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EXPERIMENTAL INVESTIGATIONS OF FORCED CONVECTIVE HEAT TRANSFER DURING OSCILLATING COMBUSTION IN A CRUCIBLE FURNACE

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Abstract- This study describes the thermo physical characteristics of conventional (steady state) and oscillating combustion in a medium size crucible furnace. The results were investigated through systematic experimentation in crucible furnace with two test parameters used are steady state (conventional)and oscillating combustion with different loads, frequencies, amplitudes and air fuel ratios. Heat transfer characteristics like temperature, heat transfer, heat transfer coefficientalong with Nusselt number,and Reynolds number were analyzed for aluminum atvarious conditions of turbulent flow.The heat transfer coefficient was examined based on heat grasped by the load from hot gases, the Nusselt number was correlated with empirical correlations involving Reynolds number and Prandtle number with load parameter.

Key words- oscillating combustion, conventional combustion, heat transfer coefficient, crucible furnace.

I. Introduction

In view of the economy and environmental impacts of the energy utilization, most of the heat transfer industries such as steel mills, glass plants and forging shops, foundry process and furnaces are focusing on energy efficient strategies and implementing new technologies [1]

Increased heat supply transmits more heat transfer and hot surfaces are predicted to lose heat faster when oriented more in horizontal state however, heat transfer rates are found to be sensitive to a critical value after which the variable rate drops [2]. The heat transfer coefficient is evaluated based on the heat carried away by the coolant and an average wall to mean fluid temperature difference. The Nusselt number is correlated through empirical correlations involving Reynolds number and Prandtl number with length parameter, the hydraulic diameter [3]. The heat transfer coefficient for different particle concentration and temperature were analyzed using forced convection heat transfer using nanofluids [4]. Results, for different Reynolds numbers and geometrical aspect ratios, are given in terms of solid and fluid temperatures, at heated walls and inside the channel at several heights, velocity profile along the channel, local and average Nusselt numbers [5]. A correlation for the average Nusselt number as a function of flow Reynolds number is provided [6].

II. Experimental Setup And Procedure

Experimental investigations have conducted in a medium-sized crucible furnace at 5kg, 10kg and 15kg of loads. Test set-Up consisting of CNG cylinder with pressure regulator, butterfly valve, blower with DC motor, manometer and temperature indicator with thermocouples. The CNG cylinder comprised a gas

Fig.1 - Experimental Setup

with 200 bar this is regulated to 0.7 bar to 7 bar by the regulator. Butterfly valve can be operating at 3 Hz 5 Hz 7 Hz by adjusting the DC motor speeds with the help of PWM (pulse width module). With the help of Manometer readings, can calculate the velocity of air, blower running with constant speed. The air-fuel ratios which are 16:1, 17:1 and 18:1 measured by varying the fuel velocity.

III. Characterization Of Oscillations

The implementation of oscillating combustion that needs a butterfly valve installed on the fuel line ahead of the burner. This butterfly valve must be able to rapidly open and close at the different frequencies, amplitudes, and duty cycles needed to optimize heat transfer, increase furnace efficiency, FUEL savings and NOx reduction. A pulse width module (PWM) controller must also be installed to DC motor all the valves on a furnace to keep the valves in proper synchronization and phasing. When oscillations occur in the fuel flow, the amplitude is adequate to produce significant variant in axial Velocity in the nozzle. These axial velocities can deviate during the oscillating combustion technology. The swirl vanes on the fuel gun type of the burner would impart a variation in tangential velocity because of this the flow around the nozzle's ring shape is having high and low regions of velocity convected along the Axial main flow of the fuel. The

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magnitude of heat release depends upon the variations in the tangential velocity of the fuel due to the oscillations created by the oscillating valve and the changes in the tangential velocity of combustion air

IV. Data Reduction

THE velocity is calculated from the flow velocity of air and the fuel. The thermo physical properties involved in these expressions are normally evaluated at the film temperature, T_f, defined as

$$T_f = \frac{T_s + T_\infty}{2} \quad (1)$$

The thermo physical properties of the air such as density (ρ), kinematic viscosity (ν), Prandtl number (P_r) and thermal conductivity (k) can be collected from heat and mass transfer data book by C.P. Kothandaraman [10]

V. Flow Across Cylinder

The flow characteristics around a cylinder depends on the magnitude of Reynolds number, which is defined as

$$R_e = \frac{u_\infty D}{\nu} \quad (2)$$

Where u_∞ = fuel velocity.

D = outer diameter of the crucible.

ν Kinematic viscosity of the fluid

The value of average heat transfer coefficient h_m is to be calculated from the mean value of the Nusselt number, which is defined as

$$Nu_m = \frac{h_m D}{k} \quad (3)$$

Where the thermal conductivity of the fluid (W/mK). The mean Nusselt number may be calculated from the correlation given by below based on the flow condition.

