Design, Fabrication, and Clean Testing of Dead-Leg Station

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Degree in Bachelor of Science In
Chemical Engineering
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ABSTRACT

This project provides a detailed analysis of varying flow rates to prove that dead-legs in a piping system, ultimately, cannot adequately be cleaned in a pharmaceutical setting. A test station, equipped with dead-legs at varying orientations, was designed, fabricated, and tested to demonstrate insufficient cleaning of the dead-legs at a wide range of flow rates. This examination is beneficial to the industry in exploring the complications that dead-legs can pose on a system.

AUTHORSHIP

All MQP members contributed equally with the design, fabrication, testing execution, writing, editing, and overall work associated with the Major Qualifying Project.

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TABLE OF CONTENTS

1.INTRODUCTION

What is a Dead-leg and Why Does it Need to be Cleaned?

A dead-leg is a volume of trapped air in a piping system that could lead to contamination of the product within the system. These are piping segments that are exposed to the process but are not impacted by normal flow, including lines closed by caps, flanges, or other fittings. Dead-legs are a prominent source of safety incidents, causing process fluid release, fluid pooling, reduced cleanability, contamination, among other complications (Sloley, 2011).

The biopharmaceutical industry set standards for dead-legs in processing equipment over a decade ago. The ratio of six times the length over the diameter of the dead-leg, L/D, was the historical maximum ratio acceptable in industry use in 1997. However, numerous studies have promoted designing the L/D ratio less than two in order to increase cleanability, which is achievable due to modern technology (ASME Standards, 2017).

Through multiple studies and observations, the industry found that the optimum cleaning of the process system was attainable with a turbulent flow rate of 5 ft/sec. If the cleaning solution passed through at this velocity, sufficient cleaning (clean in place, CIP), with dead-legs of ratio of less than 2:1, is possible.

Proper cleaning is defined when the air pocket in the dead-leg is displaced and the cleaning solution can contact the component during CIP (adequate flow rate is not enough to define actual cleaning as the process is much more complicated but that is outside the scope of the report).

Cotter Brothers Corporation designed a test similar to the one presented in this report in 2010, utilizing a fixture from 1.5 inch Schedule 40 clear PVC tubing in order to model the cleaning of the system under typical CIP. They fabricated the test station with a variety of dead-legs with varying L/D ratios. Water was used to test a range of flow rates and red dye to indicate the turbulence created by the flow of water across the legs. Cotter testing concluded that insufficient cleaning was established after the allotted time for CIP (“Standard: ASME STP/PT-065, 2013).

There are a variety of studies that prove that L/D of 2 or less possibly prevents the branch of the system from being categorized as a dead-leg, but the orientation and size of the branch are also crucial in determining complications that the branch may pose on the system. If sufficient flow is achievable through the pipeline, a branch would not constitute as a dead-leg ("Zero dead-legs," 2013).

In order to demonstrate the kind of dead-leg our project covered, refer to Figure 1, below. The illustration depicts the typical tee found in a system.

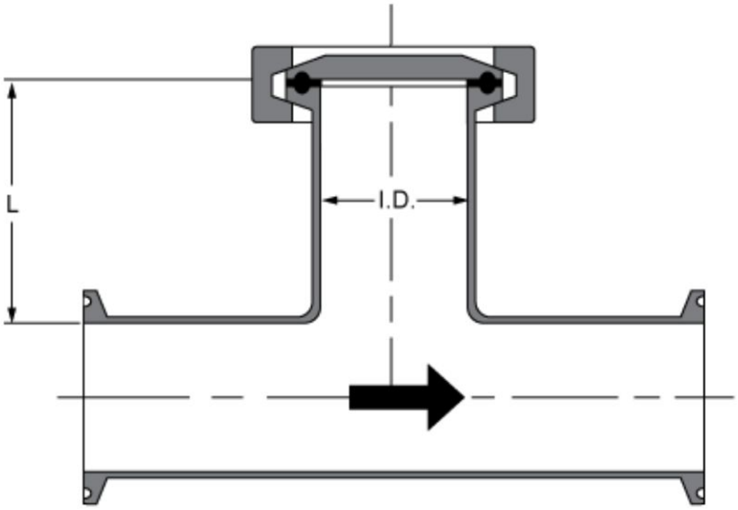
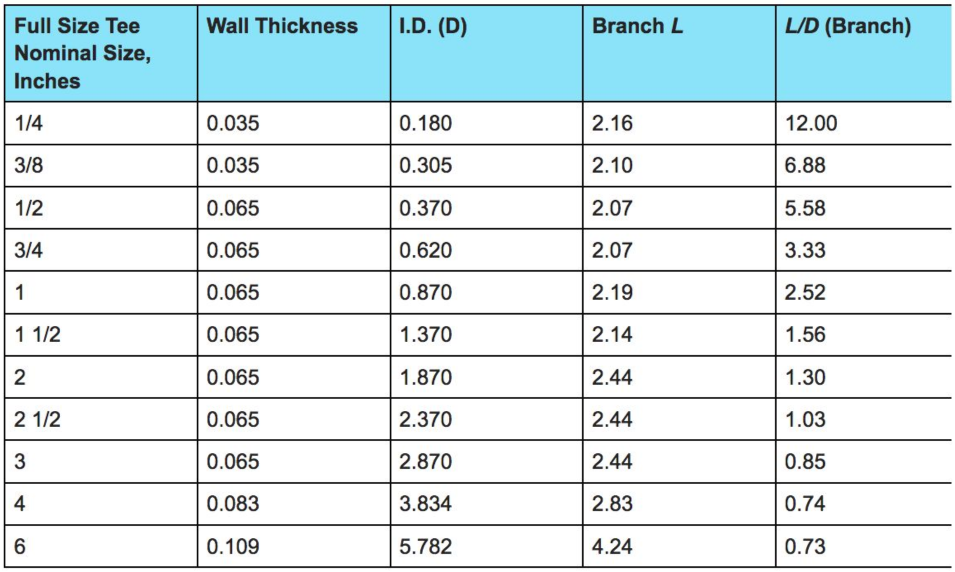


Figure 1: Illustration of a Dead-leg in a Tee ("Zero dead-legs," 2013)

Table 1: L/D Variation in Tee Size



Full Size Tee Nominal Size, Inches	**Wall Thickness**	**I.D. (D)**	**Branch *L***	***L/D* (Branch)**
1/4	0.035	0.180	2.16	12.00
3/8	0.035	0.305	2.10	6.88
1/2	0.065	0.370	2.07	5.58
3/4	0.065	0.620	2.07	3.33
1	0.065	0.870	2.19	2.52
1 1/2	0.065	1.370	2.14	1.56
2	0.065	1.870	2.44	1.30
2 1/2	0.065	2.370	2.44	1.03
3	0.065	2.870	2.44	0.85
4	0.083	3.834	2.83	0.74
6	0.109	5.782	4.24	0.73

The table above references the L/D variance for tees. The former standard ratio of cleanable size of dead-legs was a 6:1 ratio or less. Due to current findings and research, any branch above a 2:1 ratio is considered to be a dead-leg and is unable to be adequately cleaned. There are numerous points in a system that can harbor dead-legs, but the main focus in this report is on dead-legs in a tee structure.

The main goal of this report is to provide information regarding the flow conditions required to displace, or fail to displace, air from piping branches in the appropriate timeframe. In order for cleaning to take place, the cleaning solution must contact the branched components being CIP, if there is no contact with the CIP solutions, cleaning is not achieved.

2. SCOPE AND OBJECTIVES

Scope:

Design and fabricate a test station to demonstrate flow rates/velocities needed to clean/remove entrained air, etc. from piping systems and the associated branch lines (dead-legs). Additionally, construct a representative piping system to show impact of flowing at different flow rates on the dead-legs.

Objectives:

1. Identify why industry standards have changed from 6D to 2D
2. Analyze effectiveness of 5 ft/sec fluid velocity in regards to cleaning linear pipe with dead-legs.
3. Learn if lower/higher flow rates adequately remove soil from dead-legs at various orientations and sizes.
4. Learn which dead-leg orientation/specifications are most compatible with cleaning flow rates.
5. Identify dead-leg orientations/specifications that are not able to be adequately cleaned.

3. BACKGROUND

3.1 Problem Arising through the Dairy Industry

During the rise of Industrialization in America, the dairy industry had come into fruition. As the desire for dairy increased in America, the need for large-scale operations in the dairy industry also increased. Urban centers were not able to produce high enough yields to satisfy the dairy desires of their growing populations based on old techniques. Thus, the need for large scale piping systems to help the transportation of milk proceed from the cattle to the rest of the process was at an all time high.

Originally, the dairy industry created piping systems that were removable to help with the cleaning process. However, removable pipes were not the best solution because of the high chances in human error. Human labor was never consistent when it came to cleaning the pipes, which caused many early health issues in the dairy industry. Removable pipes also meant that more money needed to be spent on labor, rather than improvements to the current system. (BRIAO, V. B. and TAVARES, 2007)

Another issue with cleaning removable pipes was the dairy industry's transition from clear glass pipes to stainless steel pipes. Since the stainless steel pipes were not clear it was hard for employees to determine the cleanliness of the pipes. Due to the issues with removable pipes and lack of visibility, the dairy industry searched for an alternative cleaning method, which was found in the 1950's. The new method of cleaning was referred to as the "Clean in Place" or CIP process. The CIP system allowed for pipes to be cleaned without manual labor process of disassembly, cleaning, and assembly. Instead the CIP method would provide the piping systems with continuous pumping of rinsing material that would clean out the pipes. However, because this system was new, there were still flaws. For example, it took years for the CIP process to develop standard cleaning flow rates and tactics. Another cause for concern with the CIP process was the use of dead-legs in the piping system. Dead-legs cause an issue in the CIP process due to the lack of mixing at certain flow rates. Although the CIP process had not solved all of the problems, it became the standard for pipe cleaning in the dairy industry due to the efficiency of the process and the lack of exposure to harmful chemicals that employees experienced. Later success in the dairy industry allowed other industries to take full advantage of the CIP process, such as pharmaceutical companies (Cleaning and Sanitizing of Containers and Equipment).

3.2 Materials of Construction

Determining the correct materials of construction for the piping structure is significant in developing a successful design. In terms of piping parts alone, the following pieces are necessary: linear piping, elbows, tees, caps, ball valves, reducing bushings, female and male adapters, and PVC glue. More specifically, the piping for the main pipe line is 2" schedule 40 clear PVC piping and the dead-legs comprise of three 2" and six 1.5" schedule 40 clear PVC pipes. More specifications for length will be discussed in a following section. The elbows are at a 90 degree angle, and were used to connect main line piping when a change in direction was necessary. Tees were inserted along the main pipeline to connect dead-legs perpendicular to the main line. Reducing bushings were used between each tee and dead-leg pipe to allow the change in pipe diameter from the 2” main line to the 1.5” dead-legs. Caps were placed on each upward dead-leg to enclose the structure, while ball valves were placed on all downward dead-legs to allow drainage/blockage when necessary. Female and male adapters were placed at the start of the piping to connect the piping structure to the tank via a hose, as well as at the end of the piping to connect the piping structure to the centrifugal pump via a hose. Piping glue was used to fasten all of the parts to one another. In addition to piping parts, other materials were needed in completing the entire design. Some construction pieces include pipe hangers, plywood and a cart for the entire framework to sit on. Two pieces of 8’x4’ plywood were attached to create an 8’x8’ platform. The piping network was laid onto this platform and fastened at an angle with the pipe hangers. This entire system stood upward on a cart which was used to transport the system to different areas in which it will be utilized. Refer to Appendix 1 for the detailed bill of materials (BOM).

3.3 Material of Pipes

All piping materials were made of clear PVC. The purpose of the system was to observe different flow rates within the pipes and to ensure chemicals were being cleansed of the pipe, so it is crucial to use transparent materials in order to be able to see what is occurring internally. Therefore, the clear PVC was used to allow monitoring during testing.

3.4 Pipe Sizing

The main pipeline was 26’ long. In order to fit the entire system on the 8’x8’ board, the pipes were built in an “S” shape with three sections of 7’ horizontal pipe, a 2’ vertical section and a 3’ vertical section to connect all three horizontal segments. The dead-legs varied in length depending on the diameter of the dead-leg. There was a total of 9 dead-legs, 6 upward and 3 downward. The different orientations were tested to see if cleaning occurs better for upward or downward dead-legs. The first horizontal section had all three upward dead-legs of a 2” diameter. The corresponding length of the dead-legs were 4”, 8” and 12”. The next horizontal section had three 1.5” diameter upward dead-legs of 3”, 6” and 9” lengths. The last horizontal section had three 1.5” downward dead-legs of 3”, 6” and 9” lengths. The reason for the different dead-leg lengths comes from the dead-leg diameter. The length of the dead-leg pipes are experimented with 2D, 4D and 6D[1]. Therefore, 2D, 4D and 6D results in different lengths for the bottom horizontal sections. The reason for this variation in dead-leg diameter and length is to test and see what flow rates are necessary to potentially clear all contaminants from the highest dead-leg, or if this is even possible. Therefore, three runs were conducted at seven different flow rates to see what diameter dead-legs result in cleaner dead-legs, and how

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[1] D refers to Diameter, 2D means two times the diameter

high up the dead-leg the cleaning can occur. Whichever was more efficient was determined as the prime dead-leg length for this project.

3.5 Equipment

The two main pieces of equipment used in this experiment are a centrifugal pump and a 600 liter tank. The pump is an Alfa Laval LKH Centrifugal Pump, Size 20. More specifications of the pump can be found in Appendix 2. This pump is used to pressurize the liquid into the piping structure at various flow rates. These flow rates were altered on the pump itself. The tank is a 600 liter vessel that holds all the liquids (water, NaOH, and HCl) during the experiment. When chemicals were added to the system, they were added directly into the tank. The liquid left the tank to enter into the pipes, and returned to the vessel after a full cycle. The reentering of the liquid back into the tank resulted in splashing creating mixing between all substances. These two pieces of equipment are, respectively, the source of uniform mixing and power throughout the entire system.

3.6 How is the Fluid Velocity Affected by Materials?

Friction from the walls of the pipe and fittings used in the piping system both have effects on fluid velocity and pressure. PVC pipe in particular has a significant effect on fluid flow. At high a Reynolds numbers, these effects must be accounted for if maintaining velocity and pressure is a priority.

The Reynolds number for a fluid passing through a pipe indicates the profile of the flow. The three profiles that scientists use to categorize flow are laminar, transitional, and turbulent.

Eq. 1

$$Re = \frac{\rho V l}{\mu}$$

Reynolds numbers depend on a variety of parameters, as shown in the above equation. The characteristic of length (*l*) is adopted for the specific duct or pipe shape. For instance, a cylindrical pipe has a characteristic length equal to the diameter.

The velocity profile of a given fluid progresses from laminar, to transitional, to turbulent flow as the Reynolds number increases. Reynolds numbers are most often manipulated through changes in fluid velocity. The fluid profiles of laminar and turbulent flow through a cylindrical pipe are shown below.

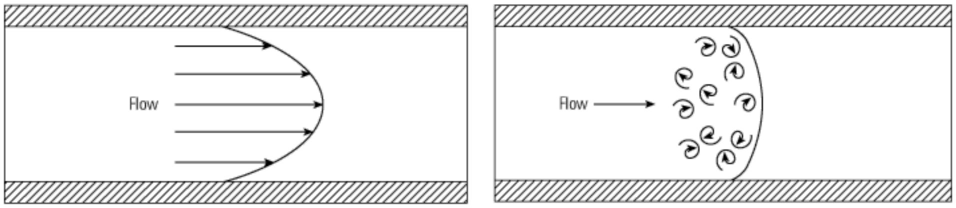


Figure 2: Laminar flow profile shown left, Turbulent flow profile shown right

Turbulent flows are characterized as much more chaotic than laminar flows. The molecules are moving sporadically as they flow down the pipe.

