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Experimental Calibration of Heat Flux from Copper Slug Calorimeter in High Speed Combustor

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ABSTRACT: *Calibration of heat flux plays a vital role in the modeling of thermal systems which requires inputs of temperatures and energy fluxes for prediction of their heat distribution. Temperatures are commonly measured by the variety of standard methods, but the measurement of heat flux is particularly challenging because it is an energy flux normal to the plane of material rather than a property of material. Therefore, the heat flux gauges that measure the heat flux is usually mounted on a material that provides a good heat sink so that the energy flow is not impeded. The measured heat flux data provides valuable information in the areas of design, development and qualifications of thermal protection systems/subsystems. A variety of techniques both intrusive and non-intrusive have been developed for the measurement of heat flux. This paper mainly deals with experimental calibration of heat flux using copper slug calorimeter. The experiment was conducted in high speed combustor test facility test rig. We also included the plots generated from DAS using "Lab View" software for the experiments conducted in the test rig.*

Keywords: *Heat Flux, Copper Slug Calorimeter, High Speed Combustor, Data Acquisition System, Lab View*

I. INTRODUCTION

Modeling of thermal systems requires inputs of temperatures and energy fluxes for prediction of their heat distribution. Temperatures are commonly measured by the variety of standard methods, but the measurement of heat flux is particularly challenging because it is an energy flux normal to the plane of material rather than a property of material. Therefore, the heat flux gauges that measure the heat flux is usually mounted on a material that provides a good heat sink so that the energy flow is not impeded. These thermal gauges must be designed and developed carefully to prevent the occurrence of uncertainty in its measurement. Also calibration must be done under actual operating condition to standardize these gauges. The measured heat flux data provides valuable information on heat distribution in a thermal system which is a primary input in designing various sub-systems like cooling system, insulation. The major application of these gauges in aerospace industry includes qualification of thermal protection systems for aerodynamic and reentry heating applications, satellite thermal control and wind tunnel measurements. Also it finds its purpose in measuring heat distributed in PCB of GPS systems and other avionic devices. In conventional industry heat flux measurements are used to design super critical boilers, heat exchangers and evaluation of heat dissipation in electrical machinery etc.

II. COPPER SLUG CALORIMETER

Slug calorimeter (also known as Slug type heat flux gauge) is a gauge that determines heat flux by measuring the rate at which a slug of material heats up while subjected to a heat source. The slug calorimeter particularly effective in high heat flux measurements arising in re-entry conditions, offers great advantages compared with other solutions in terms of cost and durability. It is widely used in various field of aerospace especially in ground testing as for dynamic testing and flight testing.

