

New Formulation for Semi-Empirical Correlations for Penetration Jets

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Abstract

Correlations for the extension of a water vapor jet injected in a liquid pool were historically proposed considering the mass flux ($\text{kg}/\text{m}^2/\text{s}$) as a constant. The results were satisfactory, however adjusting the values by linear regression. Although, it presents the following drawbacks: 1) the formulation is only valid for the specific range of data for what it was created; 2) it does not allow the analytical evaluation of the heat transfer coefficient from the extension equation. This paper proposes a new formulation for the calculation of the mass flux, in such a way to remove both of these drawbacks.

Keywords

Direct Contact Condensation, Vapor Jet, Steam Jet, Steam Mass Flux, Vapor Cavity, Reynolds Number, Jet Radius, Rate of Condensation, Non-Dimensional Jet Length, Liquid Pool, Dimensionless Transport Modulus, Condensation Driving Potential

1. Introduction

The phenomenon of Direct Contact Condensation (DCC) has been discussed in the literature since Kerney [1], due to its importance as a solution of engineering, where large values of heat transfer coefficient are needed. Through the DCC, several different sets of equipment can be designed, when, for example, condensation is in a small frame of time, or when reduced space is required.

DCC is the natural solution for applications where superheated vapor must be discharged in the atmosphere. Within this scope, DCC offers a safe alternative to reduce the heat and pressure up to the threshold where the discharge to the atmosphere is plausible, as it occurs in relief tanks.

For the nuclear industry, it emerges as a solution for containing the discharge

of the high energetic water contained in a primary loop of a Pressure Water Reactor (PWR), and also, to direct it to the chemical and radiological plant treatment facilities.

For Boiling Water Reactors (BWR), DCC emerges as a solution to recollect the water vaporized within the reactor vessel. For this, BWR plants prescribe Suppression Pools in their projects, where the DCC phenomenon takes place.

The DCC phenomenon reached well-established economic importance and has become an object of research since it is related to the safety of nuclear power plants, where it occurs as a high energetic vapor injection in a tank containing liquid compressed water. The heat transfer coefficient is increased due to the turbulent character of the interface of the jet and the bath, and this is the key to the efficiency of thermal exchange [2].

The design of devices where the DCC may occur determined the interest in the research of the phenomenon. The research focused mainly on the determination of a model for the extension of the jet, and another model for the determination of the heat transfer coefficient.

Nevertheless, the highly complex physics of this phenomenon restrains the development of a full analytical model for the extension of the jet and for its heat transfer coefficient. Experimental data are supplied to fulfill the gaps in the analytical development and semi-empirical correlations have been proposed, observing the following restrictions: 1) these correlations are valid only for the specific range of experimental data; 2) the analytical evaluation of the heat transfer directly from the length correlation was not possible, considering the available formulation.

The present work proposes a new formulation for the flux of mass in the currently presented correlations in the literature, in such a way that their validity would extend to any set of data, and which would allow a direct deduction of the heat transfer coefficient from the adjusted correlation of the dimensionless extension. This proposition grounds itself in an analytical procedure considering the 1st and the 2nd law of the thermodynamics.

2. Literature Review

The first proposal to evaluate the extension of the jet, as in [1], is a development of the mass conservation, applied to a simple model, in which a superheated vapor jet produces a cavity full of vapor, discharged in an atmospheric water bath, as presented in **Figure 1**. In Equation (1), the vapor flow rate (“ \dot{m} ”) along the injection axis “ x ” is related to the jet radius “ r ” and the rate of condensation “ R ”.

$$\frac{d\dot{m}}{dx} = -2\pi r'R \quad (1)$$

Figure 2 presents the basic configuration of the experimental set. A pressure chamber (P_C) supplies superheated vapor. After the restriction by a valve, the vapor is injected in the water pool. The setting of the experiment allows a choked flow injection since it would reduce fluctuations in the jet.

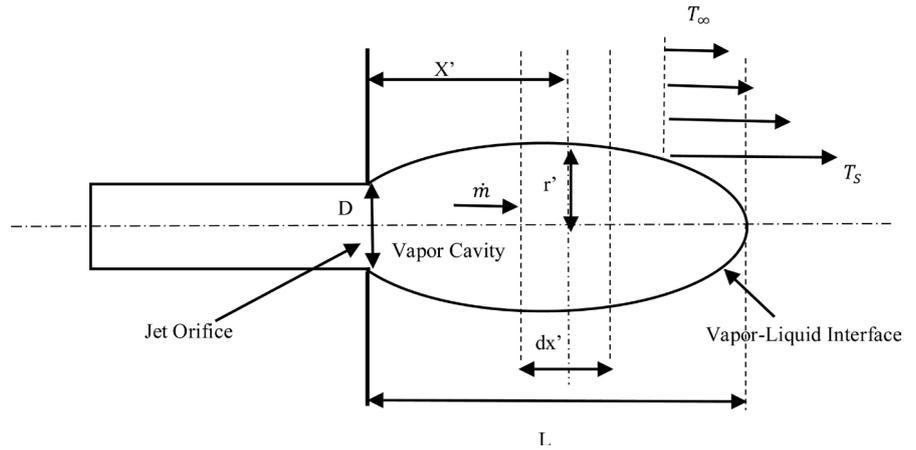


Figure 1. Dimensional variables [1].

