A MULTIPHASE MULTICOMPONENT MODELING TO SIMULATE THE HEAT AND MASS TRANSFER PHENOMENA INSIDE THE PELLETS UNDER INDURATION FURNACE PROCESS CONDITIONS

M.Sc. Flavia de Paula Vitoretti, flaviapv@metal.eeimvr.uff.br
Federal Fluminense University, Metallurgical Engineering PostGraduating Department, Av. dos Trabalhadores,420 – Volta Redonda, RJ and Professor UNIFOA.
P.hD. José Adilson de Castro, adilson@metal.eeimvr.uff.br
Federal Fluminense University, Metallurgical Engineering PostGraduating Department, Av. dos Trabalhadores,420 – Volta Redonda, RJ

Abstract. *Pelletizing of iron ore fines is an important process used to produce high quality of raw materials for the subsequent reduction processes in the ironmaking industries. The process involves the production of green pellets and subsequent induration on a traveling grate furnace to promote inner partial melt and agglomeration which confer physical and metallurgical proprieties appropriated to the subsequent reduction processes. This work focused on the influence of the inner agglomerate pellet structure on the gas flow, heat and mass transfer due to chemical reactions within the pellets agglomeration under industrial process conditions of the travelling grate furnace. A mathematical modeling based on transport equations of momentum, energy coupled with the rate equation for chemical reactions is proposed. The finite volume method is used to discretize the transport equations of momentum, mass and energy describing the behavior of a pellet in travelling grate furnace. Model predictions are shown for the temperature, gas pressure and solid concentrations along the pellet radius as function of residence time and in-furnace conditions. By using this model is possible to obtain optimized furnace conditions to attain the metallurgical and physical properties with lower energy consumption.*

Keywords: *Multiphase flow, heat and mass transfer, modeling, induration phenomena.*

1. NOMENCLATURE

C_p	Specific Heat (J kg^{-1}K^{-1})
D	Diffusivity (m^{2}s^{-1})
F	Momentum Transfer between Phases (kg m^{-2}s^{-1})
h	Reaction Enthalpy (J kg^{-1})
k	Coefficient of Mass Transfer (m s^{-1})
M	Molar Mass (Kg/mol)
R	Reaction Rate (kg m^{-3}s^{-1})
t	Time (s)
ρ	Density (kg m^{-3})
ε	Porosity
i	Phases

2. INTRODUCTION

The ultra-fine fraction of iron ore produced in the beneficiation operations took to development to agglomeration processes, in order to improve the permeability of the materials used in blast furnace and processes reduction. The pelletizing process involves two steps, the *"green pellets"* formation with the addition of binder to agglomeration (Sadrnezhaad, et. al., 2008), and then the pellets follow to induration furnace, to attain mechanical resistance and appropriate the metallurgical features required by ironmaking plants. The induration process by travelling grate can be classified in 4 different zones: drying, heating, firing and cooling. The first step ensures that the pellets are fully dried to give sequence in process. The temperature increase in the heating zone takes to begin of the reations. And these reactions continue in the next zone, firing zone, providing the melting between the particles. The cooling zone stops theses reactions due to drop in temperature and promotes resolidification and final cooling. The gas flow in each zone is sucked in the system by fans. For some authors as Barati (2008) the blow temperature should be controlled for better pellet quality and grate bar protection avoiding super heating. Therefore, a considerable attention on the inner temperature of pellet is need in order to enhance the energy efficiency of the overall process (Majumder et. al, 2009).

The focus of the current work is the induration of wet pellets in travelling grate furnace to provide the pellets temperature profile in each furnace zone, in order to support process analysis, optimization and control in pelletizing process.

3. MODELING

The mathematical model of pellet induration process in travelling grate furnace is developed to predict the details information including temperature inside of pellet along the radius at different times. In the formulation of the model, the following phenomena have been taken into account: (1) heat and mass transfer between the particles pellet and gas; (2) Oxidation magnetite; (3) evaporation of moisture.

The following assumptions were made: (1) the pellet contents small particles known as *"pellets feed"*; (2) the *"pellets feed"* have uniform size; (3) height of the pellet in bed remains constant during induration; (4) the process occurs at the steady state; (5) the pellet does not content carbon.

