Final Report

December 2007

Project Title: Advanced Scalable Clean Aluminum Melting Systems

Investigators: Dr. Subodh Das (UK), Dr. Marwan Khraisheh (UK) and Dr. Mohamed Ali (UK)

Funding Agency: KY Office of Energy Policy

Overview

The main goal of the project was to develop a numerical modeling tool that can be used to optimize the performance and operation of the melting furnace using immersion heaters. CFD models are developed to simulate heat transfer, temperature distribution, melting process, and molten metal flow. The project enabled the University of Kentucky (Center for Aluminum Technology, Center for Manufacturing and Department of Mechanical Engineering) and Secat to develop a unique capability of simulating the effect of immersion heaters on aluminum melting and can benefit the aluminum industry to optimize their furnaces (mainly holding furnaces) to improve their processes. Secat will work with its partners to promote the modeling capabilities.

In this final report, results are shown to highlight the main capabilities of the developed modeling tools:

- Studying the thermal response of a solid block initially at room temperature using different fire tube(s) alignments and configurations.

- Determining the energy and flow fields for molten metal under different immersion heaters arrangements and configurations.

- Studying the melting progress using immersion heaters including solid fraction evolution.

- Simulating the combustion process inside the fire tubes (immersion heaters).

Using these important capabilities, we can work with different industries (with different needs) to optimize the design of their melting furnaces.

For our simulations, we chose a software called STARCD. We purchased the newest version (Version 4) which has many new added features, especially in grid generation. STARCD solver provides a rich source of models for heat and mass transfer, turbulence, combustion, radiation and multiphase physics.

The geometry and the design of the furnace that was used throughout the project are similar to the furnace developed by our National Lab partner, Albany Research Lab. The specification sheets for the fire tubes (FT) were provided by fire tube manufacturers and recommended by Albany Research Lab.

Model Geometry

The basic furnace geometry used throughout the project is shown in Figure 1. Using the property of symmetry, only ¼ of the model is used to save computational time. Different immersion heaters (fire tubes) configurations were used as shown in Figures 3-6.

