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for
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Between

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and

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For the Participant:

Dr. Subodh K. Das [signature]
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President & CEO
(Title)

02/07/2008
(Date)

ORNL-851 (9/2007)

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for
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Between

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ORNL-661 (9/2007)

C/ORNL04-0696

Materials Science and Technology Division

CRADA Final Report
For CRADA Number ORNL04-0696

Scaleable Clean Aluminum Melting Systems*

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Secat Inc.

Date Published – February 2008

Prepared by the
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Materials Science and Technology Division

CRADA Final Report
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Scaleable Clean Aluminum Melting Systems*

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1. Abstract

The project entitled "Scaleable Clean Aluminum Melting Systems" was a Cooperative Research and Development Agreements (CRADAs) between Oak Ridge National Laboratory (ORNL) and Secat Inc. The three-year project was initially funded for the first year and was then cancelled due to funding cuts at the DOE headquarter. The limited funds allowed the research team to visit industrial sites and investigate the status of using immersion heaters for aluminum melting applications. Primary concepts were proposed on the design of furnaces using immersion heaters for melting. The proposed project can continue if the funding agency resumes the funds to this research.

2. Statement of Objectives

The objective of this project was to develop and demonstrate integrated, retrofitable technologies for clean melting systems for aluminum in both the Metal Casting and integrated aluminum processing industries. The scope focused on immersion heating coupled with metal circulation systems that provide significant opportunity for energy savings as well as reduction of melt loss in the form of dross. The project aimed at the development and integration of technologies that would enable significant reduction in the energy consumption and environmental impacts of melting aluminum through substitution of immersion heating for the conventional radiant burner methods used in reverberatory furnaces. Specifically, the program would couple heater improvements with furnace modeling that would enable cost-effective retrofits to a range of existing furnace sizes, reducing the economic barrier to application.

3. Benefits to the Funding DOE Office's Mission

This program is directly relevant to the Metal Casting industry since melting represents 55% of the energy used in the industry, yet there is substantial installed capital that inhibits adoption of technologies that require complete replacement to obtain benefits.

The implementation of clean melting systems for aluminum, assuming utilization in 65 units of an average size of 10,000 tons/yr (representing roughly 25% of the aluminum melted) at the end of ten years could provide economic benefits ranging from $23-$34 million per year, and energy savings ranging from 2.7-4.2 trillion Btu per year in the Metalcasting industry alone. The project will benefit DOE OTT in meeting goals of the National Energy Strategy through improved energy efficiency and improved worldwide competitiveness of U.S. industry.

4. Technical Discussion of Work Performed by All Parties

The scope of the planned work focused on immersion heating coupled with metal circulation systems that could provide significant opportunity for energy savings as well as reduction of melt loss in the form of dross. The primary objectives included:

- Evaluation and improvement of both gas-fired and electric resistance immersion heaters
- Demonstration of combined immersion heating and metal circulation in a highly instrumented 1 ton experimental furnace as well as in production melting and holding units to enable quantification of energy and melt loss reduction benefits
- A predictive modeling tool available to industry providing melting furnace design and operating parameters for both retrofit and new furnace designs

Secat, Inc. led the development team consisting of Oak Ridge National Lab (responsible for heat and fluid modeling and materials development efforts), Albany Research Center (responsible for experimental furnace development and model validation), University of Kentucky (responsible for model development and parametric studies), and E3M, Inc. (responsible for developing design and operating guidelines as well as energy and economic analyses). The group met quarterly in the first year for technical discussion and reviewing research results. The team also visited industrial companies to collect data on the use of immersion heaters for melting aluminum alloys. The project was funded for the first year. The research effort of the team was focused on the evaluation of both gas-fired and electric resistance immersion heaters. Primary concepts were proposed on the improvement of immersion heaters.

