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# Process Optimization for Liquid-Liquid Extraction

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# Process Optimization for Liquid-Liquid Extraction

A Major Qualifying Project submitted to the faculty of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the Degree of Bachelor of Science

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April 30, 2015

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## I. ABSTRACT

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Experiments were designed to confirm the reliability of an Aspen Plus model simulating an active pharmaceutical ingredient recovery process for Sunovion Pharmaceuticals. The process includes a reaction between a triflate salt compound and potassium hydroxide, followed by a liquid-liquid extraction with methyl tert-butyl ether (MTBE). The experiments looked to verify the previous work, study the effects of pH above pKa on the reaction, and study the effects of temperature on the extraction. Other solvents were examined for feasibility in the process.

It was concluded that potassium hydroxide was the best base tested for this process. Potassium carbonate resulted in a gel and, subsequently, an emulsion. Additionally, MTBE was found to be the safest and most efficient solvent. The temperature study concluded that raising the temperature to 35°C reduces MTBE usage by 16%. Regarding the simulation model, it was found that it was not always accurate. Aspen had issues predicting water solubility in MTBE.

## II. ACKNOWLEDGEMENTS

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We would like to thank our advisor, William Clark, for his guidance on the project and for providing us with the lab space and the resources needed to conduct experiments. We would also like to thank Robert Prytko and Kostas Saranteas of Sunovion Pharmaceuticals for sponsoring the project and providing us with the information needed to continue progress.

### III. EXECUTIVE SUMMARY

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The overarching goal of this project was to use a series of simulations and lab experiments to optimize an existing liquid-liquid extraction (LLE) process. The sponsor of this project, Sunovion Pharmaceuticals, had a multistep process for the formation and extraction of an active pharmaceutical ingredient (API). This project focused on the neutralization reaction and the initial solvent extraction of the API. The triflate salt compound is reacted with a base to form free base, the desired product. To extract the free base from the undesired products, an organic solvent is used with the reaction solution to form two immiscible phases – organic and aqueous. The free base favors the organic phase. The phases are separated, and the solvent in the organic phase is evaporated to leave only the desired product of free base.

Sunovion Pharmaceuticals sponsored a previous project in the 2013-2014 academic year. The previous project established the foundation of this project by creating a simulation model in the Aspen Plus simulation program to represent the process. This model was used to determine that a three wash cycle of solvent was the optimal extraction process. This project continued upon their work of optimizing the process. The objectives of this project were to examine the effects of different parameters on the product yield: different bases, reaction pH, solvents, and extraction temperature. Each variable was independently examined in the Aspen Plus software and in laboratory experiments. DynoChem software was used to model the downstream solvent swap.

#### BACKGROUND

The goal of this project was to optimize an existing API LLE using simulation software and experimental results. In industry, the production of API begins at a lab scale. When the process is successful in the lab, it is developed into a pilot production, which will eventually be scaled up to a commercial process (Carbogen, 2014). Each step requires research and optimization. By efficiently optimizing at each step, the commercial process will be more robust as well as far more efficient. This can have a massive impact on production and operational costs.

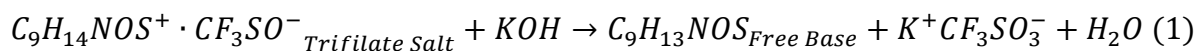
Optimizing on a lab scale as opposed to a full process scale not only saves costs and time but also allows for the examination and testing of chemistry and design criteria (Flapper et al., 2001). Similarly, there is great efficiency in using a software model to simulate the process. Software simulation reduces material and equipment costs while allowing for a wide variety of testing and analysis, such as material and energy balances, equipment sizing, cost analysis, and sensitivity analysis. In particular, the sensitivity analysis allows for examination of the effects of a variety of parameters (Papavasileiou et al., 2007). Using the data from the sensitivity analysis, the process parameters can be optimized for desired goals, such as minimal heating, maximum efficiency in yield, or maximum production. Additionally, the simulation does not involve any risk and can be scaled up in the software when necessary.

To model the three wash extraction, Aspen Plus v8.2 was used. Aspen Plus is currently the leading chemical process optimization software and is used by biochemical and polymers industries for operation, design, and optimization of manufacturing facilities (Aspen, 2015).

DynoChem is an Excel-compatible process development and scale-up program that aims to help engineers and scientists in the pharmaceutical industry (Scale-up Systems, 2014). Their modeling software includes pH control, kinetics for different reactor types, solvent swap simulations, and acid-base equilibrium.

## METHODOLOGY

The API process begins at the salt-split reaction with the triflate salt, provided by the sponsor, reacting with a base, potassium hydroxide (KOH). The salt split reaction forms free base ( $C_9H_{13}NOS$ ), potassium triflate ( $K^+CF_3SO_3^-$ ), and water, as seen in Equation 1.



After the reaction, methyl tert-butyl ether (MTBE) was added to form two immiscible phases – organic and aqueous. The free base favors the aqueous while  $K^+CF_3SO_3^-$  and water favors aqueous phase. The organic phase was separated and the MTBE was evaporated to leave only the free base. The extraction and recovery of the free base was repeated three times with diminishing amounts of MTBE. This procedure was used as the base case conditions for all subsequent studies.

The pKa of the triflate salt is 9.5, or the pH at which half the salt dissociates. In industry, it is believed that one pH unit above the pKa is sufficient to complete the reaction. The effect of pH of the reaction mixture on the product recovery was studied. Three different pH values of the reaction mixture were studied: 10.5, 11.5, and 12.5. Potassium carbonate ( $K_2CO_3$ ) was used as the base instead of KOH to obtain lower pH values.

The previous group's Aspen model and experiments were replicated to verify their conclusions. Using the model, a temperature sensitivity analysis was then conducted to minimize the amount of MTBE used. Temperatures of 25°C, 30°C, and 35°C were studied. The optimal run that saved the most amount of MTBE was tested experimentally to verify the Aspen result. In addition to the optimal condition, experiments using three three-gram washes of MTBE were run at the three temperatures to determine the effects of temperature on product extraction.

The DynoChem solvent swap model was used to simulate the downstream process. The goal of the simulation was to reach 1% of the upstream solvent and to switch the product to an acetonitrile based solution. Both put/take and constant feed methods were used. Properties of the solvents were taken from the DynoChem database. This generated spreadsheet data and a graphical representation of the data over time.

## RESULTS AND CONCLUSIONS

The Aspen model and base case conditions from the previous project were successfully replicated. However, it was noted that the Aspen model could only correctly predict the recovery of the free base product but not the water content in the organic and aqueous phases. This was also seen in the previous project's results.

The pH study was inconclusive. Using  $K_2CO_3$  resulted in a gel due to the lower pH of the reaction solution compared to the base case. To prevent the gelling from occurring, the first wash of MTBE was added before the reaction step. While no gel formed when an organic phase was present, an emulsion occurred. To prevent an emulsion from forming during the pH study, KOH, instead of  $K_2CO_3$ , was used in one stoichiometric equivalence to the triflate salt. No gelling or emulsions occurred during these experiments, but the pH was not consistent. A statistical analysis of the experimental results showed that there was not enough evidence to prove correlation between the pH and recovery.

The optimal base for the neutralization reaction was KOH. Sodium carbonate and bicarbonate both had low solubilities in water, so they were unusable in the experiments. Potassium carbonate formed either a gel or emulsion during the reaction step.

The Aspen simulations showed that using three grams for all three washes would yield an appreciable difference in recovery between 25°C, 30°C, and 35°C. However, Aspen could not take into account the difference in the organic and aqueous phases. During the laboratory experiments, poor or no phase separation was seen during the extractions. It was concluded that the organic phases might have been small enough to dissolve in the aqueous phase.

The temperature study concluded that, by elevating the temperature to 35°C, the MTBE usage could be reduced by 16% compared to the base case. Two out of five of the experimental runs had recoveries over 100%, which was concluded to be due to water present in the recovery flask used for the rotary evaporator.

From a solvent study analysis, it was determined that MTBE provided the best recovery while posing the lowest health risks as a class 3 solvent. Chloroform, ethyl acetate, diethyl ether, and trans-1,2-dichloroethylene all provided similar recoveries, but were more dangerous class 1 or 2 solvents.

Using DynoChem, three different solvents were tested under both put/take and constant feed solvent swap conditions. The base solvent MTBE was used as well as toluene and isobutyl acetate. DynoChem did not have data for the solvents tested in the solvent study. MTBE proved to be the most efficient in both time and acetonitrile required. As the boiling points of the solvent approached that of acetonitrile, the heating and amount of acetonitrile required increased.

## RECOMMENDATIONS

Only the extraction was able to be modeled in Aspen, but it is recommended that the reaction also be modeled to simulate reaction parameters. KOH was the best base of the ones

investigated, but sodium hydroxide should be investigated. Different concentrations of KOH should also be studied. Additionally, a more precise study of pH should be conducted. Though alternative safe solvents have lower recoveries, it is recommended that the Aspen model is also verified for these alternative solvents. Mixing and settling times could be observed for effect on free base recovery. A cost analysis should be completed to investigate the value of increasing heating of extraction to minimize solvent usage. Future studies should examine inputting solvent data into DynoChem for further analysis of solvent swapping capabilities.



## IV. NOMENCLATURE

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API – active pharmaceutical ingredient

Aqueous phase – a liquid phase in an LLE that contains water and its solutes

Aspen Plus – a comprehensive chemical process modeling system

DynoChem – an Excel-based software used to model chemical processes

Extraction – a chemical separation process

Free base – the compound being extracted in the LLE process, *C<sub>9</sub>H<sub>13</sub>NOS*

HPLC – high performance liquid chromatography

$K^+CF_3SO_3^-$  - potassium triflate

$K_2CO_3$  - potassium carbonate

$KHCO_3$  - potassium bicarbonate

KOH - potassium hydroxide

LC50 - lethal concentration at which 50% of the test population will die

LLE – liquid-liquid extraction

MQP - Major Qualifying Project

MSDS - material safety data sheet

MTBE – methyl tert-butyl ether

$Na_2CO_3$  - sodium carbonate

$NaHCO_3$  - sodium bicarbonate

NRTL – Non Random Two Liquid

Organic phase – a liquid phase in an LLE that contains an organic solvent and its solutes

p – p-value, or probability of rejecting the null hypothesis

Rotovap - rotary evaporator

Simulation – modeling of a chemical process using software

Software – computer programs, such as DynoChem and Aspen

Sponsor – Sunovion Pharmaceuticals

Triflate salt – any salt compound containing a triflate group, *CF<sub>3</sub>SO<sub>3</sub>H*

UNIFAC – UNIQUAC Functional-group Activity Coefficients

UNIQUAC – Universal Quasichemical

Wash – an individual step in a liquid-liquid extraction process

$\alpha$  – significance level

$\rho$  – Spearman correlation coefficient

# Table of Contents

I.	Abstract.....	II
II.	Acknowledgements.....	III
III.	Executive Summary.....	IV
	Background.....	IV
	Methodology.....	V
	Results And Conclusions.....	VI
	Recommendations.....	VI
IV.	Nomenclature.....	VIII
V.	Table of Figures.....	XIII
VI.	List of Tables.....	XIV
1	Introduction.....	1
2	Background.....	2
2.1	Process Optimization.....	2
2.2	Upstream Process of SEP-363592.....	2
2.2.1	Salt Split Reaction.....	2
2.2.2	Liquid-Liquid Extraction.....	3
2.2.3	Temperature Effects.....	3
2.2.4	Emulsions.....	3
2.2.5	Solvent Swap.....	4
2.3	Modeling Software.....	4
2.3.1	DynoChem.....	4
2.3.2	ASPEN Modeling of the SEP-363492 Extraction with MTBE.....	5
2.4	Safety Practices.....	6
3	Methodology.....	7
3.1	Reaction.....	7
3.2	Extraction.....	8
3.3	Aspen Model.....	8
3.4	Evaluating Current Optimized Process.....	11
3.5	pH Study.....	11
3.6	Temperature Variation.....	12
3.7	Temperature Study.....	13

3.8	Solvent Analysis.....	13
3.9	Solvent Swap Analysis.....	13
4	Results .....	14
4.1	Verification.....	14
4.2	pH Study.....	16
4.3	Gel and Emulsion.....	17
4.4	Equivalence Study.....	19
4.5	Temperature Study .....	21
4.6	Temperature Variation .....	22
4.7	HPLC.....	23
4.8	Solvent Study .....	25
4.9	Solvent Swap Analysis.....	25
5	Conclusions & Recommendations.....	27
5.1	Reaction.....	27
5.2	Extraction .....	27
6	References .....	29
APPENDIX A: Procedures .....		32
	Procedure for pH Experimental Runs .....	32
	Procedure for pH Meter Calibration.....	34
	Procedure for Temperature Variation Using Aspen.....	35
	Procedure for Solvent Swap Using DynoChem.....	38
	Procedure for Calculating pH Curve using DynoChem.....	39
	Procedure for Constructing Aspen .....	41
	Spearman Rank-order Correlation Test.....	44
	Aspen Input Files .....	45
Appendix B: Data .....		53
	Data for Experimental Runs.....	53
	Reproduction: Runs 1 – 2 .....	55
	Unreacted Salt Solubility: Run 3.....	56
	pH Study: Runs 4-7 .....	56
	Gel and Emulsion: Runs 8-12 .....	60
	Temperature Study: Runs 13-14 .....	63

Temperature Variation: Runs 16-18 & 29-30 .....	64
Equivalence Study: Runs 15, 20-22, 24, 27, 28 .....	65
Water Solubility Study: Runs 25, & 26.....	66
Appendix C: Material Safety Data Sheets .....	67
Potassium Hydroxide .....	67
Methyl Tert-butyl Ether .....	73
Potassium Carbonate .....	78
Sodium Bicarbonate .....	83

## V. TABLE OF FIGURES

---

Figure 1: Three wash extraction and separation .....	5
Figure 2: Molecule drawing tool for NIST approximation.....	9
Figure 3: Molecule properties for UNIFAC group contribution approximation .....	9
Figure 4: Decanter block configurations.....	10
Figure 5: Sensitivity analysis configurations per variable .....	11
Figure 6: Small reactor with a heating water jacket .....	12
Figure 7: Free base product.....	15
Figure 8: Gel formed in reaction with $K_2CO_3$ .....	16
Figure 9: Product of first 12.5 pH run (Left) .....	17
Figure 10: Product of second 12.5 pH run (Right) .....	17
Figure 11: Emulsion formed after adding first wash of MTBE to reaction.....	18
Figure 12: Summary of gel and emulsion results .....	19
Figure 13: Percent recovery vs. pH.....	20
Figure 14: Condensation on the product flask .....	22
Figure 15: One equivalence organic HPLC .....	23
Figure 16: One equivalence aqueous HPLC .....	24
Figure 17: 35°C organic HPLC .....	24
Figure 18: Temperature modification of decanter block .....	35
Figure 19: Sensitivity analysis for MTBE .....	36
Figure 20: DynoChem interface.....	39
Figure 21: DynoChem titration curve over time.....	40
Figure 22: DynoChem titration cruve .....	40
Figure 23: Menu for step 1 & 2 .....	41
Figure 24: NIST drawing window .....	41
Figure 25: Menu for step 6 & 7 .....	42
Figure 26: Menus for Decanter Blocks .....	43
Figure 27: Main menu for sensitivity analysis.....	43
Figure 28: Spearman rank correlation spreadsheet.....	45

## VI. LIST OF TABLES

---

Table 1: Base case conditions for reaction .....	7
Table 2: Expected maximum recovery of free base.....	8
Table 3: MTBE usage per extraction stage.....	8
Table 4: Aspen-predicted savings of MTBE for extraction at 35°C.....	13
Table 5: Base case results from previous project (Caravella et al., 2014).....	14
Table 6: Yield for experimental verification .....	14
Table 7: Aspen extraction results for individual species .....	15
Table 8: pH experimental results using K <sub>2</sub> CO <sub>3</sub> .....	17
Table 9: Results for one equivalence experiments .....	20
Table 10: Expected savings in MTBE for heated extraction.....	21
Table 11: Temperature study experiments vs. Aspen results .....	21
Table 12: Temperature variation results .....	23
Table 13: Recovery and important information for substitute solvents.....	25
Table 14: Solvent swap DynoChem results .....	26
Table 15: Sensitivity analysis for 35°C, showing top 10 results out of 3375.....	37
Table 16: MTBE and recovery per stage .....	38
Table 17: MTBE saved and total recovery of higher temperature runs.....	38
Table 18: Ranks of raw data .....	44
Table 19: Overview of the data and resulting recoveries .....	53
Table 20: Overview of results from all runs .....	54
Table 21: Reproduction runs.....	55
Table 22: Unreacted salt solubility .....	56
Table 23: Run 4 with bicarbonate solution.....	56
Table 24: Runs 5-7 of the pH study at a pH of 12.5 and 10.5 .....	57
Table 25: Titration for Run 5 .....	58
Table 26: Titration for Run 6.....	59
Table 27: Titration for Run 7 .....	60
Table 28: Data for the emulsion and gel solving runs .....	60
Table 29: Data for pH of gel solubility.....	62
Table 30: Runs at 25°C and low solvent amounts .....	63
Table 31: Temperature variation runs.....	64
Table 32: One equivalence run data.....	65
Table 33: Water solubility runs.....	66

# 1 INTRODUCTION

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Liquid-liquid extraction, or solvent extraction, is a physical process that separates “components of a solution by utilizing an unequal distribution of the components between two immiscible liquid phases” (Law & Todd, n.d.). Typically, the extraction process is conducted by mixing two immiscible liquid phases: an aqueous solution and an organic solvent. Some components dissolved in the aqueous solution transfer to the organic solvent, which has a higher affinity for those components. This transfer of components from one phase to the solvent phase is known as extraction (Law & Todd, n.d.).

First largely applied in the 1920s and 1930s for the removal of aromatics from kerosene in the petrochemical industry, liquid-liquid extraction has many applications in industry today (Crowell, 1997) (Kirk-Othmer, 2007). The petroleum and petrochemical industries widely use solvent extraction for obtaining high-purity aromatic compounds, such as benzene and toluene, and for separating aromatic compounds from aliphatic ones. The pharmaceutical industry also extensively uses extraction. Many pharmaceutical intermediates and products cannot be treated by methods that involve high temperatures, such as distillation, since they are sensitive to heat. Some products include antibiotics and vitamins. The food processing industry uses solvent extraction in various ways, such as refining fats and oils and protein (Kirk-Othmer, 2007).

In the 2013-2014 academic year, Sunovion Pharmaceuticals sponsored a Major Qualifying Project (MQP) to determine whether its liquid-liquid extraction system could be modeled by process simulation and to optimize the system. In this system, triflate salt reacted with potassium hydroxide (KOH) to form the free base from the reacted salt, and methyl *tert*-butyl ether (MTBE) was added to the mixture to extract the free base. The previous group concluded that the computer simulation program, Aspen Plus, could adequately simulate the liquid-liquid extraction process but not the reaction process and that three solvent washes was optimal for the extraction. They recommended for future projects to test the extraction system with different parameters, such as using different solvents, different bases, and higher temperatures (Caravella et al., 2014).

Subsequently, Sunovion Pharmaceuticals sponsored this MQP to continue the study on the liquid-liquid extraction system. Different bases, reaction pH, solvents, and extraction temperature were studied. Each variable was independently examined in Aspen Plus and in laboratory experiments. The goal of this MQP was to optimize the extraction system with regard to these parameters.



