

# Heat transfer model by boiling a 10BHP horizontal boiler

## Modelo de transferencia de calor por ebullición de una caldera horizontal de 10BHP

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## Abstract

The mathematical model of boiling in firetube boilers is deduced and analyzed taking into account the first nucleation studies, and the empirical postulates that developed the evaporation behavior equations. The amount of energy that water is capable of receiving is observed, detailing the mechanisms by which it does so. With these values it is possible to calculate the coefficient of heat transfer by convection generated in boiling, depending on the operating pressure at which the boiler works. In addition, the size of the bubbles created around the heating surfaces is calculated according to the horizontal orientation of the pipes and the home.

**Keywords:** transfer coefficient, convection, boiling, energy, firetube, pressure.

## Resumen

Se deduce y analiza el modelo matemático de la ebullición en las calderas de tipo pirotubular teniendo en cuenta los primeros estudios de nucleación, y los postulados de carácter empírico que desarrollaron las ecuaciones de comportamiento de evaporación. Se observa la cantidad de energía que es capaz de recibir el agua, detallando los mecanismos por los cuales lo hace. Con estos valores se calcula el coeficiente de transferencia de calor por convección generado en la ebullición, dependiendo de la presión de operación a la cual trabaja la caldera. Además, se calcula el tamaño de las burbujas que se crean alrededor de las superficies de calentamiento, según la orientación horizontal de los tubos y el hogar.

**Palabras clave:** coeficiente de transferencia; convección; ebullición; energía; pirotubular; presión.

## Introducción

Since the industrial revolution, the man wanted to take advantage of the resources he had around to simplify heavy work and this way achieve greater productivity in large factories. The steam engines were undoubtedly the pillar under which all the inventions of the time were built. The fact of converting water into the raw material of the operation was indispensable for the inventors of the moment.

Most machines base their operation on steam, which is why many applications in engineering include the transfer of heat for boiling. This phenomenon is due to the change that water undergoes in the transformation of the liquid phase to vapor, produced by contact with a surface that is at a higher temperature than its saturation temperature at the established pressure. This heat transfer depends on various thermophysical properties of the fluid such as density, specific heat, thermal conductivity, dynamic viscosity, latent enthalpy of vaporization and surface tension.

For the boiling phenomenon to occur, the difference in temperature that occurs is called the excess temperature. The phase change that occurs in the boilers is classified as pond boiling because the fluid is contained in a container. For the calculation of the heat transfer coefficient, the thermal resistance method is used, which allows determining the total heat transferred to the water from the combustion flame.

The first person to develop a study where the energy needed to change the phase of the water specifically evaluated was Nukiyama (1966), who, in his experiment, heated a copper rod and observed the pattern of bubble generation around the hot element (Figure one).

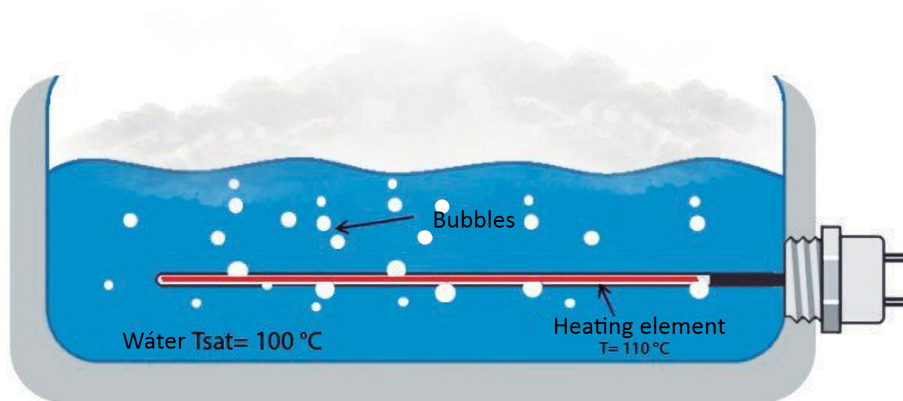


Figure 1. Outline of the nucleation study of Nukiyama  
Source: Cengel and Ghajar (2011).

Based on the above, the author of said study created the water behavior diagram when it is subjected to boiling effects as shown in Figure 2 (Cengel and Ghajar, 2011). Where  $\Delta T_{\text{excess}}$  is the difference between the temperature of the surface of the tube in contact with water and the saturation temperature. By varying the value of the pressure, changes of excess temperature, heat transfer coefficient, and boiling heat occur.

