A new methodology to calculate the cooling law of steel mill lamination coils

by Doddy Irawan Doddy Irawan

Submission date: 10-Apr-2023 06:41PM (UTC+0700)
Submission ID: 2060483873
File name: irawan2018.pdf (7.69M)
Word count: 4765
Character count: 23965

The International Journal of Advanced Manufacturing Technology
https://doi.org/10.1007/s00170-018-2081-z

ORIGINAL ARTICLE

A new methodology to calculate the cooling law of steel mill lamination coils

Doddy Irawan[1] · Antonio J. Gutiérrez-Trashorras[1] · Eduardo Álvarez-Álvarez[1] · Eduardo Blanco-Marigorta[1]

Received: 20 June 2017 / Accepted: 24 April 2018

Abstract

In the hot-rolled steel production processes, the cooling control after finishing rolling plays an important role on the final microstructure and mechanical properties of the product. Steel coils produced after lamination must be cooled from a high temperature to the ambient temperature, to be transported and sold. Usually, the coil is stored in a warehouse until it reaches the ambient temperature. Cooling process takes between 4 and 6 days, depending on weather conditions. A new methodology to obtain the coil cooling law has been developed in this paper. Numerical models were used to simulate and study the rate of the coil cooling and to obtain the values of the parameters involved in the cooling law. The geometry of the coil is a hollow cylinder with a height between 1.6 and 1.8 m and an outer diameter of about 0.9 m. Simulations of the coil cooling process were performed by using CFD techniques with ANSYS FLUENT software in transient conditions for 2D (two-dimensional) and 3D (three-dimensional) geometries to obtain the optimal rate of temperature decrease. Vertical and horizontal arrangements of the coils and also a different number of coils and rows were studied. A new equation (cooling law) based on logarithmic and arctangent terms was obtained. This equation describes conduction, convection, and radiations effects that have been proposed and verified, considering the boundary restrictions of the problem.

Keywords Computational fluid dynamics · Analytical cooling law · Numerical models · Heat transfer mechanisms · Velocity distributions

1 Introduction

Steel is an essential material in construction and manufacturing. However, some trends in steelmaking technology and steel use could affect the steel demand. Design and innovation can be expected to be the key drivers for such trends [1, 2].

Studies of the Organization for Economic Co-operation and Development (OECD) show that the value added of steel products is still limited to the share of steel demand due to intense competition. Regularly, steel production costs are very high and require substantial investments in research and development (R&D) [3].

According to the study of Pardo et al. [4], energy prices fluctuate significantly influencing energy prices in the future, and this is a challenge for policy-makers. A second study by the global commission on the economy and climate shows the efficient cost recovery in 2030 and the payback period is 2 years, with a margin increase in CO_2 emissions of approximately 20%. Meanwhile, in 2030, for a payback period of 6 years, the margin improvement in CO_2 emissions is the range between 50 and 65% [5].

Reduce input costs due to the high investment required energy efficiency and policies must take into account the impact on competitiveness. EU Commission will monitor the consequences or impact caused by carbon leakage to contribute Directive on Energy Efficiency to be sustainable development [6].

The success of technology in reducing CO_2 emissions is crucial. The challenge is the high cost and public awareness and acceptance that has been presented at the Commission's Communication on the Future of Carbon Capture and Storage in Europe [7].

The intensive energy in iron and steel industry often conducts production processes at high temperatures. The steel industry has experienced significant advances in the

---

✉ Antonio J. Gutiérrez-Trashorras
gutierrezantonio@uniovi.es

[1] Energy Department, Escuela Politécnica de Ingeniería, Edificio de Energía, Universidad de Oviedo, 33203 Campus de Viesques, Gijón, Asturias, Spain

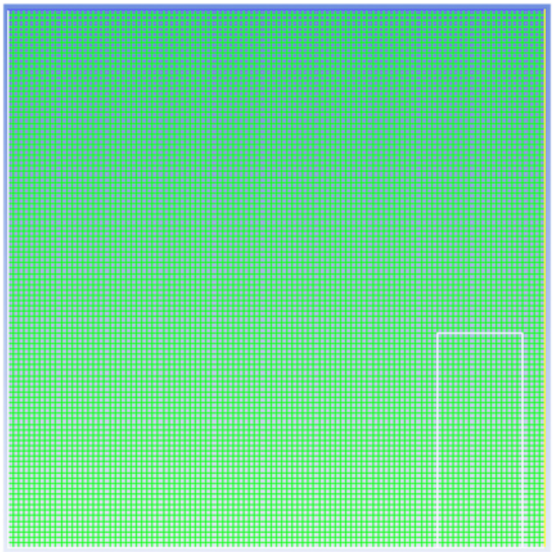


Fig. 1 2D axisymmetric mesh

development of new technique for the emission reduction and the energy efficiency. One of the possible events is the energy recovery from coil process. The goal was to analyze an innovative heat recovery solution to accomplish energy efficiency opportunities and to increase the sustainability [8]. Steel industry produces steel from raw materials (e.g., iron ore, coal, and limestone) or recycling steel scrap. Molten slag, as a kind of by-product during the steelmaking process, exhausted in extremely high temperature, and thus, it carries a great deal of high-grade heat accounting for 10% of waste energy in the steel industry and 35% of high-temperature waste heat. Unfortunately, this amount of heat is one of the few high-temperature waste heat resources that have not well recycled in the entire steelmaking industry due to immature heat recovery technologies [9].

The prediction of the profile or strip crown generated during rolling in the finishing stands of a hot strip mill with the use of artificial neural network (ANN) was studied by Sikdar and Kumari [10]. Thermal and microstructural behaviors of steels must be controlled in the cooling process of coils. A mathematical model to predict temperature changes and phase transformation during controlled cooling was presented by Nobari and Serajzadeh [11]. Also, a computational approach to study the grain size and mechanical properties of hot-rolled rod was developed by Shivpuri et al. [12]. An online Stelmor controlled cooling system for the stabilization of process operation was performed by Yu et al. [13].

Impacts of ambient temperature and humidity on hot-rolled steel cooling were studied by Czaputa and Brenn [14]. Page et al. [15] analyzed the effects of ambient conditions during air treatment operations of food, but ambient temperature and humidity effects in hot-rolled cooling have not been deeply studied.