4.1 Status of Current Technology

At the time of this writing, no commercial gas-fired or electric immersion melters were known to be in operation in the United States. Immersion technology, both gas and electric, is commonly used for heating aluminum holding furnaces, ladles, and filter and degassing boxes. The current immersion tubes are based on either an electric resistance element or combustion gases contained in a thermally conductive, nitride-bonded silicon carbide or sialon tube where the heat source at the core emanates energy through the walls of the tube and into the surrounding molten aluminum. Tube heaters used in this fashion generally are about five inches in diameter and provide 15 – 20 inches of heated length. They generate approximately 50,000 Btu/hr corresponding to heat flux of about 230 Btu / (in^2-hr) each. Typical holders utilizing this technology are charged with molten aluminum. The typical holder may contain up to 6000 pounds of molten aluminum and require five to eight heaters to maintain a casting temperature of about 1350 °F.

The ITM [8] under development by Apogee Technologies, Incorporated is an enhancement of electric heating technology. This ITP sponsored project has demonstrated that melting with immersion heaters is possible and commercially viable. The electric heater developed by Apogee Technology produces approximately 171,000 BTU/hr with corresponding heat flux of 440 Btu/(in^2-hr). These enhanced electric elements provided enough energy to demonstrate a furnace capable of melting 300 lb/hr reporting a melt efficiency of 97%. Following are touted advantages of the ITM:

- 50% reduction in energy consumption compared to conventional melting
- 80% reduction in melt loss
- Significant dross reduction

- Practicality to large-scale aluminum production
- Heaters can be adapted for holder applications
- Eventually may be redesigned to work in refit applications
- Reduced use of floor space.

Immersion tube melting technology offers clear advantages over gas-fired reverberatory aluminum melting technology. In the late 1980's, researchers in the U.S. at both Babcock and Wilcox and in Japan cooperatively at the TOHO Gas Company, Limited and the Nihon Konetsu Industrial Company, Limited in separated efforts developed melters based on single ended, natural gas-fired, ceramic tube burners.

Kimura and Taniwaki [6] discussed the development to a aluminum melting furnace designed to replace crucible furnaces. In furnaces capable of holding 750 kg, they demonstrated a melt rate of 100 kg/hr with an average reported melting efficiency of 60%. This efficiency was achieved without traditional circulation. The solid "ingots" were charge to a chamber separated from the "bail out" chamber by a partition of refractory and the tube burner(s). Their furnace employed special geometry and accommodated "ingot" melting by venting the exhaust into the charge chamber. The cool molten metal flowed through a "melting hole" into the bottom of a "heating chamber. The heating chamber contained the immersion heater. Heated metal flows from the bottom of the heating chamber to the bail out chamber. This three stage process provided very tight temperature uniformity in the bail out chamber. Reportedly in 1988, ten furnaces of this type were in commercial operation in Japan.

Babcock and Wilcox [7] with substantial support from Reynolds Aluminum demonstrated a prototype, natural gas-fired, immersed tube, puddle melter capable a melt rate of 560 lb/hr (the target was 1000 lb/hr) with a holding capacity of 10,000 lbs. However, the energy consumed was higher that expected primarily due to inefficiencies of the puddler device and the rate at which materials could be charged into the system. Even though the burners used on the prototype melter yielded thermal efficiencies of 54% and above, success in transferring this available heat into the melt was limited. A commercial version was designed targeting a 10,000 lb/hr melt rate and a holding capacity of 100,000 lbs. However, the prototype proved only as efficient as some of the best reverberatories it was intended to place. Apparently, the commercial sized version was never built even though the research team reported that they had developed solutions to the high energy consumption issues.