Generally, for engineering purposes, the flow is considered laminar for Reynolds numbers less than 2100, and the flow is considered turbulent for Reynolds numbers greater than 4000. The region between the two is most often defined as transitional flow.

The Bernoulli Equation can be used to effectively analyze flow situations. Two points across a length of pipe, with conditions known, experience some sort of loss through a variety of factors.

Eq. 2

$$h_o + \frac{P_O}{\rho g} + \frac{V_O^2}{2g} + \Delta h_p = h_1 + \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + \Delta h_f + \Delta h_m$$

Specifically, we are focusing on the major losses due to friction in pipes and related to the viscosity of the liquid, and the minor losses due to fittings. Major losses are directly related to velocity, which is squared, so the friction has a drastic effect on fluid velocity ("What Is Bernoulli's equation?").

Eq. 3

$$h_{major\ loss} = \lambda(\frac{l}{d_h})(\frac{v^2}{2g})$$

Polyvinyl Chloride piping has a significantly higher loss due to friction than steel piping. At the turbulent flow rate of 10 gallons per minute, 2” diameter PVC piping holds a loss of 0.2 feet per 100 feet of pipe, while Steel piping of the same diameter carries a loss of 0.1 feet per 100 feet. The difference becomes even more apparent with higher flow rates. At 80 gallons per minute, PVC piping causes a loss of 10.2 feet per 100 feet of pipe, while Steel piping causes a loss of 6.0 feet per 100 feet of pipe ("Losses in Pipes.").

Minor losses due to fittings are also of interest because of the complexity of our testing unit. Four elbows, and nine tees will contribute to a notable loss in the system.

Table 2: Minor losses due to fittings in our system

	90^o Elbow, sharp inside radius	Tee - run flow
2” PVC Minor loss	8.6	4.3

These losses are much higher than any loss due to friction, especially at higher flow rates. For 100 feet of PVC pipe, four elbows, and nine tees, the total loss calculates out to 17.66 feet. Adding in the thirteen fittings contributed to an additional 7.46 feet of loss.

3.7 What is Phenolphthalein?

Phenolphthalein is an organic compound that is used as an acid-base indicator. The molecular formula of phenolphthalein is $C_{20}H_{14}O_4$,with a molecular weight of 318.3 g/mol. The molecular structure is:

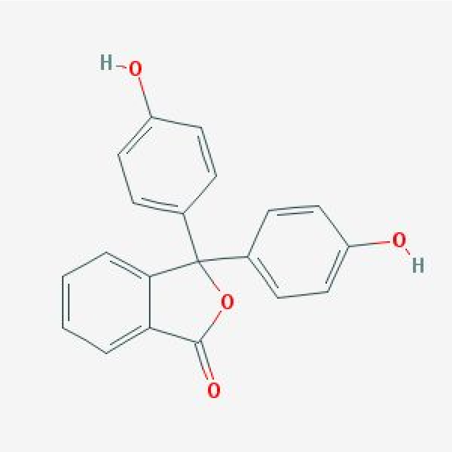


Figure 3: Phenolphthalein Structure

In the aqueous form phenolphthalein is acidic ("Phenolphthalein." National Center for Biotechnology Information). This indicator was originally used as a laxative, but modern science determined that it was carcinogenic and is no longer used as such. Instead phenolphthalein is used in a variety of biology and chemistry labs across the world. One reason why phenolphthalein is a desirable indicator is due to the low indication value. At a pH value of 8.5 the phenolphthalein changes the solution to a pink-purple type of color. Phenolphthalein also has a second color change after the pH reaches 9. Once it reaches 9 the color of the solution changes from pink-purple to a deep red. When acid is added to the indicator it will turn back from a pink-purple color to a clear solution (The Editors of Encyclopedia Britannica. "Phenolphthalein").

3.8 What is titration?

Titration allows for determining the exact endpoint of a reaction and allows for the exact amount of reactant to be produced in the titration flask. Titration gives the volume or concentration of reactant that needs to be added in order to create the solution. Most titration endpoints are easily identifiable due to a color change once the endpoint is reached. For a successful titration, the endpoint change should be known before the experiment is conducted ("What is a Titration").

4. METHODOLOGY & PROCEDURE

In order to test the cleaning of dead-legs of varying sizes and orientations, a test station needed to be designed and fabricated. A design was sketched before official measurements were built into a CAD design. The sketch can be seen in Figure 4 and the CAD design in Figure 5 (further CAD detail can be found in Appendix 4).

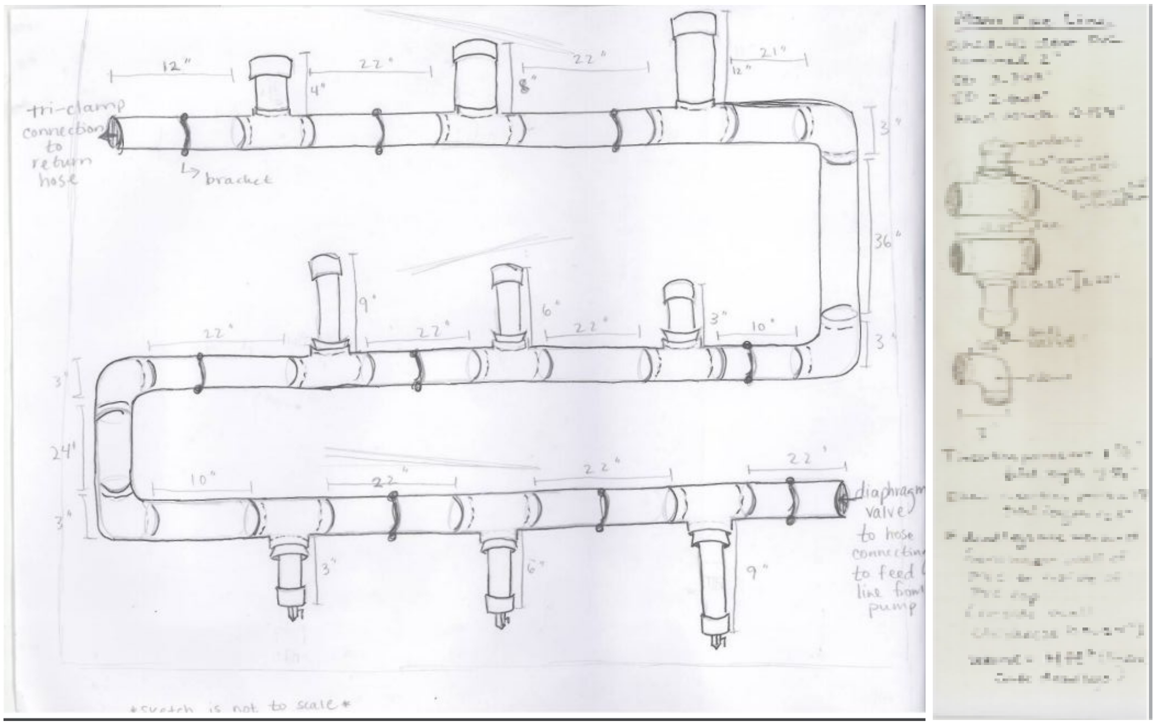


Figure 4: Design Sketch of Test Station

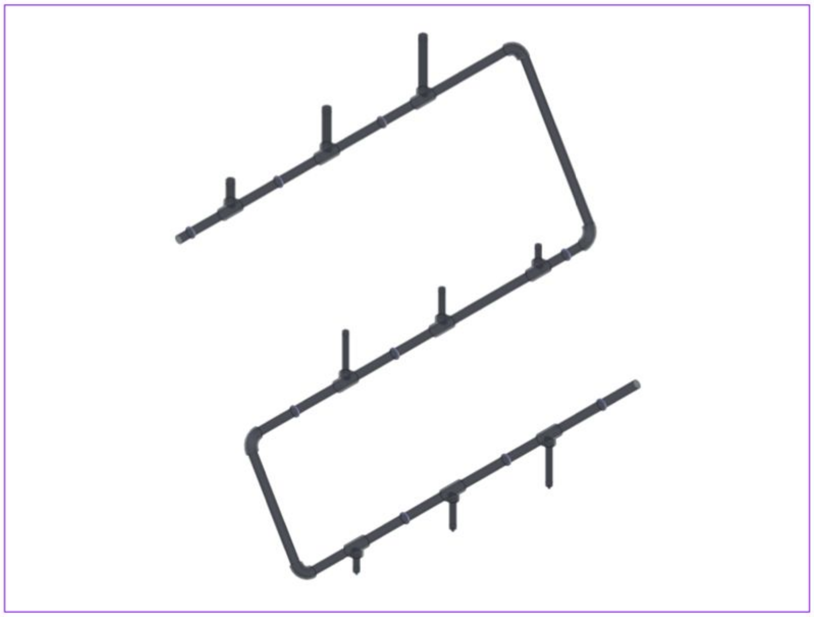


Figure 5: CAD Design of Test Station

Next, we proceeded to prepare the parts for assembly. We began by determining where the brackets would be placed on the board to correctly and securely hold the pipes in place. The general guideline for number of brackets is three brackets per linear pipeline. Since we have three sections of horizontal pipeline, we used a total of nine brackets. In order to achieve drainability, the horizontal pipelines must be slightly tilted. The general heuristic that we followed was to allow ⅛" of tilt for every square foot of piping. Therefore, each linear section was tilted approximately 1". Per section, each of the three brackets were drilled into the board equidistant from each other with a 1" slope between each to achieve the total 2" slope. Next, prior to gluing, all ends of the PVC pipe and fixtures were rubbed down and cleaned with acetone in order to remove any debris to ensure a primed base for the PVC glue to stick. Once the acetone dried and the cleansed area was no longer softened by the acetone, PVC glue was painted onto each end and the pipes and fixtures were attached. We first assembled each horizontally linear section individually, saving the elbows and vertical sections for later. This means that we only glued mainline sections of piping to tees, and then glued the bushings, dead-legs, and caps together for each dead-leg. Once those three sections were complete, we secured each of the three sections onto the board with the brackets. We then moved onto the elbows and two vertical sections. This required more thought because the piping system would be made to have a slope steeper than that of the board to balance the entire system. This piping weight would then offset the board create the balance. To achieve this, we used three different length threaded rods (for each linear section) to connect the bracket screwed into the board to the pipe holder. The threaded rods measured 12", 8", and 4". This created the slope to the system, allowing us to glue the elbows and vertical sections on at the appropriate angle. We glued an elbow to each end of the vertical pipe sections, and with the horizontal sections still on the board, we glued on the vertical sections to compete the overall pipeline assembly. An image of the fabricated test station can be see in Figure 6 below. Also shown in Figure 6 is the labeling system that was used during the experiments. The dead-legs were labeled based on the flow direction of the liquid in the piping system.

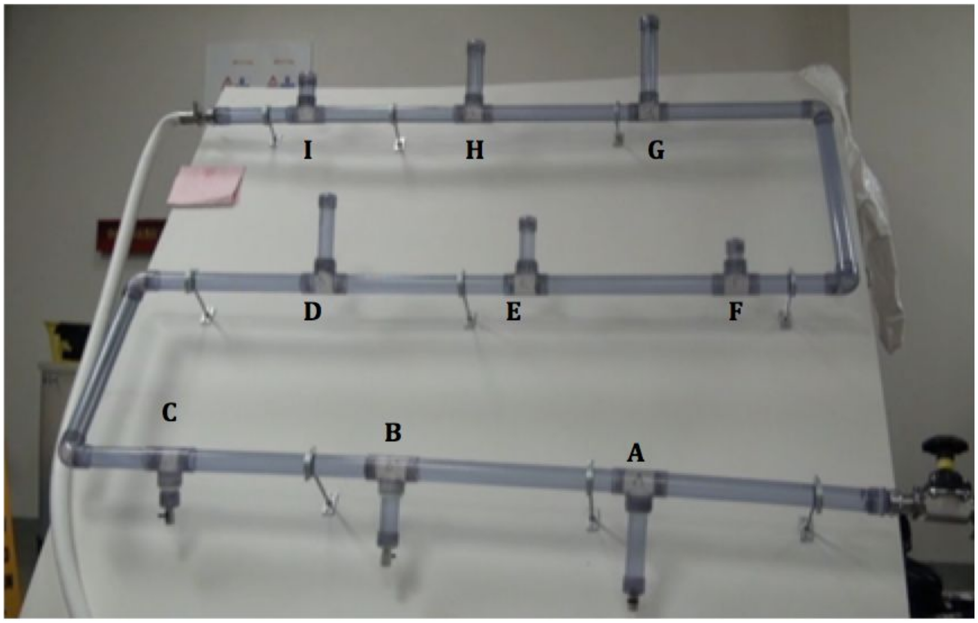


Figure 6: Labelled Test Station

4.1 Setting up testing

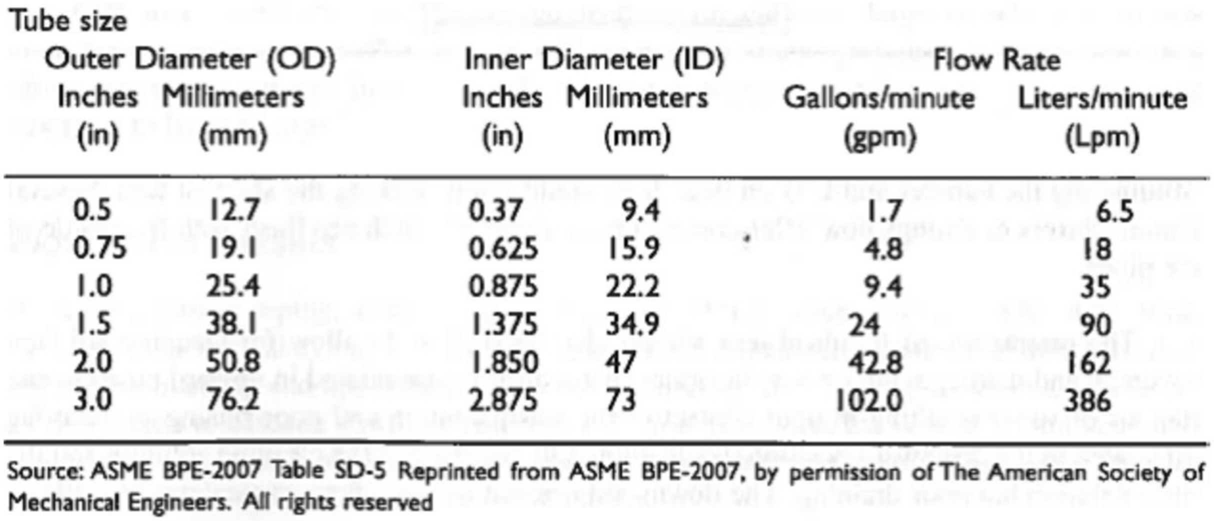
When dealing with high pressure air lines and high flow rates, caution must be taken in order to ensure safety of all operators and nearby personnel. In the testing lab, there are a number of connections required in order to use the equipment correctly. The various ports on our 600 liter storage vessel provide us with flexibility when stationing the unit around other objects in the lab. A hydraulic valve on the bottom of the vessel provides the most logical route into the pump. Connecting the pump from the bottom valve of the vessel with a flexible hose, stainless steel clamps, and rubber gaskets marks the first part to assembling our testing station. Next, the pump outlet connects to the bottom of the piping system; once again using a flexible braided hose, clamps, and gaskets. The return back to vessel connects from the top of the PVC piping system to a feed port on top of the vessel. Setting the flow in this directions provides a means of mixing the contents of the tank, without the need of an agitator. The fluid flows out the bottom of the vessel, and returns back in through the top, splashing inside.

The final piece to getting the system in operating condition requires attaching the compressed air line, and pump power lines. The compressed air line runs from the supply on the wall, for 20 feet on the ground and then into a ball valve on our storage vessel. The ball valve may be opened after making a secure connection. The power cables from the pump motor and pump control unit couple to the corresponding 240 volt and 120 volt outlets on the wall, they are color coded. After ensuring the necessary valves are have been opened, testing may begin.

