Propellant Conditioning of Nitrous Oxide During Storage and Operations

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Propellant Conditioning plays a vital role in the aerospace industry, as certain liquid propellants can become unstable under a variety of temperatures. The Tartarus project, a liquid bipropellant rocket design and test effort at the University of Alabama in Huntsville, adopted the concept by using ethane as fuel and Nitrous Oxide (N_2O) as an oxidizer. N_2O is a popular choice for amateur rocketry due to its self-pressurizing tendencies and lack of a need for cryogenic storage. However, N_2O has a higher probability for undergoing a dangerous decomposition reaction upon reaching its critical temperature of 98ºF. Large amounts of energy will be released to cause an extreme increase of pressure in the oxidizer tank, which could easily lead to a failed mission. Thus, with the likely probability of launching in the summer heat, there is a need to develop a storage and operation strategy in order to keep N_2O well below its critical temperature to prevent decomposition and safety hazards. In this paper, various existing methods were reviewed first. Then, radiator and water cooling were considered for conditioning k-bottles, and the spray cooling approach was proposed to conduct conditioning of N_2O tanks. Other factors in the proposed spray cooling method were discussed as well to meet the project requirements including cost, ease of manufacturing, material availability, and efficiency.

I. Nomenclature

A	=	Total hot/cold side heat transfer area
a	=	Area
A_{lef}	=	Effective area
α	=	Thermal diffusivity
Bi	=	Biot Number
c_p	=	Specific heat
c	=	Cold fluid
d	=	Diameter
F_o	=	Fourier Number
H	=	Height of cylinder
$h_{c,\ water}$	=	Heat transfer coefficient of water
h	=	Hot fluid
I_{sp}	=	Specific impulse
L	=	Characteristic Length
$\dot{m}$	=	Mass Flow Rate
n	=	Number of tubes
P	=	Pressure
ΔP	=	Pressure Drop
N_u	=	Nusselt Number
ρ	=	Density
Q	=	Heat transfer rate
$T_{c\,1,2}$	=	Temperature of cold fluid

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$T_{h\,1,2}$	=	Temperature of hot fluid
$\Delta T_{1,2}$	=	Difference in temperature
$\Delta T_{lm,pf}$	=	Logarithmic mean temperature difference
ΔT_m	=	Mean temperature difference
t	=	Time
U	=	Average overall heat transfer coefficient based on area
$\dot{V}$	=	Volumetric Flow Rate

II. Introduction

The goal of Project Tartarus is to develop a liquid bipropellant rocket in order to compete in the 2021 Spaceport America Cup in undergraduate liquid/hybrid division. This is a student research and development effort sponsored by the Space Hardware Club (SHC) at the University of Alabama in Huntsville (UAH). Nitrous Oxide (N_2O) is selected as the oxidizer in this bipropellant rocket design, in which ethane is used as fuel. N_2O is a self-pressurizing oxidizer and does not require cryogenic storage. N_2O also has a good amount of benefits for amateur rocketry teams but introduces difficult problems along with these benefits. Upon reaching its critical temperature, N_2O could become much more likely to undergo a decomposition reaction, thus releasing large and potentially violent amounts of energy. In rocketry, safety is paramount, so it is crucial for the team to manufacture a cost-effective method to keep tanks of Nitrous Oxide cool during both off-site storage and emergency holds or emergencies on launch day. While off-site, the N_2O will be stored in steel k-bottles. Although the k-bottles will not be in immediate danger of reaching near 90ºF while in the storage area, which is air-conditioned, they will run the risk of becoming overheated on launch day, similar to the N_2O run tanks.

Figure 1. Tartarus' main fluid panel and hold down

One such system that would work is a radiator cooling system. This type of system is easy to design as it involves wrapping tubes around an object, where the liquid absorbs the heat. The heated liquid then runs through a radiator cooling off the liquid and back through the tubes wrapped around the object cooling it off. This type of system is perfect for Tartarus because it is a proven way of cooling and the design of the system comes at a low cost. Another option considered will be to keep the k-bottles in a cooled water bath. Calculations are done to evaluate the time needed to sufficiently cool down the bottles.

