Multidisciplinary Teams for Engineering in Food Safety Applications – Bridges between Engineering and Biology

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Abstract – A team of undergraduate students from mechanical engineering and poultry science was assembled and worked cooperatively on a food safety project. The particular problem addressed was the development of a non-chemical-based clean-in-place system for cleaning the piping used to transport giblets in a poultry processing plant. The design and testing of the system required engineers to work with poultry plant processors and microbiologists. In addition to the technical challenges, there were challenges associated with implementing a multidisciplinary project into existing academic programs. In this paper, the approaches used to overcome these challenges and their effectiveness are discussed.

Keywords: Multidisciplinary teams, food safety, poultry science, biology.

INTRODUCTION

The issues in complex engineering problems are rarely contained within a single academic discipline, so multidisciplinary teams are typically required. To prepare students to face such complex problems, educational programs have increasingly provided opportunities for students to work on multidisciplinary teams. These teams can consist of students from different engineering disciplines [Shooter, 25] or a combination of engineering and technology students [Jahanian, 16]. This latter type of collaboration can be extended further in industrial projects, in which engineering students work with practicing technicians [Croissant, 9]. Engineering students can also benefit from working with students from the sciences, including the physical sciences [O'Connor, 20] and health sciences [Zhang, 31]. The application of real products and processes, even those based on advanced technology, involve many non-technical issues. For example, the development of sustainable manufacturing processes and designs requires consideration of societal and economic impacts [McKay, 19]. In addition, successful implementation of a product requires more than technical performance, so the teaming of engineering with students in business [Bhavnani, 4] or industrial design [Wesner, 30] has been used to more completely address all (technical and non-technical aspects) of complex projects. Not only do such multidisciplinary teams enhance the educational experience of the students, but they can lead to improved team performance. For example, teams with both engineering and industrial design students have been shown to produce higher quality results than teams with only engineering students [Terpenny, 26]. Another study showed that teams with higher diversity improved more during the course of a project than did teams with lower diversity [Dean, 10].

This benefit of diversity is consistent with general observations of team performance, since the effectiveness of teams is improved by including members with a mix of personalities and skills [Dutson, 11]. Forming such effective teams requires identifying team roles and selecting individuals to fill specific roles [O'Doherty, 21;

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Salama, 23]. While students prefer to self-select teams [Adams, 1], assigned teams generally perform better on complex projects. In general, successful teams consist of "compatible opposites" [Brewer, 5]. One particular example is a study which showed that teams with heterogeneous grade point averages, but more homogeneous interests, performed better than teams that were either homogeneous or heterogeneous in both aspects [Brickell, 6]. The team selection can be based on evaluation of specific individual skills [Gibbings, 13] or by tests, such as the Myers-Briggs Type Indicator (MBTI) to determine personality types, which not only indicates individual learning styles [Felder, 12], but also team performance [Jensen, 17]. One caveat in identifying effective teams is that team performance does not always correlate with individual or team learning [Schmidt, 24; Agogino, 2]. Work may not be equally distributed, so there should be a balance between individual and team activities [Kørnøv, 18]. In addition, students learn from mistakes, so students may learn more from a failed project than from an easy success. Thus, although students certainly benefit from being part of a successful team, individual learning should not be sacrificed at the expense of team performance.

The primary advantage of interdisciplinary projects is that the broad topic coverage provides ranges of information, experiences and interactions that enhance student learning [Hersam, 15]. However, this creates challenges in that all team members do not have a common academic background. For example, terminology can be a significant barrier to effective team functioning [Anthony, 3]. Thus, supplemental instruction may be required, so that individual team members can adequately communicate and make meaningful contributions [Watkins, 28]. Such supplemental instruction also provides opportunities, since, if the project does not rely members having completed specific coursework, younger students can be involved in the teams [Coyle, 8] or interdisciplinary projects can be implemented in freshman courses [Weinstein, 29].