4.2 Reconsideration of Commercial Scale, Gas-Fired Immersion Melter Technology

In the past, immersion meltering technology application to aluminum remelt furnaces has met many challenges. Some of these are as follows:

- Poor tube reliability due to thermal shock
- Poor tube reliability due to mechanical abuse

- Inability to fire tubes at a high enough rate to avoid excessive tube population of the remelt furnace.
- Perceived higher cost of the tube burners and controls
- Potential inability to melt ingots
- Potential inability to start melting without a molten heel
- Poor heat transfer between the tube and molten aluminum
- Poor thermal efficiency of tube burners
- Excessive bonding of dross to tubes
- Chemical instability of tube in molten aluminum
- Increased maintenance costs
- Inability to receive various scrap forms
- Inability to function on low bath height and lack of flexibility of circulations systems
- Cost of burner control systems
- Misapplication of tradition reverberatory guidelines to tube-based technology
- Failure to provide for the ease removal and replacement of tubes and burner
- Lack of availability of long ceramic tubes
- Failure of designers to reconfigure furnace geometries for tube burner
- Believe that tube burners cannot be added to existing furnaces
- Immersion technology is marketed by unknown companies
- Difficulty of attaching ceramic tube to metal flanges

These difficulties will have to be considered in this new study. There have been appreciable incremental improvements in tube materials, burners, refractories, pumps and circulation equipment, regenerators and recuperators, control equipment and actuators, sensors, and the basic understanding of the delivery of energy to the melting process over the past 20 years or so. Some examples of this advancement are listed below. ORNL worked on improved tube materials. Several ceramic tube manufacturers list tubes in their product literature that are advanced of materials offered in the 1980's. Product literature from several burner suppliers indicates that high capacity burners with thermal efficiency ranging from 65 – 80% are now available. Flanges are now routinely cast with the tune to accommodate joining. These improvements coupled with other advances and the successes of the ITM make gas-fired, immersion melter technology worth a fresh new look.

Even at today's natural gas prices, melting aluminum with natural gas is far more attractive that melting with electricity. Two major reasons for this is that gas melting is thermally more efficient than melting with electricity when the efficiency of electrical generation and line losses are also considered and if an extensive natural gas infrastructure is already in place the facility would be reluctant to make a capital investment in a new infrastructure for electricity. The best place for electric melting technology is at the small volume recycler/remelter who is primarily concerned with emissions.

An advance scalable clean aluminum melting system must be energy efficient. The capital and operating cost of such a system must be comparable with the price of building today's best gas-fired reverberatories utilizing regenerative or recuperative, and recirculation technology. The melt rate must be as high or higher that current melters in operation at the high volume aluminum recyclers.

4.3 Preliminary Concept

Present reverberatory designs for aluminum furnaces require shallow, high surface area baths and adequate above-the-melt chamber area to effectively radiate heat to the bath. Often furnaces are over-fired to enhance energy transfer into the metal. This excessive energy makes the surfaces of the exposed aluminum very hot. The height above the bath is often two to three times the bath depth. During the solids heating stage of melting, the melt process is aided by convective heating as well. Traditionally, the melt rate in recirculated natural gas-fired reverberatory systems is about 60 lbs/ft^2. Bath depths average 36 inches. This traditional configuration requires the energy for melting be transferred from one surface of the bath and conducted throughout the bath. This process is fundamentally inefficient. A better method is to deliver energy throughout the depth of the bath.

Consider the furnace in figure 1. This model is a recirculated bath furnace with and exterior charge well and pumping (circulation) mechanism. The main chamber would hold approximately 28,000 lbs of molten aluminum. The main chamber is where ingots and coil scrap would be charged. The bath surface area is 54 ft^2. Total volume is calculated at 162 ft^3. The charge well (for light gauge) and pump section will hold an additional 8,000 – 10,000 lbs of molten metal. Total holding capacity of this model furnace would around 36,000 lbs. Such a furnace should be capable of melting about 15% its holding capacity each hour. Hence, a targeted melt rate of nearly 5400 lbs/hour is anticipated. Assuming an efficiency of 30%, the anticipated energy required to melt and hold this amount of metal is approximately 9 MMBtu/hr (1667 Btu/lb). Ingots would be charged from the left bay door and light gauge from the right charge well. Tapping would likely be intermediate, perhaps once each shift.