There is a likely possibility of launching the rocket in the Spring or Summer, meaning the main N_2O tank will be exposed to temperatures easily reaching 90ºF. The goal is to keep the Nitrous well below 95ºF, to ensure it gets nowhere near critical temperature and causes a decomposition reaction. Cooling the N_2O tank can be achieved through a few methods, but for SHC, cost, time commitment, and material availability play key roles in the manufacturing process. While the N_2O tank is vastly smaller than the k-bottle, being only $231in^3$ in volume, the main issue is that the cooling system must be either integrated into the rocket or a separate system. Integrated a cooling system into a rocket of this magnitude is neither efficient nor cost-effective, so a separate system must be manufactured. One such system could involve a release-line variant of the radiator cooling system, working similarly to the k-bottle's form of cooling, but manufactured in a way that the tubing may be released before launch. However, this introduces new margins of error, such as failure to properly release the tubing. A better alternative could be a variant of spray cooling. Spray cooling utilizes water to cool down a hot surface by transferring heat from the surface to the water. This paper will look at currently used methods of spray cooling in the industry and how they can be applied to Tartarus, as well as considering different design aspects of the spray cooling system.

III. N_2O Chemical Properties, Risks, and Safety Hazards

Nitrous Oxide is a well-studied oxidizer and is especially popular for smaller-scale rocketry projects, like Project Tartarus. Before mentioning ways to control the problems with Nitrous, it is important to go over its advantages and disadvantages as an oxidizer, along with the safety hazards it presents to personnel and the rocket. N_2O's most attractive feature is its self-pressurizing capability, thanks to its high vapor pressure of 816psi at room temperature[1]. This self-pressurizing tendency eliminates the need for a variety of expensive and time-consuming aspects of a pressurization system, such as added weight to the rocket or the implementation of a turbopump. Also, N_2O has a somewhat low cost and is readily available for student rocketry teams, while also being less toxic in comparison to many oxidizers. However, there are some dangerous disadvantages when using Nitrous as an oxidizer. Firstly, N_2O is mainly limited to small-scale systems; compared to other commonly used oxidizer, such as LOX, it has a lower I_{sp}. N_2O also has a low critical temperature compared to some other non-cryogenic oxidizers, such as Nitrogen Tetroxide. Given Nitrous Oxide's positive heat of formation and the low critical temperature, self-decomposition can occur.

When controlled, Nitro us Oxide's decomposition reaction into Nitrogen (N_2) and Oxygen (O_2), boosts its I_{sp} and gives N_2O its place as an oxidizer. However, uncontrolled decomposition is the single biggest risk when working with N_2O. Decomposition can occur in many areas of the rocket, from the feed lines, the combustion chamber, or as discussed in this paper, in the N_2O tank. While solutions are not directly addressed in this paper, it is important to realize the dangers of decomposition in the feed system and the combustion chamber. In the feed system, heated gases from the ignition system can readily flow into the N_2O feed lines. The gases remain stable there until the oxidizer gate is opened. As a result, the two substances mix, which can quickly heat N_2O beyond its critical temperature and lead to decomposition in the feed system. Another concern lies in the combustion chamber, where a hard start may occur; this is when N_2O is allowed to accumulate in the combustion chamber, without reacting or being ignited. This hard start will result in the over pressurization of the combustion chamber and could lead to a violent chemical reaction. N_2O can decompose within its tank as well, possibly the largest hazard regarding N_2O decomposition. While there is a large amount of Nitrous present in other systems of the rocket, such as the feed system and combustion chamber, the largest portion remains in the tank. As the temperature reaches critical for the Nitrous, the pressure within the tank increases dramatically as a result of the decomposition reaction, most likely overshooting the pressure which the tank can contain, and quickly leading to mission failure.

IV. Cooling Methods for Nitrous Oxide Gas Cylinders

The first problem to address is keeping N_2O cool under moderate heat and pressure in a k-bottle during off-site storage. K-bottles are overwhelmingly larger than the N_2O tank on the main fluid panel, with the k-bottle having a volume of approximately 3662in^3, a difference of 3431in^3 between the two tanks. Due to the large size, the system must be large enough to encapsulate the entirety of the system. Previous design ideas, such as using a simple air-conditioning unit and an insulated box to circulate cool air around the bottle, were found to be inefficient due to heavy weight and power usage. An alternative would be an implementation of a shell and tub heat exchanger or a radiator cooling system. This section will consider different factors of the design process of radiator cooling along with considering other possible methods to cool the k-bottles.

