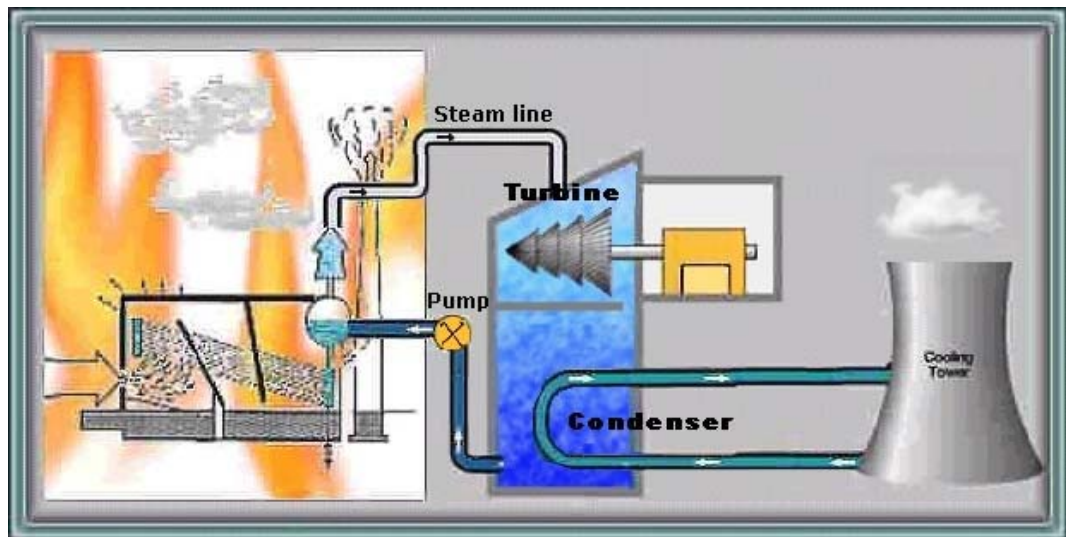


High Pressure definitions and Control limits



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High Pressure Boiler

There are several definitions about the characterization of a boiler as "High pressure boiler", "Medium" or "Low Pressure".

According to safety factors, p.e. from OSHA or from US and EU Authorities, as the border is considered the limit of the atmospheric pressure.

From the water treatment point of view, the border line is usually considered the 800 psi (55 bar, 5.5 Kpa).

Boilers operating at pressures between 800 psi and 300 psi (20 bar, 2,01 KPa) are considered as medium-pressure, while below 300 psi are considered as low-pressure.

The reason of these limits is the difference of the type of boiling. Below 300 psi the boiling type is either the nudeate boiling, either the bulk boiling (at the fire-tube boilers).

Boiling over 800 psi is under transfer (or film) boiling conditions.

At the intermediate region, the boiling type is a mixed type, and can be either film, either nucleate boiling.

Low pressure boilers are producing steam for heating purposes, so the make-up water quality requirements are lower, and can be reverse osmosis or softened.

High pressure boilers are producing steam for power generation, so the steam purity and energy balance requirements are high, so the boiler and feedwater standards are very strict. So make-up is always demineralized, while in most of systems there is condensate treatment as to improve feedwater quality and to avoid boiler water contamination due to process leaks.

Medium-pressure boilers may also employ high purity feedwaters.

As it concerns the construction, all high and medium pressure boilers are water-tube, while most of the low pressure are fire-tube boilers.

Bulk Boiling

Bulk boiling occurs when the bubbles are created inside the mass of boiling water at saturation conditions.

As system temperature increases or system pressure drops, the bulk fluid can reach saturation conditions. At this point, the bubbles created will not collapse.

The bubbles will tend to join together and form bigger steam bubbles. This phenomenon is referred to as bulk boiling.

Bulk boiling can provide adequate heat transfer provided that the steam bubbles are carried away from the heat transfer surface and the surface is continually wetted with liquid water. When this cannot occur, film boiling results.

