Immersion Wort Chiller Optimization: Project-Based Learning in Undergraduate Heat Transfer

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Abstract

Project-Based Learning (PjBL) has been adopted as a highly effective teaching-learning style worldwide in the last few decades in the engineering educational community. Major benefits for students who participated in Project-Based Learning include achieving higher level of motivation, greater depth of understanding of basic concepts, increased creativity, improved teamwork skills and interpersonal communication skills. In this paper we reported a fun example project that can be used in undergraduate heat transfer class for Project-Based Learning: Optimization of an immersion wort chiller for a small-scale home beer brewing process.

Students were self-grouped with three to five students in each group. Each group was then provided with a 10-foot-long copper tube of diameter 3/8 inch to design and optimize an immersion wort chiller that can cool a bucket of hot water as fast as possible.

Preliminary evaluation of learning experience enhancement was performed by conducting a survey among the students at the end of the semester. The purpose of the survey was to identify what they had learned in such a project, and whether or not the project improved their learning experiences. Positive feedback and outcomes were observed.

1. Introduction

Heat transfer is one of the core courses in mechanical and energy engineering curriculum at University of North Texas. This course is three credit hours and is typically taught in one semester. Topics of heat transfer cover all three modes of heat transfer: conduction, convection and radiation [1]. Instructors are often faced with the challenge of how to engage students and motivate students for the purpose of improving teaching effectiveness.

Two major approaches that had been discussed intensively to enhance teaching-learning effectiveness in the last decades are problem-based learning (PBL) [2-6], and project-based learning (PjBL) [7-10]. In problem-based learning, students gain knowledge and skills by investigating and finding solutions for open-end, complex problems with no definite "correct" answers. One common concern about problem-based learning is that students may not understand what is most important for them to learn, and for many engineering problems, unique correct answer does exist. In project-based learning in engineering community, students gain knowledge and skills by working collaboratively in groups on real-world, hands-on industrial projects with a prototype or a completed design work as the deliverable. Major benefits for students who participated in Project-Based Learning include achieving higher level of motivation, greater depth of understanding of basic concepts, increased creativity, improved teamwork skills and interpersonal communication skills. One or many previous well-defined project(s) by instructor is essential in project-based learning. Instructors can assign one identical project to all student groups or assign totally different projects to each student group. In many cases, students are also allowed and encouraged to come up with student-proposed projects. A good example for such a student-proposed project-based learning practice is the heat transfer course at Brigham Young University taught by professor Vladimir Solveig [11]. On professor Vladimir Solveig's web page of heat transfer course, at least 200 different projects completed by student groups are listed and more projects are continuously added every year. This practice has some advantages and has been proven to be successful and effective. However, a different approach we would like to propose in the paper is to make the project-based learning also competitive: assigning one identical challenging project to all groups, giving students full credits for completed projects and functional prototypes, yet honoring only the winning team(s) with bonus credits.

A previous well-defined project is essential to guarantee the success of such a competitive project-based learning. A successful project should satisfy the following criteria: (1)

Engaging: the project should be fun enough to arouse students' interests; (2) Challenging: the project should tie to all important contents of the course; (3) Achievable: prototype of the project can be completed in a period of one to two weeks. In this paper we propose an example project for heat transfer course that can satisfy all three criteria: optimization of immersion wort chiller for a mini-scale home beer brewing process. The project is engaging: most college students love beers and quite a few even developed the hobby of home beer brewing. As a matter of fact, home beer brewing is pretty popular here in Texas. Many of the authors' students have practiced home beer brewing and enjoyed their own favorite flavors of beer and the successes of such an activity. The project is also challenging: heat transfer concepts and analysis of conduction, natural convection and forced convection are all involved. Radiation is also involved but usually ignored. The project is achievable: for a group of three to four students, building and testing the chiller could be accomplished within two consecutive weekends.

2. Project Statement

A home beer brewing process may include the following steps: milling, mashing, boiling, cooling, fermenting, priming, bottling and aging [12]. For the cooling step, rapidly cooling of wort can significantly improve the finished beer's clarity and flavor. Therefore, a fast-cooling chiller is preferred. Immersion chiller is a simple yet very effective solution. Typical immersion chillers are made of coiled stainless steel or copper tubes and are commercially available at 50 to 150 US dollars [13]. All commercially available chillers share identical cylindrical helix design, which could be optimized to increase the heat transfer performance.

Immersion wort chiller design and optimization was chosen as the subject for research and educational purpose before. Joye and Smith [14] experimentally evaluated commercially available immersion chillers of different diameters, coil placements and coil without fins in different shapes. Smith and Comolli [15] successfully designed an educational module (lab demo and lab experiments) for process modeling for students studying chemical engineering at Villanova University. Our paper, however, focuses on (1) how to design a successful project for project-based learning in heat transfer class and (2) whether such a competitive project had enhanced students learning experiences or not.