## 2 BACKGROUND

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### 2.1 PROCESS OPTIMIZATION

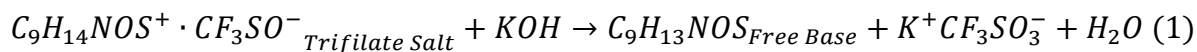
The goal of this project was to optimize an existing active pharmaceutical ingredient (API) liquid-liquid extraction using simulation software and experimental results. In industry, the production of API begins at a lab scale. When the process is successful in the lab, it is developed into a pilot production, which will eventually be scaled up to a commercial process (Carbogen, 2014). Each step requires research and optimization. By efficiently optimizing at each step, the commercial process will be more robust as well as far more efficient. This can have a massive impact on production and operational costs.

Optimizing on a lab scale as opposed to a full process scale saves costs and time but also allows for the examination and testing of chemistry and design criteria (Flapper et al., 2001). Similarly, there is great efficiency in using a software model to simulate the process. Software simulation reduces material and equipment costs while allowing for a wide variety of testing and analysis, such as material and energy balances, equipment sizing, cost analysis, and sensitivity analysis. In particular, the sensitivity analysis allows for examination of the effects of a variety of parameters (Papavasileiou et al., 2007). Using the data from the sensitivity analysis, the process parameters can be optimized for desired goals, such as minimal heating, maximum efficiency in yield, or maximum production. Additionally, the simulation does not involve any risk and can be scaled up in the software, when necessary.

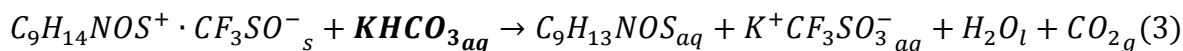
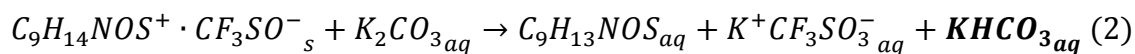
### 2.2 UPSTREAM PROCESS OF SEP-363592

#### 2.2.1 SALT SPLIT REACTION

The first step of the process is to deprotonate the SEP-363592 compound, a triflate salt, through a salt split reaction. By using a base such as potassium hydroxide (KOH), the triflate salt splits into the isolated and deprotonated free base ( $C_9H_{13}NOS$ ), potassium triflate ( $K^+CF_3SO_3^-$ ), and water. This can be seen below in Equation 1:



The triflate salt has a pKa of 9.5, meaning that at a pH of 9.5 only half the salt dissociates. In industry, it is usually assumed that complete dissociation occurs at 1 pH unit above the pKa (Prytko, 2014). In this process, the goal is to completely dissociate the salt. This requires at least a stoichiometric amount of Lewis base to interact with the triflate salt. While high pH can be reached easily with excess base, this also increases the corrosive properties of the system (CCOHS, 2015). Processing and disposal costs are increased with basic wastes, so utilizing weaker bases could reduce costs. Other weaker bases such as potassium carbonate ( $K_2CO_3$ ) and bicarbonate ( $KHCO_3$ ) can be used for reactions at lower pH. The reaction of the diprotic base is given in Equations 2 & 3 below:



### 2.2.2 LIQUID-LIQUID EXTRACTION

After the salt split reaction, the free base is now in an aqueous solution. To extract the free base from the aqueous phase, liquid-liquid extraction (LLE) is used to transfer the free base into an organic phase. In LLE, a desired solute transfers from one solvent to a second solvent. To ensure a successful LLE, the solute must have a higher solubility in the desired phase. The specification for this extraction is to transfer 98% of the free base into the organic phase (Caravella et al., 2014). In this process, methyl tert-butyl ether (MTBE) is used as the organic solvent.

LLE can be performed in multiple stages usually in counter current flow. In each stage, it is assumed that the process reaches equilibrium, where a certain amount of solute in the aqueous phase transfers into the organic phase. Each wash counts as a new stage with a new feed of MTBE; each stage extracts additional, but decreasing, amounts. It is ideal to find the minimum amount of MTBE needed to extract the maximum amount of free base from the aqueous phase.

Different solvents have different stabilities, reactivities, densities, costs, and solubilities for the solute (Caravella et al., 2014). In addition, the solubility of a solution increases with temperature, so operating at different conditions could improve the process.

### 2.2.3 TEMPERATURE EFFECTS

Temperature conditions can be manipulated to optimize the extraction process, and they must be considered for stability of biological products (Crowell, 1997). In solvent extraction from a solid matrix, increasing the temperature decreases the viscosity of the solvent and thereby allowing the solvent “to wet the matrix and solubilize the target analytes”; the increased thermal energy helps break the analyte-matrix bonds and increases diffusion of the analyte to the matrix surface (Thermo Scientific, 2013).

The effect of temperature on solvent extraction of phenolics and oils from plants has been vigorously studied. Many studies have concluded that increasing the temperature increased product yield (Asoiro & Akubuo, 2011) (Herrero et al., n.d.) (Spigno et al., 2007) (Tan et al., 2013) (Thoo et al., 2010). Although there are many studies of temperature effects of solvent extraction from solids, studies of temperature effects on liquid-liquid extraction could not be found.

### 2.2.4 EMULSIONS

An emulsion is defined as dispersion of small droplets of one liquid in another liquid (Esfeh et al., 2010). In this particular extraction process, an emulsion causes issues in separating the two immiscible phases from each other without losing product. There are several known methods to breaking emulsions including increasing settling time, adding brine or another solvent to the mixture, altering pH, and heating (PSU, n.d.). As the reaction step prior is dependent on pH and

the solubility of solvents are dependent on heating, those are not viable options. Adding another solution results in additional extraction steps, which is not optimal in this case. Increasing settling time is slow and may not always break the emulsion. A study conducted at Zhejiang University in China showed that centrifugation could be used to break emulsions (He et al., 2014). Additionally, increasing the rotations per minute improved the efficiency of breaking the emulsion. The Wilks Company claims that stirring the solvent and the emulsion phase will give better separation (Ashraf, 1995).

### 2.2.5 SOLVENT SWAP

Following extraction of the free base to the MTBE, a solvent swap is performed to transfer the free base to acetonitrile. First, the MTBE is distilled down to remove most of the volume from the solution. This is followed by a second vacuum distillation, a polish filtration, and a quick addition of MTBE.

In the lab, the process is conducted by keeping the volume of the batch between a minimum and maximum volume by feeding the second solvent when the volume reaches the minimum. This method is referred as the “put/take solvent swap” method (scale-up Systems, 2014). An alternative would be to maintain a constant feed as the distillation occurs to tightly regulate the volume of the batch.

The purpose of solvent swap is to transfer the free base from MTBE to acetonitrile, which is possible due to the different boiling points: 55°C and 82°C, respectively. This process is fundamentally a distillation procedure, except the desired product does not get transferred into the vapor phase, resulting in a transfer to the acetonitrile solution. Because of vapor-liquid equilibrium, the acetonitrile enters the vapor phase, requiring additional volume to be added. For this reason, it is possible to swap to a solvent with a lower boiling point, but it would be economically taxing due to the inefficiency.

## 2.3 MODELING SOFTWARE

### 2.3.1 DYNOCHEM

DynoChem is an Excel-compatible process development and scale-up program that aims to help engineers and scientists in the pharmaceutical industry (Scale-up Systems, 2014). Their modeling software includes pH control, kinetics for different reactor types, solvent swap simulations, and acid-base equilibrium. The previous group evaluated that DynoChem was unable to model the known ternary diagrams of water, MTBE, and acetic acid correctly. After consulting with the Scale-Up Systems representatives, no known module was capable of modeling the LLE in DynoChem (Caravella et al., 2014).

There are other uses for the DynoChem Software for this process. Although the software can not model the extraction step, it can model the downstream solvent swap step. The DynoChem solvent swapping module can predict the time, material, temperature, and many other variables for a batch process.

### 2.3.2 ASPEN MODELING OF THE SEP-363492 EXTRACTION WITH MTBE

To model the three wash liquid-liquid extraction, Aspen Plus v8.2 was used. Aspen Plus is currently the leading chemical process optimization software and is used by biochemical and polymers industries for operation, design, and optimization of manufacturing facilities. Aspen utilizes the National Institute of Standards and Technology (NIST) database, the world's largest database. It includes physical properties for 30,000 binary pairs and over 24,000 pure components, as well as parameter estimation which was used to model the free base after the salt split (Aspen, 2015).

Aspen is capable of modeling various property methods and binary interactions. The UNIFAC, UNIQUAC (UNIversal QUAsiChemical), Wilson, and NRTL (Non Random Two Liquid) are several of these methods. The UNIQUAC Functional-group Activity Coefficients method (UNIFAC) was used for this project. UNIFAC is used to give information on liquid equilibrium, which is useful for reactor design, distillation, and for this extraction process. This is completed by using interactions of functional groups and binary interaction coefficients to calculate the activity of the solution.

Aspen is not capable of modeling acid-base reactions, but the laboratory scale extraction could be simulated. The decanter block was used to model the separatory funnel. Three decanter blocks are inputted into Aspen to simulate three washes. The decanter block is able to simulate batch extraction process if the flow per time is replaced with batch charge. This is possible due to the identical solutions between batch and continuous decanters (Ralph, 2011). Each decanter block has one inlet stream and two product streams (aqueous phase and the organic phase). A mixer block simulates the recovery of all three organic phases, and the rotary evaporator is modeled by a Sep block, which removes MTBE from the free base.

Aspen solves the extraction by limiting Gibbs free energy. Gibbs free energy can be calculated by several variables which include the molar composition of each component, the temperature of the system, and the ideal gas constant. A system has reached equilibrium when Gibbs free energy is minimized. For non-ideality correction, the UNIFAC model calculates activity coefficients for the components in the mixture. Aspen can then solve for the compositions that result in minimum Gibbs free energy.

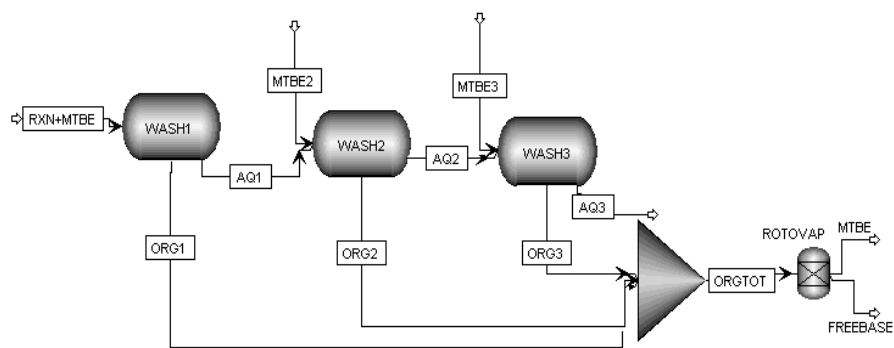


Figure 1: Three wash extraction and separation

## 2.4 SAFETY PRACTICES

A deep understanding of safety is crucial before operating lab equipment and handling chemicals. Good laboratory habits include conducting experiments in a fume hood and wearing gloves, lab coats, and safety glasses. Loose clothing and jewelry chains should not be worn, and long hair should be tied back to prevent risks with the rotary evaporator's moving parts.

Material safety data sheets (MSDS) for all MTBE and KOH are located in Appendix C. KOH is an irritant upon skin or eye contact, and should not be ingested. The lethal concentration (LC50) for mosquito fish is 80 mg/L during an exposure of 24 hours. Due to the strength of the base, it should be safely disposed (ScienceLab, 2014). Proper use of gloves, goggles, and lab coats can minimize any risk from KOH.

MTBE is a flammable liquid with an upper flammability limit of 15.1% and lower flammability limit of 2.5%. Within this concentration range, MTBE could ignite in the presence of an initiating spark. If combusted, carbon monoxide will form, which poses additional risks. Alcohol foam should be used for larger fires, but for small scale a dry chemical powder fire extinguisher should be used. The boiling point is 55°C and should be kept away from heat in a cool, ventilated area (ScienceLab, 2014).

Like KOH, MTBE poses risks as an irritant upon contact with skin and eyes, or upon ingestion. Contact with skin will result in itching, and blistering. Proper use of gloves, goggles, and lab coats will minimize these risks. However, MTBE is very volatile so inhalation can cause irritation in the respiratory tract. The LC50 for rats over a 4 hour exposure is 23,576 ppm. Effects on the lungs, nervous system, and mucous membranes can be seen from chronic exposure. MTBE should be kept in a fume hood at all times to prevent these risks, as the vapor is also denser than air. The compound is stable and non-corrosive, but can react with oxidizing agents (ScienceLab, 2014). MTBE could form peroxides which pose severe fire and explosion risks due to the presence of carbon and oxygen in the same compound. Peroxides also poses health risks from exposure (Canadian Centre for Occupational Health and Safety, 2015). While one of the weakest peroxide forming ethers, the reaction solution was checked for the presence of peroxides using test strips.

### 3 METHODOLOGY

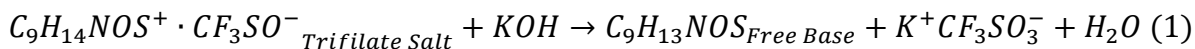
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The overarching goal of this project was to use a series of simulations and lab experiments to optimize an existing product extraction process. Aspen Plus was used as the simulation software to model the solvent extraction. The process model was compared to laboratory runs to better understand the effects on the variables. The variables included pH of the reaction, bases used, temperature of the extraction, and solvents used. The reaction between the triflate salt and the base and the solvent extraction of the free base were focused on. This project continued a previous Major Qualifying Project (MQP) that had found that a three wash system for solvent extraction was ideal. The results of the previous project were taken to be the base conditions for the project. Although the three wash system was found to be optimal, the effects of elevating the temperature of the extraction and reducing the amount of the methyl tert-butyl ether (MTBE) were examined. The goal was to retain maximum recovery while reducing the amount of MTBE used.

For the reaction step, the focus was on the pH dependence of the reaction. The pKa of the compound is 9.5. The previous method involved adding excess potassium hydroxide (KOH) to react with the triflate salt, resulting in a pH above 14, although it is believed that one pH unit above the pKa is sufficient to fully complete the reaction. Such a basic solution presents difficulty in materials of construction and disposal. The goal of examining the pH dependence was to reduce the pH of the reaction without compromising product yield. It is of note that Aspen could not model the reaction mechanism.

#### 3.1 REACTION

Before attempting to optimize the process, the reaction must be understood. The triflate salt reacts with a base to form the desired free base.



The freebase ( $C_9H_{13}NOS$ ) was assumed to be in the organic phase while the potassium triflate ( $KCF_3SO_3$ ), KOH, and water were assumed to only be in the aqueous phase. The base case runs were conducted with 10g of triflate salt and 20g of 2M KOH (2g solid KOH) – identical to the previous project's runs.

*Table 1: Base case conditions for reaction*

Compound	Weight (g)	Molecular Weight (g/mol)	Mole (mol)
Triflate Salt	10	333.35	0.030
KOH	2.018	56.11	0.036

A 0.006 mol excess of KOH was added to ensure the triflate salt completely dissociated. The pH was above 14. As the pH was well above the known pKa of 9.5, it was assumed that the reaction was complete. 0.030 mol of the free base was expected as a result. The free base has a molecular weight of 183.3 g/mol meaning that the product should have a weight of 5.5 grams. The reactants were mixed for five minutes using a magnetic stir bar.

Nitrogen is only present in the triflate salt and the free base. A balance around nitrogen shows that the free base will result in the same number of moles as the triflate salt if the reaction is completed.

*Table 2: Expected maximum recovery of free base*

Compound	Weight (g)	Molecular Weight (g/mol)	Mole (mol)	Moles of Nitrogen (mol)
Triflate Salt	10	333.35	0.030	0.030
Free Base	5.5	183.3	0.030	0.030

### 3.2 EXTRACTION

To extract the free base, solvent extraction with MTBE was used. The free base was present with the MTBE in the organic phase while excess KOH and the formed  $\text{KCF}_3\text{SO}_3$  were present in the aqueous phase. Based on the previous project, a three wash system was used. Table 3 shows the grams of MTBE used in each wash.

*Table 3: MTBE usage per extraction stage*

Wash	1	2	3
MTBE Used(g)	22.2	15	11

Wash 1 was mixed with the reaction products for five minutes and was allowed to settle for an additional five minutes. The organic phase was recovered while the aqueous phase was mixed with the next wash. This was repeated for the third wash, until all the organic phases were collected in a flask. The organic and aqueous phases were separated in a separatory funnel. The collected organic phases were run through a rotary evaporator to evaporate the MTBE. The rotary evaporator was run at 50°C with a vacuum of 400 mm Hg. The remainder of the organic phase after evaporating was the desired free base. The mass of the free base was recorded for each run. For the majority of experimental runs, the organic phases were collected and evaporated. For some of the later runs, the organic phases were evaporated individually and their mass recorded. A detailed step by step procedure can be seen in Appendix A.

### 3.3 ASPEN MODEL

The Aspen model was rebuilt following the input file and notes from the previous report. The first step to constructing the model was to specify the components involved in the model

(Caravella et al., 2014). To simplify the interaction calculations, only three species were specified: water, MTBE, and free base. The first two components are listed in the database, but the free base product was constructed using the user define settings. The molecule was drawn, and National Institute of Standards and Technologies (NIST) ThermoData Engine was used to estimate properties, as seen below in Figure 2. The triflate salt could not be modeled using this engine.

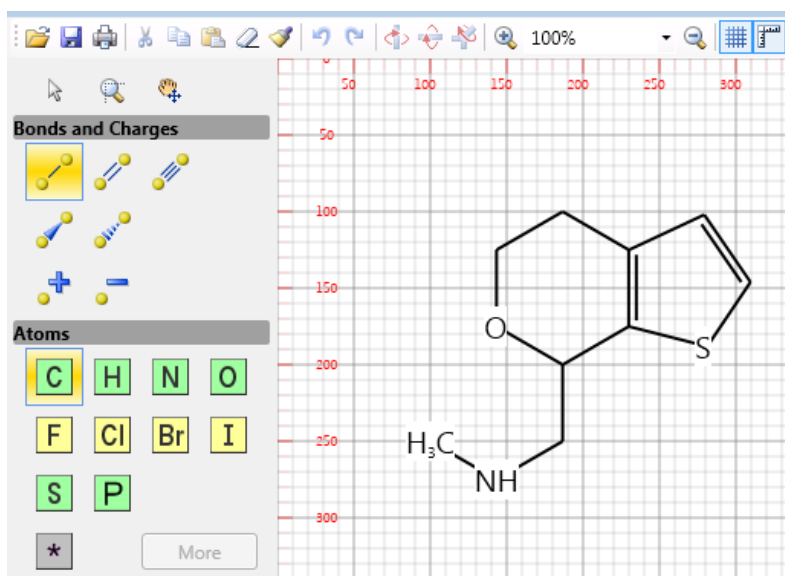


Figure 2: Molecule drawing tool for NIST approximation

The properties of the free base were further defined by entering the molecular structure menu. The functional groups of the molecule were specified by Universal QuasiChemical Functional-group Activity Coefficients (UNIFAC) notation. The methods for properties were chosen as UNIFAC, and the properties were run to confirm no errors.

General		Functional Group	Formula	Structure	Information
Enter functional groups in the molecule					
Method: UNIFAC					
Group number	Number of occurrences				
1010	2				
1005	1				
1600	1				
1710	1				
3760	1				

Figure 3: Molecule properties for UNIFAC group contribution approximation



Next, the model was constructed starting after the reaction. The product of the complete reaction entered into the first decanter block defined as WASH1. The second and third wash were modeled similarly, with additional MTBE entering as a second stream alongside the aqueous phase. The organics of each wash entered a mixer block to consolidate the organic phase into one stream. An additional block was used to simulate the rotary evaporator, separating the free base from the MTBE. The model can be seen in Figure 1 below.