The transport equations were discretized using the finite volume method with the velocity and pressure fields for gas flow calculated using the SIMPLE algorithm coupled with the temperature and chemical species fields. Each chemical species is resolved by chemical reactions that allow the mass transfer between the phases. The model is composed of coupled solution for the chemical kinetics reactions, momentum and energy transport equations (Castro, 2010). Equations (1), (2), (3) and (4) represent, respectively, the momentum, energy, mass and chemical species balances:

$$\frac{\partial(\rho_i \varepsilon_i u_j)}{\partial t} + div\left(\rho_i \varepsilon_i \vec{U}_i\, u_j\right) = div\left(\varepsilon_i \mu_i\ grad\ (u_j)\right) - grad\ (\varepsilon_i P_i) - F_i^k \tag{1}$$

$$\frac{\partial(\rho_i \varepsilon_i)}{\partial t} + div\left(\rho_i \varepsilon_i \vec{U}_i\right) = \sum_{n=1}^{nreactions} R_n^i \tag{2}$$

$$\frac{\partial(\rho_i \varepsilon_i h_i)}{\partial t} + div\left(\rho_i \varepsilon_i \vec{U}_i h_i\right) = div\left(\frac{k_i}{C_{P_i}} grad\ (h_i)\right) + \sum_{n=1}^{nreactions} R_n^i \Delta h_n^i + \dot{E}_i \tag{3}$$

$$\frac{\partial(\rho_i \varepsilon_i \phi_{i,ispecies})}{\partial t} + div\left(\rho_i \varepsilon_i \vec{U}_i \phi_{i,ispecies}\right) = div\left(\varepsilon_i D_{ispecies}^{bulk} grad(\phi_{i,ispecies})\right) + \sum_{n=1}^{nreactions} M_{ispecies} R_n^i \tag{4}$$

The pellet in the furnace means a porous sphere constituted of particles in direct contact with a gas over the entire length of the oven. Figure 1 outlines the geometry of the pellet and the grid to simulation, assuming a solid angle.

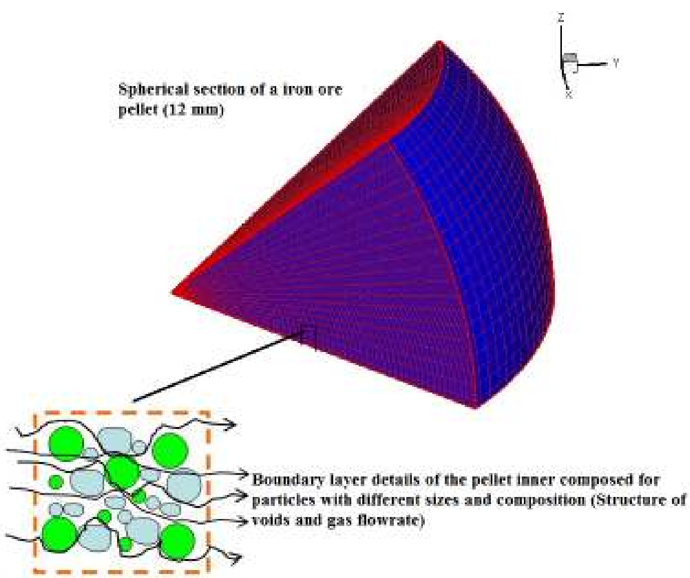


Figure 1. Grid to simulation and boundary layer in the pellet inner.

4. RESULTS AND DISCUSSIONS

The "Multiphase Multicomponent Reactive Flow, Heat and Mass Transfer coded in Fortran was developed for the numerical solution of equations describing to the gas flow inside the pellet, reaction rates and heat transfer, coupled to evolution of gas composition and the pellet. The pellet shaped is located on top of the moving bed. For the simulation were selected pellets with different diameters, with average size of 8, 12 and 15 mm.