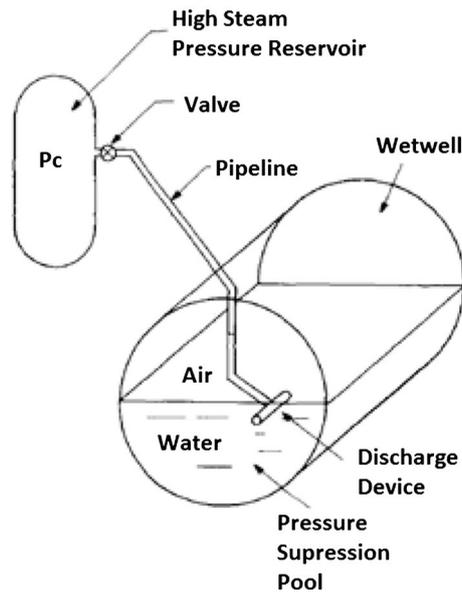


Figure 2. Illustration of the Experiment from (Sonin, 1981).

The dimensions r' and dx' are depicted in **Figure 1**. According to this proposal, there is an outflow of water along the lateral vapor-liquid interface of the jet. This amount of water, crossing the jet interface, promptly freezes, assuming the properties of the surrounding water bath. This condensation is governed by R , which takes the following form:

$$R = h \frac{(T_s - T_\infty)}{h_{gf}} \tag{2}$$

The mass flow (Equation (3)) also takes part in this development. Initial conditions are applied in Equation (4).

$$\dot{m} = \pi r'^2 G \tag{3}$$

$$\dot{m}_0 = \pi r_0'^2 G_0 \tag{4}$$

After some algebraic effort, Equation (1) and Equation (4) produce Equation

(5):

$$X = \int_1^0 \left[- \left(\frac{G_0}{G} \right)^{1/2} \cdot B^{-1} \cdot S^{-1} \right] dY \quad (5)$$

where B is defined as the driving potential for condensation (Equation (6)), and S as the dimensionless transport modulus, which is analogous to the Stanton Number (Equation (7)), although it presents some unorthodoxy, since the heat transfer coefficient (h) and the specific heat (C_p) are related to the liquid phase, and the mass flow rate (G) is related to the vapor phase. X is defined as the dimensionless jet length, Equation (8). For sake of clarity, Y replaces the term presented Equation (9).

$$B = C_p \frac{(T_s - T_\infty)}{h_{sf}} \quad (6)$$

$$S = \frac{h}{C_p \cdot G} \quad (7)$$

$$X = L/r_0 \quad (8)$$

$$Y = (\dot{m}/m_0)^{1/2} \quad (9)$$

At this point, namely Equation (5), [1] comes to a crossroad, since G and S depend on Y , and for this, Equation (5) cannot be integrated. A pure analytic result is not achievable. However, assuming G_M and S_M as constant, this author proposed the correlation, Equation (10):

$$X = \left(\frac{G_0}{G_M} \right)^{1/2} \cdot S_M^{-1} \cdot B^{-1} \quad (10)$$

And S_M is described by Equation (11):

$$S_M = \frac{h}{C_p \cdot G_M} \quad (11)$$

Considering the results of their experiment, treated by linear regression, the numeric format of Equation (12) was proposed, within 13.6% accuracy.

G_M was arbitrarily chosen as 275 kg/m²/s, constant value, related to the critical vapor mass rate of the nozzle, as a representative value of the order of the magnitude of the mass rate. The value of 1.932 for S_M in Equation (12), is partially originated from the arbitrarily chosen value of 275 kg/m²/s and the conditions of the experiment (h , and C_p), which Kerney [1] derived in their experiment, considering a linear fit of the achieved data.

$$X = \frac{1}{1.932} \left(\frac{G_0}{G_M} \right)^{1/2} \cdot B^{-1} \quad (12)$$

In [3], a method to extend the semi-empirical correlation scope, in order to present results considering fluids other than water, and pressures other than ambient in the pool was presented. To achieve it, the proposed correlation considers the influence of the fluid density.

The development is not analogous to that in [3] since it uses a full set of equation (continuity of mass, linear momentum, and energy) while [1] used only the continuity of mass. Another theoretical remark is that the former considered that there is a cross flow of vapor to the bath, which is condensed within it, while the latter considered the opposite entrainment of water into the vapor jet, which is partially evaporated, and creates a two-phase flow zone.