Any team requires coordination and leadership, but these factors are particularly important for multidisciplinary teams [Carroll, 7]. Likewise, activities and interactions outside the team (*i.e.* the local culture) affect individual, and thus team, performance [Tonso, 27], and these would be enhanced with individuals (students and faculty) from different disciplines. Such differences are further increased in international collaborations, which are important for preparing students for careers in an increasingly global environment [Grimheden, 14]. Broad application of interdisciplinary projects requires coordination at the college level, or between colleges, which creates additional administrative challenges in overcoming interdepartmental barriers [Ollis, 22]. Although it is difficult to provide all students with multidisciplinary project experiences, the first step is to provide opportunities for some students and build on successful programs to expand the availability.

One area in which such diverse multidisciplinary complementary teams are needed is in the design of engineered products for biological applications, such as the development of cleaning equipment for food processing systems. The specific application addressed in this project is equipment for cleaning pipes used in poultry processing plants.

Chicken parts, such as giblets, are transported across poultry processing plants in stainless steel pipes, which must be periodically cleaned to kill and remove harmful bacteria. There are two general approaches to cleaning these pipes. One is to disassemble the piping system and individually clean the pieces. The other is to use a clean-in-place (CIP) process, in which the piping system is flushed with a disinfectant. Cleaning the dissembled pieces is thorough, but time consuming, while the CIP process is easier, but may not effectively clean less accessible areas, such as at the joints between pipes. The disinfectant chemicals used in the CIP process must be properly disposed of, which creates additional complications. The objective of this project was to develop an improved system for cleaning the pipes. The system is based on delivering high-pressure high-temperature water inside the stainless steel pipe. The two primary advantages are that the system uses only water, which eliminates the need for the disinfectant chemicals, and could use a smaller volume of water as compared to flushing the system with a disinfectant.

TEAM ORGANIZATION

The design, fabrication and testing of a cleaning system requires a variety of expertise, so a multidisciplinary team is required. In particular, the design and fabrication of a system for delivering high-pressure high-temperature water to the inside surface of the stainless steel pipe is a mechanical engineering type problem, but because the piping is used to transport food products, additional biological issues are introduced. In addition, testing the effectiveness of the system requires microbiological analysis for determining the bacterial concentration before and after cleaning.

Mechanical engineering students were involved in the project as part of their senior design capstone experience, which is comprised of a two-course sequence where students are organized into teams and address projects that are usually sponsored by industrial partners. The primary sponsorship for this project was the U.S. Department of Agriculture Cooperative State Research, Education and Extension Service (USDA CSREES) through the Higher Education Challenge Grant Program. The USDA project was presented along with the industrially-sponsored projects to the student teams, one of which chose to work on the USDA project. Although the project was funded by the USDA, the team worked with individuals at a local poultry processing plant and with a supplier of equipment for poultry processing plants, so they gained experience in working with industry. The students received academic credit for their work in designing, building and testing the cleaning system and were graded based on written reports and oral presentations.

The poultry science curriculum does not include such a design experience, so that the work could not be used for academic credit. Instead, the microbiological analysis was performed by poultry science students who were hired as part-time researchers. In addition, poultry science faculty and staff provided input during the design process and coordinated visits to the poultry processing plants. Some of the testing was performed after completion of the senior design course, so additional students from materials engineering were employed for evaluation of the system performance. The poultry science and materials engineering students did not receive academic credit and thus were not graded for their contributions.

TECHNICAL APPROACH

Design

The general approach was to deliver high-pressure hot water to the inside of the steel pipe. The cleaning was accomplished using the rotary nozzle (NPT 3/8" (9.5 mm), 7/8" (22 mm) diameter, 2.3" (58 mm) length) shown in Figure 1, which had jets at 45° and 90° (relative to the axis of the pipe) that rotates around the entire inner circumference of the pipe for complete coverage. The 90° jets provided a larger force against the pipe surface and the 45° jets provided a flushing action. The cleaning head was mounted on the end of a 3/8" (9.5 mm) diameter hose, which was attached to a pump (see Figure 2) that could deliver up to 2.3 gallons per minute (150 ml/s) at 2000 psi (14 MPa) and could operate at temperatures of up to 190°F (88°C). The hose was fed through a stainless steel end cap that contained the hot water being flushed from the tube during cleaning. In addition to the temperature requirements mentioned above, all components were approved for use with food products.

During operation, the hose was fed into the pipe to be cleaned and the end cap was attached to the end of the pipe. The hot water was turned on and the cleaning head and pipe were pulled through the pipe. The 90° jets provided primary cleaning, while the 45° jets flushed the water and debris in the direction in which the nozzle was moving, so the waste was pushed out ahead of the nozzle.