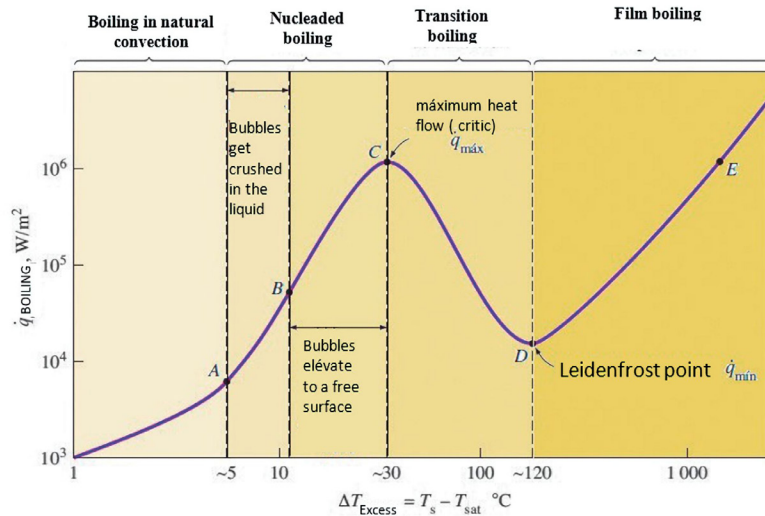


Figure 2. The typical boiling curve at 1 bar  
Source: Cengel and Ghajar (2011).

Figure 2 shows the behavior of the heat as a function of the excess temperature. It is indicated that the behavior of the boilers is between point b and c, called nucleated boiling. In this area the bubbles emerge to the surface where they remain warm enough to make the heat transfer effect and not be crushed before reaching the top (Incropera, de Witt, Bergman, and Lavine, 2011); transition zone is not entered because it has no application in the boilers.

When it is passed to the film zone, a coating on the tube made by steam is shown. Due to this, a kind of insulation is generated where it affects the heat transfer by lowering the efficiency in the exchange of energy, it can also cause the temperature of the tube to rise above its metallurgical limit and produce flaws that can lead to accidents (Cengel and Ghajar, 2011).

Rohsenow (1952), using his pond boiling method, and in accordance with heat transfer correlation theories, establishes an empirical equation, whose objective is to calculate the heat required to evaporate the water in high-pressure vessels. In general, the horizontal type peritubular boilers are in the nucleated section, since their temperature in excess must not exceed 30 °C for safety reasons.

Nowadays, many investigations show generic results obtained in vertical boilers, or with different working compounds, without considering the effects of the heat transfer characteristic of horizontal boilers. (Rojas and Mazuera, 2014, Saiz, Fockink, Ribatski, de Barros, 2004).

The objective of the present study is to generate the mathematical heat transfer model by boiling, supported by the geometry of the boiler located at Universidad Francisco de Paula Santander, which is solved with the help of the EES software, modifying the pressure of the system since it is the representative variable of the study.

## Method and mathematical model

As a fundamental premise, Table 1 shows all the variables involved in the boiling process, with their respective nomenclature and operating units.

**Table 1.**  
Characteristic nomenclature of the boiling process

Symbol	Meaning	Units
$\mu_f$	The viscosity of the saturated liquid	kg/m * s
$h_{fg}$	Vaporizing Enthalpy	J/kg
$g$	Gravitational acceleration	m/s <sup>2</sup>
$\rho_f$	The density of the saturated liquid	kg/m <sup>3</sup>
$\rho_g$	The density of the saturated gas	kg/m <sup>3</sup>
$\sigma(H_2O)$	Liquid surface tension - steam	N/m
$Cp_f$	Specific heat of the saturated liquid	J/kg * K
$\Delta T_{\text{excess}}$	Excess temperature	K
$C_{sf}$	Experimental constant	
$Pr_f$	Prandtl number of saturated liquid	
$n$	Experimental constant	

Source: the authors.

For the calculations, the following assumptions were taken into account:

- Water properties are used at a pressure greater than 1 bar (14 psi).
- It is analyzed in a steady-state.

The variable  $\Delta T_{\text{excess}}$  is replaced in the mathematical formulas by the variable  $\Delta T_{\text{ps}}$

$\Delta T_{\text{ps}}$  is the difference in temperature with respect to the saturation temperature of the water vapor for the operating pressure. This best represents the change in excess temperature at saturation pressure conditions.

Starting from the assumptions mentioned above and from the basic principles of thermodynamics and heat transfer, the following mathematical model is proposed.