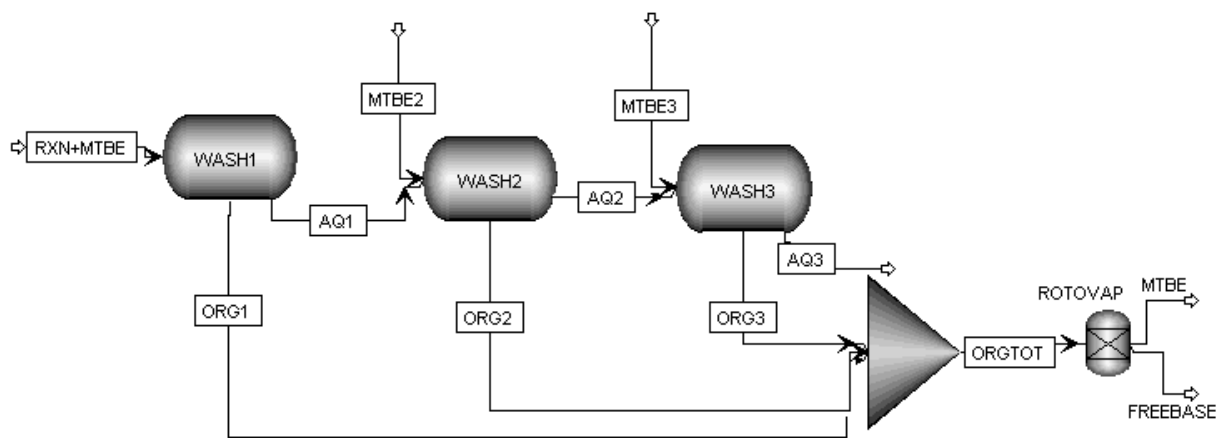


Figure 1: Aspen model process flow diagram

The decanter blocks were defined at atmospheric pressure and 25°C, as seen in Figure 4. To determine the phase split, the Gibbs free energy of the system was minimized. The phases were specified as a liquid-liquid system, with key components in each phase being specified to the correct stream.

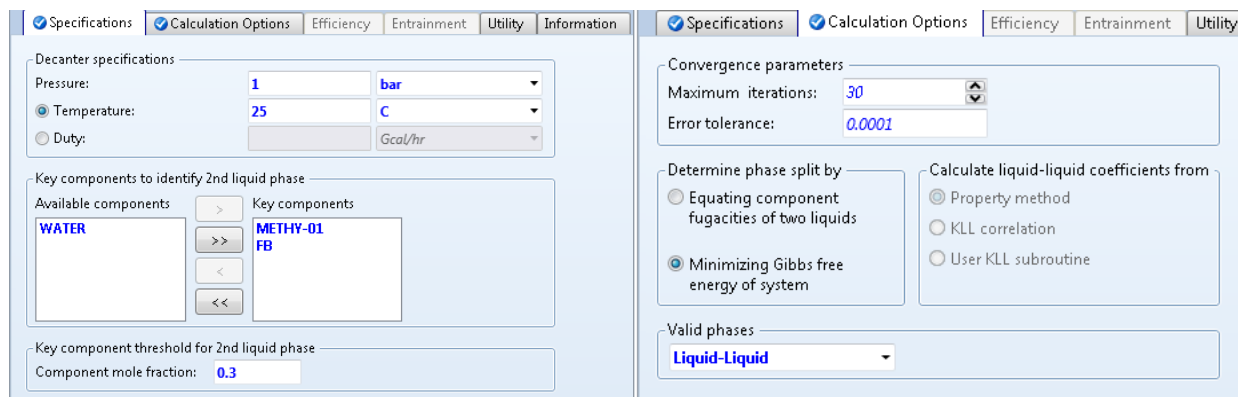


Figure 4: Decanter block configurations

A sensitivity analysis was conducted to run multiple iterations. For a single analysis, multiple variables can be defined. In the temperature variation, all three washes were inspected at the same time. The variable, as seen in Figure 5, MTBE was specified and the range for the points were given.

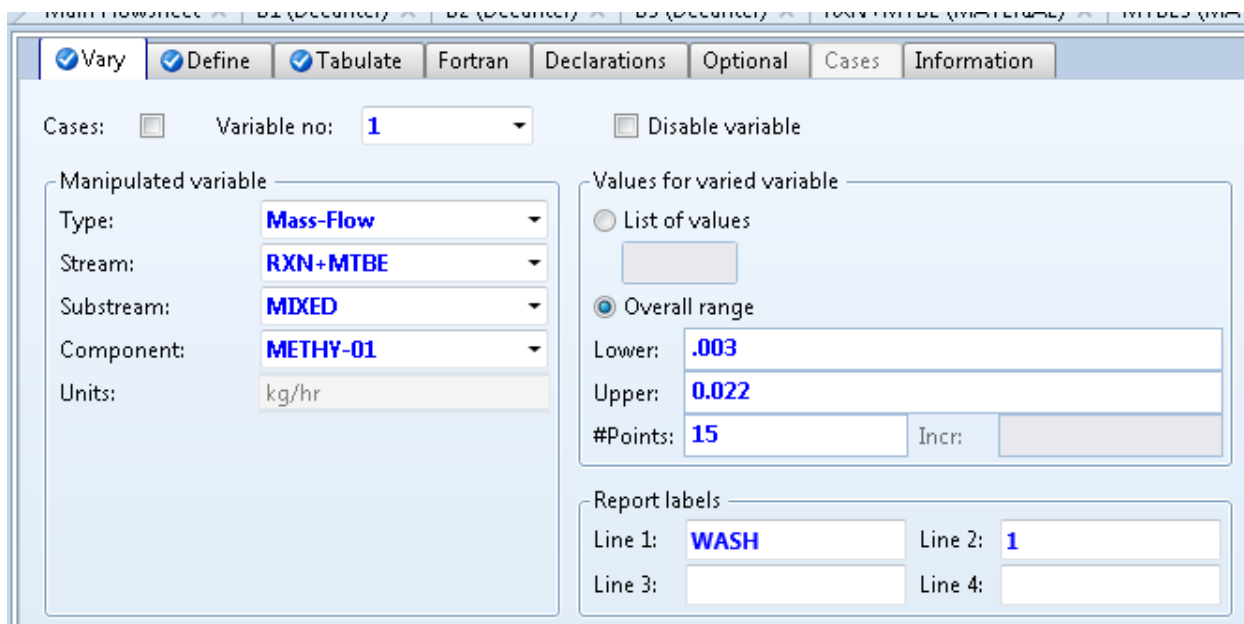


Figure 5: Sensitivity analysis configurations per variable

### 3.4 EVALUATING CURRENT OPTIMIZED PROCESS

To validate the previous results including the Aspen model, the base case process conditions were executed. Base case was considered to be the original procedure. The operation followed the procedure established by the previous MQP. Subsequent experiments with changes to the variables were compared the base case results.

### 3.5 PH STUDY

The base case reaction was run at a pH of 14. The pKa is known to be 9.5. To understand the pH dependence of the reaction, a study was designed to run the process at 10.5, 11.5, and 12.5. It is believed that a pH unit above the pKa ensures that the reaction is complete. However, no previous results were available to confirm this notion. Although the original base was KOH, a different base had to be used for the pH study. To achieve lower pH's with KOH, exorbitant amounts of water needed to be used. In practice, it is optimal to keep the aqueous and organic phases similar.

Potassium carbonate ( $K_2CO_3$ ) and bicarbonate ( $KHCO_3$ ) and sodium carbonate ( $Na_2CO_3$ ) and bicarbonate ( $NaHCO_3$ ) were used in 2M solutions. One equivalence of one of the new bases was used to ensure that the triflate salt was the limiting reactant. A one equivalence of the 2M sodium base solutions was below a pH 10 while the 2M potassium base solutions were below a pH of 11. To reach the desired pH levels, KOH was titrated using a burette.

### 3.6 TEMPERATURE VARIATION

The base case extraction was run at room temperature. Increasing temperature increases solubility in the solvent. Using the Aspen model, a series of experiments were found to show that increasing temperature and decreasing solvent amounts could still result in complete product recovery.

The first series of experiments involved drastically reducing the MTBE usage and varying the temperature from 25, 30, and 35°C. According to the model, having a higher percentage of recovery shows less variation between the differing temperatures. The Aspen model indicates that using a three wash cycle of four grams of MTBE each will give approximately 75% recovery at 25°C.



*Figure 6: Small reactor with a heating water jacket*

To ensure accuracy of the temperature, the base case procedure was carried out in a small reactor with an impeller and an outer heating water jacket that was connected to a heating element. The temperature and the stir speed was controlled via the ReactorMaster software program. The base case procedure remained unchanged except that the stirring rpm was set to 500 for the reactor.

### 3.7 TEMPERATURE STUDY

The second series of experiments was testing the optimal runs found on the Aspen model. The run with the minimum amount of MTBE used while maintaining maximum product recovery at 35 °C was conducted in the lab. Table 4 shows the variation between the washes of the temperature experiment and the base case.

*Table 4: Aspen-predicted savings of MTBE for extraction at 35°C*

Wash	1 (g)	2 (g)	3 (g)	Total (g)
Aspen at 35°C	15.28	14.15	11.05	40.48
Base Case	22.2	15	11	48.2

This set of experiments was run similar to the previous set using the small reactor and ReactorMaster.

### 3.8 SOLVENT ANALYSIS

The previous team studied the optimal number of washes and amount of MTBE used for the washes. Their recommendation for future teams was to study the product recovery using different solvents. To determine the recovery of the product, several solvents were tested in Aspen using the base case. The classes of the solvent and boiling points were also considered. Low boiling points and a solvent class of 3 were desired. A solvent class of 1 should be avoided because they are hazardous or carcinogenic. A solvent class of 2 is more desirable, but are still toxic and should be limited in products. Class 3 solvents are lowest in toxicity and have a lower risk to health. Lower boiling points were desired for feasibility in the lab as well as for the ability to solvent swap with acetonitrile.

### 3.9 SOLVENT SWAP ANALYSIS

A solvent swap analysis was completed using DynoChem modeling software. The free base was present at 20°C in 9kg of MTBE. A feed tank of acetonitrile was used to begin the solvent swap procedure. A heating element with constant parameters was used for all simulations. The goal of the simulation was to reach 1% of the upstream solvent and to switch the product to an acetonitrile based solution.

Both put/take and constant feed methods were used. The minimum volume of the vessel was designated as 15L and the maximum volume was 40L after converting rough estimates from the Sunovion flow sheet for their operation. Properties of the solvents were taken from the DynoChem database. This generated spreadsheet data and a graphical representation of the data over time.

## 4 RESULTS

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### 4.1 VERIFICATION

To become acclimated with the equipment in the lab and to verify the results of the previous group and the Aspen model, two base case runs were completed.

As seen in previous group's data in Table 5, the Aspen model agreed with the experimental data (Caravella et al., 2014). The actual recovery was always slightly higher than the Aspen prediction because of human error and/or water in the product. Water dissolved in the organic phase may not have always evaporated off in the rotary evaporator.

*Table 5: Base case results from previous project (Caravella et al., 2014)*

Run	Product Recovered (g)		
	Actual	Aspen	% Difference
1	5.965	5.326	11.3
2	5.549	5.503	0.8
3	5.553	5.39	3.0

As seen in Table 6, the reproduced runs were similar to the previous group's experimental data, verifying the previous group's results and procedure. Both runs were close to 100% recovery with similar variance.

*Table 6: Yield for experimental verification*

Base Case			
Triflate Salt (g)	Expected Free Base (g)	Actual Recovered (g)	% Recovered
10.04	5.51	5.48	99.3
10.05	5.51	5.85	106

The product was slightly viscous, transparent, and yellow, as seen in Figure 7.



*Figure 7: Free base product*

Using the previous group's procedure for constructing the Aspen simulation, the model was reconstructed. The Aspen results by the previous group matched the results of the reconstructed model, verifying the procedure. In the model, it was expected that most of the water would be in the aqueous phase because the solubility of water in methyl tert-butyl ether (MTBE) was low. The solubilities were tested experimentally, and these results can be seen in Appendix B. It was found that a three wash cycle of MTBE contained 0.655 grams of water. The rotary evaporator was run at 40°C for these solubility runs to prevent water from boiling off. In experimental runs, it was assumed that most of the water present was boiled off since the rotary evaporator was at least 10°C higher than the solubility runs.

In Table 7, the amount of water in the organic phase of the Aspen model was above the experimentally determined solubility. Even though the model could not correctly predict the water distribution, it accurately predicted the free base recovery. This model was used for predicting the amount of free base recovery in the temperature variation and solvent studies.

*Table 7: Aspen extraction results for individual species*

Aspen Extraction Results			
	Solvent (g)	Free Base (g)	Water (g)
Aqueous	0.17	0.07	9.69
Organic	47.83	5.58	8.29

## 4.2 PH STUDY

The purpose of the pH study was to determine the effects pH has on the recovery of the product. The bases considered were sodium bicarbonate ( $\text{NaHCO}_3$ ), sodium carbonate ( $\text{Na}_2\text{CO}_3$ ), potassium bicarbonate ( $\text{KHCO}_3$ ), and potassium carbonate ( $\text{K}_2\text{CO}_3$ ). A 2M solution of  $\text{NaHCO}_3$  could not be created at room temperature due to insufficient solubility.  $\text{NaHCO}_3$  and  $\text{Na}_2\text{CO}_3$  were not used in order to maintain similar volumes of aqueous and organic phases. The more soluble  $\text{K}_2\text{CO}_3$  and  $\text{KHCO}_3$  were chosen.

$\text{K}_2\text{CO}_3$  was used for the three pH runs. A gel formed during the reaction, as seen in Figure 8. The gel was pliable and white with a tinge of yellow. The stir bar was not enough to break up the gel, so the gel was physically broken using a spatula and stirring rod. After consulting Robert Prytko, the sponsor, it was determined that the solubility of the gel was dependent on pH. The pH of the reaction mixture was 9.6, much lower than that of the base case pH of 14. This was because  $\text{K}_2\text{CO}_3$ , a weak base, was used for the reaction instead of potassium hydroxide ( $\text{KOH}$ ), a strong base. The rest of the base case procedure for mixing, extraction, and evaporation was followed.



*Figure 8: Gel formed in reaction with  $\text{K}_2\text{CO}_3$*

The three runs can be seen in Table 8. For the first two runs, a pH of 12.5 was the target, but the recoveries were vastly different. The first run had a recovery of 65%, while the second had a recovery of 110%. The pH run at 10.5 had a recovery of 102%. However, it was expected that there would be less product recovered with a lower pH.

Table 8: pH experimental results using  $K_2CO_3$

pH Study - Potassium Carbonate				
Expected Free Base (g)	Actual Recovered (g)	% Recovered	pH	Gel
5.53	3.59	65.0	12.4	Yes
5.53	6.08	110	12.7	Yes
5.51	5.63	102	10.5	Yes

The varying results were most likely due to the gel interfering with the reaction step. The post-reaction mixture after breaking the gel was heterogeneous and still had very small clumps of gel, implying that the reaction might not have completed. Additionally, the heterogeneity of the solution would not result in a clean separation between the organic and aqueous phases. The products for the 12.5 pH runs were dissimilar, as seen in Figures 9 and 10. For the first run, the product was white, opaque, and viscous. The second run, the product was clear and light yellow, but was not viscous. The intensity of the yellow was less than the base case product.



Figure 9: Product of first 12.5 pH run (Left)



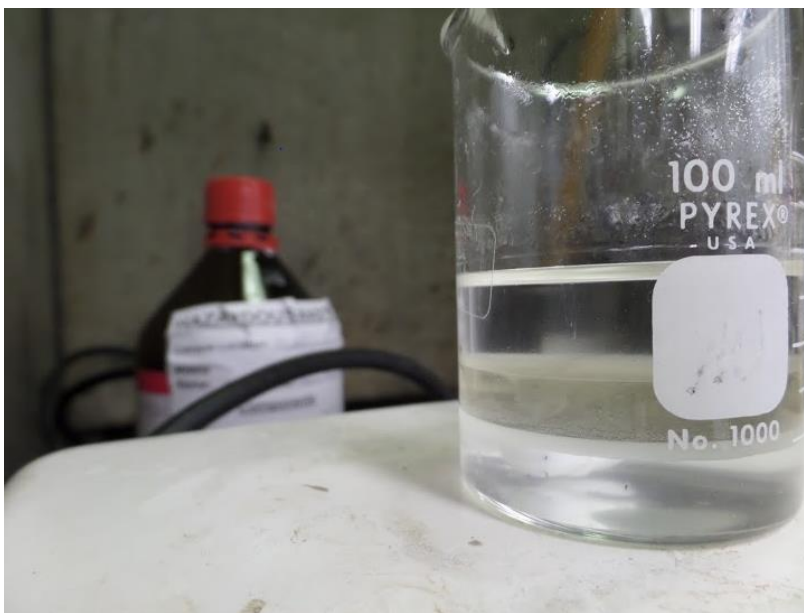
Figure 10: Product of second 12.5 pH run (Right)

#### 4.3 GEL AND EMULSION

The base case and pH study procedures were originally carried out by adding the first wash of MTBE after the reaction. After consulting the sponsor, the procedure was modified to prevent gelling. In practice, the solvent is present in the reaction step. Subsequently, the remainder of the studies were completed with the first wash present during the reaction.



In the modified pH study procedure, the first wash was added to the base, and the triflate salt was added to the resulting solution. An emulsion formed after mixing the reactants. As seen in Figure 11, the organic phase on top and the aqueous phase on the bottom were both clear. The middle phase was an emulsion and was cloudy. Extraction with a separatory funnel was impossible when an emulsion formed since there was uncertainty in the complete transfer of the free base to the organic phase.



*Figure 11: Emulsion formed after adding first wash of MTBE to reaction*

To determine whether the order that the material was added had an effect, the pH study procedure was altered again. Next, eight out of 22 grams of the first wash were added to the triflate salt before adding  $K_2CO_3$ . No emulsion occurred after the reaction, but when the remainder of the first wash was added and mixed, an emulsion occurred.

The pH study procedure was modified a third time;  $K_2CO_3$  was added to the salt and a gel began to form. MTBE was added slowly until the gel was dispersed. Four grams completely dispersed the gel and the reaction was completed. No emulsion occurred after the reaction, but again when the remainder of the first wash was added and mixed, an emulsion occurred.

Another run was conducted where KOH was titrated to raise the pH to break the gel. In this run, the gel was physically broken up first and then was mixed for several minutes after every few milliliters of KOH. It was found that at a pH of 11.2, the gel was well dispersed. A summary of the gel and emulsion results can be seen in Figure 12.

