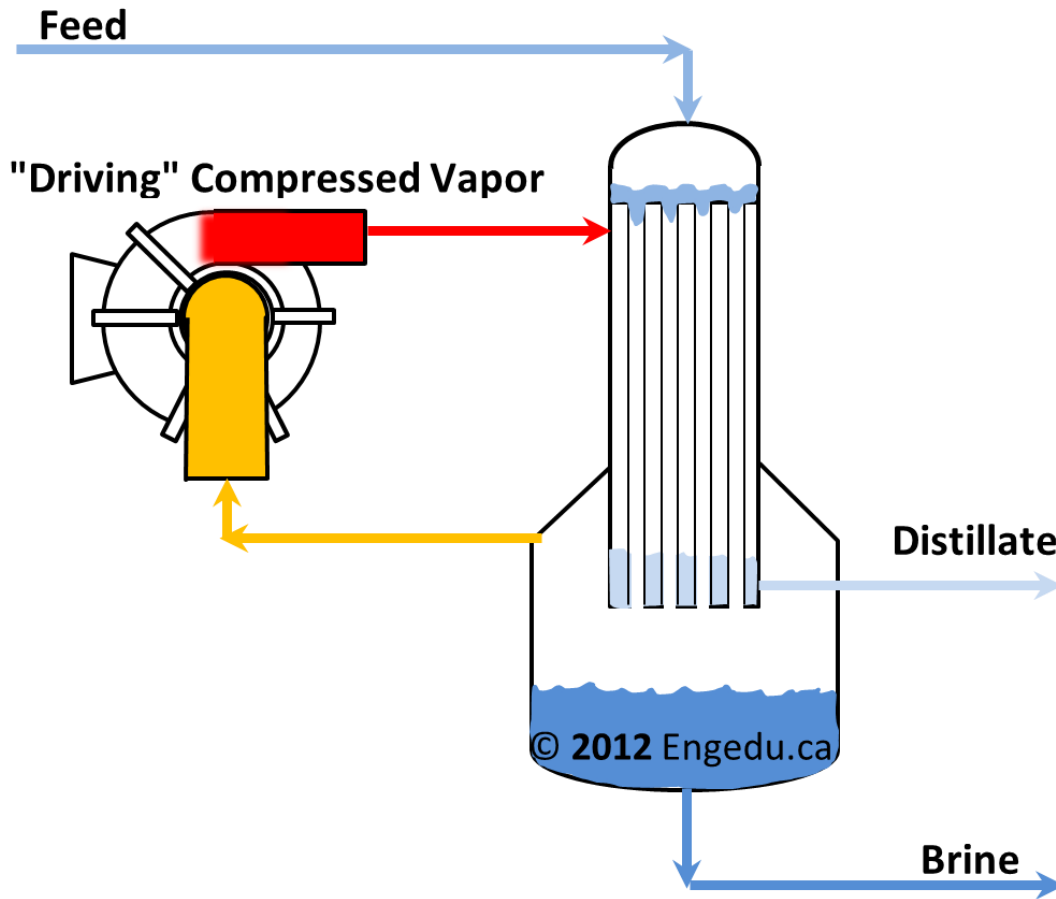
- 1- Evaporator sump: which contains the generated brine
- 2- The vertical tube: in which the main evaporation happens. The feed travels from the top and is turned into the liquid phase, which is brine, and vapour phase, which is our product (or distillate/low salinity liquid) after condensation.
- 3- Vapour chest: the space that has the duty to warm up the tube walls by keeping hot steam around them.