By Newton's law of cooling you have.

Where "h" is the coefficient of heat transfer due to boiling. Table 2 shows the most representative heat transfer coefficient ranges (Kakac, Liu, and Pramuanjaroenkij, 2012).

$$q''_{\text{BOILING}} = h_{\text{BOILING}} * (\Delta T_{\text{Excess}}) \tag{1}$$

To determine the boiling heat, the equation proposed by Rohsenow based on experimental data is used (Olivares, Ramírez, and Aldana, 2014).

**Table 2.**  
"h" characteristic values

Process	$h$ (W/m <sup>2</sup> * K)
Gases (Natural Convection)	3 - 25
Motor oil (Natural Convection)	30- 60
The flow of non-metallic liquids	100 - 10000
The flow of metallic liquids	5000 - 250000
Heat transfer by boiling water, pressure <5 bar, $\Delta T_{\text{excess}} = 25K$	5000 - 10000
Heat transfer by boiling water, pressure 5-100 bar, $\Delta T_{\text{excess}} = 20 K$	4000 - 15000
Heat transfer by film boiling	300 - 400

Source: Kakac, Liu, and Pramuanjaroenkij (2012).

The variable  $C_{sf}$  is an experimental constant that is given for the different types of surfaces, and the constant  $n$  depends on the type of fluid that is boiling. Table 3 shows the values of the most frequently used  $C_{sf}$  and  $n$  constants (Cengel and Ghajar, 2011).

$$q''_{\text{BOILING}} = \mu_f h_{fg} \left[ \frac{g(\rho_f - \rho_g)}{\sigma_{H_2O}} \right]^{0.5} \left[ \frac{C_{pf} \Delta T_{\text{Excess}}}{C_{sf} h_{fg} Pr_f^n} \right]^3 \quad (2)$$

When the materials of the fluid interface - heating surface are unknown, it is recommended to take the values of  $C_{sf} = 0.0130$  and  $n = 1.0$  (Holman, 2009).

**Table 3.**

Values of the coefficient  $C_{sf}$  and  $n$  for several fluid-surface combinations

Fluid-heating surface combination	$C_{sf}$	$n$
Water-copper (polished)	0,0130	1,0
Water-copper (striped)	0,0068	1,0
Water-stainless steel (mechanically polished)	0,0130	1,0
Water-stainless steel (grinding and polishing)	0,0060	1,0
Water-stainless steel (coated Teflon chopped)	0,0058	1,0
Water-stainless steel (chemically corroded)	0,0130	1,0
Water-brass	0,0060	1,0
Water-nickel	0,0060	1,0
Water-platinum	0,0130	1,0
n-Pentane-copper (polished)	0,0154	1,7
n-Pentane-chrome	0,0150	1,7
Benzene-chromium	0,1010	1,7
Ethyl-chromium alcohol	0,0027	1,7
Carbon-copper tetrachloride	0,0130	1,7
Isopropanol-copper	0,0025	1,7

Source: Cengel and Ghajar (2011).

When designing pressure vessels such as boilers, the peak heat flow must be considered. With this value, the maximum amount of energy that water can receive is determined, S. S. Kutateladze and N. Zuber theoretically determined an equation that establishes the maximum heat flow (Incropera, *et al.*, 2011).

Where  $C_{cr}$  depends on the geometrical configuration of the heater. For the case study, the value is 0.12. Table 4 shows  $C_{cr}$  values for other geometries of interest (Cengel and Ghajar, 2011).

$$Q_{max} = C_{cr} h_{fg} [\sigma_{H_2O} * g * \rho_g^2 (\rho_f - \rho_g)]^{\frac{1}{4}} \quad (3)$$

In this case,  $L^*$  represents the characteristic dimension that is evaluated in the geometry ranges.  $K1$  is a geometry variable of the small horizontal plane heater. In addition,  $A_{heater}$  is the cross-sectional area of the same.

**Table 4.**

Values of the  $C_{cr}$  coefficient to be used in the equation (3)

Geometry Heater	$C_{cr}$	Principal Dimension "L"	$L^*$ interval
Large horizontal plane heater	0,149	Width or diameter	$L^* > 27$
Small horizontal plane heater	$18,9 \cdot K1$	Width or diameter	$9 < L^* < 20$
Large horizontal cylinder	0,12	Radio	$L^* > 1,2$
Small horizontal cylinder	$0,12L^{-0,25}$	Radio	$0,15 < L^* < 1,2$
Big sphere	0,11	Radio	$L^* > 4,26$
Small Sphere	$0,227L^{-0,5}$	Radio	$0,15 < L^* < 4,26$

Source: Cengel and Ghajar (2011).