4.2 Determination of Flow Rates

Six different flow rates were strategically chosen to test mixability in the piping system. Ideally, a horizontal pipe requires a minimum of 5 ft/s to achieve proper cleanability. This velocity is when turbulent flow is achieved, causing an aggressive enough rate to pick up soiled particles (GMP LOGFILE Features). Table 3 displays recommended flow rates depending on pipe diameter to reach 5 ft/s. The man pipeline in the system has a 2” diameter which correlates to a 162 L/min flow rate. Therefore, this was the median flow rate to be tested. Flow rates above this were tested in case 5 ft/s was not sufficient and flow rates below were tested in order to show how mixing gradually occurs from slower flow rates to faster. Overall, using flow rates above and below a velocity of 5 ft/s allowed for a broad range of resulting data.

Table 3: Recommended flow rates to achieve 5 ft/s



Tube size					
Outer Diameter (OD)		Inner Diameter (ID)		Flow Rate	
Inches (in)	Millimeters (mm)	Inches (in)	Millimeters (mm)	Gallons/minute (gpm)	Liters/minute (Lpm)
0.5	12.7	0.37	9.4	1.7	6.5
0.75	19.1	0.625	15.9	4.8	18
1.0	25.4	0.875	22.2	9.4	35
1.5	38.1	1.375	34.9	24	90
2.0	50.8	1.850	47	42.8	162
3.0	76.2	2.875	73	102.0	386

Source: ASME BPE-2007 Table SD-5 Reprinted from ASME BPE-2007, by permission of The American Society of Mechanical Engineers. All rights reserved

As for the faster flow rates above 162 L/min, flow rates above 200 L/min were not used in order to prevent from exceeding pipe limits. To gage a variety of data points, three flow rates between 162 L/min and 200 L/min were chosen, resulting in 174 L/min, 186 L/min and 198 L/min. Two flow rates were chosen below 162 L/min, which are approximately equal intervals between 0 L/min and 162 L/min, resulting in 32 L/min and 97 L/min. Overall, these six flow rates produced a broad spectrum to view the variability of flow rates on the amount of mixing and extent of cleansing. In order to determine the amount of time each flow rate will be run for, a simple calculation was made, found in Appendix 8.

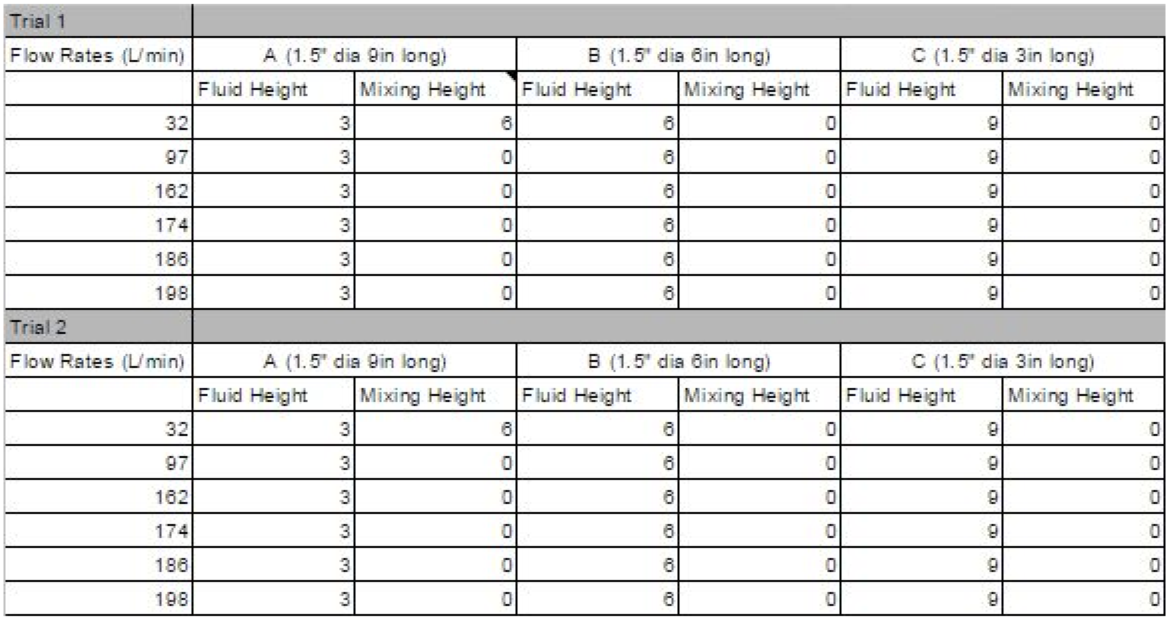
4.3 Personal Protective Equipment

To ensure personal protection and maximum caution throughout our testing, we followed the regulatory gowning requirements Pfizer follows and as directed by the MSDS sheets available in Appendix 6.

4.4 Gathering Data

The most efficient means of gathering data involved measuring both the fluid height and mixing height of each dead-leg, at each flow rate. Our excel spreadsheet provided the organization required for data analysis. The following table presents a screenshot of a portion of our excel spreadsheet (the rest of our data collection can be found in Appendix 7).

Table 4: Data Collection Excel Spreadsheet



Trial 1						
Flow Rates (L/min)	A (1.5" dia 9in long)		B (1.5" dia 6in long)		C (1.5" dia 3in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	3	6	6	0	9	0
97	3	0	6	0	9	0
162	3	0	6	0	9	0
174	3	0	6	0	9	0
186	3	0	6	0	9	0
198	3	0	6	0	9	0
Trial 2						
Flow Rates (L/min)	A (1.5" dia 9in long)		B (1.5" dia 6in long)		C (1.5" dia 3in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	3	6	6	0	9	0
97	3	0	6	0	9	0
162	3	0	6	0	9	0
174	3	0	6	0	9	0
186	3	0	6	0	9	0
198	3	0	6	0	9	0

In addition to physically measuring the fluid height and mixing height at each flow rate, we recorded close-up video of each dead-leg mixing. The fluid dynamics involved in the mixing process would be better evaluated as a description of the video, rather than simply just as two measurements.

The six flow rates chosen represent conditions in relation to five ft/sec fluid velocity. At the lower end, 32 L/min provides data for a very slow system. 198 L/min is much higher than the standard developed by the industry, while 162 L/min is exactly five ft/sec through our system. Each flow rate was repeated three times for accuracy.

5. RESULTS & DISCUSSION

Gathering data consisted of first running a basic solution through our system to initiate the change to the deep purple color which represents a dirty state, as seen in Figure 7. Recycling the equivalent of three full system volumes through the process ensured proper mixing. At this point, shutting off the pump, and adding acid to recycle three times as well, resulted in a clear solution indicating a pH below the turning point. The clear liquid represented a clean state, and the calculations regarding the acid and base addition can be found in Appendix 8.

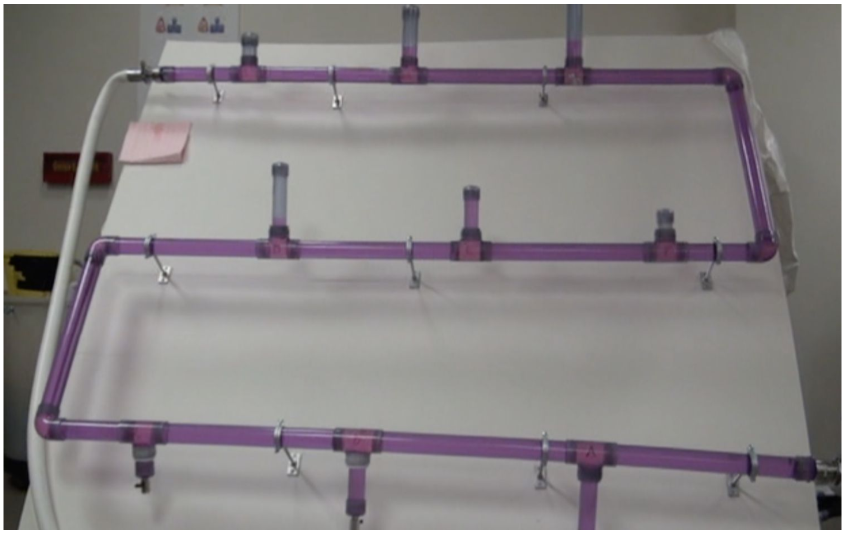


Figure 7: Test Station with Indicator

The fluid height in our upwards dead-legs represents the distance that the solution level travels up each dead-leg when the flow rate increases. The mixing height in these dead-legs represented the level of purple fluid still remaining in each component when the process undergoes a clean state. The air trapped in the dead-leg must be compressed in order for the liquid level to rise.

Table 5: Fluid Height and Mixing Height of D,E, and F

Flow Rates (L/min)	D (1.5" dia 9in long)		E (1.5" dia 6in long)		F (1.5" dia 3in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	0.125	0	6.5	0	0.125	0
97	1.25	0	6.625	0	0.75	0
162	3.333	0	6.625	0	1	0
174	3.542	0	6.875	0	1.417	0
186	3.75	0	6.875	0	1.625	0
198	4.125	0	6.875	0	1.875	0

Table 6: Fluid Height and Mixing Height of G, H, and I

Flow Rates (L/min)	G (2" dia 12in long)		H (2" dia 8in long)		I (2" dia 4in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	1.25	0	0.625	0	0.375	0
97	2.5	0	1.75	0	0.875	0
162	4.625	0	3.375	0	2	0
174	4.833	0	4.125	0	2.708	0
186	5.458	0	4.875	0	3	0
198	5.75	0	5.25	0	2.75	0

Every upwards facing dead-leg completely mixed over the allotted time. Therefore, the mixing height measured zero for all properly operating dead-legs. Dead-leg “E” experienced moderate leaking and filled completely when the pump ran. The data from dead-leg “E” presented little value, due to its malfunctioning.

The fluid heights increased with increasing flow rate. As shown in table 5, running at 32 L/min produced the lowest fluid height of 0.125 inches at dead-leg “D” and dead-leg “E”. This flow rate is not suitable for thorough cleaning dead-leg “D” measured 9 inches long, therefore 8.875 inches or 99% of the component remained unclean at 32 L/min. Dead-leg “E” measures 3 inches long, therefore 2.875 or 96% of the component remained unclean.

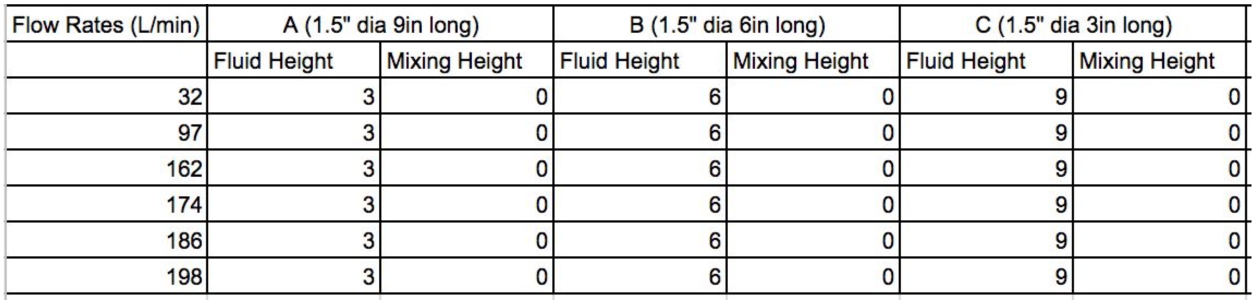
On the contrary, table 6 shows that running at 198 L/min produced the highest fluid height of the properly operating dead-legs. At a fluid height of 5.75 inches in dead-leg “G” for this flow rate, only 52% of the component remained unclean. Running at 198 L/min, dead-leg “I” produced a fluid height of 2.75 inches. These conditions correlated to only 1.25 inches or 31% of the component remaining unclean.

The flow rate of 162 L/min corresponds with the industry heuristic our advisor suggests of a minimum fluid velocity 5 ft/sec when cleaning. At 162 L/min, 2 inches or 67% of the 3 inch long dead-leg “F” remained unclean, the highest percentage. At the same flow rate, 2 inches or 50%

of the 4 inch long dead-leg “I” remained unclean, the lowest percentage. At the 162 L/min flow rate, the 1.5 inch diameter dead-legs averaged 65% remaining unclean. The 2 inch diameter dead-legs averaged 56% remaining unclean.

The dead-legs “D” and “G” both referred to six times their diameters. At the 162 L/min flow rate, they averaged 62% of their total heights unclean. Comparatively, the dead-legs “F” and “I” corresponded to two times their diameters. At the 162 L/min flow rate, these dead-legs averaged only 58% remaining uncleaned.

Table 7: Fluid Height and Mixing Height of G,H, and I



Flow Rates (L/min)	A (1.5" dia 9in long)		B (1.5" dia 6in long)		C (1.5" dia 3in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	3	0	6	0	9	0
97	3	0	6	0	9	0
162	3	0	6	0	9	0
174	3	0	6	0	9	0
186	3	0	6	0	9	0
198	3	0	6	0	9	0

The downward facing dead-legs, “A”, “B”, and “C”, all posed a different issue than the upward facing branches (data for the average of three trials can be found in Table 7, above). Mixing was much more visible within these three legs. As demonstrated in Figure 8, the mixing within the 6L/D dead-leg over time is clearly shown. The image depicts what occurs in all three of the downward facing branches (ranging from 2L/D to 6L/D), the 6L/D displaying the most dramatic mixing. Although all of the dead-legs appeared to display complete mixing at all flow rates, but when the valves were opened to drain fluid after each run, a small amount of indicator was observed. The amount was just enough to coat the bottom endcap and therefore, the results conclude that adequate cleaning cannot be achieved.

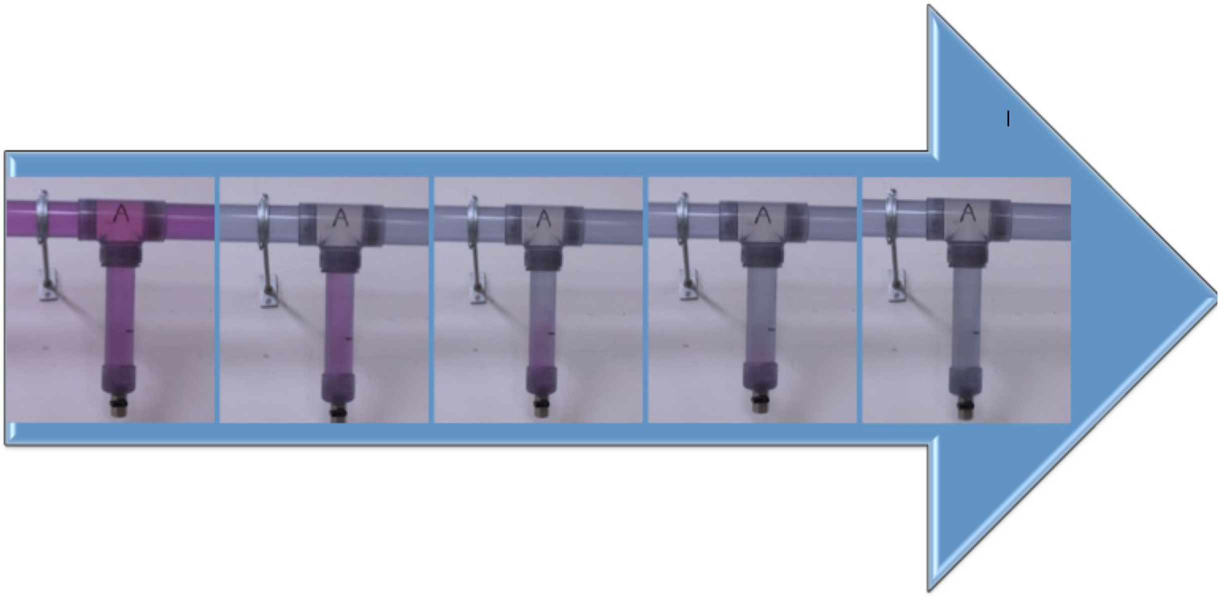


Figure 8: Visible Mixing Over Time in Dead-Leg "A"

The figure below compares "A" and "B" to demonstrate the difference in cleaning times for a 4L/D and 6L/D dead-leg. At all flow rates, dead-leg "B" appeared clean within the first 40 seconds, whereas dead-leg "A" did not visually appear clean until over 80 seconds of cleaning were achieved. The calculated time that the system was cleaned was 3 minutes as calculated.