Typical home beer brewing starter kit consists of 5 gallons of wort and the cooling (from 100 oC to 15 oC) time using 50-foot-long 3/8 inch copper tube is about 20-30 minutes. To mimic this process and meanwhile to stay in the project budget, hot water instead of real wort was used for the final project prototype performance evaluation. In the meantime, size of the wort container was scaled down from 5 gallons to 1.58 gallons. A cylindrical container with diameter of 8 inches and height of 7.25 inches was used for testing. For safety reasons, "wort" (hot water) temperature was lowered from 100 oC to about 80 oC.

Students in the class were self-grouped with three to five students in each group. Each group was provided with one 10-foot-long copper tube (O.D. =1/2 inch and I.D. =3/8 inch, wall thickness = 0.0350 inch) and asked to design an immersion chiller that could be used to cool a bucket of 1.58 gallons of hot water from 80 oC to an average of 35 oC using faucet water of 25 oC (constant) as cooling fluid. Students could add fins to the tube at their own cost if they choose such an optimization. All groups that completed the project with functional prototype would receive 100 points toward their final grade. The student group that achieved the above goal using the shortest time would be the winning group and would receive an extra 100 bonus points towards their final grade.

3. Design and Test

There were 19 students in the fall semester heat transfer class. Students were self-grouped with three to five students in each group, total four groups and they were labeled as group 1 to group 4. Each group proposed a different design as expected. These student-designed immersion chillers are illustrated in Figure 1. Table 1 summarizes the details of all four designs. Designs can be classified into two categories: helical coil and conical coil, either equipped with fins or without fins.

Tests of immersion chillers were carried out in the department undergraduate teaching lab. Faucet water of 25 oC constant was used as cooling fluid. The hot water container was a cylindrical bucket with diameter of 8 inches and height of 7.25 inches. Bucket was not insulated and open at the top yet radiation was ignored. Water volume flow rate was about 100 ml/sec, which was equivalent to mass flow rate of 0.1 kg/sec. Therefore, Reynolds number for the internal flow was about 11,731, which meant the fluid inside the copper tube was turbulent flow throughout. Temperature of "wort" (hot water) was averaged from two thermocouple measurements: one thermocouple was placed 0.25 inch above the container's bottom and the other was placed 3 inch underneath the hot water surface. Temperature data were recorded every 10 seconds until the "wort" average temperature reached 35oC. Figure 2 shows the setup used for the test. Figure 3 shows the experimental testing process and the winning team.

Figure 4 summarizes all the test results. Time needed to cool down the wort from 80 oC to 35 oC were 240 seconds for group 1, 290 seconds for group 2, 220 seconds for group 3 and 250 seconds for group 4, respectively. It was not a surprise that the design from group 3 won the competition: for natural convection, conical coil design usually performed better than helical coil design due to the fact that conical coil could cool more water on the top, therefore, promoting better natural convection. Also design from group 3 employed the fin structures. Fin structure added 13% contact surface between the tube and the wort. The reason group 2 design required the longest time for cooling was probably due to incomplete immersion of the chiller into the hot water. Other than that, results from group 1, group 3 and group 4 were pretty close. This actually indicated that the total contact area between the tube and hot water was the most important factor in the designing of such an immersion chiller. Comparisons between theoretical correlations and experimental results were not performed this time due to time constraint; this, however, could be an added requirement for the next run of design competition.

4.Survey on Learning Enhancement

A complete list of survey questions is provided in the appendix. The purpose of the survey was to identify what the students had learned in such a project, whether they preferred same-topic project competition or student-proposed projects, whether the project enhanced their learning experiences or not, and which factors were most important in designing an immersion chiller. Survey results indicated this was a very successful project for project-based learning. Nineteen out of nineteen students (100%) agreed that the design completion of immersion chiller aroused their curiosities of heat transfer; nineteen out of nineteen students (100%) liked this project; Eighteen out of nineteen students (95%) agreed that the "immersion chiller" project enhanced their learning experiences of heat transfer class. Sixteen out of nineteen students (84%) preferred project competition to student-proposed projects. Eleven out of nineteen students (58%) realized total immersion area is the most important factor in the designing. Survey results clearly indicated that immersion wort chiller optimization was a fun and effective project for Project-Based Learning. This project greatly promoted student engagement and enhanced student learning experiences. Such a project could be a good choice for heat transfer class if any engineering program would like to incorporate project-based learning approach into its curriculum.