Whitaker Correlation

For flow of gases or liquids across a single cylinder, the mean Nusselt number is given by

$$Nu_m = \left(0.4\, R_e^{0.5} + 0.06\, R_e^{0.67}\right) P_r^{0.4} \left(\frac{\mu_\infty}{\mu_w}\right)^{0.25} \quad (4)$$

For $40<R_e<10^5$ and $0.67<P_r<300$

The physical properties are evaluated at T_∞ except μ_w which is evaluated at T_w

Churchill and Bernstein Correlation

For flow of air, water and liquid sodium with constant wall temperature and constant heat flux conditions, the mean Nusselt number is given by

$$Nu_m = 0.3 + \frac{0.62 R_e^{0.5} P_r^{0.33}}{\left[1+\left(\frac{0.4}{P_r}\right)^{0.67}\right]^{0.25}} \left[1 + \left(\frac{R_e}{282000}\right)^{0.625}\right]^{0.8} \quad (5)$$

For $10^2<R_e<10^7$ and $R_e P_r>0.2$

$$Nu_m = 0.3 + \frac{0.62 R_e^{0.5} P_r^{0.33}}{\left[1+\left(\frac{0.4}{P_r}\right)^{0.67}\right]^{0.25}} \left[\left[1 + \left(\frac{R_e}{282000}\right)^{0.5}\right]\right] \quad (6)$$

For $20000<R_e<400000$ and $P_e<0.2$

The properties evaluated at the film temperature, T_f, defined as

$$T_f = \frac{T_s + T_\infty}{2} \quad (7)$$

Nakai and Okazaki Correlation

$$Nu_m = \left(0.8237 - \ln P_e^{0.5}\right)^{-1} \quad (8)$$

For $P_e<0.2$

The properties evaluated at the film temperature, T_f

Fand Correlation

$$Nu_m = \left(0.35 + 0.56 R_e^{0.52}\right) P_r^{0.33} \quad (9)$$

For $10^{-1}<R_e<10^5$ and $P_e<0.2$

The properties evaluated at the film temperature, T_f

Eckert and Drake Correlation

$$Nu_m = \left(0.43 + 0.50 R_e^{0.5}\right) P_r^{0.38} \left[\frac{P_r}{P_{r_w}}\right]^{0.25} \quad (10)$$

For $1<R_e<1000$

$$Nu_m = 0.25 R_e^{0.6} P_r^{0.38} \left[\frac{P_r}{P_{r_w}}\right]^{0.25} \quad (11)$$

For $10^3<R_e<2\text{x}10^5$

For gases the prandtl number ratio may be dropped and the fluid properties are evaluated atfilm temperature.

For liquids the ratio is retained and fluid properties are evaluated at T_∞ except P_{r_w} which is evaluated at wall temperature T_w

Zhukauskas Correlation

$$Nu_m = C R_e^{m} P_r^{n} \left[\frac{P_r}{P_{r_w}}\right]^{0.25} \quad (12)$$

For $0.7< P_r < 500$ and $1<R_e<10^6$

The properties are evaluated at T_∞ except P_{r_w}, which is evaluated at T_w .The constant n=0.37 for Pr$<$ 10 and n=0.36 for Pr >10. The value of the constant C and m are tabulated.

Hilpert, Knudsen and Katz Correlation

For gases and liquids

$$Nu_m = C\, R_e^{m} P_r^{0.33} \quad (14)$$

The physical properties are evaluated at T_f

Table 1

S.No	Re	C	N

1	0.4 to 4	0.989	0.33
2	4 to 40	0.911	0.385
3	40 to $4x10^3$	0.683	0.466
4	$4x10^3$ to $4x10^4$	0.193	0.618
5	$4x10^4$to $5x10^5$	0.026	0.805

VI. Results And Reflections

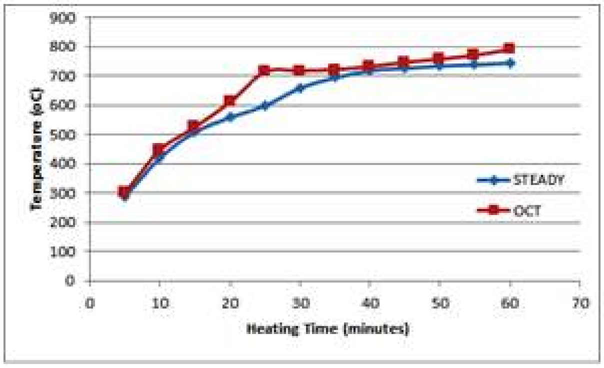

Fig 1.Relation between Heating time and Temperature.

In can be seen in the fig1 the heating time and temperature values are presented,initially the difference between the aluminum load and the flame temperature is high due to it heat exchangeis high along with the time interval.

