PROJECT OF HEAT TRANSFER

HEAT CONDUCTION: COOLING OF A SOLID BY FORCED OR NATURAL CONVECTION

2022/2023

The continuous casting machine is used in many metal industries, including the steel industry, to manufacture metal billets or slabs (rectangular, quadrangular or circular cross section with variable length) at high temperature – see illustrative images of figure 1.

These billets will subsequently be cooled down by natural (or, in some cases, by forced) convection at atmospheric air, either suspended or, for rectangular and quadrangular cross-sections, with one face in direct contact with the ground (that may be considered in this work as an adiabatic surface).

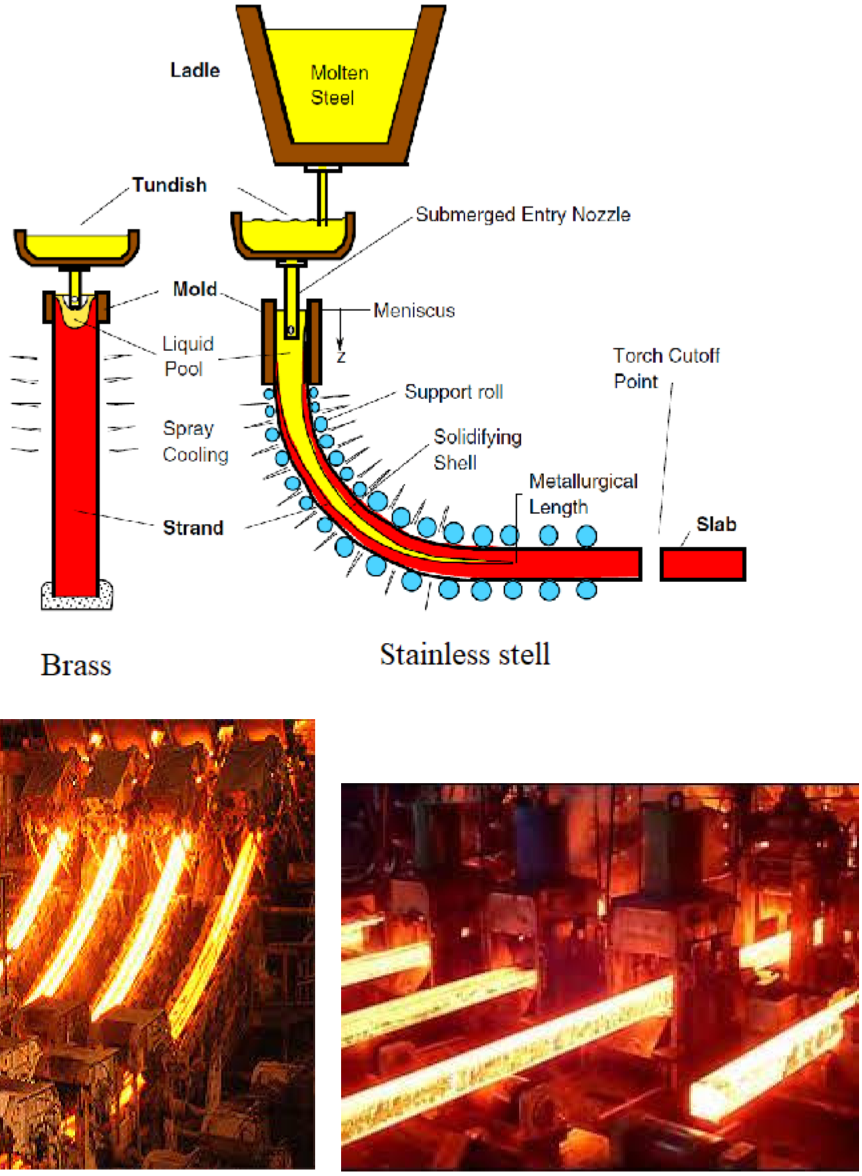

Figure 1 – Diagram of a continuous casting machine for circular brass and rectangular/quadrangular stainless steel billets and images of the steel billets manufactured in a continuous casting machine.

Consider the metal billet X in table 1 (X is a dummy letter between A and T, and is to be defined for each group) schematized in figure 2, which has just been removed from a continuous casting machine at a uniform temperature, T_{in}.

