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A comparison of Air-fuel and Low-temperature Oxyfuel Burners for Aluminium Heating and Melting

Jørgen Furu[1], Trond H. Bergstrøm[2] and Knut Marthinsen[1]
[1]Department of Materials Science, Norwegian University of Science and Technology (NTNU), Alfred Getzv. 2, Trondheim, 7034, Norway
[2]SINTEF Materials and Chemistry, Sem Sælands Vei 1, Trondheim, 7034, Norway

The demand for higher melting rates and more efficient melting in aluminium furnaces has increased as energy costs surge. Today aluminium is typically melted using gas fueled burners. Insight into how different burner systems and furnace conditions impact the heat transfer into the aluminium metal can improve furnace control and operation. In the present work heating of aluminium samples equipped with thermocouples was done in a pilot scale furnace to compare the heat transfer using a conventional air-fuel burner and a recently developed Low-temperature Oxyfuel burner at different furnace temperatures. Also the effect of the surface roughness of the samples was investigated. The experimental results showed that there was a distinct increase in heat transfer for the samples in the Low-temperature Oxyfuel case under the same furnace conditions and at a lower energy input. The results also showed that the surface roughness influence the heat transfer significantly.

Keywords: *Aluminium, Melting, Burners, Oxy-fuel, Efficiency.*

1. Introduction

There are several established heating technologies for remelting of aluminium. Gas fired burners are usually preferred in reverberatory furnaces because of high productivity and low maintenance costs. Oxy-fuel burner systems have been established as a fuel efficient alternative to regular cold air-fuel, but have been plagued with issues as wear on furnace lining and dross generation because of hot spots from high flame temperatures. Significant improvements have been made since the first burners were introduced. A Low-temperature Oxyfuel (LTOF) burner has recently been developed, lowering the maximum flame temperature and creating a spread out flame with a more uniform temperature by diluting the flame with furnace gases. The details and applications of this burner technology is discussed more in detail by Gripenberg et al. [1], and a comparison of different types of oxy-fuel burners have been done by Krishnamurthy et al.[2].

In this paper we have investigated some of the differences between LTOF and conventional cold air-fuel technology, to see how this influence the energy consumption and heating rate in aluminium applications. Experimental results are presented from heating of aluminium samples at different furnace temperature for the two technologies.

The influence of the surface emissivity of the aluminium for heat transfer is also investigated, by heating samples of different surface roughness under the same furnace conditions. Factors influencing surface emissivity of aluminium have been studied amongst others by [3-5].

2. Experimental Setup

The experiments were carried out in a cylindrical pilot scale furnace Fig. 1 with inner dimensions 4.5 m in length and 1.4 m in diameter at Linde Gas Division in Lidingö, Sweden. The furnace is equipped with 20 thermocouples in the furnace wall lining and in the flue gas system to measure the temperature. Gas composition is continuously monitored in the flue gas. Moreover all other relevant parameters for the furnace operation were logged by the furnace control system. In addition instruments measuring radiation heat flux, total heat flux, gas temperature and gas composition were used in various positions in the furnace.

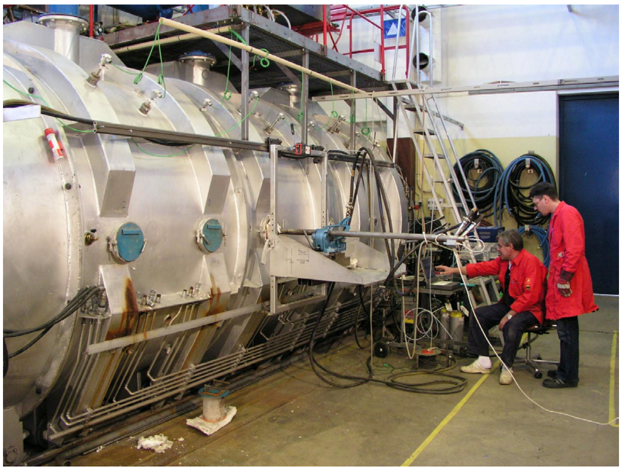


Fig. 1: Pilot scale furnace at Linde Gas, Lidingö, Sweden.