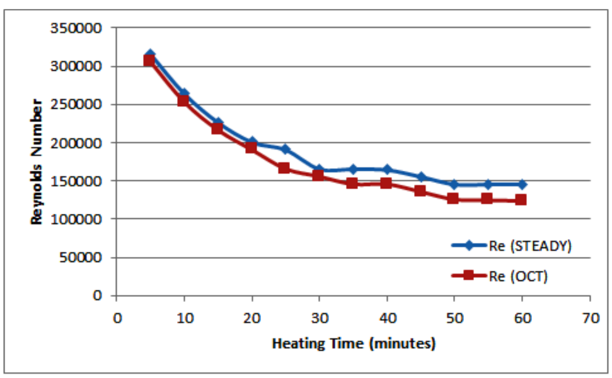

Fig 2. The relation between the heating time and Reynolds number

The Reynolds number is calculated by using $Re = \frac{vd}{\nu}$and it is observing that the Reynolds number is decreasing with time. The temperature values are increasing at regular time intervals, and Reynolds number is inversely proportional to the kinematic viscosity then Reynolds number is decreasing at higher temperature values. Moreover, the Reynolds number values are lower than the steady state condition due to property as mentioned above.

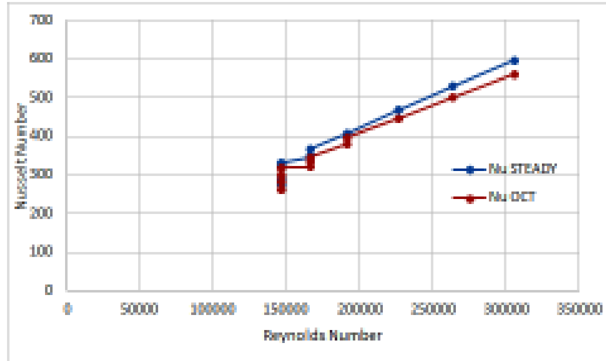

Fig 3.Relation between Reynolds number and Nusselt number

In above figure, the Nusselt number for the fluid and load are shown during the regular time intervals. The Nusselt number calculated by $Nu_m = CR_e{}^m P_r{}^{0.33}$relation. It can be observed that when Reynolds number is inversely proportional to temperature in the gas due to its kinematic viscosity. It can be seen that Reynolds and Nusselt number values are the little bit lower in case of oscillating combustion compared to steady state combustion.

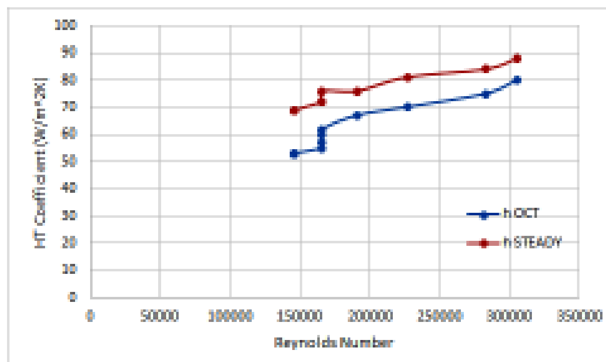

Fig 4.Relation between Reynolds number and heat transfer coefficient

The force convective heat transfer calculated by using $h = \frac{N_u k}{d}$relation. The fig 1 states that the heat transfer coefficient is directly proportional to Reynolds number. Heat transfer coefficient is the little bit lower in the oscillating combustion compare to the steady state combustion. At high-temperature values, the difference is small on Reynolds number and heat transfer coefficient then the graph follows the linear law.

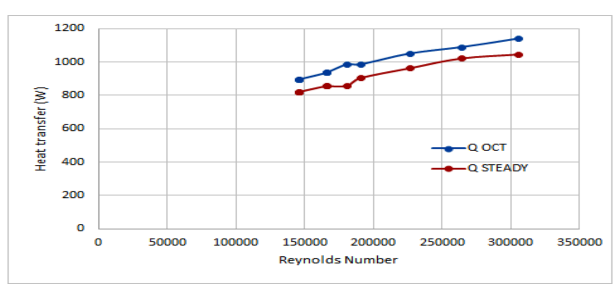

Fig 5. Relation between Reynolds number and Heat Transfer

In the above fig, it can be seen that the heat transfer evaluated by using the $Q = h A (T_1 - T_2)$ the heat transfer is increasing along with the Reynolds number due its direct proportionality. It observed that the heat transfer is higher in case of oscillating combustion technology compared to steady state technology due to its higher temperature difference values in the oscillating combustion technology.

VI. Conclusion.

Experiments were conducted to understand the physics of forced convection by using an oscillating combustion technology in a crucible furnace instead of conventional combustion.

Heat transfer features like Re, Nu, Pr, h and Q calculated from the data collected during experiments i.e. air and fuel velocities and temperature values.

The heat transfer was evaluated from the correlation of heat transfer coefficient and temperature difference for turbulent flow region.

Heat transfer taking place more effectively in presence of oscillating combustion compared to steady state combustion.

It has stated that the heat transfer to the aluminum load was high during an initial phase of time periods than later stage was due to the prevailing thermal gradients. The heat transfer was found higher for oscillating combustion technology than steady state combustion technology at all time intervals.

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