Nucleate Boiling

The most common type of local boiling encountered is nucleate boiling. In nucleate boiling, steam bubbles form at the heat transfer surface and then break away and are carried into the main stream of the fluid.

Such movement enhances heat transfer because the heat generated at the surface is carried directly into the fluid stream.

Once in the main fluid stream, the bubbles collapse because the bulk temperature of the fluid is not as high as the heat transfer surface temperature where the bubbles were created.

This heat transfer process is sometimes desirable because the energy created at the heat transfer surface is quickly and efficiently "carried" away.

Film Boiling

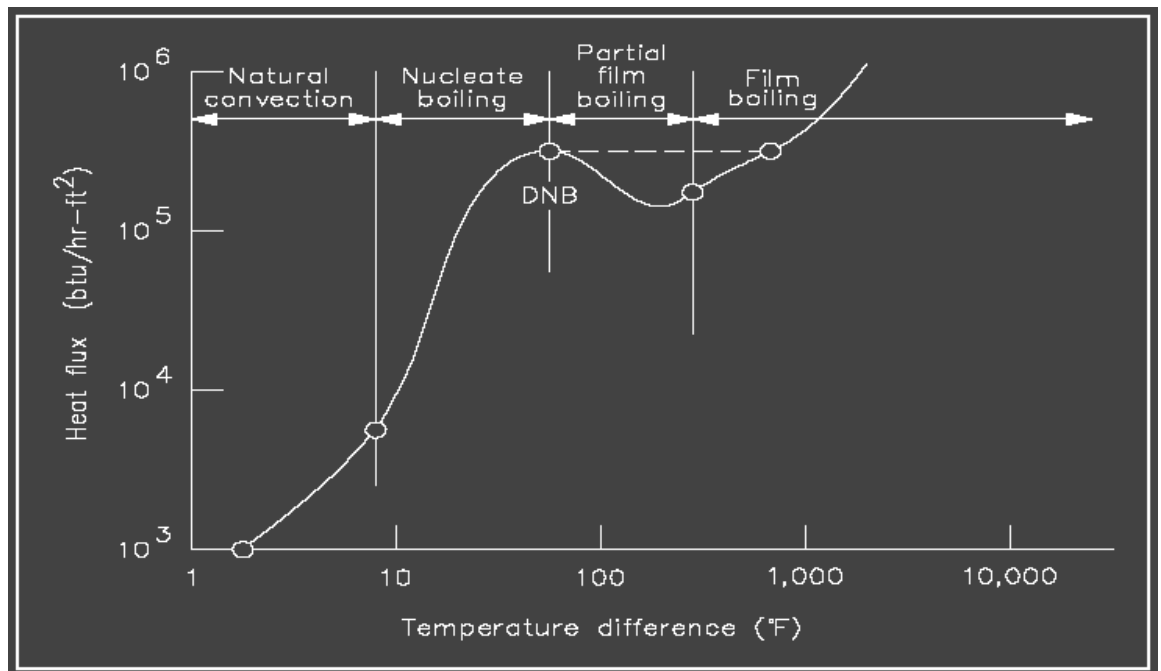
When the pressure of a system drops or the flow decreases, the bubbles cannot escape as quickly from the heat transfer surface. Likewise, if the temperature of the heat transfer surface is increased, more bubbles are created. As the temperature continues to increase, more bubbles are

formed than can be efficiently carried away. The bubbles grow and group together, covering small areas of the heat transfer surface with a film of steam. This is known as partial film boiling. Since steam has a lower convective heat transfer coefficient than water, the steam patches on the heat transfer surface act to insulate the surface making heat transfer more difficult.

As the area of the heat transfer surface covered with steam increases, the temperature of the surface increases dramatically, while the heat flux from the surface decreases. This unstable situation continues until the affected surface is covered by a stable blanket of steam, preventing

contact between the heat transfer surface and the liquid in the center of the flow channel. The condition after the stable steam blanket has formed is referred to as film boiling.