Figure 9: Visible Mixing Over Time in Dead-Leg "A" Compared to Dead-Leg "B"

5.1 Troubleshooting

The completion of a project, as a student, in a professional environment presents many obstacles. From the preparation of solutions, to the construction and operation of our station, challenges we faced required critical thinking, research, and seeking advice from experts in order to complete our project.

After successfully connecting all portions of the station together, the first run held nothing more than water in the system. At this point, flaws in the construction revealed themselves. Leaks at two critical points in the system presented insurmountable problems. One of the upwards facing dead-legs had a leak right at the adhesion point between the straight pipe and the cap. Therefore, when the flow rate increased, and the trapped air became pressurized, the air escaped and was replaced with water. The fluid level rose until the water began leaking out of the cap. Although the leak voided any data taken from that section, the leak was very slow and posed no threat to the integrity of our station. The next leak positioned itself at the adhesion point between the recycle hose back into the tank, and the final straight pipe section of our testing station. The connection involves a pvc thread, thread seal tape, and a stainless steel connector. The connection was not able to successfully seal, and a small leak dripped onto the board. Once again, the leak was very slow and posed no threat to the integrity of our station. Both leaks were virtually unfixable. Absorbing mats were positioned below the leaks.

Once we worked out our operating procedure it was time to start adding our solutions. We began with a small amount of phenolphthalein indicator and a basic sodium hydroxide solution. The amount we calculated would be required to cause the transition from a clear to a red solution was insufficient. We continued to add the basic solution until it became evident that the pH measured far above the transition point, which posed an unforeseen problem. The first solution was to add more indicator, perhaps that would help the approximately 650 liters turnover. To no avail, the additional indicator was unable to change the color. After consulting with the indicator expert on campus, he presented us with phenolphthalein powder. The powder dissolved in a 50:50 ethanol and water solution, so we prepared that indictor for addition to our system. The prepared solution drastically changed the color of our stored solution from clear to a deep red. Our group concluded that the original vials of phenolphthalein must have been expired or at the very least lost potency over time.

Pfizer's campus allocates the preparation of solutions to the Department of Solutions Services. These employees receive requests for upcoming batches or experiments and formulate them accordingly. As contractors, we had to send our requests indirectly through our full-time employee contacts. This caused one of orders to be put in late, delaying our trials, and causing scheduling conflicts with students balancing classes and making the lengthy trip to Andover. The best method for ordering solutions is to order more than you think you need, and much earlier than you need it. Being conservative in this way ensures experiments are performed sufficiently and on time.

Lastly, maneuvering a large storage vessel, testing unit, and accompanying pieces proved a difficult task. Consulting with employees in the various laboratories in which our units moved through, the final placement of our testing station lies in a position as to provide easy access to all sections, and allows employees to access all compartments needed to perform their jobs.

7. CONCLUSION

The upward oriented dead-legs experienced complete mixing at all six of the experimental flow rates, and therefore, complete cleaning was achieved. Similarly, all three downward oriented dead-legs also experienced complete mixing and cleaning at all six flow rates. However, there was an extremely minute amount of unmixed solution that remained at the very end of the caps in dead-legs A and B. This was an immeasurable amount of solution that was only seen when the valves on the caps were opened and the solution was released. Otherwise, it was too small to measure and was, therefore, not recorded as data. Overall, the downward dead-legs achieved complete mixing, but not enough to completely clean the cap.

More of an issue than improper dead-leg mixing was the trapped air in the upward dead-legs. These air pockets made it difficult for the liquid level to rise inside of the dead-legs. There was no way to rid the system of these pockets, therefore cleaning could not be extended into the tops of the dead-legs at the experimental flow rates. This was especially an issue in the taller and more narrow dead-legs. Therefore, shorter and wider dead-legs are better and more efficient in cleaning. In conclusion, although proper mixing was achieved to create complete cleaning inside of all sizes and orientations of dead-legs, this cleansing can only be achieved at a fraction of the necessary height in upward dead-legs.

8. RECOMMENDATIONS

Our team devised a number of recommendations throughout the duration of the project. First and foremost, our team advises avoiding the presence of dead-legs altogether whenever possible. With the development of technology in the biopharmaceutical field, there are numerous valve configurations to avoid dead-legs. An example of a tank valve can be seen in Figure 10 and another example of a block body in Figure 11. These newly developed configurations minimize and/or eliminate uncleanable dead-legs (“Zero Dead-legs,” 2013).

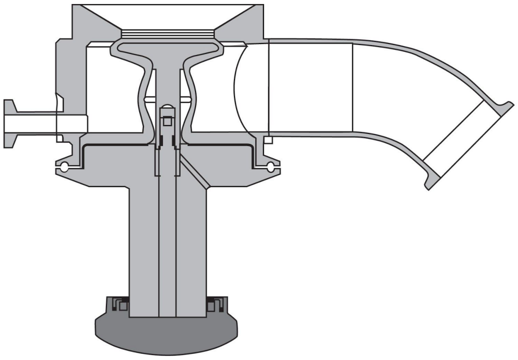


Figure 10: Tank Valve

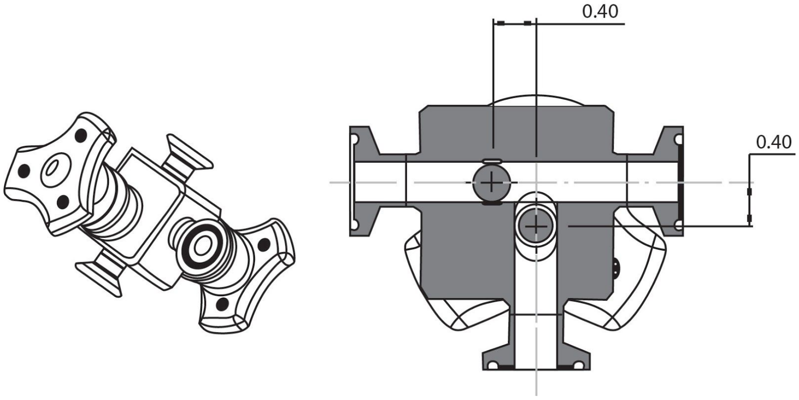


Figure 11: Complex Block Bodies

Finding appropriate fittings to prevent the dead-legs eliminates the complications that they pose on the system, such as fluid pooling and reduced cleanability/sterilization, and prevents contamination of the process. If dead-legs are not able to be avoided in the construction of a new piping system, our team recommends that the dead-legs should be no longer than 2D. Once a dead-leg starts to reach a length longer than 2L/D the efficiency of mixing slows. This could potentially create a need to use higher flow rates than desireable to clean a piping system in the required timeline.

Higher flow rates pose both benefits and risks to the system. A higher flow rate would clean the 2L/D dead-legs effectively but the system may not be able to handle the higher flow rate. For example, the other equipment in the process, such as flow meters, valves, etc., may not be rated for the higher flow rates and will therefore fail if exposed to this situation.

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Appendix 1: Bill Of Materials

PART #	# OF ITEMS	ITEM	DESCRIPTION
2CEX8	4	90 degree elbows clear schedule 40 nominal 2” PVC	Clear schedule 40 nominal 2” PVC
14P015	9	Pipe Clamps	For mounting 2” main pipe system to test station structure (3 clamps per horizontal linear pipe)
10P575	6	1’ Threaded Rods, ⅜” diameter, 16 thread size	Connects pipe clamps to station
2CEW8	9	2” PVC Tees	Clear schedule 40
2ORK14	3	Ball Valves	Bottom of each downward facing dead-leg
2CFA8	2	2” Clear PVC Female Adapters	For connections at beginning and end of piping system
2CFC8	2	2” Clear PVC Male Adapters	For connections at beginning and end of piping system
2CFD8	3	2” Clear PVC Caps	For capping the 2” dead-legs
2CFD7	6	1.5” Clear PVC Caps	For capping the 1.5” dead-legs
22FK55	6	Reducing Bushings Clear PVC	For reducing 2” pipe to 1.5” for dead-leg connections
1AAZ7	1	8’ clear schedule 40 nominal 1.5” PVC pipe	For dead-legs
1AAZ8	4	8’ clear schedule 40 nominal 2” PVC pipe	For dead-legs

Appendix 2: Pump specifications:

Alfa Laval LKH Centrifugal Pump, Size 20, 2 ½” Suction x 2” Discharge, Full Size 165mm Impeller, Single Mechanical Seal Type, Silicon Carbide Vs. Silicon Carbide Seal Face Combination, FDA EPDM Elastomers, No Leg Bracket, 213TC/215TC Frame Size, 32Ra Mechanical 7.5 HP, 3600 RPM, 3 Phase, 60 Hz, 230/460V, Inverter Duty, Wash-down Rated, Sterling Electric Motor, Vacon X series Inverter, 460V Input, 3 Phase, Wired to Motor with 20 Foot Cord

Appendix 3: Equations

Eq. 1

$$Re = \frac{\rho V l}{\mu}$$

ρ :density of the fluid (SI units [lb_m/ft^3])

V :fluid velocity (SI units [*ft/s*])

l :characteristic length (SI units [*ft*])

μ :dynamic viscosity (SI units [lb_m/ft]).

Eq. 2

$$h_o + \frac{P_O}{\rho g} + \frac{V_O^2}{2g} + \Delta h_p = h_1 + \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + \Delta h_f + \Delta h_m$$

h_o: height [ft]

P_o: pressure [psi]

g: gravitational constant [ft/s^2]

v: velocity [ft/s]

Δh_p: loss

Eq. 3

$$h_{major\ loss} = \lambda\left(\frac{l}{d_h}\right)\left(\frac{v^2}{2g}\right)$$

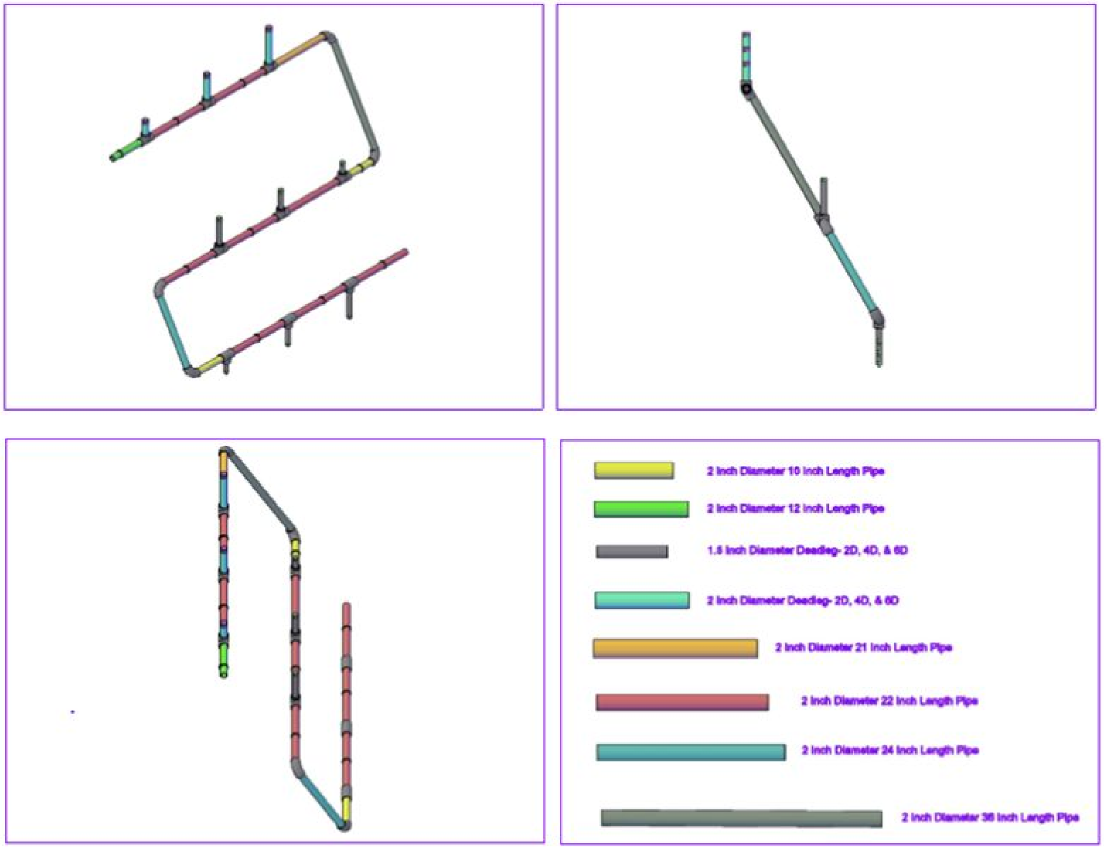
λ : friction coefficient

d_h: hydraulic diameter [ft]

v: velocity [ft/s]

g: gravitational constant [ft/s^2]

Appendix 4: Detailed CAD Design



Shown in the figure above is the piping structure designed in Autocad 3D 2016. The figure shows three different views of the piping system. The first view in the top left corner represents the piping structure in a southwest isometric view. The view in the top right corner is the piping system shown from the left side. From this view the angle of the piping system is displayed. This view also shows the vertical nature of the dead-legs. The view in the bottom left corner shows the piping system from a top left view. This is representative of looking down on the piping system from a ladder on the left side. Finally, the bottom right quadrant is the various lengths of piping that was used during the construction of the system. The horizontal pieces of the piping system were assembled in order to fit 26 horizontal feet on an 8' by 8' board. Along the horizontal piping, dead-legs at varying widths and heights were attached. The bottom row of the piping system consisted of dead-legs with a 1.5 inch diameter. The lengths of the dead-legs were 3 inches, 6 inches, and 9 inches.

The orientation of these dead-legs were downward facing. The middle row dead-legs had the same diameter and lengths as the bottom row, but had an upward orientation. The group decided to switch the orientation of the bottom and middle row in order to determine the difference in mixing between upward and downward dead-legs. Finally, the top row of dead-legs had a 2 inch diameter and had lengths of 4, 8, and 12 inches. These dead-legs had an upward orientation. The team decided to use different dead-leg diameters to determine the difference in cleaning between various sized diameters.

