

# Modeling the temperature in the wind box of sintering process

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## Abstract

At the present time software automation testing is actively developing field of software development industry. Since automation testing is relatively young field, there are no best practices and standards formulated till the end yet. Currently there are many approaches and tools in the market used by different companies. Some of them are useful and actually can save companies money on software development process. However some of the approaches and tools are just a waste of resources. In variety of tools and approaches it is hard to find the proper way of setting up automation testing solution. This work is an attempt to find the best way of doing it.

*Keywords:* sintering process, modeling, heat transfer, porous media

## 1 Introduction

The agglomeration is a process of sintering a phosphorite charge made up of different materials (phosphorite and coke particles), with a diameter of no more than 10-2 m, to obtain pie of the finished product called sinter. A common type of agglomeration is the process of sintering iron ores, to which a great deal of papers have been devoted. The problems arising in this process are similar to different ores: phosphorite, lead, zinc and other chemical elements.

Key problems in the phosphoric agglomeration: a large amount of return (about 40-50%), change in the composition of the initial charge (change in gas permeability) and control of operational (speed of sintering machine, wind box vacuuming) and initial parameters (coke content in the initial charge) after the completion of the process (based on the quality of the obtained sinter).

All solutions to the presented problems of the agglomeration process control can be divided into 2 categories: control of operational parameters - speed of sintering machine or vacuum in the wind box and control of the initial composition of the charge - change in the content of coke and moisture. In this case, as observable parameters are considered: burn-through point [1, 2, 3], flame-front position [4], heat front propagation [5], temperature in different layers (gas and solid phase) of charge [6, 7], carbon efficiency [8], the content of a certain substance in the sinter [9], quality and quantity of sinter.

As can be seen from the literature analysis, most parameters relate to the problem of temperature regulation: inside the charge during the sintering process, temperatures under the horn, at the end of the process and others. The aim of this work is to simulate the temperature in the wind boxes. Sintering gases are sucked through 26 wind boxes located under the sintering machine. Temperature simulation is necessary to determine the wind boxes in which it is necessary to install thermocouples and based on the data

from the sensors to synthesize an algorithm to control the sintering machine.

## 2 Equations of the sintering process

### 2.1 TEMPERATURE CHANGE DURING SINTERING PROCESS

The initial phosphorite charge, as well as the final sinter, is a porous material in which the solid and gas phase are considered. The temperatures of the solid and gas phase in the porous material are equal and are determined by the following equation:

$$\left( \theta_p \rho_p c_p + (1-\theta_p) \rho C_p \right) \frac{\partial T}{\partial t} + \rho C_p u \nabla T + \nabla \left( \left( -\theta_p k_p - k(1-\theta_p) \right) \nabla T \right) = Q \quad (1)$$

where  $k[W/(m \cdot K)]$  – thermal conductivity of gas,  $\rho [kg/m^3]$  – density of gas,  $C_p [J/(kg \cdot K)]$  – heat capacity at constant pressure of gas,  $\gamma$  – ratio of specific heats of gas,  $\theta_p$  – volume fraction of solid (*1- porosity*),  $k_p [W/(m \cdot K)]$  – thermal conductivity of porous matrix,  $\rho_p [kg/m^3]$  – density of porous matrix,  $c_{p,p} [J/(kg \cdot K)]$  – specific heat capacity of porous matrix,  $Q [W/m^3]$  – heat source from chemical reactions and heat from outside.

### 2.2 GAS VELOCITY IN A POROUS MEDIA

The velocity of the gas in the sintering process is described by the Ergun equation, which is used in hydrodynamics of a single-phase liquid flow in fixed layers with a certain porosity and packing density of particles. In all cases of fixed layers application, pressure drop is one of the main factors. The pressure drop in the layer  $\Delta p/L$  is depends on

the fluid velocity, its density and viscosity, the size and shape of the particles, the porosity of the layer, the surface roughness and, possibly, the presence of walls:

$$\frac{\Delta p}{L} = \frac{150\mu u(1-\varepsilon)^2}{d^2\varepsilon^3} + \frac{1.75\rho u^2(1-\varepsilon)}{d\varepsilon^3}, \quad (2)$$

where  $\mu$  [Pa·s] – dynamic viscosity of gas,  $\varepsilon$  – porosity of porous matrix,  $d$  [m] – equivalent particle size.