The process of going from nucleate boiling to film boiling is graphically represented in Figure below. The figure illustrates the effect of boiling on the relationship between the heat flux and the temperature difference between the heat transfer surface and the fluid passing it.



Four regions are represented in Figure. The first and second regions show that as heat flux increases, the temperature difference (surface to fluid) does not change very much.

Better heat transfer occurs during nucleate boiling than during natural convection. As the heat flux increases, the bubbles become numerous enough that partial film boiling (part of the surface being blanketed with bubbles) occurs.

This region is characterized by an increase in temperature difference and a decrease in heat flux. The increase in temperature difference thus causes total film boiling, in which steam completely blankets the heat transfer surface.

Departure from Nucleate Boiling and Critical Heat Flux In practice, if the heat flux is increased, the transition from nucleate boiling to film boiling occurs suddenly, and the temperature difference increases rapidly, as shown by the dashed line in the figure.

The point of transition from nucleate boiling to film boiling is called the point of departure from nucleate boiling, commonly written as DNB. The heat flux associated with DNB is commonly called the critical heat flux (CHF). In many applications, CHF is an important parameter.

Undesirable impurities in boilers.

The best for boilers is pure water. All other dissolved or suspended impurities are undesirable. In this section we are presenting the most troubleshooting and the problems related to them.

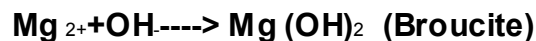
Substance	Problem
Total Alkalinity	a. Carry over b. Scale formation c. Caustic attack
Suspended Solids	a. Sludge deposition b. Carry over.
Total dissolved Solids	a. Scale formation. b. Corrosion c. Carry over
Silicate	a. Silicate deposits. b. Deposition in steam and return lines

Alkalinity

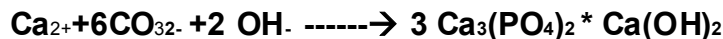
In most countries total alkalinity is the first factor that has to be examined.

The presence of alkalinity is necessary as to control corrosion tendencies and to participate to scale inhibition programs.

Magnesium requires alkalinity for its control, as to be precipitated into the boiler by the following reactions:



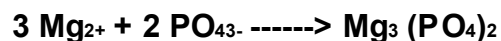
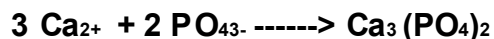
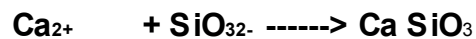
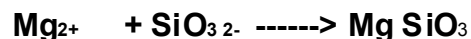
Calcium is precipitated under phosphate treatment by the reaction:



While in **all organic**:

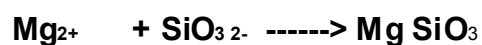


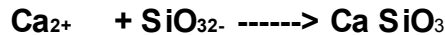
Under insufficient alkalinity, in **phosphate** treatment the reactions will be



which are hard and very difficult removable scales.

In **all organic** treatment the reactions will be:

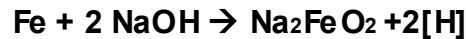




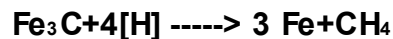
Resulting also to hard and non-removable scale.

While an alkalinity presence is necessary, the increase of its value over a certain limit will induce foaming and carry over problems and caustic attack of the boiler metals.

Caustic in excess is reacting with the iron producing Metaferric Sodium and native Hydrogen:



The [H] attacks sementite producing methane gas.



Sementite is a crystallographic substance, in very low quantity into the metal crystals and is responsible for the mechanical properties of the steel.

Its deterioration from caustic attack is proportionally deteriorating the pressure resistance of the steel, while is not leading to significant metal mass loss. The danger of explosion is obvious, so even under low pressure conditions we have to observe low caustic alkalinity excess.