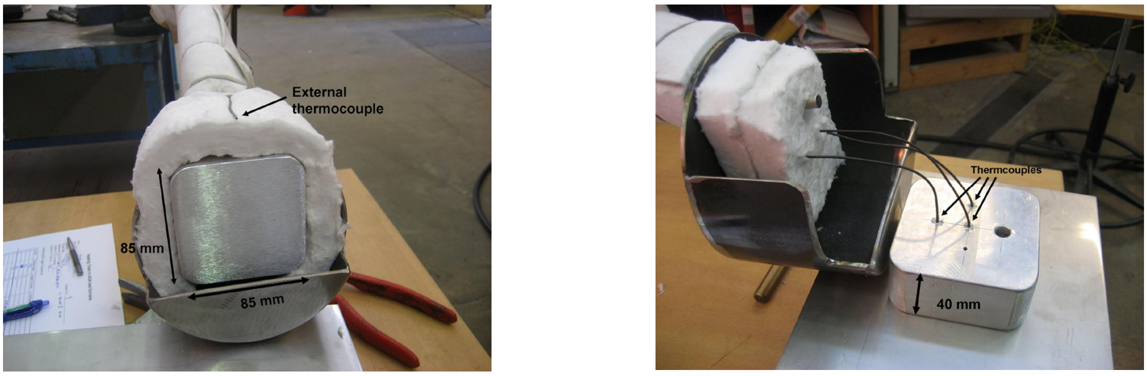
The furnace was run at two levels for both cold air-fuel and LTOF. To control the furnace temperature, the furnace was equipped with water cooled pipes in the bottom of the furnace. The inlet and outlet temperature and the flow in the pipes were continuously logged. The power input, cooling and furnace values for the different cases can be seen in Table 1.

Table 1: Overview of the burner cases considered. The furnace temperature is defined as the average of the 16 thermocouples throughout the wall of the furnace. The fuel used was a 95% propane, 5% butane mixture with a heat value of 94 MJ/Nm^3.

Burner Case	Burner Type	Burner Power (kW)	Cooling (kW)	Temperature (ºC)
Case 1	Air-fuel	311	23	1131
Case 2	Air-fuel	308	64	1016
Case 3	LTOF	257	66	1142
Case 4	LTOF	257	133	1008

Aluminium samples with front surface dimensions 85 mm x 85 mm and thickness 40 mm were mounted on a specially designed ladle construction (Fig. 2) enabling the samples to be inserted into the furnace through one of the hatches on the sides of the furnace and removed after the desired time. Every sample was equipped with 3 thermocouples type K at different distances from the front surface, Fig. 2(b). The samples were insulated on the sides and on the back to ensure heat flux only through the front of the sample. The temperature gradient in the samples was small.

The surfaces of the samples were prepared in a cutting machine and given a specific surface structure and roughness. For the four different burner cases, 4 aluminium samples with similar surface roughness were used. In addition 2 samples with a smoother surface were prepared to see the effect of different surfaces on the heat transfer.



(a) (b)

Fig. 2: One of the samples used for the heating experiments. Front side heating area of aluminium sample (a) and thermocouple placements in aluminium sample (b).

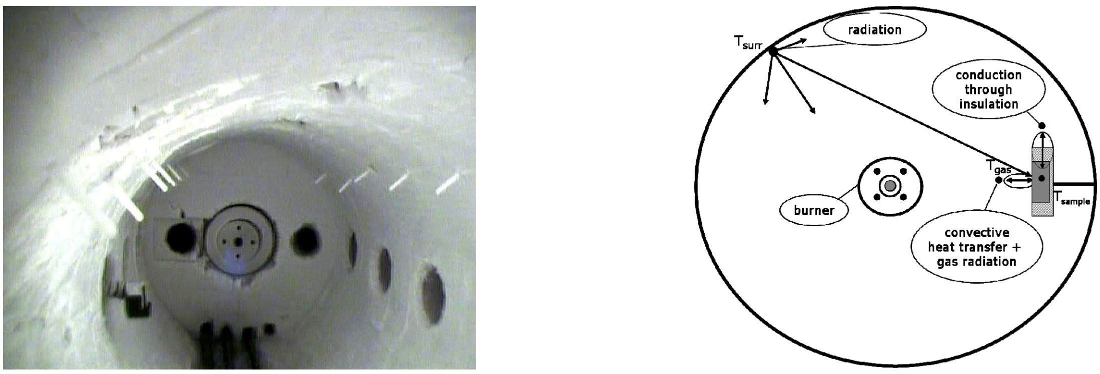
The surface roughness of the samples was measured using a Mitutoyo SJ-201[1] and the results can be seen in Table 2.

Table 2: Surface roughness measurements of the aluminium samples. 10-12 measurements were done on each sample where every measurement consisted of 5 sampling lengths of 2.5 mm in series.

Sample	Burner Case	Type	Mass	Roughness Ra (μm)
Sample 1	Case 1	Al99.9%	744	5.4
Sample 2	Case 2	Al99.9%	744	5.7
Sample 3	Case 3	Al99.9%	744	5.4
Sample 4	Case 4	Al99.9%	777	5.8
Sample 5	Case 4	Al99.9%	738	0.4
Sample 6	Case 4	Al99.9%	740	0.7

3. Results

The aluminium samples were placed at about 1875 mm downstream from the burner and 500 mm from the furnace center, see Fig. 3(a), during stable operation of the furnace and heated from room temperature up to 600ºC.