Schematic of an imaginary single tube Falling Film MVC



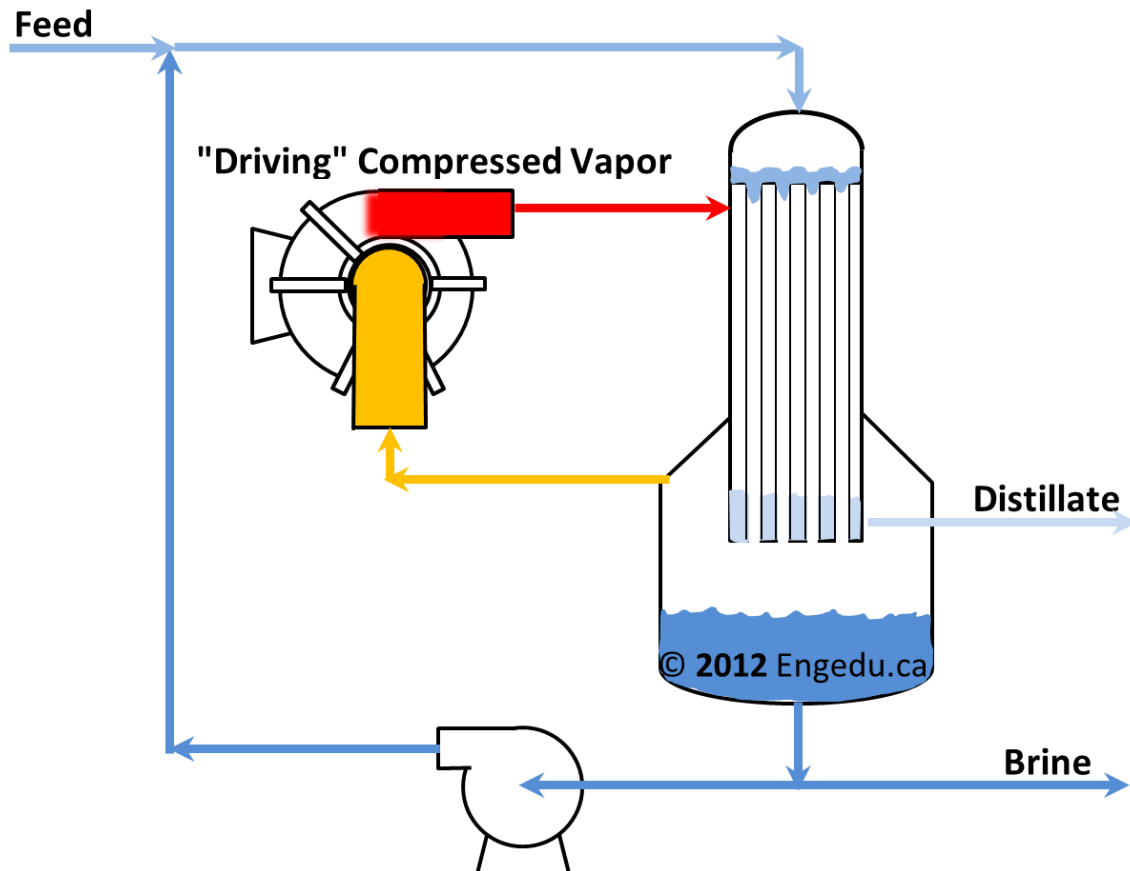
This schematic is similar to the previous one except the MVC (Mechanical Vapour Compression) concept is added to it. In this variation instead of using steam from an external source, the same vapour from the evaporator sump is used as driving steam. The benefit here is that the necessity of another condenser (to convert the vapour to distillate) goes away, since the evaporator vapour chest works as a built-in condenser and converts the vapour to distillate. However, from an overall energy point of view, without a compressor there is no external source of energy to drive evaporation. Therefore the compressor in MVC system compresses the vapour to add some energy to the system. This added energy to this vapour stream works exactly same as external energy which was added by the driving steam in the steam-driven falling film evaporator.