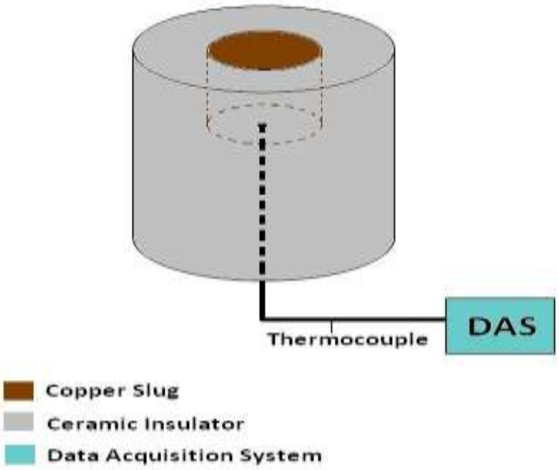

Figure 1: Schematic Diagram Of Copper Slug Calorimeter

III. COMPONENTS OF COPPER SLUG CALORIMETER

OFHC Copper is chosen as the slug material as it has high thermal conductivity. Its melting point is 1356 K. The copper slug along with the thermocouple is embedded into a silica-phenolic based ceramic insulation which can withstand temperature of 2000 K. A K–type thermocouple is attached to the rear surface of the copper slug. It can effectively measure temperature up to 1523 K. Starting from a reference temperature (room temperature), the gauge is inserted into the test rig, and after a short initial transient the temperature increases linearly versus time. Temperature is tracked for a time sufficiently long to enable accurate determination of the derivative (dT/dt), but that does not compromise the physical integrity of the gauge. At this point the gauge is removed from the flow continuing to acquire temperature data. The choice of the material used to build the slug involves several considerations. The melting temperature of the front surface is a limiting design parameter. When the surface of the calorimeter is suddenly exposed to a high heat flow, this is initially transmitted by conduction. The melting does not occur until the surface reaches a critical temperature, which depends on the structure of the material. When the melting begins, the flow by conduction is reduced and a large portion of energy is stored into the phase changing degree of freedom. In this situation the relationship between the heat flux and the temperature of the back surface becomes very complex.

IV. EXPERIMENTAL SETUP

The experiment for the heat flux measurement was conducted in the high speed combustor test rig. The objective of this test was to investigate the heat flux due to high temperature (T_g=900 K) gas flow. The figure 2 and 3 shows test facility setup. The copper slug calorimeter is integrated into the test rig for heat flux measurement. The thermocouple which attached to the back face of calorimeter is connected to the Data acquisition: NI-PXI based system. Initially pressurized air from the compressor is fed into the Test rig. The pressure regulator regulates the flow of air into the system P_i=2 bar. Once the required mass flow rate (1.8 kg/s) is obtained, the fuel pump is switched 'ON'. The fuel is burnt inside the pre-heater and made to flow through the system at required temperature. This hot mixture from pre-heater makes contact with slug which is attached at the other end of the rig. The heat flux data is directly measured.

Figure 2: Test Rig

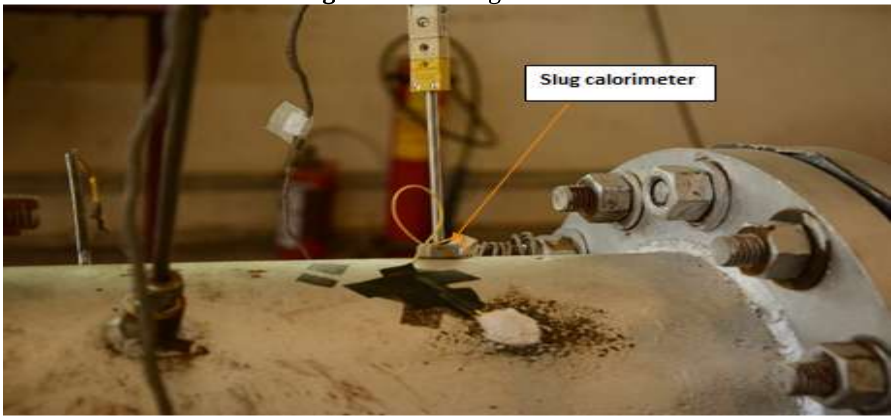

Figure 3: Copper Slug Calorimeter Mounting

V. RESULT AND DISCUSSION

Acquired data from the DAS is directly recorded in a spreadsheet file by "LABVIEW". This spreadsheet contains valuable data about various parameters like Heat flux (q), Gas temperature (T_{gas}), Skin temperature (T_{skin}), Mass flow rate (m_g), Total pressure (P_o), Slug temperature(T_{slug}) with respect to time. These data were plotted against time and the trend is discussed and analyzed to understand the change in various parameters due to transient heat transfer.