A. Design Considerations of Shell and Tube Heat Exchanger System

A shell and tube heat exchanger works by having two fluids of different temperatures flow through the heat exchanger. The liquid that needs to be cooled flows through tubes that are inside of the shell, and a second liquid flows over the tubes inside of the shell. The second liquid transfers the heat from the first liquid, cooling off the first liquid. The first liquid then flows out of the heat exchanger and cools off the system it is being used on. The second liquid flows out of the heat exchanger into a system where it is also cooled off and then flows back into the heat exchanger to repeat the process over again. When designing this type of system there are some factors to consider, such as the size of the shell and tube heat exchanger, the length of the canister that is being cooled, the heat capacitance of the two liquids being used, and the type of tubing used. In Tartarus' shell and tube heat exchanger cooling system, the tubes will wrap around the canister holding N_2O, the liquid will flow from the top of the canister to the bottom. This will cool off the tubes subsequently cooling off the canister keeping N_2O below its critical temperature.

Figure 2. Model of K-Canister and tubing used for radiator cooling system[3]

One of the first aspects to consider when designing the system will be what the two liquids used are. For one of the liquids, water, is a viable option as it is already available to the team and has a low cost. Additionally, the system will need to be set up to where it is independent from the rest of the rocket.

B. Radiator System Cycling methods

To be able to cycle both liquids throughout the system, we would need to use water pumps as they are the most cost effective. The design route taken would be to use a Shell and Tube heat exchanger. Where one liquid cools off another liquid through a heat transfer process. For Tartarus the cooling tubes will be wrapped around the outside of the K-Canister storing the N_2O. This way there is no redesign necessary to fit the cooling system on the K-Canister. The Shell and Tube heat exchanger for the cycle will be placed right before the liquid goes through the coils wrapped around the K-Canister. This is to ensure that there is not any excessive heating of the liquid after it has run through the heat exchanger. The second liquid that absorbs heat from the other liquid will be cooled by having it run through an ice bath. The way that these cycles will keep a continuous flow is using a low-power water pump.

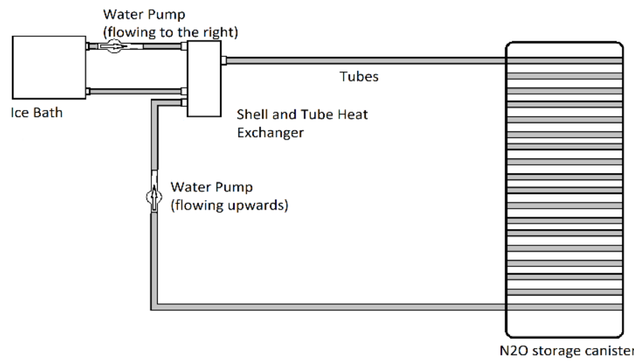

Figure 3. Schematic of Shell and Tube Heat Exchanger cooling method

C. Radiator size selection

When designing this cooling system, the size of the radiator will play a vital factor on determining the overall efficiency of the cooling system. To be able to determine what size radiator to use in the system the following equations will need to be used.