Schematic of a MVC Falling Film Evaporator



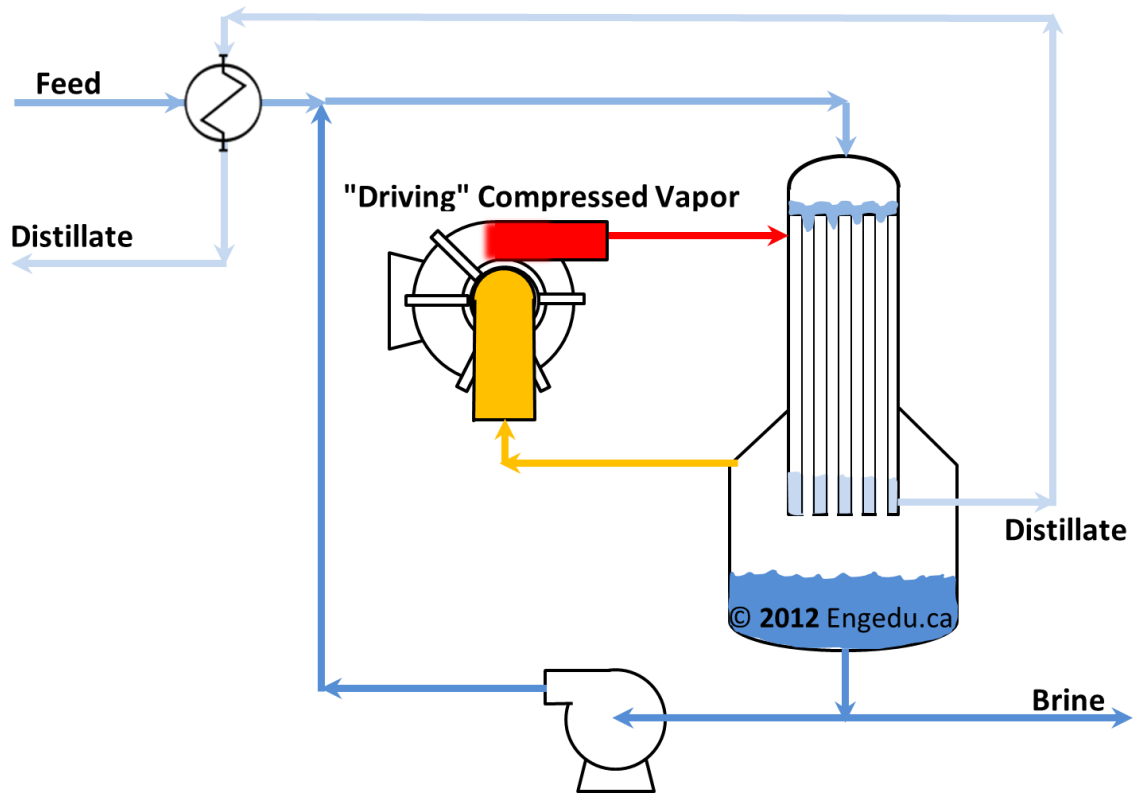
Here is schematic of a MVC, falling film, and vertical tube evaporator (this is the complete name!).

Schematic of a MVC Falling Film Evaporator With Brine Recirculation



Almost always a recirculation should be added to the system. This is because the heat exchanger portion of the evaporator should satisfy both heat transfer AND hydraulic requirements. The numbers of tubes as well as tube dimensions are decided based on the required heat transferred area. However, in a system without recirculation, some tubes at the bottom remain dry of liquid film (dry patches). To resolve this problem a recirculation stream will be added to the evaporator with flowrates in a few orders of magnitude.

Schematic of a MVC Falling Film Evaporator
Heat Integrated



This arrangement is a typical real system with heat integration. In this arrangement the feed is pre-heated by hot distillate.

