METHODOLOGY FOR CALCULATING HEAT LOSSES IN STEAM TRANSMISSION NETWORKS USING MICROSOFT EXCEL

METHODOLOGY FOR CALCULATING HEAT LOSSES IN STEAM TRANSMISSION NETWORKS USING MICROSOFT EXCEL

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Abstract -- Steam transport systems typically include large steam lines with a wide variety and number of transition elements such as valves, flanges, orifice plates, etc., installed along them. When evaluating the efficiency of the transport process through a pipe that carries steam and determining the main causes that impact energy loss, it has been found that the procedure for quantifying energy losses in pipe networks that carry steam is based on simplifications that derive from the complexity of the conditions under which they operate. This paper presents a calculation procedure for determining heat losses in the pipes of a steam transport network, which is based on geometric information about the line and the state of its thermal insulation, as well as the conditions under which the network operates. The results obtained were compared with calculations of the surface temperature and heat loss in a steam pipe with different insulation conditions. The proposed methodology has the advantage of being simple and easy to implement on a personal computer using Microsoft Excel without requiring a large investment, unlike commercial software, which is expensive and requires computer equipment with more specific characteristics.

Keywords: Thermal insulation, Energy losses, Steam transport networks, Heat transfer.

Abstract -- Steam transportation systems typically include large steam lines with a large variety and number of transition elements such as valves, flanges, orifice plates, etc., installed along with them. When evaluating the efficiency of the transportation process through a steam pipeline and determining the main causes that impact energy loss, it has been found that the procedure for quantifying energy losses in steam pipeline networks relies on simplifications that arise from the complexity of the conditions under which they operate. This paper presents a calculation procedure to determine heat losses in the pipes of a steam transportation network, which is based on geometric information of the line and the state of its thermal insulation, as well as the conditions under which the network operates. The results obtained were compared to calculations of surface temperature and heat loss in a steam pipeline with different insulation conditions. The proposed methodology has the advantage of being simple and easy to implement on a personal computer with Microsoft Excel without requiring a high investment, unlike commercial software that has a high cost and requires computer equipment with more specific features.

Key words – Thermal insulation, Energy losses, steam transportation network, Heat transfer.

INTRODUCTION

Currently, power plants are interested in implementing energy saving strategies that increase the efficiency of energy conversion processes, ensuring better use of energy and reducing its impact on the environment. Understanding how this energy loss occurs in steam pipes is an important step in establishing technical and economic parameters for:

a) operation;
b) maintenance;

c) process growth;

During the process of transporting steam in networks (Figure 1), dynamic changes occur in both its thermophysical and transport properties, which modify its terminal conditions. Understanding how these changes occur will help detect anomalies in the behavior of flow variables, in order to correct problems in the operation of the steam transport system.

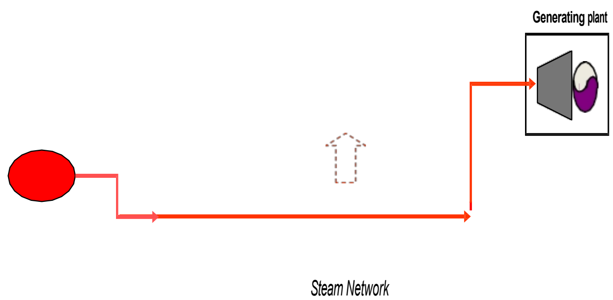

Figure 1. *Steam transport network*
Source: Own work (2021).

In particular, studies related to heat transfer in pipes can be found, such as that developed by Schroeder (1982) [1], who presents detailed studies for calculating the surface temperature of thermal insulation and heat losses or gains.
through a tube, while other flow factors vary.

The model by Marconcini and Neri (1979) [2] includes heat transfer by conduction, convection, and radiation for calculating heat losses in thermally insulated steam pipes.

The work of Peña (1986) [3] and Peña and Campbell (1988) [4], who proposed a model based on the polytropic expansion of steam as it flows through a pipe or a network of horizontal conduits large diameter thermally insulated, from which determines the pressure drop and heat transfer to the environment.