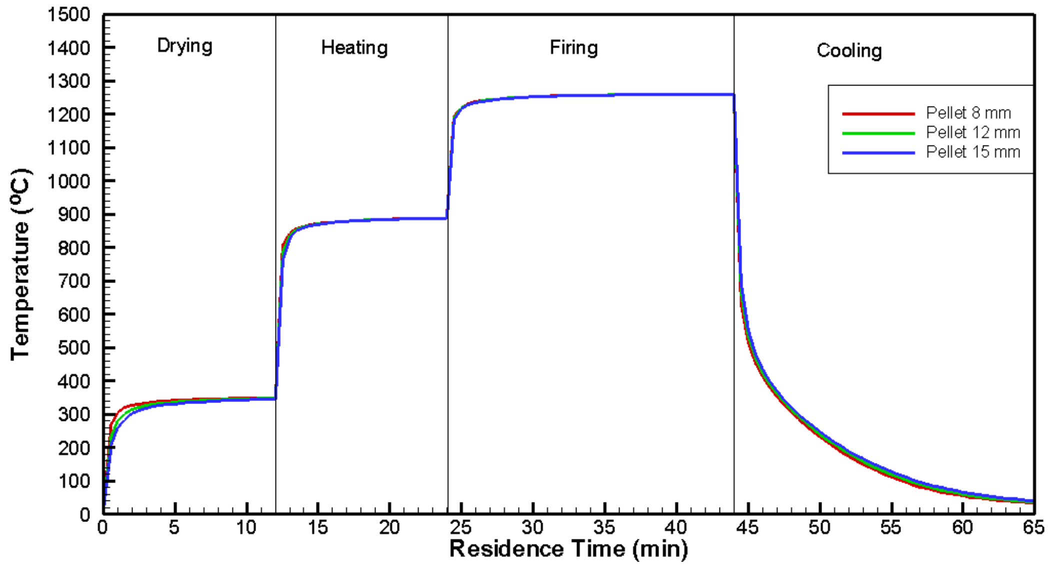
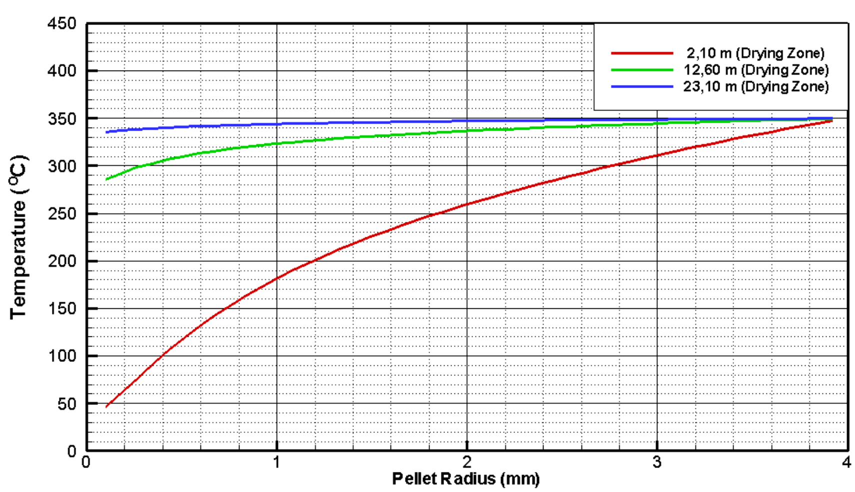


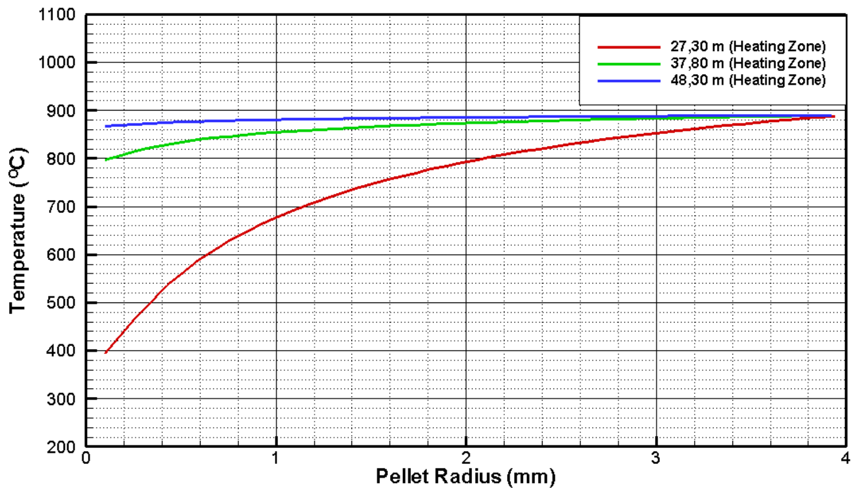
Figure 2. Average Temperature Profile between pellet and gas by residence time.