Thermal conductivity of the steel is a very important parameter to take into account when there is heat transfer by conduction. The equivalent thermal conductivity can be given as a function of material properties, strip thickness, surface characteristic of pieces, average compressive stress, and temperature. Numerical analyses for cooling of a hot-rolled coil were carried out by Park et al. [16] under various cooling conditions by using the equivalent thermal conductivity in the radial direction.

Karlberg studied the temperature distribution of the products throughout the hot strip rolling process including the last coiling operation. That coil cooling process is crucial to decide the heat flux from the coil for an accurate description of the boundary condition to predict the cooling rate [17].

Steel coils produced in steel plants after lamination must be cooled from temperatures of about 400 °C to ambient temperature, to be transported for sale. Its geometry is cylindrical with heights between 1.6 and 1.8 m. The outside diameter of

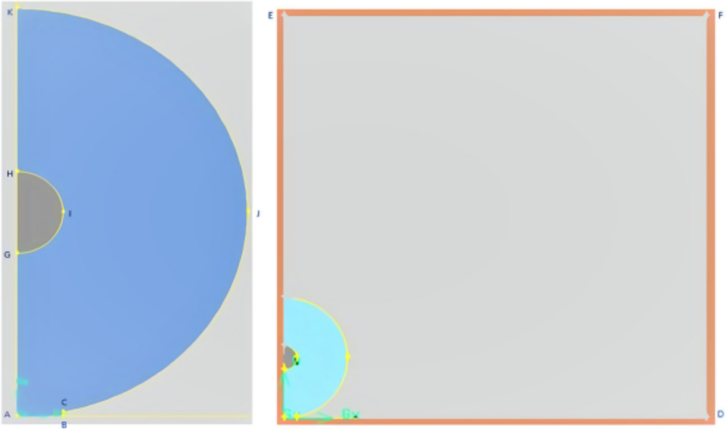


Fig. 2 Geometry of the 2D planar model

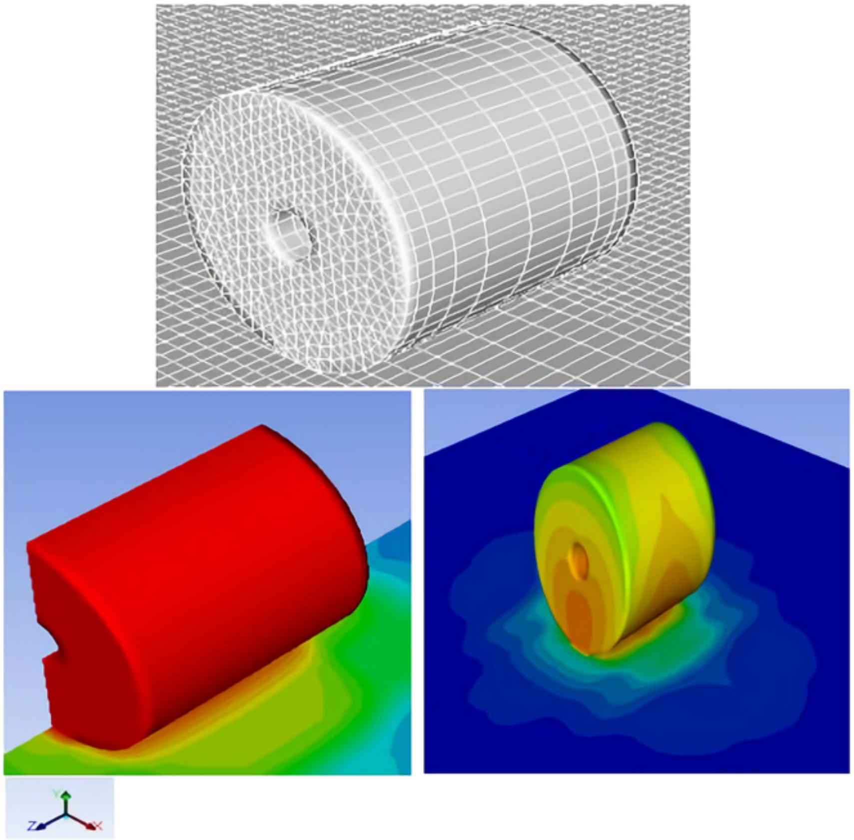


Fig. 3 3D model of one coil

the coil is about 0.9 m. They have a central hollow coaxial of several diameters (approximately of 0.18 m). Coil cooling takes between 4 and 6 days depending on weather conditions, because usually they are left to cool in a workshop that is virtually weatherproof. It produces unwanted stocks and thus represents a "bottleneck" in the marketing process [18]. The cooling by liquids is not allowed because it could change the mechanical properties of the coils.

The study of coil cooling encloses several difficulties such as the fact that the geometries are not simple and usually stored in stacks of two or three levels; it is an unsteady phenomenon, with long cooling times, involving the main heat transfer mechanisms. The knowledge of the coil cooling law by conduction, natural convection, and radiation has not been deeply studied in the literature and it is fundamental to widen the understanding of the cooling mechanisms to be able to control the cooling process.

The main objective of this paper is to obtain a methodology to calculate the cooling law of coils. This cooling law will be expressed by a mathematical equation depending on a few number of parameters. The parameters can be obtained either by simulations or experimentally, allowing to obtain the general cooling law that can be extrapolated for other cases with different geometries and conditions, and avoiding to simulate or perform the experimental studies which are complex and depend on a large number of parameters.

2 Methodology

Numerical analysis with the software ANSYS FLUENT [19] was performed to simulate the coil cooling process. The geometry and mesh were defined by using Gambit 2.4.6. 2D and 3D models were used to study the heat transfer mechanisms involved in the cooling of coils and also to characterize the temperature distributions inside the coil, as well as the temperature and velocity distributions around the coils.