This paper describes a methodology for determining heat losses in steam pipes using an application program developed in Microsoft Excel that facilitates calculations for both insulated and exposed pipes, taking into account the three basic mechanisms of heat transfer from the outer surface of the pipe to the environment.

DEVELOPMENT

The evaluation of heat losses in steam networks, taking into account the condition of their insulation, is a very important step in identifying areas for improvement, because it will reveal the magnitude of these losses in relation to those caused by other loss mechanisms.

This will make it possible to evaluate how convenient it is to maintain the insulation and metal protection of the pipes in good condition, in terms of the cost-benefit ratio obtained, due to the impact they have on reducing energy loss.

Calculating heat losses in a network of pipes that transport steam (steam pipes) is a complex problem in which the three basic mechanisms of heat transport occur simultaneously: heat conduction, convection, and thermal radiation.

Inside the steam duct, steam energy is transferred by forced convection. In this heat transfer mechanism, the analytical solution developed by Rohsenow and Choi [5] is used for the film coefficient in pipes with laminar flow:

$$Nu_m = 4.36 + \frac{0.036\, Re_{D} Pr\, D/L}{1+0.0011\, Re_{D} Pr\, D/L} \quad Ec.(1)$$

In the case of turbulent flow, Gnielinsky's correlation [6] is used to determine the internal film coefficient, which is valid from the transition region to the fully turbulent flow zone and whose mathematical expression is:

$$Nu_m = \frac{(f/8)(Re - 1000)\, Pr}{1+12.7\,(f/8)^{1/2}\,(Pr^{2/3} - 1)} \quad Ec.(2)$$

The friction factor for the turbulent flow region inside the steam duct is determined by applying Chen's correlation [7]:

$$\frac{1}{\sqrt{f}} = -2.0\log\left\{\frac{1}{3.7065}\left(\frac{\varepsilon}{D}\right) - \frac{5.0452}{Re}\log\left[\frac{1}{2.8257}\left(\frac{\varepsilon}{D}\right)^{1.1098} + \frac{5.8506}{Re^{0.8981}}\right]\right\} \quad Ec.\ (3)$$

To obtain a reliable calculation of convection inside the steam duct for low Re numbers in the flow transition zone, Abraham et al [8] recommend using Equation (8) to determine the friction factor in the range 2000 < Re < 4500:

$$f = 3.03\times10^{-12}Re^3 - 3.67\times10^{-8}Re^2 + 1.46\times10^{-4}Re - 0.151 \quad Eq.\ (4)$$

Outside the steam duct, both natural convection and forced convection can occur, depending on the prevailing weather conditions.

In the case of the forced convection mechanism with external flow that occurs outside the steam duct, the heat transfer coefficient is usually determined using semi-empirical correlations, which are a function of

Prandtl number (Pr) and Reynolds number (Re), which in turn depend on the thermophysical properties of the ambient air. A vapor duct can be assumed to be a long horizontal cylinder with cross flow. The external film coefficient is determined using the Churchill and Bernstein correlation [9], whose mathematical expression is:

$$Nu_m = 0.3 + \frac{0.62\, Re_D^{1/2}\, Pr^{1/3}}{\left[1 + (0.4/Pr)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{Re_D}{282{,}000}\right)^{5/8}\right]^{4/5} \quad Ec.(5)$$

In the event that external conditions arise in the steam duct such that heat transfer occurs by natural convection with external flow, the most commonly used correlation for horizontal cylinders is that developed by Churchill and Chu [10], which is valid for a wide range of Rayleigh number values.

$$Nu_m = \left\{0.6 + \frac{0.387\, Ra_D^{1/6}}{\left[1 + (0.559/Pr)^{9/16}\right]^{8/27}}\right\}^2 \quad Eq.\ (6)$$

To evaluate the energy losses per unit length due to heat conduction through the pipe-insulation system, as well as convection in the inside the steam duct, the concept of equivalent thermal resistance [11] can be applied, from which Equation (7) is derived:

$$\frac{q_{cd}}{L} = \frac{T_{sat} - T_w}{\frac{1}{\pi D_i h_{mi}} + \frac{\ln\left(D_o/D_i\right)}{2\pi k_{mt}} + \frac{\ln\left(D_a/D_o\right)}{2\pi k_{ma}}} \quad Eq.\ (7)$$

