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Heat Flux Measurement at Furnace Wall

Ahmed M. Amin, Ahmed H. Elaskary

Mechanical Power Engineering Department, Faculty of Engineering,
Menoufia University, Shebin Elkom , Egypt.

ABSTRACT

This paper represents a methodology for measuring heat flux of jet flame impinging on furnace wall and its temperature by using a new heat flux sensor. Impinging flame jet has a significant portion in a lot of applications as it enhances heat transfer by convection. It also increases productivity and reduces fuel consumption in addition to reduce emission pollutants. Assessment of heat transfer characteristics is crucial in industrial furnaces which are used in melting scrap metals, flame welding and shaping glass. Because of high temperatures and problems encountered in flame measurement due to thermal equilibrium and free radicals resulted from combustion, an alternative heat flux sensor is used to sustain these severe conditions. The designed heat flux sensor and its governed equations will be descried. Calibration method is applied on the designed heat flux sensor where, heat flux measurement compared to constant heat flux for a certain temperature difference.

Keywords *heat flux sensor; thermopile; temperature difference; calibration; heat flux measurement*.

NOMENCLATURE

d1	Heat receptor diameter (mm)	Greek symbols	
d2	Thermopile diameter (mm)	ΔT	Temperature difference (°c)
K	Thermal conductivity (W/m K)	σ	Distance from pellet to first thermocouple (mm)
L	Distance between the two thermocouples position (mm)	Subscript/superscript	
q’’	Heat flux (kW/m^2)	ele	Electrical
R	Electrical resistance (ohm)	rad	Radiation
T_s	Surface temperature (°c)	**s**	Surface
V	Voltage (Volt)	tot	Total
x	Distance (mm)		

1. Introduction

Heat flux sensor is a device used to measure heat rate divided by surface area of the sensor to measure heat flux. Heat flux sensor generates an electrical signal which is proportional to heat flux and is connected to data acquisition system to convert this electrical signal into voltage or temperature directly. Heat flux sensors, categorized by the virtue of their desired type of heat, can be measured such as convective, radiative and conductive heat flux. Chillds et al. [1] represents a thorough review of heat flux measurement techniques. Dejima et al [2] investigated heat transfer characteristics of an internal combustion engines using heat flux sensor.

Sing et al [3] examined interference of mounting thermopile heat flux sensors on surfaces Nakos [4] described the most common ways to measure heat flux from flame generated from hydrocarbon flames. Heat flux sensors are used in industrial fields, depending on the purpose of industrial processes. A variety of industrial applications where temperature and heat flux required; like, minerals melting, coal-fired boilers, fluidized beds and blast furnaces.

1.1 Importance and Applications

There are many applications using flame jet impingement such as: flame cutting, flame welding, and melting of scrap metal ……. etc. Flame cutting also named Oxy-Fuel. Gas cutting is a high productivity cutting method developed in more than 100 years ago. Also; in welding process, gaseous fuels are burned and produced high temperature flames which is further used to create weld joint. The flame has a leading role to create weld joint and the weld properties are highly depended on it.

Heat flux sensors used in metallurgical heat treatment which involves the careful heating of a metal or alloy in a controlled environment to alter its physical or chemical properties. Glass industry which includes sheets, bottles, plate glass and fiber glass is also intensive industry in which heat flux is an important parameter in glass production. Heat flux measurements and control are the most important parameter to design boilers and rapid thermal material processing in furnaces which is important parameter of material processing.

1.2. Problems in Measuring Heat Flux in Case of Impinging Flame

The mostly common measurement of the flame is temperature which is carried out by insertion of solid body (probe) in the flame. First the solid body should reach thermal equilibrium which is considered when there is no energy transfer between flame and solid body; but flame doesn't reach complete thermodynamic equilibrium due to large amount of energy transfer between flame and solid body .So in experimental procedures it is convenient to assume that when solid body is left in contact with flame for sufficient time until thermodynamic equilibrium reaches the corresponding thermal state. Second, during reaction of active free radicals such as OH and CH can react with impinging surface(catalytic effect); so heat released can heat this surface to higher temperature than flame as reported by Herasymenko et al,[5],and Griffiths et al [6].