$$Q = (\dot{m}c_p)(T_{h1} - T_{h2}) \tag{1}$$

$$T_{ca} = \frac{Q}{(\dot{m}cp)c} + T_{c1} \tag{2}$$

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \tag{3}$$

$$Q = UA\Delta T_m \tag{4}$$

$$A_0 = d_0 n L \tag{5}$$

Given certain parameters, the area and length of the heat exchanger that is needed to cool down the system can be found[2]. Eq. 1 is used to find the heat transfer rate Q; this is to determine how much energy, in watts, it will take to cool down a liquid to a specified temperature[2]. Eq. 2 is used to find the temperature of the cold fluid upon exit from the radiator, which is important to find the logarithmic mean temperature difference, (LMTD) of the liquid[2]. Eq. 3 is used to find the LMTD, which is the average temperature difference between the hot and cold liquids in a heat exchanger. LMTD is the main factor in determining the area of the heat exchanger, as a large LMTD factor would result in a smaller heat transfer area needed[2]. Eq. 4 is used to find the area of the heat exchanger, if the area on the heat exchanger is to small the liquid that is trying to be cooled will not cool down to the specified temperature when it exits the heat exchanger[2]. If the area is too large the liquid temperature at exit would be lower than the specified temperature, most likely resulting in a system not working properly. Eq. 5 is used to find the length of the tubes used inside of the heat exchanger; if the tubes are too short, there will not be enough heat transfer from the liquid to the tube to sufficiently cool off the liquid[2]. Using these 5 equations is crucial for determining the size of the radiator, as because of the monetary restraints of Tartarus, multiple radiators will not be able to be tested. The calculations will need to be done beforehand to be able to pick the right size radiator the first time. Though this system for cooling is relatively easy to design there are no guarantees that it will work the first time, due to different ambient temperatures and altitudes. This is also possibly a costly system to design and develop, but future work will be done to implement this effective system into Tartarus.

D. Radiator Cooling System Considerations

Another cooling system that could be considered is a type of radiator cooling. Radiator cooling works by using a radiator to transfer the heat from the hot liquid, coming from the system out into the air sending cool liquid back into the system. Inside of the radiator, there are thin aluminum fins attached to flattened aluminum tubes parallel to one another. Inside of the aluminum tubes is a turbulator; this is to increase the turbulence throughout the tube so that all the liquid comes into contact with the walls dissipating the heat[2]. As the liquid flows from the inlet of the radiator to the outlet, the aluminum fins transfer the heat from the tubes out into the air flowing through the radiator. For this system to work, in Tartarus' case, the radiator will not be able to let air flow through it cool off the liquid. This is because the air that would be cooling off the heated liquid will be warmer than the liquid, because the launch will take place in the New Mexican desert during the summer. To fix this issue, the radiator will be submerged into a cool bath, allowing the cooled liquid from the bath to cool down the heated liquid flowing through the radiator. With this cooling system, just like the heat exchanger cooling system, the design considerations are the same: the size of the radiator, the length of the canister that is being cooled, the heat capacitance of the two liquids being used, and the type of tubing used. When designing this cooling system, the size of the radiator plays a vital factor on determining the efficiency of the cooling system. If the radiator is too small the heated liquid will not cool down to the specified temperature when it exits the radiator in the ice bath. On the other hand, if the radiator is too large, the heated liquid will cool down lower than the specified temperature when exiting the radiator, most likely resulting in a system not working properly. To determine the right size radiator to use the same equations used for the heat exchanger are used[2]. The size of the radiator will need to be calculated in the design process, so that different sized radiator will not be needed, as errors in this calculation could lead to time and money lost for the project.

E. Ice and Water-Cooling Method

While the radiator system is a great fit for Tartarus' requirements, there are other options available. One such method, while seemingly crude, could be surprisingly effective: ice-cooling. The 60in tall k-bottles could simply be placed in horizontal tubs measuring approximately 65in in height. This will allow the team to place large amounts of ice around and on top of the cylinder, keeping it cooled. As with all designs, there are some inherent flaws with ice-cooling. Firstly, the team would always require a steady source of ice on hand at the storage location; this may not be difficult, but team members taking extended trips away from the storage location could lead to potential problems. Additionally, personnel would have to load this ice into the bath frequently, taking care to pour in the correct amount. Finally, the storage area must receive unfaltering power to maintain its room temperature. Losing power for extended periods of time or turning off temperature control could lead to the ice melting much more rapidly and causing the N_2O to possibly get overheated, especially during warmer times of the year.