In the model was possible to predict the average temperature between the pellet and gas during overall process. Figure 2 shows the temperature profiles in each zone. It is observed that the differences of the temperatures between the three pellets with different sizes are only observed at the beginning of the zones.

Figures 3, 4 and 5 compare the behavior of the pellet with different diameters, at beginning, middle and end of each zone. It is observed in Fig. 3 that as the temperature progress inward the pellet with 8 mm the gas flows through the pores and as time is passed the temperature became uniform due to the combined effect of heat conduction and inner convection. At the beginning of each zone the surface of pellet instantly reaches the gas temperature due to high external effective heat coefficient which accounts for convective and radiation effects, in the interior of the pellet the conduction of the heat through the pores plays the major role and leads to the temperature center of the pellet to remain lower. This behavior is observed for all zones with the cooling region inverting the temperature gradient.



(a)



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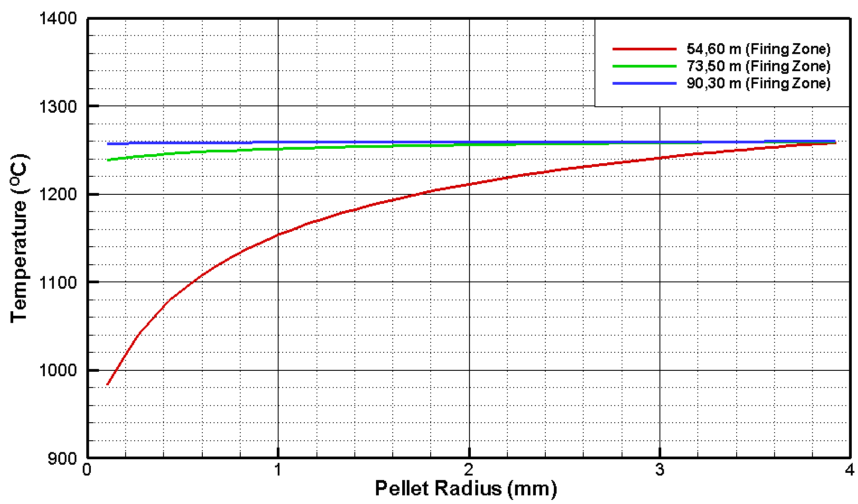

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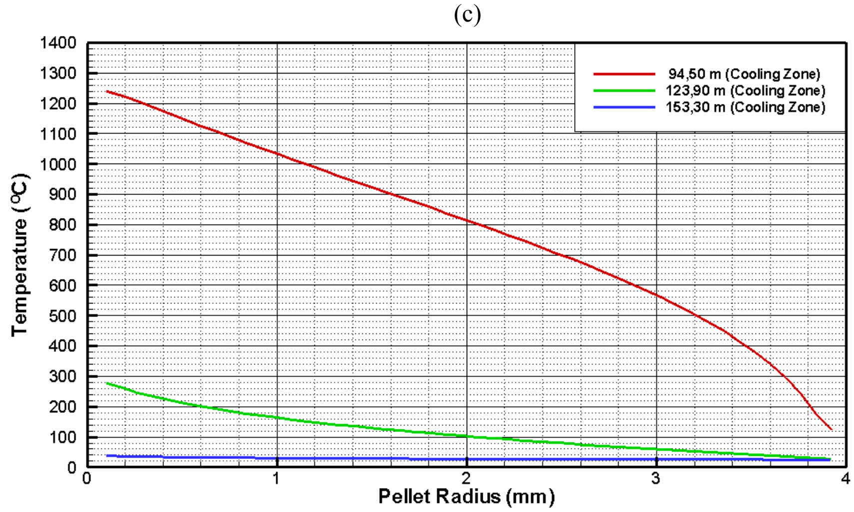
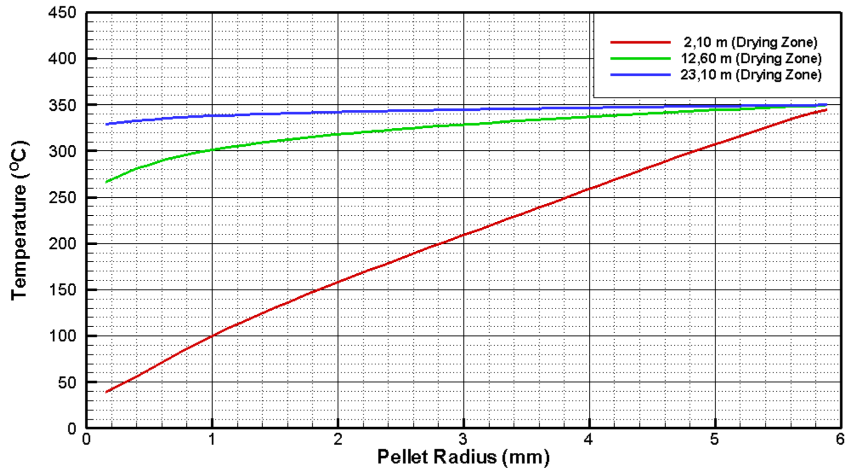