There are undesirable phenomena like flame instability which is necessary to be cared about during flame measurement .Also chemiluminescence which is not preferred to exist. There are thermocouples of refractory alloys that are used in measurement of high temperatures but due to errors associated with thermal catalytic effect of free active reaction and distortion of boundary layer [7-8].

The common problems related to issue of measuring heat flux and temperature are the measurement in chemically reacting medium. Also, uncertainties associated with measurement in case of impinging flames, thermocouples must be perfectly protected to withstand high temperature and had the required temperature range. Different errors can occur during measurement such as human error or sensor failure.
So, our objectives are to design a new heat flux sensor which can overcome the problems associated with thermodynamic equilibrium that is related to large amounts of heat transfer between flame and solid body due to chemical reaction of free active radicals CH and OH. Also the designed heat flux sensor is used to measure the total heat flux and radiation heat flux separately.

2. Heat Flux Sensor Technique and its Implementation

Finding out a new technique to design a heat flux sensor to measure heat flux and explain heat transfer characteristics is crucial in many industrial applications. Measuring equipment of heat flux was designed on the principle of heat conductivity type heat flow sensor.

2.1 Principle of Heat Flux Sensor and its Realization

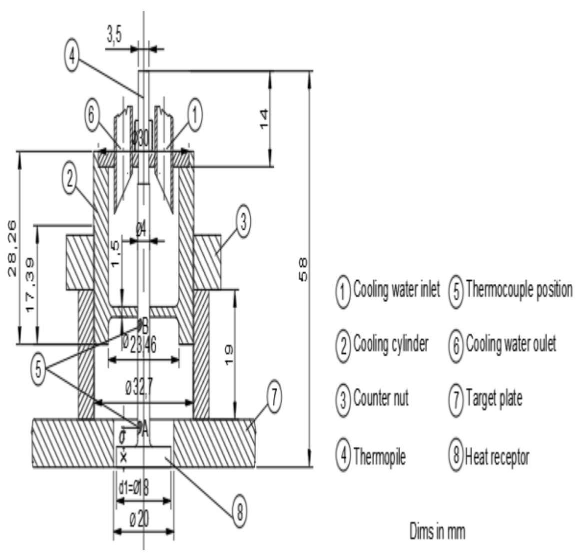

Fig 1- Total heat flux sensor

Heat flux sensor-consists of two parts as shown in Fig 1: i. a circular flat pellet heat receptor with diameter d1=18 mm, and ii a cylinder AB with diameter d2=4mm.These two parts of thermopile are combined in a common aluminum hollow and cooled with water.

Thermocouples of type K were installed through distance L=13 mm and then soldered in their place, All wires were thermally and electrically insulated. The copper thermopile with its thermocouples were connected into a data acquisition system is connected through PC which recorded temperature measurement corresponded to the heat received by pellet.

Under steady state condition the heat resulted due to chemical reaction and distortion of thermal boundary layer was transmitted due to convection and radiation through thermopile and given by:

$$q''_{tot}=(\frac{K}{L})(\frac{d2^2}{d1^2}).\Delta T \quad kW/m^2 \qquad (1)$$

The designed heat flux sensor was implemented as depicted in Fig 2.

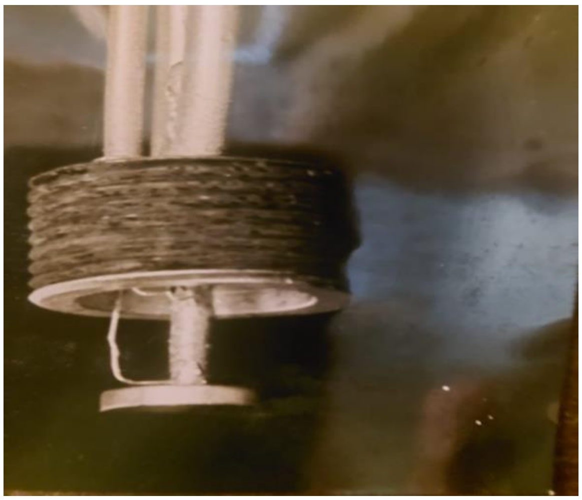

Fig 2- Heat flux sensor

2.2 Surface Temperature (T_s)

Any conventional method of measuring the furnace temperature would interfere with the flow caused by impingement and the difficulty of accurate measurements of the heat transfer between the thermopile and the hot gases. Adding to theses ,no thermodynamic equilibrium exists in the chemically reacting gases impinge on furnace wall .For these reasons it would necessarily to measure the temperature difference between A and B (ΔT) and the temperature at A(T_1) and then convert the later temperature to the surface temperature (T_s)taking into consideration the thermopile geometry. Calculation of the surface temperature (T_s) was given as following:

$$T_s=T_1+\frac{\Delta T}{L}[\sigma+\frac{d2^2}{d1^2}(x-\sigma)] \quad [^oc] \qquad (2)$$