This development also presented a point where the integration of the continuity of the mass is not possible since the integrand is not a defined function of the mass cross flow. An approximated correlation is considered, and this further development, considering experimental data, yields:

$$X = 35.5 \left(\frac{G_0}{G_w} \right)^{1/2} \cdot B^{-1} \cdot \left(\frac{\rho_\infty}{\rho_w} \right)^{-1/2} \quad (13)$$

where G_w is not an arbitrary fixed value since it was considered the mass flux in the point where the jet finishes an isentropic expansion. After that, the jet allows entrained water in. The “ W ” properties are calculated considering the laws of the Thermodynamics, for the depth in which the jet starts the two-phase flow. The average absolute deviation found was 21.9%, higher than the value found in the precedent work.

A slightly better average absolute deviation is found both by Kerney [1] and Weimer [3], when they depart of the condition to have a priori fixed value exponents, and consider them a free product of the regression. No further development of the latter was found in the literature.

Based on previous work, Chun [4], consider that the characteristics of the jet are mainly dependent on 1) the degree of subcooling of the bath, 2) the steam mass flux, 3) the nozzle direction and 4) the depth of the nozzle. The efficiency of the Direct Contact Condensation as a mechanism of heat transfer is also praised, although attention is called to the fact that no reliable correlation to determine the length of the jet exists. According to this paper, much of the disagreement is related to the fact that, experimentally, the length of the jet is obtained by a visual method, what raises issues related to the geometric limits of the jet. In this paper, the end of the jet was considered as the interface between pure vapor and two-phase flow regions. Theoretical development was not presented, and this paper focused on the development of new values for old parameters. The theoretical expression has its roots in Kerney [1], as shown in Equation (14).

$$X = F \left(\frac{G_0}{G_M}, B, S_M \right) \quad (14)$$

Empirically, through visual method, the values of X are determined, which allows Chun [4] propose Equation (15), within a 20% dispersion,

$$X = 0.5923 \cdot \left(\frac{G_0}{G_M} \right)^{0.3444} \cdot B^{-0.66} \quad (15)$$

In sequence, as product of a regression, it is also proposed a correlation for the heat transfer coefficient, Equation (16):

$$\frac{h}{C_p \cdot G_M} = 0.8012 \cdot \left(\frac{G_0}{G_M} \right)^{0.3444} \cdot X^{-1.0079} B^{-0.6247} \quad (16)$$

The value of G_M is also not mentioned throughout the work, for what is supposed that in [4], Chun considered the fixed value of 275 kg/m²/s as formerly proposed.

Proceeding a similar experiment (vapor injection in a subcooled water pool, atmospheric pool), reference Kim, *et al.* (2001) produced the correlation as presented in Equation (17) and Equation (18):

$$X = 0.503 \cdot \left(\frac{G_0}{G_M} \right)^{0.47688} \cdot B^{-0.70127} \quad (17)$$

$$\frac{h}{C_p \cdot G_M} = 1.4453 \cdot \left(\frac{G_0}{G_M} \right)^{0.13315} \cdot B^{0.03587} \quad (18)$$

The value of G_M was again considered 275 kg/m²/s, as originally proposed. It is worth to notice that Equation (10), Equation (15) and Equation (17) are reasonably similar in their forms. Both are directly obtained from the original mathematical development.

Gulawani, in [5] and Kang, in [6] present CFD as a new tool to perform the geometric analysis of the jet, and its heat transfer coefficient. Shah, in [7], also by CFD analysis, found heat transfer coefficients ranging between 0, 6 and 08 MW/m²/K and a dimensionless length ranging between 3.8 and 8.

In [8], it was experimentally proposed a different form of correlation. For instance, this model includes a pressure correction factor, as shown in Equation (21):

$$X = 0.868 \left(\frac{P_0}{P_a} \right)^{0.2} \cdot \left(\frac{G_0}{G_M} \right)^{0.5} \cdot B^{-0.60} \quad (21)$$

This correlation is within a 40% band of error.

This development leads to the proposal of another heat transfer correlation, as shown in Equation (22):

$$S_M = \frac{h}{C_p \cdot G_M} = 0.576 \left(\frac{P_0}{P_a} \right)^{0.2} \cdot \left(\frac{G_0}{G_M} \right)^{0.5} \cdot B^{-0.4} \quad (22)$$

Xu, in [9] proposed a different configuration of an experiment when a vertical pipe injected vapor in a flow of water instead of a pool. The extension and the heat transfer coefficient correlations were determined to have the Reynolds number as a parameter. The results presented the dimensionless extension between 0.29 and 4.64 and the heat transfer coefficient between 0.34 MW/m² K and 11.36 MW/m² K.

Chong, in [10] proposed a correlation for a straight-pipe nozzle, based on the original formulation. Under this work, the dimensionless extension correlation,

the geometry of the orifice nozzle was considered, through the imposition of a geometrical factor $(\varepsilon/\varepsilon')^2$, which represents the expansion ratio between a straight-line nozzle and actual orifice nozzle (for straight-line nozzle, $(\varepsilon/\varepsilon')^2 = 1$), as presented in Equation (21).

$$X = 0.3866 \left(\frac{\varepsilon}{\varepsilon'} \right)^2 \cdot \left(\frac{G_0}{G_M} \right)^{0.78} \cdot B^{-0.80} \quad (23)$$

As a summary, **Table 1** presents the main correlations for determining the dimensionless length in the literature, within the scope of this work.