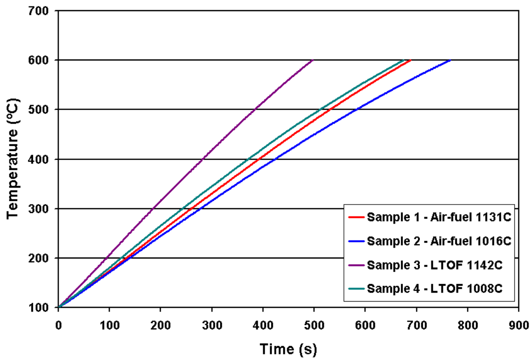
(a) (b)

Fig. 3: Camera inside furnace showing heating of aluminium sample for Case 4 (a). Heat transfer mechanisms for aluminium sample inside furnace (b).

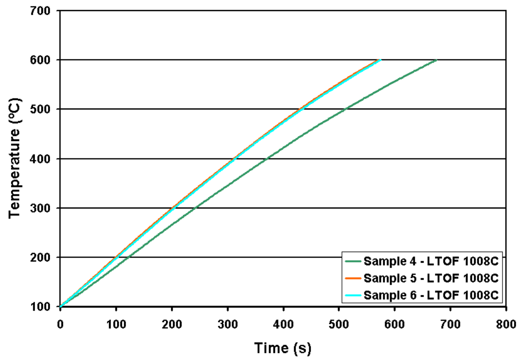
[1] www.mitutoyo.com

To eliminate differences in the start up phase, results are compared in the temperature range 100ºC to 600ºC.

The results for the heating trials in Fig. 4(a) show a distinct difference between the burners at the same furnace temperature. The LTOF burner heats the aluminium samples faster than the air-fuel burner at both levels. Fig. 4(b) shows the difference between samples run under the same furnace condition.



(a)



(b)

Fig. 4: Heating curves for aluminium samples. Temperature for each sample is the average of 3 thermocouples inside sample. Same surface roughness (Ra ~5.5 µm) under different furnace conditions (a), and surface roughness (Ra) 5.8 µm, 0.4 µm and 0.7 µm for samples 4, 5 and 6 respectively under furnace Case 4 (b).

From Table 3 we see that the average heat flux is 39% higher in Case 3 compared to Case 1 and 18% higher in Case 4 compared to Case 2. It should also be noted that this is with the air-fuel cases running at a higher power input and with less cooling in the furnace. Run under the same power input and cooling, the differences would be even higher.

Table 3: Heating trial results for the samples. The wall temperature around the sample is the average of 6 thermocouples in the furnace lining in the proximity to the sample. The gas temperature was measured in the position of the sample using a suction pyrometer.

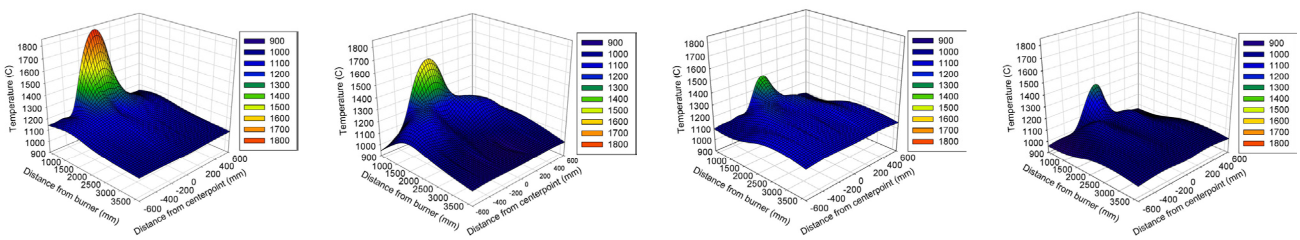
Sample	Case	Burner Type	Wall Temp (around sample)	Gas Temp	Heating time 100-600ºC (s)	Average heat flux (kW/m2)
1	Case 1	Air-fuel	1151	1163	688	79
2	Case 2	Air-fuel	1034	1134	766	71
3	Case 3	LTOF	1152	1191	497	109
4	Case 4	LTOF	1018	1051	675	84
5	Case 4	LTOF	1021	1051	571	94
6	Case 4	LTOF	1020	1051	575	94

The surface of the aluminium sample has an impact on the heat transfer into the metal as we can see from the results for samples 4-6 in Table 3. From literature ([4, 5]) one would expect the emissivity of the surface to decrease for a smoother surface. This was not the case in these experiments where the smoother surface actually gave an increase in the average heat flux of 12%. This suggests that other properties of the surface also influenced the heat transfer which so far has not been identified. Sample 6 was run as control sample for Sample 5 at a different time to confirm the consistency in the trials and gave a near overlapping heating curve as we can see from Fig. 4(b).

