Center for Aluminum Technology
University of Kentucky
1505 Bull Lea Road, Lexington, KY 40511
Phone: 859-514-4989, Fax: 859-514-4988

Project Report

Aluminum Melting Furnace Design Optimization to Improve Energy Efficiency by Integrated Modeling

Sponsor:
Governor's Office of Energy Policy, Energy R&D Program

Principle Investigator:
Dr. Subodh K. Das
Phone: 859-514-4955, E-mail: skdas@engr.uky.edu

Additional Researchers:
Dr. Zhengdong Long
Associate Director, Center for Aluminum Technology, University of Kentucky

Dr. Mohamed Hassan Ali
Professor, Mechanical Engineering Department, University of Kentucky

Shridas Ningileri
Project Manager, Secat, Lexington KY

Recipient Organization:
Center for Aluminum Technology, University of Kentucky

University Partner:
Dept. of Mechanical Engineering at University of Kentucky

Industrial Partners

Secat, Inc.
Ohio Valley Aluminum Company
Arco Aluminum Inc.
Aleris International Inc.

July 14, 2008

1. Executive Summary

The “Aluminum Melting Furnace Design Optimization to Improve Energy Efficiency by Integrated Modeling” Project (account number 3048101400) is sponsored by Kentucky Governor’s Office of Energy Policy. This two-year project started on 5/15/2007 with project kick-off meeting on July 17, 2007. The research is carried out by a team consisting of researchers from the University of Kentucky Center for Aluminum Technology, University of Kentucky Department of Mechanical Engineering, Secat, Inc and aluminum industry partners consisting of ARCO Aluminum, Inc., Ohio Valley Aluminum Company, and Aleris International Inc.

The goal of this proposal is to develop a workable tool for optimization of aluminum re-melting furnace design in order to increase energy efficiency and reduce environment impacts. The specific objective of this project was initially proposed to develop a predictive integrated modeling tool to be made available to industry for optimizing melting furnace design and operating parameters for energy savings.

The following activities were carried out to achieve the project goals: (1) On-site furnace evaluations were performed for three commercial scale furnaces A, B and C. Two of them were round top reverberatory furnaces and the other one was rectangular reverberatory furnace; (2) The non-commercial AFMVIEW software and the commercial Star-CD package were evaluated and StarCD was selected for combustion modeling; (3) The materials database based on JMATPro software were established to predict melting/solidification, temperature dependent thermal/physical properties and fluid flow parameters of different aluminum alloys; (4) Combustion models were established for furnace A, B and C. The flue species, temperature and energy efficiency were predicted and compared with measured data; (5) The melting and liquid flow model based on the ProCAST software are utilized for commercial furnace C; (6) “What if” scenario studies to improve the furnace design and operating parameters has been conducted for the aluminum industrial partners.

The three technical reports have been submitted and discussed with aluminum industrial partners. One project technical review meeting was hold at Lexington, KY on February 25, 2008. Several aluminum industrial partner specific technical reports were submitted and discussed.

The major achievements from this project include: (1) Successful on-site evaluations of commercial furnace for benchmark and modeling establishment and validation; (2) Development of practical furnace modeling tools for furnace design and operation parameter optimization; (3) Suggestions to improve the energy efficiency were proposed to aluminum industrial partners based on on-site evaluation and modeling; (4) “what if” scenarios studies of furnace re-design have been carried out for aluminum industrial partners for better energy efficiency.

Project team will continue to refine the modeling techniques including the melting model based on ProCAST, and provide “what if” scenario studies for melting furnace design and operating process optimization to improve energy efficiency.

It is to be noted that the data used is proprietary to the participants. Therefore, only generic data with furnaces identified as A, B and C has been presented in this report.

2. Project introduction

Aluminum melting furnaces operate at energy efficiency ranging from 10% to 38% with a strong potential to achieve over 40% efficiency improvement. Such enhancements in energy efficiency require good design and optimal operations [1, 2]. There are significant opportunities and challenges, particularly for modifying existing furnaces, to increase the energy efficiency. Due to the complex combustion parameters including gas flow, radiation and heat transfer, as well as liquid metal flow behavior during aluminum melting, it is very difficult to obtain intuitive solutions for furnace designs and operations. Therefore, the goal of this proposal is to develop a workable tool for aluminum re-melting furnace design optimization to increase energy efficiency and reduce environment impacts.