Appendix 5: Clean Time Calculations

$Linear\ Volume : 14ft^3$

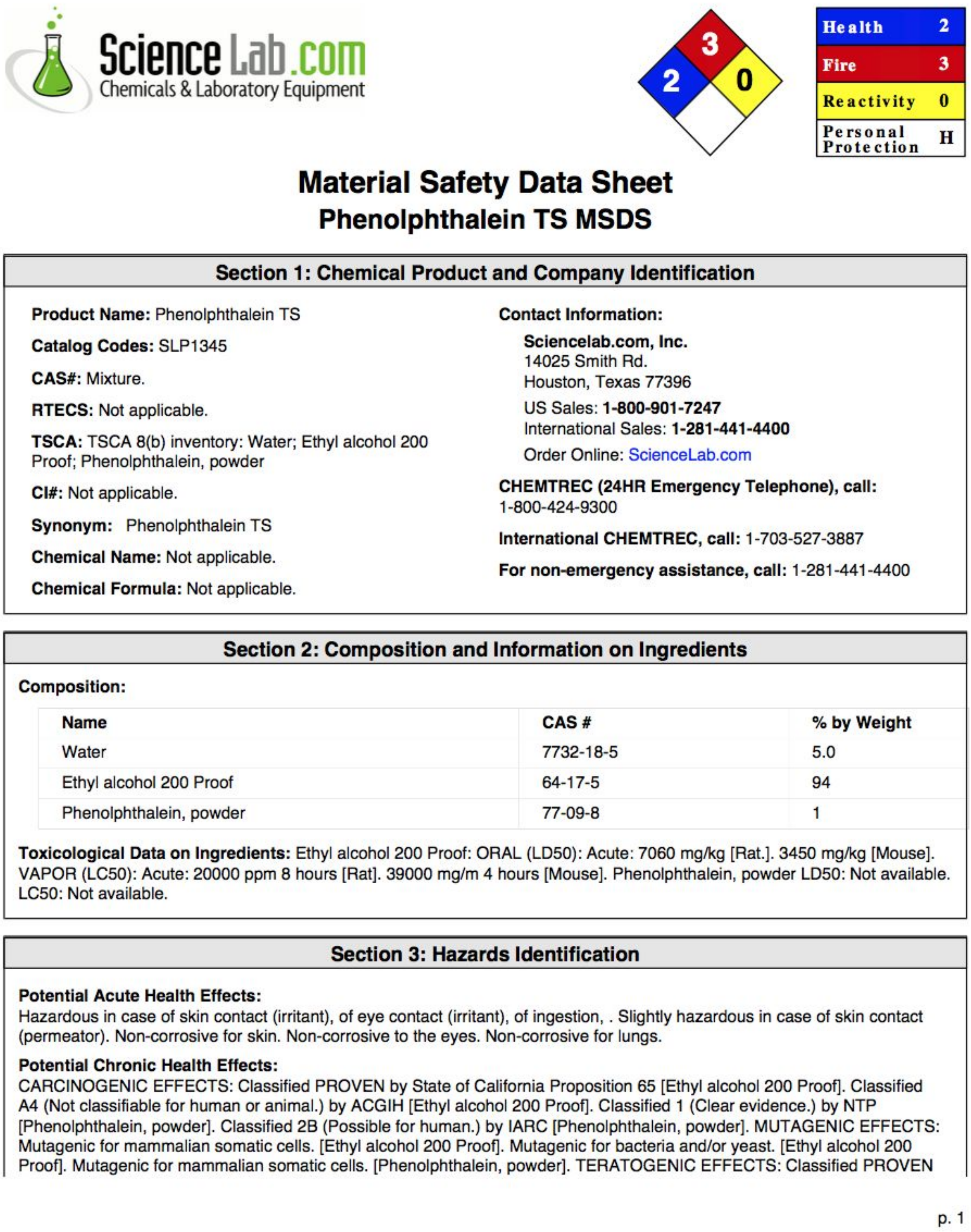
$1ft^3 = 28.32L$

$14ft^3 * (28.32L/ft^3) = 396.48L$

$162L/min\ from\ chart\ for\ 5ft/s\ found\ in\ Table\ 3$

$396.48L * (1min/162L) = 2.447min\ to\ adequately\ clean$

Appendix 6: Phenolphthalein MSDS



Health	2
Fire	3
Reactivity	0
Personal Protection	H

Material Safety Data Sheet
Phenolphthalein TS MSDS

Section 1: Chemical Product and Company Identification

Product Name: Phenolphthalein TS

Catalog Codes: SLP1345

CAS#: Mixture.

RTECS: Not applicable.

TSCA: TSCA 8(b) inventory: Water; Ethyl alcohol 200 Proof; Phenolphthalein, powder

CI#: Not applicable.

Synonym: Phenolphthalein TS

Chemical Name: Not applicable.

Chemical Formula: Not applicable.

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call: 1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Water	7732-18-5	5.0
Ethyl alcohol 200 Proof	64-17-5	94
Phenolphthalein, powder	77-09-8	1

Toxicological Data on Ingredients: Ethyl alcohol 200 Proof: ORAL (LD50): Acute: 7060 mg/kg [Rat.]. 3450 mg/kg [Mouse]. VAPOR (LC50): Acute: 20000 ppm 8 hours [Rat]. 39000 mg/m 4 hours [Mouse]. Phenolphthalein, powder LD50: Not available. LC50: Not available.

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, . Slightly hazardous in case of skin contact (permeator). Non-corrosive for skin. Non-corrosive to the eyes. Non-corrosive for lungs.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Classified PROVEN by State of California Proposition 65 [Ethyl alcohol 200 Proof]. Classified A4 (Not classifiable for human or animal.) by ACGIH [Ethyl alcohol 200 Proof]. Classified 1 (Clear evidence.) by NTP [Phenolphthalein, powder]. Classified 2B (Possible for human.) by IARC [Phenolphthalein, powder]. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. [Ethyl alcohol 200 Proof]. Mutagenic for bacteria and/or yeast. [Ethyl alcohol 200 Proof]. Mutagenic for mammalian somatic cells. [Phenolphthalein, powder]. TERATOGENIC EFFECTS: Classified PROVEN

for human [Ethyl alcohol 200 Proof]. DEVELOPMENTAL TOXICITY: Classified Development toxin [PROVEN] [Ethyl alcohol 200 Proof]. Classified Reproductive system/toxin/male [POSSIBLE] [Ethyl alcohol 200 Proof]. The substance is toxic to blood, the reproductive system, liver, upper respiratory tract, skin, central nervous system (CNS). The substance may be toxic to kidneys. Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. Immediately flush eyes with running water for at least 15 minutes, keeping eyelids open. Cold water may be used. Get medical attention.

Skin Contact:
In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention if symptoms appear.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Flammable.

Auto-Ignition Temperature: The lowest known value is 363°C (685.4°F) (Ethyl alcohol 200 Proof).

Flash Points:
The lowest known value is CLOSED CUP: 12.78°C (55°F). OPEN CUP: 12.78°C (55°F). (Cleveland). (Ethyl alcohol 200 Proof)

Flammable Limits: The greatest known range is LOWER: 3.3% UPPER: 19% (Ethyl alcohol 200 Proof)

Products of Combustion: These products are carbon oxides (CO, CO_2).

Fire Hazards in Presence of Various Substances:
Highly flammable in presence of open flames and sparks, of heat. Slightly flammable to flammable in presence of oxidizing materials. Non-flammable in presence of shocks, of reducing materials, of combustible materials, of organic materials, of metals, of acids, of alkalis, of moisture.

Explosion Hazards in Presence of Various Substances:
Slightly explosive in presence of oxidizing materials, of acids. Non-explosive in presence of open flames and sparks, of shocks.

Fire Fighting Media and Instructions:
Flammable liquid, soluble or dispersed in water. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use alcohol foam, water spray or fog.

Special Remarks on Fire Hazards:

Containers should be grounded. CAUTION: MAY BURN WITH NEAR INVISIBLE FLAME Vapor may travel considerable distance to source of ignition and flash back. (Ethyl alcohol 200 Proof)

Special Remarks on Explosion Hazards:
Ethanol has an explosive reaction with the oxidized coating around potassium metal. Ethanol ignites and then explodes on contact with acetic anhydride + sodium hydrosulfate (ignites and may explode), disulfuric acid + nitric acid, phosphorous(III) oxide platinum, potassium-tert-butoxide+ acids. Ethanol forms explosive products in reaction with the following compound : ammonia + silver nitrate (forms silver nitride and silver fulminate), iodine + phosphorus (forms ethane iodide), magnesium perchlorate (forms ethyl perchlorate), mercuric nitrate, nitric acid + silver (forms silver fulminate) silver nitrate (forms ethyl nitrate) silver(I) oxide + ammonia or hydrazine (forms silver nitride and silver fulminate), sodium (evolves hydrogen gas). (Ethyl alcohol 200 Proof)

Section 6: Accidental Release Measures

Small Spill:
Dilute with water and mop up, or absorb with an inert dry material and place in an appropriate waste disposal container.

Large Spill:
Flammable liquid. Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not touch spilled material. Prevent entry into sewers, basements or confined areas; dike if needed. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep locked up.. Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, acids, alkalis.

Storage:
Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Splash goggles. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
Ethyl alcohol 200 Proof TWA: 1000 (ppm) from ACGIH (TLV) [United States] [1999] TWA: 1000 (ppm) from OSHA (PEL) [United States] TWA: 1900 (mg/m3) from OSHA (PEL) [United States] TWA: 1000 (ppm) from NIOSH TWA: 1000 (ppm) [United Kingdom (UK)] TWA: 1920 (mg/m3) [United Kingdom (UK)] TWA: 1000 STEL: 1250 (ppm) [Canada]Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor: Not available.

Taste: Not available.

Molecular Weight: Not applicable.

Color: Colorless.

pH (1% soln/water): Neutral.

Boiling Point: The lowest known value is 78.5°C (173.3°F) (Ethyl alcohol 200 Proof). Weighted average: 79.58°C (175.2°F)

Melting Point: May start to solidify at -114.1°C (-173.4°F) based on data for: Ethyl alcohol 200 Proof.

Critical Temperature: The lowest known value is 243°C (469.4°F) (Ethyl alcohol 200 Proof).

Specific Gravity: Weighted average: 0.8 (Water = 1)

Vapor Pressure: The highest known value is 5.7 kPa (@ 20°C) (Ethyl alcohol 200 Proof). Weighted average: 5.53 kPa (@ 20°C)

Vapor Density: The highest known value is 1.59 (Air = 1) (Ethyl alcohol 200 Proof). Weighted average: 1.54 (Air = 1)

Volatility: Not available.

Odor Threshold: The highest known value is 100 ppm (Ethyl alcohol 200 Proof)

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, methanol, diethyl ether, acetone.

Solubility:
Easily soluble in cold water, hot water, methanol, diethyl ether. Soluble in acetone.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Incompatible materials, heat, sources of ignition. (Ethyl alcohol 200 Proof)

Incompatibility with various substances: Reactive with oxidizing agents, acids, alkalis.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Ethanol rapidly absorbs moisture from the air. Can react vigorously with oxiders. The following oxidants have been demonstrated to undergo vigorous/explosive reaction with ethanol: barium perchlorate, bromine pentafluoride, calcium hypochlorite, chloryl perchlorate, chromium trioxide, chromyl chloride, dioxygen difluoride, disulfuryl difluoride, fluorine nitrate, hydrogen peroxide, iodine heptafluoride, nitric acid nitrosyl perchlorate, perchloric acid permanganic acid, peroxodisulfuric acid, potassium dioxide, potassium perchlorate, potassium permanganate, ruthenium(VIII) oxide, silver perchlorate, silver peroxide, uranium hexafluoride, uranyl perchlorate. Ethanol reacts violently/expodes with the following compounds: acetyl bromide (evolves hydrogen bromide) acetyl chloride, aluminum, sesquibromide ethylate, ammonium hydroxide & silver oxide, chlorate, chromic anhydride, cyanuric acid + water, dichloromethane + sulfuric acid + nitrate (or) nitrite, hydrogen peroxide + sulfuric acid, iodine + methanol + mercuric oxide, manganese perchlorate + 2,2-dimethoxy propane, perchlorates, permanganates + sulfuric acid, potassium superoxide, potassium tert-butoxide, silver & nitric acid, silver perchlorate, sodium hydrazide, sulfuric acid + sodium dichromate, tetrachlorisilane + water. Ethanol is also incompatible with platinium, and sodium. (Ethyl alcohol 200 Proof)

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Eye contact. Inhalation.

Toxicity to Animals: Acute oral toxicity (LD50): 3450 mg/kg [Mouse]. (Ethyl alcohol 200 Proof).

Chronic Effects on Humans:
CARCINOGENIC EFFECTS: Classified PROVEN by State of California Proposition 65 [Ethyl alcohol 200 Proof]. Classified A4 (Not classifiable for human or animal.) by ACGIH [Ethyl alcohol 200 Proof]. Classified 1 (Clear evidence.) by NTP [Phenolphthalein, powder]. Classified 2B (Possible for human.) by IARC [Phenolphthalein, powder]. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. [Ethyl alcohol 200 Proof]. Mutagenic for bacteria and/or yeast. [Ethyl alcohol 200 Proof]. Mutagenic for mammalian somatic cells. [Phenolphthalein, powder]. TERATOGENIC EFFECTS: Classified PROVEN for human [Ethyl alcohol 200 Proof]. DEVELOPMENTAL TOXICITY: Classified Development toxin [PROVEN] [Ethyl alcohol 200 Proof]. Classified Reproductive system/toxin/male [POSSIBLE] [Ethyl alcohol 200 Proof]. Contains material which may cause damage to the following organs: kidneys.

Other Toxic Effects on Humans:
Hazardous in case of skin contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of skin contact (permeator).

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans:
May affect genetic material (mutagenic) Causes adverse reproductive effects and birth defects (teratogenic) , based on moderate to heavy consumption. May cause cancer based on animal data. Human: passes through the placenta, excreted in maternal milk. (Ethyl alcohol 200 Proof)

Special Remarks on other Toxic Effects on Humans:
Acute potential health effects: Skin: causes skin irritation Eyes: causes eye irritation Ingestion: May affect behavior. Moderately toxic and narcotic in high concentrations. May affect metabolism, gastrointestinal tract, blood, liver. May affect respiratory tract, cardiovascular and urinary systems. Experimentaly tumorigen. Inhalation: May cause irritation of the respiratory tract, headache, drowsiness, nausea, narcosis. (Ethyl alcohol 200 Proof)

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: CLASS 3: Flammable liquid.

Identification: : Ethanol (Ethyl alcohol 200 Proof) UNNA: 1170 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
California prop. 65: This product contains the following ingredients for which the State of California has found to cause cancer, birth defects or other reproductive harm, which would require a warning under the statute: Ethyl alcohol 200 Proof; Phenolphthalein, powder California prop. 65: This product contains the following ingredients for which the State of California has found to cause birth defects which would require a warning under the statute: Ethyl alcohol 200 Proof California prop. 65: This product contains the following ingredients for which the State of California has found to cause cancer which would require a warning under the statute: Ethyl alcohol 200 Proof; Phenolphthalein, powder Rhode Island RTK hazardous substances: Ethyl alcohol 200 Proof Pennsylvania RTK: Ethyl alcohol 200 Proof Florida: Ethyl alcohol 200 Proof Massachusetts RTK: Ethyl alcohol 200 Proof New Jersey: Ethyl alcohol 200 Proof TSCA 8(b) inventory: Water; Ethyl alcohol 200 Proof; Phenolphthalein, powder

Other Regulations: OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200).

Other Classifications:

WHMIS (Canada):
CLASS B-2: Flammable liquid with a flash point lower than 37.8°C (100°F). CLASS D-2A: Material causing other toxic effects (VERY TOXIC).

