Design, fabrication, and testing of a digitally controlled charcoal smoker – A capstone project

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ABSTRACT

There are many smokers available in the market nowadays. The two popular options are either electric or charcoal heated, each with their own downfalls. This capstone project built and tested a self-monitoring smoker that uses the smoke from burnt charcoal box to smoke chicken or meat in a separate smoker chamber. The objective of this capstone project was to design, build and test a charcoal smoker that is capable of maintaining its smoker chamber at a constant temperature that would be set by the user. The temperature of the smoker was controlled by the air flow rate into and out of the chamber using dampers at the inlet and exhaust ports. The project tested three set temperatures: 200˚C, 215˚C, and 250˚C. The temperature was maintained as needed within some margin ±5˚C. This fluctuation was due to airflow dampers opening and closing. To demonstrate the performance of the smoker, a raw chicken was smoked for 3.5 hours and it was smoked as intended. The smoker took approximately eight minutes to reach 200˚C. The project was led by a team of three senior MET (mechanical engineering technology) students. The project revealed the high impact on the level of understanding of students. Students performance and project outcomes were assessed against ABET learning outcomes, such as (1) applying knowledge, techniques, and skills to engineering technology activities, (2) applying knowledge of mathematics, science, and engineering to engineering technology programs, (3) conducting tests, measurements, calibration and improving processes, (4) problem solving: ability to identify, formulate, and solve engineering problems, (5) teamwork and (6) effective communication: ability to communicate effectively.

Keywords: *Automatic temperature control, Design and fabrication, Charcoal smoker, Capstone design*

1. INTRODUCTION
Meat smoking has been a process used for a very long time. It started as a mean of not only flavoring but for preserving food as there were no refrigerators at that time. Smokers were so popular that most farms and homesteads all had their own smokehouse or shack. Nowadays, people still like to use smokers for tasting and flavoring purposes. There are two types of smokers: electrical or charcoal smokers. Charcoal will require continuous monitoring by the user to keep feeding coal into the coal box. Electric smokers have more control over the temperature by turning the heating coils on/off depending on the sensor feedback embedded inside the smoker chamber, however, the main disadvantage for electric smokers is that the taste is not the same as for charcoal smokers.

No current commercial smokers are readily available unless if specially customized, that combines between charcoal and control of the smoker chamber temperature. Control over the smoker chamber will need a temperature sensor, a control unit, actuators and some sort of mechanism to increase or turn off the flame in the charcoal burning box.

To overcome the shortage in current smokers, a team of three senior students in the MET (mechanical engineering technology) program at University name decided to design, fabricate and build, and test a self-controlled charcoal smoker. The main objectives of the project were (1) to design and build a charcoal smoker that would maintain and adjust its temperature as necessary to meet a set temperature by the user and (2) eliminate the continuous monitoring by the user and, thus, building a standalone unit.

2. BRAINSTORMING AND PRELIMINARY DESIGN
The team started searching for available options and decided to mimic the functionality of a regular charcoal smoker in its shape, by having a charcoal burning chamber connected to a smoker chamber, as shown in Figure 1. Air was allowed to enter the firebox from the side and would then move to the smoker chamber before leaving through the exhaust pipe. However, a control system was deemed necessary to control the volumetric flow rate of air entering the burner which in turn controls the temperature of the smoker: if temperature is lower than a specific temperature, which is usually set by the user and is usually around 200 ˚C, then the air inlet dampers would open allowing more air. After the temperature was met, the inlet dampers are to be shut blocking any more air. The team decided to use a thermocouple inside the smoker chamber whose output would be connected to an Arduino. The Arduino

would then be connected to two actuators that open and close the dampers of the inlet and exhaust ports. The set temperature, which was usually set around 200 ˚C as other set temperature for other smokers, was varied by the user using a potentiometer. An LCD screen was connected to the Arduino to allow the user to see the set temperature. A wiring diagram for the Arduino, LCD and actuator is shown in Figure 2a and the final Arduino is shown in Figure 2 (b).
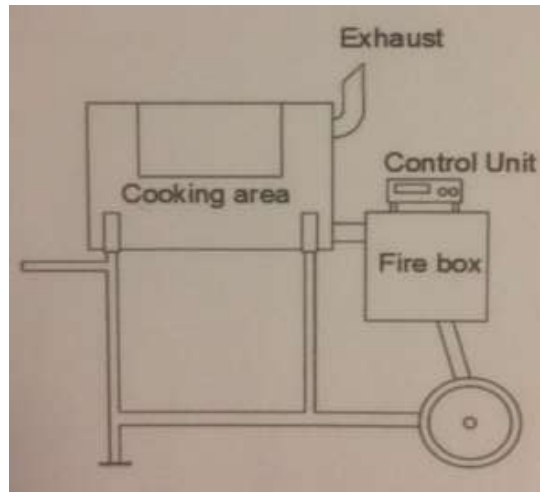