Depending on the orientation of the coils and the number of coils, different models were used to obtain the more appropriate one for each arrangement. For the simulation of one coil, 2D axisymmetric and planar models were used, as well as a 3D model. The simulation of three coils was done by using a 3D model. These models allow

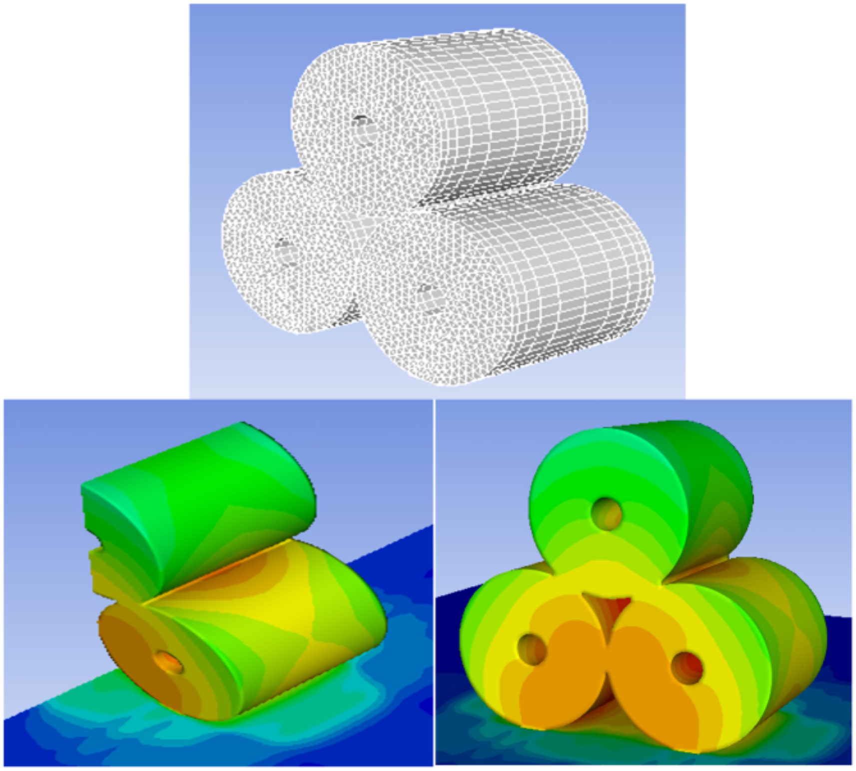


Fig. 4 3D model of three coils

characterizing the heat transfer mechanisms taking place in the coil cooling and obtaining the temperature decrease along time during the cooling process. Consequently, the analytical equations of temperature inside the coil versus time, under different configurations: one vertical coil, one horizontal coil, rows of coils, etc., can be obtained (cooling law).

2.1 2D axisymmetric model of one vertical coil

The coil was assumed to be located vertically in a spacious room measuring 4.5 m × 4.5 m. Conduction, natural convection, and radiation processes were considered for the 2D axisymmetric case. The number of cells used was 10,000. Mesh elements were quad and type paved.

Figure 1 shows a vertical cross section of the mesh were the *x* axis is the symmetry axis of a vertical steel coil (only half of the section is shown).

Pressure inlet was used on the top of the mesh as boundary condition to simulate the natural convection. The employed model was 2D axisymmetric. The RNG k-epsilon turbulence model (viscous) and discrete ordinate model (radiation) were selected. Heat transfer was enabled and the energy equation activated. Also, the standard properties of steel and air (as an ideal gas) were selected.

2.2 2D planar model of one horizontal coil

The coil was assumed to be located horizontally in a spacious room measuring 6 m × 6 m. Conduction, natural convection, and radiation processes were considered for the 2D planar case. The number of cells was 110,202. Mesh elements were quad and type paved.

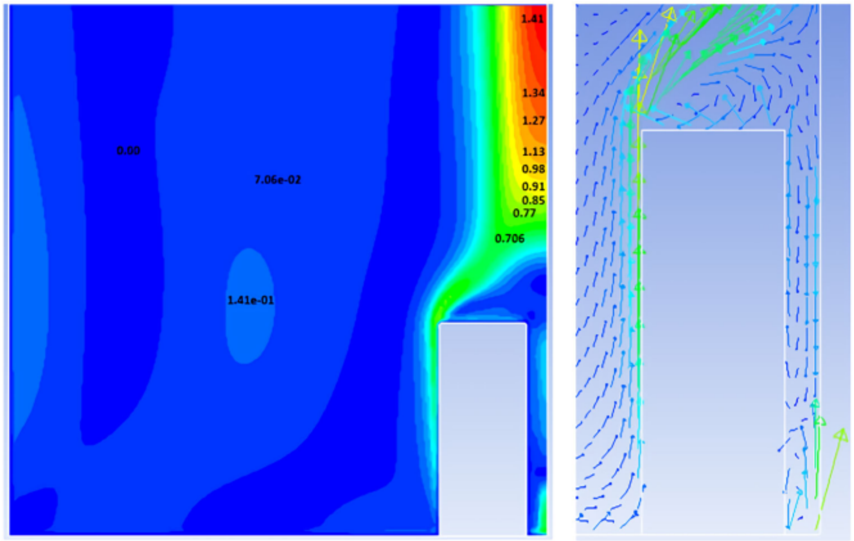
Figure 2 shows a vertical cross section of the horizontal coil were the symmetry axis of the coil is perpendicular to the drawing *x* (only half of the section is shown).

Pressure inlet was used on the top of the mesh as boundary condition and symmetry for the left-hand side axis. The employed model was 2D planar and the rest of the model parameters and material properties were the same as those defined for the 2D axisymmetric model.