According to the **American Boilers Manufacturers STANDARDS** limit the alkalinity to **boilers**, in ppm as **CaCO₃**. according to the following table

Drum Pressure (psi)	Total Alkalinity (ppm)	P Alkalinity (ppm)
0-220	1000	0.07 M
220-350	800	0.07 M
350-500	600	0.07 M
500-650	400	0.07 M
650-900	150	> 0.5 M
900-1100	100	> 0.5 M
1100-1450	50	> 0.5 M

pA and mA in ppm as CaCO₃.

Suspended Solids.

Except of iron oxides, suspended solids are suddenly carried into the boiler from make-up or condensate. Mostly are created into the boiler as a result of the reactions of the hardness.

Maximum permissible concentration is related to the efficiency of the sludge conditioner and the antifoam in use.

If the chemicals supplier has not defined another ratio, we suggest to keep the Total hardness in the feedwater, below the limits of the table:

Drum Pressure (psi)	Total hardness (ppm)
0-220	5
220-350	3
350-500	2
500-650	1
650-900	0.5
900-1100	0.5
1100-1450	0.2

Values in ppm as CaCO₃.

Total dissolved Solids.

The total Dissolved Solids (TDS) value will be responsible for corrosion, foaming and scale or sludge deposition.

In high pressure boilers, while is in use demineralized water, we suggest the following rule:

$$\text{NCmax} = \text{Max TDS}_{(\text{boiler})} / \text{TDS}_{\text{MU}}$$

TDS_{MU} is the total dissolved Solids in Make-up in mg/l. and **TDS_(boiler)** is according the following table:

Drum Pressure (psi)	TDS (ppm)
0-220	4000
220-350	3000
350-500	2000
500-650	1500
650-900	500
900-1100	300
1100-1450	100

Silica

Silicates are forming silicate deposits, while the present a kind of volatility.

So an amount of silica escapes to the steam, and when steam condenses, it is deposited as pure solid silica..

For High pressure boilers, we suggest you to use the relationship:

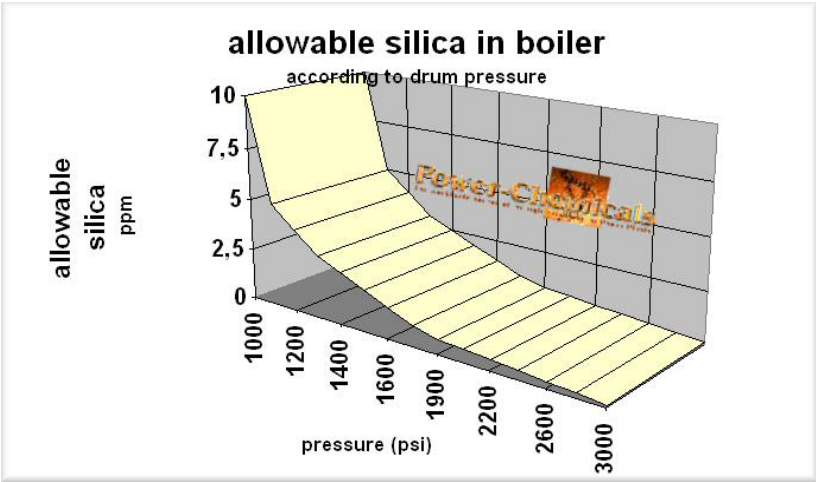
$$NC_{max} = \text{Max SiO}_2 \text{ (boiler)} / \text{SiO}_2 \text{ (MU)}$$

SiO₂ (MU) is the concentration of silicates in the make-up water (as ppm of equivalent **SiO₂**).

As for **Max SiO₂ (boiler)** till 1000 psi you can use the following table:

Drum Pressure (psi)	Silica (ppm)
0-220	200
220-350	150
350-500	90
500-650	40
650-900	15
900-1100	10

while for drum pressures over 1000 psi, you can use the following diagram



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