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The breakup of Thermal Boundary Layer over a Cylinder (Crucible) in a Gas Fired Furnace by using Oscillating Combustion Technology

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Abstract- Present work describes the influence of thermal boundary layer on the distribution of heat transfer across a cylinder (crucible) particularly examined. The experimental investigations performed in the specially designed medium size crucible furnace, and the data has recorded in a conventional (steady state) as well as oscillating combustion technology mode. The comparisons have been taking place to verify the significance of oscillations at different frequencies, and amplitudes which are influence the breakup of thermal boundary layer formation during the conventional combustion mode. The thermal boundary layer obstructs the heat transfer from the flame to load (cylinder) due to its thickness. The heat losses can minimise by applying oscillating combustion due to its luminous and fuel rich and fuel lean zones this technology needs an oscillating valve it was designed and developed by author and incorporated in the fuel line and ahead of the burner to create oscillations in a flame. And it has been operated at different frequencies 3 Hz, 5 Hz and 7 Hz also amplitudes 30^0, 60^0 and 90^0.

Keywords: *thermal boundary layer, crucible furnace, oscillating combustion technology, frequencies, amplitudes.*

I. INTRODUCTION

Oscillating combustion technology is innovative and straightforward process employed to study its Influence on thermal boundary layer requires an oscillating valve to be incorporated on the path of fuel flow to create oscillations [1]. An analysis was performed to study the classical problem of thermal boundary and hydrodynamic layers in a uniform stream of fluid over a flat plate [2].Given present formulation, the governing equations reduced to the well-known Blasius similarity equation and the full boundary equation with two parameters the wall flux exponent m and Prandtl number Pr [3].To justify the implications of the oscillations in fuel line reaching the burner which breaks up the thermal boundary layer formed during a steady state combustion mode, tests conducted on the furnace in the non-oscillating mode, an oscillating mode of combustion and comparisons have been made [4].The asymptotic solutions were derived and compared with the numerical solutions of the full boundary-layer equation [5]. So researchers in the field of heat transfer paid tangible attention toward boundary layer problem [6]. To be precise, it required accounting for the thermal boundary layer perturbation due to the radiative flux sent over the surface, which means to know the evolution of the transfer coefficient during the measurement [7].

II. EXPERIMENTAL SETUP

The figure 1 showing the experimental setup which consisting of entire apparatus and main instruments. It has a test section with medium sized crucible furnace.

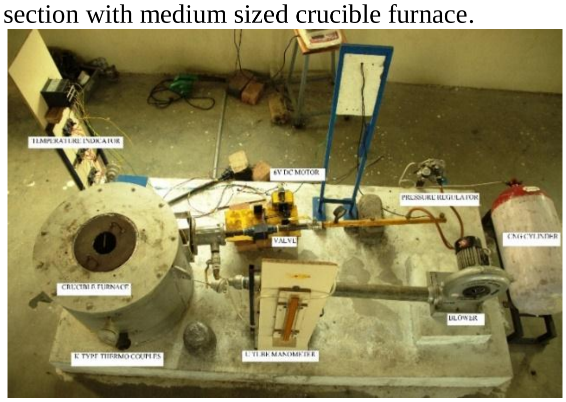

Figure 1. Experimental Setup

Test set-Up consisting of a medium-sized furnace, CNG cylinder with pressure regulator, blower DC motor, butterfly valve, manometer and temperature indicator with k-type thermocouples. The CNG cylinder comprised a gas with 200 bar this is regulated to 0.7 bar to 7 bars by the regulator. Butterfly valve can be operating at 3Hz 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. In this work, the experiments conducted on the Aluminum loads such as 5kg,10kg and 15kgs etc. The furnace divided into three zones such as upper zone middle zone and a lower zone, and the six k-type thermocouples were fixed at different locations to record the temperature of the furnace at different time intervals (periods) as shown in fig. A 10mm holes drilled at these locations for inserting the and holes are sealed to prevent any leakages. The experiments have been performed on different days thus maintaining the initial heating conditions for all days.

