TACKLING REAL-WORLD CHALLENGES: A CAPSTONE PROJECT THAT STANDS OUT

When a team of Mechanical Engineering Technology students at NAIT – calling themselves the "Gear Heads" – took on the challenge of redesigning Argus' phosphate dip tank, they knew this would be no ordinary school project. The current dip tank was heated by an open flame, causing uneven heating and warping of the inner tank. For their capstone project, Aicel De Vera and her team decided to tackle this problem by designing a fluid-jacket solution for the dip tank that, when assembled, would enhance heat distribution and modularity.

The Gear Heads Team
Left to Right: Aicel De Vera, Ethan Nott, and Leo Punongbayan

The project would test their collaboration skills, persistence, and ability to think creatively under pressure. After many hours spent modelling, calculating, and refining their work, the team's dedication paid off. The Gear Heads conceived their innovative "tank-within-a-tank" design that not only enhanced the tank's heating efficiency but also made it safer and more durable. The project would receive the prestigious top prize 2024 from Technology Accreditation Canada (TAC) for their "Design of Fluid-Jacketed Phosphate Dip Tank" report.

We had a chance to interview Aicel De Vera, Engineering Technologist at Argus, about the Capstone project, working together as the Gear Heads to win the award and the experience it has given her that she can bring forward in her career as an Engineer.

Inspiration and Challenge

What inspired your team to focus on redesigning the phosphate dip tank for your Capstone project?

"In my 3rd term at NAIT, my instructor has announced in class that he was looking for capstone project sponsors for our batch. So, I reached out to Randy Wiltermuth, P.L. (Eng.), Engineering Manager – Technology & Services at Argus, and asked if there were any Argus projects that he would like the MET students to work on as a capstone project. Long story short, Randy has submitted the phosphate dip tank as the project. Since I have ties with Argus, the project was given to my group.

I am really lucky to have found groupmates who find this project interesting and challenging as well. This project presented an excellent opportunity for our team to apply our theoretical engineering *knowledge and skills (3D Modeling) in a practical, impactful way. We were excited to tackle a real-world problem and present a solution that could potentially benefit the industry."*

What were the biggest challenges with the existing tank design that you aimed to resolve?

"The open flame design exposes the tanks to localized extremely high temperatures due to direct contact with fire. This could cause uneven temperature distribution which can warp the tanks. The warping of the tank causes parts and components to deform and misalign with one another, making disassembly difficult. This has caused Argus to replace some parts in a short period of time.

Another one is making the inner tank removable for cleaning and maintenance. This challenge has made us go back to the drawing board multiple times. Every time we came up with an idea on how to bolt the inner tank to the outer tank and tried it on 3D CAD, we always found flaws that would make it expensive to assemble or impractical to do."

Design Innovations

Could you explain the concept behind the "tank-within-a-tank" design and its advantages over the traditional setup? How did you ensure even heat distribution while maintaining modularity in your design?

"The tank-within-a tank design is to somewhat similar to the current phosphate tank set-up. The fluid jacket dip tank is a specially designed tank where the walls of the tank are lined with a layer of heating fluid. The dip tank (which we called the inner tank) holds the phosphate media. Underneath the inner tank are tubes (fire tubes) where hot air is blown in to and heats the lining fluid which in turn heats the phosphate media. The inner tank, the heating fluid, and the fire tubes are all inside a bigger tank (which we called the outer tank). The tubes are branched to allow a larger heat transfer area which can heat the fluid more efficiently. A suction fan needs to be installed at the end of the firetube exhaust to create induced convection throughout the heating tube. Induced convection helps avoid cold spots.