Heat is transferred to the aluminium sample mainly through radiation from the furnace walls and radiation and convection from the hot combustion gases as schematically indicated in Fig. 3(b). Heat conduction through the insulation covering the sample sides and back is assumed to play a negligible role.

Radiation heat transfer from the furnace walls to the aluminium sample can under certain simplifying assumptions be expressed as $Q_{rad} = A\varepsilon\sigma(T_w^4 - T_s^4)$, where A is the surface area of the sample, ε is the emissivity of the sample, T_W is the furnace wall temperature and T_s is the temperature of the sample surface. When comparing the burner cases with the approximate same furnace temperature, i.e. Case 1 with Case 3 and Case 2 with Case 4, the radiation from the walls can be assumed to be the same.

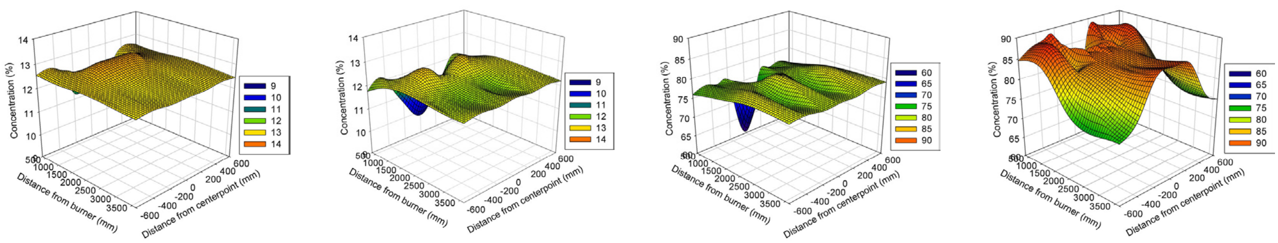
Convection heat transfer from the furnace gases to the aluminium sample can be expressed as $Q_{conv} = Ah(T_g - T_s)$, where h is the convection heat transfer coefficient and T_g is the gas temperature. h is a function of the flow conditions and is influenced by the flow velocity. There could hence be a difference in the convection heat transfer coefficient between the air-fuel and oxy-fuel cases. The differences in gas temperature, Fig. 5, between the burner cases will also result in a small difference in the convection heat transfer.



(a) (b) (c) (d)

Fig. 5: Gas temperatures in horizontal mid plane of furnace for Case 1-4 in (a)-(d) respectively. 24 measurement points taken through hatches in the furnace with 1-2 minute averages in each point from 375 mm to 3620 mm downstream from the burner. Temperatures over 1350ºC were not measured because of limitations of the measuring device but instead extrapolated and may not be the true temperature. Adiabatic flame temperature for propane combusted with air is 1990ºC and propane with pure O_2 2822ºC [6].

The main difference in heat transfer between the LTOF and air-fuel cases is assumed to be due to differences in gas radiation. Gas radiation depends on the composition of the gases and the gas temperature along with the sample emissivity and temperature. Only gases with asymmetric molecules, such as H_2O and CO_2, participate in radiation in a gas mixture. Diatomic molecules such as N_2 and O_2 are more or less transparent to radiation except for under extremely high temperatures [7]. The measured concentration of CO_2 in the furnace mid plane for the four burner cases are shown in Fig. 6. The measurements clearly show the difference between the gas composition in the LTOF and air-fuel cases. The H_2O-vapor concentration should be equally higher in the LTOF case compared to the air-fuel case as they are both formed as a product of the combustion. The high concentration of N_2 in the air-fuel cases lowers the gas emissivity.



(a) (b) (c) (d)

Fig. 6: CO_2 concentration in horizontal mid plane of furnace on a dry basis for Case 1-4 in (a)-(d) respectively. Based on 24 measurement points in the furnace using 1-2 minute averages in each point.

4. Conclusions and future work

The experiments performed clearly demonstrated some of the differences between Low-temperature Oxyfuel (LTOF) and air-fuel technology in an aluminium melting application. There was a definite higher heating rate for aluminium samples when comparing the two LTOF cases with the two air-fuel cases. This is believed to be because of differences in gas radiation.

The impact of surface properties on the heat transfer to the aluminium samples was also investigated and the results showed a significant difference between different surface structures run under the same furnace conditions. The reason for the difference in heat transfer between the surfaces of the samples is not known and will be investigated in further work.

Further work will also include CFD modeling of the experiments which hopefully will enable quantification of the individual impact of gas radiation, wall radiation and convection heat using air-fuel and LTOF burners respectively.

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