2.3 The Principle of the Radiation Heat Flux Equipment and its Realization

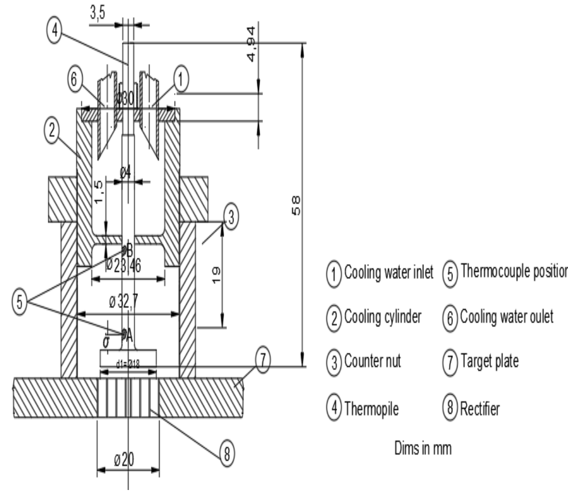

Fig 3- Radiation heat flux sensor

The radiometer used to measure q''_{rad} was performed using nearly the same instrument for q''_{tot}. as shown in Fig 3 which shows principle of operation.

Shifting the heat receptor of the thermopile with a definite distance from impinging surface inside the common hollow block and installing copper rectifier (spiral foil) as shown in Fig 3.

This rectifier has two functions; the first is to prevent heat transfer by convection through thermopile and the second to allow all the incident radiation rays to enter parallel and perpendicular to the surface of pellet whatever the angle of incident.

The heat pellet absorbs practically all the parallel radiation (from 95% to 98%) whatever the wavelength intercepted by blackened and oxidized surface .So radiation heat flux is calculated as reported in F.Bosnyakov[9].

$$q''_{rad}=(1/\pi).\ q''_{tot} \quad kW/m^2 \qquad (3)$$

2.4 Calibration of Proposed Heat Flux Sensor and their Realization

The heat flux sensor gave the characteristics of its thermopile, but it didn't supply the absolute indication of heat flux due to losses from core structure of thermopile and the pellet. So, it has to be calibrated carefully.

Heat flux sensors were calibrated by providing constant heat flux through cartridge heater (40w &24v) as it had a constant resistance and it was put in Copper block which it had a suitable size to the sensor . Each of heat flux sensor and its appropriate copper block were a perfectly insulated using mineral wool and connected to power supply and an Avometer as shown in Fig 4.

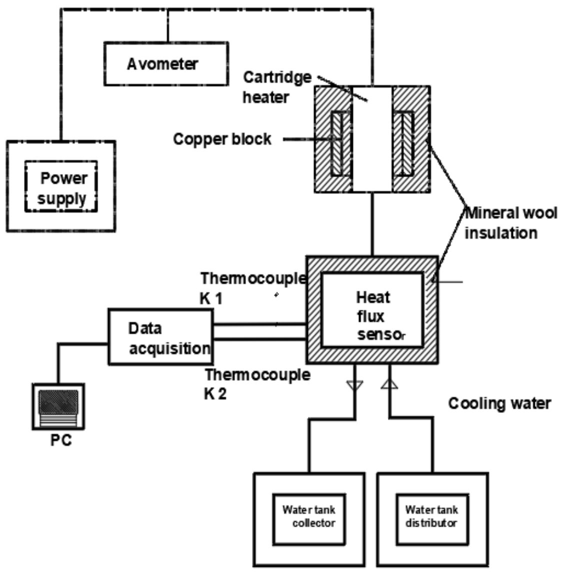

Fig 4- Layout of calibration circuit

By changing power supply and measuring voltage through Avometer as shown in Fig 5 and determining power which is corresponding to heat transferred to pellet of heat flux sensor via cartridge heater and heat flux can be calculated.