Table 1 – Dimensions and materials of the metal billets. Initial temperatures and convection mechanisms and coefficients. Solid position.

Metal billet *X* (material)	**H (cm)**	**W (cm)**	**D (cm)**	**L (cm)**	**T_{in} (ºC)**	**Convection mechanism; h [W/m^{2}K]**	**Solid Position**
A (stainless steel)	**40**	**40**		**400**	**900**	**Natural; 40**	**Suspended**
B (brass)	**30**	**30**		**500**	**1500**	**Forced; 250**	**Lower face on the ground**
C (stainless steel)	**20**	**20**		**300**	**1100**	**Natural; 50**	**Suspended**
D (brass)	**30**	**30**		**500**	**1300**	**Forced; 200**	**Lower face on the ground**
E (stainless steel)	**40**	**40**		**400**	**900**	**Natural; 45**	**Lower face on the ground**
F (brass)	**30**	**30**		**500**	**1400**	**Forced; 180**	**Suspended**
G (stainless steel)	**20**	**20**		**300**	**1200**	**Natural; 30**	**Lower face on the ground**
H (brass)	**30**	**30**		**500**	**1300**	**Forced; 200**	**Suspended**
I (stainless steel)	**12**	**12**		**400**	**1000**	**Forced; 220**	**Lower face on the ground**
J (stainless steel)	**50**	**50**		**500**	**800**	**Natural; 30**	**Suspended**
K (brass)	**24**	**24**		**300**	**1150**	**Forced; 250**	**Lower face on the ground**
L (stainless steel)	**40**	**40**		**600**	**850**	**Natural; 25**	**Suspended**
M (stainless steel)	**15**	**15**		**300**	**700**	**Natural; 50**	**Suspended**
N (stainless steel)	**10**	**10**		**400**	**1000**	**Forced; 240**	**Lower face on the ground**
O (stainless steel)			**30**	**600**	**900**	**Natural; 30**	**Suspended**
P (stainless steel)			**30**	**30**	**900**	**Natural; 30**	**Suspended**
Q (brass)			**40**	**600**	**1200**	**Forced; 250**	**Suspended**
R (brass)			**40**	**40**	**1200**	**Forced; 250**	**Suspended**
S (stainless steel)			**60**	**600**	**700**	**Natural; 20**	**Suspended**
T (stainless steel)			**60**	**60**	**700**	**Natural; 20**	**Suspended**

U (brass)	[redacted]	**50**	**600**	**1000**	**Natural; 30**	**Suspended**
V (brass)	[redacted]	**50**	**50**	**1000**	**Natural; 30**	**Suspended**
W (brass)	[redacted]	**60**	**600**	**800**	**Forced; 130**	**Suspended**
X (brass)	[redacted]	**60**	**60**	**800**	**Forced; 130**	**Suspended**
Y (brass)	[redacted]	**30**	**600**	**1200**	**Forced; 200**	**Suspended**
Z (brass)	[redacted]	**30**	**30**	**1200**	**Forced; 200**	**Suspended**