Fig. 1: Preliminary and initial design showing main units: smoking cooking area, charcoal firebox, control unit, and exhaust

The smoker was selected to be a keg barrel with a 15-inch diameter and 22-inch in length. The volume of the burning firebox to smoker ratio was estimated based on bbq-superstar online calculator (D., 2017). The results came as $17.5 \times 10.5 \times 10.5$ in^3 or any geometry with a volume of 1930 in^3.
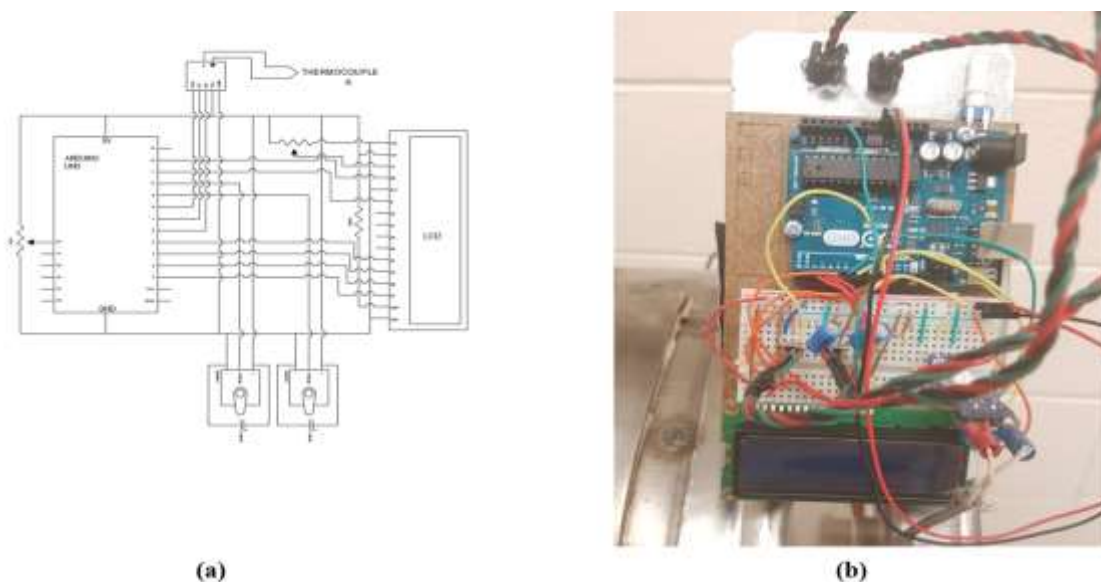

Fig. 2: Arduino wiring (a) schematic, (b) actual product

3. FINAL DESIGN AND FABRICATION
The stand that would hold the smoker and firebox was designed from a 1-inch pipe. A door was cut through the smoker barrel as shown in Figure 3(a). Two 3-inch holes were made in the bottom of the smoker, one of them is shown in Figure 3(a), each to be connected to the firebox and exhaust pipe. The piece that was cut from the barrel was hinged to the outer surface and used as a door. Upon testing, there was some leakage from the door, thus high-temperature leather seal was used around the door perimeter to minimize the leakage as shown in Figure 3(b). At the initial stage, a thermometer was attached to the inner surface of the door (Figure 3c) that was then replaced with a thermocouple and connected to the Arduino. The finalized smoker chamber is shown in Figure 5.

Fig. 3: (a) Smoker chamber with door opening and exhaust shown in the bottom, (b) finalized smoker with door hinged and leather insulation around the periphery, (c) smoker door closed with initial thermostat