The objective of this proposal is to determine and confirm the reliability of the CFD model for combustion simulation in the furnace followed by the optimization of a workable tool for industrial application. This tool will be achieved by the following tasks and demonstrated in Figure 1:

1. Evaluation of the existing AFMVIEW software and the Star-CD package based on the available data from the previous DOE project.
2. Thermodynamic studies on melting/solidification, temperature dependent thermal/physical properties and fluid flow parameters of different aluminum alloys.
3. Establishment of the melting and liquid flow model based on the ProCAST software.
4. Integrated modeling package including CFD and ProCAST based Finite Element Analysis (FEA) model.
5. Comprehensive parametric study to evaluate the effect of various designs and operating parameters on melting efficiency.

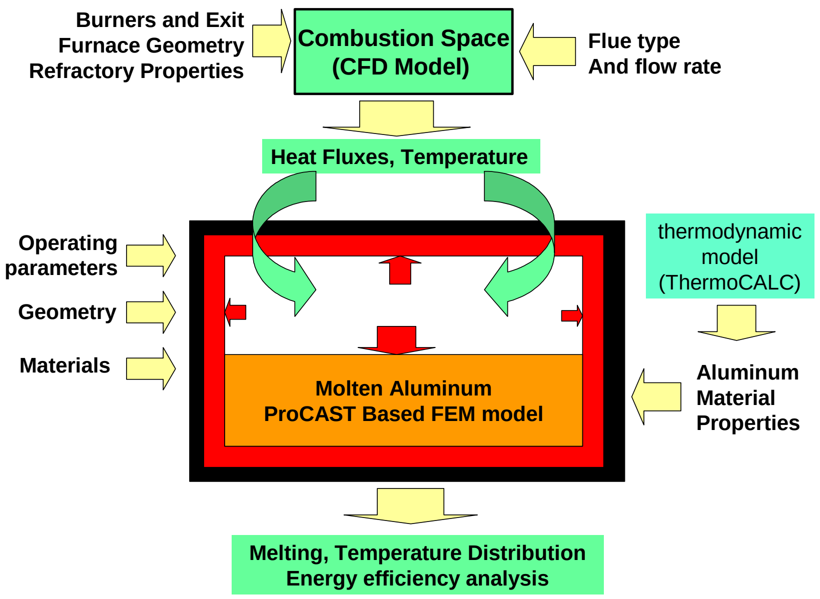

Figure 1: Project tasks

3. Major Accomplishments

3.1 On-site furnace evaluations

The onsite furnace evaluations were performed for three commercial scale furnace A, B and C at different plants. Furnace A is a rectangular reverberatory furnace and furnace B and C are round top reverberatory furnaces. The flue species after combustion, flue temperature and outside/inside wall temperature at different operating stages were measured.

3.1.1 Furnace A

Figure 1-a shows the top view of the open-well reverberatory melting furnace A. Figure 1-b gives the photograph of side door of furnace A. The furnace has a melting capacity of 150,000lb. It is a 26’ x 16’ rectangle with a 6.5’ x 16’ arched loading-side, through which the scrap is melted down into the furnace. A 20” thick, 12” maximum high, 146” wide arch separates the loading side from the main furnace. The furnace is charged with solid aluminum scraps comprised of aluminum scrap (mainly construction materials), prime and internal returns. Two burners are mounted on the east rear wall facing the charge wall with arch open. The combustion exhausts are emitted through the charging arch, directly preheating the scrap. A hood is constructed over the charge well to collect the flue gas and discharge it to a 60” diameter exhaust duct. Since there is no flue gas chimney, per say, for this unit, the flue gas measurements were carried out in this duct at high and low fire conditions.

Figure 2 is the energy balance chart of furnace A based on on-site measurement. It can be seen that the energy efficiency is 26.3%. The heat loss by flue is 62.5 %, heat loss through furnace walls by thermal conduction is 2.7 %, heat loss by dross production and removal is 1.5 %, the remaining heat losses includes radiation and convection heat losses during the door openings is 7%.