One can notice that the constant value of $G_M = 275$ kg/s is broadly found (up to 2015) in the literature ([1] [4] [5] [7] [8] [9] [11] and [10]). For each one of these, S_M takes a different constant value, valid only for the respective correlation and for the respective range of data. A more realistic formulation of G_M would be of great interest since it directly impacts the formulation of X , S_M and h .

3. Development

The experimental works under this scope are related to the development of a correlation for the non-dimensional length and heat transfer coefficient, through the propositions of variations of the originally proposed development from which results in the length correlation (Equation (10)). The extension of the works studied shows concern related to increasing the accuracy in a variety of experimental settings and parameters, in order to reduce the band of adjustment numerical error, since no fully analytical model is yet available.

The band of the error band is determined by fluctuations, which were neglected when Equation (5) was approximated. Sonin, in [12] experimentally investigated this phenomenon related to pressure waves propagating along the pool, while Youn [13] focused the particular case in which pressure waves are

Table 1. Extension correlation selected in the literature.

Dimensionless Extension	Equation Number
$X = 0.5200 \left(\frac{G_0}{G_M} \right)^{1/2} \cdot B^{-1}$	(12)
$X = 35.5 \left(\frac{G_0}{G_w} \right)^{1/2} \cdot B^{-1} \cdot \left(\frac{\rho_c}{\rho_w} \right)^{-1/2}$	(13)
$X = 0.5923 \cdot \left(\frac{G_0}{G_M} \right)^{0.3444} \cdot B^{-0.66}$	(15)
$X = 0.503 \cdot \left(\frac{G_0}{G_M} \right)^{0.4768878} \cdot B^{-0.70127}$	(17)
$X = 0.868 \left(\frac{P_s}{P_a} \right)^{0.2} \cdot \left(\frac{G_0}{G_M} \right)^{0.5} \cdot B^{-0.60}$	(21)
$X = 0.3866 \left(\frac{\varepsilon}{\varepsilon'} \right)^2 \cdot \left(\frac{G_0}{G_M} \right)^{0.78} \cdot B^{-0.80}$	(23)

created by a low mass flux of injection. The case where multiple jets are simultaneously created by different holes was explored by Cho [14]. The fluctuations related to turbulence, for example, were not originally considered in the analytical development of the semi-empirical correlations. This analysis indicates that some fluctuation is intrinsic to the process and offers an open field to research.

The experimental works follow a standard: the length of the jet is observed, what allows the definition of a correlation of length and the determination of the heat transfer coefficient. The experimental data collected supplies complementary information in order to complement the development of Equation (5).

In order to achieve a more realistic value of G_M , this paper proposes a new correlation. This value is developed through the application of the 1st and 2nd law of the thermodynamics in the jet, considering it an isentropic discharge, and a function of the conditions in the pressure chamber, as displayed from Equation (24) to Equation (30):

$$G_M = \rho_x \cdot V_{Crit} \quad (24)$$

$$V_{Crit} = \sqrt{2 \cdot (h_0 - h_{crit})} \quad (25)$$

$$h_0 = h(P_0, T_0) \quad (26)$$

$$h_{crit} = h(P_{crit}, s_{crit}) \quad (27)$$

$$P_{crit} = 0.577 \cdot P_0 \quad (28)$$

$$\rho_x = \rho(101.3 \text{ kPa}, s_{Crit}) \quad (29)$$

$$s_{crit} = s_0 \quad (30)$$

Within the scope of this paper, the proposed correlations of G_M (Equation (24)) substituted the formerly constant value of $G_M = 275 \text{ kg/m}^2/\text{s}$ in those correlations presented in **Table 1**. The numerical analysis that follows considered the experimental data obtained from Kerney [1].

4. Results

1) The Validity of G_M as Product of an Isentropic Process

Table 2 presents some important data related to the numerical procedure. Item (i) presents the least square adjustment error when this procedure is applied to the correlation in the respective literature. All the correlations in item (i) were applied to the experimental data presented in Kerney [1]. Item (ii) presents the adjustment error found when the least square procedure is applied to the correspondent correlation when using the value of G_M as proposed in Equation (24), as suggested by this paper. The experimental data comes also from Kerney [1]. The percentage difference between (i) and (ii) is presented in item (iii). Item (iv) presents the value of S_M as found in the respective literature, while (v) presents S_M recalculated, where the data originally used by each respective author is swapped by the data presented in Kerney [1]. The difference from (iv) and (v) can be explained as a consequence of the fact that each correlation stands only for the range of data of the experiment for what it was developed. So,

changing the parameters of the experiment (e.g. the temperature of the pool, pressure of injection, mass flux, etc.), the correlation would also have to be changed in its parameters (S_{M_b} and the exponents of G_0/G_{M_b} B). This is evidenced with the small difference for the column of Equation (12), but greater for the remaining columns. Last item, (vi), evaluates the value of S_M as a product of the isentropic relation in Equation (24). The difference between correspondent values of references (v) and (vi) is small, indicating that the isentropic correlation stands for a broad range of parameters.