The next part was designing and fabricating the burning firebox. It was cut off a tools box to meet the calculated volume of 1930 in^3 that is compatible with the volume of the smoker (15-inch diameter with 22-inch length). The original tools box is shown in Figure 4(a). The box was flipped on its side to use its door as a side door for the fire-box. Two curved brackets, with the same curvature as that of the smoker, were welded to the top side of the firebox, shown in Figure 4(b), to support the smoker along with other two curved brackets on the stand (shown in Figure 5). Two interfering holes with 2-inch diameter each were drilled through the side of the firebox to serve as the air inlet ports where linear dampers were installed to control the air flow into the firebox. These are shown in Figure 4(c). The box was finalized by adding high-temperature ceramic insulation (Figure 4(d)) on the inner surface of the door and by grinding off the old paint which was not heat resistant before applying 2 coats of high-temperature paint. To secure the door, a pop-up bracket was welded to the box that pops-up when the door is pushed through it. After the box was done, it was bolted to the stand and then the smoker was bolted on top of it as shown in the final product assembly in Figure 5. The two actuators that open and close the dampers at the inlet and exhaust ports are shown in Figure 4(c) and Figure 5, respectively. As discussed earlier, the thermocouple output was connected to the Arduino which in turn activates the actuators to open or close the dampers to allow air through the product increasing the temperature of the smoker chamber or blocking any air to maintain the temperature. The final assembled product is shown in Figure 5 after installing wheels to the stand, painting the stand, applying another coat of paint to the fire-box, and connecting all wires to the Arduino.

(a)   (b)

(c)   (d)

Fig. 4: Smoker box (a) cut from tools box, (b) paint removed and first coat or high temperature paint applied, (c) air inlet ports drilled and dampers installed with actuators connected to the Arduino, (d) high temperature ceramic insulation installed on the inner surface of the burner firebox

Fig. 5: Final product with main components labeled

4. PRODUCT TESTING AND RESULTS

In the initial design, one damper only was used at the inlet port. Also there was no leather seal around the smoker door. Among testing, two observations were made: first the temperature was too high and was difficult to maintain at the set temperature and second there was significant leakage through the smoker door. To overcome this, a second damper and actuator were installed at

the air exhaust. When both dampers are opened, the air would be driven from the inlet to the outlet port. The dampers' actuators were controlled by the Arduino based on the smoker chamber temperature. The temperature is maintained by opening and closing the two dampers at the inlet and exhaust ports to control the air flow rate into the burner and the smoker. The results for the first test done are shown in Figure 6. It took the smoker chamber approximately 8 minutes to reach to the set temperature of 200˚C. The fluctuations in the temperature of approximately ±5˚C around the set temperature was due to the opening and closing of the dampers. To flatten out these fluctuations, the damper-actuator connecting link angle was slightly adjusted so that the dampers do not close completely. After this adjustment, the new testing results are shown in Figure 7 where it can be seen that the steady state temperature is more flat around the set temperature. Thus, the first goal for this project was achieved which was building a smoker that would maintain its own temperature and adjust it as necessarily.
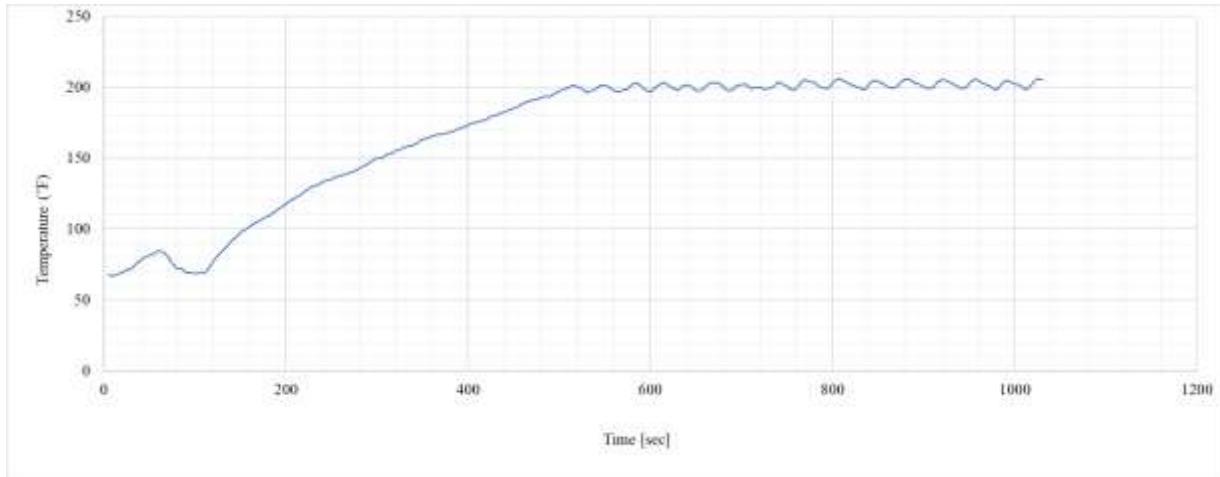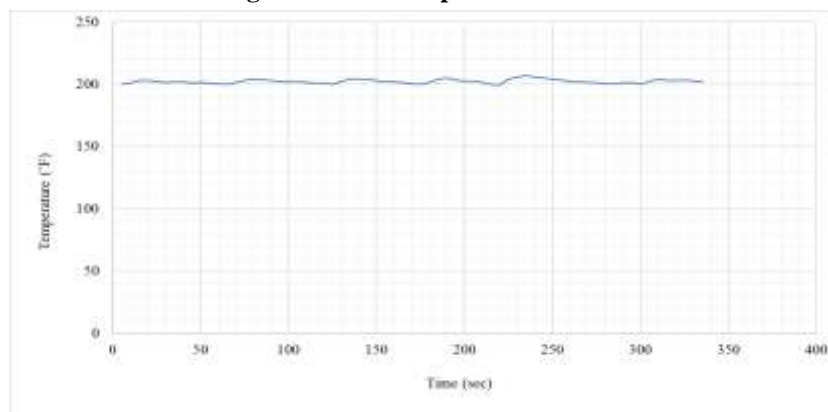