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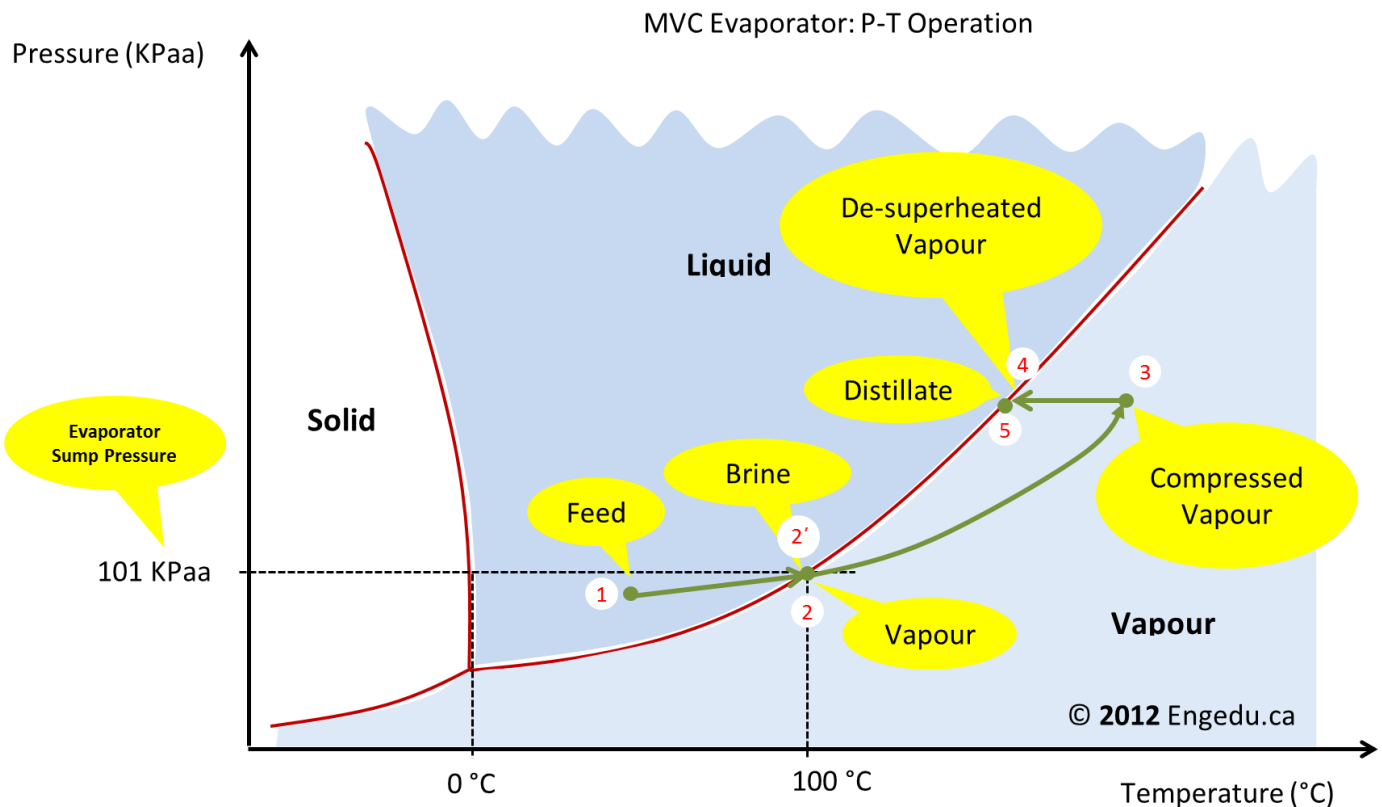
Until now, we have discussed the mechanical and process features of evaporators.

Here, we will talk about the thermodynamic aspects of evaporator. Two diagrams are selected for this purpose: the first one is a pressure-temperature diagram and the second one is a temperature-entropy diagram.

The first one basically tells us the state of process fluids in each segment of the evaporator. The second one observes the evaporator as energy exchange equipment and clarifies the energy consumption or release during different steps of evaporation.