Where

$$L^* = L * \left[ \sqrt{\frac{g(\rho_f - \rho_g)}{\sigma}} \right] \quad (4)$$

$$K1 = \frac{\sigma}{g(\rho_f - \rho_g) * A_{Heater}} \quad (5)$$

The values of density, enthalpy, dynamic viscosity and number of Prandtl, which depend on the operating pressure of the boiler, are resolved through extrapolation of the functions included in the library of the program for water vapor, in accordance with the algorithm built to solve the problem, Table 5.

**Table 5.**

EES programming code, thermal parameters, and model solution

EES Code
A\$='Steam_IAPWS'
P_caldera=30 [psi]
P_operación=P_caldera*convert(psi;bar)
P_ebullicion=P_caldera*convert(psi;KPa)
mu_f=VISCOSITY(A\$;X=0;P=P_ebullicion)
rho_f=DENSITY(A\$;X=0;P=P_ebullicion); rho_g=DENSITY(A\$;X=1;P=P_ebullicion)
T_sat=T_SAT(A\$;P=P_ebullicion)
sigma_H2O=SURFACETENSION(A\$;T=T_sat)
Cp_f=CP(A\$;X=0;P=P_ebullicion)
Cp_g=CP(A\$;X=1;P=P_ebullicion)
DELTA_T_ps=Ts2-T_sat
DELTA_h_vap=Enthalpy_vaporization(A\$;P=P_ebullicion)
g=9,81 [m/s^2]
Csf=0,013; n=1
h_fg=h_f-h_g
h_f=Enthalpy(A\$;x=1;P=P_ebullicion)
h_g=Enthalpy(A\$;x=0;P=P_ebullicion)
h_agua=ENTHALPY(Water;T=T_agua;P=P_ebullicion)
Pr_f=PRANDTL(A\$;X=0;P=P_ebullicion)
Q_ebullicion_max=(0,12*DELTA_h_vap*rho_g*((sigma_H2O*g*(rho_f-rho_g)/rho_g^2))^(1/4))*1000
Q_ebullicion_max=(mu_f*h_fg*((g*(rho_f-rho_g))/sigma_H2O)^0,5*((Cp_f*DELTA_T_ps_max)/(Csf*h_fg*Pr_f))^3)*1000
h_ebullicion_H=(Q_ebullicion_H)/DELTA_T_ps
R_ebullicion_H=1/(h_ebullicion_H*A_ex_H)
D_burbuja=0,0148*beta*sqrt((2*sigma_H2O)/(g*(rho_f-rho_g)))
Beta=180

Source: the authors.

To determine the heat that the water absorbs in the boiler, the method of thermal resistance is used. Developing a heat transfer circuit, the losses generated in the chimney and outside the boiler are considered. In Figure 3, radiation resistance ( $R_{rad}$ ), fouling or fouling ( $R_{f1}$  and  $R_{f2}$ ) and conduction ( $R_{ac,H}$ ) are typical of each type of boiler, working fuel and structural materials (Quiñónez, Pindo, and Adum)., 2008, Flórez, 2011).

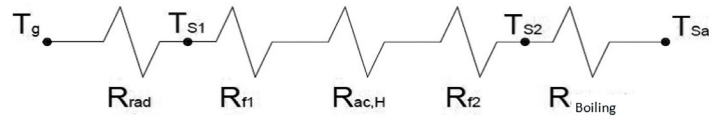


Figure 3. Resistance arrangement  
Source: the authors.

Next, in Table 6, the thermal resistance values caused by the combustion gases inside the pipe of the hearth are mentioned. Likewise, the contamination deposited outside the heat pipes caused by the feeding water must be considered.

**Table 6.**  
*Parameters of fouling present in boilers*

Type of fouling (impurity)	Symbol	Value [units]
Fouling due to combustion gases	$R_{f1}$	0,001761 [m <sup>2</sup> *K/W]
Fouling for boiler feeding water	$R_{f2}$	0,000176 [m <sup>2</sup> *K/W]

Source: Kakac, Liu, and Pramuanjaroenkij (2012).