One possible concept using the same general arrangement, the furnace in figure 1 converts into the furnace of figure 2 where tube heaters are strategically placed about the main hearth. Anticipating an overall efficiency of 60% for the converted melter, the energy required would reduce to 4.54 MMBtu/hr (841 Btu/lb) to maintain the same 5400 lb/hr. Assume that his energy may be distributed among 12 natural gas-fired tubes, 6 inches in diameter and 36 heated inches of length, each releasing of 380,000 Btu/hr. Table 1 summarizes some of the critical parameters for the conceptualized conversion. Each tube should be immersed completely in the bath once molten. In the melting state, the radiant energy will be in closer proximity to the solid charge and provide better heat transfer based both on distance and the improved radiative properties of the ceramic tube in comparison to traditional alumino-silicate refractory furnace walls and various types of flames. Insertion of the tubes in direct contact with the molten aluminum changes the energy transfer mode from radiation-convection to conduction-convection. There is more surface area for the tubes to transfer energy than the walls of typical reverbratory. Getting the tubes down into the melt and shifting the heat transfer from convective to conductive is anticipated to allow the melter to run cooler.

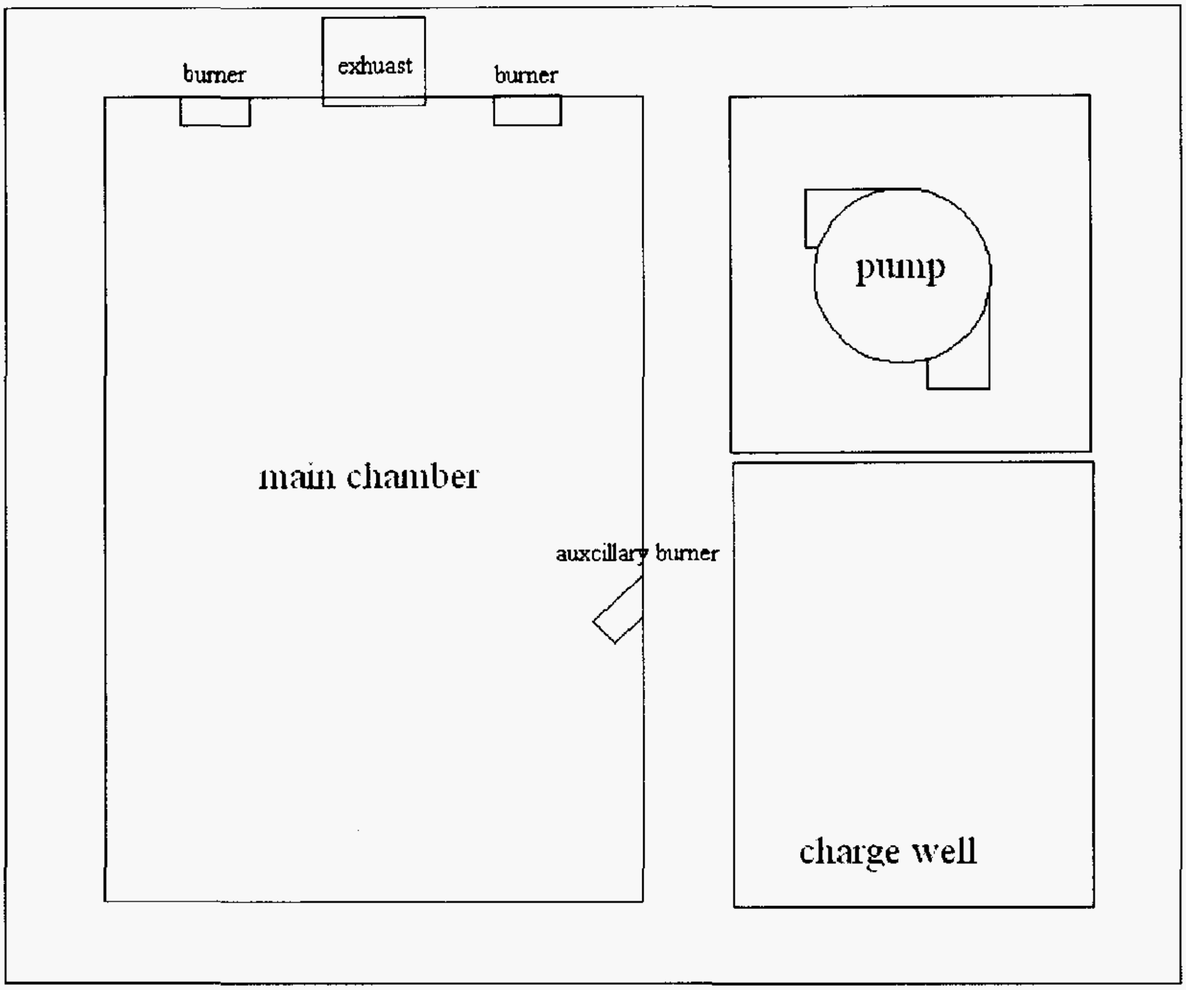

Figure 1: Generic Sketch of a Side-well Aluminum Re-melt Furnace. Main chamber dimensions are 6' l x 9' w x 3' d.

Also during the start-up period on solid aluminum, the exhaust gas from each tube may be directed into the main hearth to assist in the melting of heavy, high surface area solids. Or the exhaust from the tubes might be used to pre-heat metallic charge material in a separate chamber.