5.Conclusions

In this paper, we presented a heat exchanger design competition project that will effectively enhance students' learning experience: the designing competition of an immersion chiller for a mini-scale home beer brewing process. Students who participated in the project were provided with a 10-foot-long copper tube of diameter 3/8 inch to design an immersion chiller that can be used to cool a bucket of hot water from 80 oC to an average of 35 oC as quickly as possible. Preliminary evaluation of the effectiveness of learning enhancement of such a project competition was obtained by conducting a survey among the students at the end of the semester. The purpose of the survey was to identify what the students had learned in such a project, whether they preferred same-topic project competition or student-chosen projects, whether the project enhanced their learning experiences or not, and which factors were most important in designing an immersion chiller. Positive feedback and outcomes were observed.

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Table 1 Design summary

Group	Design	Diameter (inch)	Coil spacing (inch)	Fin
Group 1	Double helix	I.D.= 5	2	No
		O.D.= 7		
Group 2	Conical coil	Upper D=7.125	1.25	No
		Lower D=4.5		
Group 3	Conical coil with fins	Upper D=6.5	1	Rectangular fin L=2.25, W=0.5
		Lower D=3		# of fins: 21
Group 4	Single helix with fins	5.5	1.5	Junk radiator L=6, W=1
				# of fins: 4

(a) group 1 (b) group 2 (c) group 3 (d) group 4

Figure 1 Student-designed immersion chillers

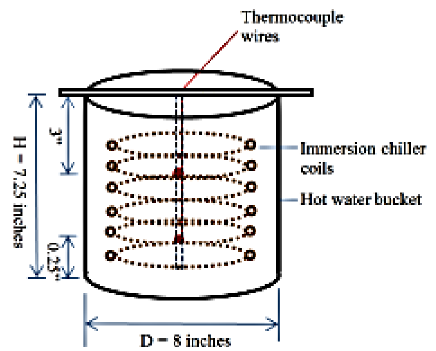

Figure 2 Immersion chiller test setup

(a)Immersion chillers under testing (b) winning group (group 3) with their design

Figure 3 Test the immersion chillers

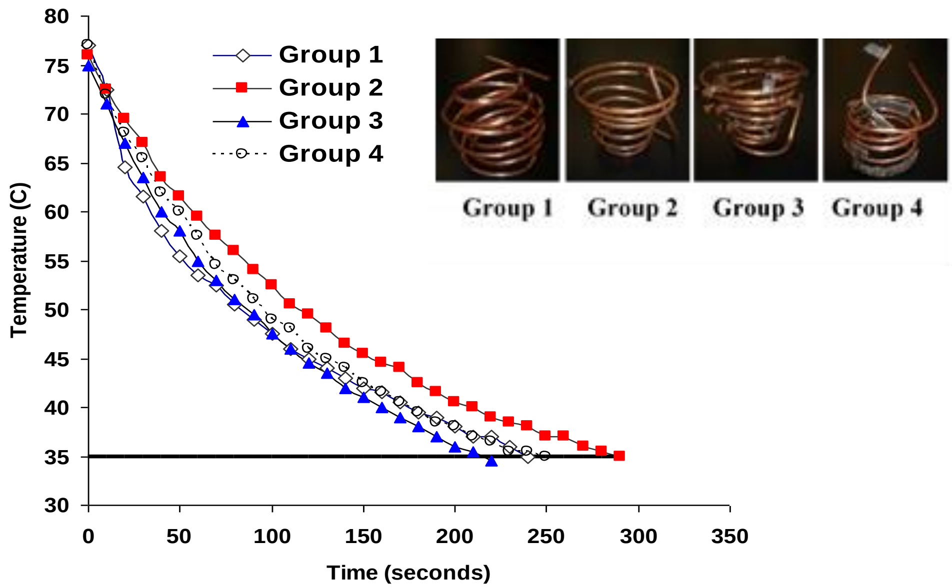

Figure 4 “Wort” average temperatures vs. time

Appendix: Student Survey Questionnaire

(1) The "immersion chiller" project aroused my curiosity of heat exchanger design

☐ Yes ☐ No

(2) I liked the project

☐ Yes ☐ No

(3) The "immersion chiller" project helped me understand heat transfer better

☐ Yes ☐ No

(4) I think MY group project design was successful

☐ Yes ☐ No

(5) Which type of project do you prefer for heat transfer class?

☐ Topics picked by students, each group having different topics

☐ A competitive project: all groups work on same project

(6) Which one of the following factors do you believe is the most important factor in the designing of the immersion chiller? Check all applicable answers.

☐ Total area of the tube immersed in the hot water

☐ Shape of the tube cross-sectional area

☐ Materials of the tube

☐ Spacing between the tube coils

(7) Which of the following heat transfer mode(s) is/are involved in the immersion chiller heat transfer? Check all correct answers.

☐ Conduction

☐ Internal flow forced convection

☐ Natural convection

(8) Which of the following treatments do you believe will enhance the heat transfer rate?

☐ Add fins to the tube

☐ Increase the cold water mass flow rate

☐ Stirring the hot water