The result of the Rohsenow equation allows calculating the coefficient of heat transfer by convection and from there to calculate the resistance by boiling.

$$\frac{Q_{BOILING}}{\Delta T_{ps}} = h_{BOILING} \quad (6)$$

Resistance by boiling

$$R_{BOILING} = \frac{1}{h_{BOILING} \pi D_{ex} L} \quad (7)$$

Where  $D_{ex}$  is the external tube diameter and L is the length.

Another important parameter that influences the heat transfer by boiling is the size of the bubbles that are created outside the heating surface. By means of equation (8), we obtain the approximate diameter of these bubbles in the nucleation stage according to the Fritz equation (Welty, Wicks, and Wilson, 1994, Hamzekhani, Maniavi, and Akbari, 2014).

$$D_{Bubble} = 0,0148 * \beta * \sqrt{\frac{2 * \sigma_{H_2O}}{g * (\rho_f - \rho_g)}} \quad (8)$$

Where  $\beta$  is the degree of inclination between the bubble and the heating surface, in boilers of horizontal type this value is 180 °, with respect to the X axis (horizontal), which means that it is in full contact with the surface of the tube.

The tests were made with the geometry of a commercial boiler of the nominal power of 10 BHP, Figure 4. The variables of combustion, flame temperature and thermophysical constants of the materials and fluids involved were identified.



Figure 4. Experimental data collection, Continental F10C boiler  
Source: the authors.

The measurements used in the calculations are given in the international system, and some pressure measurements are given in the English system, since, due to its manufacturing origin, it is the characteristic of the boiler study, as shown in Table 6.

The code used in the academic software EES is described based on the measurements taken in the boiler, to solve the equations and generate the graphs that represent the boiling performance of the studied boiler during its operation Table 7 (Klein, 2016).

**Table 7.**  
*Boiler operation data*

Description	Data
Nominal power	10 BHP
Fuel type	ACPM
Nominal fuel consumption	3 gal/h
Actual fuel consumption	1,2 gal/h
Excess of air	20 %
Environmental temperature	30 °C
Feeding water temperature	28 °C
Fuel temperature	28 °C
Atmospheric pressure	97,53 KPa
No. of steps in the boiler	2
Total household length	1,00 m
The effective length of the home	0,75 m
Inside diameter of the home	0,25 m
The outside diameter of the home	0,30 m
Tube bundle length	0,85 m
The effective length of the tube bundle	0,75 m

The inner diameter of the tube	0,057 m
The outside diameter of the tubes	0,067 m
No. of tubes in the beam	21
The outside diameter of the shell	0,83 m
The thickness of the breastplate	0,002 m
Type of insulation	Lana de Vidrio
Insulation thickness	0,055 m

Source: the authors.

## Results

The curve in Figure 5, was obtained with the Rohsenow equation at different excess temperatures with an operating pressure of 2,068 bar (30 psi) and an air excess of 120%, the points identified are the maximum energy for the boiling point and the boiling point of the boiler that is being worked on.

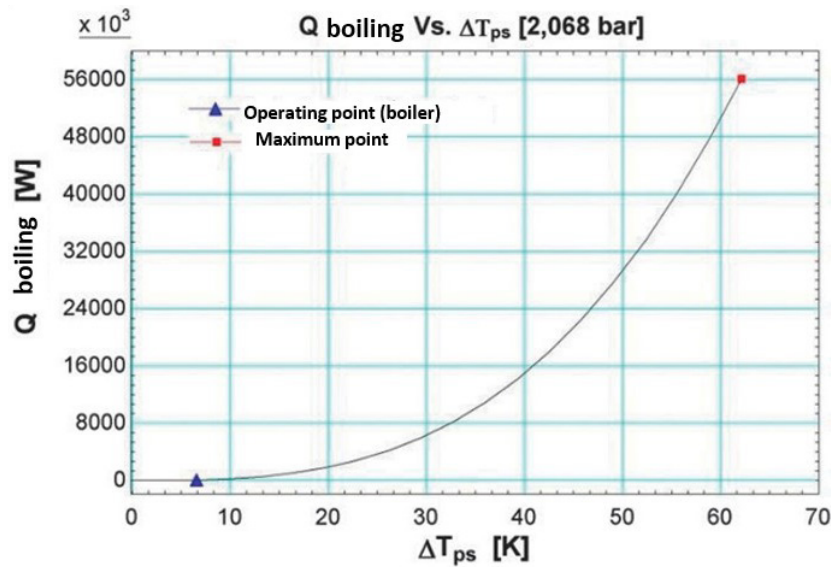


Figure 5. Boiling heat vs excess temperature at a pressure of 2,068 bar (30psi)

Source: the authors.