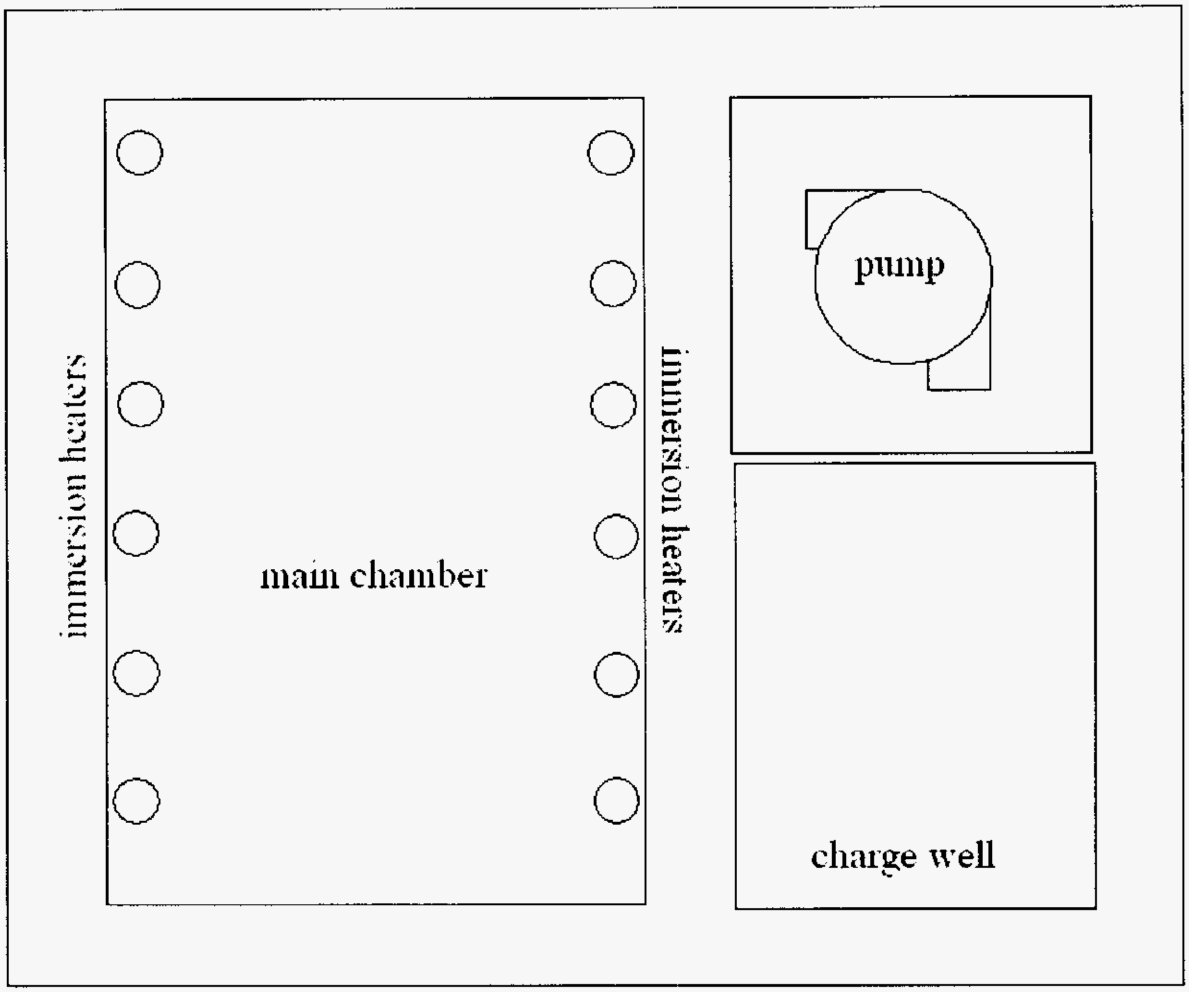

Figure 2: Concept of possible conversion of the generic sidewell aluminum melter in figure 1 to an immersed tube melter. All dimensions remain the same as in figure 1.

After the solids had slumped, the exhaust of the tubes could by-pass the furnace chamber. Any available heat from the tube burner effluent would more easily be recoverable due to the "clean" nature of the products of combustion because they had not contacted the contaminants from aluminum burning, off-gas, and fluxing conditions. The heat collected may be used to heat water or generate electrical power. The cleanness of the tube burner exhaust would better promote the use of supplemental heat collection equipment because the fouling normally associated with such systems could be avoided. Another advantage of an immersed melter approach is that the depth of the aluminum bath is limited only by the length of the heating element. Often the head area is two to three time the bath depth in reverberatory furnaces. Some of this is to accommodate charging, but it is also by design to allow the walls and roof of the reverb to provide more radiative surface area to heat the aluminum charge. This may allow aluminum recyclers the potential to expand capacity without expanding floor area. Existing furnace could be relined