2.3 3D model of one horizontal coil

The coil was assumed to be located horizontally in a spacious room measuring 12 m × 12 m × 12 m. Conduction, natural convection, and radiation processes were considered for the

Fig. 5 Velocity distributions. 2D axisymmetric model



Contour of velocity

Vector velocity

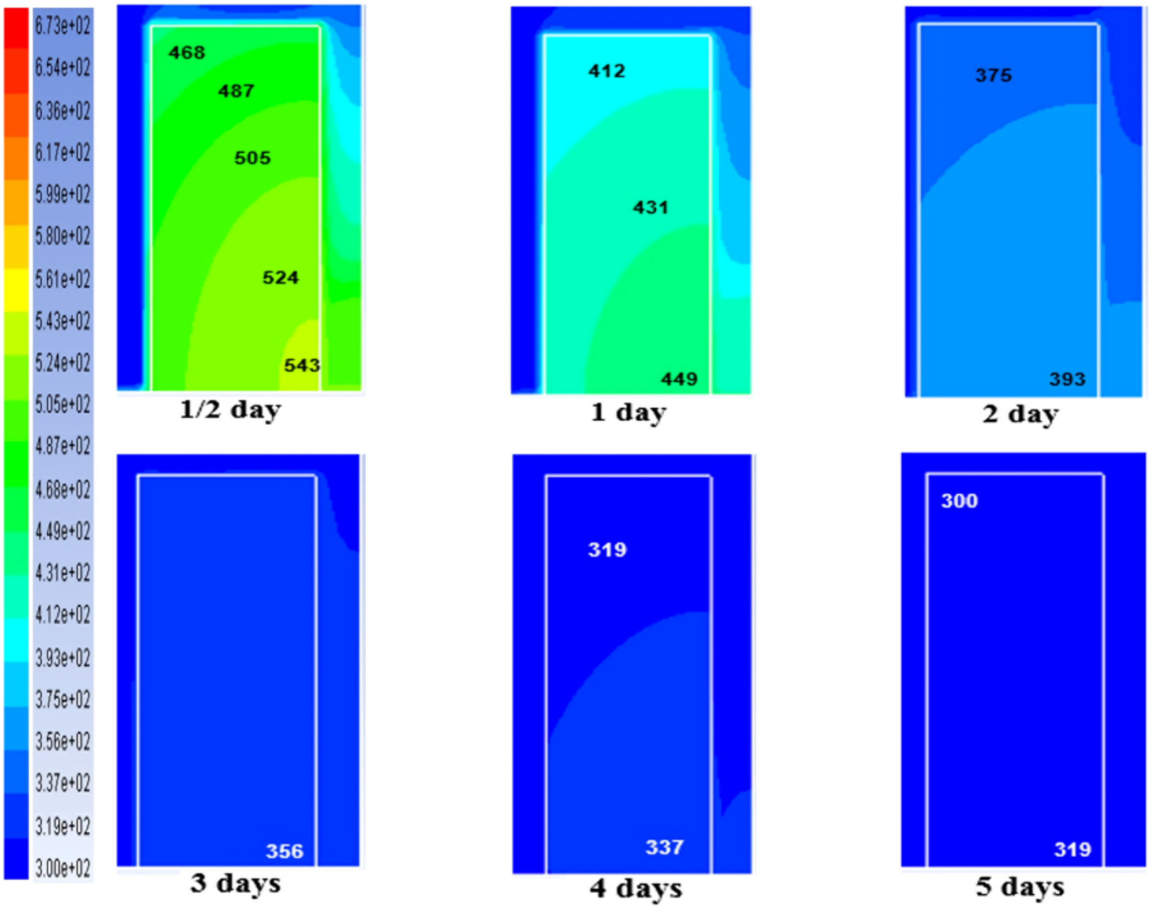
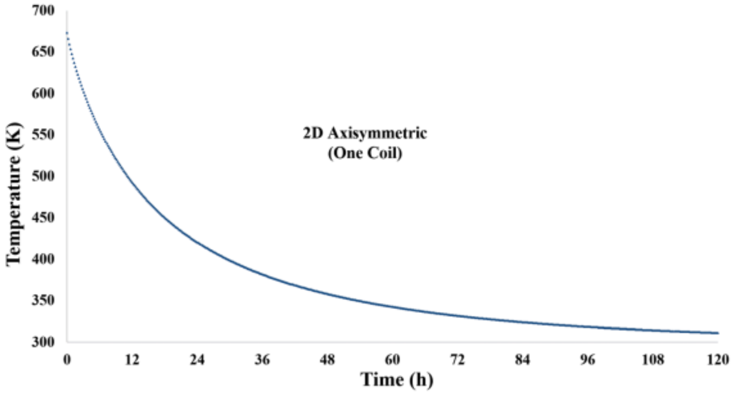


Fig. 6 Temperature distribution (K) during the coil cooling. 2D axisymmetric model

Fig. 7 Average temperature during cooling of a vertical coil. 2D axisymmetric model



3D cooling simulation. The number of cells used was 386,340. Elements were quad and type paved. The employed model was 3D and the rest of the model parameters and material properties were the same as those defined for previous models (Fig. 3).

The first step of testing simulations was using steady flow (time-steady), which aims to obtain a constant temperature (673.15 K) in the coil and the direction of the air velocity during the coil cooling. Once the steady flow is completed, its solution was used as the initial conditions for the transient solver.

2.4 3D model of three horizontal coils

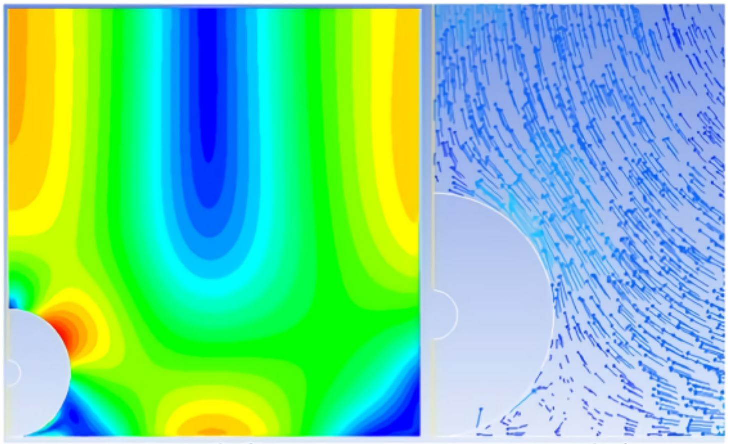
or the simulation of a 3D geometry of the three coils, 488,100 cells were used. The size of the room was 12 m × 12 m × 12 m. The results of the steady flow (time-steady) were used to obtain the initial conditions for the transient solver, analogous to the previous case (Fig. 4). The rest of the model parameters and material properties were the same as those defined for previous models.