The maximum excess of temperature that was obtained in the boiler with a pressure of 2,068 bar (30 psi) was 62.1 k producing a maximum or critical heat of 56.13 kW. This is the amount of physically available energy that the device can handle. From this energy, the saturation temperature was calculated and checked with the thermal expansion limit of the steel. This more than anything a safety assessment, it is not intended to reach the pressure limits.

By varying the pressure inside the boiler, the behavior of the variables involved in boiling is observed, as shown in Figures 6, 7, 8, 9.

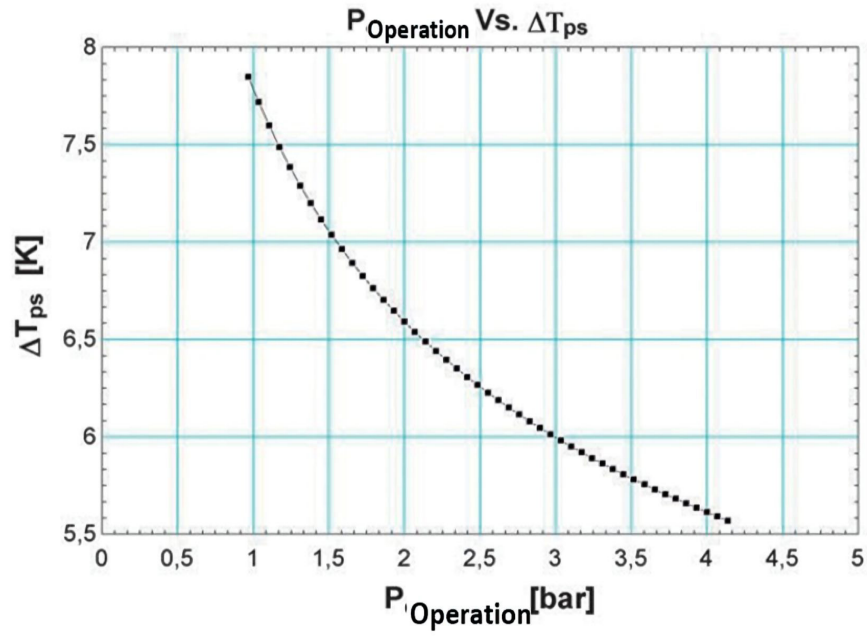


Figure 6. Temperature excess vs. operating pressure  
Source: the authors.

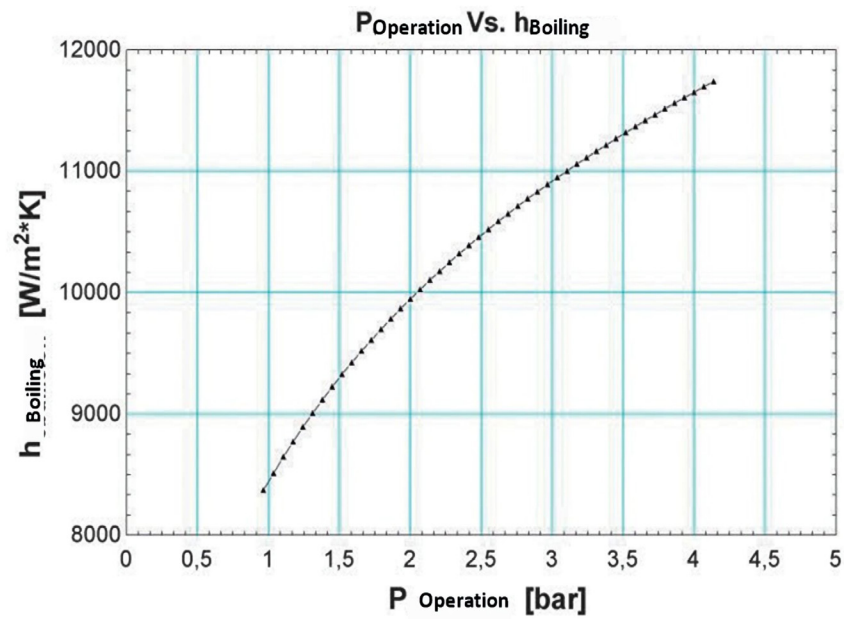


Figure 7. Coefficient of heat transfer vs. the operating pressure  
Source: the authors.

