AC 2007-2442: CHEM-E-CAR COMPETITION: INCORPORATING SAFETY WITH THE HELP OF INDUSTRY PARTNERS.

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Chem-E-Car Competition: Incorporating Safety with the help of Industry Partners.

ABSTRACT

The Chem-E-Car competition has been utilized for the last five years as part of multiple courses in the chemical engineering curriculum at Oklahoma State University. Typically, a number of teams comprised of two to three juniors were formed in the Fall semester for the competition to be held in the subsequent Spring semester. Three to four sophomores were included to enhance cross-class participation and to provide application-oriented examples. A folder containing compartments for log sheets, pictures/sketch, reaction/safety, analysis, and calibration was given to each team. During the Fall and Spring semesters, the teams had to complete certain tasks and place them in the folder. Initial tasks included identifying the chemical reaction(s) used in powering the car, providing the accompanying material safety data sheets, and sketching the car with associated pictures of the prototype. At the end of the Fall semester, reports were shipped to ChevronPhillips (the sponsoring organization) for review and feedback from Dr. Dave Register. Feedback from ChevronPhillips was given to the students in the Spring semester. The first task for the students was to respond to the concerns raised in the report. On the day of the competition, the students presented a poster to the ChevronPhillips judges, and the competition was conducted according to the national guidelines. The outcome of these interactions from the perspective of the students, as well as from Dr. Dave Register is discussed. Also, lessons learned from the viewpoint of instructors are included.

INTRODUCTION.

The Chem-E-Car competition is a powerful tool to enhance technical writing skills, provide engineering analysis opportunities [1], and apply team management skills. Since its beginning in 1999, the Chem-E-Car Competition has evolved as the major attraction at the regional, national, and international American Institute of Chemical Engineers (AIChE) student conferences [2]. The basic principle of the competition is that each team has to design a car that will carry up to 500 mL of water and travel a specified distance (up to 100 feet). Teams are notified of the water weight and travel distance one hour prior to the competition. A chemical reaction must be used to propel the car, and no mechanical mechanisms may be used to stop the car. The components of the car must fit within a shoebox that is 40 cm ×30cm×18 cm. Detailed rules are posted on the AIChE website [3].

While the creation of these cars is fun, the competition is often entertaining and is a valuable recruiting and retention tool [4, 5]. However, the contest clearly reveals issues of process safety, reliability, economics, reproducibility, teamwork and environmental care that face chemical engineers in industry everyday. Interestingly, thorough safety analysis via thermodynamics and/or reaction engineering is often overlooked. For example, estimation of the gas pressure via reaction kinetics and thermodynamics for the acetic acid/baking soda reaction, a popular reaction used to propel a car, is rarely calculated. Further, many pressure vessels have been constructed not knowing the strength of materials and lack of incorporating pressure relief valves which has resulted in unwarranted accidents. In 2006, national AIChE made a significant effort to address the safety and environmental aspects of the Chem-E-Car competition through the incorporation of a required safety training seminar. Detailed information on the safety must be adequately described in a required poster presentation prior to the competition.

Over the past five years, we have utilized reaction-powered cars to provide a hands-on experience for students through designing and building cars propelled by chemical reactions in multiple chemical engineering courses at Oklahoma State University. Within the school, an annual Chem-E-Car competition is held, based on national AIChE rules. Preparation for the competition begins in the Fall semester in the junior thermodynamics course and ends in the Spring semester chemical reaction engineering course. The sophomores join the teams in the spring semester and are included to enhance cross-class participation and to provide application-oriented examples. This annual event is supported by ChevronPhillips both financially and in reviewing the reports submitted by the students. In this report, we summarize the interaction of industrial partners in incorporating the safety of the Chem-E-Car competition.

TEAM FORMATION.

During the Fall semester, teams of 3-4 students were chosen in the Thermodynamics course. Students were allowed to select their own teams, although the faculty member makes the final decision regarding the team members. After the formation, each team was given a folder containing various compartments for log sheets, pictures/sketch, reaction/safety, analysis, and calibration. In addition, information on the Chem-E-Car rules, scheduled tasks (**Table 1**), and brief instructions on what is expected was provided. For each scheduled task, students were told to submit the entire folder, placing the required document in the corresponding compartment. Further, log-sheets were also given to individual students and at the bottom of the log-sheet there was a location for the signature of other team members. Students were required to write the number of hours in the log-sheet and submit the signed log-sheet. Comparison of the number of hours within the team was used to evaluate the team participation. A reimbursement of $150 per vehicle was allowed.