2.5 Cooling law: equation of the temperature decrease

The total heat transfer from the coil to the ambient may be considered as a combination of convection and radiation effects. Radiative cooling is described by the Stefan-Boltzmann law which states that rate of heat loss per unit surface area of a body at temperature T is proportional to $T^4 - T_0^4$, where T_0 is the mean temperature of the surroundings. Thus, the combined rate of heat energy loss from a body of surface area A due to both convection and radiation is:

$$hS(T-T_0) + \varepsilon\sigma A\left(T^4-T_0^4\right) \tag{1}$$

Fig. 8 Velocity distributions. 2D planar model



Contour velocity

Vectors velocity

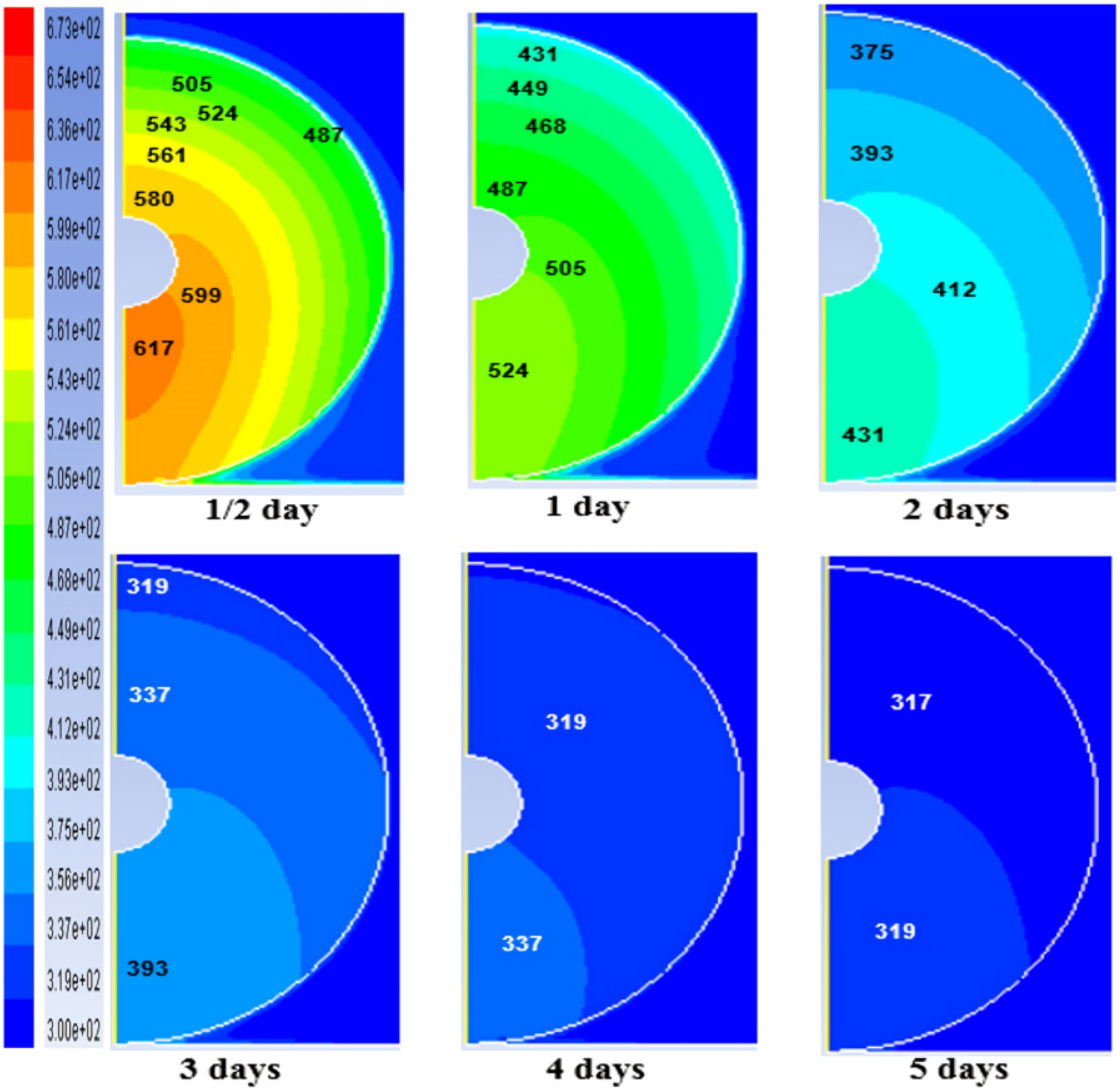


Fig. 9 Temperature distributions. Cooling of one coil and 2D planar model

where h is the convection heat transfer coefficient for pure convection and depends on the cooling conditions. ε is the emissivity of the surface and σ is the Stefan-Boltzmann constant.

The energy balance of the coil can be expressed analytically:

$$-m\,C_P\,\frac{dT}{dt} = \dot{Q}_{\text{Convection}} + \dot{Q}_{\text{Radiation}} \tag{2}$$

where $C_p = \partial Q/\partial T$ is the specific heat capacity of the body.

$$-m\,C_p\,\frac{dT}{dt} = Ah(T - T_0) + A\varepsilon\sigma\left(T^4 - T_0^4\right) \tag{3}$$

Thus, the rate of change of temperature (cooling rate) of the coil is given by:

$$-\frac{dT}{dt} = k_1(T - T_0) + k_2\left(T^4 - T_0^4\right) \tag{4}$$

with

$$k_1 = \frac{Ah}{m\,Cp};\, k_2 = \frac{A\varepsilon\sigma}{m\,Cp} \tag{5}$$

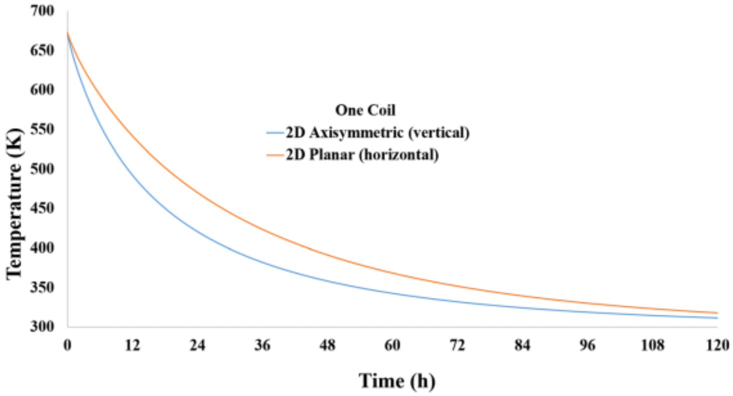


Fig. 10 Comparison between the average temperatures for vertical and horizontal coils