with deeper hearths and less head space (plenum). Increased surface area might be achieve with using higher numbers of small diameter heating elements or by increasing the diameter of some or all of the immersed tubes. Many possibilities and arrangements exist. This technology is anticipated to be flexible enough to prove useful to small and large traditional users of reverberatory technology alike.

Table 1: Some of the critical parameters for the conceptualized immersion melting furnace

Parameter	Units	Value
Furnace Capacity	Lbs	36,000
Main Chamber Volume (6ft X 9ft X 3ft)	Ft^3	162
Main Chamber Area	Ft^2	54
Targeted Melt Rate	Lbs/hr	5400
Energy needed to Melt (theoretical from RT to 1400 °F)	Btu/hr	2,700,000
Number of tubes (6" OD X 36" long)		12
Thermal Efficiency of Tube Heaters	%	70
Efficiency of Melter/Holder with Tube Heaters	%	85
Overall Efficiency of Melter/Holder	%	60 (841 lb/hr)
Gross Energy per Immersion Tube	Btu/hr	4,540,000
Gross Energy Input per Immersion Tube	Btu/hr	380,000
Cross-Sectional Area of Single Tube (6" OD X 36" long)	Ft^2	0.2
Volume of Single Tube (6" OD X 36" long)	Ft^3	0.59
Surface Area of Single Tube (6" OD X 36" long)	in^2	679
Heat Flux (thermal efficiency = 70%)	Btu/hr-in^2	391
Percent of Main Chamber Area Occupied by Tubes	%	4.4
Percent of Main Chamber Volume Occupied by Tubes	%	4.3

