Note

Heat transfer at thin molten layer crystallization
I. Molten layer cooling stage

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Summary. The paper presents a theoretical study of heat transfer at the cooling stage of the crystallization process of a horizontal molten layer. The obtained mathematical model, based on a physical model and on the differential equation for temperature, enabled to study the influence of some parameters (the global heat transfer coefficient between the molten layer and the cooling agent and the thickness of the layer) on the temperature distribution inside on urea molten layer.

1 Introduction

Thin molten layer crystallization is a process encountered in chemical industry at rotating drum crystallizors. This process has three stages: molten layer cooling, crystallization (solidification) and cooling of the solid crust.

References exist [1]—[15] concerning heat transfer in the three stages with special emphasis on crystallization. Some papers [10]—[14] refer to the temperature distribution in the thermal limit layer at the surface of the molten layer or to the temperature distribution as a function of time and a spatial coordinate in the solidified zone. Most of these papers also deal with the determination of crystallization process duration. These papers deal with the crystallization of a molten drop [11], [12], and of spherical or plane molten layers [10], [13], [14].

In the papers [10], [12]—[14] the molten layer temperature is equal to the melting temperature and in this case the molten layer cooling stage is absent. Paper [11] deals only with the cooling stage at a molten spherical particle crystallization.

This paper presents a study of heat transfer in the cooling stage of a plane molten layer. The molten layer is placed on a horizontal plate cooled with a flowing fluid. The other side of the layer is in direct contact with the surrounding environment.

A physical model for the molten layer cooling process was conceived, this process being described by a differential equation for the temperature field. The solution for this equation, with appropriate initial and Cauchy boundary conditions, gives a mathematical model which makes

1 Urea is a chemical compound obtained as spherical grains after the solidification of a molten matter in granulation towers. In the solid state its density is 1330 kg/m³ at 25 °C, its melting point is 132.7 °C at 1 atm and the specific heat is 22.26 cal/mol.K = 1554.5 J/Kg.K at 25 °C. In the molten state its density is 1225 Kg/m³ at 132.7 °C, the specific heat is 30.54 cal/mol.K = 2132.7 J/KgK at 132.7 °C and its thermal conductivity is 0.362 Kcal/mhK = 0.4213 W/mK.
possible the determination of the temperature distribution inside the molten layer. This model was used to study the influence of the global heat transfer coefficient \( K \) over the temperature profile for urea molten layers with a thickness of 0.005 m and 0.01 m.

2 Mathematical model

The molten layer cooling stage takes place until melting temperature is attained \( (T_m) \) at the surface of the layer in direct contact with the metal plate (which is more intensely cooled). Initially \( (t = 0) \) the molten layer temperature is \( T_0 > T_m \). Since the molten layer has a surface in contact with air, heat transfer takes place in two directions: from the layer to the metal plate and also to the surrounding air.

For the mathematical description of the cooling stage a physical model was conceived (Fig. 1).

As illustrated in Fig. 1 the heat transfer is only in one direction \( (x) \): to the cooling agent (mostly) and to the external medium. Inside the molten layer heat transfer is achieved only through conductivity. This process is described by [15], [16]

\[
\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2}; \quad t > 0, \quad x \in (0, \delta)
\]  

with initial and boundary conditions

\[
T(0, x) = T_0; \quad x \in [0, \delta]
\]  

and

\[
\lambda \frac{\partial T}{\partial x} (t, 0) = \infty [T(t, 0) - T_1], \quad -\lambda \frac{\partial T}{\partial x} (t, \delta) = K[T(t, \delta) - T_2]; \quad t > 0
\]

where \( \alpha \) and \( T_1 \) are the thermal diffusivity and the temperature of the cooling agent, \( T_0 \) and \( \delta \) are the initial temperature and the thickness of the molten layer, \( T_2 \) is the temperature of the