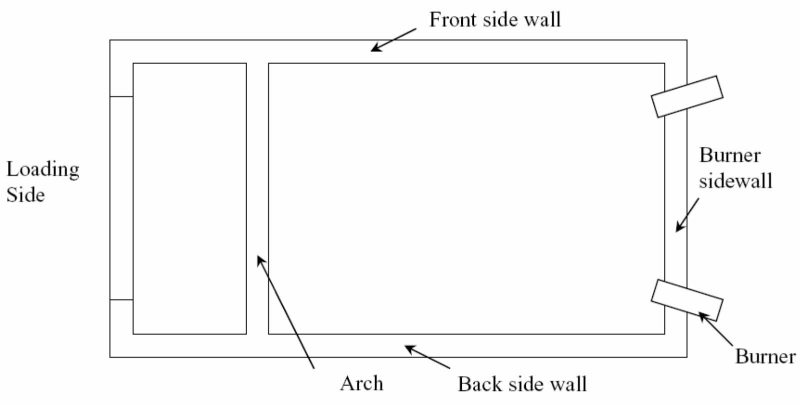

Figure 1-a. Top view of furnace A

Figure 1-b: side view showing the side door

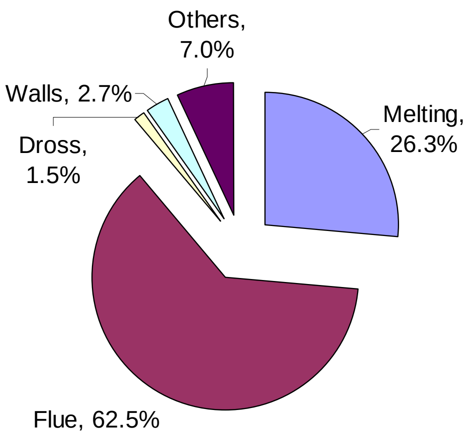

Figure 2: Energy balance of Furnace A based on measurement

3.1.2 Furnace B

Figure 3 shows the plane view of the furnace B and photograph of front door of furnace B. The furnace has a melting capacity of 110,000 lb. It is a 20' outer diameter circular reverberatory furnace with the roof movable for charging. The furnace is charged with solid aluminum scrap, prime and re-melted scrap in the form of sows and T-bars. The combustion products are exhausted through the flue (chimney) at the other end of the furnace door. The furnace side walls and roof have a refractory lining for insulation in order to reduce heat losses from the furnace.

Figure 4 is the energy balance chart of furnace B based on on-site measurement. It can be seen that the energy efficiency is 27.5%. The heat loss by flue is about 55.6 %, heat loss through furnace walls by thermal conduction is 3.4 %, heat loss by dross production and removal is 1.7%, the remaining heat losses includes radiation and convection heat losses during the door openings is 11.8%.