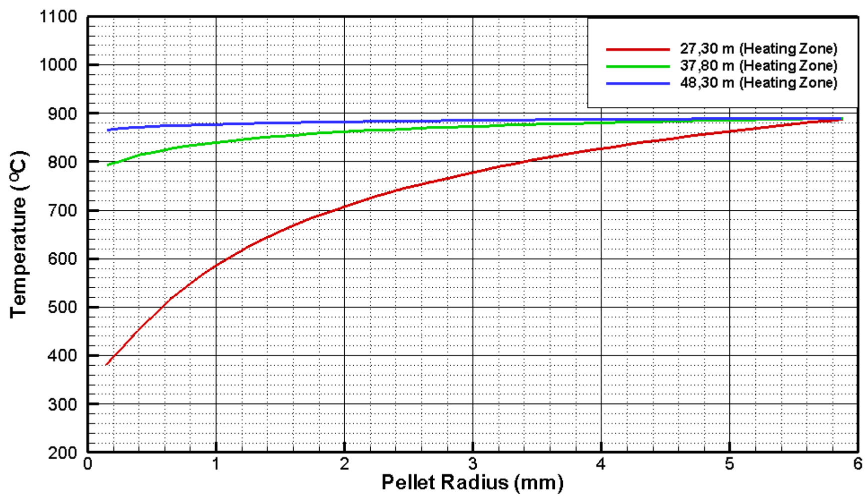
(d)

Figure 3. Temperature profiles within an individual pellet of 8 mm diameter along the furnace zones, (a) drying zone, (b) heating zone, (c) firing zone and (d) cooling zone

Figure 4 shows similar trend for the temperature pattern, although the rate of heating and cooling are strongly dependent of the pellet diameter. These results confirmed the strong dependency of the suitable residence time for each granulometric range and suggest that narrow distribution will produce more uniform properties of the fired pellets and justify the production of strictly controlled green pellets.



(a)



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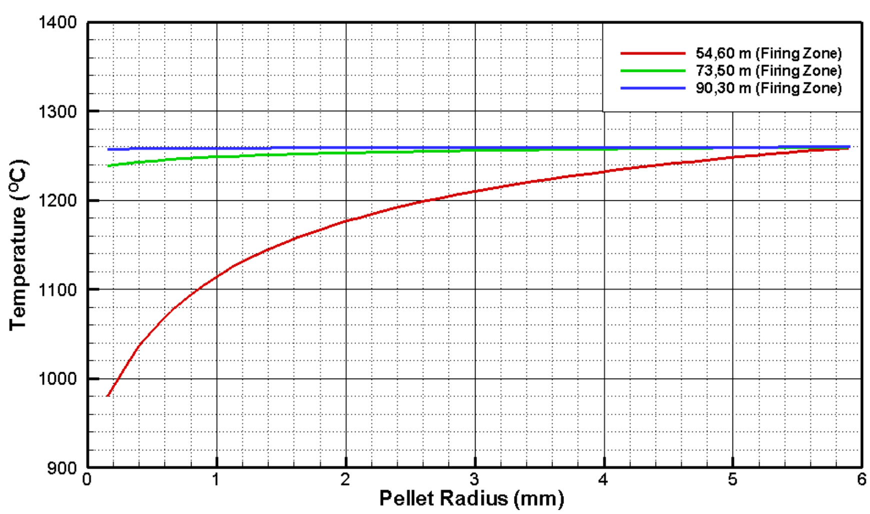