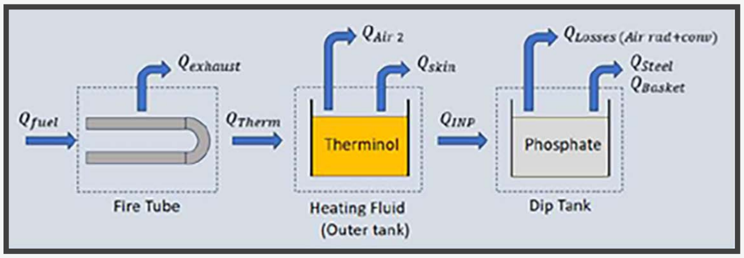
The main advantage of this design is consistent and evenly dispersed heating due to the heating fluid "jacketing" the inner tank. This "jacketing" effect is beneficial because the heating fluid will insulate and heat the phosphate media at the same time. Since the inner tank is heated indirectly through the heating fluid, there will be far less warping than having an open flame directly underneath it. Warping can cause difficulties with disassembling due to the bolt hole misalignment."

Technical Aspects

What role did Therminol 55 play in your design, and why was it chosen as the heating medium? What specific calculations or simulations were crucial to finalizing the structural and thermal aspects of your design?

"In the absence of thermodynamic simulation software, the foundation of the final design was established through the conceptualization of the basic thermodynamic model:

The manganese phosphate's operating temperature is 200°F. This temperature is the basis for all the thermodynamic calculations. However, since the phosphate media is heated by a heating medium, its temperature is equally as important. When doing the calculations to solve for this temperature, two scenarios were looked at, (a) when 2000lb is dipped or (b) 500lb is dipped.



The first step is to solve the energy loss of the two previously stated cases. Solving for this, both the material and cage must be considered as well as the losses in the air in the inner tank. These heat values can be summed up together and represented by Q_{INP} in the diagram, which is the energy going into the inner tank. This must be equal to the energy going out of the inner tank represented by $Q_{Losses\ (Air\ rad + conv)}$ and $Q_{steel+basket}$.

Then the thermal resistance of the convection regions and inner tank wall must be calculated. Once this is done the heating medium's temperature can be calculated. When 2000 lb mass is dipped the heating medium must be 225°F, and when 500 lb mass is dipped the heating medium must be 205°F.

This temperature is near the boiling point of water, which means an oil-based heating medium must be used. These calculations helped to spec the heating medium. Therefore, Therminol 55 was selected for its high boiling point, heat capacity, and availability in the North American market.

Next, is to analyze the heat balance in the outer tank (Therminol tank). To determine the required heat input in the outer tank (Q_{Therm}), all the heat losses from the outer tank external skin (Q_{SKIN}), air above the outer tank ($Q_{Air\ 2}$), and the heat given up to the inner tank (Q_{INP}) must be accounted for.

The heat input to the Therminol (Q_{therm}) was calculated to be 150,000 BTU per hour, considering a cycle of 2000 lb of steel dipped in the inner (phosphate) tank every 15 minutes.

Lastly, the heat balance in the fire tube was analyzed to determine the amount of heat input in the fire tube, representing the fuel consumption (natural gas firing rate) needed to provide the heat value of Q_{therm} and accounting for heat losses in the exhaust gas ($Q_{exhaust}$). This calculation is necessary to determine the required heat transfer area of the fire tube which was then used to design the size of the tubes and the number of passes. It was calculated that a minimum of 19.7 ft^2 of area is needed to facilitate the heat transfer while maintaining the desired operating temperatures. This translates to the need to have a minimum tube size of 2 inches in diameter, 80 inches long with 7 passes. Since equal heat distribution is an essential objective of this project, it was decided a 4" diameter inlet tube will be installed in the middle of the tank which branches out to 2 opposite directions at the other end of the tank, downsizing to 2 inches diameter tubes thereafter.

Heat loss at the outer tank is mitigated using 1" thick ceramic fiber insulation. This helps lower the Q_{SKIN}, resulting to lower operating temperature of Therminol and reduced heat input requirement.

The following calculations are for the thickness of the tanks, stress calculations of structural supports of both inner and outer tank, and sizing of fire tubes.