Table 1. Time Table of Events in 2005-2006 Competition

Day	Date	Task to be completed
		ChE 3473: Thermodynamics Course
Wednesday	Oct 13	Teams identified: 3 per team, 1 team with 4
Friday	Oct 22	Chemical reactions identified: Safety and environmental report
Wednesday	Nov 3	Detailed sketch of car
Wednesday	Nov 17	Thermodynamic equilibrium of CO_2 system- group homework
Friday	Dec 3	First prototype built with a picture and initial test
	Dec 10	Shipped to ChevronPhillips
	Jan 10	Received from ChevronPhillips
		ChE 3123: Chemical Reaction Engineering Course
	Jan 31	Memorandum on the progress of the car and response to Dr. Dave Register's comments
Friday	Feb 11	Preliminary calibration chart
Friday	Feb 25	Reaction engineering analysis with measured parameters
Friday	Mar 11	Final calibration chart; demonstration to faculty
Thursday	Mar 24	3:00 - 4:00 p.m. Poster set up
Thursday	Mar 24	4:00 – 5:00 p.m. Poster presentations w/snacks
Thursday	Mar 24	5:00 – 7:00 p.m. Car competition
Thursday	Mar 24	7:00 – 8:30 p.m. Dinner and Awards Ceremony

REACTION IDENTIFICATION AND SAFETY.

Prior to any construction, the first assignment was to identify the reaction(s) that would be used to propel the car. Teams were told to write a two-page report that included the reaction information as well as the safety and environmental issues. Attachment of appropriate MSDS sheets for reactants and products was also required. Further, teams had to write the report in their own words rather than the direct copying of parts from the MSDS sheets. Safety precautions, clean up issues, procedures for emergencies, etc were also required in the report. For example, if a team selected decomposition of the hydrogen peroxide reaction using catalase, the team wrote that the car would be propelled by the gas formed from the reaction

$$2H_2O_2 \xrightarrow{Catalase} 2H_2O + O_2 .$$

As the reaction proceeded, the conversion rate of the hydrogen peroxide decreased and the oxygen gas pressure increased within the reactor. If the initial report contained some vague safety considerations, the faculty member notified the team to make sure that the students were aware of the safety precautions and were not considering unsafe chemicals.

BUILDING THE CAR.

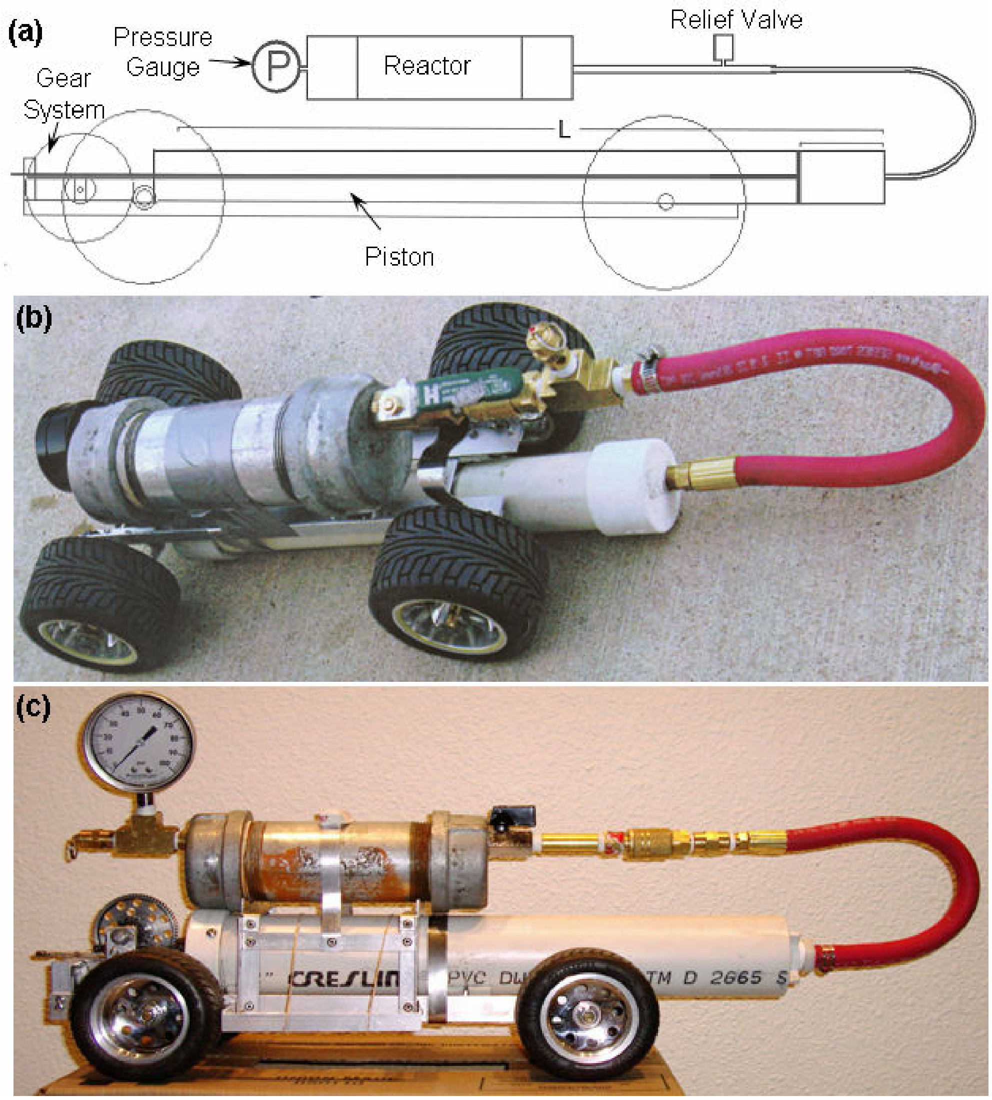
The next task was submission of a hand-drawn sketch of the car, suitable for guiding car prototype assembly. In the instructions, teams were told that the sketch must include car dimensions, reaction vessel dimensions and other appropriate details. Also, a detailed list of materials required to build the prototype and a price estimate should be submitted. An example of the sketch submitted by one of the groups is shown in **Figure 1a.** The parts list submitted by the same group is shown in **Table 2**. Following the prototype submission, teams were instructed on the thermodynamic analysis for a baking soda-vinegar reaction (used as an example) using an equation of state and assuming complete reaction. All teams were then required to utilize thermodymic principles to provide an estimate of the maximum pressure and temperature for their given car and reaction system.