DSCL (EEC):
R11- Highly flammable. R22- Harmful if swallowed. R45- May cause cancer. S2- Keep out of the reach of children. S46- If swallowed, seek medical advice immediately and show this container or label. S53- Avoid exposure - obtain special instructions before use.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 3

Reactivity: 0

Personal Protection: h

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 3

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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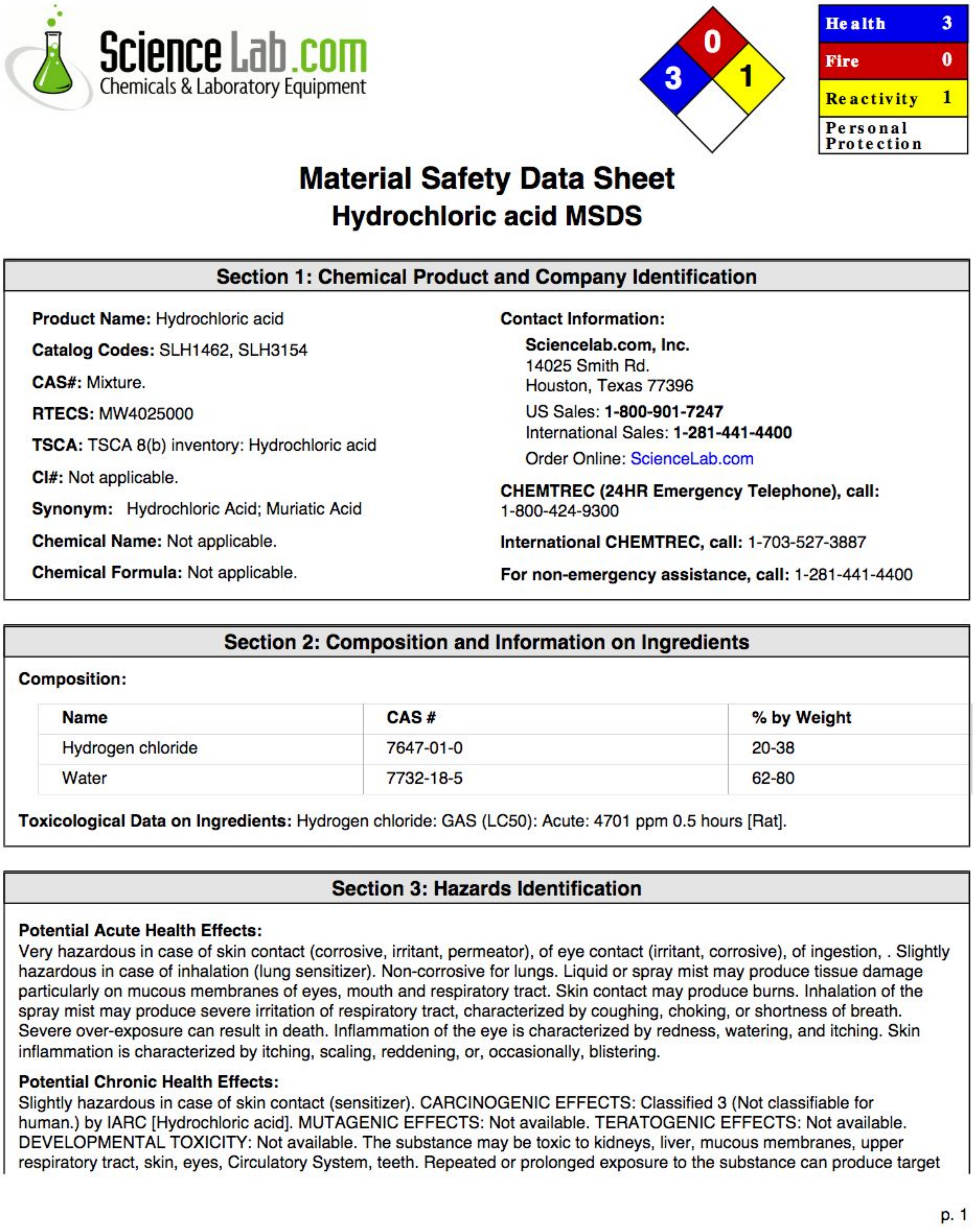

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Health	3
Fire	0
Reactivity	1
Personal Protection	

Material Safety Data Sheet
Hydrochloric acid MSDS

Section 1: Chemical Product and Company Identification

Product Name: Hydrochloric acid

Catalog Codes: SLH1462, SLH3154

CAS#: Mixture.

RTECS: MW4025000

TSCA: TSCA 8(b) inventory: Hydrochloric acid

CI#: Not applicable.

Synonym: Hydrochloric Acid; Muriatic Acid

Chemical Name: Not applicable.

Chemical Formula: Not applicable.

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

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International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Hydrogen chloride	7647-01-0	20-38
Water	7732-18-5	62-80

Toxicological Data on Ingredients: Hydrogen chloride: GAS (LC50): Acute: 4701 ppm 0.5 hours [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects:
Very hazardous in case of skin contact (corrosive, irritant, permeator), of eye contact (irritant, corrosive), of ingestion, . Slightly hazardous in case of inhalation (lung sensitizer). Non-corrosive for lungs. Liquid or spray mist may produce tissue damage particularly on mucous membranes of eyes, mouth and respiratory tract. Skin contact may produce burns. Inhalation of the spray mist may produce severe irritation of respiratory tract, characterized by coughing, choking, or shortness of breath. Severe over-exposure can result in death. Inflammation of the eye is characterized by redness, watering, and itching. Skin inflammation is characterized by itching, scaling, reddening, or, occasionally, blistering.

Potential Chronic Health Effects:
Slightly hazardous in case of skin contact (sensitizer). CARCINOGENIC EFFECTS: Classified 3 (Not classifiable for human.) by IARC [Hydrochloric acid]. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to kidneys, liver, mucous membranes, upper respiratory tract, skin, eyes, Circulatory System, teeth. Repeated or prolonged exposure to the substance can produce target

organs damage. Repeated or prolonged contact with spray mist may produce chronic eye irritation and severe skin irritation. Repeated or prolonged exposure to spray mist may produce respiratory tract irritation leading to frequent attacks of bronchial infection. Repeated exposure to a highly toxic material may produce general deterioration of health by an accumulation in one or many human organs.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention immediately.

Skin Contact:
In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Cover the irritated skin with an emollient. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention immediately.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention immediately.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic, infectious or corrosive. Seek immediate medical attention.

Ingestion:
If swallowed, do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: of metals

Explosion Hazards in Presence of Various Substances: Non-explosive in presence of open flames and sparks, of shocks.

Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards:
Non combustible. Calcium carbide reacts with hydrogen chloride gas with incandescence. Uranium phosphide reacts with hydrochloric acid to release spontaneously flammable phosphine. Rubidium acetylene carbides burns with slightly warm hydrochloric acid. Lithium silicide in contact with hydrogen chloride becomes incandescent. When dilute hydrochloric acid is used, gas spontaneously flammable in air is evolved. Magnesium boride treated with concentrated hydrochloric acid produces spontaneously flammble gas. Cesium acetylene carbide burns hydrogen chloride gas. Cesium carbide ignites in contact with hydrochloric acid unless acid is dilute. Reacts with most metals to produce flammable Hydrodgen gas.

Special Remarks on Explosion Hazards:

Hydrogen chloride in contact with the following can cause an explosion, ignition on contact, or other violent/vigorous reaction: Acetic anhydride AgClO + CCl4 Alcohols + hydrogen cyanide, Aluminum Aluminum-titanium alloys (with HCl vapor), 2-Amino ethanol, Ammonium hydroxide, Calcium carbide Ca3P2 Chlorine + dinitroanilines (evolves gas), Chlorosulfonic acid Cesium carbide Cesium acetylene carbide, 1,1-Difluoroethylene Ethylene diamine Ethylene imine, Fluorine, HClO4 Hexalithium disilicide H2SO4 Metal acetylides or carbides, Magnesium boride, Mercuric sulfate, Oleum, Potassium permanganate, beta-Propiolactone Propylene oxide Rubidium carbide, Rubidium, acetylene carbide Sodium (with aqueous HCl), Sodium hydroxide Sodium tetraselenium, Sulfonic acid, Tetraselenium tetranitride, U3P4 , Vinyl acetate. Silver perchlorate with carbon tetrachloride in the presence of hydrochloric acid produces trichloromethyl perchlorate which detonates at 40 deg. C.

Section 6: Accidental Release Measures

Small Spill:
Dilute with water and mop up, or absorb with an inert dry material and place in an appropriate waste disposal container. If necessary: Neutralize the residue with a dilute solution of sodium carbonate.

Large Spill:
Corrosive liquid. Poisonous liquid. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not get water inside container. Do not touch spilled material. Use water spray curtain to divert vapor drift. Use water spray to reduce vapors. Prevent entry into sewers, basements or confined areas; dike if needed. Call for assistance on disposal. Neutralize the residue with a dilute solution of sodium carbonate. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep locked up.. Keep container dry. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Never add water to this product. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, organic materials, metals, alkalis, moisture. May corrode metallic surfaces. Store in a metallic or coated fiberboard drum using a strong polyethylene inner package.

Storage: Keep container tightly closed. Keep container in a cool, well-ventilated area.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Face shield. Full suit. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves. Boots.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
CEIL: 5 (ppm) from OSHA (PEL) [United States] CEIL: 7 (mg/m3) from OSHA (PEL) [United States] CEIL: 5 from NIOSH CEIL: 7 (mg/m3) from NIOSH TWA: 1 STEL: 5 (ppm) [United Kingdom (UK)] TWA: 2 STEL: 8 (mg/m3) [United Kingdom (UK)]Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor: Pungent. Irritating (Strong.)

Taste: Not available.

Molecular Weight: Not applicable.

Color: Colorless to light yellow.

pH (1% soln/water): Acidic.

Boiling Point:
108.58 C @ 760 mm Hg (for 20.22% HCl in water) 83 C @ 760 mm Hg (for 31% HCl in water) 50.5 C (for 37% HCl in water)

Melting Point:
-62.25°C (-80°F) (20.69% HCl in water) -46.2 C (31.24% HCl in water) -25.4 C (39.17% HCl in water)

Critical Temperature: Not available.

Specific Gravity:
1.1- 1.19 (Water = 1) 1.10 (20%and 22% HCl solutions) 1.12 (24% HCl solution) 1.15 (29.57% HCl solution) 1.16 (32% HCl solution) 1.19 (37% and 38%HCl solutions)

Vapor Pressure: 16 kPa (@ 20°C) average

Vapor Density: 1.267 (Air = 1)

Volatility: Not available.

Odor Threshold: 0.25 to 10 ppm

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, diethyl ether.

Solubility: Soluble in cold water, hot water, diethyl ether.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Incompatible materials, water

Incompatibility with various substances:
Highly reactive with metals. Reactive with oxidizing agents, organic materials, alkalis, water.

Corrosivity:
Extremely corrosive in presence of aluminum, of copper, of stainless steel(304), of stainless steel(316). Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Reacts with water especially when water is added to the product. Absorption of gaseous hydrogen chloride on mercuric sulfate becomes violent @ 125 deg. C. Sodium reacts very violently with gaseous hydrogen chloride. Calcium phosphide and hydrochloric acid undergo very energetic reaction. It reacts with oxidizers releasing chlorine gas. Incompatible with, alkali metals, carbides, borides, metal oxides, vinyl acetate, acetylides, sulphides, phosphides, cyanides, carbonates. Reacts with most metals to produce flammable Hydrogen gas. Reacts violently (moderate reaction with heat of evolution) with water especially when water is added to the product. Isolate hydrogen chloride from heat, direct sunlight, alkalies (reacts vigorously), organic materials, and oxidizers (especially nitric acid and chlorates), amines, metals, copper and alloys (e.g. brass), hydroxides, zinc (galvanized materials), lithium silicide (incandescence), sulfuric acid(increase in temperature and pressure) Hydrogen chloride gas is emitted when this product is in contact with sulfuric acid. Adsorption of Hydrochloric Acid onto silicon dioxide results in exothmeric reaction. Hydrogen chloride causes aldehydes and epoxides to violently polymerize. Hydrogen chloride or Hydrochloric Acid in contact with the folloiwng can cause explosion or ignition on contact or

Special Remarks on Corrosivity:

Highly corrosive. Incompatible with copper and copper alloys. It attacks nearly all metals (mercury, gold, platinium, tantalum, silver, and certain alloys are exceptions). It is one of the most corrosive of the nonoxidizing acids in contact with copper alloys. No corrosivity data on zinc, steel. Severe Corrosive effect on brass and bronze

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Eye contact. Inhalation.

Toxicity to Animals:
Acute oral toxicity (LD50): 900 mg/kg [Rabbit]. Acute toxicity of the vapor (LC50): 1108 ppm, 1 hours [Mouse]. Acute toxicity of the vapor (LC50): 3124 ppm, 1 hours [Rat].

Chronic Effects on Humans:
CARCINOGENIC EFFECTS: Classified 3 (Not classifiable for human.) by IARC [Hydrochloric acid]. May cause damage to the following organs: kidneys, liver, mucous membranes, upper respiratory tract, skin, eyes, Circulatory System, teeth.

Other Toxic Effects on Humans:
Very hazardous in case of skin contact (corrosive, irritant, permeator), of ingestion, . Hazardous in case of eye contact (corrosive), of inhalation (lung corrosive).

Special Remarks on Toxicity to Animals:
Lowest Published Lethal Doses (LDL/LCL) LDL [Man] -Route: Oral; 2857 ug/kg LCL [Human] - Route: Inhalation; Dose: 1300 ppm/30M LCL [Rabbit] - Route: Inhalation; Dose: 4413 ppm/30M

Special Remarks on Chronic Effects on Humans:
May cause adverse reproductive effects (fetoxicity). May affect genetic material.

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: Corrosive. Causes severe skin irritation and burns. Eyes: Corrosive. Causes severe eye irritation/conjuntivitis, burns, corneal necrosis. Inhalation: May be fatal if inhaled. Material is extremely destructive to tissue of the mucous membranes and upper respiratory tract. Inhalation of hydrochloric acid fumes produces nose, throat, and larryngeal burning, and irritation, pain and inflammation, coughing, sneezing, choking sensation, hoarseness, laryngeal spasms, upper respiratory tract edema, chest pains, as well has headache, and palpitations. Inhalation of high concentrations can result in corrosive burns, necrosis of bronchial epithelium, constriction of the larynx and bronchi, nasospetal perforation, glottal closure, occur, particularly if exposure is prolonged. May affect the liver. Ingestion: May be fatal if swallowed. Causes irritation and burning, ulceration, or perforation of the gastrointestinal tract and resultant peritonitis, gastric hemorrhage and infection. Can also cause nausea, vomitting (with "coffee ground" emesis), diarrhea, thirst, difficulty swallowing, salivation, chills, fever, uneasiness, shock, strictures and stenosis (esophogeal, gastric, pyloric). May affect behavior (excitement), the cardiovascular system (weak rapid pulse, tachycardia), respiration (shallow respiration), and urinary system (kidneys- renal failure, nephritis). Acute exposure via inhalation or ingestion can also cause erosion of tooth enamel. Chronic Potential Health Effects: dyspnea, bronchitis. Chemical pneumonitis and pulmonary edema can also

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:

Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Class 8: Corrosive material

Identification: : Hydrochloric acid, solution UNNA: 1789 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
Connecticut hazardous material survey.: Hydrochloric acid Illinois toxic substances disclosure to employee act: Hydrochloric acid Illinois chemical safety act: Hydrochloric acid New York release reporting list: Hydrochloric acid Rhode Island RTK hazardous substances: Hydrochloric acid Pennsylvania RTK: Hydrochloric acid Minnesota: Hydrochloric acid Massachusetts RTK: Hydrochloric acid Massachusetts spill list: Hydrochloric acid New Jersey: Hydrochloric acid New Jersey spill list: Hydrochloric acid Louisiana RTK reporting list: Hydrochloric acid Louisiana spill reporting: Hydrochloric acid California Director's List of Hazardous Substances: Hydrochloric acid TSCA 8(b) inventory: Hydrochloric acid TSCA 4(a) proposed test rules: Hydrochloric acid SARA 302/304/311/312 extremely hazardous substances: Hydrochloric acid SARA 313 toxic chemical notification and release reporting: Hydrochloric acid CERCLA: Hazardous substances.: Hydrochloric acid: 5000 lbs. (2268 kg)

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada):
CLASS D-2A: Material causing other toxic effects (VERY TOXIC). CLASS E: Corrosive liquid.

DSCL (EEC):
R34- Causes burns. R37- Irritating to respiratory system. S26- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. S45- In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

HMIS (U.S.A.):

Health Hazard: 3

Fire Hazard: 0

Reactivity: 1

Personal Protection:

National Fire Protection Association (U.S.A.):

Health: 3

Flammability: 0

Reactivity: 1

Specific hazard:

Protective Equipment:
Gloves. Full suit. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Face shield.