Integrating and considering the boundary restrictions of the problem, the equation suggested was:

$$t = a \cdot \mathrm{In}\left(\frac{T_i - T_0}{(T+c) - T_0}\right) + b \cdot \mathrm{arctg}\left(\frac{T_i - (T+c)}{T_i - T_0}\right) \tag{6}$$

with T_i = 673.15 K and T_0 = 300 K being the initial temperature of the coil and the ambient temperature respectively.

$$t = a \cdot \ln\left(\frac{(673.15 - 300)}{(T+c) - 300}\right) + b \cdot \mathrm{arctg}\left(\frac{673.15 - (T+c)}{(673.15 - 300)}\right) \tag{7}$$

Finally, for each of the studied cases, the values for a, b, and c are to be determined to fit the numerical results, as described in the following section.

3 Results and discussion

3.1 Cooling simulation of one vertical coil. 2D axisymmetric model

The flow air velocity around the coil at the end of the cooling is shown in Fig. 5. The main flow outside the coil is going up according natural convection because there is a remaining part of the coil at higher temperature than the atmospheric one. During the cooling process, velocity distributions have similar distributions but different values. The closest the initial conditions, the highest the velocity magnitudes. In the first 12 h, the cooling process occurs very rapidly because the air density differences between the different parts are very great due to great temperature differences (buoyancy effect). In the following hours and days, the flow velocity is slower due to the fact that the coil temperatures are much lower (Fig. 6).

The evolution of the average temperature of the coil is presented in Fig. 7.

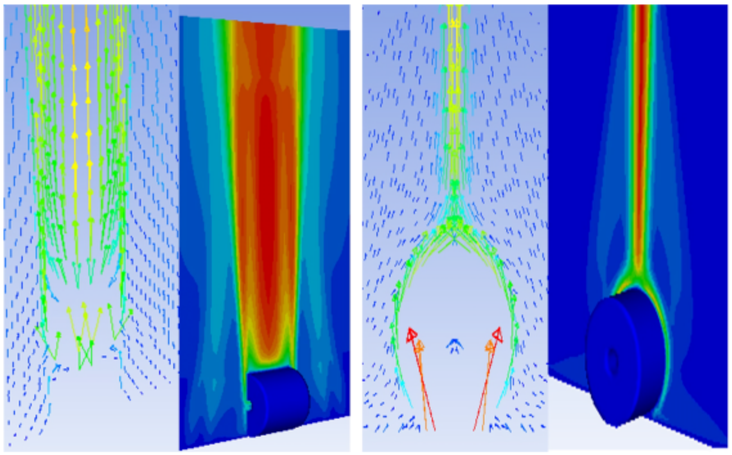


Fig. 11 Velocity distributions on a vertical plane containing the symmetry axis of the coil and on a vertical plane perpendicular to the symmetry axis of the coil. 3D model for one coil

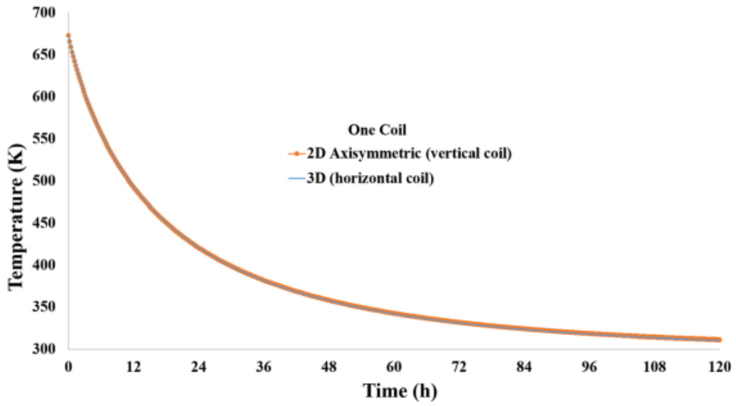


Fig. 12 Comparison of the average temperature between 2D axisymmetric (vertical coil) and 3D (horizontal coils) models

Initial cooling rates are greater than the final ones according to the lower effect of the heat transfer mechanisms throughout time.

3.2 Cooling simulation of one horizontal coil. 2D planar model

The air velocity around the horizontal coil during the cooling is shown in Fig. 8. Analogous to the vertical arrangement, the main flow outside the coil is going up according natural convection. The closest the initial conditions, the highest the velocity magnitudes. Figure 9 shows the temperature distributions during the cooling.

3.2.1 Comparison between vertical and horizontal arrangements of the coils

According to the 2D simulations, the better way to cool the coils is to locate them vertically as shown in Fig. 10. Initially, the cooling rate is greater for the vertical coil than for the horizontal one. This is coherent with the natural convection that is stronger for the vertical arrangement. The temperature differences are greater in the vertical dimension because the planar model considers only 1 m length (instead of 1.8 m) and it does not take into account the edge effects that increase the heat transfer released to the ambient. Nonetheless, after 5 days, the average temperature is quite the same.

It is more realistic to compare the vertical coil simulated with the 2D axisymmetric model with the horizontal 3D simulation of one coil because both simulations consider the real length of 1.8 m and the edge effects.

