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THE MOVING-SLAB HEATING IN THE FURNACE FOR VARIOUS PRODUCTION PLANS

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Abstract

The reheating furnace in occasional production time has to be charged with slabs having different sizes in length, width and thickness. This production plan was put due to economical and productivity consideration. Moreover in the future development, the slab grade might be improved to high grades. It is our expectation that the furnace can be fired for different production plans above. The strategy for firing the burners from zone to zone has to be determined precisely to meet the designed heating curves for the various slabs. A suggest to guide in the formulation of the furnace firing strategy was developed in this work. This suggestion is based on a three-dimensional mathematical model for heated slabs in the furnace. This mathematical model was coded for the computational simulation. The code was able to simulate three-dimensional effects of furnace operational parameters and variety of slab length group. The results reasonably represent the slab-heating curve for different operational parameters. Unsymmetrical firing practices can be shown their effect to the 3D temperature distribution of the slab.

Keywords: 3D temperature distribution; reheating furnace; slab heating; slab length group

Introduction

One of the most furnace uses is reheating process of the steel slab, which are cooled, inspected, crack-repaired, and heated continuously in the reheating furnace before rolling. In the reheating furnace, the material is heated at high temperature in order to obtain the metal workability (plasticity) that required for rolling. Besides this major purpose and for special steels, the material is heated to gain specific metallurgical properties. It is implemented to obtain the instance solution of alloys as they are subjected to uniform heating for a given period at a closely controlled temperature. In general, the slab is subjected to the combined convective and radiative heat fluxes at the surfaces. When one mode of energy transfer at the surface predominates the other, two limiting cases arise: pure thermal radiation and pure convection. The radiation boundary condition is obviously always non-linear and the convection boundary condition is non-linear except for the very important case of forced convection with the heat transfer coefficient independent of surface temperature. In many engineering problems dealing with transient heat conduction the radiative and convective surface fluxes are of the same order of magnitude. Thus, transient heating and cooling of slab by both forced convection and radiation is of considerable practical interest.

The reheating furnace has to be charged with slabs having different sizes in length, width and thickness. The production plan was put due to economical and productivity consideration. In order to achieve high-grades products, the slab might be enhanced in terms of their specific metallurgical properties. It is our expectation that the furnace can be fired for different production plans above. The strategy for firing the furnace from zone to zone has to be determined precisely to get the designed heating curves for the various slabs. Due to the limitation of the automatic furnace control system, the furnace operational parameters cannot be precisely chosen for different production plant to fulfil the production grade quality and energy efficiency. A suggestion to guide the formulation of the furnace firing strategy is based on a three-dimensional simulation for slab heating within furnace. In the present model, the heat transfer boundary conditions are generated by the fuel combustion from burners in each zone, hot refractory walls, and internal furnace mechanical support.

Kim *et al.* (2000) presented heat transfer analysis for slabs heated in a walking-beam type of a

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reheating furnace by the commercial code, FLUENT Inc. The steady state, three-dimensional analyses is performed for turbulent reactive flow and radiative heat transfer in the furnace. However, three-dimensional transient calculation is performed for conduction in a slab with the boundary condition given in terms of the calculated local heat flux in the furnace or from measurement data.

The moving boundary condition will be used in order to accomplish the real condition in terms of the slab moving along furnace. The three-dimensional transient calculation is needed, in order to perform the detail temperature distribution of the slab. However, it is difficult to get the robust algorithm that performed combined steady state in heat gas flow and transient state in the slab heating. The complete numerical method that will be used to solve this problem was detail considered in the previous paper applied for three-dimensional slab temperature distribution (Istadi *et al.*, 2001; Buchori *et al.*, 2000).

and variety of slab length group arrangement. The results reasonably represent the slab-heating curve for different operational parameters. The profile of gas flow pattern along the reheating furnace was also simulated by FLUENT software.