Fig. 6: Smoker temperature test # 1

Fig. 7: Smoker chamber temperature testing after slight change in damper angles

After the temperature was successfully maintained, a whole chicken was smoked for almost two hours at 215˚C. The smoker chamber temperature is shown in Figure 8a and the smoked chicken is shown in Figure 8b. Two observations can be seen from Figure 8a, first the temperature was maintained accurately around 215˚C with ±1-2˚C. The second observation was the spikes in the temperature curve. These spikes were due to the opening of the smoker door to check on the chicken. Since the thermocouple was attached to the smoker door, thus, whenever the door is opened the temperature would drop. However, the temperature returned momentarily to the set temperature after the door was shut close. It is worth mentioning that the first spike in the steady state temperature (215 C) was observed 45 minutes after the set temperature was met which means that the temperature smoker did not need to be opened for 45 minutes and, thus, achieving the other goal of this product which is building a smoker that won't need continuous monitoring by the user.
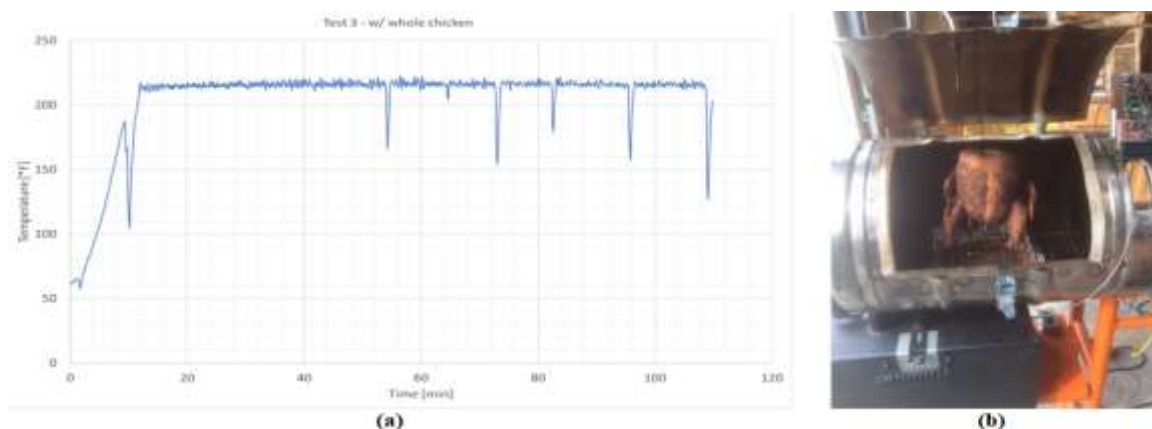

Fig. 8: (a) Testing the smoker with a new set temperature and (b) while smoking a whole chicken

5. PROJECT ASSESSMENT

Through the implementation of the project, the students got experience in many aspects needed in industry after their graduation such as brainstorming, preliminary and final design, testing and measurements, product improvement in addition to improving their written and oral communication skills. The outcomes of the project were evaluated against ABET learning outcomes summarized in Table 2. Performance assessment and feedback were done through the evaluation of biweekly submitted reports. There were four main categories toward the final GPA of the student: biweekly and final draft reports (15%), final report (50%), presentation (25%), and teamwork evaluation (10%). The details of the four categories are as follows:

1) Biweekly reports: constituted 15% of the final GPA. These reports summarized the work of the previous two weeks. Each report was recorded on a log-book that included minutes of meetings, weekly list of pending and completed goals, notes from outside research, calculations, sketches and drawings, test plans, collected data, and analyses.