The flow in a saturated porous medium can be modelled using the Darcy law or the Darcy-Brinkman model, depending on the specific pore size. If, for a given pore size, the influence of viscosity on fluid flow can be ignored, the Darcy law can be applied, and the flow is described solely by a variable pressure. If the pore size is large enough that the fluid can transmit the moment changes by shearing, then Brinkman's equation should be applied. It allows to find the same variables as the Navier-Stokes equations, but it includes terms that take into account the porosity of the medium through which the liquid flows [10]. Then the equations of motion in a porous material can be determined by following equation:

$$\rho \frac{\partial u}{\partial t} = \nabla \left[ -pI + \frac{\mu}{\varepsilon} (\nabla u + (\nabla u)^T) \right] - \left( \frac{\mu}{k} + \beta_f |u| + \frac{\rho \nabla u}{\varepsilon^2} \right) u, \quad (3)$$

where  $k$  [m<sup>2</sup>] – permeability of porous matrix, Then, taking into account the Ergun Equation (2) [11]:

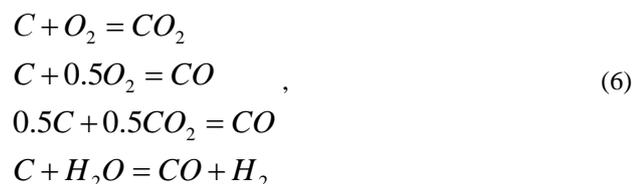
$$k = \left[ \frac{150\mu u(1-\varepsilon)^2}{d^2\varepsilon^3} \right]^{-1} \cdot \frac{1}{f_p f_{pbase}}, \quad (4)$$

$$\beta_f = \frac{1.75\rho u^2(1-\varepsilon)}{d\varepsilon^3} \cdot \frac{1}{f_p f_{pbase}}, \quad (5)$$

where  $f_p$  – factor for the change of porosity up on sintering shrinkage,  $f_{pbase}$  – global calibration constant in Ergun's equation = 3.5.

### 2.3 HEAT OF COKE COMBUSTION

The agglomeration process is accompanied by the release of heat due to coke combustion. In the combustion of coke, the following chemical reactions are usually considered:



The reaction rate is determined depending on the concentration of the substances:

$$R_j = k^f \prod c_i^j, \quad (7)$$

where  $k^f$  – constant of reaction rate determined by Arrhenius

equation:

$$k^f = A^f \exp\left(\frac{-E^f}{R_g T}\right), \quad (8)$$

where  $A^f$  – forward frequency factor,  $E^f$  [J/mol] – forward activation energy,  $R_g$  – universal gas constant.

Then the heat released by the reaction is determined by the equation:

$$Q_j = -R_j H_j, \quad (9)$$

where  $H_j$  – enthalpy of  $j$ -reaction

### 2.4 CONCENTRATION CHANGE

The change in the concentration of gases in the Equation (6,7) is determined by

$$c_i = \frac{\rho \omega_i}{M_i}, \quad (10)$$

where  $\omega_i$  – mass fraction of gas  $i$ :

$$\varepsilon \rho \frac{\partial \omega_i}{\partial t} + \nabla j_i + \rho(u \cdot \nabla) \omega_i = R_i, \quad (11)$$

where  $j_i$  – a variable that includes the diffusion model of the process.

### 3 Thermophysical properties

Determination of thermophysical properties (TPS) of ore materials require numerous experiments, since the mineral and chemical composition of samples are different, and certain elements are changed due to temperature variation. The solution of the problem consists in obtaining the dependences of the thermal conductivity and heat capacity of substances on the structural features, chemical and mineral composition on the basis of the TPS models of the composite structure, taking into account the temperature changes.

The composition of the initial charge includes carbonate phosphorites (fraction of  $P_2O_5$  = 18-25%) and coke. Data on heat capacity, heat conductivity, density can be determined from various reference books [12, 13]. Then the thermophysical properties of the charge can be determined as follows (for example, heat conductivity):

$$c_p = \sum \varpi_i c_i, \quad (12)$$

### 4 Overview

This work discusses the main differential equation for modeling temperature in the wind boxes under the sinter machine:

- Heat transfer in porous media
- Gas velocity in porous media
- Heat source from chemical reaction
- Transport of concentrated species in porous media for gases
- Thermophysical properties of initial charge and sinter

## 5 Conclusion

The sintering process is one of the important processes to obtain elements from ores, accompanied by a huge amount of return as a result of non-operative control and non-stationary nature of the initial charge. Therefore, controlling the operation of the sinter machine is an urgent and necessary task. In this paper, an analytical method was chosen to model the agglomeration process, which takes into account all the physico-chemical processes taking place during the sintering. For each process, the basic differential equations and properties necessary to obtain an adequate model were determined.

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## 6 Further research

The implementation of this model should also provide for the boundary conditions for each equation. Later on, based on these equations, a two-dimensional model will be constructed that considers one pallet with the initial charge and also the heat supplied from the outside under the horn. PDE method will be used to solve the differential equations. Main result of the simulation is to determine wind boxes, where thermocouples should be installed and develop an algorithm for controlling the agglomeration process.