The inner tank rests on the eleven (11) vertical C-channels of the outer tank's supporting frame, column analysis had to be done to size the C-channels to ensure they could support the load of both the inner tank and phosphate media. A safety factor of two (2) was used to allow for a large threshold of safety with this safety factor considered the C-channels were sized at 3". While the C-channels are taking all of the axial force from the inner tank, the tank walls experience stress due to static fluid pressure from heating fluid and phosphate media.

To ensure that the tank wall thicknesses are adequate the flat plate theory was used to solve for the wall thickness of the inner and outer tanks in order to avoid bulging of sheet metal. The C-channels are considered as stiffeners in the flat plate theory analysis, so the number of C-channels used in the inner and outer tank is also influenced by the calculations. The result of these calculations were a thickness of 7/64" for the inner tank and 3/16" for the outer tank.

When the inner tank is bolted to the outer tank, it displaces 9.5 ft^3 of the heating fluid. This creates an upward buoyant force which can pose a problem during disassembly. After calculating for the buoyant force, it was found out that it is lower than the weight of the inner tank + phosphate media.

To ensure that the weight of the fire tubes is properly supported and will not warp or deform the outer tank sheet metal, reinforcing pads were designed to increase the strength at the areas having pipe penetration. This results in the use of gauge 12 stainless reinforcing sheet metal to increase the thickness at the penetration area. In addition, pipe support or stanchions were used to support the weight of the fire tubes at the points of minimum sag.

The chosen design makes use of heat transfer fluid which enables even heat distribution of the phosphate dip tank due to the natural convection of the heat transfer fluid. This prevents the issue of warping of the tanks. The chosen heat transfer fluid, Therminol 55, was selected for its high heat capacity and boiling point. A high heat capacity means it easily stays at a consistent temperature, while a high boiling point means that it can accommodate operational adjustments depending on process demand."

Team Dynamics

How did your team approach collaboration and decision-making during the project?

"Each team member had specific roles based on their expertise. This helped distribute the workload evenly and ensuring accountability. We focused on open communication and held regular meetings to make sure everybody is on the same page. Due to differences in our class schedules, we mostly talk through Teams. We also relied on our Gantt chart to stay mindful of deadlines. On some occasions, we were not able to meet our deadlines. We hit dead ends and had to go back to the drawing board to re-assess our design. Though we did not use or have any special software for our collaboration, consistent meetings and updates helped us a lot to finish the project."

Were there moments where differing opinions led to better outcomes for the project?

"Yes, absolutely. Since the beginning of the capstone project, the tank-within-a-tank design is not favored by all of us. We spent weeks finalizing our viable ideas. It has been constantly compared with steam or the use of heat exchanger. In the end, we went with the tank-within-a-tank design. First reason was Argus does not need to invest on new equipment such as heat exchangers. Our tanks are designed to mimic the sizes of the current phosphate tanks so they can easily be used and installed in the phosphate area. Also, Argus has already an experience with "fluid-jacket" phosphate tank.

As the project progresses, when each of one of us brought different viewpoints to the table, it helped us see the problem from various angles. We are also grateful that our instructors were always giving us advice/suggestions on things that we could have not thought ourselves. As I have mentioned above, there were few times where we had to go back to the drawing board because our ideas did not work after trying it out with 3D modelling. Frustrations started to weigh in, but our instructors were there to ease them up."

Practical Applications

How does your design impact operational efficiency, safety, and maintainability for end-users like Argus?

"With the use of fluid jacket, even heat distribution can be ensured and can prevent constant issues with warping and difficulties with disassembly reducing downtime and costs. Some of the components of the current phosphate tank set up can be reused with our design. By optimizing heat transfer, the fluid jacket can reduce energy consumption."

Award Significance

How did it feel to have your project recognized with this prestigious award?

"It was awesome. It was on Thanksgiving Day when I shared the news with my family, and they had the same joy as I did when I found out we won. It felt like a validation of all the hard work, dedication, and creativity we put into the project. It feels nice to represent Argus and be recognized locally and nationally."