In order to determine the heat loss from the external surface of the pipe to the environment, a heat balance (see Figure 2) must be performed on this surface, from which the following is derived Equation (8).

$$\frac{q_{cd}}{L} = \frac{q_{cv}}{L} + \frac{q_r}{L} \quad Eq.\ (8)$$

The calculation of the heat transferred by convection between the outer wall of the steam duct and the ambient air, per unit length, is evaluated by applying Newton's cooling law [12], from which we obtain:

$$\frac{q_{cv}}{L} = h_m\, \pi D_a \left(T_w - T_\infty\right) \quad Eq.\ (9)$$

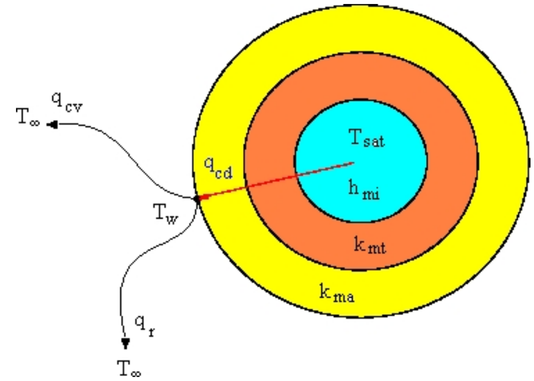

Figure 2. *Heat balance on the outer surface of a vapor duct*
Source*:* Own work (2021)

The heat transferred to the environment by thermal radiation from a duct depends on its absolute temperature and the nature of its outer surface. Assuming that both the steam duct and the surrounding air are gray bodies, the heat loss per unit length is evaluated according to Stefan-Boltzmann's law [13]:

$$\frac{q_r}{L} = \varepsilon\, \sigma\, \pi D_a \left(T_w^4 - T_\infty^4\right) \quad Eq.\ (10)$$

Substituting equations (9) and (10) for the in Equation (7), we obtain an implicit equation for iteratively evaluating the temperature of the outer surface (T_W) of the steam duct:

$$f(T_w) = \frac{T_{sat} - T_w}{\frac{1}{\pi D_i h_{mi}} + \frac{\ln\left(D_o/D_i\right)}{2\pi k_{mt}} + \frac{\ln\left(D_a/D_o\right)}{2\pi k_{ma}}} - h_m\, \pi D_a \left(T_w - T_\infty\right) - \varepsilon\, \sigma\, \pi D_a \left(T_w^4 - T_\infty^4\right) = 0 \quad Ec.(11)$$

Equation (11) is solved by applying the method of Newton-Raphson [14] for the calculation of roots of algebraic equations.

With regard to the calculation of the overall heat transfer coefficient based on the internal area [15], it is important to consider theoretically that heat transport to the environment is carried out by means of heat conduction and convection mechanisms.
Both mechanisms will be considered by the overall heat transfer coefficient as if they were pure convection.

$$\frac{q_{cd}}{L} = \frac{q_{cv}}{L} + \frac{q_r}{L} = U_{mi}\, \pi D_i \left(T_{sat} - T_\infty\right) \quad Eq.\ (12)$$

Clearing the overall heat transfer coefficient based on the internal area of Eq. (12) and substituting the value of (qcd/L) from Eq. (7), we obtain Eq. (13), which represents the fundamental equation for calculating the overall coefficient in the Excel-based application program.

$$U_{mi} = \frac{\dfrac{T_{sat}-T_w}{\dfrac{1}{h_{mi}\pi D_i}+\dfrac{\ln\left(D_o/D_i\right)}{2\pi k_{mt}}+\dfrac{\ln\left(D_a/D_o\right)}{2\pi k_{ma}}}}{\pi D_i\left(T_{sat}-T_\infty\right)} \qquad Eq.\ (13)$$

In order to facilitate the process of calculating the overall heat transfer coefficient for a specific pipe geometry in the network and considering the state of the thermal insulation, a calculation program was developed using Microsoft Excel software (see Figure 3), which automates the process of calculating the overall coefficient for the operating characteristics of the pipe network.