For the analysis of **Table 2**, it is evidenced by the dependence of S_M on the range of parameters employed in the experiment, since items (iv) and (v) present a large difference. When the isentropic formulation of G_M (Equation (24)) is used in item (vi), this difference is vastly reduced (see items (v) and (vi)).

The currently proposed distribution of G_M as an isentropic relation (Equation (24)), applied to the experimental data within Kerney [1], follows a logarithmic path along the pressure in the chamber axis (P_C), as presented in **Figure 3**. Equation (30) presents $G_M = G_M(P_C)$ as a product of regression.

$$G_M = 127.6367 + 26.4510 \cdot \ln(P_C) \quad (30)$$

The graphics in **Figures 4-7** present comparisons between the correlations proposed by the respective authors, considering $G_M = 275 \text{ kg/m}^2/\text{s}$ constant, as originally proposed by Kerney [1] *versus* the currently proposed correlation for G_{M_b} within the scope of this paper, Equation (24). The respective results were plotted against the experimental data.

As noticed, the correlations considering both propositions of G_M found a narrow agreement, what validates the use of G_M as the product of an isentropic assumption (Equation 24) as proposed by the present paper.

2) Heat Transfer Coefficient

Once the value of G_M is specified by Equation (24), the heat transfer coefficient (h) can be analytically derived from Equation (11), in conjunction with the adjusted value of S_{M_b} which is obtained from the linear coefficient of the least square adjustment in the correlations of **Table 1**. In this section, this value of heat transfer coefficient, this way obtained, is compared with values found

Table 2. Numerical parameters of the method.

Item	Description	Equation (12)	Equation (15)	Equation (17)	Equation (21)
(i)	Adjustment Error ($G_M = 275 \text{ kg/m}^2/\text{s}$)	2.268	2.762	2.241	2.949
(ii)	Adjustment Error (G_M as in Equation 24)	2.409	2.907	2.407	2.458
(iii)	Difference in Percentage (i) and (ii)	6.255%	5.273%	7.403%	16.65%
(iv)	S_M literature, calculate by the respective author, and with data from the respective author	1.923077	1.688334	1.988072	1.152074
(v)	S_M ($G_M = 275 \text{ kg/m}^2/\text{s}$) recalculated with Kerney [1]	1.918281	0.59453	0.776398	0.534474
(vi)	S_M (G_M as in Equation 24), calculate with data from Kerney [1]	1.850481	0.581395	0.749625	0.514933

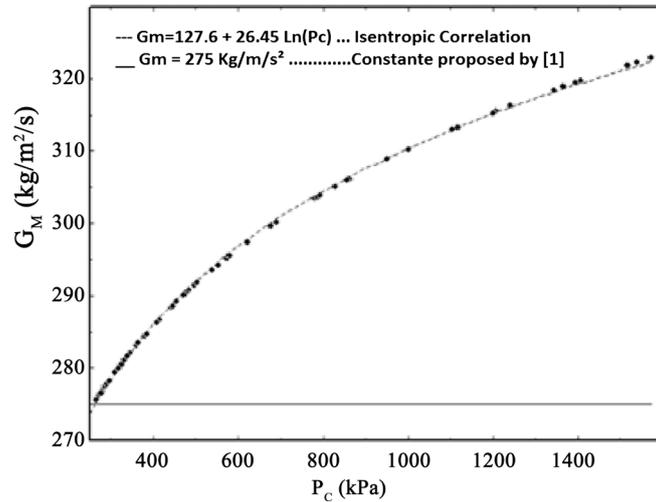


Figure 3. G_M as isentropic relation (Equation (24)) vs. pressure in the chamber (P_c) for Kerney [1], experimental data.

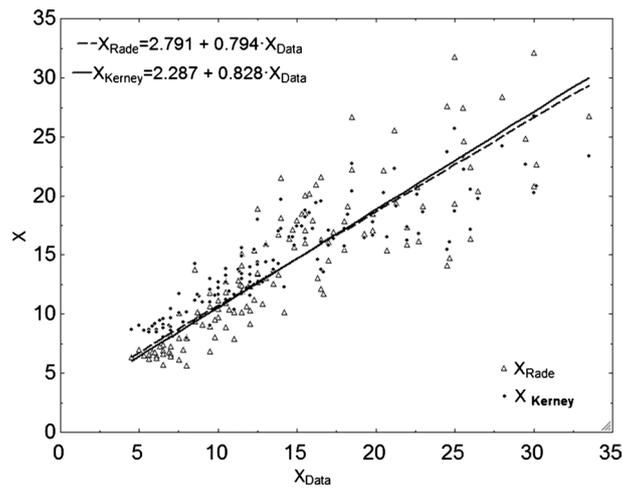


Figure 4. Correlation of Kerney [1], vs. Data X dispersion using $G_M = 275 \text{ kg/m}^2/\text{s}$ constant and by G_M as an isentropic formulation (Equation (24)).

