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MAKER: Using 3D Printed Experimental Design and Measurement of Internal and External Flow Convection Coefficient Using 3D Printed Geometries

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I am a graduate student at Indiana University Purdue University Indianapolis (IUPUI) pursuing a masters in Mechanical Engineering. I completed my undergraduate studies at IUPUI and received a B.S. in Mechanical Engineering. For my graduate studies, my focus is in thermal/fluid sciences and systems/controls. Currently, the research I am involved with is in the area of electrical propulsion. Specifically, it is electrical propulsion by means of pure ionic emission. The objective of the research is to construct an experimental test chamber to test different propellants for the characterization of an optimal propulsive system. The optimal system is determined by the specific impulse and propellant flow rate. The one with the highest specific impulse and the lowest flow rate is the desired propulsive system. Although my primary focus is with this, I participate in many projects related to controls and heat transfer. Aside from my research, I focus heavily on the advancement of engineering education at the collegiate level. I work on revising and updating laboratory experiments to help improve student understanding of how concepts are applied and utilized. I also spend time writing design optimization MATLAB codes for various applications.

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Abstract

The convection heat transfer is explored for a new academic laboratory experiment to help address the lack of practical experimentation that feature cutting-edge technologies. A cost-effective design is generated with three core principles: 1) Low Cost, 2) Low Maintenance, and 3) Concept Visualization. This is achieved through the following description of the apparatus. The acrylic-plastic chamber has a square base with a designated height. At the bottom of the chamber, there is a rectangular section removed to act as an inlet to the chamber. A high powered mini turbine fan is located at the top of the chamber. The fan acts as the driving force that pulls in the surrounding air from the inlet to generate a flow within the chamber. A door is located on the front of the chamber to allow for interchanging of different test geometries. The geometries being used are 3D printed to components either in the form of a fin (External Flow) or a hollowed channel parallel to the flow (Internal Flow). The components are mounted to the door with cylindrical heater connecting the two. The components are heated until steady state, where the average temperature along the surface is calculated. The velocity, surface temperature, and ambient temperature are record using a data acquisition system. The resulting convection coefficients are then determined.

Introduction

With technology becoming more of a dependency in the engineering laboratory teaching environment, older more hands on approaches and visual experiences of conducting experiments are becoming less of a norm. With the introduction of sophisticated technology, student involvement is becoming more and more limited. This limitation comes in the form of a little to no practical involvement in the experimentation. Without direct involvement, students can become less likely to develop practical skills. Practical skills that help foster the understanding of conceptual knowledge. It allows for them gain crucial skills in diagnosing problems on a conceptual and instrumental level.[3]

Numerous studies have been conducted over the years on the significance of emphasizing practical skills in the classroom/laboratory. Students are either placed in one of two categories: active or passive. For the students who are considered active, their dependency on engagement in experimentation in the course laboratory is critical to their understanding of fundamental concepts.[1] This unbalance, or gap, in the teaching education leads to several unprepared engineers moving into the workplace without sufficient skills required to contribute right away. The engineering students enter the workplace with a lack of critical thinking, inability to effectively communicate, and an absence of skills in identification/evaluation of problems in their respective fields.[4] These skills are all obtainable through the practical and visual laboratory experimentation.

To address this issue, convection heat transfer was the area of experimentation that was chosen for our focus on improving the practicality of the laboratory experience. Specifically, the aim is to do at it at an affordable cost while maintaining the ability to improve the undergraduate students' conceptual understanding through practical visualization.

Fundamental Theory

Convection heat transfer was chosen due to its complex dependency of on several variables and challenging visualization of how its physical meaning. Convection has two mechanisms that allow it to transfer energy. The first mechanism is random molecular motion, which is due to a temperature gradient existing in the fluid. The second mechanism (which acts as an identifier for convection as a mode of heat transfer) is the presence of a bulk fluid motion.[2] With the presence of a bulk fluid motion, fluid properties, fluid velocity, object geometry, and more must now be considered in the analysis of the problem under consideration. A simplified version of convection comes in the form of Newton's Law of Cooling

$$q^{"} = h(T_s - T_\infty) \tag{1}$$

where $q^{"}$ is the heat flux (W/m^2), h is the convection heat transfer coefficient, T_s is the surface temperature, and T_∞ is the ambient fluid temperature.