3.3 Cooling simulation of one horizontal coil. 3D model

To complete the study, a 3D model was used in order to obtain more accurate results. Figure 11 presents the velocity distributions on a vertical plane containing the symmetry axis of the coil and on a vertical plane perpendicular to the symmetry axis of the coil. It can be seen that the maximum air flow is concentrated in a vertical thin layer going up above the coil all along the length because it is maintained close to the rounded surface until it reaches the higher part of the coil. The vertical

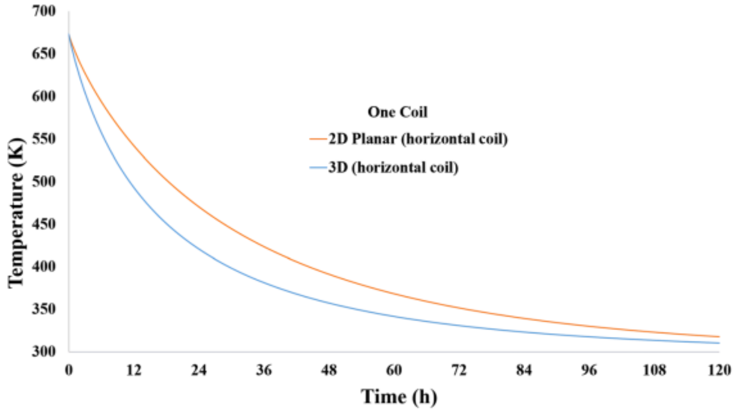


Fig. 13 Comparison between the average temperature for 2D Planar and 3D horizontal coils

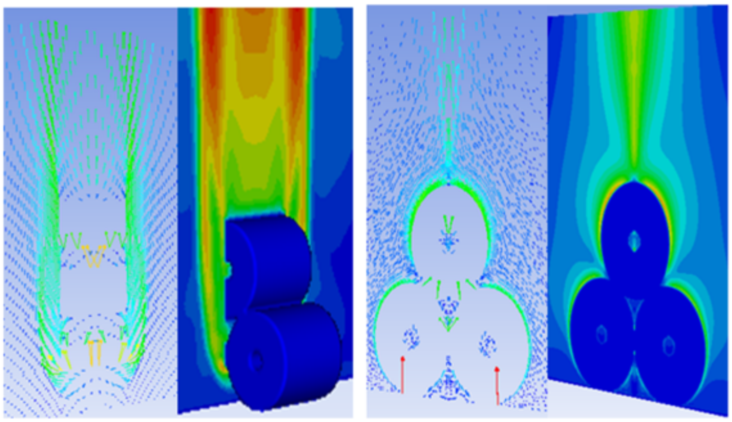


Fig. 14 Velocity distributions. 3D simulation of three coils

mass of fluid going up from the coil is due to big gradients of temperature.

First, the vertical coil simulated with the 2D axisymmetric model is compared with the horizontal 3D simulation of one coil. Figure 12 shows that the average temperature follows a very similar evolution through time in both cases. Due to space limitations, coils are placed in rows in the warehouse. To locate the coils vertically is more difficult and dangerous than to locate them horizontally. It is easy to transport and locate the horizontal coils by taking them by the hollow. Also, to lock the coils horizontally is easier using the hollows.

Figure 13 shows average temperature versus time for one horizontal coil simulated with the 2D planar model compared with the 3D simulation. Initially, the cooling rate is greater for the 3D than for 2D planar model. After 5 days, the average temperature is almost the same.

3.4 Cooling simulation of three horizontal coils. 3D model

Figure 14 shows the velocity distributions on a middle plane parallel to the symmetry axes of the coils and on a vertical plane perpendicular to the mentioned axes. It is similar to the velocity field for one coil (Fig. 11) and the maximum air flow is concentrated in a vertical thin layer above the coils all along their length but farther from the coils than in the case of one coil. This is coherent with the lower gradient of temperature inside the three coils (same temperature differences than for one coil but bigger distances).

Similar results to the ones obtained with the 3D simulation for one horizontal coil were obtained for three horizontal coils placed in two rows. The cooling rate is greater for the 3D simulation of one coil than the rate obtained for three coils, all along the time (Fig. 15). After 5 days, the difference is very small, but obviously, the remaining temperature for three coils is a little bit greater.

3.5 Cooling law equation parameters

The parameter values of Eq. 7 for the cases studied were obtained by the method of least squares and the goodness of fit was measured by the coefficient of determination (R^2). Those values are shown in Table 1.

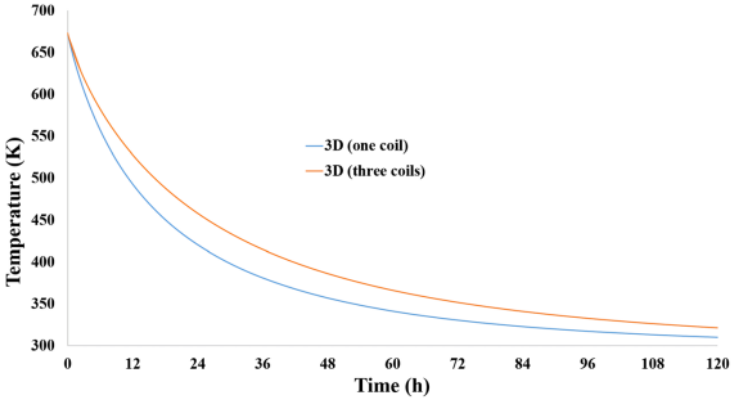


Fig. 15 Comparison between the average temperature for 3D models of one and three coils (horizontally oriented)

Table 1 Equation parameters for the studied models

	a (× 10^{-5})	b (× 10^{-5})	c	R^2
2D axisymmetric	1.296	− 1.074	− 4.539	0.9997
2D planar	1.552	− 0.744	− 1.691	0.9999
3D one coil	1.393	− 1.021	− 3.425	0.9999
3D three coils	1.595	− 1.087	− 6.771	0.9998

For all the models, the coefficient of determination is very close to 1. It means that the equation fits very well with the data obtained with the simulations.

Parameter "a" is the coefficient affecting the natural logarithm that comes from both mechanisms: convection and radiation. This parameter has of the same order of magnitude as $(m\ C_p)/(Ah)$, which is $1/k_1$. This is coherent with the mathematical development.

Parameter "b" multiplies the function arctangent, which is a correction of the main term (natural logarithm) due to radiation. It takes into account that the heat transfer by radiation depends on the deference of the fourth powers of the absolute temperatures (according to Boltzmann's law), and it decreases along the time of cooling. Therefore, parameter "b" is negative.

Parameter "c" accounts for the conduction inside the coil. T represents the average temperature and $T + c$ the temperature at the surface of the coil. Therefore, parameter "c" measures the difference between the surficial and the average temperatures. During the cooling process, parameter "c" is negative.