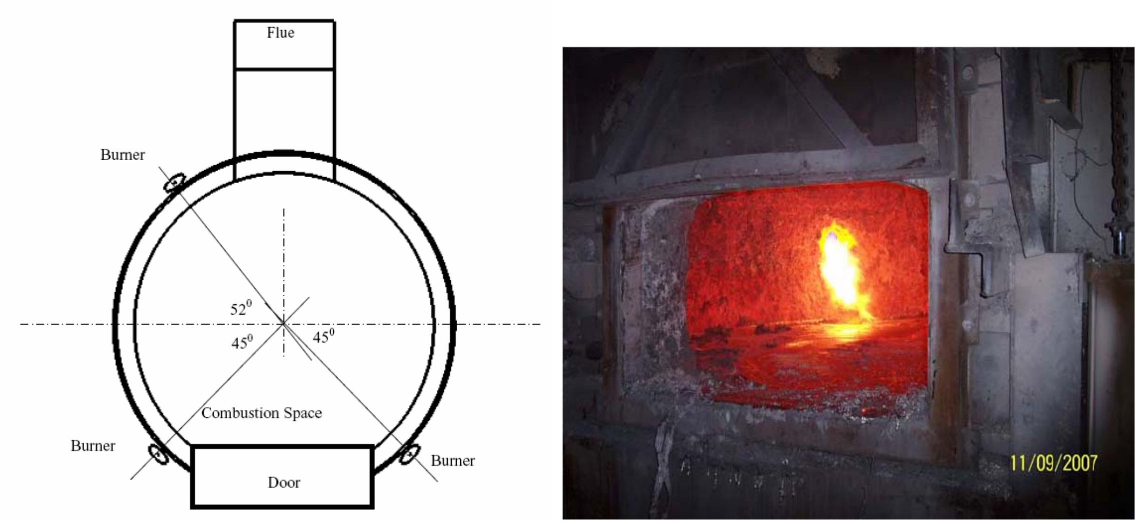

Figure 3: Furnace B: round top reverberatory furnace

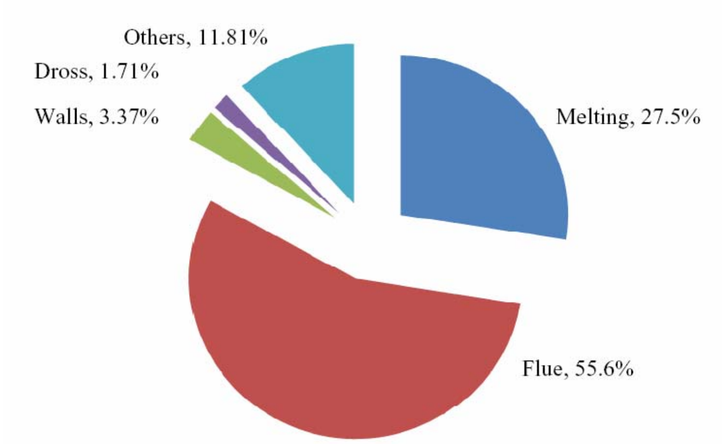

Figure 4: Energy balance of Furnace B based on measurement

3.1.3 Furnace C

Figure 5 shows the cross-section of Furnace C. The furnace has a melting capacity of 150,000 - 175,000 lb. It is a 28-32 foot outer diameter circular reverberatory furnace with a movable roof for charging. The furnace is charged with solid aluminum scrap, prime and re-melted scrap in the form of sows and T-bars as well as molten from runaround plant scrap melted in an induction furnace. The combustion products are exhausted through the flue (chimney) at the other end of the furnace door. The furnace side walls and round top are covered by heat insulation materials to reduce heat losses from the furnace.

Figure 6 is the energy balance chart of the furnace C based on on-site measurement. It can be seen that the energy efficiency is 38 - 42%. The heat loss by flue is about 38-42 %, heat loss through furnace walls by thermal conduction is 0.7-2.7 %, heat loss by dross production and removal is 0.3-2.3%, the remaining heat losses includes radiation and convection heat losses during the door openings is 15.5- 17.5%.