The heat transfer coefficient h dependence on the flow conditions and geometry adds to the addition of variables that are used in its determination. Whether or not it is internal and external flow that is taking place matters for analysis. Most importantly, when an object is undergoing forced convection, the determination of the Nusselt number with respect to the type of flow (internal/external) is a requirement. The Nusselt number is defined as the following

$$Nu = \frac{hL}{k_f} = f(Re_L, Pr) \tag{2}$$

where L is the characteristic length (m), k_f is the film conduction coefficient $\left(\frac{W}{m \cdot K}\right)$. From the above equations, it can be seen that the determination of the convection coefficient is requires many known quantities.

Designed Apparatus

The proposed design is shown in Figure 1 below for the apparatus. The device is setup so that the flow of air, which is supplied by a fan, flows through the apparatus at the top and out at the bottom. The door is equipped with a groove to allow for interchangeable parts manufactured by a standard 3D printer.

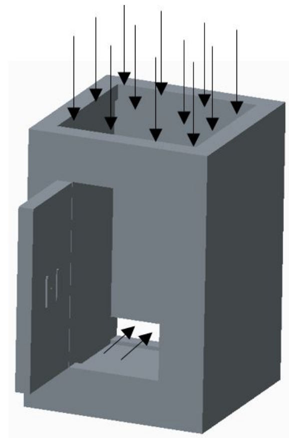

Figure 1: Apparatus Chamber

For each manufactured part, a base plate with the appropriate dimensions created with the unique design being tested protruded from the surface. This allows for multiple designs to be tested by the students. The development of single fin or fin arrays is also possible as shown in Figures 2 and 3 for both internal and external flow. The benefit to this is students could potentially design and develop their own version of an optimal fin or fin array and test it in the chamber. The students' designs could be easily produced through the cost effective method of 3D printing.

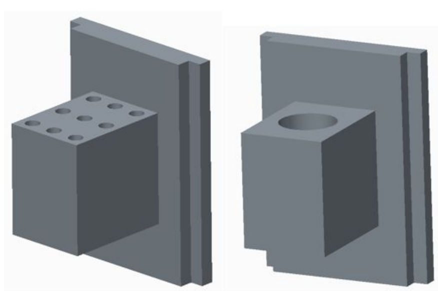

Figure 2: Internal Flow 3D Component

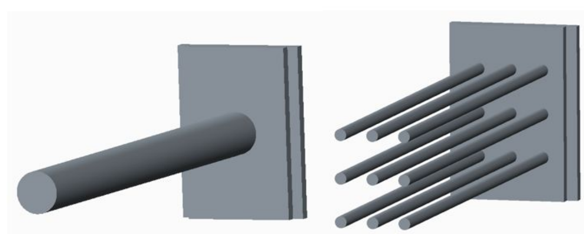

Figure 3: External Flow 3D Component

The method for measuring the convection coefficient is given through 5 steps. (1) Set the velocity on the Fan to a desired value. (2) Place a cylindrical heater inside the component (heater is wired through door) and set the input. (3) Wait until steady state is achieved and then record the temperature using thermocouples placed along the component and ambient temperature of fluid as well. (4) Using empirical formulations provided in several texts, determine Nusselt formulation. (5) Calculate the convection coefficient for the given conditions.

Future Work

The next steps are to build and test the apparatus. Once the apparatus is constructed, multiple tests will be conducted in order to verify its functionality and usability. A key addition to the apparatus would be an infrared camera to allow the students to better monitor the temperature distribution as it approaches steady state. The development of this apparatus allows students to engage in a practical laboratory experiment that offers a great deal towards their understanding of convection heat transfer both physically and visually.

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