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Heat Transfer Characteristics of Impinging of Flame Jet on Flat Plate

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Abstract – Spiral flow heat exchangers are known as excellent heat exchanger because of far compact and high heat transfer efficiency. Spiral type heat exchanger is a unique design where it consists of single fluid as working fluid for heat exchange. Here heat transfer takes place between solid and fluid, and hence can be called as conjugate heat transfer. Heat transfer characteristics are observed at various Reynolds number and base temperature. The concept of K-type thermoelectric effect is used which is direct conversion of temperature difference to electric voltage, to measure temperature at various point in the heat exchanger. This study investigates the heat transfer from Liquid Petroleum Gas (LPG) flames impinging normal to the water cooled copper metal disc (150mm*150mm*6mm*10mm*2mm) segmented into two spiral channels. The correlates that are apply to the small region on the target, such as the stagnation point, are referred to as the local heat flux. Correlations that apply to a large region of the target, such as the whole area of heating region is referred as the average heat flux by measuring heat transfer over the target. Next the correlations are arranged by the type of heat transfer, for natural convection with low Reynolds number, here for this experimental work only the natural convection is considered. Finally the correlations are arranged by the flow type, either laminar or turbulent and heating height (z/d ratio).

Keywords: Reynolds Number, Natural Convection, Thermal Conductivity, Heat Transfer, Flame Impingement.

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INTRODUCTION

The objective in nearly all industrial combustion applications is to transfer the thermal energy, which is produced from the combustion process, to some type of load. In most of those applications, high heat transfer rates are required especially in circumstance where the energy consumption is relatively high. Flames that impinge on a wall provide an efficient and flexible way to transfer energy in industrial applications. In such processes, a large amount of energy is transferred to the impingement surface. Due to this reason, directly impinging flame jets are widely used as a rapid heating technology in many industrial applications, including heating of metals, tempering glass, annealing of materials and melting of scrap metals. Stagnation flames are also used to modify the surface properties of various materials. For example, premixed methane-air flames can beneficially alter the properties of polymer films [4]. In most of these applications, in order to avoid shifting a flame in an uncontrolled manner, the flame is stabilized by being attached to a simple device known as a burner. Accordingly, it has been concluded that the use of directly impinging flame jets with high velocity burners instead of other techniques, such using as furnaces, has a lot of advantages. First, the heat transfer is enlarged. Second, energy can be saved by switching on the burners only when the heat is demanded [3]. Also, one can avoid materials melting by simply turning off the burners. Finally, the heat can be applied locally.

A. Equivalence Ratios

This ratio directly influences the sooting tendency and the level of dissociation in the combustion products. Fuel-lean flames ($\Phi < 1$) produce only non-luminous radiation, since no soot is generated. Flames at or near stoichiometric equivalence ratio ($\Phi = 1$)

generate the highest flame temperatures, because of complete combustion. Fuel-rich flames (Φ > 1) produce a combination of both luminous and nonluminous thermal radiation. Therefore, it was demonstrated that equivalence ratios have a very important effect on the heat transfer characteristics of an impinging flame jet system, and many studies have been performed to explore its thermal effect. Furthermore, equivalence ratio is proven to have effect on the stability and dynamics of a premixed flame[1].

Equivalence

$$\text{Ratio}= i.e,\ \phi = \frac{(Fuel/oxidant)actual}{(Fuel/oxidant)stoich}$$

B. Reynolds number

Reynolds number of the air/fuel jet is defined as:

Re=du/v

Where d diameter of burner,

u velocity of mixture gases and v kinematic viscosity.

A broad range of Reynolds numbers at the burner (Re) has been used. They vary from 350 to 3700.