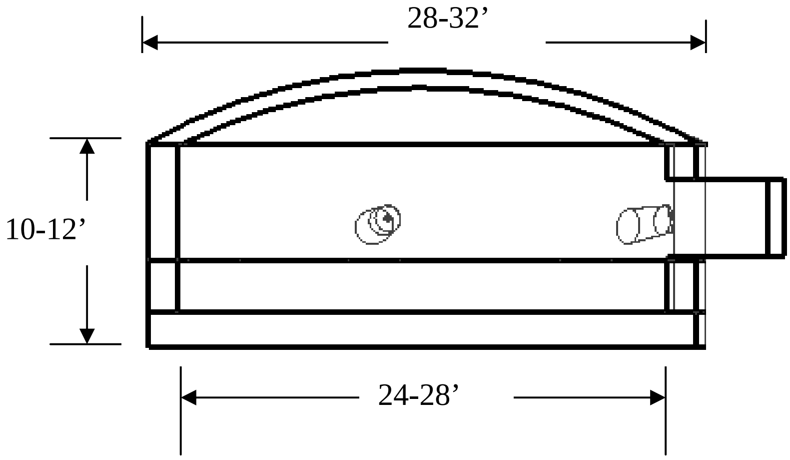

Figure 5 - A cross section of the Furnace C

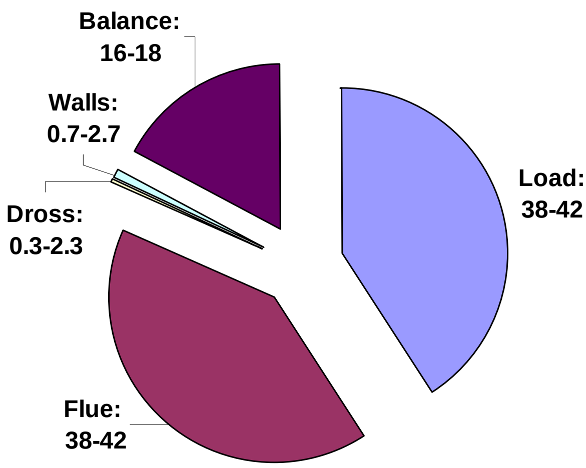

Figure 6: Energy balance of Furnace B based on measurement

3.2 The materials database establishment

Different aluminum alloys have different melting and fluid behavior and therefore will greatly affect the energy needed for reverberatory melting furnace.

The JMATPro software was established to predict melting/solidification, temperature dependent thermal/physical properties and fluid flow parameters of different aluminum alloys. These thermo-mechanical properties are key inputs for combustion model and melting model.

The industrial survey for interested alloys has been conducted. Table 1 summarized the alloys and its chemical composition.

Alloys	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
1100	0.38	0.38	0.13	0.04			0.08	
2024	0.40	0.40	4.35	0.60	1.50	0.08	0.20	0.12
3003	0.48	0.56	0.13	1.25			0.08	
3004	0.24	0.56	0.25	1.25	1.05		0.20	
3105	0.48	0.56	0.24	0.55	0.50	0.16	0.32	0.08
5005	0.24	0.56	0.16	0.16	0.80	0.08	0.20	
5754	0.32	0.32	0.08	0.25	3.10	0.15	0.16	0.12
5052	0.20	0.32	0.08	0.08	2.50	0.25	0.08	
5083	0.32	0.32	0.08	0.70	4.45	0.15	0.20	0.12
5182	0.16	0.28	0.12	0.35	4.50	0.08	0.08	0.20
6061	0.60	0.56	0.28	0.12	1.00	0.20	0.20	0.12
7075	0.32	0.40	1.60	0.24	2.50	0.23	5.60	0.16

Table 1: chemical composition of interested alloys

3.3 The combustion models

The non-commercial AFMVIEW software was initially proposed as an alternative code for combustion model. However, it does not have the ability to build complex geometry (such as round top and arch door) required from program industrial partners. Therefore, the commercial Star-CD package was used for combustion modeling.

The combustion CFD models were established for furnace A, B and C. Furnace B and C have similar round top geometry design and Furnace A has rectangular furnace design. Therefore, the combustion models of Furnace A and B will be demonstrated in this report.

3.3.1: Combustion model of Furnace A

The flue species, temperature and energy efficiency were predicted and compared with measured data. Figure 7 gives the temperature contour of furnace A. The flow pattern and velocity can be found in the Figure 8.

Table 1 gives the comparison of flue species as well as energy efficiency and heat losses between calculated and measured results. It shows that the model results are pretty close to measured results except the energy efficiency. In the model, the preheat to the charging scraps in the feeding arc was included in the calculation, While this preheat was not included in the measurement due to limited data from plant.