Mathematical Modeling and Numerical Solution of Heat Transfer of Steel-Slab Reheating Furnace

The continuous heat control of slab implies that the temperature of each slab heated must be known all the time and all the position especially for three-dimensional temperature distribution. In fact that it is difficult to accurately measure the three-dimensional slab temperature inside the furnace that existing in radiating environment. The heat sensed by the pyrometer pointing the slab actually is not only the heat radiated by the slab but also the heat radiated by the flue gas and by the wall surface that reflecting into slab. Moreover, the heat is partly absorbed by the flue

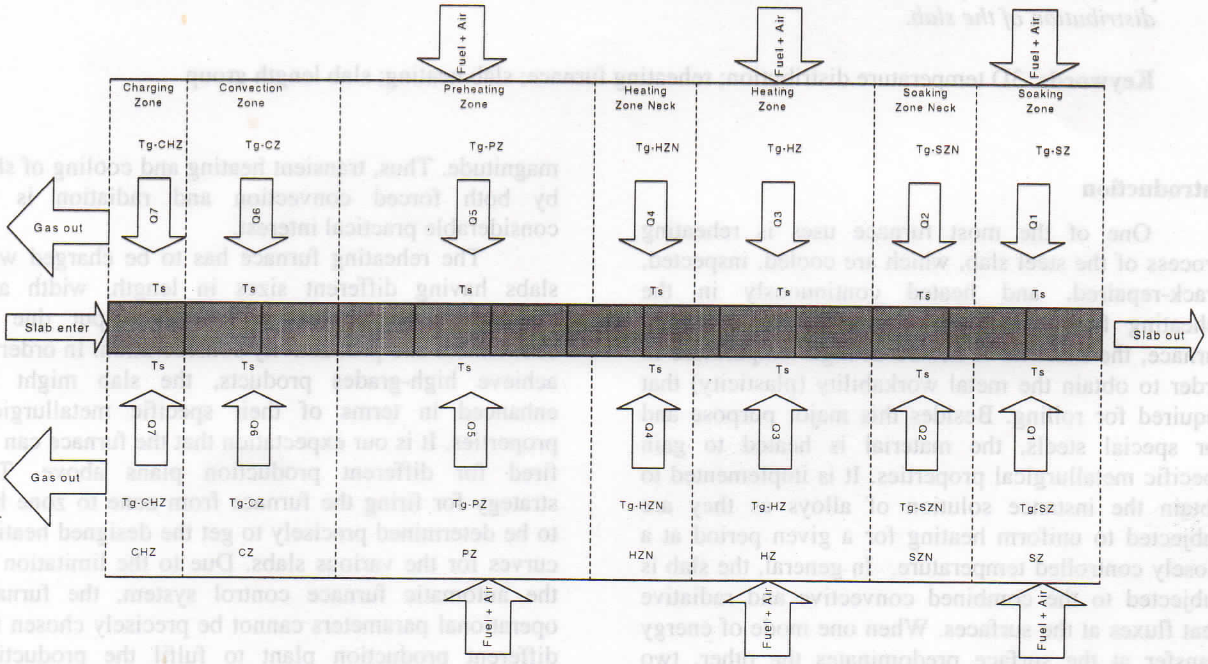

Figure 1. Domain Configuration of Steel-Slab Reheating Furnace and furnace zone

In this paper, the strategy for firing the furnace from zone to zone has to be determined precisely to get the designed heating curves for the various slabs in terms of their size and arrangement. A suggest to give the guide in the formulation of the furnace firing strategy was developed in this work. This suggestion is based on a three-dimensional mathematical and numerical model for slabs heating in the reheating furnace. The mathematical and numerical model was coded for the computational simulation in FORTRAN code. The code was able to simulate three-dimensional effects of furnace operational parameters

gas. These undesirable radiation and absorption effect cause measurement errors that may reach about 150 °C. According to these facts, it is necessary to get the real temperature distribution within the slab as well as the furnace gas. It can be obtained by deriving the mathematical and numerical model that based on the physical model.