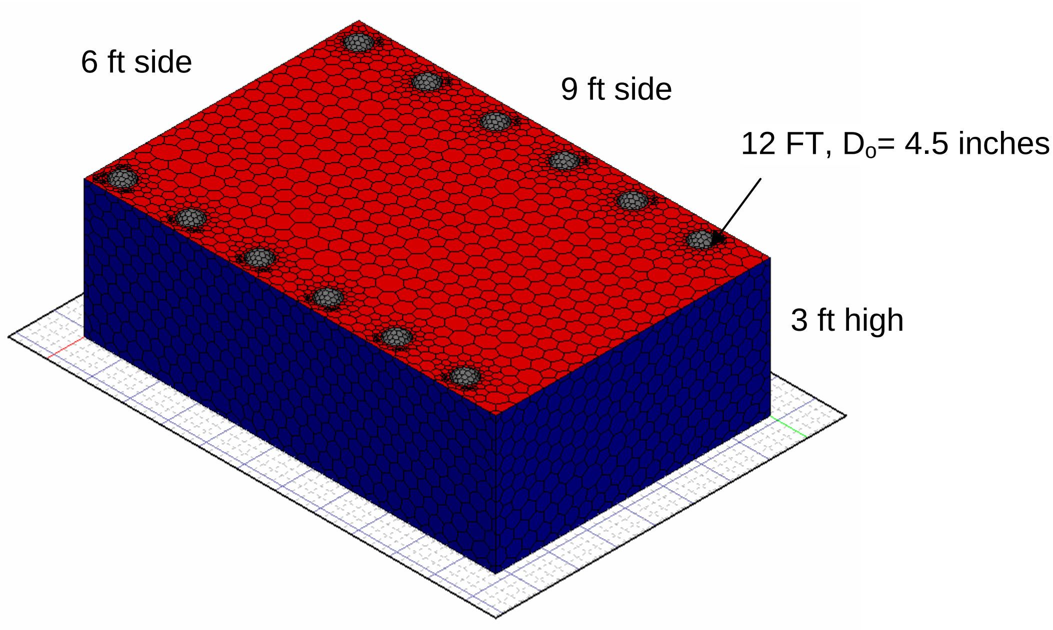


Fig.1 Full scale meshed solid domain metal block

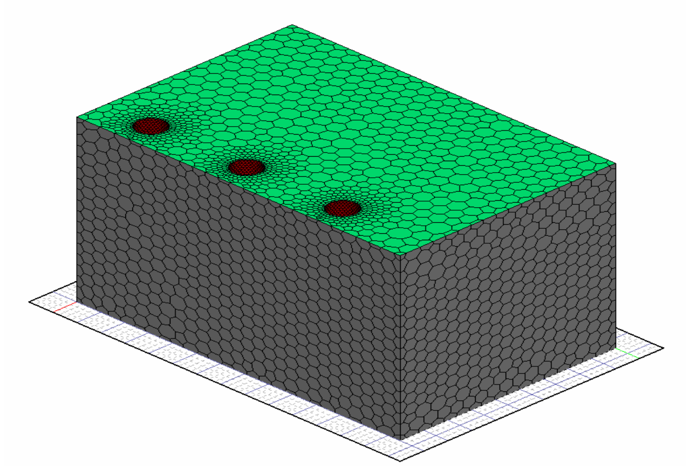


Fig.2 One quarter of the solid domain metal block

Conventional Tube Geometry

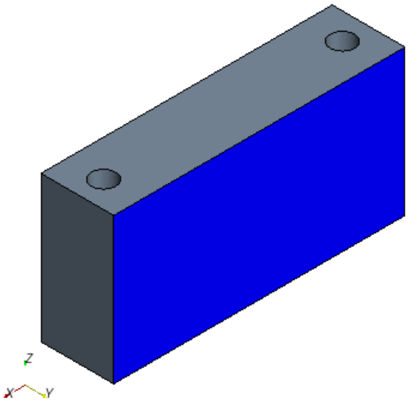


Fig. 3. 2-sides fire tube geometry without burners, 72x18x36 inches, d=6

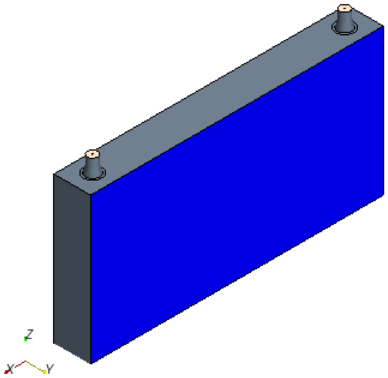
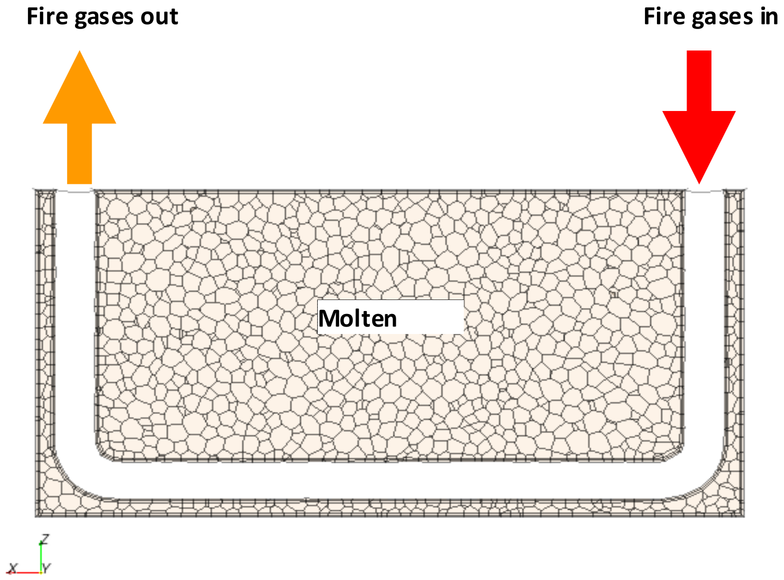


Fig. 4 2-sides fire tube geometry with burner, 72x9x36 inches, d=3.5inches

New Innovative U-tube Geometry



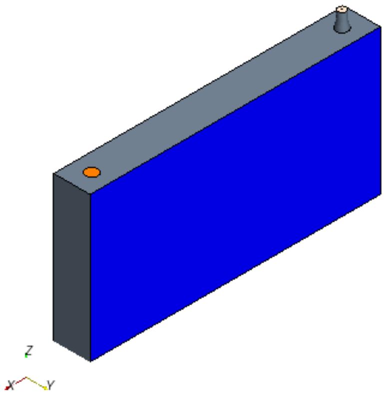


Fig.5 u-tube geometry, 72x9x36 inches, d=3.5 inches

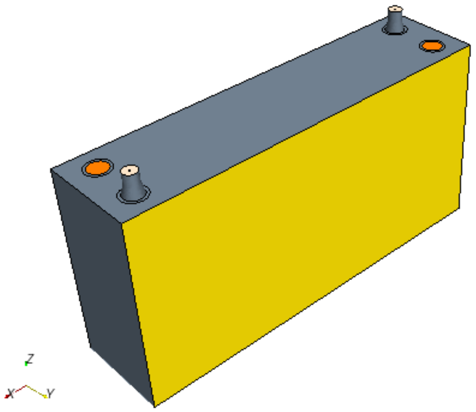


Fig.6 Counter u-tube geometry (2 u-tubes), 72x18x36, d=3.5 inches

CFD Analysis for Immersion Heaters

The modeling process included the following:

1. Building a geometrical model for the furnace. In our analysis, we used the lab scale melting furnace built by Albany Research Lab. The immersion heaters were chosen based on fire tube manufactures specifications as recommended by Albany Research Lab.

2. The basic geometrical model includes the aluminum metal block and fire tubes. The boundary condition around the metal block is assumed to be adiabatic (outer walls including the top surface). The only source of heat is coming from the boundaries of the fire tubes. Only one fourth of the full block model was used because of symmetry to reduce the computational time.

3. The first attempts to simulate the fire tube boundary condition considered constant temperature contact surface with a thermal resistance calculated from the thermal conductivity and thickness of the fire tube. The constant temperature was determined based on the average burning gas temperature (1800 K). The combustion calculation at this stage was done using an equilibrium flame model.

4. The second attempts to simulate the fire tube boundary condition considered a more practical flame model to represent the practical flame temperature distribution in the fire tube. In this stage two different fire tubes alignments have been considered, vertical tube and u-tube (see Figures 3-6).

5. The CFD analysis is applied to the solid aluminum phase including melting and to the molten metal liquid phase. The results are presented for each phase separately. In the solid phase analysis, temperature distributions of the aluminum solid/liquid mixture are presented showing the liquid fraction for different fire tube configurations. For the molten metal phase (liquid) analysis, flow and temperature distributions are presented.

6. Physics model details:

    a. Combustion: Eddy break up (EBU) has been used with three global reactions mechanism
    b. Flow: turbulent, standard K-ε, and high y+
    c. Radiation: CO2 and H2O emission

Solid Phase-Melting Analysis

The following figures show the liquid fraction evolution with time for different fire tube configurations and designs. The goal of presenting the figures is to highlight the capabilities of the developed models and to also highlight that using innovative design configurations such as the U-tube design proposed here, melting efficiency can be enhanced. The results also show that using certain fire tube designs and configurations would not be efficient for the purpose of melting.

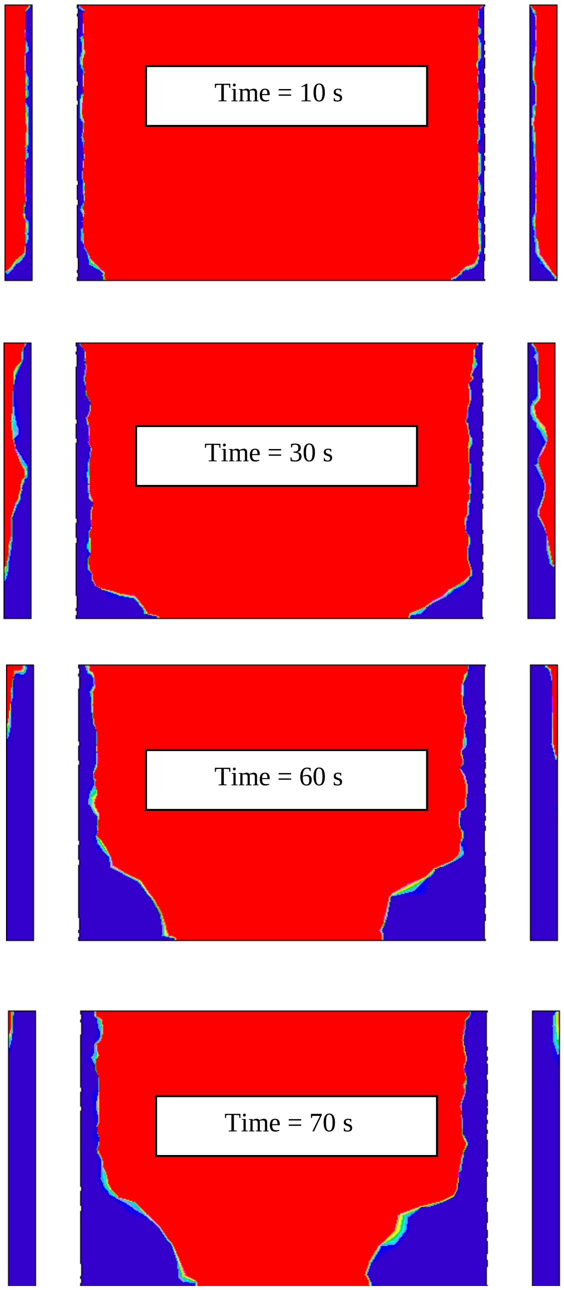


Fig. 7-a: Melting progress in the aluminum block using separated vertical fire tube, D = 6 inches, side view