The process of calculating the thermophysical properties of air and steam is performed automatically. To determine the thermal and transport properties of air, a linear interpolation is performed based on the air film temperature, using a table containing the properties of air at standard atmospheric pressure. The thermodynamic properties of water vapor are determined using a library of functions programmed in Visual Basic and embedded in Excel, which is based on the IAPWS-IF97 industrial standard [16].

The thermal conductivity of the insulation and pipe material is evaluated using exponential adjustments, based on conductivity versus temperature tables provided by the manufacturer.

In this program embedded in Excel (see Figure 4), the internal and external surface temperatures of the steam duct, the temperature of the pipe-insulation interface, and the heat transferred from the inside of the pipe to the outside (ambient air) are evaluated per unit length.

DISCUSSION AND ANALYSIS OF RESULTS

As mentioned above, in order to reduce the computational effort required to determine the overall heat transfer coefficient in a steam duct, a series of spreadsheets were generated in Microsoft Excel (Figure 3), which has separate sheets, one for calculating insulated pipes and another for bare pipes (without insulation).

On each of these sheets, you can manipulate the data relating to the environmental conditions prevailing outside the steam duct (temperature and velocity of the wind), modify the emissivity of the materials involved in thermal radiation (outer cover of the steam duct or pipe material), and also change their operating conditions (pressure and mass flow). For temperature, as well as for the thermal and transport properties of steam, these spreadsheets assume that the steam is saturated. In determining the overall heat transfer coefficient for bare pipes, only heat conduction through the insulation was excluded.

Cálculo de la Pérdida de Calor en Tuberías

Tubería Completa, incluyendo la protección metálica

ITERA

		Datos			
V [m/s]	0.28		σ[W/m²-K⁴]		ε
T_∞ [°C]	26.67		5.669E-08		0.30
Dnom, Ced	3	10, 20	12, 20		
Di [in]	3.000	10.250	12.250		
De [in]	3.500	10.750	12.750		
Da [in]	5.500	13.750	16.750		
P_{sat} [barg]	69.303	3.935	3.620		
T_{sat} [°C]	286.13	151.44	148.99		
T_i [°C]	185.478	151.443	148.986		
T_e [°C]	185.419	151.417	148.964		
T_W [°C]	55.775	50.274	45.435		
T_f [°C]	41.223	38.472	36.053		
k_{mt}	48.360	49.190	49.250		
k_{ma}	0.048	0.051	0.051		
h interna					
ρQ[ton/hr]	50.000	310.306	308.673		
ρQ[kg/s]	13.889	310.306	308.673		
ρ [kg/m³]	36.708	2.642	2.483		
μ [kg/m-s]	1.897E-05	1.404E-05	1.396E-05		
K[W/m-K]	6.304E-02	3.181E-02	3.144E-02		
Cp[J/Kg-K]	5369.883	2409.031	2386.749		
Pr	1.616	1.063	1.059		
Re_D	1.22E+07	1.08E+08	9.05E+07		
e [in]	6.00E-03	6.00E-03	6.00E-03		
f	0.02343	0.01730	0.01662		

Figure 3. *Excel program for calculating the overall heat transfer coefficient* **Source:** Own work (2021)

In the case of steam ducts that do not have an outer metal cover (mechanical protection), the user can choose to calculate with a fully insulated pipe and change the emissivity of the metal plate to that of the insulation.

45	R_T	1.4854	0.7633	0.8592
46	q/L	155.0820	132.5474	120.5228
47	Um	2.4968	1.2988	1.0080
48	T_i [°C]	286.135	151.443	148.986
49	T_e [°C]	286.039	151.417	148.964
50	T_W [°C]	73.181	50.274	45.435
51				
52	IT	Tw_{n+1}	Tw_{n+1}	Tw_{n+1}
53	1	385.471	367.203	366.413
54	2	348.469	326.618	322.680
55	3	346.337	323.440	318.615
56	4	346.331	323.424	318.585
57	5	346.331	323.424	318.585

program for calculating heat loss
Source: Own work (2021).

The validation process was carried out by comparing the results obtained by the Excel-based application program with those reported by a program developed for use on HP-67 and HP-97 programmable calculators, which is designed to calculate the surface temperature of steam pipes based on practical cases reported in [1].