Based on the above reasons, the authors have developed a three-dimensional physics-based thermal model for calculation of the slab temperatures. The model is the tool that used to simulate the various kinds of operation types of furnace especially for their effect to three-dimensional temperature distribution of the slab. Based on the zoning of gas and surface, the material and heat balance within zones are then calculated to obtain the gas zone and slab surface temperature. The gas zones have the different temperature depends on the fuel and air flow rate, heat flux to the slab, and thermal radiation heat transfer. By the numerical model, the calculated zone temperature is used to determine the thermal profile of the furnace and to obtain the three-dimensional dynamic temperature distribution of the slab for its movement along reheating furnace from Charging to Soaking zone. The predicted average and surface temperature of slab can be calculated in real time.

The configuration of the reheating furnaces that steel slab included was depicted in Figure 1. The furnaces will be divided into seven distinct zones along the direction of slabs moving. However, in this paper, each of zones has the same gas temperature. Further, each of zones will be divided into control volumes that having the same gas temperature in terms of Zone Method application. These zones are: Charging (CHZ), Convection (CZ), Preheating (PZ), Heating Zone Neck (HZN), Heating (HZ), Soaking Zone Neck (SZN) and Soaking zone (SZ). In the proposed method, slabs move in the opposite direction to the primary flow of combustion product gas in an uptake type furnace. The skid system to support slabs distorts the heat flux in the bottom section by providing conduction paths between the slab and coolant in the skid pipe. The skid system and other structural components in the lower zone block thermal radiation from burner flames. The furnace is bounded by refractory walls in which heat will be lost. The output gas was exhausted to the environment via recuperator to get the low temperature.

Heat energy may be transferred by conduction, convection and thermal radiation in this process. Conduction is the heat transfer by diffusion or transfer of heat energy through a mass or body of matter by particle or molecular contact from the warmer to the colder parts. Heat applied to one end of a body will give greater kinetic energy to the atoms or molecules that share this increased energy with their neighbors and hence heat is propagated or conducted along the body. From the Fourier's law, we can infer the differential equation that governs the three-dimensional heat transfers in a steel-slab body. The conduction heat transfer in a slab is described by the following transient three-dimensional Fourier equation,

$$\rho\, Cp \frac{\partial T}{\partial t} = \lambda \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) \qquad (1)$$

Conductivity is assumed independent on the position, heat flow and temperature, and no heat generated or absorbed. Heat flux that transferred from gas to the slab is contributed by combination convection and thermal radiation. In this paper, the thermal radiation is still conducted by black body by assuming that depends only to emissivity of the surface. Furthermore, in the future, the comprehensive thermal radiation that incolve emissivity, reflectivity and absorptivity will be considered by zone method. It will perform all of main contribution of thermal radiation that depends on the furnace geometries. Beside that, the influence of temperature distribution of each zone may be considered completely. The heat load to the slab can be written as follow:

$$Q = h\, A\, (T_g - T_s) + A\, \varepsilon\, \sigma\, (T_g^{\,4} - T_s^{\,4}) \qquad (2)$$

The first and second term denote convection and thermal radiation heat transfer, respectively. The thermal radiation flux was predicted by emissivity value of slab surface, while the convective flux was expressed by coefficient of convection heat transfer. In the future, it will be predicted by calculating the directed exchange area that depends on the furnace geometries.

The complete numerical method that will be used to solve this problem was detail considered in the previous paper (Istadi *et al.*, 2001; Buchori *et al.*, 2000) based on the Finite Volume Method (FVM) (Patankar, 1980) applied for three-dimensional slab temperature distribution. Heat transfer between the fixed combustion gas and the moving slab had been performed by the robust algorithm by FORTRAN code. It is the difficulty of the solution of moving boundary condition.

Result and Discussion

The planning of furnace operations simulation is described briefly in Table 1. The varieties of slab arrangement are applied to supply the rolled steel grade that depends on the market demands. The slab arrangements are single size group and length group. The single size group in this simulation is performed to the slab with 12 m of length and the length group is the slab with 12, 10, 9 and 7 m of length. This group is conducted due to the following steel grade of market demand. The length group are involving the zigzag and the centre length group as depicted in Figure 2. Each of zones was divided to four sections that are Section 1, Section 2, Section 3 and Section 4 from one end to another end of zone. Each of section will be controlled their fuel and air flow rate by regulating their pipe valve. The change of operation parameter will also be conducted by change heating time. The standard operation of reheating furnace by this model is Stein Heurtey operation standard. However, temperature distribution profiled by Stein Heurtey operation was not close to real conditions and only one dimension.

