Measuring the effect of surface roughness on convection coefficient with infrared thermal camera

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***Abstract*– The purpose of this work in progress report is to show that infrared images can be employed to prove that surface treatment can be used in order increase the convection coefficient. Improving heat transfer coefficient using simple surface treatment methods such as subtractive sand blasting or additive microsphere coating could allow us to save energy. The 1st phase of this work is to prove that an accurate high-resolution indirect measurement of the convection coefficient can be made with IR thermal images history. A hot sphere is cooled down and a history of the temperature profile is recorded. Experimental setup is discussed including a controlled heating and data acquisition setup that captures the data of the cooling wind speed and surface temperatures VS time. A numerical model will be used to simulate the relationship between the rate of cool down VS the several coefficient of convection profiles.**

Keywords—thermography, convection coefficient, infrared, surface roughness.

I. Introduction

It has been shown that the surface roughness can influence the heat transfer coefficient for a variety of scenarios including examples such as a flow over horizontal immersed tubes [1]. Further more it has also been investigated that there is an effect over the heat transfer performance caused by subtractive treatments such as sand blasting on a single-phase micro channel heat sink [2], or a plate heat exchanger [3]. Similarly it has been discussed ways in which the use of additive treatment such as surface coating technology increases heat transfer [4].

Heat transfer behaviour is usually studied taking measurements of dissipated heat and temperature over a range of time. Infrared images have been used to obtain temperature measurements for many mechanical applications [5]. It conveniently provides a non-invasive method to study surface temperature profiles. This non-invasive characteristic is particularly useful for the study of the effect of a flow on a surface convection heat transfer since there is no interference with the flow. These images have been used to measure the heat transfer coefficient on jet fluids heating vertical disk [6] as well as the convective heat transfer for many other applications [7].

We propose a method to obtain quick temperature history data in order to obtain the convection coefficient for a variety of fluid flows over different geometries. The connection between the temperature measurement and the convection coefficient will be made with a numerical theoretical analysis using finite element model for these geometries. Then a quick assessment is proposed to characterize the effect of different surface treatments on the heat transfer behaviour of such surfaces.

II. Numerical Models

In order to create a relationship between the coefficients of convection we will use a numerical finite element model with proper boundary conditions. Solutions for the heat diffusion equation "(1)" will be presented under the assumption that there is no heat generation inside the body [8]:

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}=\frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{1}$$

Where T is Temperature, t is time, α is the thermal diffusivity, and x,y,z spatial coordinates. We can define proper boundary conditions "(2)" performing an energy balance on elements with areas in contact with the fluid.

$$q_\theta + q_\phi + q_r - hA\left(T_s - T_\infty\right) = mc_p\frac{\partial T}{\partial t} \tag{2}$$

Where q_θ, q_Φ, and q_r represent the net heat transfer by conduction coming from both tangential directions (latitudinal and longitudinal) and radial direction. The variable h is the convection coefficient to be determined, T_s and T_∞ the variable temperature of the surface and the constant temperature of the fluid respectively. The variables m and c_p are the mass and specific heat of the element. The last partial derivative represent the change in temperature with respect to time and can be used as the direct parameter for comparison between the measured system and the numerical model. Initial uniform conditions will be applied in order to simplify the numerical model.

Numerical models will have material property inputs to fix the value of α, and c_p inside the volume. All properties will be temperature dependent. A designed geometry will define the coordinates of the volume boundaries. Initial uniform temperatures will be defined for the volume and a bulk fluid temperature will be fixed in order to simplify the calculations. The thermal convection coefficient h will be represented as the function h(x) of the coordinate x which is parallel to the fluid flow. This will be made under the assumption that when a fluid hits a sphere towards the region of stagnation point it separates through the sphere symmetrically as presented in Fig 1a, which shows a front image of a fluid hitting a sphere. Under this assumption it is clear that h actually depends on a parametric variable, which describes the travel of a particle along the velocity streamlines. The function h(x) will be defined and applied to surface exposed elements in order to obtain temperature profiles history that matches the thermography images.

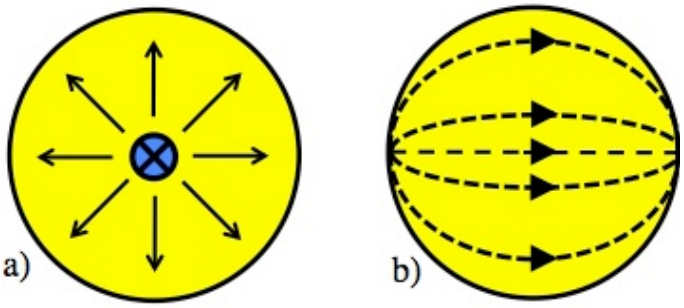

Fig. 1 Symmetric streamlines of flow over sphere. Front down stream view a) and side view with projected streamlines b).

III. Thermography System and It's Calibration

In order to rely on infrared camera measurements we need to make sure that the surface emissivity at experimental temperatures are as close to a black body as possible. Local emissivities can be measured in order to study the potential effect of relative roughness on them. If the emissivity does not change for the outer radius of a projected circle we can assume that directional emissivity is uniform and high for the outer radius. Alternatively we can setup multiple cameras that accurately give proportional if not exact readings. An initial polished sphere will be subjected to certain measurements for a period of time. A proper range of the time will be one that accurately predicts a proper range of change in temperature.

Accurate image processing is required to obtain high spatial resolution. Due to diffraction limit of infrared wavelength, resolution will depend on the numerical aperture of the infrared lens. Another factor that could limit the resolution is the thermography data is the amount of pixels in the collection plane. Calibration of the thermography system will be made using thermocouples.

Several tests will be performed in order to establish how to obtain the best measurements. A study will be made in order to see the relationship between the angle of incidence of a surface and the directional emissivity. Several images will be taken and the data will be extracted in a matrix file that relates measurements to pixels. A direct relationship between the pixels and the actual dimensions of the sphere can be correlated with proper calibration, which includes camera distance and angle control. To make the study as accurate as possible we will follow the wind streamlines on top of the sphere. Assuming symmetric flow over the sphere, one could make a projection of the velocity profile at the boundary layer on top of the sphere surface as presented in Fig 1b. Even though one could simplify the study and use the coordinate x to plot the temperatures, the data points used to compare to the numerical simulation results will be extracted from the projection curves in order to follow over the stream flow. Several plots of temperature VS x can also be graphed in order to see the influence of the directional emissivity on the images. Depending on the resolution of the image there might be blurred regions that mix the data of the sphere temperature and the surrounding background. Attempts will be made to either minimize or to compensate for the size of this region. The thermography camera will be positioned on top and side view of the convection experimental setup in order to obtain a better profile of the h(x) function.

IV. Convection Experimental Setup

The experimental setup will consist of a fan capable of providing a forced steady convection together with an anemometer to ensure constant uniform velocity. The entire experiment will be performed inside a wind tunnel for flow control. A convection oven will be used to slowly heat a sphere to obtain an initial uniform temperature as specified in the numerical model. A sphere made of a material whose surface resembles a black body as much as possible (emissivity of 1) will be used in order to minimize errors in thermography data collection. The sphere will be mounted on a thin post in order to minimize its influence over the stream flow. An optical system, which consists of lenses and a timed camera, will be used to collect the data at a regular time interval. Image processing will be used in order to filter the data at the surface of the sphere on the locations with high directional emissivity in order to avoid the storage of unnecessary large amount of data. This same processing will allow us to plot temperature VS position & time curves in order to estimate the h(x) convection coefficient function.

Acknowledgment

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