Testing

An apparatus for testing the cleaning device was constructed from 3" (76 mm) diameter sanitary stainless steel pipe, which is the type of pipe typically used in poultry processing plants. As shown in Figure 3, the apparatus includes 90° bends, since such locations are more difficult to clean than straight sections of pipe. The piping system is attached to a PO Diaphragm Poultry Pump (Murzan, Inc, Norcross, GA), which is widely used in the poultry industry and could be used to circulate the giblets through the piping system.

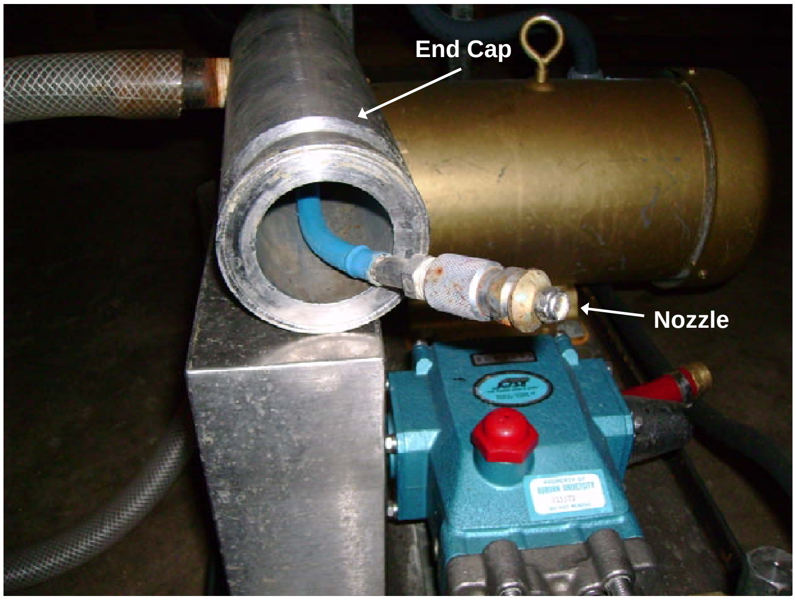

Figure 1. Cleaning nozzle and end-cap.

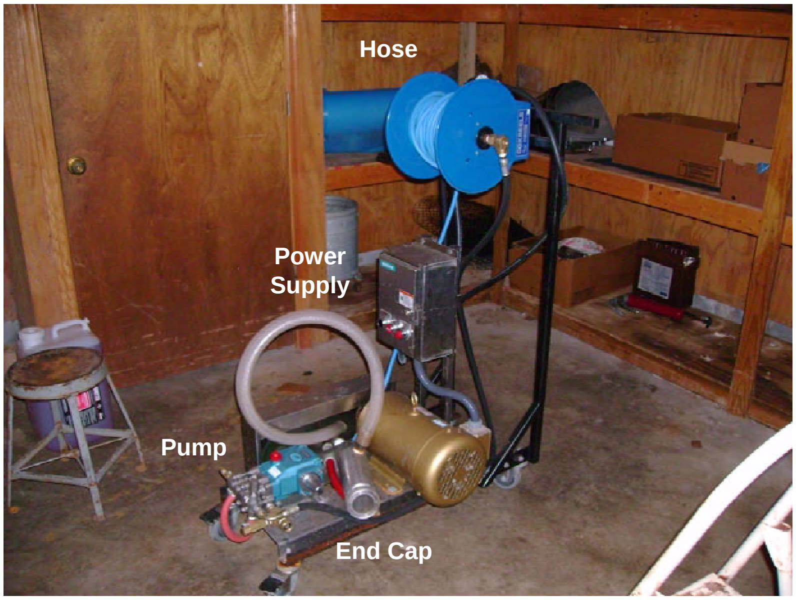

Figure 2. High-pressure hot-water cleaning system.