The simulation results were depicted in figures below that describe the variation of slab arrangement and heating time or/and fuel flow rate manipulations. However, the all result of the furnace operations cannot be depicted in this paper. From the Figure 3 and 4, it is shown that the changed condition involving heating time and fuel flow rate cause the increasing of slab average temperature. The three-dimensional temperature distribution of a slab was shown in Figure 5 and 6 for mesh and contour profile, respectively. This temperature profile will help engineers to analyse detail of the slab temperature distribution. The simulation results for the length group of centre position were depicted in Figure 3,4,5, 6, and for the length group of zigzag position in Figure 7,8,9,10.

The three-dimensional profile of heat gas flow field was depicted in Figure 11. In this figure, the flow field pattern of gas flow from Soaking zone and throughflow to Charging zone was detail depicted. The problem of gas flow will be analysed by this profile. The contour profile of gas flow in the Heating zone will be depicted in Figure 12. The two-dimensional gas flow profile can be obtained by this profile. However, the all result of flow field profile cannot be depicted in this paper.

Table 1. The planning of furnace operations simulation

No	Slab arrangement	Slab length	Fuel and air flow rate	Heating time
1	Single size group	12 m	Standar (Stein Heurtey)	133 minutes
2	Single size group	12 m	Standar (Stein Heurtey)	180 minutes
3	Single size group	12 m	Sect. 1&4 0.3x, Sect. 2&3 1.3x	180 minutes
4	Length group (zigzag)	12 m	Standar (Stein Heurtey)	133 minutes
5	Length group (zigzag)	12 m	Sect. 1&4 0.3x, Sect. 2&3 1.3x	133 minutes
6	Length group (zigzag)	12 m	Sect. 1&4 0.3x, Sect. 2&3 1.3x	180 minutes
7	Length group (zigzag)	10 m	Standar (Stein Heurtey)	133 minutes
8	Length group (zigzag)	9 m	Sect. 1&4 0.3x, Sect. 2&3 1.3x	180 minutes
9	Length group (zigzag)	7 m	Sect. 1&4 0.3x, Sect. 2&3 1.3x	180 minutes
10	Length group (Center)	12 m	Standar (Stein Heurtey)	133 minutes
11	Length group (Center)	12 m	Sect. 1&4 0.3x, Sect. 2&3 1.3x	180 minutes
12	Length group (Center)	10 m	Standar (Stein Heurtey)	133 minutes
13	Length group (Center)	10 m	Sect. 1&4 0.3x, Sect. 2&3 1.3x	180 minutes

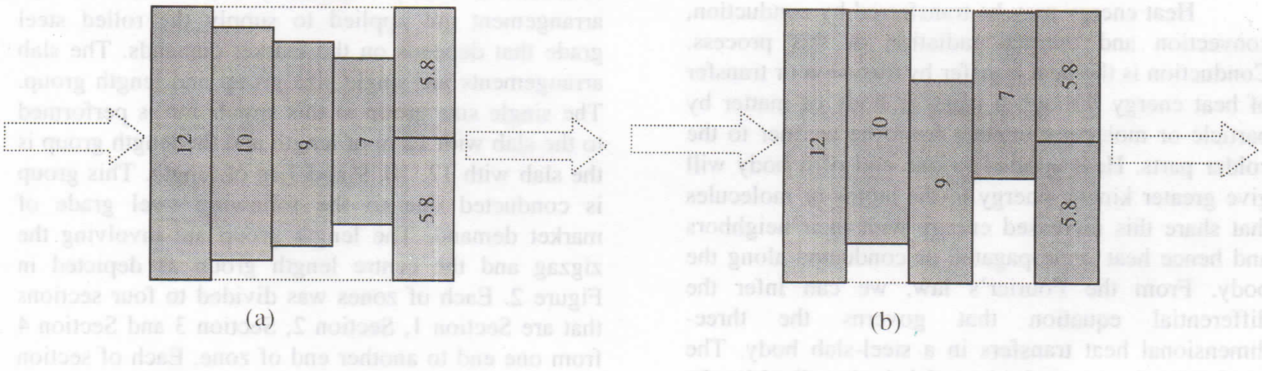

Figure 2. Slab arrangement of Length Group; (a) Centre Position, (b) Zigzag Position