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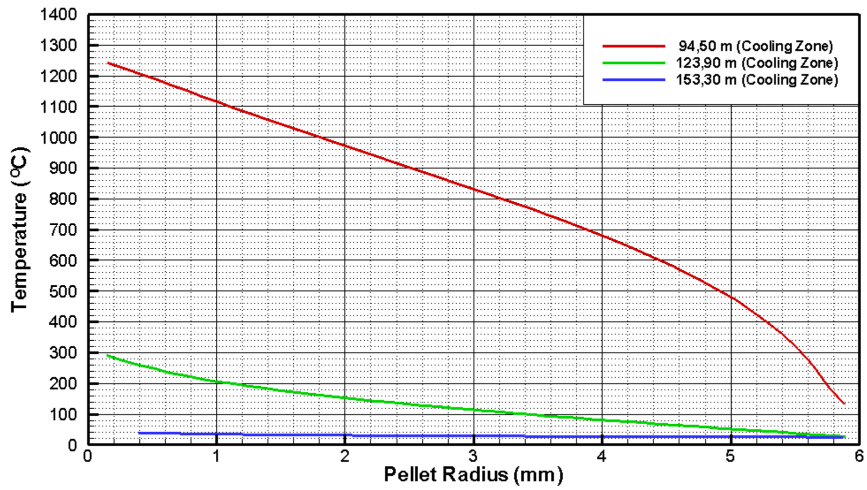
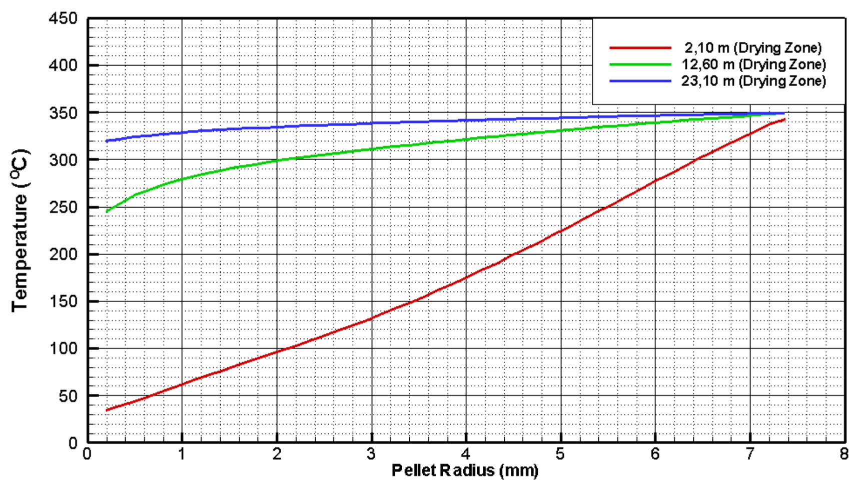


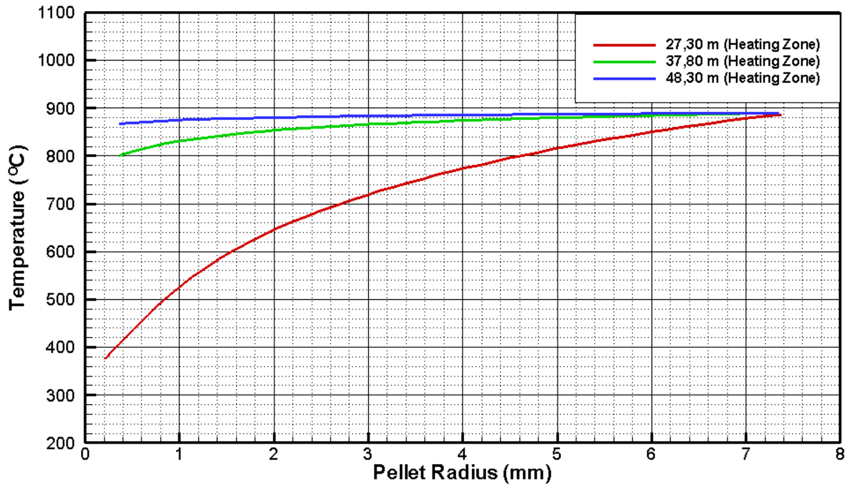
(d)

Figure 4. Temperature profiles within an individual pellet of 12 mm diameter along the furnace zones, (a) drying zone, (b) heating zone, (c) firing zone and (d) cooling zone

Figure 5 shows the temperature radial distribution for pellet with 15 mm of diameter. It is observed lower temperature gradient in the drying zone due to higher consumption of heat during the evaporation of water, indicating that the heat transfer within the pellet is the controlling mechanism for temperature increase, which was not observed for smaller pellets. For the other zones the temperature pattern showed similar behavior although larger thermal gradient is observed, as expected.