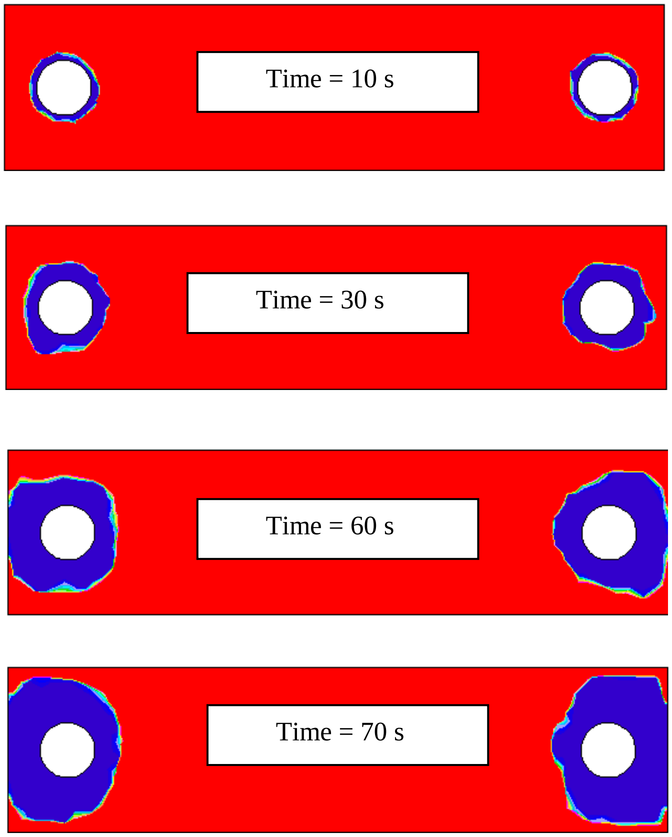


Fig. 7-b: Melting progress in the aluminum block using separated fire tube, D = 6 inches, top view

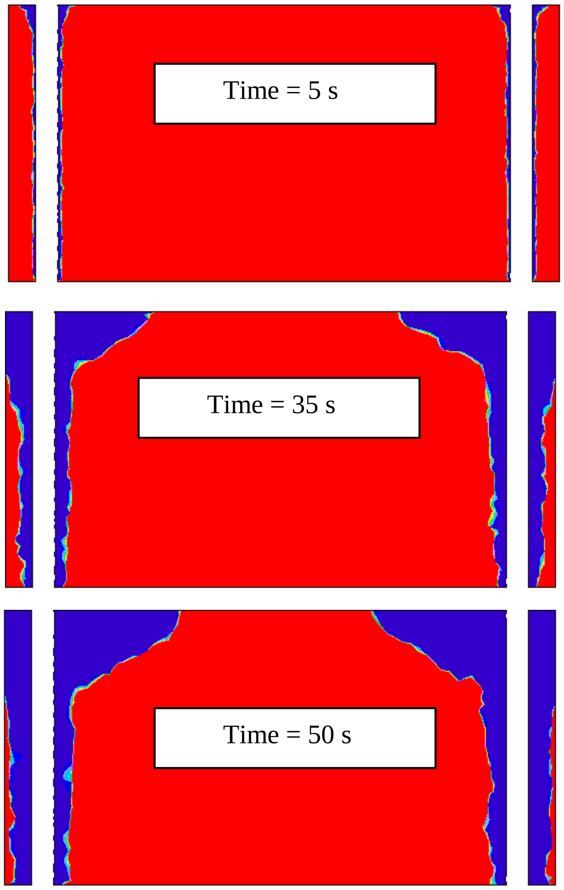


Fig. 8-a: Melting progress in the aluminum block using separated fire tube, D = 3 inches, side view

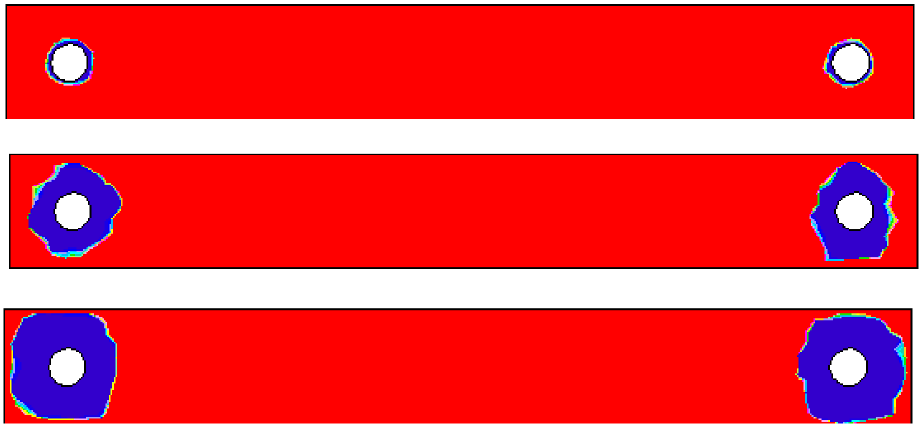


Fig. 8-b: Melting progress in the aluminum block using separated fire tube, D = 3 inches, top view