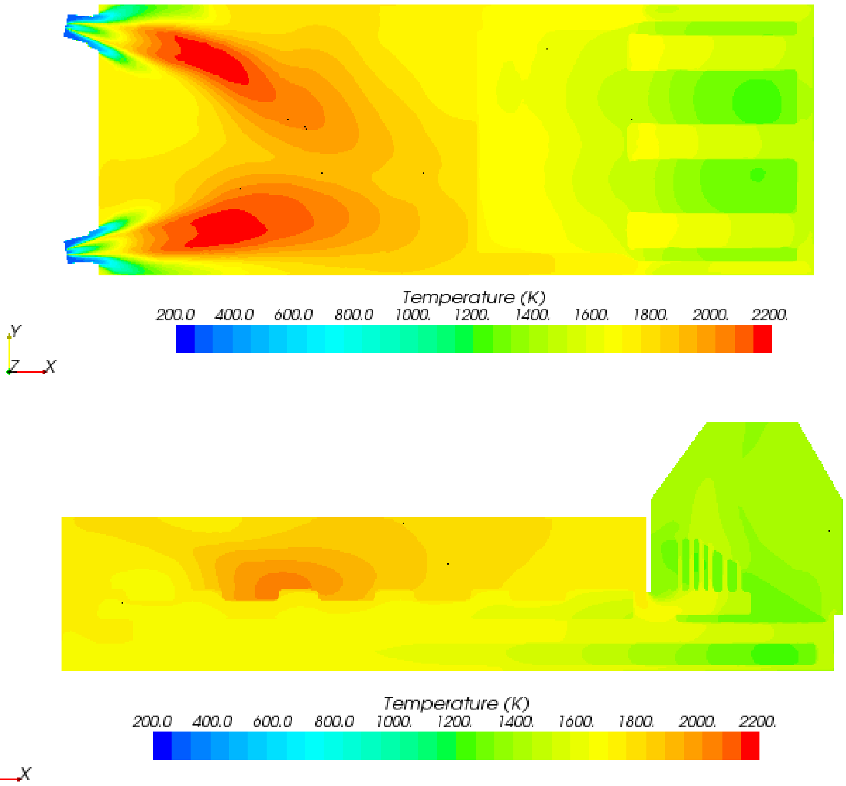

Figure 7: Temperature contour of Furnace A

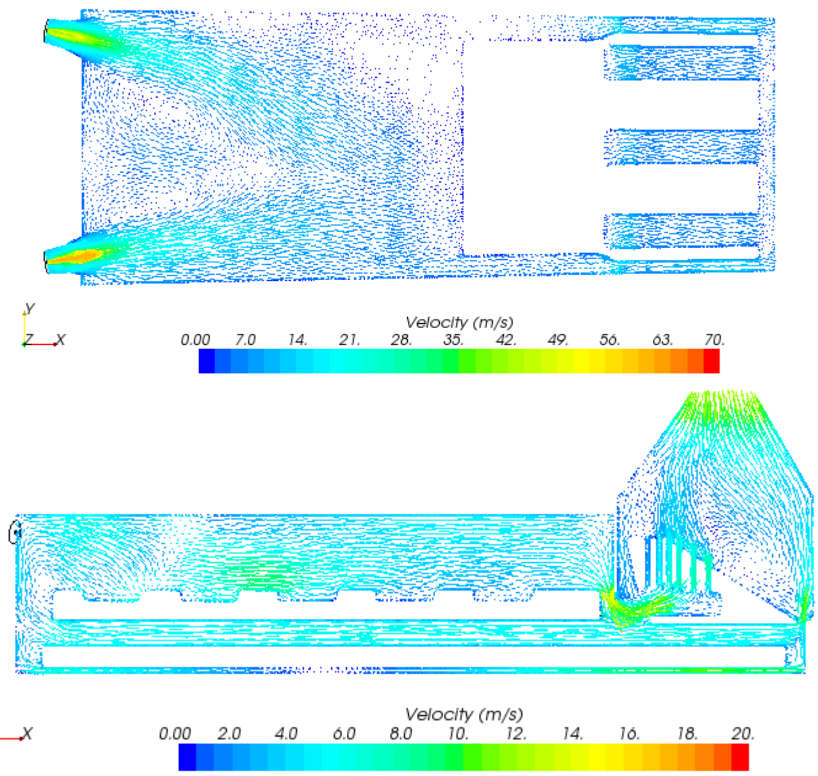

Figure 8: Velocity contour of Furnace A

	CO_2, mass%	H_2O, mass%	CO, mass%	O_2, mass%
Model	11.6	9.5	0.017	5.3
Measure	9.1	10.5	0	5.14

	Qw, MW	Q_{flue}, MW	Q_{load}, MW	$Q_{burners}$ MW	ηth, %
Model	0.24	4.8	3.8	8.786	43.25
Measure	0.24	5.53	2.33	8.786	26.3

Table 1: Combustion species, heat balance and efficiency of furnace B

3.3.2: Combustion model of Furnace B

Figure 10 gives the temperature contour of furnace B. The temperature at flue is 1500 K (2240 ^oF) which is close to the plant record of 2100 ^oF. The flow pattern and velocity can be found in the Figure 11. In average, the exhaust flow velocity at the furnace exit is about 4.75m/s. The flue

Figure 12 gives the contours of flue species including CO_2, CO, H_2O and O_2. Table 3 give the comparison of flue species as well as energy efficiency and heat losses between calculated and measured results. It shows that the model results are pretty close to measured results.