III. LITERATURE REVIEW

L. Prandtl first introduced the concept of the boundary layer in 1904, and since this concept has applied to various fluid flow problems. When a viscous fluid flow over a cylinder. The stationary solid boundary layer of fluid which is coming in contact with the surface of the boundary. Adheres to it and condition of no slip occurs (the no-slip condition implies that the velocity of particular fluid at a solid bou6ndary must be same as that of boundary itself). Thus, the layer of fluid which cannot slip away from the boundary surface undergoes retardation. This retarded layer further causes retardation of the adjacent layer of the flame. Thereby growing a small zone near the boundary surface in which the velocity of the fluid increases rapidly from zero at the boundary surface and approaches the velocity of the mainstream.The layer which is adjacent to the boundary is known as the boundary layer. The boundary layer is initiating whenever there is relative motion between the boundary and the fluid.

IV. THERMAL BOUNDARY LAYER OVER A CYLINDERS

Thermal boundary layer developed over cylinders due to the difference in free stream temperature (T_∞) and the cylinder temperature is (T_W). Consider the flow of fluid at unia form temperature (T_∞) over a cylinder of surface temperature (T_W). We define the non dimentional temperature θ(x,y) as

$$\theta = \frac{T - T_\infty}{T_\infty - T_w}$$

Where T is the temperature of the fluid at a location (x,y). Also called the local temperature of the fluid. At the surface of the plate, the fluid temperature is equal to the wall temperature, hence

$$\theta = 0 \text{ at } y = o$$
$$\theta \to 1 \text{ at } y \to \infty$$

One may notice that, at each value of x along the plate, at a particular location of y, the value of θ is equal to 0.99. the locus of such point for the different value of x known as thermal boundary layer and thickness defined as thermal boundary layer thickness δ_t (x). the relative thickness of thermal boundary layer and the velocity layer depend on the value of Prandtl number (P_r) for the fluid

$$\text{for } P_r = 1 \quad \delta_t = \delta$$
$$\text{for } P_{r<<} 1 \quad \delta_t >> \delta$$
$$\text{for } P_r >> 1 \quad \delta_{t <<} \delta$$

On the temperature distribution T (x, y) in the thermal boundary layer is known the heat transfer rate from the flame to the cylinder is determined from

$$q = \frac{\partial T}{\partial y} \quad \text{at } y=0$$

The heat flux is given as

$$q = h(T_\infty - T_W)$$

h denotes local heat transfer coefficient.

V. RESULTS AND REFLECTIONS

Relation Between Heating Time and Temperature Distribution.

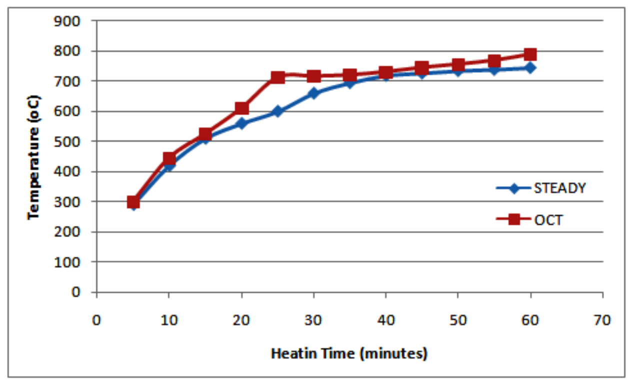

Fig 2. The plot of Heating time and temperature.

It has seen from the Fig 2 that the rise in temperature was significantly more up to 20 minutes of the time interval for both steady state and oscillating combustion mode. But there was a small increment of the rise in temperature for oscillating combustion technology in comparison to steady state combustion technology. It may happen due to a significant amount of heat absorption by the load in a medium size furnace due to the temperature gradient between the load and furnace temperature. After some time interval again, there is the rise in temperature in both oscillating combustion technology in comparison to steady state combustion technology but rise in temperature is significant in oscillating combustion technology.