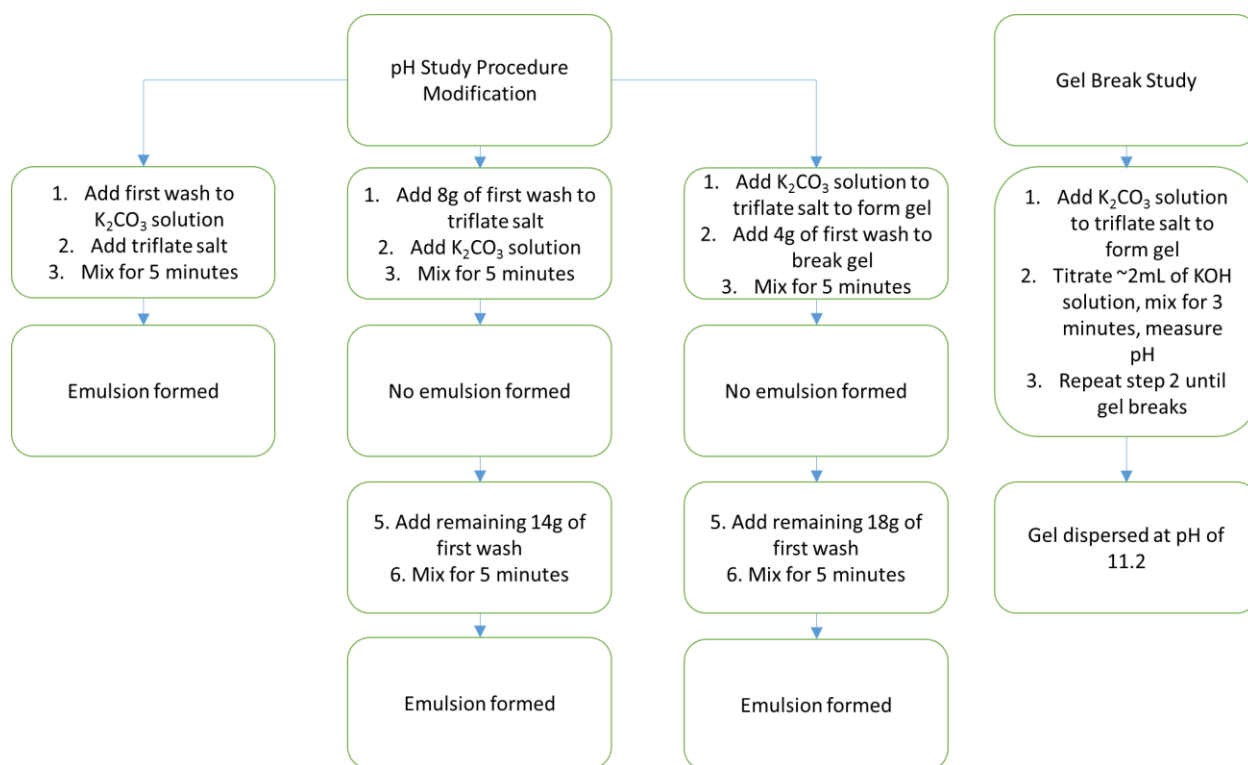


Figure 12: Summary of gel and emulsion results

The results show that when using  $K_2CO_3$  as the base and mixing the first wash to the reaction mixture, an emulsion occurs. The pH variation study was discontinued since  $K_2CO_3$  consistently resulted in a gel or an emulsion. The cause of the gel was due to the insolubility at lower pH. However, the cause of the emulsion was unknown. Recommended by the sponsor, another study was conducted using equivalent stoichiometry of triflate salt and KOH.

#### 4.4 EQUIVALENCE STUDY

The purpose of these runs was to study the effect of fewer pH units above the  $pK_a$  of 9.5 on recovery. Gels and emulsions were avoided by using 2M KOH with an initial pH of 14. To react 0.30 mole of the triflate salt, 0.30 mole of KOH was used. It was expected that there would be less recovery and a lower pH compared to the base case since no excess base would be present. KOH flakes of 85% purity were used. However, in the first run, the purity was not taken into account, meaning that less than one equivalence of base was used. This run had the lowest recovery in the equivalence study. A single pH was not consistently replicated throughout the study. The rest of the recoveries were all above 100% as seen in Table 9.

Table 9: Results for one equivalence experiments

pH Study - 1 EQ of KOH				
Triflate Salt (g)	Expected Free Base (g)	Actual Recovered (g)	% Recovered	pH
10.02	5.50	4.88	88.7	10.8
10.01	5.50	6.60	120	12.5
10.01	5.50	6.59	120	10.9
10.01	5.50	6.63	121	12.6
10.05	5.51	5.70	103	11.4
10.01	5.49	7.67	140	13.1
10.02	5.50	6.68	121	10.4

From inspecting Figure 13, it seemed that there was no correlation between the pH of the post-reaction mixture and the percent recovered of free base. The Spearman rank-order correlation test was performed to statistically support this conclusion. The first run with the miscalculation was not included either in Figure 13 or in the Spearman rank-order correlation test since it was not a true one-equivalence run.

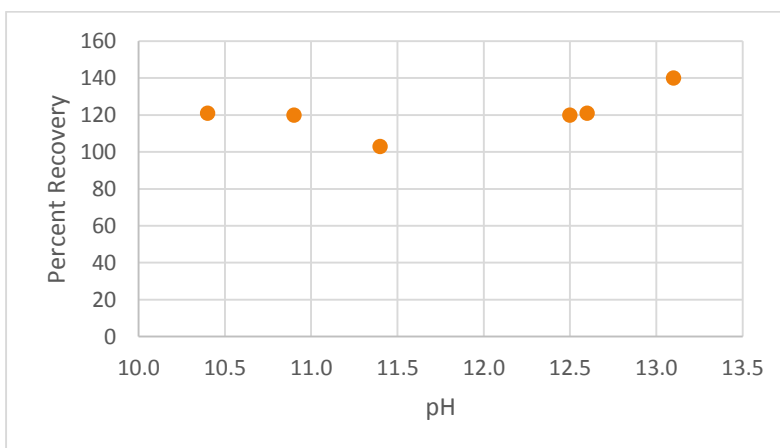


Figure 13: Percent recovery vs. pH

The Spearman rank-order correlation test resulted in a Spearman correlation coefficient of  $\rho = 0.441$  and a p-value of  $p > 0.10$ . The Spearman correlation coefficient indicated that there was a moderately weak positive association between pH and recovery. However, with a p-value greater than the significance level of  $\alpha = 0.05$ , the null hypothesis of no correlation between pH and recovery could not be rejected since there was not enough evidence. Future pH studies with more precision could show that there is a correlation between pH and recovery.

#### 4.5 TEMPERATURE STUDY

The procedure for the temperature study was determined by conducting a sensitivity analysis in Aspen Plus V8. The goal was to maintain the same recovery as the base case, but to minimize the amount of solvent used by increasing the temperature of the extraction. As seen in Table 10, Aspen determined that the optimal amount of solvent required at 35°C was 15.28g, 14.15g, and 11g for the first, second, and third washes respectively. This came to a total of 40.43g of MTBE total for the process, which saved 7.57g, or 16%, of MTBE compared to the base case.

*Table 10: Expected savings in MTBE for heated extraction.*

Solvent Usage Comparison				
Washes	1st (g)	2nd (g)	3rd (g)	Total (g)
Base Case	22	15	11	48
Temperature Study (35°C)	15.28	14.15	11	40.43

The Aspen prediction was experimentally tested in the laboratory. In Table 11, the free base recovery per wash and the total recovery can be seen.

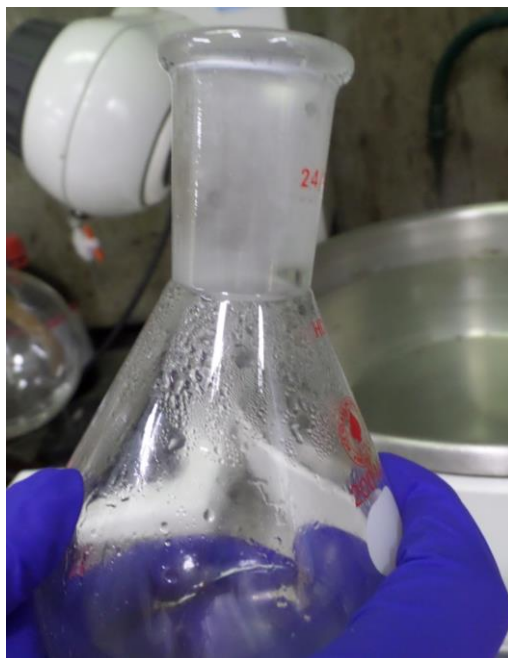
*Table 11: Temperature study experiments vs. Aspen results*

	Input (g)	Wash 1 Recovery (g)	Wash 2 Recovery (g)	Wash 3 Recovery (g)	Total Recovery (g)	Recovery (%)
ASPEN	5.5	4.15	1.05	0.25	5.45	98.2
RUN 16	5.5	5.94	0.39	-0.61	5.72	101
RUN 17	5.5	-	-	-	6.37/5.40	98.0
RUN 18	5.5	4.45	1.79	0.13	6.368	113
RUN 29	5.5	6.15	1.36	-0.02	7.489	133
RUN 30	5.5	4.91	1.39	-0.35	5.913	105

Yields over 100% could be explained by water dissolved in the organic phase. This can be seen in the condensation in the product flask from the rotary evaporator in Figure 14. In most runs, the third wash had negative recovery, which could be due to water evaporating that had been collected in previous washes. The Aspen model did not match the per stage recovery. The previous project's Aspen model could also not accurately predict the per wash recoveries (Caravella et al., 2014).

In Run 17 the recovery was initially 6.37g. The flask was left uncovered in the fume hood overnight, and the product mass had decreased to 5.40g. However, according to the sponsor, leaving the flask uncovered was not acceptable practice as the content of the vapor is unknown and was not done for subsequent runs. Run 29 with 133% recovery was conducted with the

temperature of the rotary evaporator set to 40°C when it was usually 50°C. This resulted in a higher recovery than the other runs. Run 30 was conducted at 60°C and resulted in a more accurate recovery of 105%, indicating a larger presence of water that was not removed when evaporating at lower temperatures. Generally, with a higher temperature, solubility increases. It was believed that more water was present in the organic phase at 35°C than in the base case.



*Figure 14: Condensation on the product flask*

#### 4.6 TEMPERATURE VARIATION

The temperature variation study was also determined by an Aspen sensitivity analysis. The goal of this study is similar to the temperature study of minimizing MTBE usage, but also to determine the accuracy of Aspen. The temperatures studied were 25°C, 30°C, and 35°C. Aspen predicted a recovery of 75% if three washes of three grams were used. Two 25°C runs were attempted as seen in table 12. The first run resulted in a 203% recovery and the second run had no phase separation. The organic phase was too small for a phase separation and most likely dissolved into the aqueous phase. This indicated that Aspen could not accurately predict solubility issues with a smaller organic phase.

Table 12: Temperature variation results

Experimental Results				
Triflate Salt (g)	Expected Free Base (g)	Actual Recovered (g)	% Recovery	Temperature (°C)
10.01	3.986	8.10	203	25
10.13	3.986	N/A	N/A	25

#### 4.7 HPLC

High-performance liquid chromatography (HPLC) was conducted by Robert Prytko on product samples from two separate runs to better understand the recovery percentages above 100%. The free base has a peak around 8.5-8.55. Two known impurities have peaks at 9.41 and 9.62.

As seen in Figure 15, the organic phase of a one equivalence run, Run 20, displayed the expected peaks with an additional peak at 8.055. According to Prytko, this peak is not uncommon. Figure 16 shows the aqueous phase of the same run. There were several peaks that are not the impurities or free base. Again according to Prytko, these are also not uncommon to see. The aqueous phase had a significant amount of free base which was not optimal for the process. A Karl-Fischer titration test was also conducted to determine water content. The test was conducted twice on each organic sample to ensure precision. The organic phase was found to contain 4.68% or 3.17% water. These numbers were high but also had a large difference between duplicate runs. It was believed that there are issues with the third wash that cause a large amount of water to be present in the organic phase and a significant amount of free base in the aqueous phase.

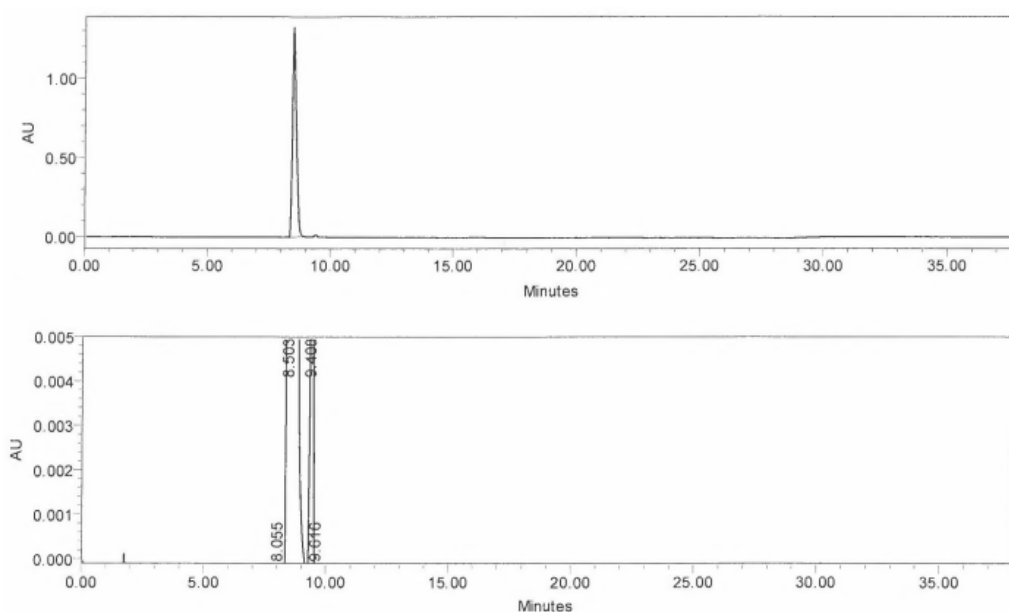


Figure 15: One equivalence organic HPLC

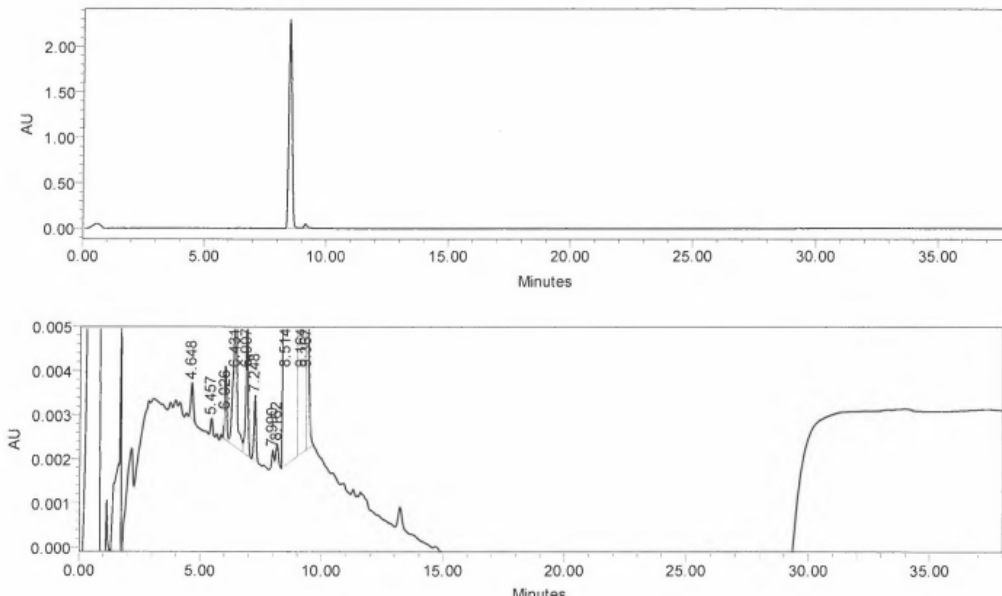


Figure 16: One equivalence aqueous HPLC

Tests were conducted similarly on an organic sample from the 35°C temperature study. Results from Run 18 were used. Again, the HPLC chromatogram showed expected results, as seen in Figure 17. The Karl-Fischer test showed that the organic phase contains 1.91% and 1.37% water. Although this was lower than the one equivalence run, the spread between the two values was, again, higher than normal. It was possible that condensate mass on the flask was being weighed with the product mass, as even without impurities and Karl-Fischer water taken into account there is still excess mass.

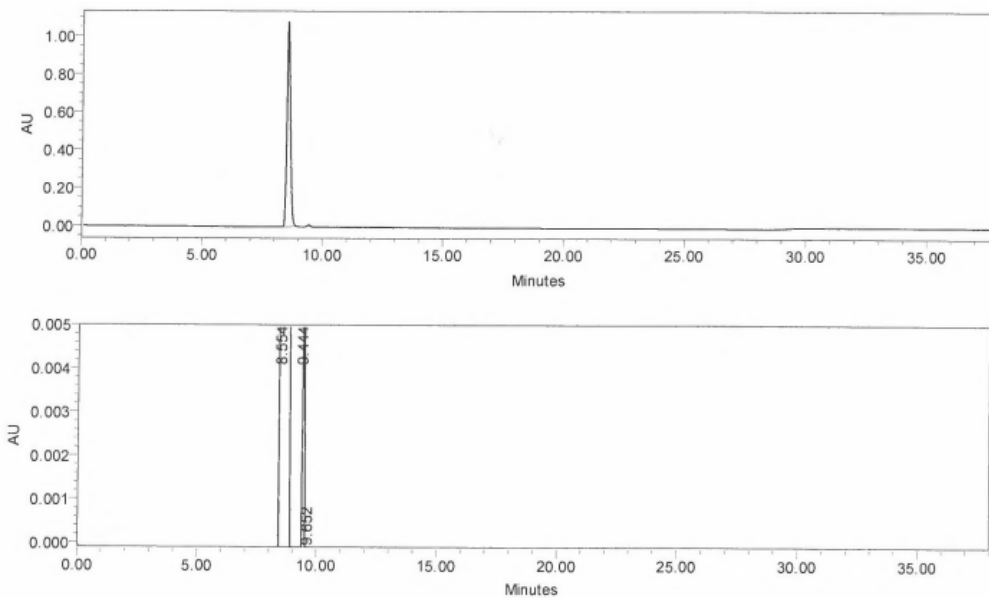


Figure 17: 35°C organic HPLC

#### 4.8 SOLVENT STUDY

The purpose of this solvent study was to find possible alternatives to MTBE. According to Aspen, trans-1,2-dichloroethylene would extract 100% of the product from the aqueous phase. However, trans-1,2-dichloroethylene is a class 1 solvent. The next best recoveries from Aspen were ethyl acetate and diethyl ether, which are both class 3 solvents. Diethyl ether was not tested because it is an ether that forms explosive peroxides. Ethyl acetate has a boiling point of 77.1°C, which is higher than desired due to the solvent swap downstream. It was concluded that the current solvent, MTBE was the optimum solvent out of the solvents researched.

*Table 13: Recovery and important information for substitute solvents*

Solvent	% Recovery	BP °C	Class
MTBE	98.69	55.2	3
Chloroform	99.02	61.2	2
Cyclohexane	13.21	80.74	2
Diethyl Ether	98.45	34.6	3
Ethyl Acetate	99.50	77.1	3
Heptane	9.27	98.42	3
Hexane	11.32	68	2
Pentane	14.65	36.1	3
Trans-1,2-Dichloroethylene	100.00	48.5	1

#### 4.9 SOLVENT SWAP ANALYSIS

Using DynoChem, three different solvents were tested under both put/take and constant feed solvent swap conditions. The base solvent MTBE was used as well as toluene and isobutyl acetate.



Table 14: Solvent swap DynoChem results

Solvent	Time to complete constant feed rate swap (hrs.)	Amount of Acetonitrile Used in constant feed (kg)	Time to complete min. / max swap (hrs.)	Amount of Acetonitrile Used min. / max swap (kg)
MTBE	2.612	27.212	3.184	34.648
Isobutyl Acetate	16.327	308.277	-	-
Toluene	8.816	66.767	10.776	87.277

As seen in the table above, MTBE proved to be the most efficient in both time and acetonitrile required. As the boiling points of the solvents approached that of acetonitrile, the heating and amount of acetonitrile required increased. In the case of isobutyl acetate, it could not complete a run in DynoChem under the conditions.

It is key that if any alternative solvent is used, it must be compatible with this solvent swap step. The alternative solvent has to be below the boiling point of acetonitrile. As mentioned in the solvent study, the only alternative solvent that meets both conditions is diethyl ether. However, DynoChem only has select solvents in their database, so no simulations could be done with diethyl ether.

## 5 CONCLUSIONS & RECOMMENDATIONS

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The overarching goal of the project was to optimize the process using simulation and experimental analysis. The analysis focused on the effects of pH and bases on the reaction, and temperature and solvent on the extraction.