Table 2. Parts list with cost

Parts	**Cost**
Wheels	$24.60
Aluminum Stock	$15.50
Large Gears	$56.80
Small Gears	$7.00
Chain	$17.50
Rod:	$2.00
Reactor	$13.50
Relief Valve	$3.00
Tees and Fittings	$7.50
Gauge	No Cost
Chemicals:	$60.00
TOTAL	**$200**

After approval from the instructors, each teams was allowed to build their car and provide a corresponding picture. The teams also needed to state in writing how the car functioned on the initial test (i.e. Did it work?, How far did it go?, etc.). They were told that points would be deducted if it appeared that the prototype was a last minute effort with no testing. An example of the first prototype is shown in **Figure 1b**. Following all of the above tasks, all submitted information (without the grading sheet) was sent to CheveronPhillips for additional safety review.

Figure 1.



SAFETY REPORT AND FOLLOW-UP.

Following submission of the reports to ChevronPhillips, safety reviews for each report were received in the beginning of the spring semester from Dr. Dave Register, an employee at ChevronPhillips. Dr. Register commented (**Figure 2**) on the safety aspect of the car as well as the general concerns on the functionality of the car. In particular, concerns on personal protective equipment, handling, and disposal of the reactants were discussed in the report. At the beginning of the chemical reaction engineering course (Spring semester), the notebooks containing previously completed task from the Fall semester and the review comments from Dr. Register were returned to the teams. The teams were asked to submit a memorandum within three weeks (**Figure 3**) addressing the concerns in Dr. Register's review.

Figure 2. An example of a Review Report

Wheels of Mass Destruction

SAFETY:
- Good coverage so far but needs some elaboration.

- H_2O_2 can be quite hazardous depending on the concentration. This should be discussed some more, as well as the use of any personal protective equipment (PPE) needed (gloves, glasses, handling techniques, etc.)

- In previous projects, the H_2O_2 – beef liver catalyzed reaction has been strong. How will you handle loading, mixing, and sealing the reaction vessel? Also, at the pressures you are considering, the steel pipe should not be a problem but the fittings and PVC drive unit may need some caution.

- I suspect your pressure will need to be increased. It looks like there is a relief valve just downstream of the reactor output valve. Have you determined the relief pressure you should use?

GENERAL:
- Good work so far. The design appears to be sound. You have identified a major source of reliability – coupling the toothed output shaft to the drive sprocket. I suspect 'play' and alignment of the toothed shaft allows it to disengage from the sprocket. Some attention to better support for the shaft may be fruitful. I've suggested to another team that consulting with a fellow student in ME might be beneficial. Same suggestion here – but perhaps you could split the consulting fee (most likely a pizza will do) with the 'Back Row Boys' to everyone's advantage and enjoyment.

- Good MEs and EEs are major assets to ChE projects. Don't be reluctant to seek their advice and expertise.

Good luck!
David Register, PhD
Senior Research Fellow
Chevron Phillips Chemical Co.

FINAL TASKS AND COMPETITION.