Impact Mass of Stock on Melting Time At 30^0 Amplitude

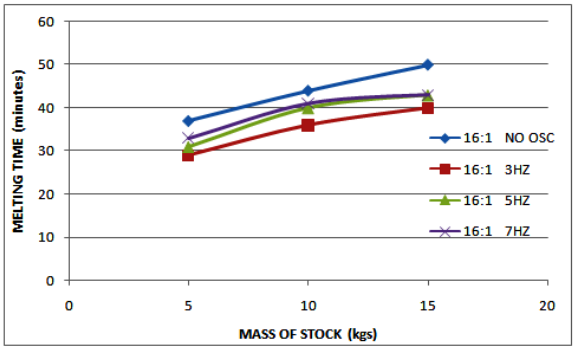

Fig.3. The plot of the mass of stock and melting time at 16:1 AFR and 30^0 amplitudes

The experiments have performed in the steady state and oscillating combustion mode of operation at different amplitudes such as 30^0, 60^0, and 90^0. The data have discussed in this article is at 30^0 amplitudes and different frequencies such as 3hz, 5hz and 7hz. It is seen from the observations has made from figure 3 and which is representing the plot between the aluminium melting time and load (weight of the stock). It is noticed that the melting time concerning the weight if the stock minimum at the 30^0amplitude in the butterfly valve (i.e., oscillating valve). The melting time of the furnace controlled when compared with the initial steady state of the crucible furnace by introducing the oscillating valve. This is achieving due to more luminous fuel lean and fuel-rich zones which are created in the flame because of it; the load heats up faster, and it is also break up the thermal boundary layer. The heat transfer from the flame to the load increases due to oscillating combustion technology and increased turbulence created by the oscillations produced by the valve. The decrease in melting time of the load is the result of the high value of the heat transfer due to the oscillating combustion which is simple retrofit and economic.

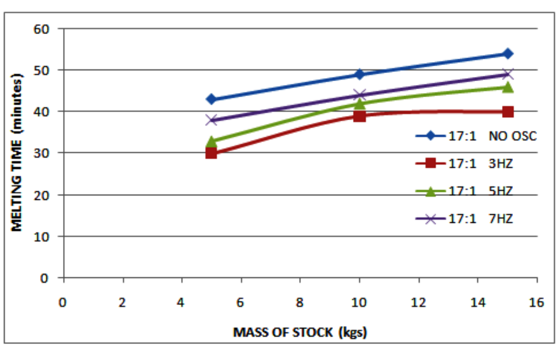

Fig 4. The plot of the mass of stock and melting time at 17:1 AFR and 30^0 amplitudes

As per the observations have made from fig 4 which represents the relation between the mass of the stock and melting. According to natural phenomena, the melting time is directly proportional to the weight of the stock it has noticed that the melting time in all the loads in oscillating combustion technology is shallow when compared with the steady state combustion and it is varying at different frequencies of the oscillations. It has pointed out that melting time concerning weight of the stock is minimum at a rich air-fuel ratio at 16:1 and 5Kg of the load in 30^0 amplitudes.