The program, which can be used on programmable calculators, is based on the premise that the heat conducted through the insulation must be balanced with the heat exchange that takes place between the outer surface and the atmosphere through convection and radiation mechanisms. For simplicity, the program assumes that the temperature of the inner surface of the insulation is equal to the temperature inside the pipe.

The program assumes that the surface temperature of the insulation is an unknown dependent variable, so an estimated value is proposed for it and the heat transferred by each heat transfer mechanism (conduction, convection, and radiation) is calculated. Once the result for each mechanism has been obtained, a comparison is made between the heat transferred by conduction through the steam duct (pipe and insulation) and the sum of the heat transferred from the outer surface to the atmosphere by convection and radiation.

In this way, by clearing the surface temperature and substituting the equations of the three heat transfer mechanisms, using the method of successive approximations, the program is able to estimate the surface temperature.

The case study analyzed for comparison of results is a carbon steel steam pipe with a nominal diameter of 3" (3.5" outside diameter) that carries steam at 150 psig (10.341 barg) and 366
^{0}F (185.6 ^{0}C). It is insulated with 1" of fiberglass insulation glass with a thermal conductivity of 0.0028 Btu/hr-ft-^{0}F (0.048 W/m-^{0}C) and a fabric cover with matte paint with emissivity (ε) of 0.94. For carbon steel, ε = 0.79, while the ambient air temperature is 80^{0}F (26.67^{0}C).

The variables to be used for calculating heat loss per unit length and surface temperature are:

a) It is assumed that the pipe is insulated and has a fabric cover painted with matte paint;

b) Assume that the pipe is insulated and has a fabric cover painted with 26% aluminum paint (ε = 0.30);

c) Assume that the pipe is bare (without insulation and without a fabric cover);

Figures 5 to 7 show the results obtained using the Excel-based application program for each of the variants indicated above.

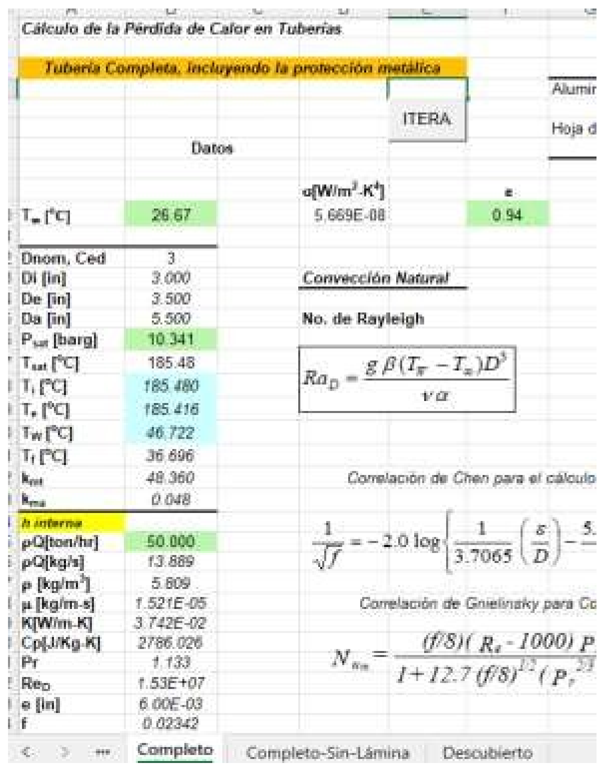

Figure 5. *Solution to case a) using the Excel-based application program*
Source: Own work (2021)

It can be seen that the geometric data and operating conditions of the case study were replaced in the Excel spreadsheet: internal diameter, external diameter, steam pressure, thermal conductivities of the pipe and its insulation, and pipe roughness. A high steam flow (50 tons/hr) was taken into account to ensure that the internal film coefficient is large, given that the program with application in programmable calculators does not consider convection inside the steam duct.