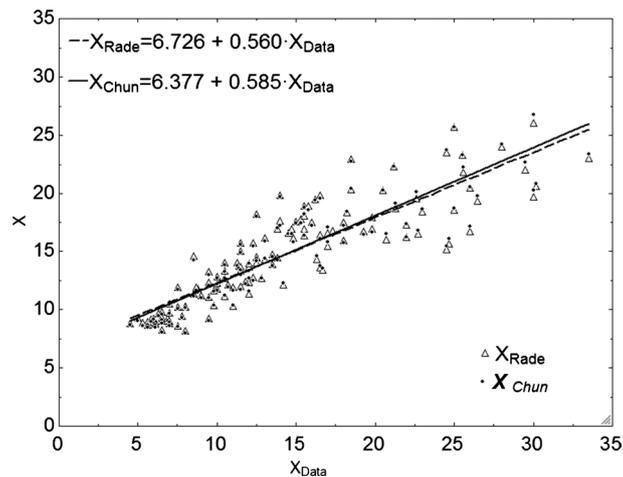


Figure 5. Correlation of Chun [4], vs. Data (X dispersion using $G_M = 275 \text{ kg/m}^2/\text{s}$ constant and G_M as an isentropic formulation, Equation (24)).

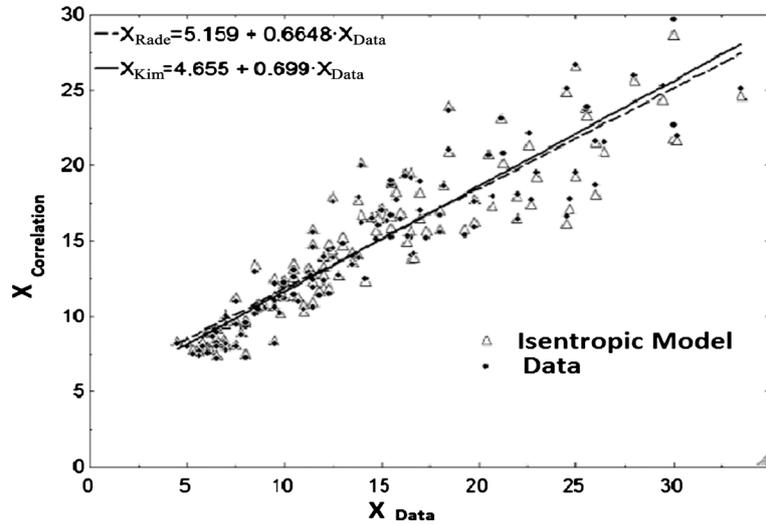


Figure 6. Correlation Kim [11], vs. Data (X dispersion using $G_M = 275 \text{ kg/m}^2/\text{s}$ constant and G_M as an isentropic formulation, Equation (24)).

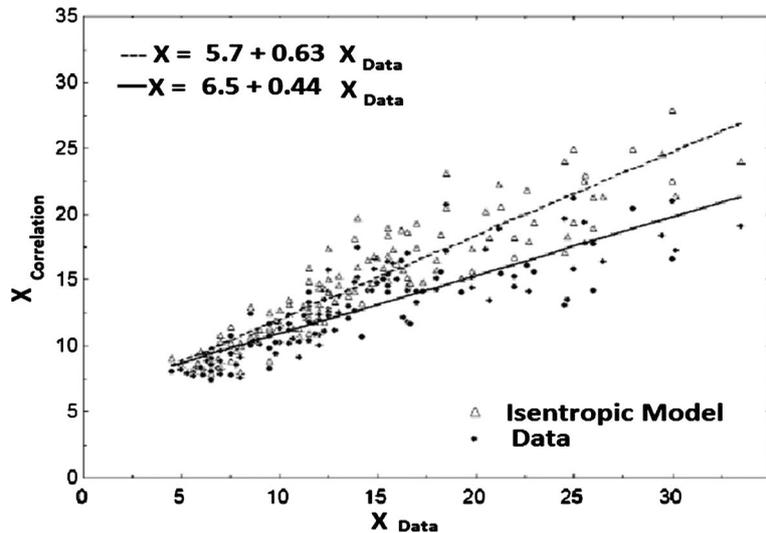


Figure 7. Correlation of Wu [8], vs. Data (X dispersion using $G_M = 275 \text{ kg/m}^2/\text{s}$ constant and G_M as an isentropic formulation, Equation (24)).

through the application of correlations in the literature (Equation (16) and Equation (18)).

Figure 8 and **Figure 9** present h as a smooth function of P_C . Both sets of data belong to the same magnitude order, which indicates that this procedure to obtain h may be valid.

In **Figure 9**, difference decreases as long as the pressure in the chamber increases. On the other hand, **Figure 10** and **Figure 11** present the value of the heat transfer coefficient, found through the application of the least square procedure in an extension correlation in order to determine M with data from Kerney [1]. These values are plotted vs G_0 . When “ h ” is represented as a function of “ G_0 ”, its smoothly dependence on “ G_0 ” is easily observed. Once more, both results belong to the same magnitude order.