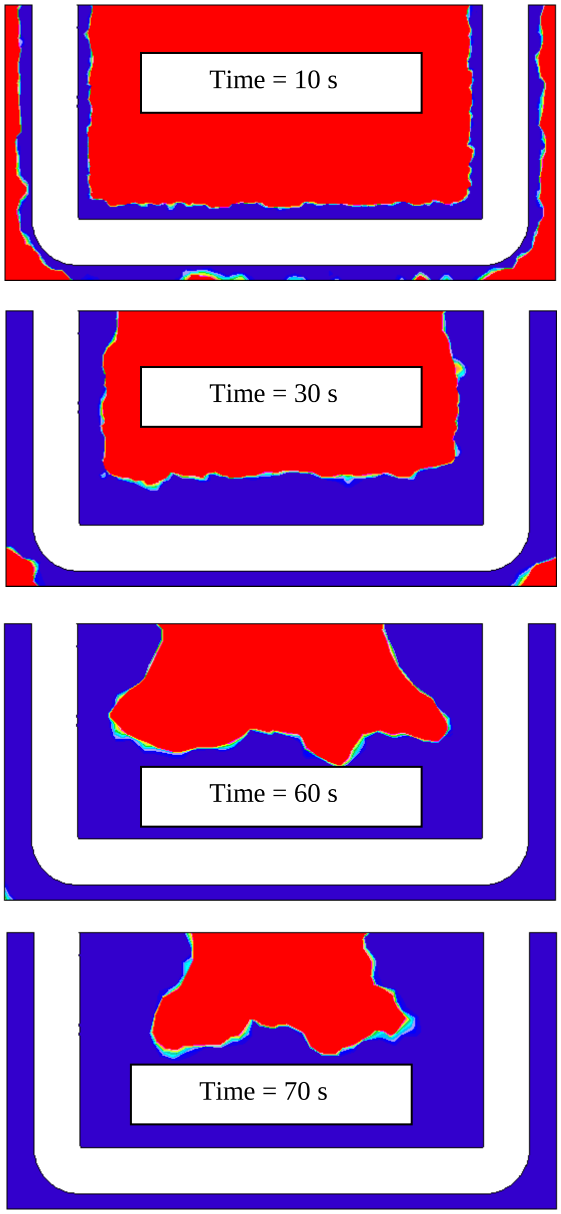


Fig. 9-a: Melting progress in the aluminum block using u-shaped tube, D = 6 inches, side view

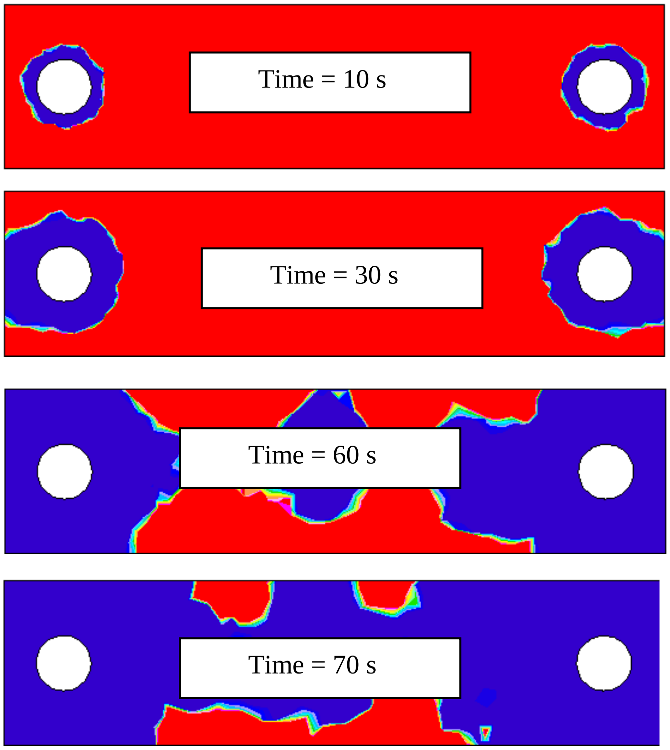


Fig. 9-b: Melting progress in the aluminum block using u-shaped tube, D = 6 inches, top view

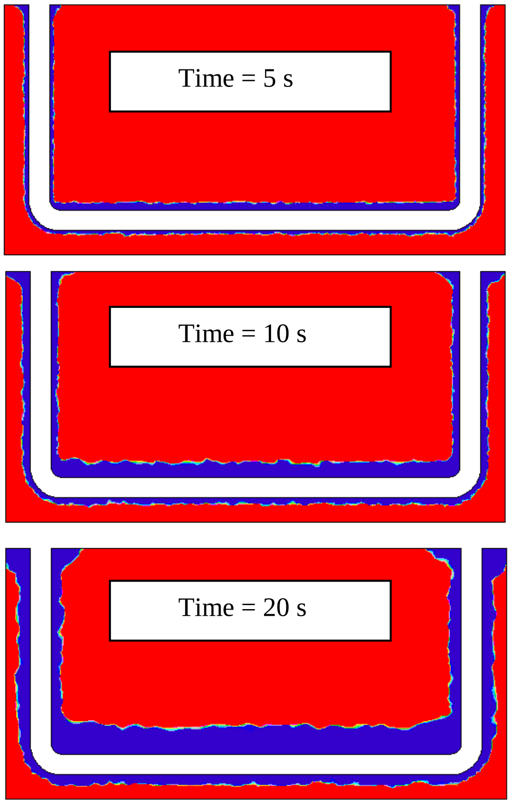


Fig. 10-a: Melting progress in the aluminum block using u-shaped tube, D = 3.5 inches, side view

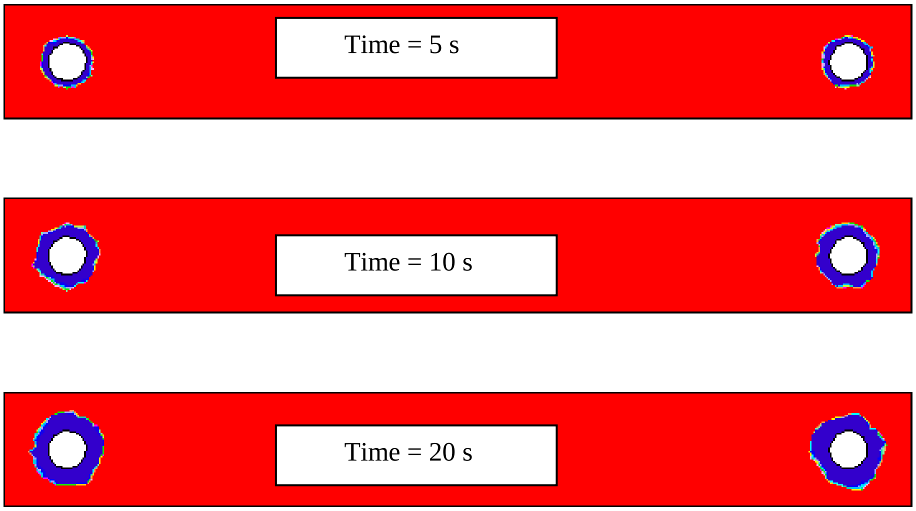


Fig. 10-b: Melting progress in the aluminum block using u-shaped tube, D = 3.5 inches, top view

In the previous figures, the liquid fraction evolution was shown. In the following figures, we present the temperature distribution for an aluminum solid block subjected to two different configurations of fire tubes. The two configurations represent Figures 4 and 6 shown above. For each configuration (design), the temperature contours are shown before and after reaching equilibrium.