According to Table 1, the results are coherent with the previous ones. 2D axisymmetric parameters are quite similar to the ones of the 3D simulation for one coil. For three coils, the absolute values of the parameters are greater than for one coil. Parameter "c" is greater in absolute value for three coils than for one coil, meaning that the difference between the average and the surface temperatures is greater. The cooling rate is greater when the absolute values of the parameters are lower.

The trends of the results obtained by this methodology are the same as those obtained experimentally by other authors [20, 21]. Besides, the fitting obtained by means of the mathematical equation exposed here is more realistic than those proposed by other authors that do not take into account the effect of radiation. The results obtained are internally supported by the physical reasoning performed in the development of the analytical expressions.

4 Conclusions

A methodology to calculate the cooling law of hot-rolled coils was developed in this paper. Different analyses of one and three coils placed in two rows were presented. The cooling law is expressed by a mathematical equation depending only on three parameters and it is composed of two terms: natural logarithm and arctangent. The values of these parameters have been obtained by numerical analysis with the software ANSYS FLUENT. 2D and 3D models were used to study the heat transfer mechanisms involved in the cooling of coils and also to characterize the temperature distributions inside the coil, as well as the temperature and velocity distributions around the coils. The trends of the results obtained by this methodology are the same as those obtained experimentally by other authors.

The cooling law for one coil placed vertically and horizontally is almost the same but, due to space limitations, coils are placed in rows in the warehouse. It is easy to handle, transport, and lock the coils horizontally. Also, the cooling rate was calculated for one coil and three coils. The cooling rate is greater for one coil than the rate obtained for three coils horizontally oriented, but the total time to cool them is almost identical.

The values of the three parameters defined by the equation of the cooling law obtained are very good because the coefficient of determination is very close to 1. Also, the values are coherent with the physical concepts of heat transfer mechanisms. Parameter "a" is the coefficient affecting the natural logarithm that comes from both convection and radiation mechanisms. Parameter "b" multiplies the function arctangent. It takes into account that the heat transfer by radiation depends on the difference of the absolute temperatures raised to the fourth power and that it decreases along time. Parameter "c" accounts for the conduction inside the coil and it measures the difference between the surficial and the average temperatures.

The methodology allows quantifying temperatures, times, and cooling rates by means of the cooling law for the cases studied. It could be interesting to study the influence of geometrical parameters, the number of coils and rows, and thermal properties of the materials by following the defined methodology for a larger number of cases, in order to be able to extrapolate the results to different cases and avoid the simulations.

References

1. Wang X, Tang L (2008) Integration of batching and scheduling for hot rolling production in the steel industry. Int J Adv Manuf Technol 36(5–6):431–441
2. Yadollahpour MR, Bijari M, Kavosh S, Mahnam M (2009) Guided local search algorithm for hot strip mill scheduling problem with

considering hot charge rolling. Int J Adv Manuf Technol 45(11–12):1215–1231

3. OECD DSTI/SU/SC. The future of the steel industry: selected trends and policy issues. 73rd Steel Committee Meeting Paris, 6–7 December 2012
4. Pardo N, Moya JA (2013) Prospective scenarios on energy efficiency and CO2 emissions in the European iron & steel industry. Energy 54:113–128
5. Estimates of emissions reduction potential for the 2015. Report. https://newclimateeconomy.report/workingpapers/wp-content/uploads/sites/5/2016/04/Estimates-Reduction-Potential-NCE-20151.pdf. (Last accessed June 2017)
6. EC–European Commission. (2012). Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency. Official Journal of the European Union, L, 315(1)
7. European Commission. On the future of carbon capture and storage in Europe COM (2013)
8. Villar A, Arribas JJ, Parrondo J (2012) Waste-to-energy technologies in continuous process industries. Clean Techn Environ Policy 14(1):29–39
9. Das B, Prakash S, Reddy PSR, Misra VN (2007) An overview of utilization of slag and sludge from steel industries. Resour Conserv Recycl 50(1):40–57
10. Sikdar S, Kumari S (2009) Neural network model of the profile of hot-rolled strip. Int J Adv Manuf Technol 42(5–6):450–462
11. Nobari AH, Serajzadeh S (2011 Mar 31) Modeling of heat transfer during controlled cooling in hot rod rolling of carbon steels. Appl Therm Eng 31(4):487–492
12. Phadke S, Pauskar P, Shivpuri R (2004) Computational modeling of phase transformations and mechanical properties during the cooling of hot rolled rod. J Mater Process Technol 150(1):107–115
13. Yu, Wan-Hua, et al. Development and application of online Stelmor controlled cooling system. Appl Therm Eng 29.14 (2009): 2949–2953
14. Czaputa K, Brenn G (2012) The convective drying of liquid films on slender wires. Int J Heat Mass Transf 55(1):19–31
15. Le Page, Jean-François, et al. Development of an approximate empirical-CFD model estimating coupled heat and water transfers of stacked food products placed in airflow. J Food Eng 92.2 (2009): 208–216
16. Park SJ, Hong BH, Baik SC, K. H (1998) Finite element analysis of hot rolled coil cooling. ISIJ Int 38(11):1262–1269
17. Karlberg M (2011) Modelling of the temperature distribution of coiled hot strip products. ISIJ Int 51(3):416–422
18. Irawan D, García A, Gutiérrez AJ, Álvarez E, & Blanco E Modeling of coil cooling using 2D and 3D computational fluid dynamics (CFD), The 3rd International Congress on Water, Waste and Energy Management, 18th–20th July 2016, Rome
19. Fluent ANSYS (2012) 14.5, theory guide; ansys. Inc., Canonsburg, PA
20. Witek S, Milenin A (2018) Numerical analysis of temperature and residual stresses in hot-rolled steel strip during cooling in coils. Arch Civil Mech Eng 18(2):659–668
21. Cheng J, Liu Z, Dong H, Gan Y (2006) Analysis of the factors affecting thermal evolution of hot rolled steel during coil cooling. J Univ Sci Technol Beijing Miner Metall Mater 13(2):139–143

A new methodology to calculate the cooling law of steel mill lamination coils

ORIGINALITY REPORT

14%	15%	4%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

MATCH ALL SOURCES (ONLY SELECTED SOURCE PRINTED)

10%

★ www.researchgate.net

Internet Source

Exclude quotes	On	Exclude matches	< 2%
Exclude bibliography	On		