(a)



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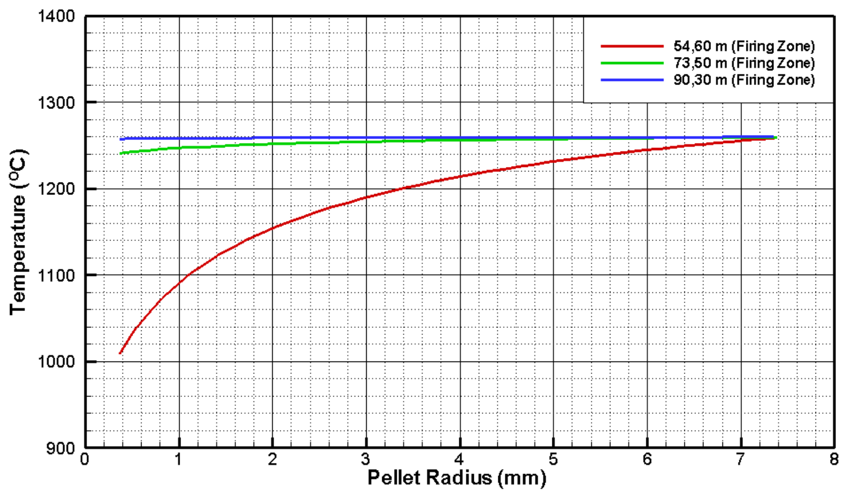

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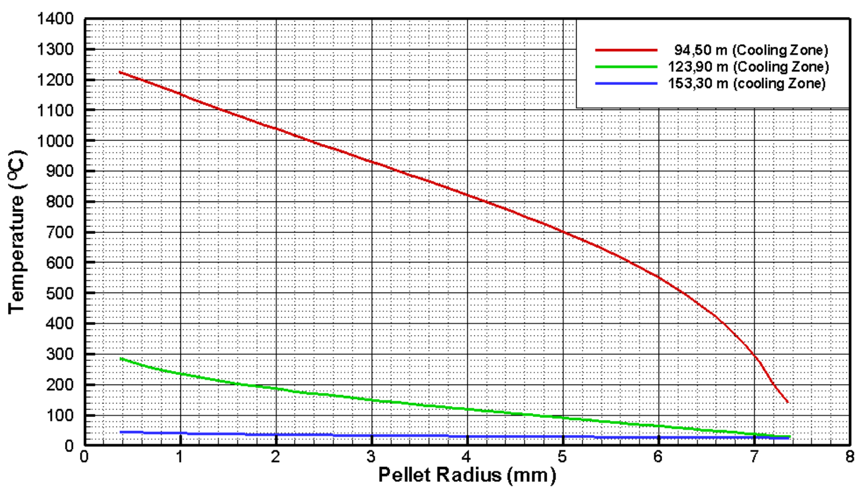

(d)

Figure 5. Temperature profiles within an individual pellet of 15 mm diameter along the furnace zones, (a) drying zone, (b) heating zone, (c) firing zone and (d) cooling zone

5. CONCLUSIONS

A mathematical model able to predict the behavior the individual pellet in the overall process was developed. The model implementation allowed to predict the temperature profiles of the pellet along the radius for each furnace zones. Numerical results for pellets with different diameters showed the impact of charging pellets with wider granulometric distribution in the furnace and indicated that the properties of the pellets could be significantly different since the thermal cycle of the individual pellets has strong effect on the phase transformations and induration phenomena.

6. ACKNOWLEDGEMENTS

The research presented in this paper was conducted at the Federal Fluminense University (UFF), Metallurgical Engineer School (EEIMVR), Brazil from July, 2009 until September, 2011.

We would like to thank to CAPES and REUNI by scholarship for master degree.

We would like to thank to UNIFOA by job opportunity as professor in University.

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