### 5.1 REACTION

Potassium hydroxide was the best tested base for the neutralization reaction step. Sodium carbonate and sodium bicarbonate could not form 2M solutions at room temperature. Potassium bicarbonate was not used because potassium carbonate ( $K_2CO_3$ ) provided us with a low enough pH. However,  $K_2CO_3$  resulted in a gel, and when the solvent was present in the reaction, an emulsion occurred. The equivalence study was inconclusive; however, the Spearman correlation coefficient hinted that there was a slight positive correlation between pH and recovery. Additional tests should be done to confirm this. These tests should be done by using a more precise analytical scale to measure one equivalent of triflate salt and base. Future projects should experiment with other bases, in particular sodium hydroxide, as well as different concentrations. It is also recommended that a computer model be built for the reaction step to allow for simulation of parameters.

### 5.2 EXTRACTION

The Aspen simulation results were evaluated in the lab. The Aspen optimized wash cycle at 35°C showed a 16% reduction in solvent usage while maintaining maximum recovery. A cost analysis should be conducted to examine the benefits of reducing solvents versus detriments of increasing the temperature. Other temperatures, such as 25°C and 30°C, should be investigated in a similar manner.

The temperature variation study used a series of small washes that were suggested by Aspen. However, the washes were so small that the extraction did not occur properly. Aspen predicted that the washes would show a 75% recovery, but experimentally they could not be completed. Another example of Aspen deviating from experimental results was the water content in the organic phase of the extraction. The model claimed that the organic and aqueous phases both have relatively equal amounts of water. In the lab, the organic phase only contained a small amount of water. The model correctly predicted the solvent and free base recovery but did not accurately predict the water content.

To further optimize the effects of the liquid-liquid extraction on recovery, mixing and settling times should be investigated. Mixing and settling times were only five minutes in this procedure. This might not have been enough time for the phases to fully partition.

Several solvents were tested in Aspen for their recoveries. Although some had higher recoveries than the current solvent, these solvents were not safe to use in the laboratory and in

pharmaceutical processes. Methyl tert-butyl ether was the best solvent for safety and extraction. Future studies should examine safer solvents at different temperatures to examine their recoveries.

DynoChem was able to model the downstream process of solvent swap. As several solvents were not present in the DynoChem database, future studies should further examine the possibilities of adding solvent data to help model solvents examined in the solvent study.

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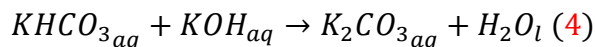
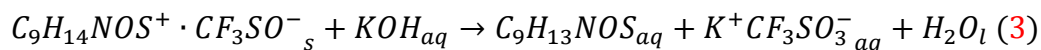
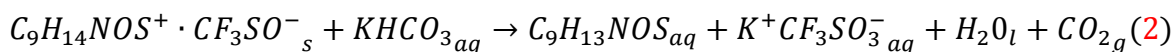
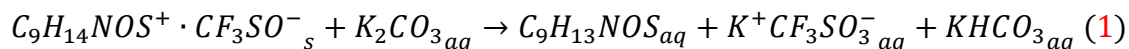
# APPENDIX A: PROCEDURES

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## PROCEDURE FOR PH EXPERIMENTAL RUNS

This procedure details how to complete an entire experimental run including the rotary evaporator use, the salt split reaction step, and pH control. The details for weighing and the size of the beakers and flasks are best for the 10g of salt scale. Depending on the variable being tested, some of the masses might be changed in different experimental runs.

### Reactions



### Materials:

2M KHCO<sub>3</sub>, 2M K<sub>2</sub>CO<sub>3</sub>, 2M KOH, Triflate Salt, MTBE, Dry Ice

### Equipment:

(2) 50mL beaker, 400mL beaker, 100mL flask, Mass Scale, Separatory Funnel, Magnetic Stir Plate, Parafilm, Ring Stand, Rotary Evaporator, 10mL Pipette, pH Probe, 25mL Burette

### Procedure:

1. Clean all glassware used in the lab.

*Note: Acetone was used to clean the glassware, and was disposed of in a waste container.*

2. Place scale into fume hood.

Caution! As a precaution the entire procedure should be done in a fume hood. Extra precaution should be given to steps involving MTBE. See MSDS for details.

3. Measure the weight of the dry 100mL flask, and collection flask.

*Note: To weight the round-bottom flask a ring might be needed to place on the scale, and it should be weighed as well.*

4. Measure out 15g of 2M KHCO<sub>3</sub> into a 50 mL beaker.
5. Measure out 10g of triflate salt and place into a 400mL beaker.
6. Pour the aqueous 2M KHCO<sub>3</sub> into the salt beaker to ensure better transfer.
7. Place the pH probe into the solution.

8. Place 25 mL of 2M  $K_2CO_3$  into the burette.
9. Titrate 2M  $K_2CO_3$  drop wise until desired pH is reached.

*Note: Use 15g of  $K_2CO_3$  and titrate with KOH for pH 12 and above.*

10. Place the solution on a magnetic stir plate, and mix for 5 minutes.
11. Measure out 22g of MTBE into a 50mL beaker.
12. Add MTBE to 400mL beaker with solution.
13. Mix MTBE and free base solution for 5 minutes on the magnetic stir plate.

*Note: Covering the solution tightly with Parafilm will prevent MTBE evaporation.*

14. Place contents into a separatory funnel and cover with Parafilm.
15. Let contents separate into organic (top) and aqueous (bottom) phase for 5 minutes.
16. Drain the aqueous phase out of the separatory funnel back into the 400mL beaker.
17. Drain the organic phase out of the separatory funnel into the 100mL flask.
18. Repeat steps 8-14 twice: using 15g and then 10g of MTBE.

*Note: The organic phase should be collected in the same 100mL flask for all three washes. Individual isolations can be performed, but do not match aspen simulations.*

19. Place dry ice into the rotary evaporator condenser.
20. Fill the bath with water.
21. Place the recovered organic phase, 100mL flask, onto the rotary evaporator with clip.
22. Ensure that the pump exhaust is released to the back of the fume hood.
23. Configure valve near the condenser so that a vacuum can be pulled.
24. Turn on hot water bath to 50°C.

*Note: Ensure that controller is accurately reaching the desired temperature. The current one should be set to ~40°C to reach the target temperature.*

25. Begin to rotate the flask between 50 to 100 RPM.
26. Turn on vacuum pump to pull ~400 mmHg.
27. Wait an adequate amount of time to allow complete evaporation of MTBE.
28. Remove 100mL flask and measure the mass.
29. Remove collection flask and measure mass.
30. Dispose of products in designated waste containers.
31. Clean glassware.
32. Open the top of the condenser to allow dry ice to evaporate into the hood.



## PROCEDURE FOR PH METER CALIBRATION

The pH probe used in the laboratory requires a calibration before use, and every few hours. Due to the accuracy of the pH tests, the meter was tested in the buffer solutions to ensure accurate readings. The calibration below is done with three points, but it could be done with a pH of 9 and 12.46. Then the probe could check for an accurate reading on the pH 11 buffer. It is important to note that the probe is only accurate in the range in which it is calibrated.

### **Materials:**

pH 9 buffer, pH 11 buffer, pH 12.46 buffer, reference fluid

### **Equipment:**

(2) 50mL beaker, pH probe, instrumentation device, storage fluid/container

1. Fill the pH probe to the top with reference material by removing the seal at the top.

*Warning!:* Make sure the probe does not dry out, or it may affect the accuracy of the device.

2. Connect the pH probe to the instrumentation device.
3. Turn on the device by pressing the power button in the middle.

*Note:* Do not press any other buttons during power up, or it may generate an error.

4. Remove the pH probe from the storage fluid, and place into the pH 9 buffer vessel.
5. Press the calibrate button, chart with points, on the upper left corner of the device.
6. Allowing the pH to stabilize, change the pH measured to read 009.00 by using the up arrow, down arrow, and the decimal switch button to the left of the arrows.
7. Remove the pH probe from the buffer, and rinse with distilled water over a beaker.
8. Place the pH probe in the pH 11 buffer container.
9. Press the measure button, on the upper right corner of the device.
10. Repeat step 6, but input the correct pH of 011.00.
11. Pour the pH 12.46 buffer into the 50mL beaker, so it will submerge the pH probe.
12. Repeat steps 8-10 for the pH 12.46 buffer, inputting the pH of 012.46.
13. Clean the probe with distilled water.
14. Dispose of the pH 12.46 buffer, and clean the glassware.
15. Place the pH probe back into the storage fluid.
16. Wrap the storage container with Parafilm to prevent the probe from drying.

## PROCEDURE FOR TEMPERATURE VARIATION USING ASPEN

A temperature variation study was done using Aspen to model on the effects of raising the temperature. It was decided that since the base case occurred at room temperature that Aspen simulations would be performed for two additional temperatures at 30°C and 35°C. Due to the approach to the boiling point we were advised to not go closer than 20°C to prevent loss of solvent. These Aspen simulations were modifications on the base case. To perform the analysis, the decanter blocks were set to the correct temperature that the extractions would be set at.

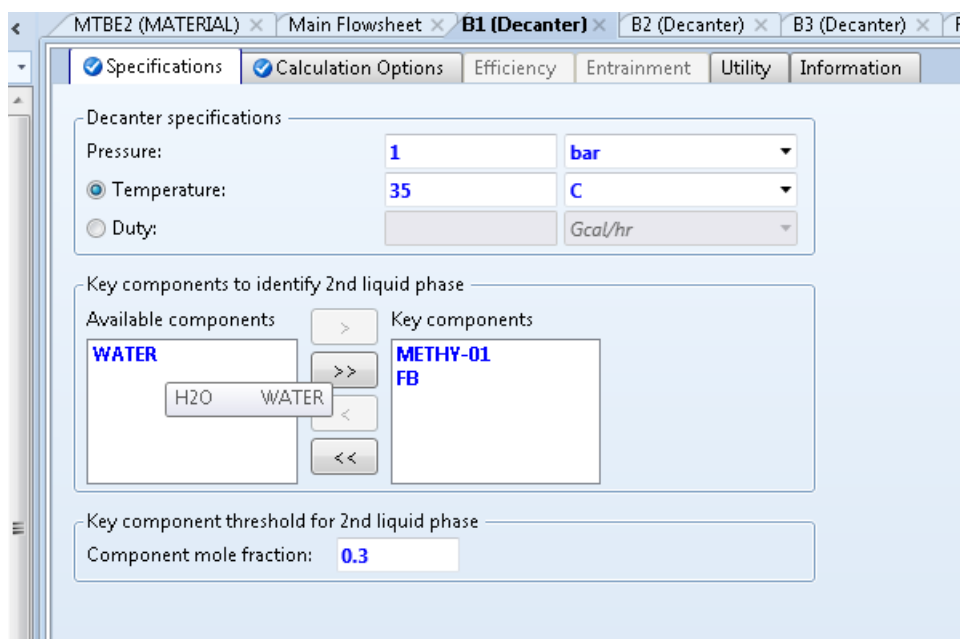


Figure 18: Temperature modification of decanter block

Since the reaction is not modeled in Aspen, it is assumed again that 100% of the salt is converted into free base. A sensitivity analysis was done varying the amounts of MTBE in all three decanter blocks. This resulted in 3375 iterations, as 15 different conditions were set for each block. The upper limit of the MTBE usage was selected as the base case. This would mean only results that saved MTBE would be displayed, as high recovery at higher temperature and material usage can already be expected. The lower limit was set to 3g per wash, as the model was unable to correctly analyze the washes at very low amounts of MTBE.

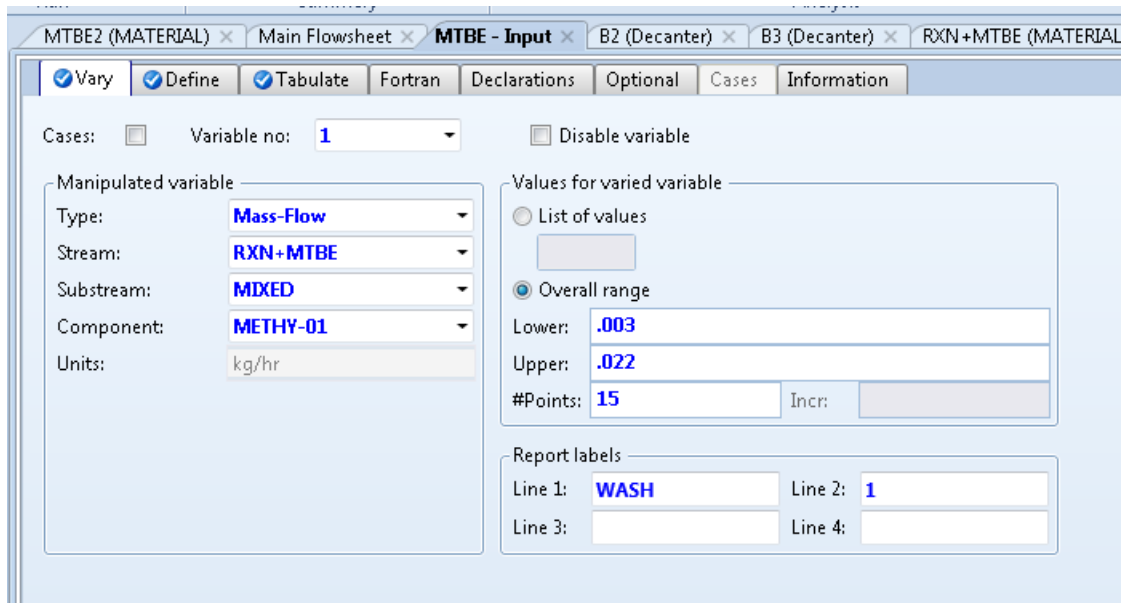


Figure 19: Sensitivity analysis for MTBE

The final iterations were then put into Excel where they were checked with the recovery requirement set by Sunovion. After determining which runs yielded over 98%, the remaining runs were organized by their total MTBE saved. The runs which saved the most materials were selected to be investigated by lab experiments. Below is a sample from the data sheet of the results for 35°C. This was also done for 30°C.

Table 15: Sensitivity analysis for 35°C, showing top 10 results out of 3375

Row/Case	Status	VARY 1	VARY 2	VARY 3					
		WASH 1	MTBE2	MTBE3					
			MIXED	MIXED					
			METHY-01	METHY-01					
			MASSFLOW	MASSFLOW	KG				
		KG/HR	KG/HR	KG/HR	Total	Saved	KMOL/HR	Recovery	Above 98%
2235	OK	0.0152	0.0141	0.0110	0.0404	0.0076	2.95E-05	0.98397	0.00397
2249	OK	0.0152	0.0150	0.0104	0.0406	0.0074	2.95E-05	0.9841	0.0041
2472	OK	0.0166	0.0150	0.0093	0.0409	0.0071	2.95E-05	0.98399	0.0039867
2445	OK	0.0166	0.0133	0.0110	0.0409	0.0071	2.97E-05	0.99024	0.0102393
2668	OK	0.0179	0.0133	0.0099	0.0411	0.0069	2.97E-05	0.99012	0.0101196
2459	OK	0.0166	0.0141	0.0104	0.0411	0.0069	2.97E-05	0.99041	0.0104086
2250	OK	0.0152	0.0150	0.0110	0.0412	0.0068	2.97E-05	0.99063	0.0106344
2864	OK	0.0193	0.0116	0.0104	0.0413	0.0067	2.97E-05	0.99005	0.0100523
2682	OK	0.0179	0.0141	0.0093	0.0414	0.0066	2.97E-05	0.99026	0.0102594
2655	OK	0.0179	0.0124	0.0110	0.0414	0.0066	2.97E-05	0.99039	0.0103934

After determining the best washes, they were then input directly into the model. Since the sensitivity only output the total recovery, a per wash recovery was determined for the system.

*Table 16: MTBE and recovery per stage*

(°C )	Input (mol)	Input (g)	MTBE 1 (g)	Base 1 (g)	MTBE 2	Base 2	MTBE 3	Base 3	Total
30	0.03	5.65	17.93	4.32	15.00	1.01	11.00	0.23	43.93
30	0.03	5.65	20.64	4.47	13.29	0.86	10.43	0.22	44.36
30	0.03	5.65	19.29	4.40	14.14	0.93	11.00	0.23	44.43
35	0.03	5.65	15.21	4.25	14.14	1.05	11.00	0.25	40.36
35	0.03	5.65	15.21	4.25	15.00	1.07	10.43	0.23	40.64
35	0.03	5.65	16.57	4.34	15.00	1.00	9.29	0.21	40.86

The final results of the temperature variation analysis are below. It was decided that the highlighted run would be modeled in the lab. This gave the highest amount of MTBE saved out of all the over 6000 runs performed in the sensitivity analysis. The per runs amount of recovery were 4.25g, 1.05g, and 0.25g for the three washes respectively.

*Table 17: MTBE saved and total recovery of higher temperature runs*

(°C)	MTBE Saved (g)	% Saved	Base (mol)	Recovery	Base (g)
30	4.07	0.92	0.03	0.98	5.56
30	3.64	0.92	0.03	0.98	5.56
30	3.57	0.93	0.03	0.98	5.56
35	7.64	0.84	0.03	0.98	5.55
35	7.36	0.85	0.03	0.98	5.56
35	7.14	0.85	0.03	0.98	5.55

## PROCEDURE FOR SOLVENT SWAP USING DYNOCHEM

DynoChem has a program capable of calculating the solvent swap between two solvents. It has the capability of calculating it in two ways: Either by keeping the volume of the batch between a minimum and maximum volume with a constant feed rate, or feeding to the maximum volume when the volume reaches the minimum.

The program ran with different solvents, and generated information in terms of volume of desired solvent to swap, and time it takes to complete the solvent swap. The effects of different solvents and temperatures upstream were examined, but this would give insightful information on the downstream process. While the washing steps might improve by changing solvents, it could increase costs in the solvent swap process.

1. Input mass of solvent being swapped.
2. Input temperature of the feed & batch.
3. Input heat transfer coefficients for the heat exchanging device.
4. Input minimum and maximum volumes

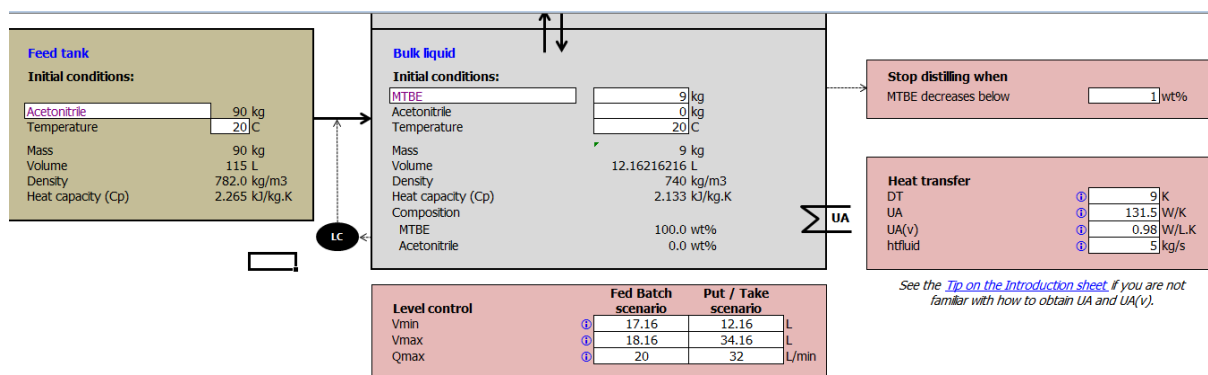


Figure 20: DynoChem interface

#### Assumptions:

- Minimum volume is the volume of the batch at start (12.16L for 9kg of MTBE), and the maximum volume is minimum with the addition of 32L acetonitrile.
- For constant feed, the minimum volume is 5L above the starting batch, and the maximum volume is 6L above.
- Assumed to be a constant value of 9kg – weight of solvent unknown.
- The batch runs at 20°C, and the feed was assumed to be at room temperature as well.
- Kept at the default parameters of the file.