For each test, approximately 100 pounds (45 kg) of chicken giblets, previously inoculated to reach approximately 10^5 CFU of *Campylobacter jejuni* per gram of food product were placed in the hopper and then pumped through the tubing for 15 minutes. The system was then emptied and microbiological samples were collected by swabbing an area of 10 cm^2 from three areas in the pipe in two locations: near the hopper and near the pump (see Figure 3). The cleaning nozzle was then inserted into the pipe near the pump and pushed though the pipe it reached the hopper. With the nozzle just inside the end of the pipe near the hopper, the hot water (140°F / 60°C) was turned on and the nozzle was pulled through the tube. After cleaning, samples for microbiological analysis were collected from the same two locations as those collected before cleaning. The pipe was then cleaned with a conventional sanitizing process, which consisted of filling the piping system with 15 gallons (57 liters) of a quaternary ammonium cleaning solution (R-Square Products, Inc, Gainesville, FL) at 140°F (60°C) and pumping the solution through the piping system for 20 minutes. A third set of samples for microbiological analysis was collected after this cleaning process.

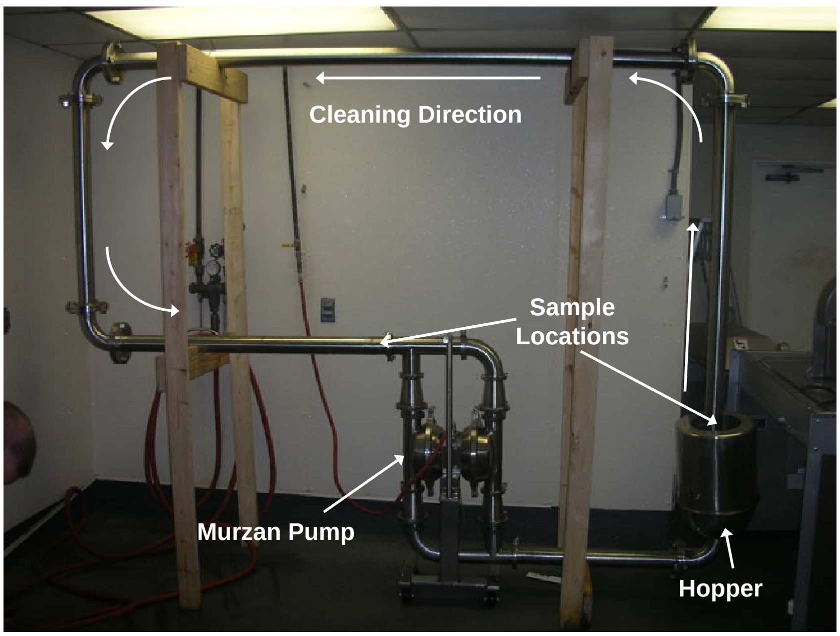

Figure 3. Apparatus for testing of cleaning system.

The collected samples were analyzed for *E. coli*/Coliform and total aerobes using aerobic plates and *Campylobacter* using enumeration on modified Campy-Cefex (mCC) agar plates. In all cases, 10 grams of the product were mixed with 90 ml of sterile phosphate buffer solution (PBS) and stomached for 60 minutes. Serial 10-fold dilutions were made in PBS tubes and duplicate films or plates were inoculated from each dilution. *E. coli*/Coliform and aerobic plate counts were incubated at 99°F (37°C) for 48 hours and mCC plates were incubated at 108°F (42°C) for 48 hours under an atmosphere containing 10% CO_2, 5% O_2, and 85% N_2. *Campylobacter* presumptive colonies were identified under a phase contrast microscope. The bacterial counts were converted to $\log_{10}$ CFU/ml for analysis.

RESULTS

Technical

The results of four independent tests of the cleaning system are summarized in Table 1. The concentrations of all organisms decreased after the high-pressure water cleaning treatment. The decreases in mean concentration of *E. coli* and coliforms were not statistically significant based on Duncan's test (SAS Program) using the ANOVA procedure, with significance set at $P \leq 0.05$. However, the decreases in *C. jejuni* in both locations and APC near the hopper were larger and statistically significant. The magnitude of the decrease in APC near the pump was similar to that near the hopper, but had considerably more variance and thus was not statistically significant. There were further decreases in the bacteria concentrations with the sanitizer cleaning procedure, but the reductions were relatively small and the concentrations were not statistically different from those after the high pressure water cleaning treatment. Thus, the team was successful in designing, building and testing a cleaning device that performed similarly to a conventional cleaning procedure.