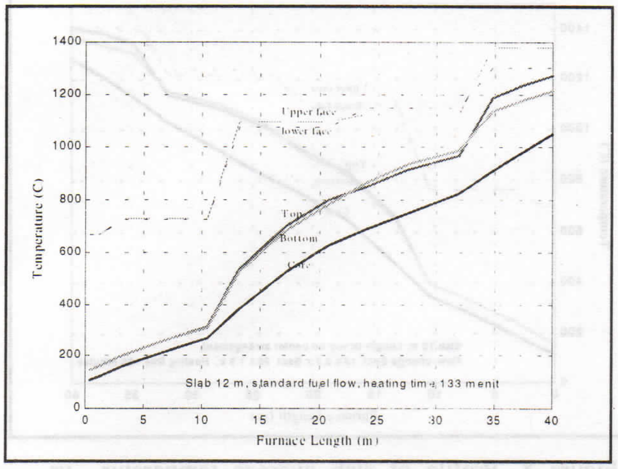

Figure 3. Profile of slab average temperatur vs furnace length at standar condition (12 m length, 133 menit, and standar fuel flowrate, centre position)

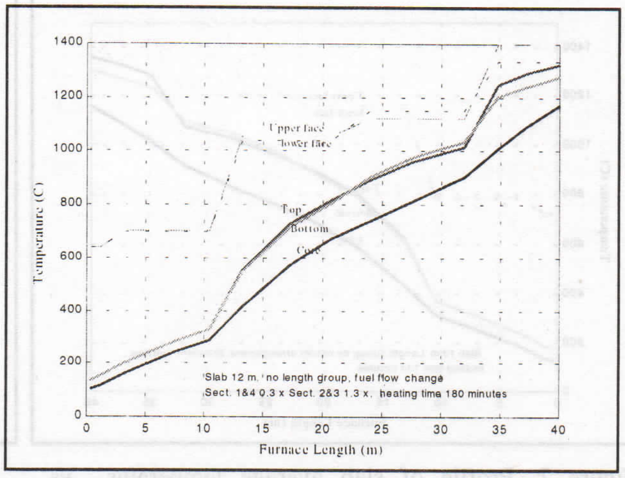

Figure 4. Profile of slab average temperatur vs furnace length at changed condition (12 m length, 180 /minutes, and fuel flowrate Section 1&4 changed to 0.3 x and Section 2&3 changed to 1.3 x, centre position)

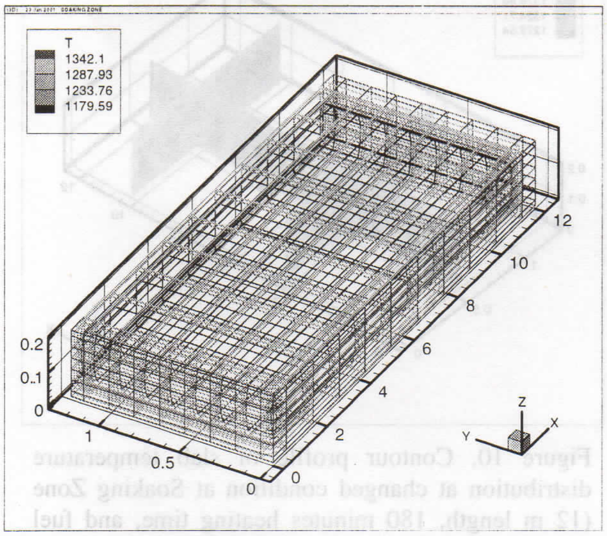

Figure 5. Three-dimensional slab temperature distribution at changed condition at Soaking Zone (12 m length, 180 minutes heating time, and fuel flowrate Section 1&4 changed to 0.3 x and Section 2&3 changed to 1.3 x, center position)