#### PROCEDURE FOR CALCULATING PH CURVE USING DYNOCHEM

DynoChem attempted to model the relationship of concentration of triflate salt and pH. Using the “Components distribution as a function of pH” model in the “Modelling of acid base equilibria and pH sensitive reactions” Knowledge Base. The only information needed to run the model was the reaction, the rate constant, and the equilibrium constant ( $K_{eq}$ ). We are not concerned with time dependency right now, so the rate constant was assumed to be very high and first-order ( $1 \cdot 10^4$  1/s) to give a fast reaction. The equilibrium constant was calculated from the  $pK_a$  ( $K_{eq} = 10^{-pK_a} = 10^{-9.5} = 3.16 \cdot 10^{-10}$ ). One graph obtained from DynoChem was pH solution, amount of base added per minute, and amount of salt and free base versus time. The other graph

obtained was amount of salt and free base versus pH. The graphs obtained are shown below. According to the Henderson-Hasselbalch equation ( $pH = pKa + \log\left(\frac{[A^-]}{[HA]}\right)$ ), the salt and free base amount should intersect at the pH value equal to the pKa of 9.5, but the intersection point was around pH=12.1. This could be due to the limitations of the software or incorrect inputs.

**salt 1 mol/L**

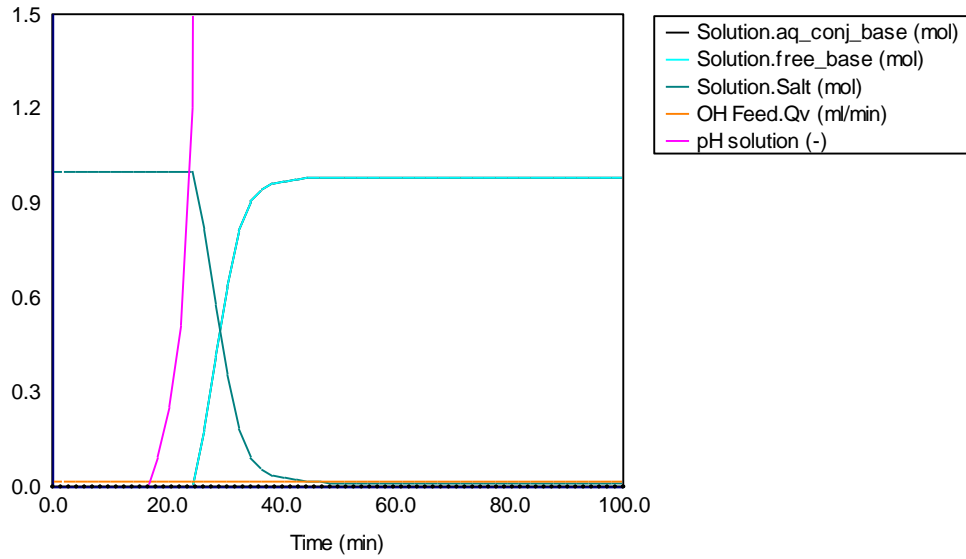


Figure 21: DynoChem titration curve over time

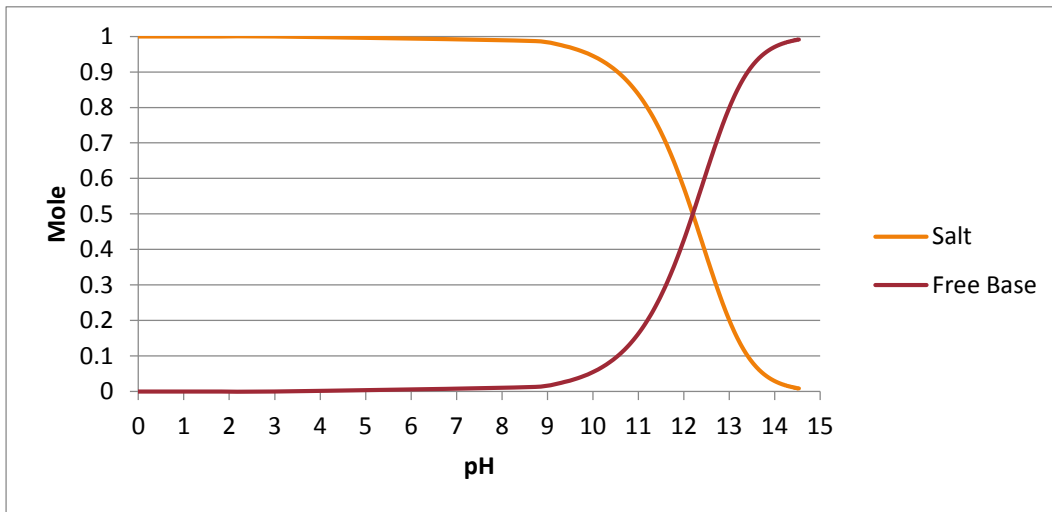


Figure 22: DynoChem titration curve

## PROCEDURE FOR CONSTRUCTING ASPEN

This will be a step by step guide to constructing the Aspen model. This appendix section will go into a more detailed description than the methodology.

1. Specify the water and MTBE in Properties > Components > Specifications > selection > Find.

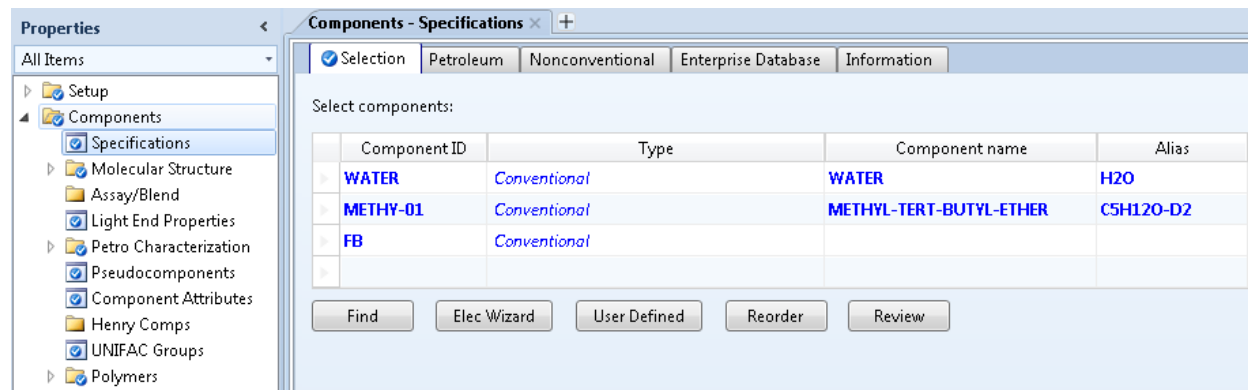


Figure 23: Menu for step 1 & 2

2. Click **User Defined** to specify Free Base. Specify Component ID hit **Next**.
3. Click **Draw/Import/Edit Structure** to enter the NIST drawing window.
4. Draw the Free Base and **save**.

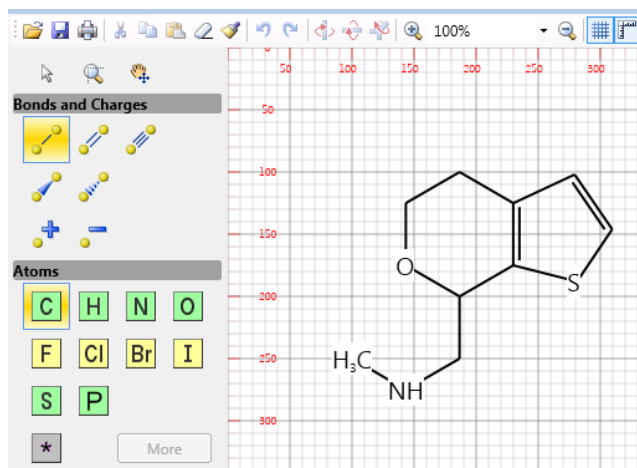


Figure 24: NIST drawing window

5. Click **Next**. Click **Evaluate Now** next to evaluate using NIST TDE.
6. Go to Properties > Components > Molecular Structure > Free Base.
7. Enter UNIFAC Group numbers and occurrences in the **functional group** tab.



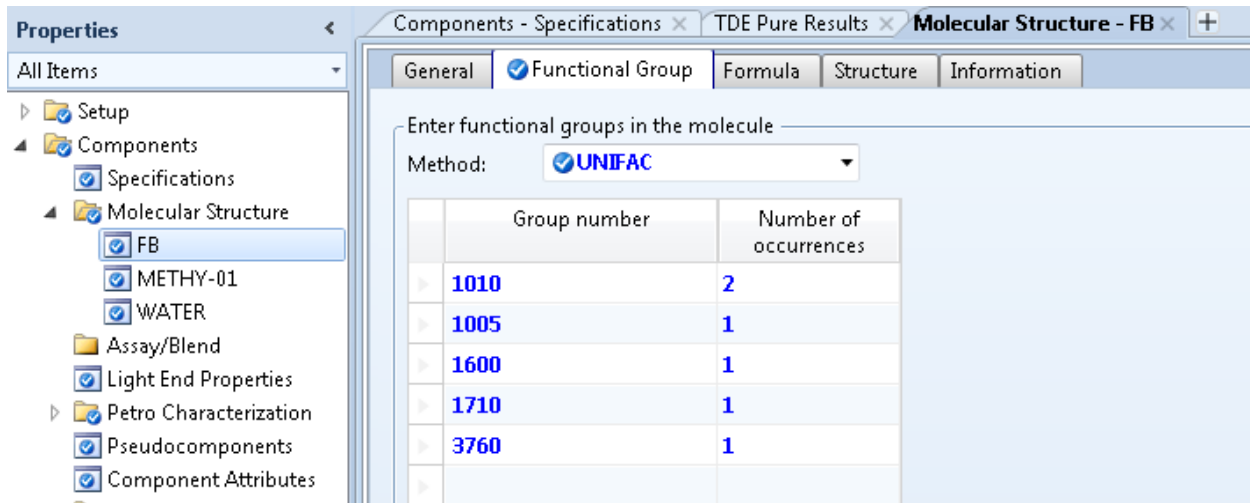


Figure 25: Menu for step 6 & 7

8. Navigate to Properties > Methods > Specifications > Global.
9. Enter UNIFAC as the **base method**.
10. Hit run to estimate properties.
11. Construct the stages of the extraction using decanter blocks.
12. Add all necessary streams.

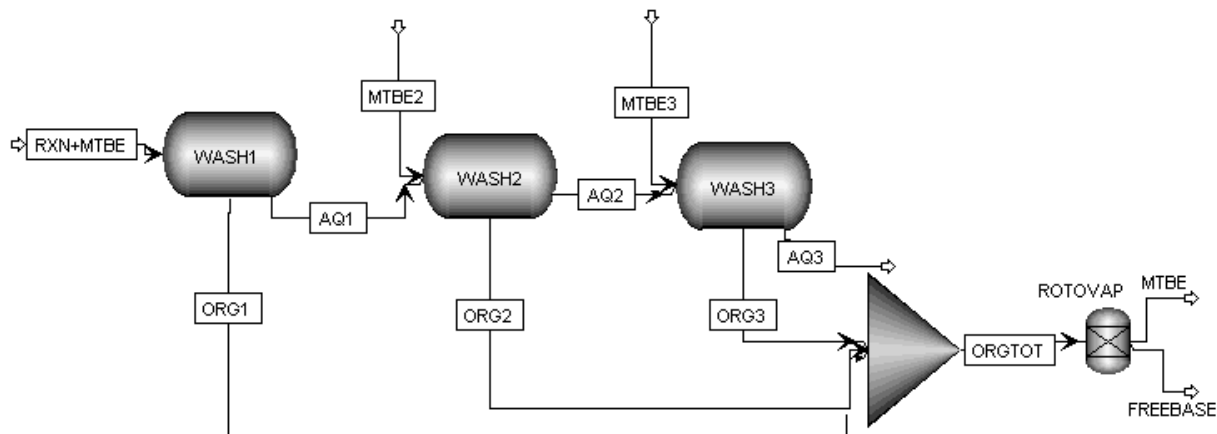


Figure 1: Three wash extraction and separation

13. Navigate to the decanter blocks under **Simulation > Blocks**.
14. Enter the decanter conditions and key components in **Specifications**.
15. Select minimizing Gibbs free energy of system, and specify liquid-liquid phases.

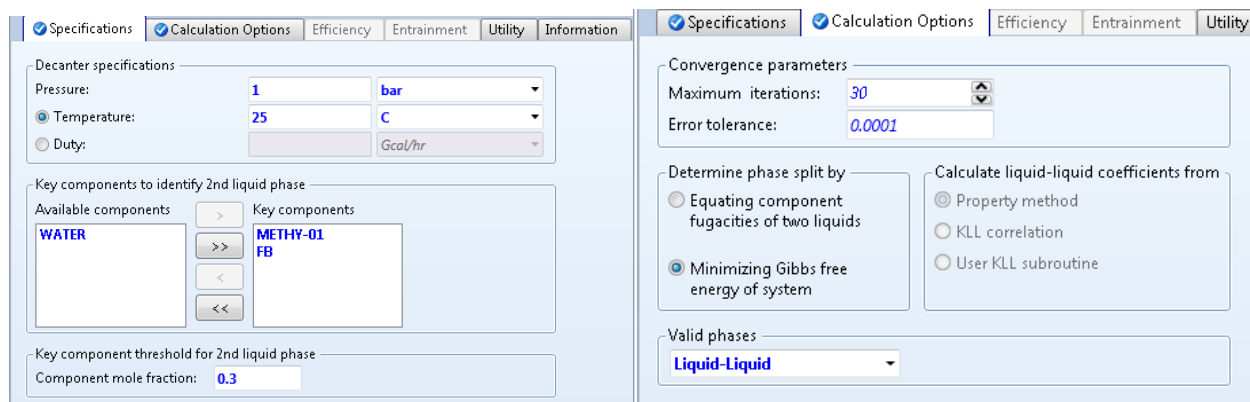


Figure 26: Menus for Decanter Blocks

16. Repeat the process for the multiple decanter blocks.

Note: Ensure that the streams leaving the decanter block are not swapped.

17. Specify conditions for the final reaction mixture.

Note: This free base amount is the reacted free base, and not the triflate salt.

18. Specify the wash amounts in the additional MTBE streams. The first wash should be in the reaction stream, or a MTBE1 stream should be added.

For Sensitivity analysis:

1. Go to Model Analysis tools > Sensitivity > New...
2. In the **Vary** tab specify the manipulated variable.

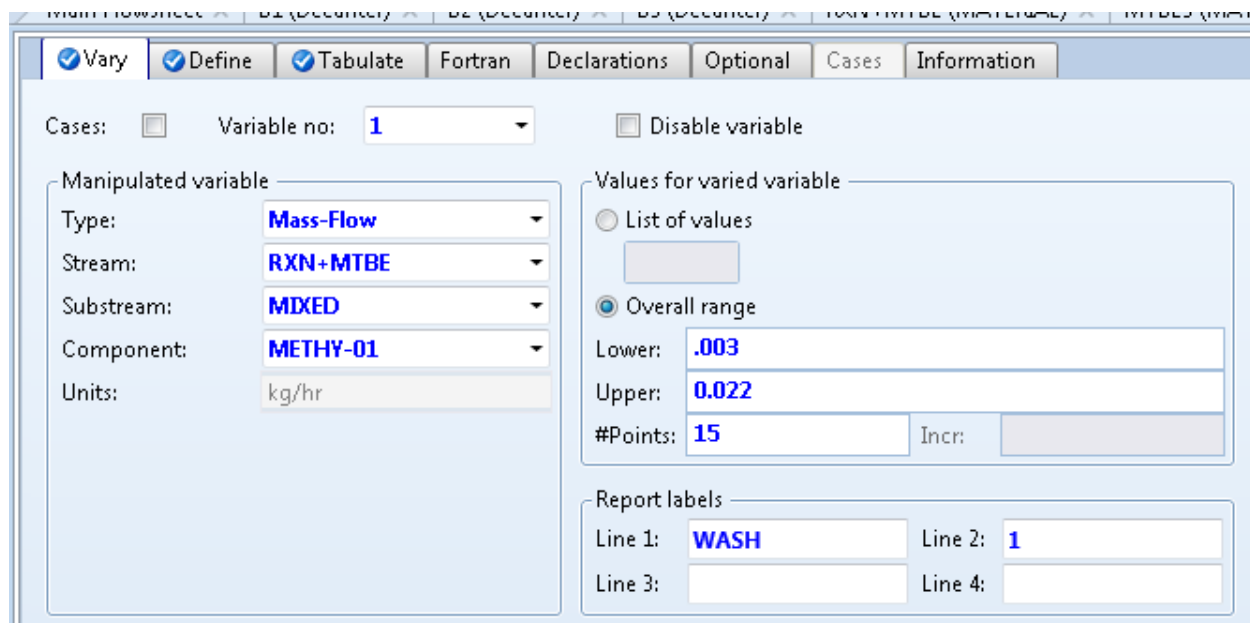


Figure 27: Main menu for sensitivity analysis

3. Select the values or range of test values for the variable. Enter the variable name in labels.
4. Repeat this procedure for each tested variable for the study.

Note: Be careful of the number of points evaluated. Iterations = (#Points)<sup>(#Variables)</sup>.

5. In the **define** menu select the variable that will be reported.

Note: Only defined variables will show up on the sensitivity analysis study.

## SPEARMAN RANK-ORDER CORRELATION TEST

The Spearman rank order correlation is a nonparametric statistical test to measure the association between two ranked variables (Lund & Lund, n.d.) (McDonald, 2014). This test was used to determine whether there was a correlation between pH of the post-reaction mixture and product recovery in the equivalence study. To rank the data, the raw data was inputted into an online website that computed the ranks from raw data (Lowry, n.d.). The website, VassarStats, was created by Richard Lowry, a professor of psychology emeritus at Vassar College. The website contained a free online textbook on inferential statistics and various statistical calculators. The ranks of the raw data can be found in Table 18. The data of first run were not included in the test since the run was not truly one equivalence.

*Table 18: Ranks of raw data*

pH	% Recovered	Rank of pH	Rank of % Recovered
12.5	120	4	2.5
10.9	120	2	2.5
12.6	121	5	4.5
11.4	103	3	1
13.1	140	6	6
10.4	121	1	4.5

The Spearman correlation coefficient was calculated using a premade spreadsheet for Microsoft Excel obtained from the online textbook, *Handbook of Biological Statistics*, by John McDonald, a professor of biological sciences at the University of Delaware (McDonald, 2014). To use the spreadsheet, the independent values (pH) and the dependent values (percent recovery) were inputted, as seen in Figure 28. The spreadsheet automatically plotted the data and calculated the Spearman rank-order correlation coefficient, degrees of freedom, and p-value.

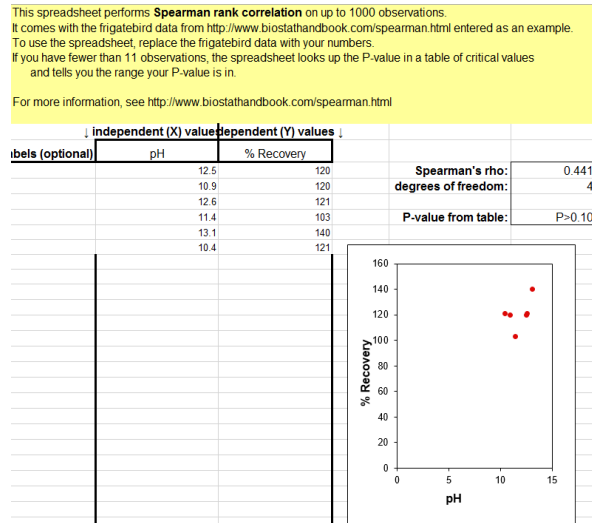


Figure 28: Spearman rank correlation spreadsheet

The Spearman correlation coefficient was calculated to be  $\rho = 0.441$  and the p-value to be  $p > 0.10$ . The significance level was conventionally chosen to be  $\alpha = 0.05$ .

