MAKER: Laboratory Improvements for Mechanical Engineering (Phase 2)

Mr. Joseph Michael Derrick, Indiana University Purdue University Indianapolis

I am a young professional engineer who has graduated from Purdue University in Indianapolis with a masters in Mechanical Engineering. It should also be noted that I also received my B.S. in Mechanical Engineering from there as well. My graduate studies was focused in thermal/fluid sciences and systems/controls. Currently, my interests lie in aerospace applications with an emphasis in space propulsion and satellite design. Although my primary focus is with aerospace applications, 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.

Mr. Michael Golub, Indiana University Purdue University, Indianapolis

Michael Golub is the Academic Laboratory Supervisor for the Mechanical Engineering department at IUPUI. He is an associate faculty at the same school, and has taught at several other colleges. He has conducted research related to Arctic Electric Vehicles and 3D printed plastics and metals. He participated and advised several student academic competition teams for several years. His team won 1st place in the 2012 SAE Clean Snowmobile Challenge. He has two masters degrees: one M.S. in Mechanical Engineering and an M.F.A. in Television Production. He also has three B.S. degrees in Liberal Arts, Mechanical Engineering, and Sustainable Energy.

Mr. Vaibhav R. Shrivastav
Dr. Jing Zhang, Indiana University Purdue University, Indianapolis

Dr. Jing Zhang's research interests are broadly centered on understanding the processing-structure-property relationships in advanced ceramics and metals for optimal performance in application, and identifying desirable processing routes for its manufacture. To this end, the research group employs a blend of experimental, theoretical, and numerical approaches, focusing on several areas, including:

1. Processing-Microstructure-Property-Performance Relationships: thermal barrier coating, solid oxide fuel cell, hydrogen transport membrane, lithium-ion battery 2. Physics-based Multi-scale Models: ab initio, molecular dynamics (MD), discrete element models (DEM), finite element models (FEM) 3. Coupled Phenomena: diffusion-thermomechanical properties 4. Additve Manufacturing (AM) or 3D Printing: AM materials characterization, AM process (laser metal powder bed fusion, ceramic slurry extrusion) design and modeling

(http://www.engr.iupui.edu/˜jz29/)

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

Abstract

The convection heat transfer is explored for a new academic laboratory experiment to help address the lack of practical experimentation due to the continued integration of technology. The objective is to design an experiment to be used in the laboratory that enhances the student understanding of convection process and principles. 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 plexiglass 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 has become more and more limited. This limitation comes in the form of little to no practical involvement in the experimentation. Without direct involvement, students become less likely to develop practical skills. Practical skills that help foster the understanding of conceptual knowledge. It allows for them to 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 imbalance, or gap, in the teaching education leads to several unprepared engineers moving into the workplace without sufficient skills required to contribute right away. 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] Skills such as these are obtainable through 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 physical visualization. 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

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

(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. Analysis of convection problems also depend on whether the flow is internal or external. 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

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

(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 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.

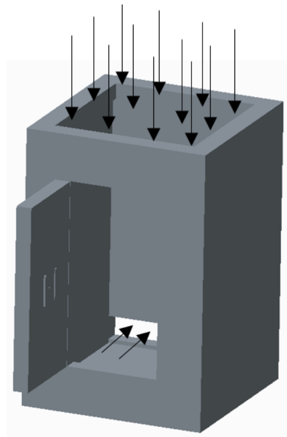
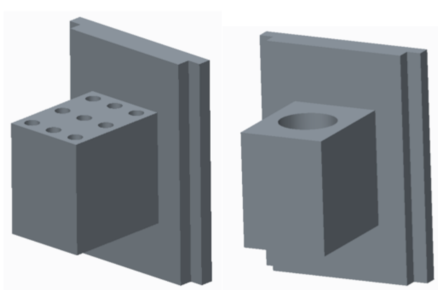


Figure 1: Apparatus Chamber

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 array is also possible as shown in Figures 2 and 3 for both internal and external flow. The benefit to being able to design the test geometry gives student groups unique control on the outcome of the experiment. Students are able to explore how fin or fin array designs impact the rate of heat transfer and the heat transfer convection coefficient in the convection heat transfer process. The students' designs could be easily produced through the cost effective method of 3D printing.



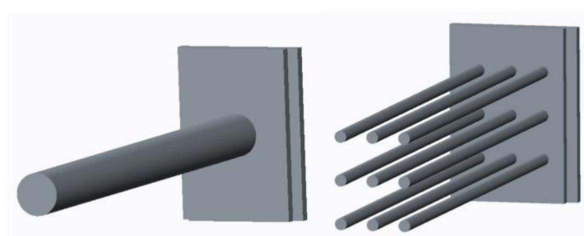


Figure 2: Internal Flow 3D Component *Figure 3: External Flow 3D Component*

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.

Additionally, when testing and verification is completed, an assessment study will be conducted to identify its impact on student learning. This will be completed by implementing the apparatus into the laboratory curriculum for the next upcoming academic year. A preliminary survey will be issued prior to performing experiment. The survey will cover fundamental theoretical questions. After completion of the experiment, an exit survey will be issued.

References

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