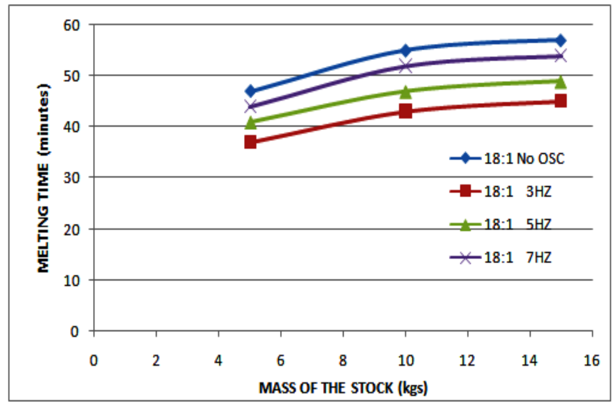

Fig 5 Plot of the mass of stock and melting time at 18:1 AFR and 30^0 amplitudes

It has pointed out that the melting time taken for the various mass of the stock is further reduced due to oscillations which are created by the butterfly valve at lower frequencies. The melting time taken for the different loads further reduced due to oscillations by the oscillating valve at different frequencies and amplitudes. It can happen because of the oscillating mode of operation the butterfly valve can open and close steadily at higher amplitudes and lower frequencies. It is facilitating to increase the frequencies the heat transfer which reduces the heating time. The heating time difference which is shortens by 10 minutes to 20 minutes from steady state combustion mode to oscillating combustion technology as compared to some conditions (cases).

Relation Between Melting Time and Reynolds Number

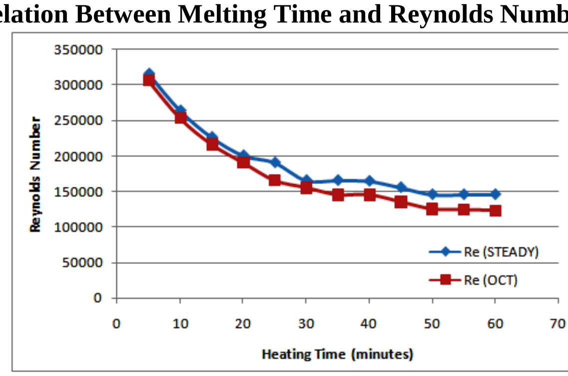

Fig 6. The plot of heating time and Reynolds number

The Reynolds Number evaluated by the following equation $R_e = \frac{u_\infty D}{\nu}$ at the steady state and oscillating combustion stat,e plotted in Fig 6. From the figure 6, it is found in the Reynolds number at the progressive time intervals and the decrement found to be less in oscillating combustion technology compared to steady state combustion technology. Reynolds number decreasing with time and Reynolds number is very low in an oscillating combustion technology compared to steady state combustion technology. This is because Reynolds number is a ratio of inertia force to viscous force. For gases, temperature is directly proportional to the viscous force at regular time intervals. This result in increase in furnace temperature causing the Reynolds number decreasing rapidly up to 20 minutes of the time interval and gradually for the remaining period.

Relation Between Melting Time Nusselt Number

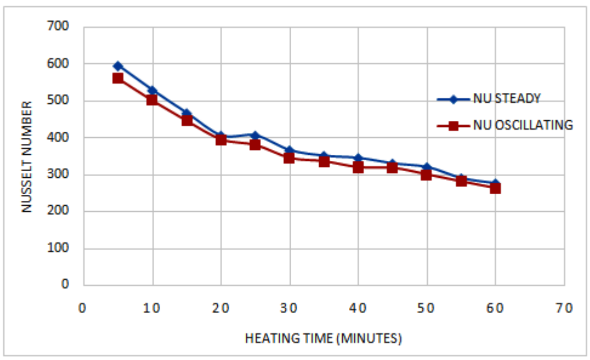

Fig 7. The plot of heating time and Nusselt number

The Nusselt number evaluated by using the equation $N_u = \frac{hd}{k} = C\,(R_e{}^n)\,P_r{}^{0.33}$ at the three different locations. Nusselt number is a function of Reynolds number and Prandtle number and it is,directly proportional to the Reynolds number. Nusselt number decreasing from time to time and found very low in a oscillating combustion technology compared to steady state combustion technology. In Regular time intervals the furnace temperature found increases and the Nusselt number decreasing rapidly upto 20 minutes of time and decreasing graduyally upto 50 minutes of time.