The Spearman correlation coefficient indicates the strength of association of the two variables. A coefficient value of  $\rho = 1$  indicates perfect correlation, a value of  $\rho = 0$  indicates no correlation at all, and a value of  $\rho = -1$  indicates perfect inverse correlation. Values of  $0 < \rho < 1$  and  $-1 < \rho < 0$  indicate some degree of positive and negative correlation, respectively (GraphPad Software, Inc., 2015). The p-value indicates whether the association between the two variables are statistically significant. A p-value greater than the significance level means that there is not enough evidence to show that there is association between the two variables; this does not necessarily mean that there is no association.

## ASPEN INPUT FILES

```

;
;Input Summary created by Aspen Plus Rel. 28.0 at 09:41:19 Fri Apr 3, 2015
;Directory R:\MQP\LE.35Optimized Filename R:\MQP\le.35optimized.inp
;

```

```

IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=C &
VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum' &
MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg' &
MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l' &
PDROP=bar

```

DEF-STREAMS CONVEN ALL

DESCRIPTION "

Chemical Simulation with Metric Units :  
C, bar, kg/hr, kmol/hr, Gcal/hr, cum/hr.

Property Method: NRTL

Flow basis for input: Mole

Stream report composition: Mole flow  
"

DATABANKS 'APV82 PURE28' / 'APV82 AQUEOUS' / 'APV82 SOLIDS' / &  
'APV82 INORGANIC' / NOASPENPCD

PROP-SOURCES 'APV82 PURE28' / 'APV82 AQUEOUS' / 'APV82 SOLIDS' &  
'APV82 INORGANIC'

COMPONENTS

WATER H2O /  
METHY-01 C5H12O-D2 /  
FB

ADA-SETUP

ADA-SETUP PROCEDURE=REL9

SOLVE

RUN-MODE MODE=SIM

FLOWSHEET

BLOCK B1 IN=RXN+MTBE OUT=AQ1 ORG1  
BLOCK B2 IN=AQ1 MTBE2 OUT=AQ2 ORG2  
BLOCK B3 IN=AQ2 MTBE3 OUT=AQ3 ORG3  
BLOCK B4 IN=ORG3 ORG1 ORG2 OUT=ORGTOT

PROPERTIES UNIFAC

PROPERTIES NRTL

STRUCTURES

UNIFAC FB 1010 2 / 1005 1 / 1600 1 / 1710 1 / 3760 &  
1

ESTIMATE ALL

PROP-DATA PCES-1

IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=C &  
VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum' &  
MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg' &  
MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l' &  
PDROP=bar

PROP-LIST RKTZRA

PVAL FB .2344427150

PROP-DATA TDE-1

IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE='N/sqm' TEMPERATURE=K &  
VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum' &  
MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg' &  
MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l' &  
PDROP=bar

PROP-LIST OMEGA / ZC / VC / PC / TC / MW / TB / SG / &  
VLSTD

PVAL FB 0.60398 / 0.263 / 0.4762 / 3568527.9 / 778 / &  
183.27 / 550.5 / 1.309 / .1402000000

PROP-DATA USRDEF

IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=C &  
VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum' &  
MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg' &  
MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l' &  
PDROP=bar

PROP-LIST MW

PVAL FB 188.17

;TDE Aly-Lee ideal gas Cp

; "Heat capacity (Ideal gas)"

PROP-DATA CPIALE-1

IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
MOLE-HEAT-CA='J/kmol-K' HEAT-TRANS-C='kcal/hr-sqm-K' &  
PRESSURE=bar TEMPERATURE=K VOLUME=cum DELTA-T=C &  
HEAD=meter MASS-DENSITY='kg/cum' MOLE-ENTHALP='kcal/mol' &

MASS-ENTHALP='kcal/kg' MOLE-VOLUME='cum/kmol' HEAT=Gcal &  
MOLE-CONC='mol/l' PDROP=bar  
PROP-LIST CPIALEE  
PVAL FB 85471.03 469447.8 -1120.756 256582.5 500.4814 0 &  
8.31447 200 1000

;TDE Watson equation for heat of vaporization  
; "Enthalpy of vaporization or sublimation (Liquid vs. Gas )"

PROP-DATA DHVLT-1  
IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=K &  
VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum' &  
MOLE-ENTHALP='J/kmol' MASS-ENTHALP='kcal/kg' &  
MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l' &  
PDROP=bar  
PROP-LIST DHVLTDEW  
PVAL FB 18.4679 0.5461876 0.1617902 -0.2728796 778 4 255 &  
778

;TDE expansion for liquid molar density  
; "Density (Liquid vs. Gas )"

PROP-DATA DNLEXS-1  
IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=K &  
VOLUME=cum DELTA-T=C HEAD=meter MOLE-DENSITY='kmol/cum' &  
MASS-DENSITY='kg/cum' MOLE-ENTHALP='kcal/mol' &  
MASS-ENTHALP='kcal/kg' MOLE-VOLUME='cum/kmol' HEAT=Gcal &  
MOLE-CONC='mol/l' PDROP=bar  
PROP-LIST DNLEXSAT  
PVAL FB 2.100053 4.778674 1.464926 0.1756092 -0.07657542 &  
0 0 778 6 240 778

;ThermoML polynomials for liquid thermal conductivity  
; "Thermal conductivity (Liquid vs. Gas )"

PROP-DATA KLTMPL-1  
IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=K &

THERMAL-COND='Watt/m-K' VOLUME=cum DELTA-T=C HEAD=meter &  
MASS-DENSITY='kg/cum' MOLE-ENTHALP='kcal/mol' &  
MASS-ENTHALP='kcal/kg' MOLE-VOLUME='cum/kmol' HEAT=Gcal &  
MOLE-CONC='mol/l' PDROP=bar  
PROP-LIST KLTMLPO  
PVAL FB 0.2156676 -0.000222956 0.000000256662 -2.877521E-10 &  
4 200 700

;ThermoML polynomials for vapor thermal conductivity  
; "Thermal conductivity (Gas )"

PROP-DATA KVTMLP-1

IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=K &  
THERMAL-COND='Watt/m-K' VOLUME=cum DELTA-T=C HEAD=meter &  
MASS-DENSITY='kg/cum' MOLE-ENTHALP='kcal/mol' &  
MASS-ENTHALP='kcal/kg' MOLE-VOLUME='cum/kmol' HEAT=Gcal &  
MOLE-CONC='mol/l' PDROP=bar  
PROP-LIST KVTMLPO  
PVAL FB -0.004558092 0.00001715581 0.0000000823644 &  
-3.56068E-11 4 560 1160

;PPDS9 equation for liquid viscosity  
; "Viscosity (Liquid vs. Gas )"

PROP-DATA MULPPD-1

IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=K &  
VISCOSITY='N-sec/sqm' VOLUME=cum DELTA-T=C HEAD=meter &  
MASS-DENSITY='kg/cum' MOLE-ENTHALP='kcal/mol' &  
MASS-ENTHALP='kcal/kg' MOLE-VOLUME='cum/kmol' HEAT=Gcal &  
MOLE-CONC='mol/l' PDROP=bar  
PROP-LIST MULPPDS9  
PVAL FB 0.00002578544 1.971326 2.013121 925.5743 -25.46359 &  
296 770

;ThermoML polynomials for vapor viscosity  
; "Viscosity (Gas )"

PROP-DATA MUVTML-1



IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=K &  
VISCOSITY='N-sec/sqm' VOLUME=cum DELTA-T=C HEAD=meter &  
MASS-DENSITY='kg/cum' MOLE-ENTHALP='kcal/mol' &  
MASS-ENTHALP='kcal/kg' MOLE-VOLUME='cum/kmol' HEAT=Gcal &  
MOLE-CONC='mol/l' PDROP=bar  
PROP-LIST MUVTMLPO  
PVAL FB -0.000000796883 0.0000000238910 -1.501594E-12 &  
-6.475801E-16 4 560 1160

PROP-DATA SIGDIP-1

IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=C &  
VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum' &  
MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg' &  
MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l' &  
PDROP=bar  
PROP-LIST SIGDIP  
PVAL FB 86.10518210 1.222222220 1.28658805E-9 -1.4446487E-9 &  
5.7385765E-10 277.3500000 489.2900000

;TDE Wagner 25 liquid vapor pressure  
; "Vapor pressure (Liquid vs. Gas)"

PROP-DATA WAGN25-1

IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE='N/sqm' TEMPERATURE=K &  
VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum' &  
MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg' &  
MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l' &  
PDROP=bar  
PROP-LIST WAGNER25  
PVAL FB -9.252672 2.853329 -5.430383 -4.391381 15.08766 &  
778 240 778

PROP-DATA NRTL-1

IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr' &  
HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=C &  
VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum' &  
MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg' &  
MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l' &  
PDROP=bar

PROP-LIST NRTL

BPVAL WATER METHY-01 0.0 1106.976400 .3000000000 0.0 0.0 &  
0.0 52.37000000 100.2000000

BPVAL METHY-01 WATER 0.0 686.1436000 .3000000000 0.0 0.0 &  
0.0 52.37000000 100.2000000

STREAM MTBE2

SUBSTREAM MIXED TEMP=25.00000000 PRES=1.000000000  
MASS-FLOW METHY-01 0.01415

STREAM MTBE3

SUBSTREAM MIXED TEMP=25.00000000 PRES=1.000000000  
MASS-FLOW METHY-01 0.01108

STREAM RXN+MTBE

SUBSTREAM MIXED TEMP=25.00000000 PRES=1.000000000  
MASS-FLOW WATER 0.018 / METHY-01 0.01528 / FB 0.00565

BLOCK B4 MIXER

PARAM PRES=1.000000000 NPHASE=1 PHASE=L  
BLOCK-OPTION FREE-WATER=NO

BLOCK B1 DECANTER

PARAM TEMP=35. PRES=1.000000000 LL-METH=GIBBS &  
L2-COMPS=METHY-01 FB L2-CUTOFF=0.3  
BLOCK-OPTION FREE-WATER=NO

BLOCK B2 DECANTER

PARAM TEMP=35. PRES=1.000000000 LL-METH=GIBBS &  
L2-COMPS=METHY-01 FB L2-CUTOFF=0.3  
BLOCK-OPTION FREE-WATER=NO

BLOCK B3 DECANTER

PARAM TEMP=35. PRES=1.000000000 LL-METH=GIBBS &  
L2-COMPS=METHY-01 FB L2-CUTOFF=0.3  
BLOCK-OPTION FREE-WATER=NO

EO-CONV-OPTI

SENSITIVITY MTBE

DEFINE OUTPUT MOLE-FLOW STREAM=ORGTOT SUBSTREAM=MIXED &  
COMPONENT=FB  
TABULATE 1 "OUTPUT"

```
VARY MASS-FLOW STREAM=RXN+MTBE SUBSTREAM=MIXED &  
  COMPONENT=METHY-01 LABEL="WASH" "1"  
RANGE LOWER=".003" UPPER="0.022" NPOINT="15"  
VARY MASS-FLOW STREAM=MTBE2 SUBSTREAM=MIXED &  
  COMPONENT=METHY-01  
RANGE LOWER=".003" UPPER="0.015" NPOINT="15"  
VARY MASS-FLOW STREAM=MTBE3 SUBSTREAM=MIXED &  
  COMPONENT=METHY-01  
RANGE LOWER=".003" UPPER=".011" NPOINT="15"
```

PROPERTY-REPORTS

DISABLE

SENSITIVITY MTBE

```
;  
;  
;  
;  
;
```

## APPENDIX B: DATA

### DATA FOR EXPERIMENTAL RUNS

Table 19: Overview of the data and resulting recoveries

Experiment: Reproduce Results									
Exp Number	Date	Washes	Wash Amounts	Salt Used	Recovery				
1		41922	3 22.00/15.00/11.00	10.0445	5.479				
2		41943	3 22.00/15.00/11.00	10.045	5.851				
No runs 19 or 23 due to lack of other materials (still massed salt)									
Experiment: Property									
Exp Number	Date	Washes	Wash Amounts	Salt Used	Recovery	Property			
3	11/5/2014	3	22.00/15.00/11.00	1.0255	0.046	Un-Reacted Salt Solubility			
25	3/18/2015	1	44g	0	0.372	Water Solubility in MTBE			
26	3/18/2015	3	22.00/15.00/11.00	0	0.655	Water Solubility in MTBE			
Experiment: pH Variation									
Exp Number	Date	Washes	Wash Amounts	Salt Used	Recovery	Base Used	pH	Gel	
4	11/19/2014	3	22.00/15.00/11.00	5.01	N/A	Sodium Bicarbonate	N/A	No	
5	12/5/2014	3	22.00/15.00/11.00	10.074	3.593	Potassium Carbonate	12.4	Yes	
6	12/8/2014	3	22.00/15.00/11.00	10.07	6.077	Potassium Carbonate	12.7	Yes	
7	12/8/2014	3	22.00/15.00/11.00	10.03	5.628	Potassium Carbonate	10.5	Yes	
8	1/20/2015	3	22.00/15.00/11.00	10.034	Emulsion	Potassium Carbonate	9.7	No	
9	1/21/2015	3	22.00/15.00/11.00	10.049	Emulsion	Potassium Carbonate	N/A	No	
10	1/21/2015	3	22.00/15.00/11.00	10.0116	Emulsion	Potassium Carbonate	12.4	No	
11	1/22/2015	3	22.00/15.00/11.00	10.003	Emulsion	Potassium Carbonate	10.5	No	
12	2/15/2015	3	22.00/15.00/11.00	10.0129	N/A	Potassium Carbonate	11.2	Yes	
15	2/20/2015	3	22.00/15.00/11.00	10.0194	4.881	Potassium Hydroxide	10.8	No	
21	3/2/2015	3	22.00/15.00/11.00	10.028	N/A	Potassium Hydroxide	N/A	No	
20	3/2/2015	3	22.00/15.00/11.00	10.01	6.6	Potassium Hydroxide	12.5	No	
22	3/3/2015	3	22.00/15.00/11.00	10.014	6.59	Potassium Hydroxide	10.9	No	
24	3/16/2015	3	22.00/15.00/11.00	10.013	6.63	Potassium Hydroxide	12.6	No	
27	3/18/2015	3	22.00/15.00/11.00	10.046	5.699	Potassium Hydroxide	11.4	No	
28	3/19/2015	3	22.00/15.00/11.00	10.0081	7.673	Potassium Hydroxide	13.1	No	
Expieriment: Temperature									
Exp Number	Date	Washes	Wash Amounts	Salt Used	Recovery	Temperature			
13	2/17/2015	3	3.00/3.00/3.00	10.0108	8.101	25°C			
14	2/17/2015	3	3.00/3.00/3.00	10.127	N/A	25°C			
16	2/21/2015	3	15.28/14.15/11.05	10.017	5.724	35°C			
17	2/23/2015	3	15.28/14.15/11.06	10.04	6.369 / 5.401	35°C			
18	2/26/2015	3	15.28/14.15/11.07	10.0136	6.368	35°C			
29	3/19/2015	3	15.28/14.15/11.08	10.048	7.489	35°C			
30	3/24/2015	3	15.28/14.15/11.08	10.0056	5.913	35°C			

Table 20: Overview of results from all runs

Experiment: Property	
Results	Exp Number
Prefers Aqueous Phase / does not dissolve in only MTBE	3
Recovery of mass with only water and MTBE	25
Higher recovery from multiple washes without salt	26
Experiment: pH Variation	
Details / Results	Exp Number
Sodium could not form a 2 mol solution at room temperature	4
	5
	6
	7
added MTBE of 1st wash to salt reaction mixture while reacting	8
added MTBE of 1st wash to salt reaction mixture while reacting	9
added some of MTBE to salt and then add K <sub>2</sub> CO <sub>3</sub>	10
added salt to K <sub>2</sub> CO <sub>3</sub> and then add some MTBE	11
Determined pH to break Gel	12
Used 85% purity KOH for the 1 eq	15
Flask fell off rotary arm: Run Terminated	21
6.29112 after taking 4.62% water out from the KF	20
5.63612 after taking out water from KF	22
	24
	27
lowered Rotovap temp to 40 C	28
Expieriment: Temperature	
Details/ Results	Exp Number
	13
No Phase Separation from First Wash	14
	16
After allowing to sit in the hood mass went down	17
6.2463 after taking 1.91% water out from the KF test	18
	29
	30

## REPRODUCTION: RUNS 1 – 2

*Table 21: Reproduction runs*

Run	1	2		
mass of ring (g)	3.56			
Mass of flask and ring (g)	138.281			
Mass of Flask (g)	131.028			
Mass of Salt (g)	10.002		10.0045	
Mass of 2M KOH (g)	20.06		20.0097	
pH of reaction	14.3		14	
T of reaction (C)	19.3			
mass of beaker (g)	31.3284			
Mass of MTBE 1 (g)	21.9982		21.9967	
Mass of 400ml beaker & aq phase 1( g)	193.8			
Mass of MTBE 2(g)	14.991		15.078	
Mass of 100ml beaker & aq phase 2 (g)	73			
Mass of MTBE 3(g)	11.0052		11.0047	
Mass of 100ml beaker & aq phase 3 (g)	72.6215		WASH 1	WASH 2
Mass of flask, ring, and product	143.76		145.764	144.9
Mass of product	5.479		7.483	6.619
				5.851

Notes: 5 minutes may not be enough for reaction. The pH of product: 11-12

## UNREACTED SALT SOLUBILITY: RUN 3

Table 22: Unreacted salt solubility

initial salt (g)	1.029
water (g)	15.1791
MTBE (g)	19.993
mixing time (min)	5
settling time (min)	5
initial roto flask + ring (g)	138.15
roto flask+ring+org phase (g)	156.718
final roto flask + ring + salt (g)	138.196
initial beaker for aq phase (g)	50.1683
aq phase (g)	16.1178
salt recovered (g)	0.046
% recovery	4.47036

Notes: salt did not dissolve in solely MTBE when mixed for ~2 minutes. Salt completely dissolved in water/MTBE mixture when mixed for 5 minutes.

## PH STUDY: RUNS 4-7

Table 23: Run 4 with bicarbonate solution.

	Theoretical Calc.	NaHCO <sub>3</sub> Prep	Actual Soln Amt
Salt (g)	5		
Salt (mol)	0.01499925		
NaHCO <sub>3</sub> (mol)	0.01499925	0.1	0.100019046
NaHCO <sub>3</sub> (g)	1.260041998	8.4007	8.4023
NaHCO <sub>3</sub> aq (mol/L)	1	1	0.999660624
Water (L)	0.01499925	0.1	0.100053002
Water (g)	14.99880006	99.997	100.05
pH		8.5	9

Notes:

Sodium bicarbonate could not form the solution at room temperature. Run was terminated.