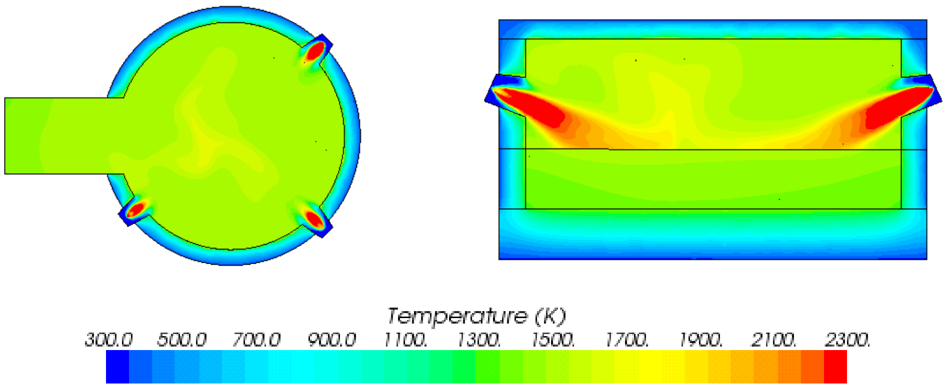

Figure 10: Temperature contour of Furnace B

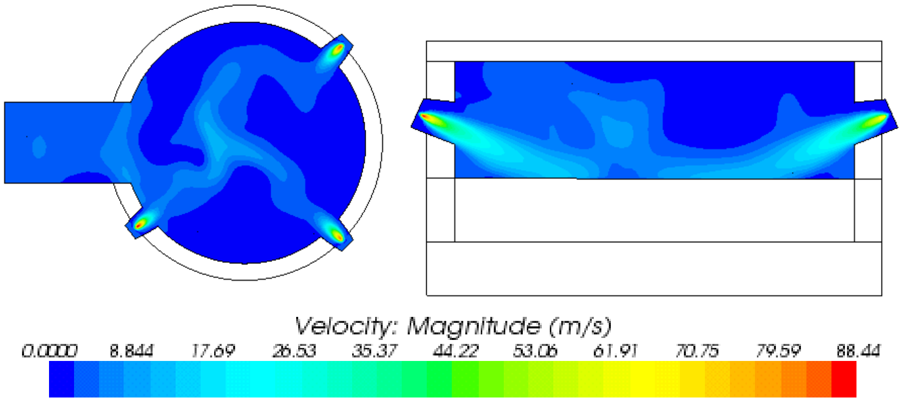

Figure 11: Velocity contour of Furnace B

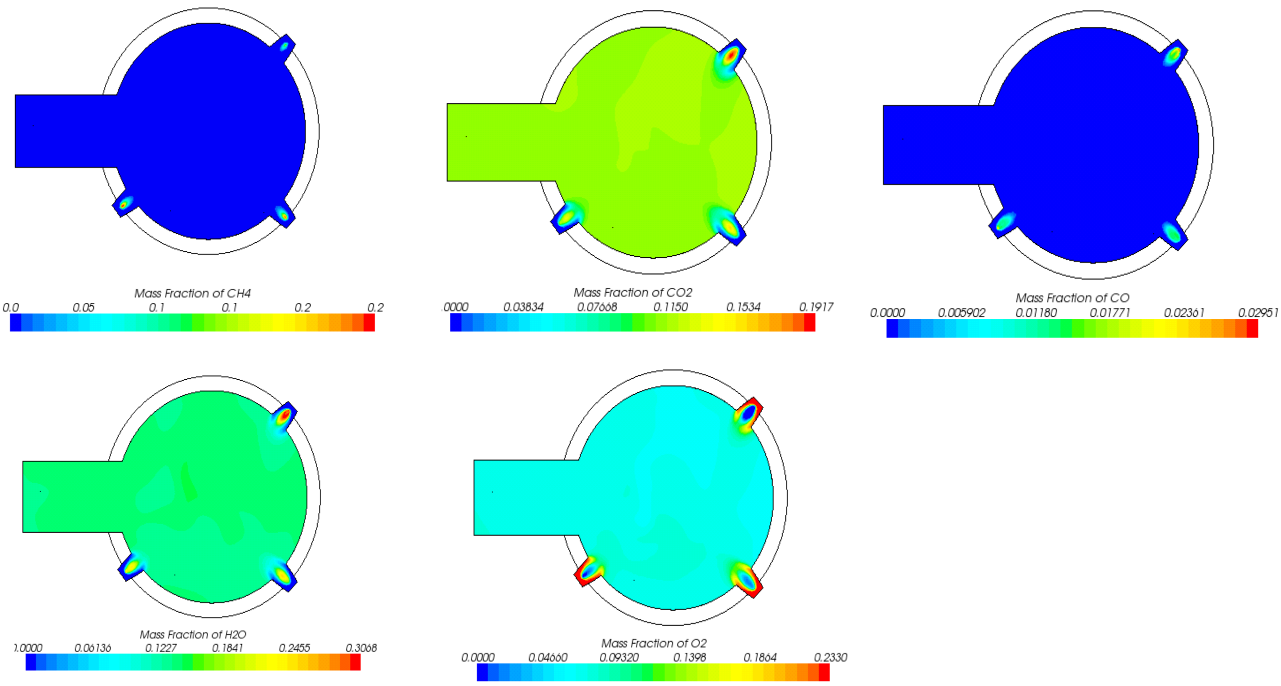

Figure 12: combustion species contours of furnace B

	CO_2, mass%	H_2O, mass%	CO, mass%	O_2, mass%
Model	8.0	16.0	0	5.0
Measure	8.5	17.3	0	1.7

	Qw, MW	Q_{flue}, MW	Q_{load}, MW	$Q_{balance}$, MW	ηth, %
Model	0.2484	3.93	1.7	5.9	28.8
Measure	0.2334	3.85	1.9	6.93	27.5

Table 3: Combustion species, heat balance and efficiency of furnace B

3.4 The melting and liquid flow model

The aluminum melting model is under investigation. The model is based on the ProCAST FEM software.

3.5 "what if" scenario studies for furnace re-design

Based on established modeling technique, different "what if" scenario studies based on requests from industrial partners have been carried out to improve the furnace design and operating parameters in order to achieving better energy efficiency and less emissions. The following is the list of main "what if" scenario studies. Due to proprietary protection concerns from industrial partners, the detail results will not presented in this report

1. Arc height furnace design
2. Furnace wall height design
3. Aluminum metal stirrer
4. Height of metals
5. Exhaust location
6. Sidewalls modification
7. Inlet air temperature.

4. Summary