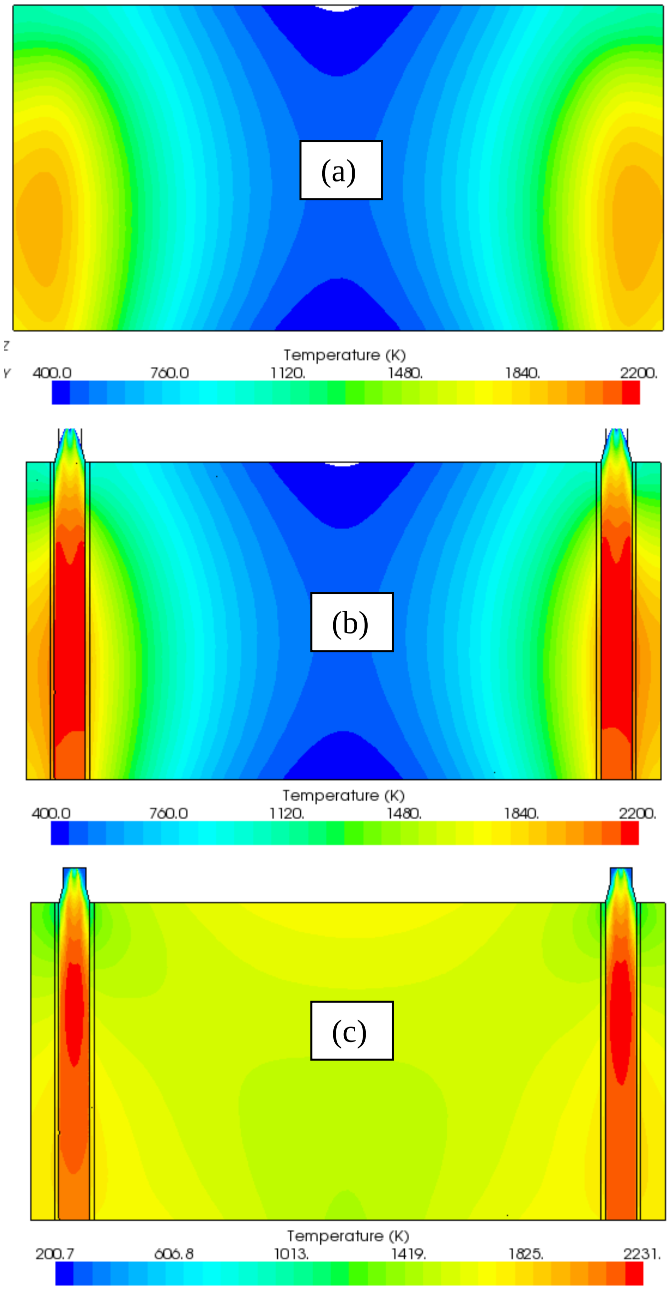


Fig.11: Temperature contour for geometry shown in fig.4, (a) symmetry and (b) tubes section before reaching equilibrium, (c) tubes section on each side and center

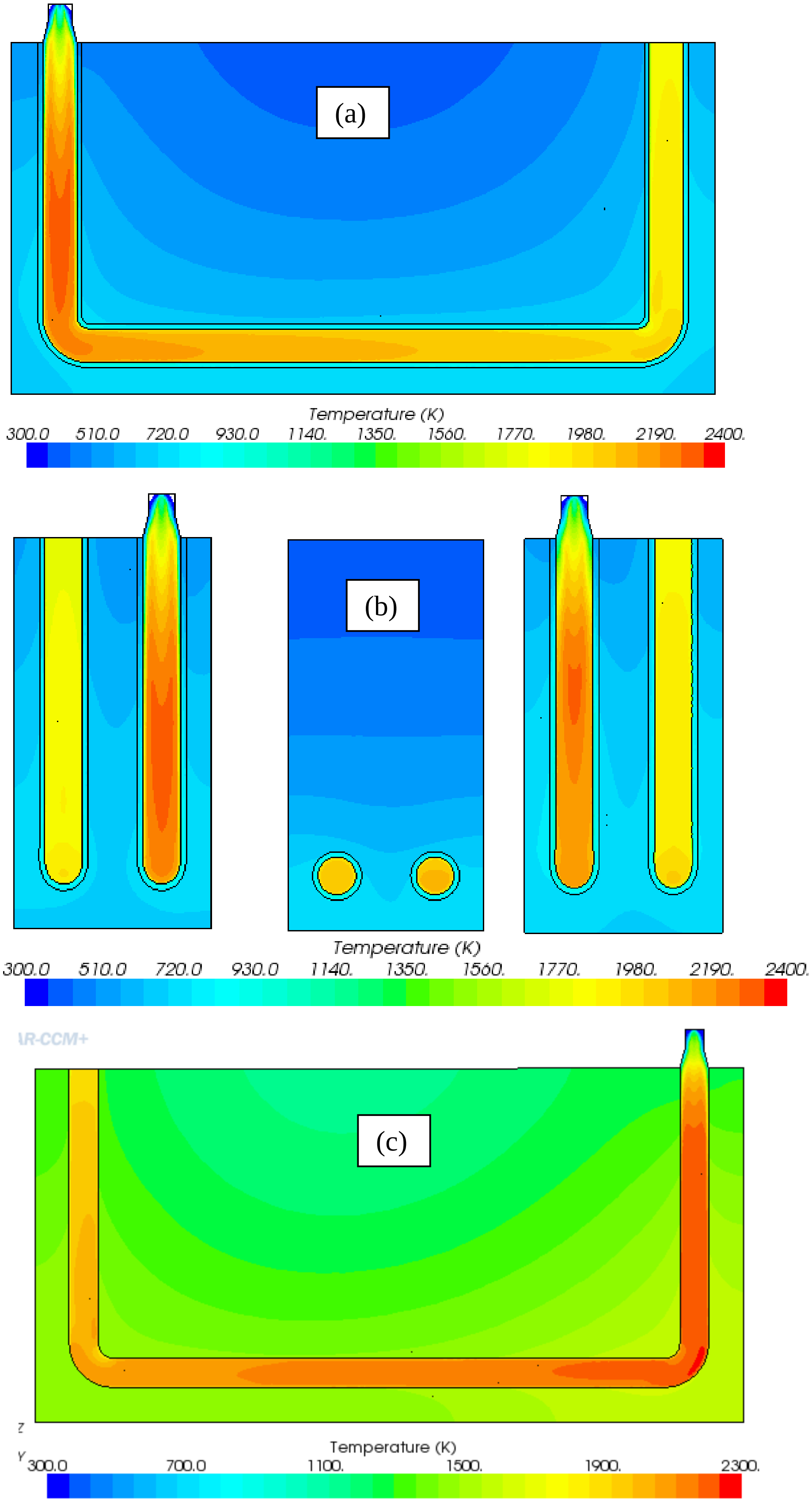


Fig.12: Temperature contour for geometry shown in fig.6, (a) y-section and (b) x-section before reaching equilibrium, (c) y-section after 1 hour.