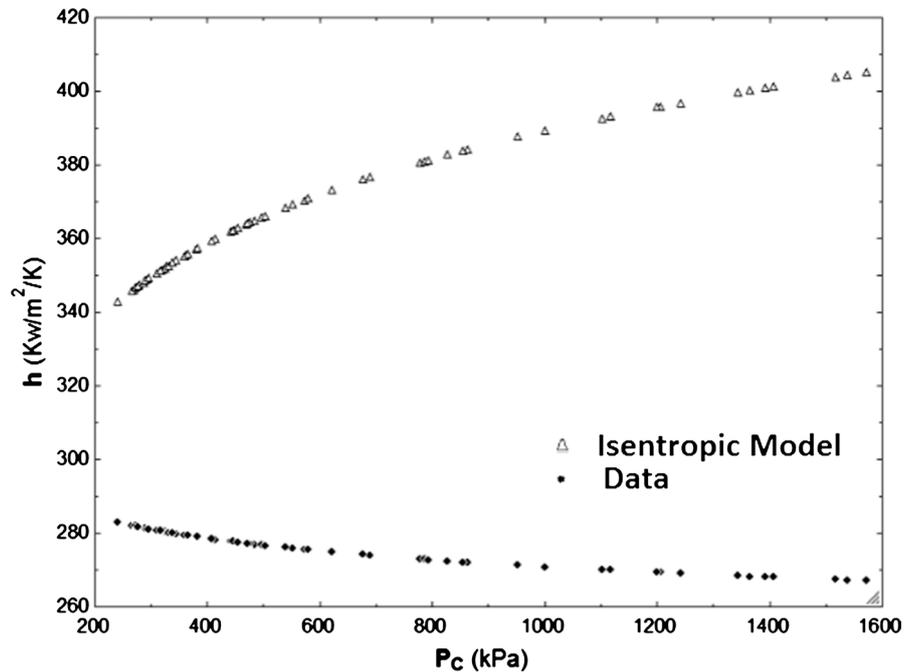


Figure 8. Heat Transfer Coefficient vs Pressure in the Chamber. G_M from an isentropic relation (Equation (24)); h from the correlation of Chun [4], Equation (16); Data from Kerney [1].

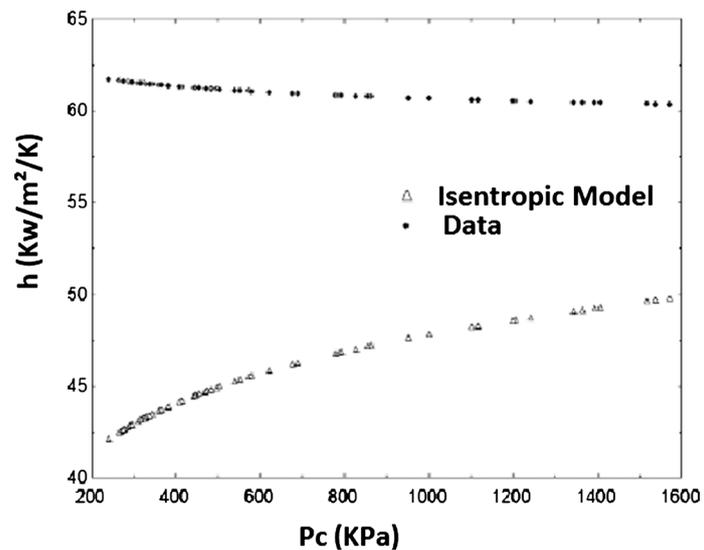


Figure 9. Heat Transfer Coefficient vs Pressure in the Chamber. G_M from an isentropic relation (Equation (24)); h from the correlation of Kim [11], Equation (18); Data from Kerney [1].

5. Conclusions

The decision to maintain S_M as a constant is numerically satisfactory since the chosen value is adjusted by the linear regression to fit the found data. Through this premise, any value proposed for G_M would generate the same adjustment error. This decision, proposed originally by Kerney [1], has been assumed up to works in 2015, although it does not depict the physics of the problem.

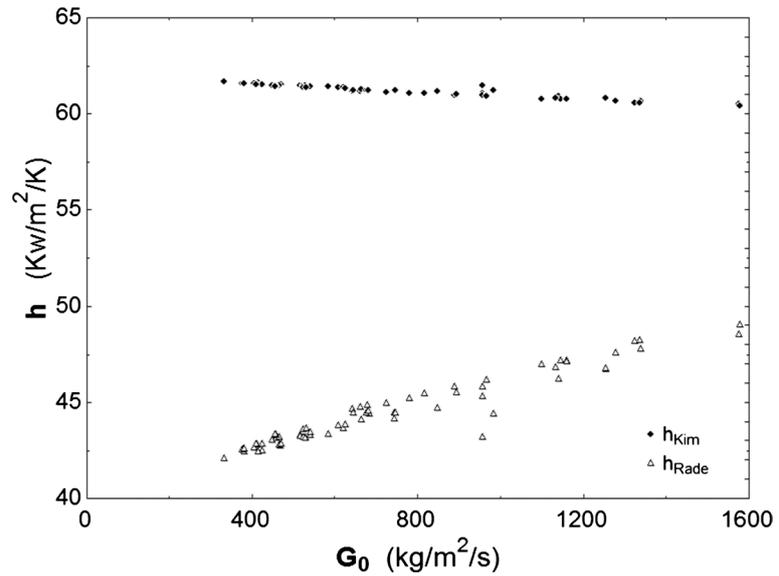


Figure 10. Heat Transfer Coefficient considering G_M from Equation (24) vs. mass flux ratio. h from correlation of Chun [4] vs. mass flux ratio. Data from Kerney [1].