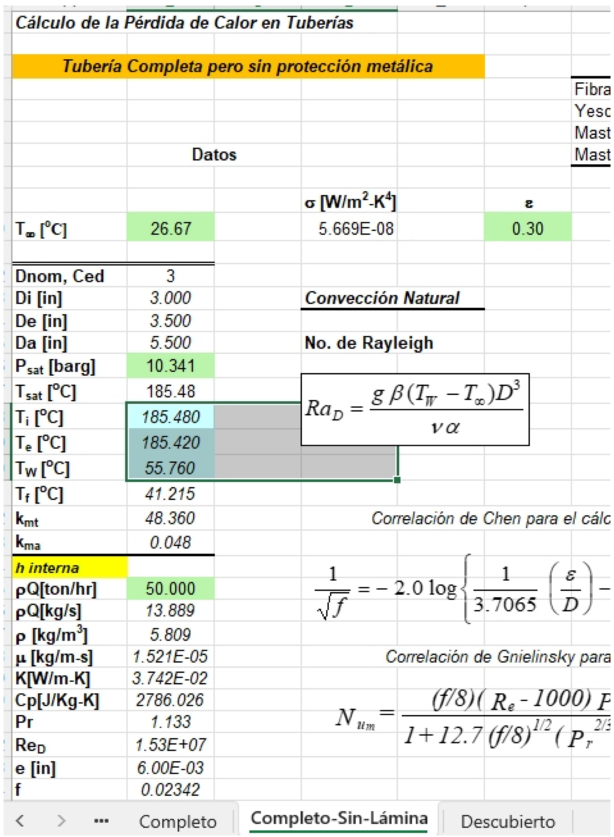

Figure 6. *Solution to case b) using the Excel-based application program*
Source*:* Own work (2021).

Table 1 compares the results obtained by the Excel-based application program and the program running on HP-67 and HP-97 programmable calculators for the different isolation state cases analyzed.

It can be seen that the difference between the results calculated by both programs is minimal, as the relative error does not exceed 2%, which is considered quite acceptable.

Previous work, such as that carried out by Peña [3] and Peña and Campbell [4], predicts heat and pressure losses in large-diameter horizontal pipe networks with thermal insulation using a model based on a single equation that takes into account the polytropic expansion of steam as it flows through the network. The model determines the pressure, the temperatures of the insulation and the steam, the enthalpy, and the humidity of the steam along the pipe, when its diameter, thickness, and type of insulation are known. However, the cases analyzed by these authors include only relatively short pipe sections, compared to the total length of steam pipe networks typical of the industry today.

Table 1. *Comparison of results for different case studies analyzed*

	Caso de Estudio Analizado					
	a)		b)		c)	
Herramienta utilizada	T_w [°C]	q/L [W/m]	T_w [°C]	q/L [W/m]	T_w [°C]	q/L [W/m]
Programa de aplicación basado en Excel	46.7	93.41	55.8	87.33	184.9	835.22
Programa con aplicación en calculadoras programables [8]	46.2	93.88	54.9	88.04		838.91
	1.08	0.50	1.59	0.81		0.44
	Diferencia Relativa [%]					

Source*:* Own work (2021)

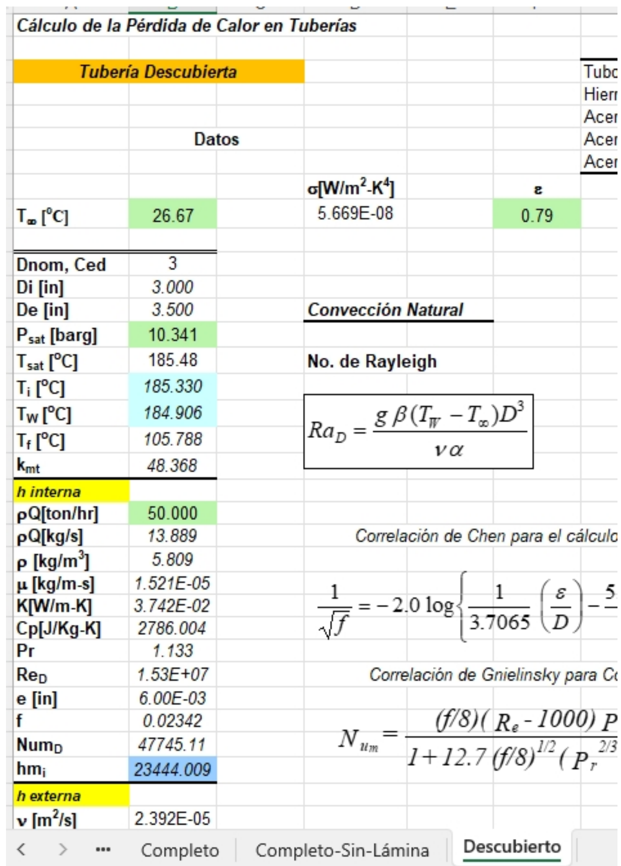

Figure 7. *Solution for case c) using the Excel-based application program*
Source*:* Own work (2021)