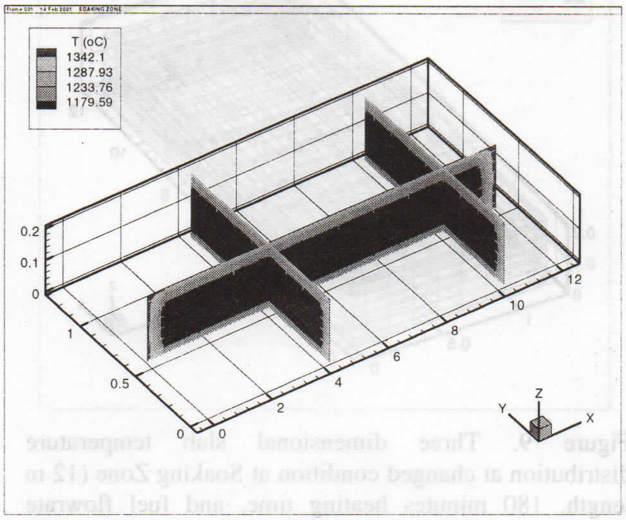

Figure 6. Contour profile of slab temperature distribution at changed condition at Soaking Zone (12 m length, 180 minutes heating time, and fuel flowrate Section 1&4 changed to 0.3 x and Section 2&3 changed to 1.3 x, center position)

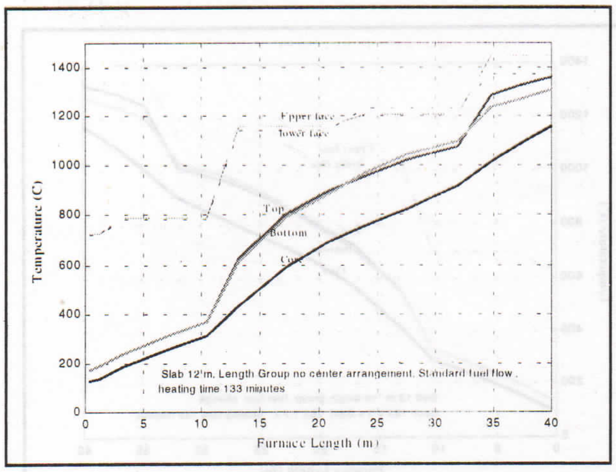

Figure 7. Profile of slab average temperatur vs furnace length at standar condition (12 m length, 133 minutes heating time, and standar fuel flowrate, zigzag position)

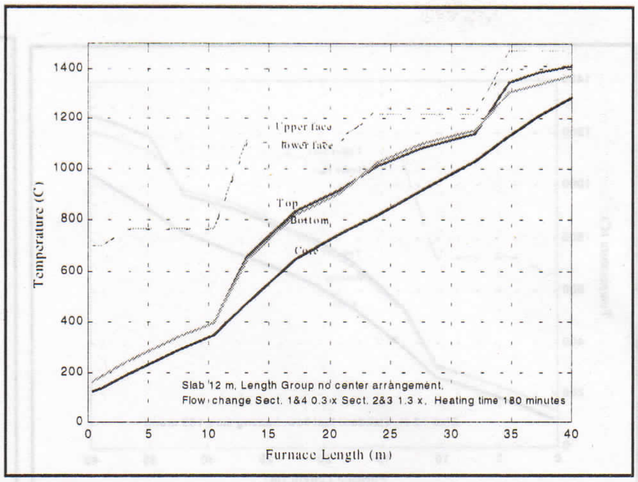

Figure 8. Profile of slab average temperatur vs furnace length at changed condition (12 m length, 180 minutes heating time, and fuel flowrate Section 1&4 changed to 0.3 x and Section 2&3 changed to 1.3 x, zigzag position)