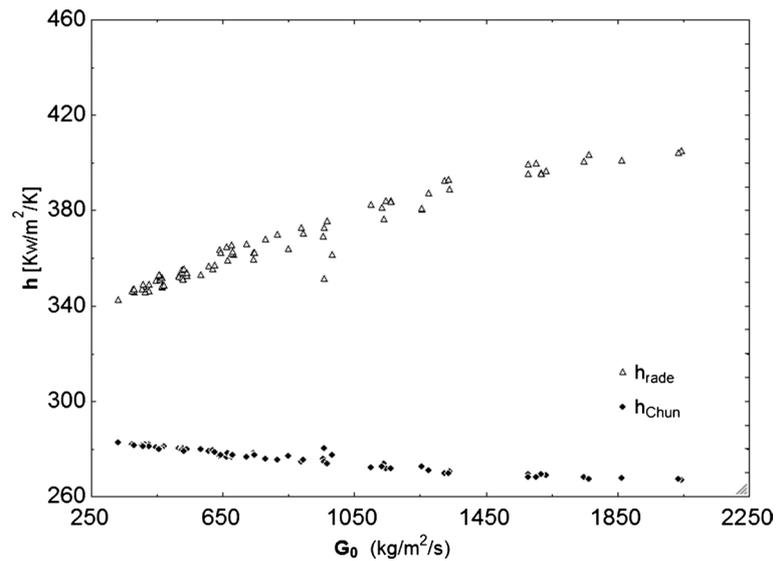


Figure 11. Heat Transfer Coefficient considering G_M from Equation (24) vs. mass flux ratio. h from the correlation of Kim [11] vs. mass flux ratio. Data from Kerney [1].

A full analytic function is not possible to be achieved since the area and the variation of major parameters as a function of the flux of mass in Equation (5) are unknown. These gaps have been fulfilled with experimental data, allowing the propositions of correlations, which present some degree of adjustment error, and are suitable only for the range of the experimented data.

This work presented satisfactory arguments to question the original formulation, where the mass flow rate (G_M) is constant. This original formulation stands as reasonable when a formulation for the extension of the jet is proposed since any constant value proposed fits when applied the linear regression. Although it presents the following drawbacks: 1) the formulation is only valid for the specific

range of data for what it was created; 2) it does not allow the analytical evaluation of the heat transfer coefficient from the extension equation, Equation (10).

This way, the isentropic formulation of G_M adds flexibility for the extension jet equation, once it is less dependent of experimental data, and allows the analytical evaluation of the heat transfer coefficient from the extension equation.

Considering the scope of correlations presented in this work, the proposed correlation of G_M as an isentropic function of the pressure chamber stands as reasonable and would apply to any extension of thermodynamical conditions.

Besides, the isentropic formulation of G_M allows the direct deduction of the heat transfer coefficient from the formulation of the extension, which reduces the dependence on experimental data. The present analysis indicates the possibility to reduce the dependence on experimental data to determine h , and points to a direction where more experimental efforts could be expended.

Further works could focus on the reinforcement of the presented correlation through the experimental analysis, considering a large range of parameters.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Nomenclature

A	Heat Transfer Area (m^2)
B	Condensation Driving Potential
C_p	Water Specific Heat ($\text{J/kg/}^\circ\text{C}$)
G	Steam Mass Flux ($\text{kg/m}^2/\text{s}$)
h	Average Heat Transfer Coefficient ($\text{W/m}^2\text{ }^\circ\text{C}$)
h_{fg}	Condensation Enthalpy (kJ/kg)
L	Steam Jet Length (m)
\dot{m}	Vapor Flow Rate (kg/s)
P	Pressure (kPa)
r	Jet Radius (m)
R	Rate of Condensation (kg/m/s^2)
S	Dimensionless Transport Modulus
T	Temperature ($^\circ\text{C}$)
x	Axial Coordinate (m)
X	Non-Dimensional Jet Length
ρ	Density (kg/m^3)

Subscripts

A	Atmospheric Conditions
C	Conditions in the Pressure Chamber
f	Conditions of Saturated Liquid
S	Conditions in the Vapor-Bath Interface
g	Conditions of Saturated Vapor
∞	Average Conditions in the Pool, Far Away from the Jet
0	Conditions in the Nozzle
M	Average Conditions over the Interface Surface
W	Developed as [3]