Relation Between Reynolds Number and Nusselt Number

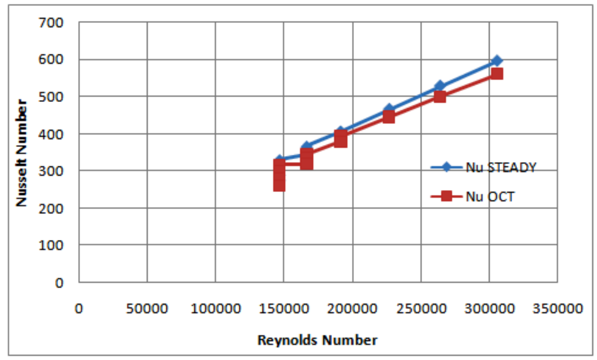

Fig 8 plot between the Reynolds number and Nusselt number

From the relation which mentioned as $N_u = C\,(R_e{}^n)\,P_r{}^{0.33}$ due to direct proportionality between Reynolds nimber and Nusselt number the plots have been made in the above figure which are drawn between steady state combustion and oscillating combustion technology. At higher temperatures the Reynolds and Nusselt numbers are low due to viscosity property of the gases.

Specific Energy Consumption at Different Frequencies And 30^0 Amplitude

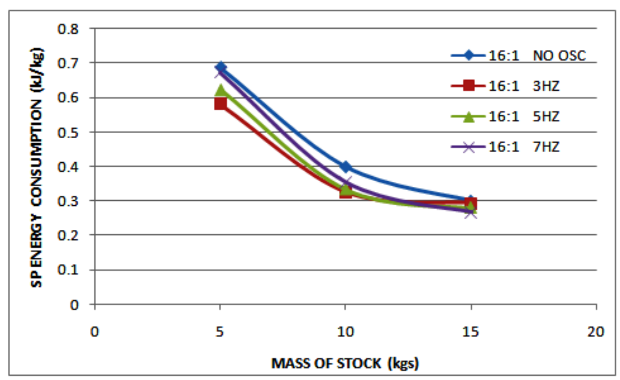

Fig 9. The plot between the mass of stock and specific energy consumption at 16:1 AFR and 30^0 amplitudes

The Specific energy consumption data was evaluated for the steady-state and oscillating combustion state at 30^0 amplitudes and 3 Hz 5 Hz and 7 Hz of frequencies. Specific energy consumption (SEC) defined as the ratio of fuel or Energy consumed to the quantity of metal processed. Effective utilisation of furnace and standby losses will play a vital role in achieving the maximum specific energy consumption. Effective usage has an Effect on specific energy consumption and is an often neglected. If the furnace is at a temperature, then standby losses of the occur whether or not a product is in the furnace.

It is precisely evident that specific energy consumption is low at lower frequencies and increasing along with the frequency of oscillations due to its proportionality. It is indicating that at higher frequencies the combustion slowly leads to the steady state combustion.

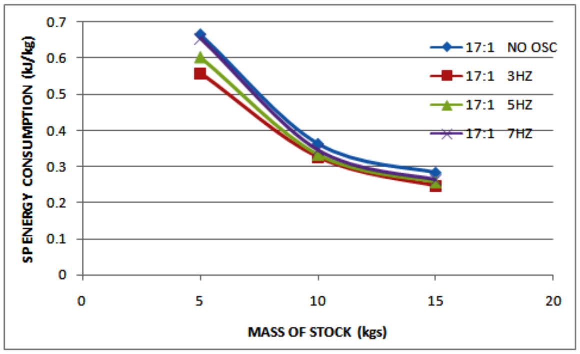

Fig 10. The plot between the mass of stock and specific energy consumption at 17:1 AFR and 30^0 amplitudes.

It can notice that there is minimum in specific energy consumption at 18:1 AFR at 30̊ amplitude and a3Hz frequency and 15 Kgs or load.

It precisely is seen that the specific energy consumption is more at 7Hz and 5Kgs of the load. It is indicating that the fuel consumption at above-cited conditions is more The Fig 1,2,3drawn at 30̊ amplified and at 16:1, 18:1 Air fuel ratio it has been observed that at rich air-fuel ratios the specific energy consumption is more compared to the lean air-fuel ratios. In a steady state as well as oscillating combustion state.