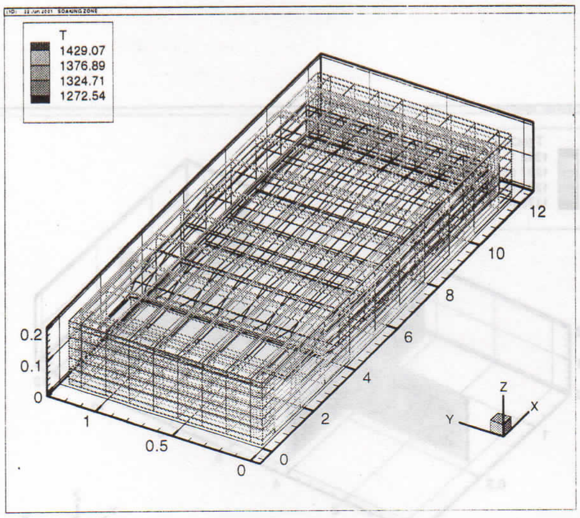

Figure 9. Three dimensional slab temperature distribution at changed condition at Soaking Zone (12 m length, 180 minutes heating time, and fuel flowrate Section 1&4 changed to 0.3 x and Section 2&3 changed to 1.3 x, zigzag position)

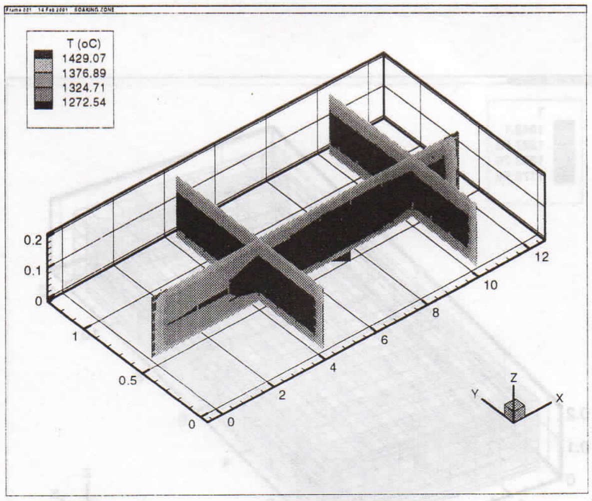

Figure 10. Contour profile of slab temperature distribution at changed condition at Soaking Zone (12 m length, 180 minutes heating time, and fuel flowrate Section 1&4 changed to 0.3 x and Section 2&3 changed to 1.3 x, zigzag position)

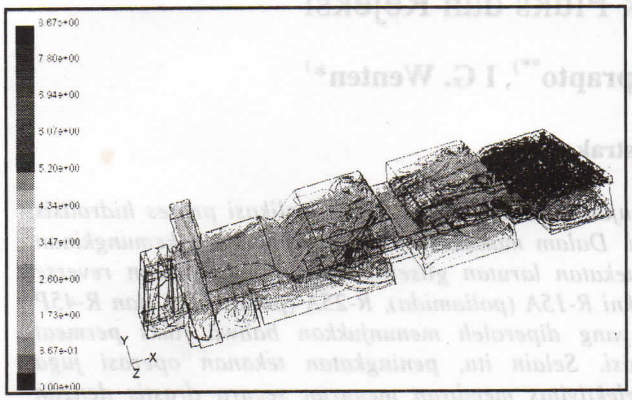

Figure 11. Profile of heat gas flow field at overall zones from Preheating to Soaking zone, velocity in m/s

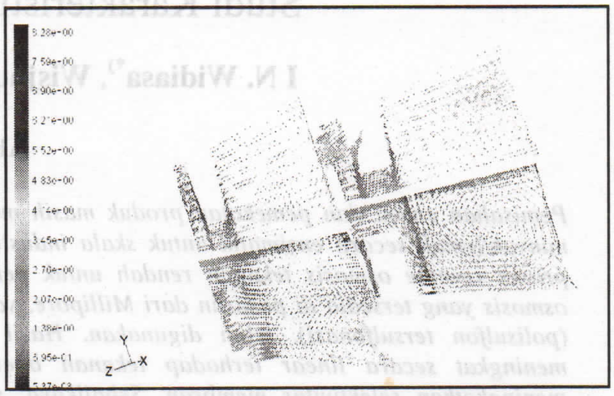

Figure 12. Vector plot of heat gas flow field at Heating zone, velocity in m/s

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