Each of the biweekly reports had a general theme as follows:

Report 1 Proposal
Report 2 Conceptual Design
Report 3 Preliminary Design
Report 4 Critical Design
Report 5 Proceed to Test
Report 6 Draft - Final Report
Each report was evaluated based on rubrics given in Table 1.

Table 1: Rubrics used for evaluating biweekly reports

Points	4	3	2	1	0
Weekly notes from supervisor and other parties	Notes exceeded expectations	Notes were appropriately relative to meeting content	Notes qty & quality were missing some meeting contents	Some evidence of notes	No evidence of notes
Legibility	Exceeded expectations	All entries clear & legible	75% or less clear & legible	50% or less clear & legible	25% or less clear & legible
Readability	Exceeded expectations, cross-referenced	Well identified entries	< 75% are identified, erratic flow in places	50% are identified, erratic flow in most places	< 25% identified, erratic flow
Completeness	Well documented, flow and content of entries demonstrated forethought, connections, and results, in and between process phases	75% of flow and content of entries demonstrated forethought, connection, and results	50% of flow and content of entries demonstrated forethought, connection, and results	Flow and content were spotty and unconnected	No evidence of forethought, connections, or results in and between process phases
Lab Notebook Guidelines (items i-viii above)	Followed all criteria	Criteria followed about 75% of the time	Criteria followed about 50% of the time	Criteria followed about 25% of the time	No evidence of following guidelines

The purpose of the draft final report was to evaluate the project and to see the percent completion. This was done before the presentation in order to provide the students with enough feedback for their presentations.

2) Final report (50% of final GPA): submitted by the end of the semester after getting feedback from the project supervisor, guests, and other faculty members, who served as external evaluators, and then embedding their comments, suggestions, and corrections in the final report.
3) Presentation (25% of final GPA): The student presented results of the project to interested MET faculty members and guests.
4) Team evaluation (10% of final GPA): The remaining 10% of the grade were assigned to team evaluation where the team members evaluated each other and submitted, separately, their evaluation for themselves and other team members. This self-evaluation was half the 10% assigned to team evaluation. The other half was obtained through oral testing where the instructor asked each team member some questions and evaluated his knowledge to the design, manufacturing, and implementation of the project. It should be noted that although the first half of team evaluation contributed to 5% of the final GPA, but since the project supervisor is not able to accurately predict the percentage work done by each member, a secured evaluation form that is accessible by the student and the instructor was used to decide if someone did not participate at all. Although this seems to be partially biased, especially when having some personal issues between two members in a team, a confession by more than two members that one team member did not participate equally would be a strong reason for a low grade for that member.

Table 2 shows the relation between the ABET learning outcomes and the category/ies that were used to meet these expectations.

Table 2: ABET ETAC students learning outcomes rubrics used for project assessment and the respective means used to meet these outcomes

	ABET ETAC Rubric/Learning Outcomes	Means used to meet the rubrics
(1)	Apply knowledge, techniques, and skills to engineering technology activities	Final Report and biweekly reports
(2)	Apply knowledge of mathematics, science, engineering, and technology to engineering technology problems	Final report and biweekly reports
(3)	Conduct tests, measurements, calibration and improve processes	Biweekly reports, draft report, and final report
(4)	Problem Solving: ability to identify, formulate, and solve engineering problems	Project proposal and biweekly reports
(5)	Teamwork	Self-evaluation (described previously)
(6)	Effective Communication: ability to communicate effectively	Presentation and biweekly reports

6. CONCLUSIONS

By the end of this project, the students were able to: (1) build a charcoal smoker that detects maintains the smoker's temperature, (2) tested and validated the accuracy of the smoker temperature, and (3) modified their design to have fewer fluctuations in the readings.

A major drawback or limitation of this system is its inability to detect the meat or chicken temperature and, thus, needed the user to check on it. A future provision would be installing a secondary thermocouple which would measure the meat/chicken temperature when inside the smoker.

Assessment rubrics reflected students expectations from ABET learning outcomes. The capstone assessment should be redesigned to include the other ABET outcomes such as ethics in the working environment and to allow better teamwork evaluation.

7. REFERENCES

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BIOGRAPHY

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