Section 16: Other Information

References:

-Hawley, G.G.. The Condensed Chemical Dictionary, 11e ed., New York N.Y., Van Nostrand Reinold, 1987. -SAX, N.I. Dangerous Properties of Indutrial Materials. Toronto, Van Nostrand Reinold, 6e ed. 1984. -The Sigma-Aldrich Library of Chemical Safety Data, Edition II. -Guide de la loi et du règlement sur le transport des marchandises dangeureuses au canada. Centre de conformité internatinal Ltée. 1986.

Other Special Considerations: Not available.

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Last Updated: 05/21/2013 12:00 PM

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Health	3
Fire	0
Reactivity	2
Personal Protection	J

Material Safety Data Sheet
Sodium hydroxide MSDS

Section 1: Chemical Product and Company Identification

Product Name: Sodium hydroxide

Catalog Codes: SLS3298, SLS1081, SLS2503, SLS3925, SLS1705

CAS#: 1310-73-2

RTECS: WB4900000

TSCA: TSCA 8(b) inventory: Sodium hydroxide

CI#: Not available.

Synonym: Caustic Soda

Chemical Name: Sodium Hydroxide

Chemical Formula: NaOH

Contact Information:

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Houston, Texas 77396

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1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Sodium hydroxide	1310-73-2	100

Toxicological Data on Ingredients: Sodium hydroxide LD50: Not available. LC50: Not available.

Section 3: Hazards Identification

Potential Acute Health Effects:
Very hazardous in case of skin contact (corrosive, irritant, permeator), of eye contact (irritant, corrosive), of ingestion, of inhalation. The amount of tissue damage depends on length of contact. Eye contact can result in corneal damage or blindness. Skin contact can produce inflammation and blistering. Inhalation of dust will produce irritation to gastro-intestinal or respiratory tract, characterized by burning, sneezing and coughing. Severe over-exposure can produce lung damage, choking, unconsciousness or death. Inflammation of the eye is characterized by redness, watering, and itching. Skin inflammation is characterized by itching, scaling, reddening, or, occasionally, blistering.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to mucous membranes, upper respiratory tract, skin, eyes. Repeated or prolonged exposure to the substance can produce target organs damage. Repeated exposure of the eyes to a low level of dust can produce eye irritation. Repeated skin exposure can produce local skin destruction, or dermatitis. Repeated inhalation of dust can produce varying degree of respiratory irritation or lung damage.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention immediately.

Skin Contact:
In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Cover the irritated skin with an emollient. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention immediately.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention immediately.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic, infectious or corrosive. Seek immediate medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: metals

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available. Slightly explosive in presence of heat.

Fire Fighting Media and Instructions: Not available

Special Remarks on Fire Hazards:
sodium hydroxide + zinc metal dust causes ignition of the latter. Under proper conditions of temperature, pressure and state of division, it can ignite or react violently with acetaldehyde, ally alcohol, allyl chloride, benzene-1,4-diol, chlorine trifluoride, 1,2 dichlorethylene, nitroethane, nitromethane, nitroparaffins, nitropropane, cinnamaldehyde, 2,2-dichloro-3,3-dimethylbutane. Sodium hydroxide in contact with water may generate enough heat to ignite adjacent combustible materials. Phosphorous boiled with NaOH yields mixed phosphines which may ignite spontanously in air. sodium hydroxide and cinnamaldehyde + heat may cause ignition. Reaction with certain metals releases flammable and explosive hydrogen gas.

Special Remarks on Explosion Hazards:
Sodium hydroxide reacts to form explosive products with ammonia + silver nitrate. Benzene extract of allyl benzenesulfonate prepared from allyl alcohol, and benzene sulfonyl chloride in presence of aquesous sodium hydroxide, under vacuum distillation, residue darkened and exploded. Sodium Hydroxde + impure tetrahydrofuran, which can contain peroxides, can

pH (1% soln/water): 13.5 [Basic.]

Boiling Point: 1388°C (2530.4°F)

Melting Point: 323°C (613.4°F)

Critical Temperature: Not available.

Specific Gravity: 2.13 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water.

Solubility: Easily soluble in cold water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Incompatible materials, moisture, moist air

Incompatibility with various substances:
Highly reactive with metals. Reactive with oxidizing agents, reducing agents, acids, alkalis, moisture.

Corrosivity: Not available.

Special Remarks on Reactivity:
Hygroscopic. Much heat is evolved when solid material is dissolved in water. Therefore cold water and caution must be used for this process. Sodium hydroxide solution and octanol + diborane during a work-up of a reaction mixture of oxime and diborane in tetrahyrofuran is very exothermic, a mild explosion being noted on one occassion. Reactive with water, acids (mineral, non-oxidizing, e.g. hydrochloric, hydrofluoric acid, muriatic acid, phosphoric), acids (mineral, oxidizing e.g. chromic acid, hypochlorous acid, nitric acid, sulfuric acid), acids (organic e.g. acetic acid, benzoic acid, formic acid, methanoic acid, oxalic acid), aldehydes (e.g. acetaldehyde, acrolein, chloral hydrate, foraldehyde), carbamates (e.g. carbanolate, carbofuran), esters (e.g. butyl acetate, ethyl acetate, propyl formate), halogenated organics (dibromoethane, hexachlorobenzene, methyl chloride, trichloroethylene), isocyanates (e.g. methyl isocyanate), ketones (acetone, acetophenone, MEK, MIBK), acid chlorides, strong bases, strong oxidizing agents, strong reducing agents, flammable liquids, powdered metals and metals (i.e aluminum, tin, zinc, hafnium, raney nickel), metals (alkali and alkaline e.g. cesium, potassium, sodium), metal compounds (toxic e.g. berylium, lead acetate, nickel carbonyl, tetraethyl lead), mitrides (e.g. potassium nitride, sodium nitride), nitriles (e.g. acetonitrile, methyl cyanide), nitro compounds (organic e.g. nitrobenzene, nitromethane), acetic anhydride, chlorohydrin, chlorosulfonic acid, ethylene cyanohydrin, glyoxal, hydrosulfuric acid, oleum, propiolactone, acylonitrile, phorosous pentoxide, chloroethanol, chloroform-methanol, tetrahydroborate, cyanogen azide, 1,2,4,5 tetrachlorobenzene, cinnamaldehyde. Reacts with formaldehyde hydroxide to yield formic acid, and hydrogen.

Special Remarks on Corrosivity: Very caustic to aluminum and other metals in presence of moisture.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Eye contact. Inhalation. Ingestion.

Toxicity to Animals:
LD50: Not available. LC50: Not available.

Chronic Effects on Humans:
MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. May cause damage to the following organs: mucous membranes, upper respiratory tract, skin, eyes.

Other Toxic Effects on Humans:
Extremely hazardous in case of inhalation (lung corrosive). Very hazardous in case of skin contact (corrosive, irritant, permeator), of eye contact (corrosive), of ingestion, .

Special Remarks on Toxicity to Animals:
Lowest Published Lethal Dose: LDL [Rabbit] - Route: Oral; Dose: 500 mg/kg

Special Remarks on Chronic Effects on Humans: May affect genetic material. Investigation as a mutagen (cytogenetic analysis)

Special Remarks on other Toxic Effects on Humans:

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Class 8: Corrosive material

Identification: : Sodium hydroxide, solid UNNA: 1823 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
Illinois toxic substances disclosure to employee act: Sodium hydroxide Illinois chemical safety act: Sodium hydroxide New York release reporting list: Sodium hydroxide Rhode Island RTK hazardous substances: Sodium hydroxide Pennsylvania RTK: Sodium hydroxide Minnesota: Sodium hydroxide Massachusetts RTK: Sodium hydroxide New Jersey: Sodium hydroxide Louisiana spill reporting: Sodium hydroxide California Director's List of Hazardous Substances: Sodium hydroxide TSCA 8(b) inventory: Sodium hydroxide CERCLA: Hazardous substances.: Sodium hydroxide: 1000 lbs. (453.6 kg)

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): CLASS E: Corrosive solid.

DSCL (EEC):
R35- Causes severe burns. S26- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. S37/39- Wear suitable gloves and eye/face protection. S45- In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

HMIS (U.S.A.):

Health Hazard: 3

Fire Hazard: 0

Reactivity: 2

Personal Protection: j

National Fire Protection Association (U.S.A.):

Health: 3

Flammability: 0

Reactivity: 1

Specific hazard:

Protective Equipment:
Gloves. Synthetic apron. Vapor and dust respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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Last Updated: 05/21/2013 12:00 PM

cause serious explosions. Dry mixtures of sodium hydroxide and sodium tetrahydroborate liberate hydrogen explosively at 230-270 deg. C. Sodium Hydroxide reacts with sodium salt of trichlorophenol + methyl alcohol + trichlorobenzene + heat to cause an explosion.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. If necessary: Neutralize the residue with a dilute solution of acetic acid.

Large Spill:
Corrosive solid. Stop leak if without risk. Do not get water inside container. Do not touch spilled material. Use water spray to reduce vapors. Prevent entry into sewers, basements or confined areas; dike if needed. Call for assistance on disposal. Neutralize the residue with a dilute solution of acetic acid. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep container dry. Do not breathe dust. Never add water to this product. In case of insufficient ventilation, wear suitable respiratory equipment. If you feel unwell, seek medical attention and show the label when possible. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, reducing agents, metals, acids, alkalis, moisture.

Storage: Keep container tightly closed. Keep container in a cool, well-ventilated area. Hygroscopic. Deliquescent.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:
Splash goggles. Synthetic apron. Vapor and dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor and dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
STEL: 2 (mg/m3) from ACGIH (TLV) [United States] TWA: 2 CEIL: 2 (mg/m3) from OSHA (PEL) [United States] CEIL: 2 (mg/m3) from NIOSHConsult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid. (Deliquescent solid.)

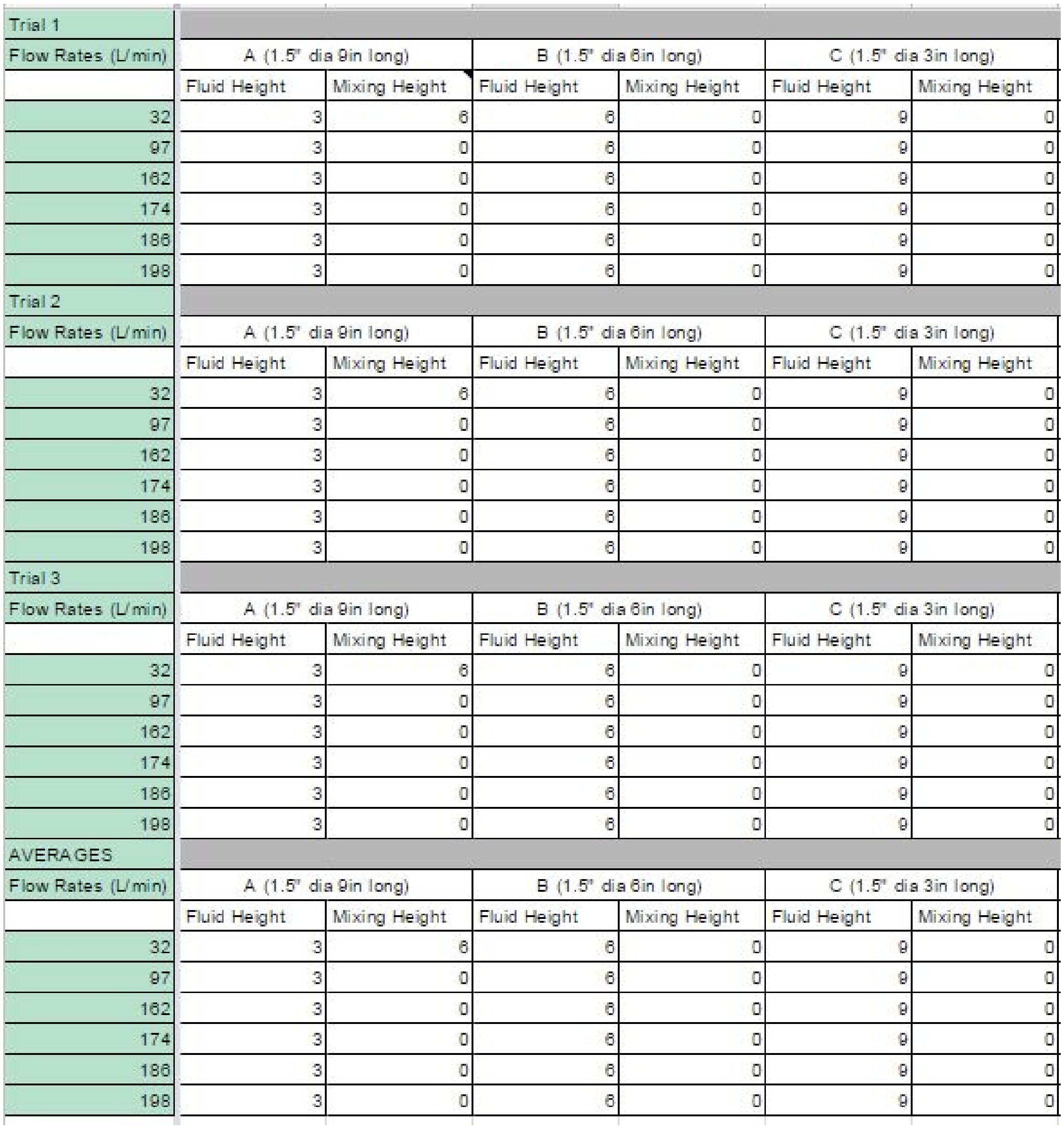
Odor: Odorless.

Taste: Not available.

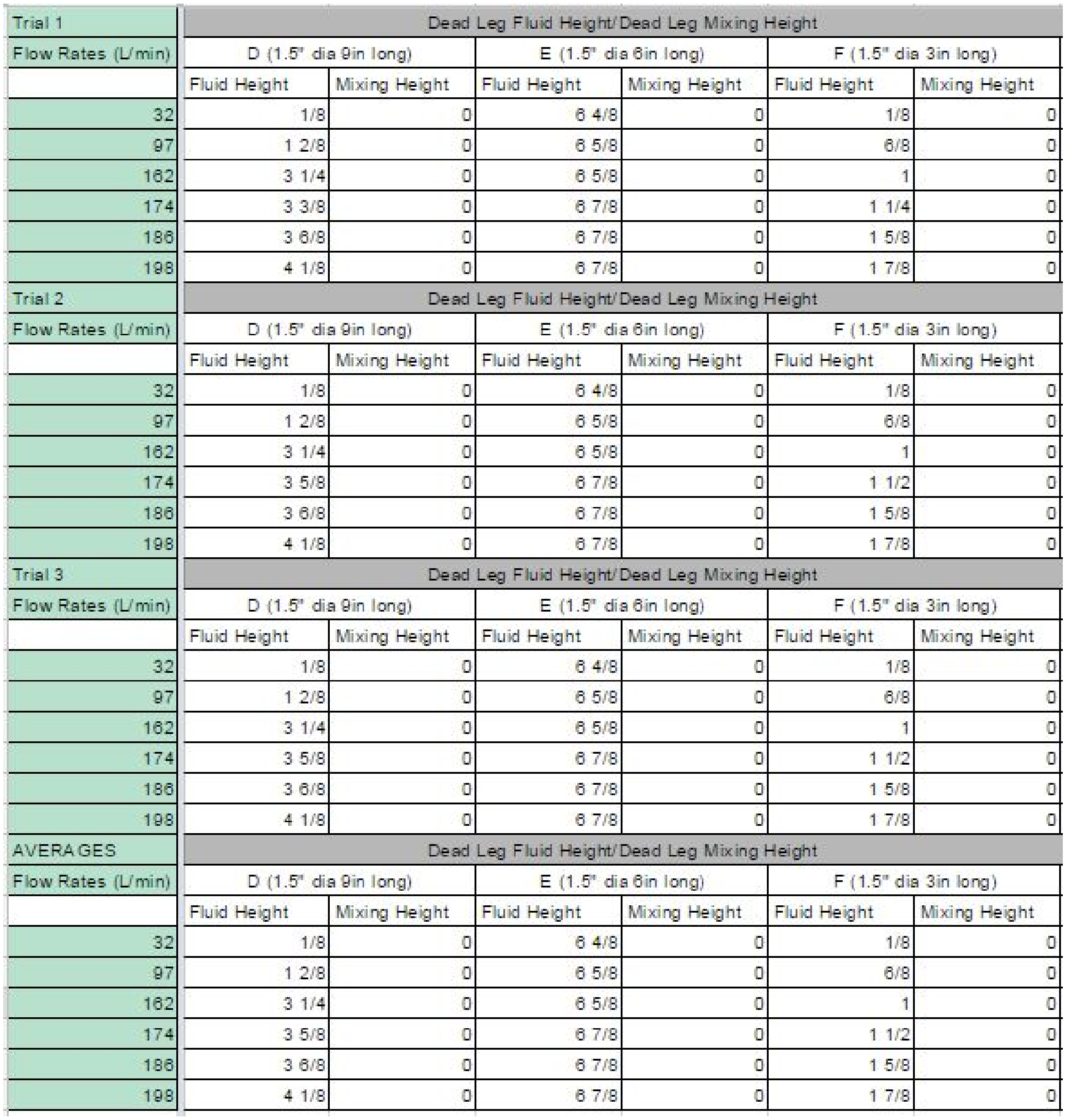
Molecular Weight: 40 g/mole

Color: White.