Another feasible option would be letting the tank cool off in water when it is exposed to the New Mexican summer heat on launch day. A cooled tub of water would allow the tank to potentially quickly cool off, preventing decomposition in the large k-bottle; decomposition here would be catastrophic and lead to large damage. Modeling a time for effective cooling for such a method is possible, as well. A few aspects will have to be assumed in this problem; it can be assumed that the tank will be fully submerged in the water bath to negate thermal radiation, no internal Nitrous convection, a full-steel K-bottle, and a 1 inch wall thickness.

$$h_{c,water} = \frac{N_u k_{water}}{H} \tag{5}$$

$$\theta_c = A_1 e^{-\lambda^2 F_o} \tag{6}$$

$$F_o = \frac{\alpha t}{L^2} \tag{7}$$

$$\alpha = \frac{k}{\rho c_p} \tag{8}$$

With the given equations, it is possible to get a rough time estimate of the time it takes for the k-bottles to cool down from an initial temperature to a target temperature. It was calculated that k_{eff} is 7.658 W/m*K, given a standard height and diameter of a k-bottle. Ultimately solving for t in Eq. 7, we are able to use Eq. 5 to calculate $h_{c,water}$ to be 119.62, thus obtaining a Bi of 1.8. A Bi of this scale rules out the lumped capacitance method, meaning an unsteady heat transfer approach is required. Thus, we must find a F_o to solve for t in Eq. 7. It was decided to use a long-term approximation, as shown in Eq. 6, to be more accurate, considering the assumptions that were already made which decrease accuracy. The resulting F_o was 0.304. Finally, α was calculated using Eq. 8, allowing Eq. 3 to be fully solved for t. The final time to cool the k-bottle from 90ºF to 70ºF was found to be about 22.5 minutes, a reasonable time.

V. Methods of Cooling N_2O Run Tanks

Apart from keeping N_2O at safe temperatures during off-site storage, it is also crucial to maintain this temperature during unplanned holds and emergencies that may occur during the unpredictable and constantly evolving launch day. While the oxidizer tank holds less N_2O and has a much smaller mass than the k-bottle that are used for storage, a few new problems arise that were not considered for the storage cooling. One new issue is the fact that this cooling system must not interfere with the rocket itself, so it must be either a sub-system that is integrated into the rocket or a separate system from the rocket. Additionally, this system must be quick to activate and foolproof, as failure of this cooling system would lead to the oxidizer tank and N_2O overheating, likely causing rapid mission failure. One method that fits the team's criteria is the spray cooling of the oxidizer tank.

A. Design Considerations of Spray Cooling Systems

1. Introduction to Spray Cooling Systems

Spray Cooling is becoming more frequently used in the aerospace industry due to its many benefits and relative ease of use. Spray cooling, a method of forced convection heat transfer, involves a liquid, such as water, being projected into an atomizing nozzle, thus creating a spray with many droplets of the liquid[4]. The droplets will spray onto a heated surface, forcing heat from the object/surface to the droplets, thus lowering the temperature of the heated object. There are many factors to consider while designing a spray cooling system, such as the liquid's effectiveness at transferring heat from the source to itself, the inlet pressure, the distance from the nozzle to the surface, the potentially adverse reactions between the surface being cooled and the droplets, and the method of atomization[4]. In Tartarus' case, the method used will be a variation of spray cooling, as the N_2O tank at approximately 90°F will not be nearly enough to instantly evaporate the water. Thus, the nozzle will spray water onto the tanks, creating a water film flowing off the tank, and transferring some of the tank's heat to the water. One of the first design aspects to consider will be the liquid used to cool down the N_2O tank; water will be the most viable option, as it is readily available to the team and has a low cost. Additionally, setting up the system a suitable distance from the rocket will also be an important task, as it is imperative to have enough water to be cooling with the warm tank, but not too close to interfere with electronics or other subsystems.

2. Tank-to-Nozzle Delivery Methods

To bring the water from our 150 PSI tank to the nozzle, we need to create a simple system that either ensures enough pressure is in the tank to force the water to evacuate the nozzle or use a water pump that works similarly. There are a few design routes the team could pursue given these constraints. One such design would work similarly to the rocket's gaseous Nitrogen (GN2) supercharge system. In the system shown in Figure 1, the GN2 would pressurize the 150 PSI water tank, causing water to run up to our nozzle and spray onto our tanks. This system could be easily controlled with either a manual gate valve that controls the GN2 flow or a solenoid valve for ease of access and eliminating the need for personnel to get close to a nearly critical temperature N2O tank. Similarly, the team could purchase a relatively inexpensive water pump, creating a pump system. The water reservoir could also be placed underneath the run tank, allowing some of the non-evaporating water to be cycled through the system once more. Both of the water delivery methods are shown in Fig. 4. For this project, the water pump would be the ideal method for delivering the water, as the pump will be cheap, effective, and there will be no need to hassle with N_2 and its potential dangers.