Project team has successfully performed on-site evaluations of commercial furnaces for benchmark and modeling establishment and validation. The furnace modeling tools for furnace design and operation parameter optimization have been developed. The "what if" scenarios studies of furnace re-design for aluminum industrial partners have been carried out for better energy efficiency.

The three technical reports have been submitted and discussed with aluminum industrial partners. One project technical review meeting was hold at Lexington, KY. Several aluminum industrial partner specific technical reports were submitted and discussed.

Project team will continue to refine the modeling techniques including melting model based on ProCAST, and provide "what if" scenario studies for melting furnace design and operating process optimization to improve energy efficiency.

References:

[1]: King, P. E., Hatem, J. J. and Golchert, B. M., ENERGY EFFICIENT OPERATION OF SECONDARY ALUMINUM MELTING FURNACES, Light Metals 2006 Edited by A.T. Tabereaux TMS (The Minerals, Metals & Materials Society)

[2] King, P. E., Golchert, B. M., Li, T. X., Hassan, M., and Han Q., "Energy Efficient Operation of Aluminum Furnaces," Proceedings of the 9th AustralAsia Aluminum Cast House Technology Conference, Melbourne, Australia, September 2005.

[3] http://minerals.usgs.gov/minerals/pubs/commodity/aluminum/aluminyb02r.pdf

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[5] http://www.thinkkentucky.com/kyedc/pdfs/Aluminum_Report.pdf