Prior to the competition, teams were asked to generate a preliminary calibration chart for the performance of the car. The calibration chart had to include information on the distance traveled (y-axis). The x-axis was appropriately chosen (i.e. reaction composition, reactant volume, etc.) depending upon the car design. Teams also had to provide a reaction engineering analysis that would predict how far the car would travel based on the starting chemical composition(s). As part of the analysis, teams had to show predictions versus experimental results. The analysis had to use chemical reaction principles (kinetic rate laws or instantaneous reaction analysis coupled with mass balances, physics, etc. if needed) to predict the distance traveled by the car (calibration information could be coupled with the engineering analysis to aid in the prediction). If parameters were needed, estimates or measurements were required. Two

Figure 3. Example of a response report

Memo

To: Dr. Randy Lewis, Dr. Sundar Madhially

From: Paul Engel, Tyler Langley, Murtaza Gulamhusein

Date: January 31, 2005

Re: Response to Dr. Dave Register's Comments

Response to Dr. Dave Register's Comments

After the response from Dr. Register, We made a few alterations to the design as well as the handling of the chemicals. Personal protective equipment was also placed into consideration, therefore safety gloves and goggles will be used frequently while mixing and dispensing the chemicals. If contact with chemical occurs, immediate treatment will be performed by washing the affected area under cool running water.

The 10% hydrogen peroxide concentration would be quite hazardous; therefore we decided the chemicals will be transported while stored safely and upright in a cooler box. The mixing of hydrogen peroxide and beef liver will be performed separately, that is, initially, the hydrogen peroxide will be squirted with the aid of a syringe through the inlet, and the inlet closed. Thereafter, the beef liver is squirted into the nozzle with the valve been closed. Once sufficient beef liver is place into the nozzle, the inlet is blocked and the valve opened for a split second. The reactor is shaken until the required pressure is obtained. The valve connected to the piston is opened and the piston system propels the car to move forward.

Over the winter break a few more rectifications were done on the car. Firstly, we had a problem with the car's extending drive shaft (steel rod with a chain tack welded on it), whereby it kept jumping off the gears, therefore we redesigned the same piston with greater accuracy and precision. Another of the problems, excessive torque was corrected with gearing down of the drive train about 4:1, this was very successful as we are now obtaining a suitably low torque to attain appropriate distance. The results after the alterations were impressive as a consistent pressure to distance ratios were obtained from test runs.

Future Plans

In the next few weeks, we will make more test runs on the car. The purpose for these test runs is to develop the calibration charts and have a better precision as to the pressure to distance ratios. With this calibration we will also be able to determine how much of each chemical and catalyst is needed for the runs.

weeks prior to the competition, teams had to demonstrate the performance of the car to the instructor(s). This provided an opportunity to ensure the safety aspect of the car in addition to fine-tuning the car assembly (**Figure 1c**).

On the day of the competition, poster sessions were held in addition to the race competition. The poster sessions followed the rules of the national AIChE Chem-E-Car contest. The competition was attended by five to six ChevronPhillips employees. They graded the posters and gave the prize money to the winning teams. During the presentation ceremony, they emphasized the importance of safety in industry and talked about how actions performed by employees can affect the safety on a job.

ASSESSMENT AND CONCLUSIONS.

Assessment of the student surveys given at the end of the competition suggested that students enjoyed the overall experience of the competition despite the long duration of the project. Students liked the aspect of designing, building, and incorporating the safe operation of the car. Some students noted that they liked the fact that they could do engineering analysis. In addition, feedback and the presence of industrial partners provided a more professional environment and increased the seriousness of the safety. The ChevronPhillips employees enjoyed the interaction with the students and encouraged the continuation of the Chem-E-Car competition for as long as possible.

The project documentation continues to evolve each year. The use of notebooks and a formal project format is valuable, providing the documents for outside review at each stage of the project. Preliminary assessment of the cars provided an opportunity to question the ability of some of the approaches and to sense where students were encountering issues. According to Dr. Register, it was helpful in evaluating both the safety and practicality of each project. Although the project notebooks were beneficial, Dr. Register expressed concern that the students were providing documentation in preference to content, similar to tendencies in industry. A one page Executive Summary of each project's aims, methods and basic chemistry might be helpful for an outside reviewer.

An advantage of utilizing industrial partners is that they encourage students to branch out when seeking advice on some components of the projects. In particular, some of the mechanical and electrical problems that continue to be encountered can be solved almost immediately by any Mechanical or Electrical Engineering major. The typical trend observed during the competition was that the teams tended to work in isolation from other engineering disciplines, potentially wasting time and effort. It would be beneficial to see a trend among students to be more inclusive of other areas of science and engineering.

From the point of view of the instructors, all aspects of this competition (including industrial interaction) provided an opportunity to emphasize safety aspects which are not always clearly addressed in the chemical engineering curriculum. Spreading the work-load in two semesters made it easier for teams to complete the assigned tasks. Finally, analysis of the project prior to assembly minimized concerns regarding the safe operation of the car.

References:

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