3. Nozzle Selection

Another aspect to consider is the type of nozzle used for the spray cooling system. There is a wide variety of nozzles available, but a few meet Tartarus' needs more than others. For spray cooling, it is essential to have many atomized water particles, or simply a large amount of droplet spray. Some nozzles simply do not compare with others for droplet spray content, such as a full-cone nozzle, which boasts a smaller number of large particles[4]. Some other nozzles, such as the in-line flat jet pressure nozzle/flat-fan, atomize quicker and produce smaller particles, yet their method of delivering water is not what is required. Flat jet nozzles deliver liquid in a spray paint-like fashion, which, for the oxidizer tank, is not ideal, as much of the water may miss the tank altogether. Another consideration would be the popular hollow-cone nozzle. This nozzle breaks up the liquid using centrifugal forces just as it leaves the nozzle's orifice, resulting in a fine mist and many droplets. Finally, a twin-fluid nozzle system could be utilized; this nozzle uses two distinct and angled streams of water that are met with an airstream in the middle to propel and atomize the water outwards, resulting in an excellent and efficient nozzle for our system, but this system would require much more work, as we would require an atomizing gas, as well as the expensive nozzle system. Given the monetary restraints of Tartarus, the ideal nozzle would be a centrifugal hollow-cone nozzle, which will sufficiently deliver water to our heated Nitrous tank and quickly relieve it of heat.

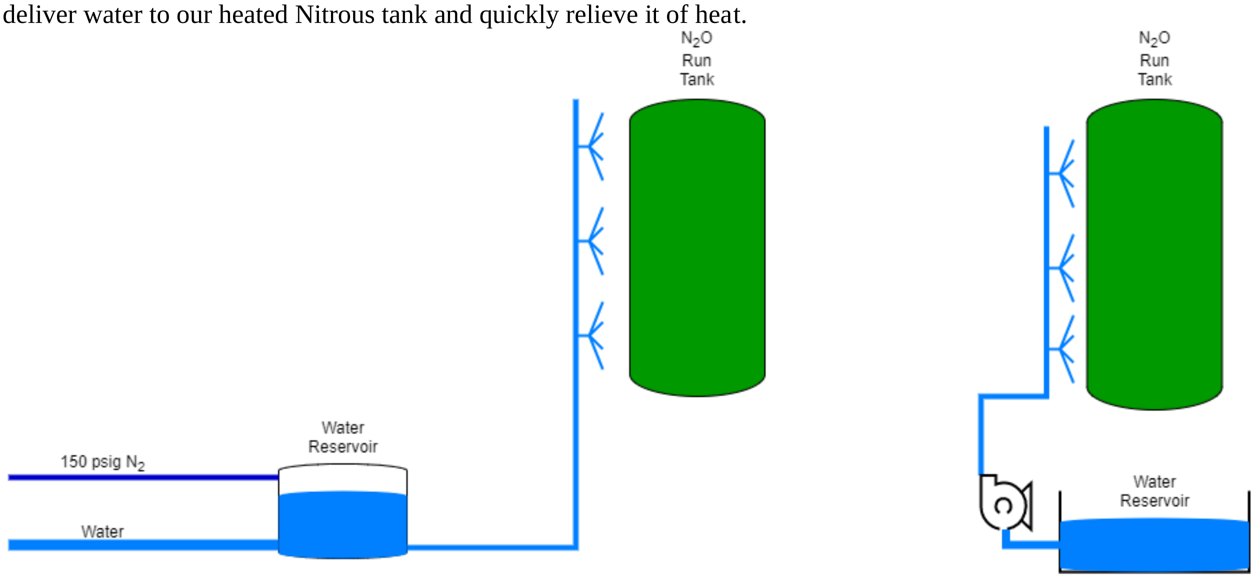

Figure 4. Design Schematics of Spray Cooling for N_2O Run Tanks

4. Additional Design Considerations and Future Work

Another consideration for the spray cooling system would be calculating the amount of water needed per unit time. Calculating an $\dot{m}$ would allow the team to utilize this data for future work involving transient heat transfer.