Molten Metal (Liquid) Phase Analysis

The following figures show the flow field and temperature distributions for the fire tube configurations shown in Figures 4 and 6. It can be seen from the figures that the flow and temperature fields are much more homogenous after equilibrium. In addition, the new proposed u-tube configuration is much more effective than the conventional vertically aligned tubes.

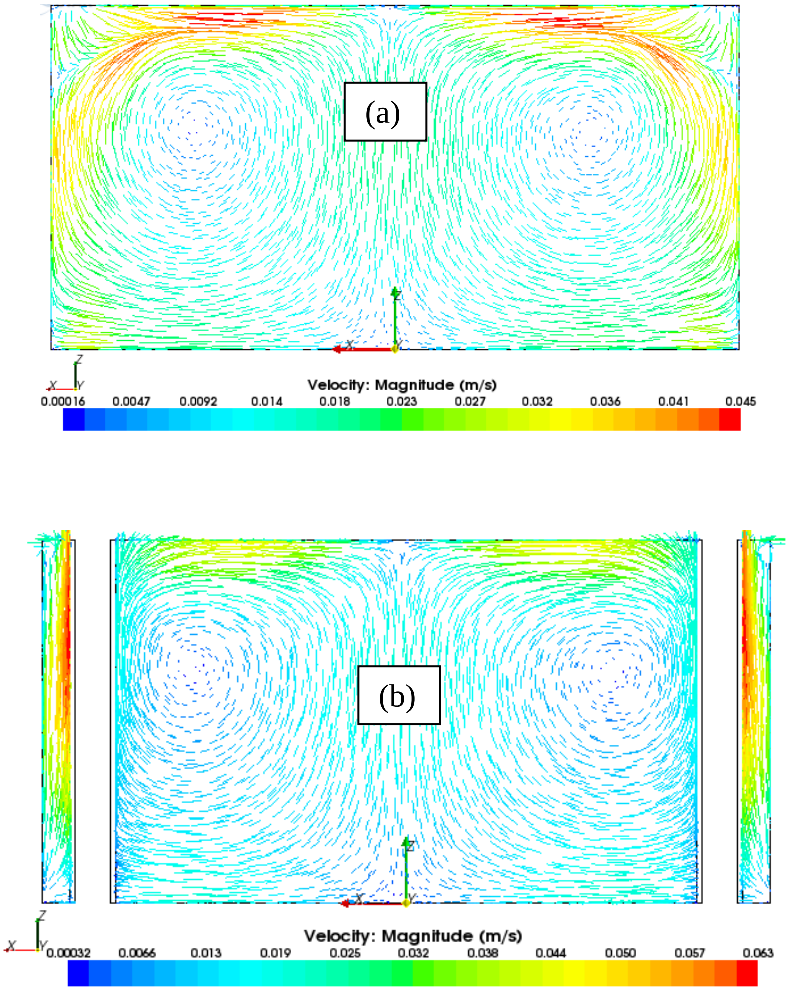


Fig.13: flow velocity fields for the geometry shown in fig.4, (a) symmetry and (b) tubes section. Before reaching equilibrium

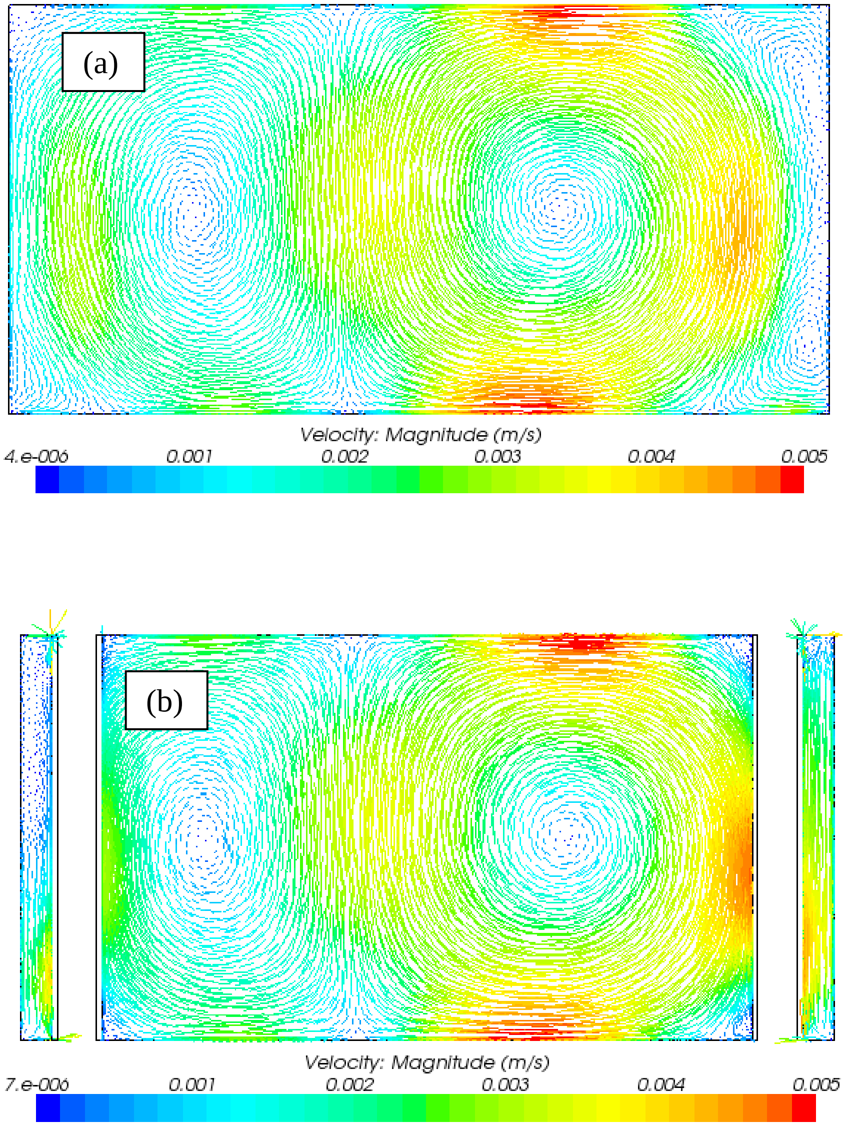


Fig.14: flow velocity fields for geometry shown in fig.4, (a) symmetry and (b) tubes section. After reaching equilibrium