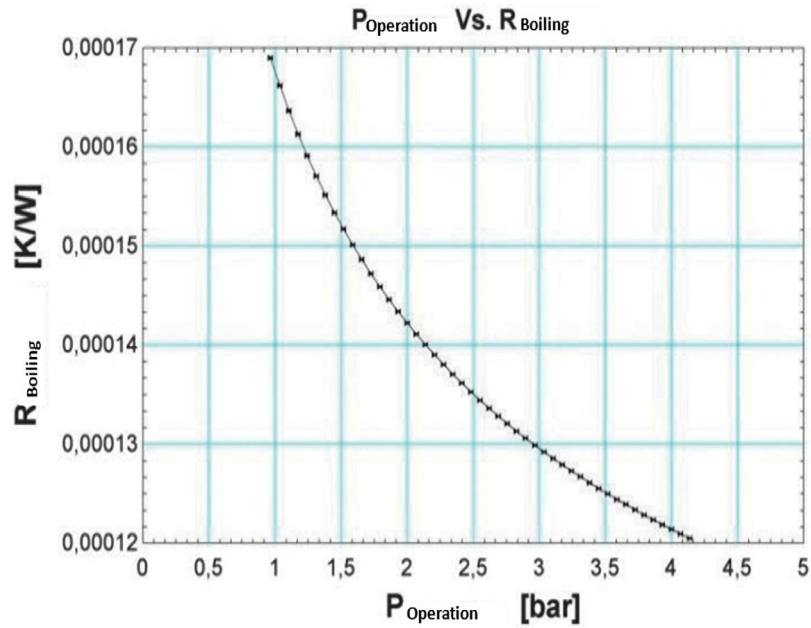


Figure 8. Thermal resistance vs. operating pressure  
Source: the authors.

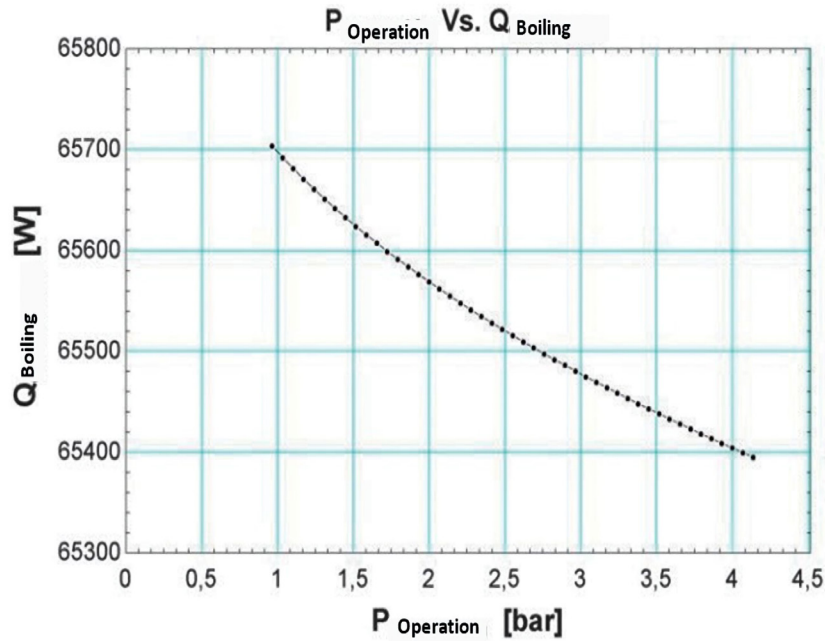


Figure 9. Boiling heat vs. operating pressure  
Source: the authors.

When there is an environment with low pressure inside the boiler, it is necessary that the temperature at which the water evaporates is lower. However, the fuel heats the surface of the container to the same temperature. As the operating pressure increases, the saturation temperature also increases, decreasing the temperature excess.

Figures 7 and 9 have similar behavior since the heat that is transmitted to the water depends directly on how high the convection coefficient is by boiling. Otherwise, it goes with Figure 8, because it represents the resistance that steel offers when transmitting all the heat to the water.

When solving the mathematical model, it results that the diameter of the bubbles at the operating pressure of 2,068 bar (30 psi) is 0.009172 m  $\approx$  9.2 mm for the horizontal type boiler ( $\beta = 180^\circ$ ) inclination regarding the X axis

## Conclusions

The values shown in Figure 5 are for the pressure of 1 bar, as the boilers work at higher pressures, these values are modified. By calculations, it is determined that the temperature excess between each zone varies for each pressure.