C. Impinging flame jets structure

The flow structure of an impinging axisymmetric flame jet on a flat plate is basically divided into four characteristics regions: the flame jet region, the free jet region, the stagnation region and the wall jet region. A generalized picture of a single circular flame jet is shown schematically in once an unburned gas mixture exits the burner nozzle, it enters the flame jet region. Thus, it faces a sudden expansion as the gases react in the flame front. Then, the resulting burnt gas mixture enters the free jet region. The free jet region potentially consists of a core and a fully developed region. The potential core plays an important role in ignition and flame stability. The fluid in the potential core is not affected by contacting with surrounding fluid, and has characteristics such as the flow in the nozzle [2]. The jet flow in the fully developed region is of a constant velocity profile. In general, in a free jet region, the velocity remains constant for the laminar case if the plate has no perceptible influence on the flow. The stagnation region is also known as the impingement region. The stagnation region is characterized by a pressure gradient, in which the velocity of the mixture decreases in the axial direction due to the influence of the plate on the flow. Also, the static pressure distribution around the impingement surface is used to determine the extent of the stagnation region. Close to the plate, a viscous boundary layer will develop that has approximately a constant thickness in the impingement zone [3]. Once the jet turns in a radial direction and the gases enter the wall jet region, the viscous boundary layer thickness will increase.

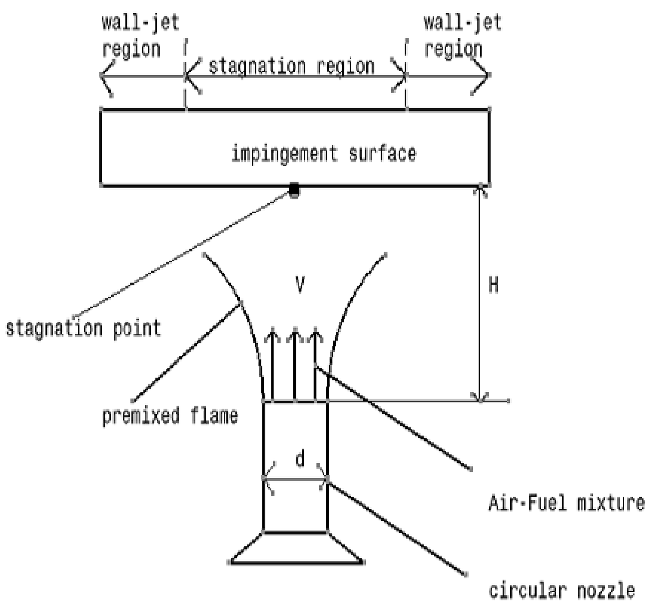

Fig.1.Schematic of Experimental setup

II. FLAME IMPINGEMENT EXPERIMENTAL SETUP

In this section, I present the description of the experimental setups, i.e. flame impinging on a flat plate and flame impinging on a cylindrical surface. These experimental setups are designed to identify the influence of different parameters: cold gas velocity, equivalence ratio, and burner-to-plate distance on the heat flux characteristics of the impinging flame jet. Furthermore, it allows for obtaining more accurate measurements for the surface temperature using the thermo graphic phosphor technique, and thus a more accurate calculation of the heat flux. The experiment was designed in such a way that one-dimensional stagnation point geometry is approximated. The structure of this experiment is composed of two main structural components: the heat receiver as a heat absorption system, and the burner as a heat generation system, as shown schematically in Figure 1.

Fig.2.Photograpic View of Experimental Setup

Here for heating the target plate we use the LPG gas mixture with air which will passes through the hosh pipe to the burner, in between the hosh pipe we used calibrated orificemeter with two pressure taps, the orificemeter is used for measuring the amount of fuel consumption to heat the target plate which is calculated by the differential head of the manometer readings where it is connected with two hosh pipes one as inlet and the other one as outlet to the orificemeter pressure taps.

a) The entire hose pipe connection is checked for any leakage

b) For continuous impinging of flame to the target plate maintained constant with constant rate of fluid flow and respective height.

c) The temperature of the water-inlet and water-outlet is noted for every reading using the thermometer.

III. RESULTS AND DISCUSSION

Flame impinging normally on a flat plate, this type of configuration has been widely applied in many industrial processes. Hence, it has attracted much research. Flame impinging normally on a flat plate, this type of configuration has been widely applied in many industrial processes. Hence, it has attracted much research.