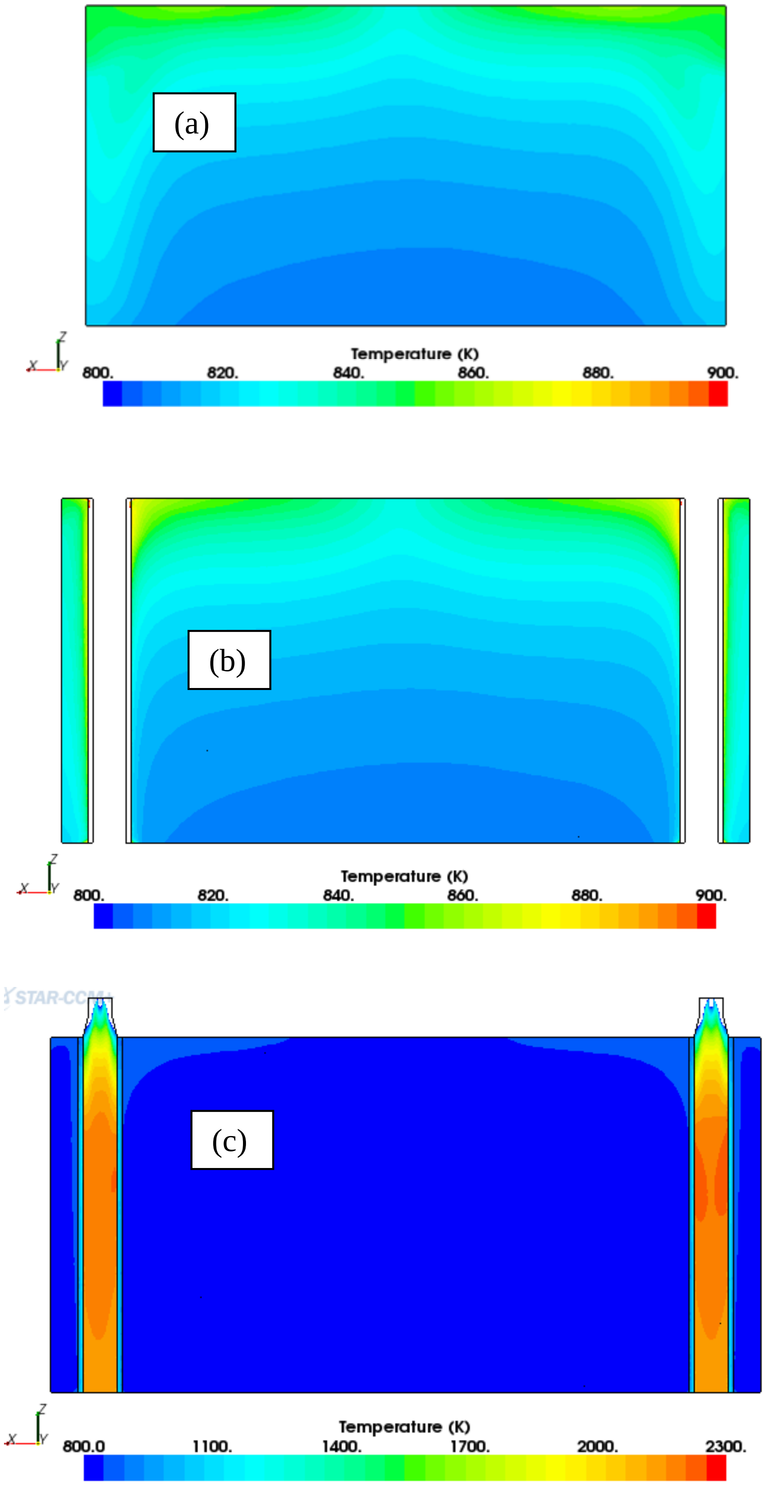


Fig.15: Temperature contours for the geometry shown in fig.4, (a) symmetry and (b) tubes section before reaching equilibrium, (c) tubes section after reaching thermal equilibrium.