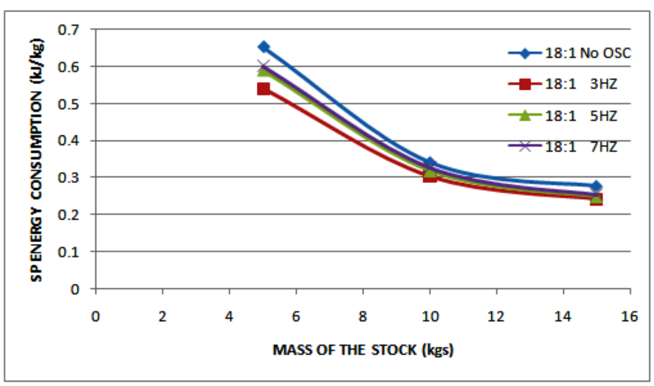

Fig 11. The plot between the mass of stock and specific energy consumption at 18:1 AFR and 30^0 amplitudes.

The Fig 9, 10, 11 were drawn between the effect of the mass of stock and specific energy consumption. It has noticed from the figures the specific energy consumption value to be higher for the entire air-fuel ratio and at the mass of stock in steady state combustion with compared to oscillating combustion technology.

Relation Between Reynolds Number and Heat Transfer

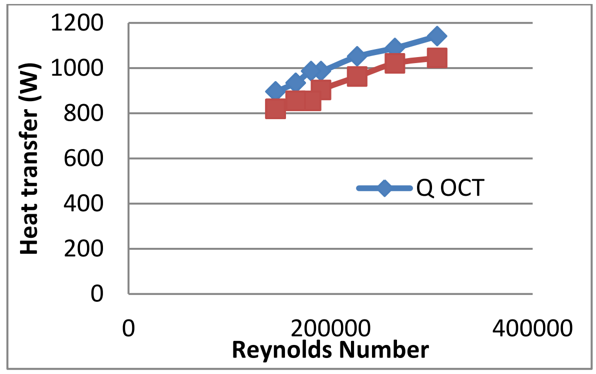

Fig 12. The plot of Reynolds number and Heat Transfer

The heat transfer calculations have been done using the relation $Q = hA(T_1 - T_2)$ and it is shown in fig 12. By …noticing the above relations, the, heat transfer is directly proportional to the Reynolds Number due to it the heat transfer is increasing along with the Reynolds number up to certain time. The comparisons have done between the oscillating combustion and steady state combustion technology the above figure is depicting that the oscillating combustion technology is more reliable, cheap, environmental friendly and most suitable for all the heat transfer industrial purposes.

VI. CONCLUSION

In this article, the author designed and developed a model for oscillating combustion technology in a crucible furnace. The temperature distribution, Reynolds number, Nusselt number, heat transfer coefficient, specific energy consumption, was examined within standard boundary layer theory. However, there is a most significant declaration in oscillating combustion technology shown by our calculations; there would be a remarkable change in the thermal characteristics such as deterioration of melting time, enhanced heat transfer coefficient, heat transfer and efficiency of the furnace in oscillating combustion technology as compared with the steady state combustion technology. There is a massive increase in thermal efficiency of the furnace at stoichiometric air-fuel ratios i:e at 17:1 and at higher loads. There would be a exceptional fuel saving in the oscillating combustion technology as compared with steady state combustion technology due to its fuel rich and fuel lean zones which are created by the butterfly valve in the oscillating combustion technology. There are considerable changes in the specific energy consumption in OCT as compared with the steady state combustion technology. By all the above-indicated characteristics we can break up the thermal boundary layer which is surrounded by the crucible which was caused to obstruct the heat transfer from the flame q to the load. It can be possible only by oscillating combustion technology due to its fuel rich and fuel lean zones which are created by butterfly valve (oscillating valve) and is designed, fabricated and installed in the gas line ahead of the burner.

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