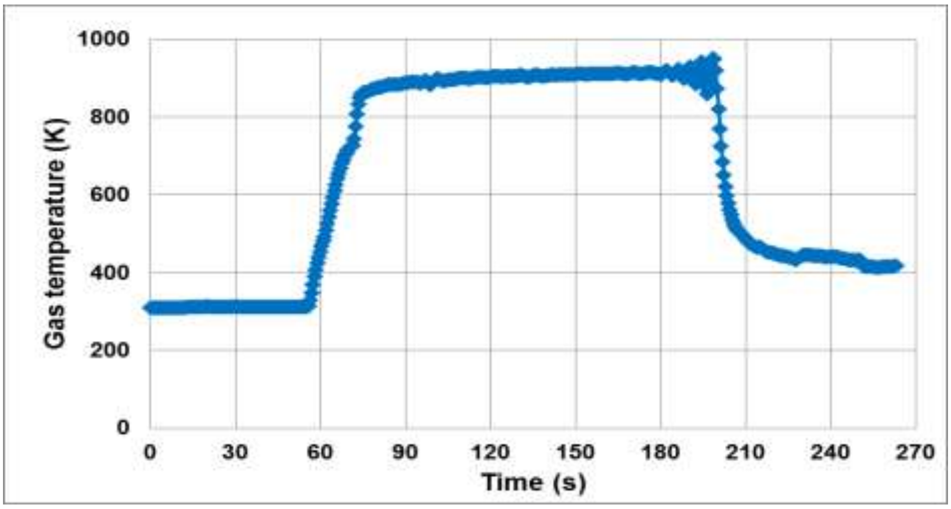

Figure 4: Gas Temperature vs Time

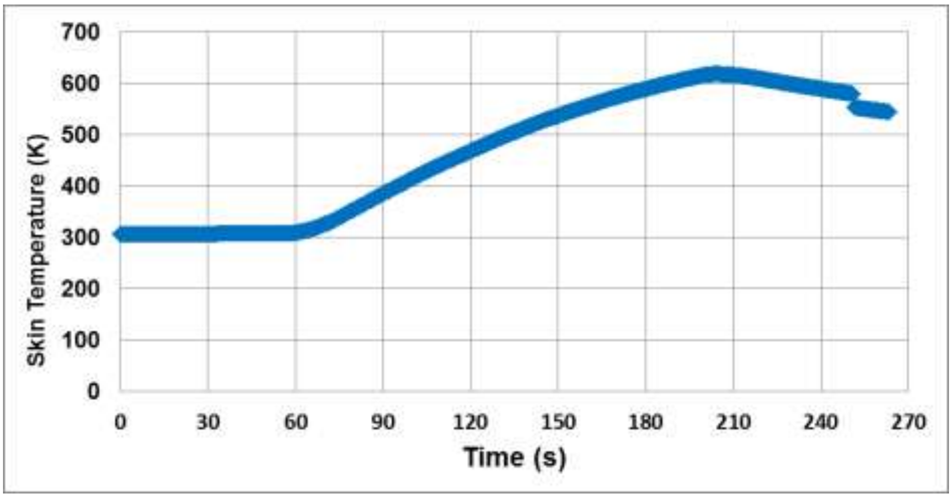

Figure 5: Skin Temperature vs Time

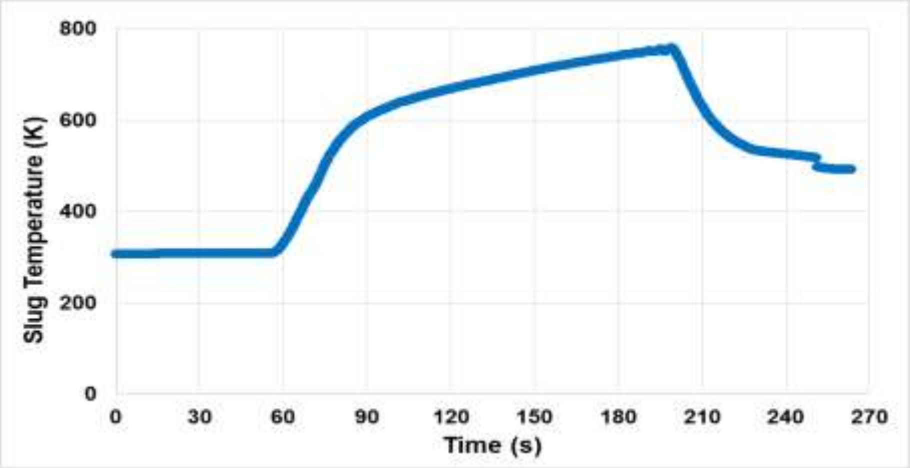

Figure 6: Slug Temperature vs Time

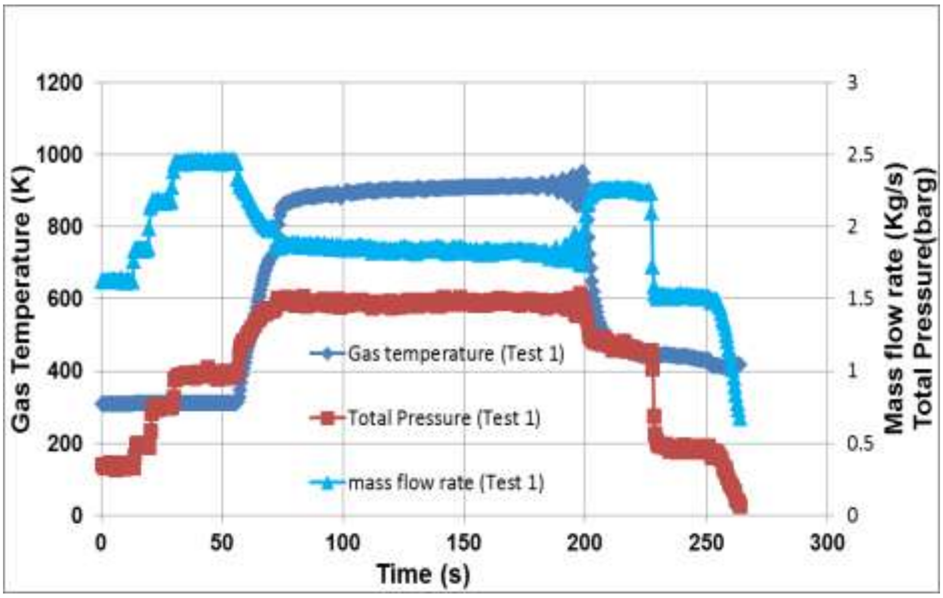

Figure 7: Test Rig Parameter vs Time

VI. EXPERIMENTAL INFERENCES

From the entire graph plotted with time, the trend starts increasing when time was at 55 sec. So it is evident that from t= 0s to t= 55s, the experiment was done in cold flow with gas temperature T_G =303K. After 55th second, Heat addition process was done by injection of fuel (White Kerosene) into the pre-heater followed by spark ignition. We could witness from the graph that after heat is added into the test rig, the magnitude of T_{skin}, T_{slug} and T_g rapidly claims to its highest point especially heat flux (q).The heat flux value reached to a maximum value of 180.9 kW/m^2. This sudden increase in heat flux is because of heat added to the air and the rate of change of temperature will be high. From an initial value of 303 K to a final value of 900K, almost 600K rise in gas temperature within a short interval 2-3 seconds. Since heat flux is proportional to dT/dt, the heat flux reaches its peak during this period.