What aspects of the project do you think stood out most to the judges?

"I believe what stood out the most is that we were able to show analysis and justifications for our design through our calculations. This project covered most of what is taught in Mechanical Engineering: Fluid Mechanics, Strength of Materials, Cost Estimating, 3D CAD, and most especially Thermodynamics. Also, we got a lot of compliments with our 3D models and the accuracy of our drawings."

The contest, open to TAC nationally accredited programs, saw twenty submissions. A panel of TAC certified auditors from select engineering technology and applied science disciplines form the technical review panels to conduct an initial rating of the reports. The top two reports from each reviewer in each discipline group were assessed by a final judging panel of four certified professionals, each with extensive education, industry, and audit backgrounds. Reports were scored on their topic selection, methodology, research, analysis, conclusions, originality, innovation, and presentation.

"On behalf of TAC and our Board, I extend sincere congratulations to the winners of the 2024 Technology Report Contest," stated Derek Tsang, TAC Chair. "The top three submissions exemplify our mission to promote excellence in engineering technology and applied science education. This year's winning reports were thoroughly researched, well-supported by experimentation, and addressed highly relevant topics. We thank students and the project sponsors for their participation and support."

https://www.technologyaccreditation.ca/Students/2023_Technology_Report_Contest_(1)

Lessons and Skills

What were the biggest lessons learned from this experience, both as an engineer and a team player?

"Even if the design is good on paper, it might not be the same in reality. Make sure to give thorough attention to details when 3D modeling your design. Since fabrication is not part of the scope of this project, 3D modeling will be the closest way to determine if the design will work or not. Have a clear understanding of the scope of the project to avoid unforeseen issues and ensure smooth execution. Support and trust each other. The failure of one is a failure of all."

How has working on this project prepared you for future roles in engineering or design?

"The challenges we faced shaped our ability to think critically and develop new solutions. Managing timelines and deliverables gave us a basic understanding and experience in project management. This project also gave us an opportunity to do cost estimating and gave us knowledge on different options of fabrications available in the market and decide which is more practical and cost effective."

Acknowledgments

Are there any mentors, peers, or resources that were particularly instrumental in your project's success?

"Our instructors Derek Walker, Scott Sparling, Audrey Claydon, and Michelle Zhang with all their inputs with the Thermodynamic side and manufacturability of the project.

Argus for giving us the opportunity to work on this project.

Randy Wiltermuth with all his help and guidance with all our questions about the phosphate tanks."

Future Potential

Do you see opportunities to further develop or refine this design for broader industrial applications?

"Yes. Our capstone project did not include capture and exhaust of off-gases and a method for loading/unloading parts in the tank due to time constraints.

I also believe the method we used to bolt the inner tank to the outer tank can be significantly improved."

What advice would you give to future students embarking on similar Capstone projects?

"Start early and plan thoroughly. Break down the project into manageable tasks and set deadline. Leverage team strength. I believe these were the things that helped us the most with our capstone project. We divided and conquered the tasks. One of us was in charge of calculation, one of was in charge of starting the technical report, making notes of technical stuff as we went, and the other one was in charge of 3D modeling. With this approach, each one of us has smaller tasks to finish and helped us focus a lot better. Do not be afraid to ask questions. Don't forget to enjoy the process. You will learn a lot from each other. Last but not the least, choose your group wisely. I am glad and thankful to have Leo and Ethan in this capstone project. I would choose them again if I would have to do this all over again."

Personal Growth

How has this project shaped your career aspirations or areas of interest within engineering?

"I found out how much I enjoy 3D modeling. Even though it required hours of 3D modeling, it didn't feel like a big obligation. I enjoyed it a lot especially the troubleshooting errors."

Argus is incredibly proud of Aicel and her team for what they achieved with this project. Congratulations, Gear Heads!