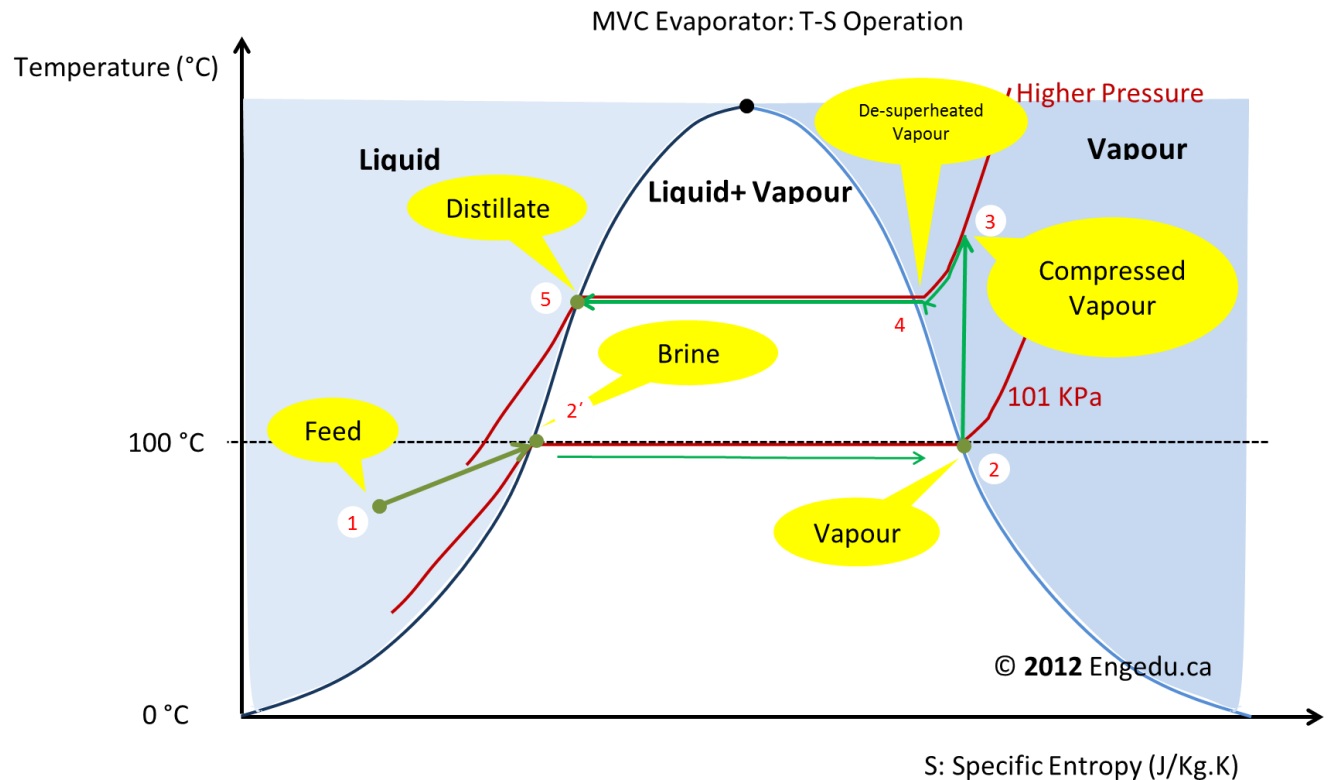
The diagrams are drawn for the case that the boiling point rise (BPR) is zero.

To explain BPR, it should be mentioned that by dissolving anything in water its boiling point will be increased; the more dissolved materials there are, the higher the boiling point. The difference between the boiling point of the water solution and pure water is BPR.



At the beginning, Point 1 is feed which is a water stream in liquid form (sub-cooled liquid). As it can be seen point 1 has a temperature of around 40°C and pressure of atmospheric (close to 101 KPa). This stream gets heated to reach Point 2, which is achieved partially by preheating outside of the evaporator (in a heat exchanger) and then heating inside of the evaporator tubes. In Point 2, main evaporation happens. When a liquid film travels from the top of the tubes to the bottom of the tubes it theoretically stays at Point 2. Basically in Point 2 at the end of the tubes we have brine (which is depicted as Point 2') and vapour. The story of brine part is finished here and it is withdrawn from the evaporator, while the vapour continues its journey in the evaporator. When vapour is extracted from the top space of the brine sump and goes through the compressor, it travels from Point 2 to Point 3. At Point 2, vapour was saturated but at point 3, as it is seen, it is a superheated vapour. This vapour supposedly releases its heat to the tube walls and eventually to the falling films in the vapour chest. Because the duty of this steam is heat transfer, it should be de-superheated. Going from Point 3 to 4 (or de-superheating) can happen outside of evaporator (by injecting water in it) or at the beginning of the vapour chest entrance. At the beginning of Point 4 there is de-superheated vapour and at the bottom a saturated liquid which is in fact the distillate (Point 5).

The temperature of distillate can be further decreased by external heat exchanger (feed preheater).



At the beginning, the feed (Point 1) is a liquid. It will be heated up to 100°C in order for it to start to evaporate. The feed will then travel from the top of the tubes to the bottom and gradually generate some vapours. At the bottom of the tube bundle the (non-vapourized) liquid film is actually brine (Point 2'). At the constant temperature, vapour will be emitted from the falling liquid film and will be pushed down toward the top of the evaporator sump at Point 2. This vapour is removed from the evaporator body and will be compressed adiabatically (no heat transfer with environment) by a compressor to get to Point 3. Point 2 was vapour in its saturated state and Point 3 is the superheated vapour. When this vapour goes to give off its heat to the falling film, it will be de-superheated (Point 4) and will then be condensed (going from Point 4 to Point 5). Point 5 is distillate in its saturated state, which can be further cooled by going through the feed preheater.