4.4 Summary

Reverberatory furnaces are inherently inefficient. Even reverberatories using advanced burners, recirculation, and heat recovery technology have proved to be at best 45% efficient in melting. In order to achieve more efficient aluminum remelt operations, immersion tube burners have been investigated by researchers in the U.S., Japan, and Europe. Researchers in Japan and Europe have demonstrated natural gas-fired, immersion tube melter technology with claimed melt efficiencies greater that 60%. Babcock and Wilcox of the U.S. in a GRI sponsored program did prove the technical feasibility of a 10,000-pound immersion melter, but problems with their feed system and improperly sized burners and tubes hurt overall melt efficiency. Even though the problems were addressed and a commercial scale 100,000-pound unit was design, apparently construction was not pursued. Most recently, Apogee Technology, Incorporated has reported success with and electric immersed elements in an ITP (U.S. D.O.E.) sponsored program reporting ITM melting efficiencies up to 97%.

Natural-gas immersion technology will be more generally accepted by traditional users of gas-fired reverberatory furnaces as opposed to electric. Electric energy is typically more expensive than natural gas. Users of natural gas are unlikely to be comfortable making the capital investment to switch their natural gas infrastructure over to an electrical infrastructure. Considering electric energy from its generation to use, electric energy from fossil and nuclear sources is only approximately 40% efficient. Natural gas-fired ceramic tube can demonstrate thermal efficiencies of 70% and higher. If the heat transfer strategies are appropriately managed, melt efficiencies for aluminum remelting should closely compare to the thermal efficiencies of the natural gas-fire tubes.

5. Subject Inventions

No inventions have been filed.

6. Commercialization Possibilities

The project has excellent commercial potential but the fund was provided only enough for the evaluation of current technologies. The research and the development part of the project was cancelled by DOE due to funding cuts.

7. Plan for Future Collaboration

The team is still expecting funding from the federal agency to complete the research and development of the proposed project.

8. Conclusions

Advances in natural gas burners design for ceramic tube burners, advances in thermally conductive ceramic tubes, the push to recycle more aluminum and the move away from primary aluminum production in the U.S., and escalating energy prices create a good environment to reinvigorate investigations into converting natural gas-fired, reverberatory aluminum remelt furnaces into highly efficient immersion tube melters operating much in the same way they operate now. This technology is anticipated to serve the small and large secondary aluminum processor alike.

9. References

[1] Aluminum Industry Technology Roadmap, The Aluminum Association Incorporated, Washington, D.C., 2003

[2] Fiscal Year 2004 Annual Report, Aluminum Industry of the Future, Industrial Technologies Program, Energy Efficient and Renewable Energy, U.S. Department of Energy (Washington, D.C.), February 2005

[3] S. K. Das et al., "Energy Implications of the Changing World of Aluminum Metal Supply", *JOM*, August 2004, Vol. 56, No. 8, pp. 14 – 17

[4] E. L. Rauch et al., "Improving Energy Efficiency and Productivity of a Modern Melter Installation," Aluminum Industry Energy Conservation Workshop XI – Energy and the Environment - Papers, Jacksonville, FL, November 1 – 2, 1990, The Aluminum Association Incorporated (Washington, DC), pp. 455 – 468

[5] E. M. Ramsey, "PLC Control of Air/Fuel Ratio and NOx," Aluminum Industry Energy Conservation Workshop XI – Energy and the Environment - Papers, Jacksonville, FL, November 1 – 2, 1990, The Aluminum Association Incorporated (Washington, DC), pp. 469 – 488

[6] Y. Kimura and K. Taniwaki, "Development of Immersion Type Aluminum Melting Furnace," Proceedings of the 1989 International Gas Research Conference, Tokyo, Japan, pp. 1471 – 1480

[7] Gas-Fired Immersed Ceramic Tube Aluminum Melter. Phase 2. Final Report (December 1988), Babcock and Wilcox, GRI Contract No. 5083-235-0911, 1989

[8] Aluminum Project Fact Sheet, Isothermal Melting Process (ITM), Industrial Technologies Program, Energy Efficiency and Renewable Energy, U.S. Department of Energy (Washington, D.C.), March 2004

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