$$P_1 + \frac{1}{2}\rho v_i^2 = P_2 + \frac{1}{2}\rho v_f^2 \quad (9)$$

$$\dot{m} = \rho V a \quad (10)$$

$$C_d = \frac{\dot{m}}{a\sqrt{2\rho \Delta P}} \quad (11)$$

Using the pressurized water tank of 150psi, Eq. 9 can be used to determine a volumetric flow rate of 43ft/s. With $\dot{V}$, it is now possible to calculate the mass flow rate out of the ¼ inch pipe using Eq. 10, which measures 20lb/s. This is clearly a large amount of water required; however, nozzles were not considered here. Applying a discharge coefficient is necessary here to not only obtain a more reasonable answer, but also allow the team to modify the area of the nozzle orifices as it sees fit. By applying Eq. 11 and using a C_d of 0.7 to account for the square edges of the orifices, a new $\dot{m}$ is calculated at 13.1lb/s. Referring back to Eq. 11, it is possible to notice a few things; while the $\dot{m}$ and density of water is irreversible in the equation, the effective area of the nozzle orifices and pressure drop from our tank to the atmosphere can be tweaked. This opens up a path for future work to be done involving nozzle selection and water tank/pressure selection.

B. N_2O Venting and Draining

On launch day, under nominal conditions, the Nitrous run tanks will be constantly venting a small amount of gas to assist temperature and pressure control. While venting causes a small amount of oxidizer to be lost to the atmosphere, it is a simple way to keep both pressure and temperature of N_2O in check. However, it is possible for venting's effects to be overcome by the 100°F summer heat, creating the need for the spray cooling system. By using a thermocouple, the team can monitor the temperature of the run tanks and N_2O and begin spray cooling the system when the tanks reach around 90°F. Ideally, the spray cooling system would quickly and effectively cool the run tanks, negating the need for venting, or at the very least, slowing down the need for it. However, real world conditions bring anomalies with them, from possibly higher summer heat than normal to gusting winds sweeping across the tanks. The more outside sources of heat there are acting on the tanks, the more imprecise heat transfer measurements become, leaving room for spray cooling to fail in cooling effectively. There is also the unlikely possibility of the spray cooling system failing all together; while the system is not overly complicated, there is still room for problems, such as the water pump not receiving enough water to naturally cool itself. In the event of temperatures of the run tanks reaching nearly 95°F, with the spray cooling or future system designs failing or completely drained of resources, a full system drain and purge will be initiated. The entirety of the rocket's oxidizer will be vented and drained into the atmosphere. While the N_2O will still retain the heat, it will no longer be under pressurized conditions, so the decomposition reaction will no longer be a safety hazard. A drain and purge is very effective, but all the oxidizer is essentially lost, meaning the launch day is either over, or necessitating another run tank of N_2O on the same day. Thus, while there are countermeasures in place to ensure a full, pressurized decomposition reaction does not occur, it would be ideal to avoid using these extreme measures and instead keep the N_2O cooled within the run tanks.

VI. Conclusion

In order to reap the benefits of N_2O as an oxidizer, it is necessary to engineer and integrate new designs for Tartarus' rocket. While there are proved and effective methods to keep N_2O cooled in the large-scale aerospace industry, the team's small-scale, budget and personnel constraints, and limited knowledge on complex machinery limits the available options. Spray, radiator, and water cooling are the most simple yet effective methods available to the team and with the research committed on this paper, the team now has a baseline to begin engineering an efficient and cost-effective cooling system for the run tanks and k-bottles of N_2O.

VII. Future Work

The Tartarus project is still ongoing and there is still a plethora of work to be done and creating a system for cooling N_2O can quickly become complicated due to the nature of heat transfer problems under real world scenarios. There will still be plenty of future work for the team to do, and one of the first steps will be to estimate the amount of heat our k-bottle and/or run tanks will absorb while exposed to New Mexican summer heat. Work has already begun, but with many assumptions, such as a perfect afternoon with no wind, and a complete black bodied run tank, the numbers are inaccurate, but at least give the team somewhere to work from. Additionally, the team will begin to start manufacturing and testing spray cooling systems and nozzles to ensure the system does not fail on launch day.

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