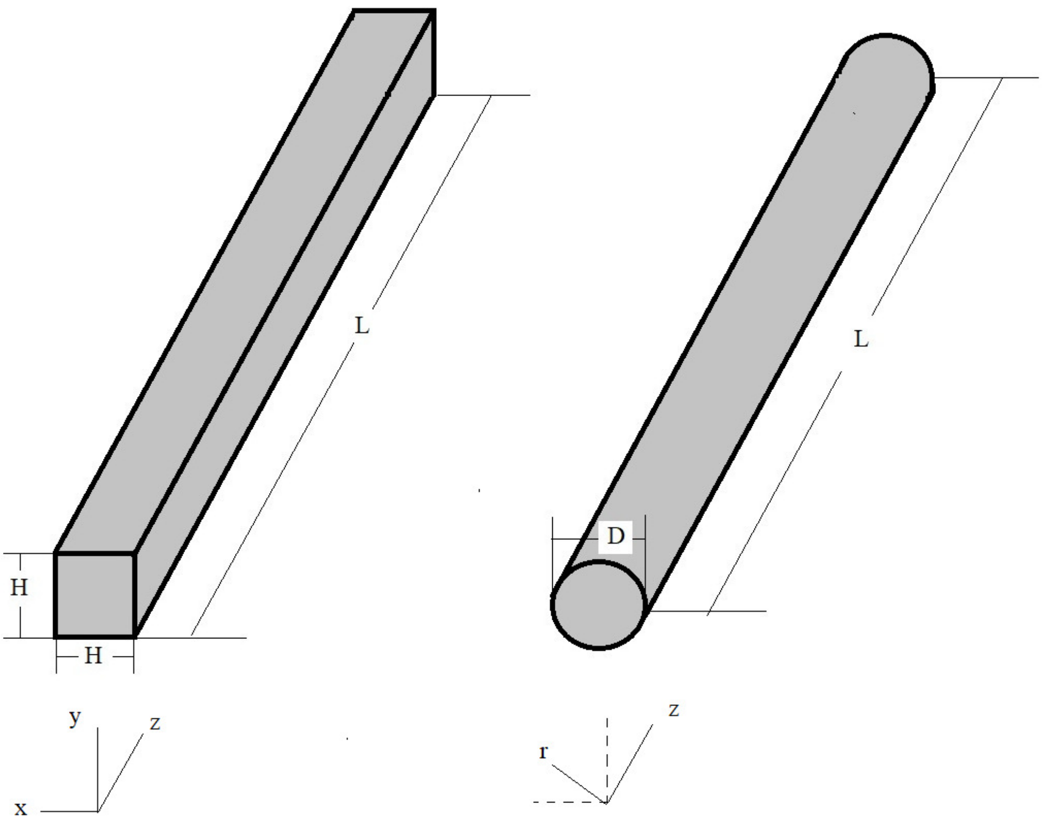

Figure 2 – Schematic of a stainless steel billet

The properties of the solids materials are displayed in table 2.

Table 2 – Properties of the metal billets materials.

Physical properties		
Material → Property ↓	**Brass**	**Stainless steel**
Density ρ [kg/m^3]	**7930**	**8500**
Specific heat c [J/kg K]	**385**	**460**
Thermal conductivity [W/m K]	**121**	**16,3**
Thermal diffusivity [m^2/s]	**39,6×10^{-6}**	**4,2×10^{-6}**

The solid is at its initial temperature (T_{in} with values displayed in Table 1) that is uniform. Then, the solid is cooled down by natural or forced convection, either suspended or with one surface on the ground (as displayed in Table 1) in atmospheric air at constant temperature (T_{air} = *20 ºC*), with the axis along dimension *L* at the horizontal position.

a) Determine the Biot number of your case. Independently from the Bi value obtained, use the lumped capacitance method to determine the time temperature evolution of the solid, $T(t)$. Pay attention to the characteristic dimension, L_c, used by convention for the lumped capacitance method.

b) With the h (convection coefficient) value of Table 1 for your case, determine the most adequate temperature distribution solution (analytical equation) as function of time and space. For the parallelepiped-shaped billets determine the 3D solution $T3DP(x, y, z, t)$, and the 2D solution $T2DP(x, y, t)$ at the central vertical plane. For the cylindrical billets determine the 2D solution $T2DC(r, z, t)$ or the 1D solution $T1DC(r, t)$ and find which is the most adequate.

c) Use the TEACH-C code with the convection heat transfer coefficients of Table 1 for your case to determine the 2D spatial temperature distribution solution with time (at the central vertical plane). Make sure that your numerical solution is grid-independent and obtained with the smallest computational effort. From such solution, extract the time evolution temperatures i) at the solid geometrical centre (both for cylindrical and parallelepiped-shaped geometries), and ii) at the centre of each of the largest faces (for the quadrangular cross-section), or at the centreline of the cylindrical surface. Note that in all cases with quadrangular cross-section, $L \gg H$ and, therefore, the problem may be treated as a two-dimensional case.

d) Plot $T(t)$ for the solid centre obtained in a), b) and c) in a graphic of the non-dimensional temperature as a function of the Fourier number.

e) Plot $T(t)$ obtained in a), b) and c) for the centre of the largest faces of the solid (quadrangular cross section) or for the centre of the cylindrical surface in a different graphic of the non-dimensional temperature as a function of the Fourier number.

f) Based on questions d) and e) draw conclusions about the different methods and the accuracy obtained.

Note: The structure of the written report and the classification criteria will be displayed soon in a different document.