Appendix 7: Data Collection



Trial 1						
Flow Rates (L/min)	A (1.5" dia 9in long)		B (1.5" dia 6in long)		C (1.5" dia 3in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	3	6	6	0	9	0
97	3	0	6	0	9	0
162	3	0	6	0	9	0
174	3	0	6	0	9	0
186	3	0	6	0	9	0
198	3	0	6	0	9	0
Trial 2						
Flow Rates (L/min)	A (1.5" dia 9in long)		B (1.5" dia 6in long)		C (1.5" dia 3in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	3	6	6	0	9	0
97	3	0	6	0	9	0
162	3	0	6	0	9	0
174	3	0	6	0	9	0
186	3	0	6	0	9	0
198	3	0	6	0	9	0
Trial 3						
Flow Rates (L/min)	A (1.5" dia 9in long)		B (1.5" dia 6in long)		C (1.5" dia 3in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	3	6	6	0	9	0
97	3	0	6	0	9	0
162	3	0	6	0	9	0
174	3	0	6	0	9	0
186	3	0	6	0	9	0
198	3	0	6	0	9	0
AVERAGES						
Flow Rates (L/min)	A (1.5" dia 9in long)		B (1.5" dia 6in long)		C (1.5" dia 3in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	3	6	6	0	9	0
97	3	0	6	0	9	0
162	3	0	6	0	9	0
174	3	0	6	0	9	0
186	3	0	6	0	9	0
198	3	0	6	0	9	0



Trial 1	Dead Leg Fluid Height/Dead Leg Mixing Height					
Flow Rates (L/min)	D (1.5" dia 9in long)		E (1.5" dia 6in long)		F (1.5" dia 3in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	1/8	0	6 4/8	0	1/8	0
97	1 2/8	0	6 5/8	0	6/8	0
162	3 1/4	0	6 5/8	0	1	0
174	3 3/8	0	6 7/8	0	1 1/4	0
186	3 6/8	0	6 7/8	0	1 5/8	0
198	4 1/8	0	6 7/8	0	1 7/8	0
Trial 2	Dead Leg Fluid Height/Dead Leg Mixing Height					
Flow Rates (L/min)	D (1.5" dia 9in long)		E (1.5" dia 6in long)		F (1.5" dia 3in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	1/8	0	6 4/8	0	1/8	0
97	1 2/8	0	6 5/8	0	6/8	0
162	3 1/4	0	6 5/8	0	1	0
174	3 5/8	0	6 7/8	0	1 1/2	0
186	3 6/8	0	6 7/8	0	1 5/8	0
198	4 1/8	0	6 7/8	0	1 7/8	0
Trial 3	Dead Leg Fluid Height/Dead Leg Mixing Height					
Flow Rates (L/min)	D (1.5" dia 9in long)		E (1.5" dia 6in long)		F (1.5" dia 3in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	1/8	0	6 4/8	0	1/8	0
97	1 2/8	0	6 5/8	0	6/8	0
162	3 1/4	0	6 5/8	0	1	0
174	3 5/8	0	6 7/8	0	1 1/2	0
186	3 6/8	0	6 7/8	0	1 5/8	0
198	4 1/8	0	6 7/8	0	1 7/8	0
AVERAGES	Dead Leg Fluid Height/Dead Leg Mixing Height					
Flow Rates (L/min)	D (1.5" dia 9in long)		E (1.5" dia 6in long)		F (1.5" dia 3in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	1/8	0	6 4/8	0	1/8	0
97	1 2/8	0	6 5/8	0	6/8	0
162	3 1/4	0	6 5/8	0	1	0
174	3 5/8	0	6 7/8	0	1 1/2	0
186	3 6/8	0	6 7/8	0	1 5/8	0
198	4 1/8	0	6 7/8	0	1 7/8	0

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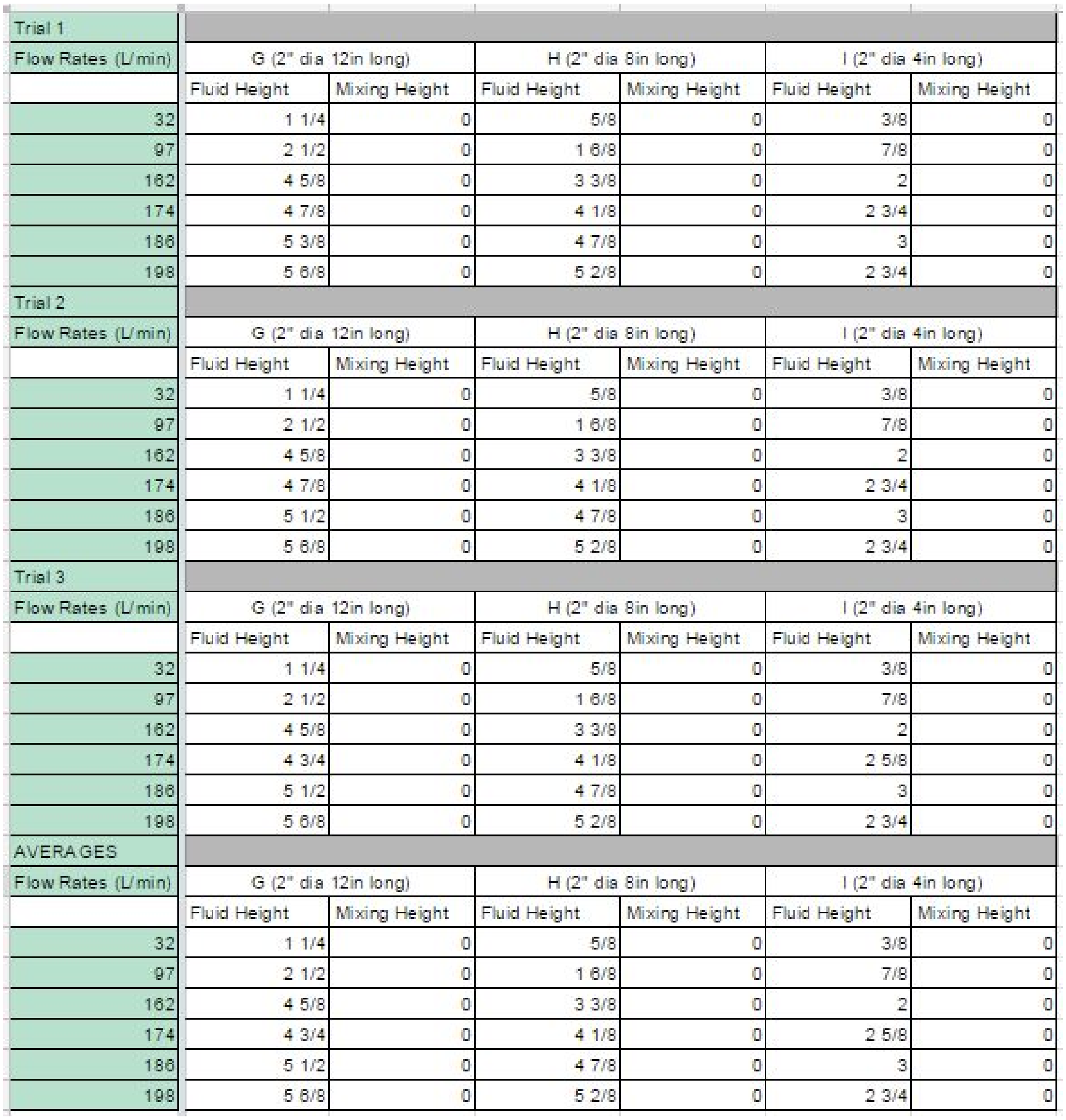
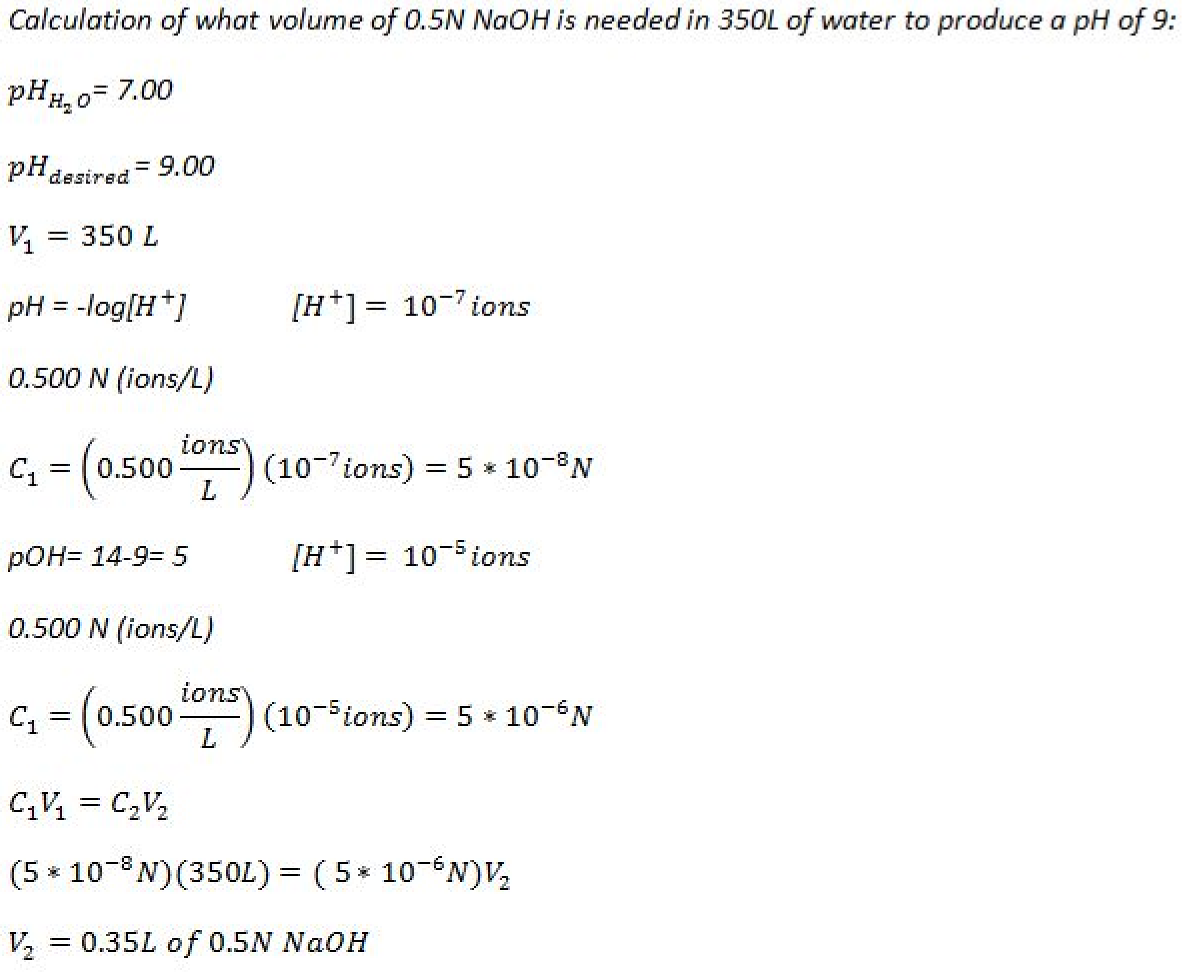


Trial 1						
Flow Rates (L/min)	G (2" dia 12in long)		H (2" dia 8in long)		I (2" dia 4in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	1 1/4	0	5/8	0	3/8	0
97	2 1/2	0	1 6/8	0	7/8	0
162	4 5/8	0	3 3/8	0	2	0
174	4 7/8	0	4 1/8	0	2 3/4	0
186	5 3/8	0	4 7/8	0	3	0
198	5 6/8	0	5 2/8	0	2 3/4	0
Trial 2						
Flow Rates (L/min)	G (2" dia 12in long)		H (2" dia 8in long)		I (2" dia 4in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	1 1/4	0	5/8	0	3/8	0
97	2 1/2	0	1 6/8	0	7/8	0
162	4 5/8	0	3 3/8	0	2	0
174	4 7/8	0	4 1/8	0	2 3/4	0
186	5 1/2	0	4 7/8	0	3	0
198	5 6/8	0	5 2/8	0	2 3/4	0
Trial 3						
Flow Rates (L/min)	G (2" dia 12in long)		H (2" dia 8in long)		I (2" dia 4in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	1 1/4	0	5/8	0	3/8	0
97	2 1/2	0	1 6/8	0	7/8	0
162	4 5/8	0	3 3/8	0	2	0
174	4 3/4	0	4 1/8	0	2 5/8	0
186	5 1/2	0	4 7/8	0	3	0
198	5 6/8	0	5 2/8	0	2 3/4	0
AVERAGES						
Flow Rates (L/min)	G (2" dia 12in long)		H (2" dia 8in long)		I (2" dia 4in long)	
	Fluid Height	Mixing Height	Fluid Height	Mixing Height	Fluid Height	Mixing Height
32	1 1/4	0	5/8	0	3/8	0
97	2 1/2	0	1 6/8	0	7/8	0
162	4 5/8	0	3 3/8	0	2	0
174	4 3/4	0	4 1/8	0	2 5/8	0
186	5 1/2	0	4 7/8	0	3	0
198	5 6/8	0	5 2/8	0	2 3/4	0

Appendix 8: Calculation of Acid and Base Addition



Calculation of what volume of 0.5N NaOH is needed in 350L of water to produce a pH of 9:

pH_{H_2O}= 7.00

$pH_{desired}$ = 9.00

$V_1 = 350\ L$

$pH = -log[H^+]$ $[H^+] = 10^{-7}\, ions$

0.500 N (ions/L)

$$C_1 = \left(0.500\,\frac{ions}{L}\right)(10^{-7} ions) = 5 * 10^{-8}N$$

pOH= 14-9= 5 $[H^+] = 10^{-5}\, ions$

0.500 N (ions/L)

$$C_1 = \left(0.500\,\frac{ions}{L}\right)(10^{-5} ions) = 5 * 10^{-6}N$$

$C_1V_1 = C_2V_2$

$(5 * 10^{-8}N)(350L) = (\,5 * 10^{-6}N)V_2$

$V_2 = 0.35L\ of\ 0.5N\ NaOH$

The same volume of HCl will be needed to return the solution to a pH of 7.