The conditions under which the boiler operates, ie the convective boiling coefficient and its respective boiling heat (Figures 7 and 9), depend directly on the operating pressure of each boiler. Because the pressure and saturation temperature of the fluids are directly proportional, increasing the pressure considerably lowers the work of the steam generating device. However, in order to increase the pressure, an increase in the air-fuel ratio must be generated, which generates an increase in fuel consumption (gas, coal, diesel).

By observing the highest point of boiling, the maximum amount of energy that will be transmitted is obtained. In addition, we get to know the excess temperature limit, since exceeding these limits will compromise the functionality of the boiler and accidents may occur.

In the EES program, the values "lower", "upper" and "guess" must be considered, which represent the minimum, maximum values and the tentative value of the result. The iteration of the results depends on them, it also helps the program to iterate from less infinity and evaluate the zero (0), not produce errors and stop the evaluation routine.

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## References

- Cengel, Y. y Ghajar, A. (2011). *Transferencia de calor y masa*. 4a Edición. U.S.A.: McGraw-Hill. pp. 580 – 595.
- Flórez, D. (2011). *Diseño y Construcción de una Caldera de Paso Continuo y Determinación del Coeficiente convectivo de Transferencia de Calor para la Zona de Ebullición*. (Tesis de pregrado). Universidad Nacional de Colombia. Facultad de Minas. Medellín, Colombia.
- Hamzekhiani, S., Maniavi, M. y Akbari, A. (2014). Bubble departure diameter in nucleate pool boiling at saturation: Pure liquids and binary mixtures. *International journal of refrigeration*, 46, 50-58.  
<https://doi.org/10.1016/j.ijrefrig.2014.07.003>
- Holman, J. P. (2009). *Heat Transfer*. 10<sup>th</sup> Edition. U.S.A.: McGraw-Hill Education. pp. 505 – 506.
- Incropera, F., de Witt, D., Bergman, T. y Lavine, A. (2011). *Fundamentals of Heat and Mass Transfer*. U.S.A. 7<sup>th</sup> Edition. John Wiley & Sons. pp. 657 – 664.

- Kakac, S., Liu, H. y Pramuanjaroenkij, A. (2012). *Heat exchangers, selection, rating and thermal design*. 3<sup>rd</sup> Edition. U.S.A.: CRC Press. pp. 41 – 42.
- Klein, S.A. (2016). *Handbook Engineering Equation Solver EES*. F-Chart Software.
- Nukiyama, S. (1966). "The Maximum and Minimum Values of the Heat Q Transmitted from Metal to Boiling Water under Atmospheric Pressure," *International Journal of Heat Mass Transfer*, 9(12), 1419-1433. [https://doi.org/10.1016/0017-9310\(66\)90138-4](https://doi.org/10.1016/0017-9310(66)90138-4)
- Olivares, R., Ramírez, L. y Aldana, D. (2014). Modelación matemática de la transferencia de calor en un intercambiador de calor abierto para producción de panela granulada. *Simposio Peruano de Energía Solar y del Ambiente (XXI- SPES)*. Universidad de Piura. Piura – Perú.
- Quiñonez, N., Pindo J. y Adum, V. (2008). *Desarrollo de software para el análisis y diseño térmico de calderas pirotubulares horizontales con quemadores a diésel y bunker*. (Tesis de pregrado). Guayaquil, Ecuador: Escuela Superior Politécnica del Litoral.
- Rohsenow, W. M., (1952). A Method of Correlating Heat Transfer Data for Surface Boiling Liquids. *Transactions of ASME*, 74, 969-976.
- Rojas, B. y Mazuera, H., (2014). *Análisis, diagnóstico y propuesta de mejora de los principales componentes operacionales que afectan la eficiencia de la caldera pirotubular del laboratorio de vapor de la Universidad Autónoma de Occidente*. (Tesis de pregrado). Facultad de Ingeniería, departamento de Energética y Mecánica, Universidad Autónoma de Occidente, Santiago de Cali – Colombia. pp. 72-80
- Saiz, J. M., Fockink, E., Ribatski, G., de Barros, S.F. (2004). Evaluation of the Rohsenow Correlation Through Experimental Pool Boiling of Halocarbon Refrigerants on Cylindrical Surfaces. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, 26(2), 218-230. <https://doi.org/10.1590/S1678-58782004000200015>
- Welty, J., Wicks, C. y Wilson, R. (1994). *Fundamentos de transferencia de momento, calor y masa*. 2<sup>a</sup> Edición. México: Limusa Editores. pp. 450 – 451.