Another relevant study is that carried out by Cruickshank, Ordoñez, and Castillo, who developed an adiabatic model to simulate the steam pipeline network of the Cerro Prieto geothermal plant [17], in which the momentum conservation equation is solved without predicting temperature profiles and without taking into account the condensate rate in purges.

The Excel-based application program has the advantage of being accurate, as it incorporates more current and precise correlations, and it performs a more complete calculation, without applying simplifications or considerations to the heat transfer mechanisms by which a steam pipeline loses heat to the environment.

CONCLUSIONS

This paper described a calculation methodology for determining heat losses in pipes carrying saturated steam, which was implemented in Microsoft Excel, taking advantage of this software to facilitate iterative calculations and the programming of formulas for the automatic evaluation of the thermophysical properties of water and air, as well as the thermal conductivities of the pipe and its insulation (Excel-based application program).

This program considered the three basic mechanisms for heat transfer between the steam pipe and the surrounding air, selecting the best correlations for calculating the friction factor inside the pipe and the internal (steam and pipe) and external (external surface and surrounding ambient air) film coefficients for convection.

Separate calculations were designed in Excel spreadsheets to take into account the insulation status of the steam duct, making it possible to calculate heat loss and temperature at the different interfaces of the pipe-insulation-outdoor environment system in both insulated and bare steam ducts (pipes without insulation).

To verify the results obtained using the Excel-based application program, heat loss calculations were performed for an example of a steam pipe with different insulation conditions [1] and these were compared with the results obtained using a program developed for the same purpose, but with application on HP-67 and HP-97 programmable calculators, which is simpler since it is based on the premise that heat conducted through the insulation only occurs through convection and radiation mechanisms, assuming that the temperature of the inner surface of the insulation is equal to the temperature inside the pipe.

The results obtained were satisfactory, since the relative differences in the calculation of both the heat loss to the environment and the temperature of the external surface of the steam duct between the two programs did not exceed 2%.

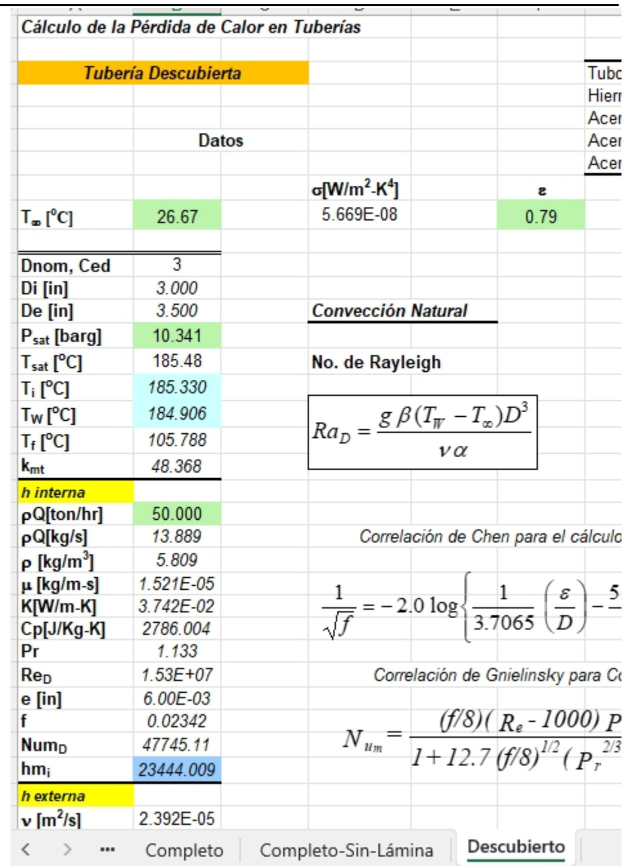

Figure 7. *Solution to case c) using the Excel-based application program.*
Source: Own work (2021).