Table 1. Results of microbiological analysis before and after cleaning treatments

	Log$_{10}$ CFU/ml (standard error of the mean)							
	C. jejuni		APC		*E. coli*		Coliforms	
Sample from giblets	5.0 (0.7)		5.7 (0.8)		3.3 (1.5)		2.3 (1.3)	
	Hopper	Pump	Hopper	Pump	Hopper	Pump	Hopper	Pump
Pre-Cleaning	4.5 $(0.9)^A$	4.0 $(0.4)^A$	5.3 $(0.3)^A$	5.5 $(0.3)^A$	2.5 $(1.4)^A$	2.3 $(1.4)^A$	3.1 $(1.1)^A$	3.2 $(1.2)^A$
Post Cleaning – Water	**2.3 $(0.8)^B$**	**2.0 $(0.7)^B$**	**4.0 $(0.1)^B$**	4.0 $(1.2)^A$	1.6 $(1.0)^A$	1.8 $(1.1)^A$	2.1 $(1.2)^A$	1.9 $(1.1)^A$
Post Cleaning – Sanitizer	**1.7 $(0.6)^B$**	**1.8 $(0.6)^B$**	**3.6 $(0.7)^B$**	3.5 $(0.2)^A$	1.2 $(0.8)^A$	0.5 $(0.5)^A$	2.1 $(1.0)^A$	1.5 $(1.3)^A$
	Reduction Log$_{10}$ CFU/ml							
Water	**2.2**	**2.0**	**1.5**	1.5	0.9	0.5	1.0	1.3
Sanitizer	0.6	0.2	0.4	0.5	0.4	1.3	0.0	0.4
Total	2.8	2.2	1.9	2.0	1.3	1.8	1.0	1.7

^{A}Not statistically ($P \geq 0.05$) different from pre-cleaning
^{B}Statistically ($P \leq 0.05$) different from pre-cleaning

Educational

The successful accomplishment of the project objectives required a combination of knowledge and skills that none of the individual members possessed. Although the team members of one discipline may have relied on the members of the other discipline to accomplish tasks outside their skill-sets, they did need to stretch outside their comfort zones and learn about the other discipline. The mechanical engineers were not able to perform the microbiological testing, but they did need to learn about methods for sanitization (*e.g.* temperature requirements) and deal with use of components approved for use with food products. Similarly, the poultry science members did not build or design the test apparatus, but in responding to questions from the mechanical engineering students designing the systems were exposed to the practical constraints in the design and fabrication of engineering systems.

The mechanical engineering team was evaluated in terms their design, which included meeting the biological constraints imposed by the food processing system. However, their understanding of biological issues was not evaluated separately. Similarly, while the poultry science students were exposed to engineering problems, there understanding of these issues was not evaluated. Although not explicitly evaluated, each group gained an appreciation of considerations outside their own discipline.

DISCUSSION

The project was successful in providing students with exposure to and understanding of a discipline other than their own. However, the engineering and biological tasks were relatively distinct, so the interaction between the disciplines was primarily on a consulting or advice level, rather than the two groups working side-by-side throughout the process. Similar arrangements are used in actual product development, so the project provided experience in realistic situations. However, the multidisciplinary experience would have been enhanced if the students could have worked more closely together.

One of the barriers to having the students work together is the nature of their involvement in the project. The mechanical engineering students were involved in the project as part of a formal senior design course that they must pass to graduate. Poultry science program does not require such a design course. Although there are independent study courses that could be used for work on the project, these are not required for graduation. Because of the low interest in such elective courses, the poultry science students were hired as part-time researchers. While it is certainly possible for students receiving academic credit for work to collaborate directly with those doing the work as part of employment, the differences in scheduling and motivation create challenges for close interaction. For example, with the increased course-related demands towards the end of the semester (*e.g.* exams, papers, presentations), students often spend fewer hours working on part-time employment, so at the end of the semester the level of activity for one group (senior design students) increases while that of the other group (student employees) decreases.

CONCLUSIONS

A multidisciplinary team of engineering and biological science students successfully designed, fabricated and tested a device for clean-in-place cleaning of stainless steel pipes in a poultry processing plant. The project provided valuable experience for the students in learning about another discipline and working with individuals from that discipline.

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