Burner-to-plate distance and its effects

The separation distance between the burner exit and the target surface can significantly affect the impinging flame structure, and thus heat transfer characteristics. A number of studies were cited in the literature showing the effect of separation distance. It is observed that the heat flux at the stagnation point is measured. The distance between the burner and the target plate is important from the perspective of heat transfer and flame stability, especially when the other operation conditions are fixed or cannot be altered easily. It is obvious that the separation distance will play a significant role for the design of heating equipment that makes use of direct flame jet impingement. Many studies have investigated the effect of plate-to-burner distance on the heat transfer. For the ethanol/air flame, the effect of this operational condition has not been tested yet, even though currently it is commonly used in domestic heating. In our case, stoichiometric ethanol/air flames were investigated at three burner-to-plate distances; namely H=10 mm.

Sr No	Inlet Temp of water ($t_i C^0$)	Outlet temp of water ($t_o C^0$)	Distance b/w target plate & torch in cm (z/d ratio)cm	Manometer Readings in cm			Time taken for collecting 1000ml of water t(sec)	Discharge (Q) m^3/s	R_e	Q in J/S	Qmax in J/S	Q/Qmax
				LHS	RHS	Diff		10^{-6}		10^{-3}		
1	32	44	1	48.4	47.8	0.6	252	3.968	1391	198.9	1.52083	0.13078
2	33	48	1	47.5	46.5	1	202	4.95	1736	310.8	1.95556	0.15893
3	34	50	1	47.4	44.4	3	224	4.46	1564	298.7	1.7379	0.17186
4	35	46	1	47.9	43.7	4.2	132	7.58	2658	349	2.82454	0.12356
5	36	44	1	48.4	42.5	5.9	122	8.196	2874	271	3.0379	0.08920

Table.No.1. Varying the fluid flow rate by keeping constant flame distance

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The temperatures on the hot side are highest for the small distance, with little difference between the temperatures on the water side. As previously noted, the main reason for that behavior is the high convection coefficient on the water side. In other words, the thermal resistance on the water side is high because the inlet water temperature is relatively low (20°C). The water temperature remains nearly uninfluenced due to the high water flow rates; the wall temperatures also remain nearly constant on this side. For H=10 mm, the temperature difference between the both sides vary between 305 K and 309K. These temperatures are used in the following for the heat flux evaluation.

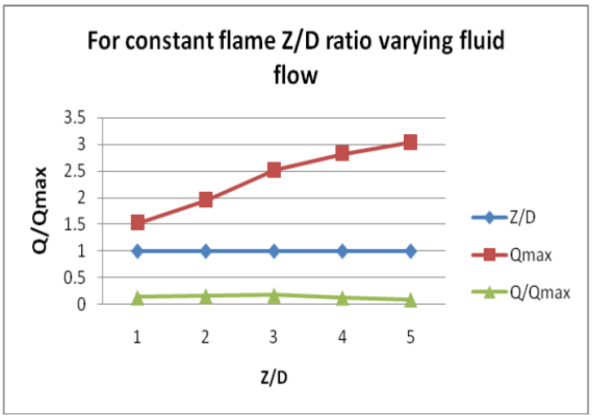

Fig3. for varying the fluid flow rate by keeping constant flame distance

IV. CONCLUSION

This research work was conducted to achieve a better understanding of the stagnation point heat flux characteristics of impinging flame jets, namely ethanol/air and ethanol/hydrogen/air flames. This study was essentially experimental. The method followed to determine the heat flux was as follow: From these experimental results, two distinct regimes can be distinguished: At low flow rates, the flame is burner-stabilized. In this regime, an increase of the cold gas velocity does not only increase the total combustion enthalpy flux but also reduces the heat loss to the burner. This leads to an increased flame temperature. When the plate-to-burner (H) is decreased, the stagnation point heat flux is increased. The relatively high stagnation point heat flux occurred when H= 15mm. The lowest stagnation point heat flux occurred when H = 60 mm.

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