The plot between mass flow rate and time also provides important information that after fuel is added to the pre-heater at t= 55s, the mass flow rate drops steeply. This drop in mass flow rate occurs mainly because, the mass flown into the system is converted to energy or in other words, when combustion occurs, the fuel is burnt along with air at 2bar pressure, the mass of fuel-air available at that instant is utilized into thermal energy. So there will be considerable decrease in mass flow rate. Simulated parameters such as Gas Temperature, Total pressure and mass flow rate were maintained almost stable for a period of 120s, from t =73-74s to t =195s.

VII. CONCLUSION

Over this period, the trend of heat flux vs. time graph can be analysed into two parts. (i) From t = 73s to 105.5s, the graph loses it shape and steeply drops. This is because when gas temperature is maintained as almost stable, the value of dT falls steeply with time and thereby reducing the magnitude of heat flux. (ii) From t=106s to 195s, a series of trend is generated ranging from 5kW/m^2 to 20kW/m2. The heat flux measured using analytical approach with steady state equations has yielded a value of 8.89kW/m^2. Also the trend line yields a similar value as most of the points in graph fell around a range of 10-20 kW/m^2. It was evident that copper slug calorimeter holds 10% uncertainty in its measurement. So by adding the factor of uncertainty to the analytical value, it holds a range of 7.5- 10 kW/m^2. From experimental approach, it is proven that heat flux value measured has a range of 7-10kW/m^2.

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