Improving Laboratory Education at the Mechanical Engineering Program at ESPOL: The Design of a Jet Impingement Cooling Experimental Setup

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ABSTRACT

The advancement of technologies such as electronics and manufacturing demands more advanced thermal management techniques. Jet impingement cooling is one of the most promising technologies. This project aims to design a single free-surface jet impingement cooling setup to be constructed at the thermofluids laboratory. The project is part of an effort to improve laboratory education at the mechanical engineering program with student participation.

As part of the design process, an extensive literature review on jet impingement, experimental techniques was performed.

The design uses steady state methodology to measure global heat transfer coefficient and is able to provide different rates of cooling flow, two diameters of jets, regulation of power supply and adjustment of surface-nozzle distance.

Keywords: Jet impingement cooling, laboratory education, Direct liquid cooling.

1. INTRODUCTION

During the last decades, the need to remove high heat fluxes have become critical. Hot rolling process, annealing of metals, tempering of glass, electronics cooling are some typical applications that needs high heat removal techniques.

Different techniques have been developed to achieve high heat flux rates among them jet impingement cooling (Leocadio & Passos, 2009,Meng, 2002),. Webb (Webb & Ma, 1995) provides an extensive review of studies about sumerged jets impingement and free-surface jet impingement. Kandlikar (Kandlikar & Bapat, 2007) performed a comparative study of jet impingement, spray and micro channel chip cooling as high heat removal solutions.

The scope of the project is single free-surface jet. A fluid jet strikes on a hot surface, where due to its normal deceleration, parallel acceleration and velocity change on the surface it is possible to obtain high heat flux rates (Fig 1). This work integrates theorical and experimental studies of Jet impingement cooling (Webb & Ma, 1995, Womac et al., 1993, Zumbrunnenet al., 1990).

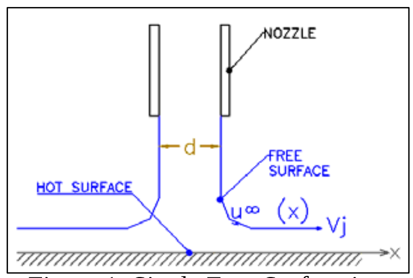

Figure 1: Single Free-Surface jet

2. OBJECT

The main purpose of the present work is to design an experimental setup which will be ready for its construction and assembly.

Once the experimental setup is built and ready in operative conditions, it will be possible to use it to measure heat fluxes and calculate average coefficient of convective heat transfer.

Finally the results must be compared with theorical correlations found at scientific literature (Webb & Ma, 1995).

3. METHODOLOGY

Several possibilities options of measuring heat transfer rate were considered: steady state methods, transient methods. The selection of methodology was based on simplicity, accuracy, and cost.

The procedure selected to measure heat flux is one-direction conduction model, which uses the Fourier's law (Incropera & DeWitt, 1999).

$$q_x \int_{x_o}^{x} \frac{dx}{A(x)} = \int_{T_o}^{T} k(T)\,dT \qquad (1)$$

In addition, the model will employ stationary state methodology (equation 2) to measure heat transfer rate in order to simplify design, and mathematical models and to decrease costs.

$$q'' = h(T_s - T_\infty) \qquad (2)$$

4. DESIGN

For the experimental setup, the following are the main design criteria:

i. Low Cost
ii. Simplicity
iii. Minimun size
iv. Control of parameters
v. Accuracy

Figure 3 provides a general layout from the experimental set. Its principal elements are the following: Reservoir tank, Diaphragm pump, Nozzle, Piping, Rack and pinion vertical positioner, Conductor block, Insulation, Electrical heaters, Thermocouples, Flowmeter, and Data Acquisition system.

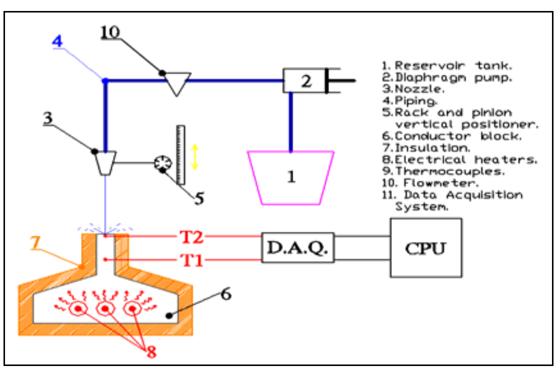

Figure 2: Layout of experimental set proposed.

The Experimental setup was designed to use water as cooling fluid, the reservoir tank has a capacity around 500 liters. Four parallel diaphragm pumps have been specified with maximun flow is 0.85 l/min each. Two nozzles with outlet diameter of 1 and 2 milimeters were consider. The conductor block is of aluminium alloy 2024, due to its conductivity and machinability, designed with a neck on the top surface to obtain horizontal isotherms and a finite element code was used to ensure the applicability of one-direction conduction model. Glass ceramic was selected as insulation due to its machinability and water resistance. The design uses 3 electrical heaters of 100 watts each, thermocouples K type and a infrared flowmeter.
D.A.Q system has 4 diferential channels, 14 S/s (samples by second) and 24-bit resolution.

5. ERROR ANALYSIS

An error propagation analysis was performed employing Kline – McClintock method.

$$\pm \delta F = \left[\left(\frac{dF}{dx_1}\right)^2 (\delta_1)^2 + \left(\frac{dF}{dx_2}\right)^2 (\delta_2)^2 + \cdots + \left(\frac{dF}{dx_n}\right)^2 (\delta_n)^2\right]^{1/2} \qquad (3)$$

Finally an error percentage around 24.3% was estimated, using simulated results by ANSYS software.

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