$\text{Power}=\frac{v2}{R}$	kW	(4)
$\text{Area}=\frac{\pi}{4}d_1^2$	m^2	(5)
$q''_{elec}=\frac{Power}{Area}$	kW/m^2	(6)

Fig 5- Power supply and Avometer

The temperature difference which corresponding to heat flux of electrical heater is recorded using data acquisition system and both total heat flux and electrical heat flux calculated and plotted on graph against temperature difference n Fig 6

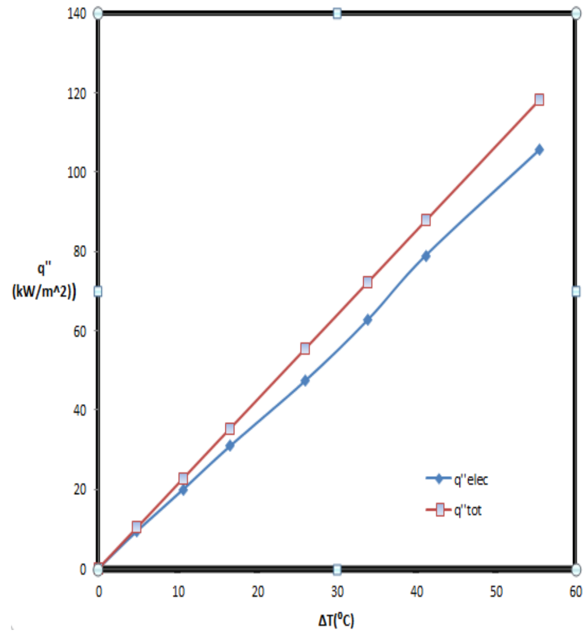

Fig 6- Calibration curve of heat flux sensor against temperature difference

3. Conclusions

A new technique is used to design heat flux sensors for both total and radiation heat flux. The following conclusions were drawn:

1. This technique is used to avoid the problems of thermal equilibrium during reaction of free active radicals such as OH and CH.
2. The design of heat flux sensor makes it suitable for characterizing heat flux at normal and oblique jet flame impingement in many industrial applications.
3. Heat flux sensor can be arranged for measuring total heat flux and radiation heat flux in addition to surface temperature.
4. Heat flux sensor shows accuracy in many applications like flame cutting, flame welding, melting of scrap metal, metallurgical heat treatment, glass manufacture and rapid thermal material processing.

4. References

[1] Childs, P. R. N., Greenwood, J. R., & Long, C. A. (1999).Heat flux measurement techniques. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 213(7), 655-677.

[2] Dejima, K., & Nakabeppu, O. (2022). Local instantaneous heat flux measurements in an internal combustion engine using a MEMS sensor. Applied Thermal Engineering, 201, 117747.

[3] Singh, S. K., Yadav, M. K., & Khandekar, S. (2017). Measurement issues associated with surface mounting of thermopile heat flux sensors. Applied Thermal Engineering, 114, 1105-1113..

[4] Nakos, J. T. (2010). Description of heat flux measurement methods used in hydrocarbon and propellant fuel fires at Sandia (No. SAND2010-7062). Sandia National Laboratories (SNL), Albuquerque, NM, and Livermore, CA (United States).

[5] HERASYMENKO, V., SEHEDA, O., & STADNYK, B. (2015). The features of flame temperature measurement. Advances in IT and Electrical Engineering, 23(34-3), 81-85.

[6] Griffiths, E., & Awbery, J. H. (1929). The measurement of flame temperatures. Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character, 123(792), 401-421.

[7] Shannon, K. S., & Butler, B. W. (2003, November). A review of error associated with thermocouple temperature measurement in fire environments. In Proceedings of the 2nd Fire Ecology Congress.

[8] Yilmaz, N., Gill, W., Donaldson, A. B., & Lucero, R. E. (2008). Problems encountered in fluctuating flame temperature measurements by thermocouple. Sensors, 8(12), 7882-7893.

[9] Bosnjakovic, F., & Knoche, K. F. (1998). Technische,thermodynamic.,Birkhäuser Germany