Other programs such as those described in [3] and [4] do not consider different conditions according to the state of the steam duct insulation (complete, without mechanical protection, and bare) and are not suitable for large pipe networks. Other authors [17] developed an adiabatic model to simulate steam duct networks without predicting temperature profiles and without taking into account the condensate rate in purges. However, the Excel-based application program is more comprehensive in its calculations, as it incorporates more accurate correlations for calculating both internal and external film coefficients, as well as allowing for more detailed calculations for the thermophysical properties of water and air, and the thermal conductivities of the pipe and its thermal insulation.

As future work, we are considering using this Excel-based application program to determine the surface temperature of steam pipes with different insulation conditions (complete with mechanical protection, complete without mechanical protection, and completely bare) and operating conditions (pressure and steam mass flow) in industrial networks, using field-measured data using infrared technology as a reference.

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BIBLIOGRAPHY

[1] Schroeder, F.S. Calculating heat loss or gain by an insulated pipe. Chemical Engineering, January 25, 1982, pp. 111-114.

[2] Marconcini, R. and Neri, G., Numerical simulation of a steam pipeline network, Geothermics, Vol. 7, 1979, pp. 17-27.

[3] Peña, J. M., Energy losses in horizontal steam lines. GRC Transactions, Vol. 10, 1986, pp. 347-252.

[4] Peña, J. M. and Campbell H., Evaluation of heat losses in geothermal steam lines, Proceedings, 3rd Latin American Congress on Heat and Mass Transfer, Guanajuato, Gto., July 4-7, 1988, pp. 53-64.

[5] Rohsenow, W. M. H.Y. Choi., Heat, Mass and Momentum Transfer, 1961, 391.

[6] Gnielinsky, New equations for heat and mass transfer in turbulent pipe and channel flow, Int. Chem. Eng., Vol. 16, No. 2, 1976, pp. 359-368.

[7] Chen N. H., An explicit equation for friction factor in pipes. Industrial and Engineering Chemistry Fundamentals 18, 1979, 296–297.

[8] P. Abraham, E. M. Sparrow, W. J. Minkowycz, Internal-flow Nusselt numbers for the low-Reynolds number end of the laminar-to-turbulent transition regime, Int. J. Heat Mass Tran., 54, 2011, 584–588.

[9] Churchill, S. W. and Bernstein, M. A., Correlating Equation for Forced Convection from Gases and Liquids to a Circular Cylinder in Cross Flow. J. Heat Transfer, 99, 1977, pp. 300-306.

[10] Churchill, S. W., & Chu, H. H., Correlating equations for laminar and turbulent free convection from a horizontal cylinder. International journal of heat and mass transfer, 18(9), 1975,1049-1053.

[11] Incropera, F. P., Dewitt, D. P., Bergman, T. L., & Lavine, A. S., Fundamentals of heat and mass transfer. 2007. Hoboken, NJ: John Wiley; 1985.

[12] Ozisik, M. N., Heat transfer: a basic approach. McGraw-Hill; 1985

[13] Holman, J. P., Heat Transfer, 10th edition. Mc-Graw Hill Higher education;2010.

[14] Chapra, S. C., Canale, R. P., Ruiz, R. S. G., Mercado, V. H. I., Diaz, E. M., & Benites, G. E., Numerical Methods for Engineers (Vol. 5, pp. 154-196). New York, NY, USA: McGraw-Hill; 2010.

[15] Kreith, F., & Bohn, M. S., Principles of heat transfer, St. Paul: West Publishing Company;1993.

[16] Wagner, W., & Kretzschmar, H. J., IAPWS industrial formulation 1997 for the thermodynamic properties of water and steam. International steam tables: properties of water and steam based on the industrial formulation IAPWS-IF97, 2008,7-15.

[17] C. Cruickshank, E. Ordoñez, and G. Castillo (1990), Mathematical model of the steam pipeline network at the geothermal power plant, UNAM, Project Report 9361.

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