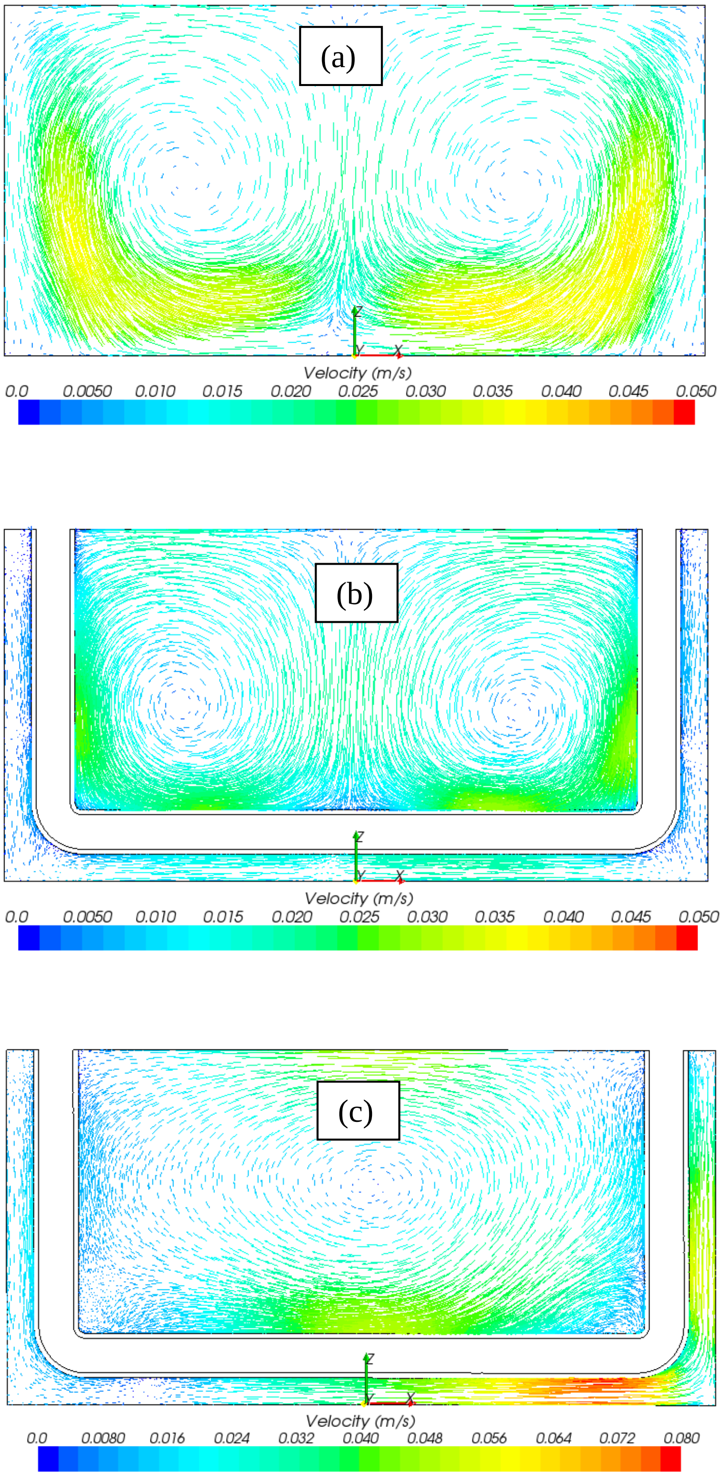


Fig.16: flow fields for the geometry shown in fig.6, (a) mid-section and (b) tubes section before reaching equilibrium, (c) tubes section after reaching thermal equilibrium.

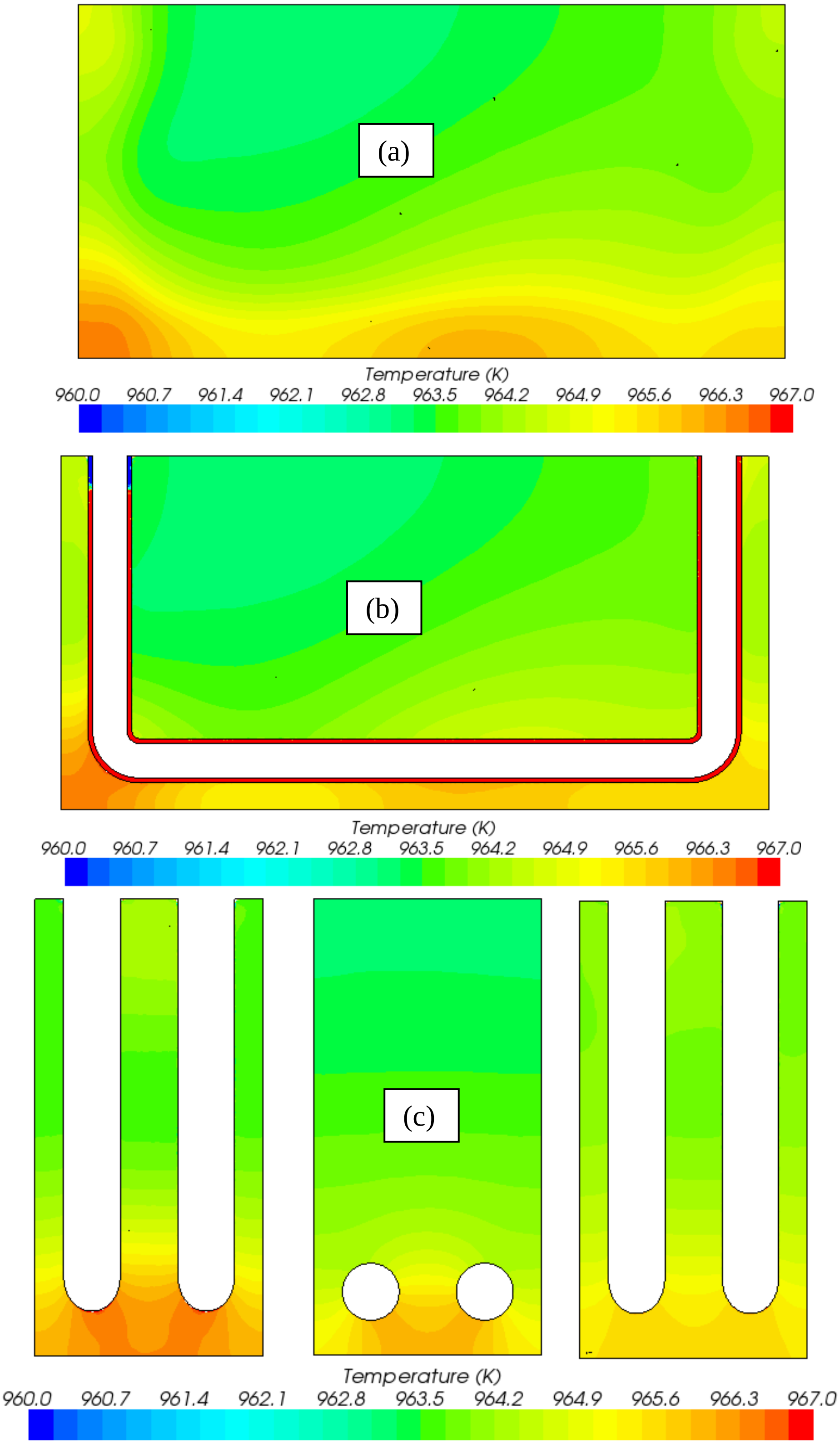


Fig.17: Temperature contour for geometry shown in fig.6, (a) mid-section and (b) tubes section before reaching equilibrium, (c) tubes section on each side and center

In order to evaluate the effectiveness of the two designs shown in Figures 4 and 6 for use in molten metal analysis, the results in Figures 15 and 16 are further analyzed and the heat flux for each design is evaluated. The results are summarized in the table below.

Model	Input Heat (kW)	Heat Transfer (kW)	Efficiency (%)
2 Vertical Fire Tubes Configuration (Figure 15)	3600	260	7.2
2 U-Tube Configuration (Figure 16)	3600	600	16.6

It can be seen that the amount of heat transfer in the case of the 2-u-tube configuration is much more than the conventional configuration of vertical tubes. In addition, the efficiency is more than doubled for the new proposed design.

Summary

The results presented in this final report clearly show the strong capabilities of the developed models in the course of this project. Temperature distributions, flow fields and liquid fraction evolutions can be determined for various burner tubes designs and configurations. The results can be used to optimize the design of melting or holding furnaces using immersion heaters. The models can also be used to examine the effectiveness of using immersion heaters for specific functions (e.g. melting, homogenizing molten metal etc.). Numerical simulations are effective and accurate methods of examining potential solutions and can significantly minimize the need for expensive experimental trial and errors.