*Table 24: Runs 5-7 of the pH study at a pH of 12.5 and 10.5*

Run	5	6	7
Mass of flask+ring (g)	138.15	138.15	138.185
Mass of Salt (g)	10.074	10.065	10
Mass of K <sub>2</sub> CO <sub>3</sub> (g)	18.228	18.22	18.2117
KOH volume (mL)	12.2	13	7.8
Mass of MTBE1 (g)	22.007	21.98	21.9702
Mass of MTBE2 (g)	14.99	14.998	15.0312
Mass of MTBE3 (g)	11.006	11.012	10.99
Mass of Product,Flask, Ring (g)	141.743	144.227	143.813
Mass of Product	3.593	6.077	5.628
pH	12.4	12.7	10.5

Notes (5):

When salt and K<sub>2</sub>CO<sub>3</sub> soln mixed, salt clumped up and was gel-like  
after breaking up the clump and mixing for a bit, solution became cloudy and white  
after mixing for +20 minutes, solution became a clear, yellow and there were no clumps

pH was 9.6 after mixing salt and 2M K<sub>2</sub>CO<sub>3</sub>

pH was 9.7 after adding 1 drop of KOH

Product was white, opaque, and viscous

Notes (6):

Product is clear and pale yellow and not viscous



Notes (7):

When salt and 2M K<sub>2</sub>CO<sub>3</sub> mixed, salt clumped and was gel-like. After mixing for +10 minutes, clump was gone, but 2 liquid phase formed: white-opaque layer on top and yellow viscous layer on bottom

Initial pH after mixing salt and 2M K<sub>2</sub>CO<sub>3</sub> was 9.6

Titrations for Runs 5-7

*Table 25: Titration for Run 5*

initial 2M KOH (ml)	final 2M KOH(ml)	amounted 2M KOH added (ml)	pH
22.2	25	2.8	10
15.5	22	6.5	10
12.3	12.5	0.2	10.5
12.5	15.2	2.7	12.4
	TOTAL	12.2	

Table 26: Titration for Run 6

Amount of KOH (ml)	pH
0	9.8
2	10
4	10.4
6	10.7
8	10.7
10	11.1
12	11.7
13	12.9
added 1 ml of DI water	12.8
2 ml DI	12.8
3 ml DI	12.8
4 ml DI	12.7
5 ml	12.7

Table 27: Titration for Run 7

initial 2M KOH (ml)	final 2M KOH(ml)	amounted 2M KOH added (ml)	pH
0	0	0	9.6
10.5	10.6	0.1	9.7
10.6	11	0.4	9.8
11	12.5	1.5	9.9
12.5	12.9	0.4	9.9
12.9	13.4	0.5	10
13.4	15	1.6	10.1
15	16	1	10.2
16	16.6	0.6	10.4
16.6	17.7	1.1	10.6
17.7	18.3	0.6	10.5

GEL AND EMULSION: RUNS 8-12

Table 28: Data for the emulsion and gel solving runs

Run	8	9	10	11
2M K <sub>2</sub> CO <sub>3</sub> added(g)	18.236	18.2174	18.2033	18.2032
Salt Added (g)	10.0024	10.0355	10.0116	10.003
MTBE Wash 1 (g)	22.007	22.006	21.99	22.157
MTBE added to reaction mixture from Wash1 (g)	0	0	8	4

Notes (8):

Emulsion formed after mixing 1st MTBE wash, salt, and K<sub>2</sub>CO<sub>3</sub>. There were 3 separate phases: top was clear, middle was murky, and bottom was clearer

After mixing again for 5min, emulsion was still present

After adding 5 ml of 2M KOH and mixing for 5 min, emulsion was still present

After letting emulsified mixture sit overnight, emulsion did not disappear. Nothing noticeable changed

Run terminated

Notes (9):

Emulsion formed after mixing 1st MTBE wash, salt, and  $K_2CO_3$ . There were 3 separate phases: top was clear, middle was murky, and bottom was clearer

Run terminated

Notes (10):

No emulsion present after mixing some with mtbte. 2 phases: yellow clear layer on top, clear transparent layer on bottom

Emulsion appears after adding the rest of the first wash and mixing for 5 minutes. There were 3 phases: a clear transparent top phase, a yellow translucent middle phase, and a clear translucent bottom phase

Run terminated

Notes (11):

Gel formed when Salt added to  $K_2CO_3$

Gel disappeared when 4g MTBE added

After adding 8.5 ml of KOH and mixing for 5 minutes, an emulsion formed. Top layer is clear, middle layer is yellow and translucent, and bottom layer is clear

Run terminated

Table 29: Data for pH of gel solubility

2M K <sub>2</sub> CO <sub>3</sub> (g)	Salt Added (g)	EXP NUM		
18.237	10.0129	12		
initial 2M KOH (ml)	final 2M KOH(ml)	amounted 2M KOH added (ml)	pH of top layer	pH of bottom layer
0	0	0	10.4	10.4
0	2	2	10.1	10.1
2	4	2	10.2	10.2
4	6	2	10.3	10.3
6	8	2	10.7	10.7
8	10	2	11	11
10	11	1	11.2	11.2

Notes (12):

At 11.2 the gel appeared well dispersed in the solution.

TEMPERATURE STUDY: RUNS 13-14

Table 30: Runs at 25°C and low solvent amounts

EXP NUM	13	14
Flask+Ring mass (g)	138.22	138.21
Salt mass (g)	10.0108	10.127
2M KOH mass (g)	20.013	20.01
MTBE 1 mass (g)	3.006	3.006
ORG1 mass (g)	7.841	N/A
MTBE 2 mass (g)	3.0033	N/A
ORG2 mass (g)	7.737	N/A
MTBE 3 mass (g)	3.005	N/A
Flask, Ring, Product mass (g)	146.321	N/A
Product mass (g)	8.101	N/A

Notes (13):

Long phase separation times with poor boundaries.

Large amounts of aqueous seemed present in organic streams.

Notes (14):

No phase separation in first wash.

Run Terminated.

TEMPERATURE VARIATION: RUNS 16-18 & 29-30

*Table 31: Temperature variation runs*

EXP NUM	16	17	18	29	30
Flask+Ring mass (g)	138.194	138.183	138.181	138.181	138.152
Salt mass (g)	10.017	10.045	10.0136	10.048	10.0056
2M KOH mass (g)	20.01	20.153	20.0537	20.02	20.038
MTBE 1 mass (g)	15.22	15.2856	15.21	15.29	15.2132
ORG1 mass (g)	5.94	-	4.449	6.1539	4.909
MTBE 2 mass (g)	14.19	14.152	14.149	14.145	14.145
ORG2 mass (g)	6.329	-	6.235	7.509	5.948
MTBE 3 mass (g)	11.001	11.021	11.056	11.031	11.005
Flask, Ring, Product mass (g)	143.918	144.552	144.549	145.67	144.065
Product mass (g)	5.724	6.369 / 5.401	6.368	7.489	5.913

Notes (30):

Water bath set for ~60C to ensure only product remains after rotary evaporator.

## EQUIVALENCE STUDY: RUNS 15, 20-22, 24, 27, 28

Table 32: One equivalence run data

EXP NUM	15	20	21	22	24	27	28
Flask+Ring mass (g)	143.023	138.146	-	138.253	138.155	138.212	138.117
Salt mass (g)	10.0194	10.028	-	10.014	10.013	10.046	10.0081
2M KOH mass (g) (Flakes in 14.59 H <sub>2</sub> O)	1.683	15.95	-	15.886	15.8606	15.857	15.864
Organic pH	10.8		-	10.9	12.6	11.2	11.2
Aqueous pH	10.8		-	10.9	12.6	11.4	13.1
MTBE 1 mass (g)	22.197	22.32	-	22.43	22.002	22.158	22.159
ORG1 mass (g)			-	2.224	3.753	3.821	3.635
MTBE 2 mass (g)	15.012	15.18	-	15.092	15.027	14.999	15.01
ORG2 mass (g)			-	5.161	5.747	4.603	5.897
MTBE 3 mass (g)	10.999	11.0147	-	11.01	11.01	10.99	11.038
Product mass (g)	4.881	N/A	-	6.59	6.63	5.257	6.743

Notes (20):

Rotary Evaporator arm fell off, resulting in flask entering distilled water of rota-vap.

Experiment Terminated.

Notes (21):

The reaction vessel valve was open, and the experiment solution was compromised.

Experiment Terminated.



WATER SOLUBILITY STUDY: RUNS 25, & 26

*Table 33: Water solubility runs*

EXP	25	26
water (g)	18.08	18.101
MTBE Wash 1 (g)	22.21	43.828
MTBE Wash 2 (g)	15.05	N/A
MTBE Wash 3 (g)	11.01	N/A
1st wash (g)	0.732	0.372
2nd wash (g)	0.57	N/A
3rd wash (g)	0.655	N/A
% water in MTBE	1.357%	0.849%

# APPENDIX C: MATERIAL SAFETY DATA SHEETS

## POTASSIUM HYDROXIDE



Health	3
Fire	0
Reactivity	2
Personal Protection	J

### Material Safety Data Sheet Potassium hydroxide MSDS

Section 1: Chemical Product and Company Identification	
<b>Product Name:</b> Potassium hydroxide	<b>Contact Information:</b>
<b>Catalog Codes:</b> SLP4096, SLP3085, SLP4900, SLP2071	<b>Sciencelab.com, Inc.</b> 14025 Smith Rd. Houston, Texas 77396
<b>CAS#:</b> 1310-58-3	US Sales: <b>1-800-901-7247</b> International Sales: <b>1-281-441-4400</b>
<b>RTECS:</b> TT2100000	Order Online: <a href="http://ScienceLab.com">ScienceLab.com</a>
<b>TSCA:</b> TSCA 8(b) inventory: Potassium hydroxide	<b>CHEMTREC (24HR Emergency Telephone), call:</b> 1-800-424-9300
<b>CI#:</b> Not available.	<b>International CHEMTREC, call:</b> 1-703-527-3887
<b>Synonym:</b>	<b>For non-emergency assistance, call:</b> 1-281-441-4400
<b>Chemical Name:</b> Potassium Hydroxide	
<b>Chemical Formula:</b> KOH	

Section 2: Composition and Information on Ingredients		
<b>Composition:</b>		
<b>Name</b>	<b>CAS #</b>	<b>% by Weight</b>
Potassium hydroxide	1310-58-3	100
<b>Toxicological Data on Ingredients:</b> Potassium hydroxide: ORAL (LD50): Acute: 273 mg/kg [Rat].		

Section 3: Hazards Identification
<b>Potential Acute Health Effects:</b> Very hazardous in case of skin contact (corrosive, irritant), 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.
<b>Potential Chronic Health Effects:</b> 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 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 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:**

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, acids

**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.

**Fire Fighting Media and Instructions:** Not applicable.

**Special Remarks on Fire Hazards:**

Violent reaction or ignition under appropriate conditions with acids, alcohols, p-bis(1,3-dibromoethyl) benzene, cyclopentadiene, germanium, hyponitrous acid, maleic anhydride, nitroalkanes, 2-nitrophenol, potassium peroxodisulfate, sugars, 2,2,3,3-tetrafluoropropanol, thorium dicarbide. Molten ortho -nitrophenol reacts violently with potassium hydroxide. When potassium hydroxide and tetrachloroethane are heated, a spontaneously flammable gas, chloroacetylene, is formed. When phosphorus is boiled in a solution of potassium hydroxide, phosphine gas is evolved which is spontaneously flammable. 1,2-Dichloroethylene and Potassium hydroxide reaction produces chloroacetylene which is spontaneously flammable in air. Potassium Persulfate and a little Potassium hydroxide and water will ignite. When wet, attacks metals such as aluminum, tin, lead, and zinc, producing flammable hydrogen gas.

**Special Remarks on Explosion Hazards:**

Potentially explosive reaction with bromoform + crown ethers, chlorine dioxide, nitrobenzene, nitromethane, nitrogen trichloride, peroxidized tetrahydrofuran, 2,4,6-trinitrotoluene. Reaction with ammonium hexachloroplatiate(2-) + heat forms heat sensitive explosive product. Potassium hydroxide will cause explosive decomposition of maleic anhydride. Detonation will occur when potassium hydroxide is mixed with n-methyl-nitroso urea and methylene chloride. Nitrogen trichloride explodes on contact with potassium hydroxide.

### 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 ingest. Do not breathe dust. 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 organic materials, metals, acids, moisture.

**Storage:** Keep container tightly closed. Keep container in a cool, well-ventilated area. Do not store above 23°C (73.4°F).

### 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:**

CEIL: 2 (mg/m<sup>3</sup>) from OSHA (PEL) [United States] CEIL: 2 (mg/m<sup>3</sup>) from ACGIH (TLV) [United States] Consult local authorities for acceptable exposure limits.

### Section 9: Physical and Chemical Properties

**Physical state and appearance:** Solid. (Solid pellets.)

**Odor:** Odorless.

**Taste:** Not available.

**Molecular Weight:** 56.11 g/mole

**Color:** White.

**pH (1% soln/water):** 13 [Basic.]

**Boiling Point:** Decomposition temperature: 1384°C (2523.2°F)

**Melting Point:** 380°C (716°F)

**Critical Temperature:** Not available.

**Specific Gravity:** 2.044 (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, hot water. Insoluble in diethyl ether.

#### Section 10: Stability and Reactivity Data

**Stability:** The product is stable.

**Instability Temperature:** Not available.

**Conditions of Instability:** Incompatible materials, dust generation, exposure to moist air or water.

**Incompatibility with various substances:**

Highly reactive with acids. Reactive with organic materials, metals, moisture.

**Corrosivity:**

Extremely corrosive in presence of aluminum, brass, and zinc. Slightly corrosive in presence of copper, of stainless steel(304). Non-corrosive in presence of stainless steel(316).

**Special Remarks on Reactivity:**

Hygroscopic (absorbs moisture from air). When dissolved in water or alcohol or when the solution is treated with acid, much heat is generated. Reacts violently with acids, halogens, halogenated hydrocarbons, maleic anhydride, organic anhydrides, isocyanates, alkylene oxides, epichlorhydrin, aldehydes, alcohols, glycols, phenols, cresols, caprolactum solution. Also incompatible with nitro compounds (nitrobenzene, nitromethane, nitrogen trichloride), organic materials, acid anhydrides, acid chlorides, magnesium, peroxidized tetrahydrofuran, chlorine dioxide, maleic dicarbide, sugars. When wet attacks metals such as aluminum, tin, lead, and zinc.

**Special Remarks on Corrosivity:**

When wet, attacks metals such as aluminum, tin, lead, and zinc, producing flammable hydrogen gas. Severe corrosive effect on brass and bronze.

**Polymerization:** Will not occur.

#### Section 11: Toxicological Information

**Routes of Entry:** Absorbed through skin. Inhalation. Ingestion.

**Toxicity to Animals:** Acute oral toxicity (LD50): 273 mg/kg [Rat].

**Chronic Effects on Humans:**

MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. May cause damage to the following organs: 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), of eye contact (corrosive), of ingestion, .

**Special Remarks on Toxicity to Animals:** Not available.

**Special Remarks on Chronic Effects on Humans:** May affect genetic material based on animal data.

**Special Remarks on other Toxic Effects on Humans:**

Acute Potential Health Effects: Skin: Causes severe skin irritation and burns. Eyes: Causes severe eye irritation and burns. May cause irreversible eye injury. Inhalation: Causes severe irritation and burns of the respiratory tract and mucous membranes. Irritation may lead to chemical pneumonitis Ingestion: Harmful if swallowed. May cause severe and permanent damage to the digestive tract. Causes severe irritation and burns of the gastrointestinal (digestive) tract with abdominal pain, vomiting and possible death. May cause perforation of the digestive tract. Chronic Potential Health Effects: Chronic contact with dilute solutions of potassium hydroxide can cause dermatitis. Inhalation can produce chronic productive cough, and shortness of breath.

### Section 12: Ecological Information

**Ecotoxicity:** Ecotoxicity in water (LC50): 80 mg/l 24 hours [Mosquito Fish].

**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:** : Potassium hydroxide, solid UNNA: 1813 PG: II

**Special Provisions for Transport:** Not available.

### Section 15: Other Regulatory Information

**Federal and State Regulations:**

New York release reporting list: Potassium hydroxide Pennsylvania RTK: Potassium hydroxide Florida: Potassium hydroxide Minnesota: Potassium hydroxide Massachusetts RTK: Potassium hydroxide New Jersey: Potassium hydroxide California Director's List of Hazardous Substances: Potassium hydroxide TSCA 8(b) inventory: Potassium hydroxide CERCLA: Hazardous substances.: Potassium 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 D-1B: Material causing immediate and serious toxic effects (TOXIC). CLASS E: Corrosive solid.

**DSCL (EEC):**

**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.

**Created:** 10/10/2005 08:23 PM

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

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# METHYL TERT-BUTYL ETHER



Health	2
Fire	3
Reactivity	0
Personal Protection	H

## Material Safety Data Sheet Methyl tert-butyl ether MSDS

Section 1: Chemical Product and Company Identification	
<b>Product Name:</b> Methyl tert-butyl ether	<b>Contact Information:</b>
<b>Catalog Codes:</b> SLM2152	<b>Sciencelab.com, Inc.</b> 14025 Smith Rd. Houston, Texas 77396
<b>CAS#:</b> 1634-04-4	US Sales: <b>1-800-901-7247</b> International Sales: <b>1-281-441-4400</b>
<b>RTECS:</b> KN5250000	Order Online: <a href="http://ScienceLab.com">ScienceLab.com</a>
<b>TSCA:</b> TSCA 8(b) inventory: Methyl tert-butyl ether	<b>CHEMTREC (24HR Emergency Telephone), call:</b> 1-800-424-9300
<b>CI#:</b> Not available.	<b>International CHEMTREC, call:</b> 1-703-527-3887
<b>Synonym:</b>	<b>For non-emergency assistance, call:</b> 1-281-441-4400
<b>Chemical Name:</b> Methyl tert-Butyl Ether	
<b>Chemical Formula:</b> C5-H12-O	

Section 2: Composition and Information on Ingredients		
<b>Composition:</b>		
<b>Name</b>	<b>CAS #</b>	<b>% by Weight</b>
Methyl (tert-)butyl ether	1634-04-4	100
<b>Toxicological Data on Ingredients:</b> Methyl tert-butyl ether: ORAL (LD50): Acute: 4000 mg/kg [Rat]. 5960 mg/kg [Mouse]. VAPOR (LC50): Acute: 23576 ppm 4 hour(s) [Rat].		

Section 3: Hazards Identification
<b>Potential Acute Health Effects:</b> Extremely hazardous in case of eye contact (irritant), of ingestion. Very hazardous in case of skin contact (irritant), of inhalation. Hazardous in case of skin contact (permeator). Inflammation of the eye is characterized by redness, watering, and itching. Skin inflammation is characterized by itching, scaling, reddening, or, occasionally, blistering.
<b>Potential Chronic Health Effects:</b> Extremely hazardous in case of eye contact (irritant), of ingestion. Very hazardous in case of skin contact (irritant), of inhalation. Hazardous in case of skin contact (permeator). CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance is toxic to lungs, the nervous system, mucous membranes. Repeated or prolonged exposure to the substance can produce target organs damage. Repeated or prolonged inhalation of vapors may lead to chronic respiratory irritation.

Section 4: First Aid Measures
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**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. Do not use an eye ointment. Seek medical attention.

**Skin Contact:**

After contact with skin, wash immediately with plenty of water. Gently and thoroughly wash the contaminated skin with running water and non-abrasive soap. Be particularly careful to clean folds, crevices, creases and groin. Cold water may be used. Cover the irritated skin with an emollient. If irritation persists, seek medical attention. Wash contaminated clothing before reusing.

**Serious Skin Contact:**

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

**Inhalation:** Allow the victim to rest in a well ventilated area. Seek immediate medical attention.

**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. Loosen tight clothing such as a collar, tie, belt or waistband. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek immediate medical attention.

**Serious Ingestion:** Not available.

**Section 5: Fire and Explosion Data**

**Flammability of the Product:** Flammable.

**Auto-Ignition Temperature:** 224°C (435.2°F)

**Flash Points:** CLOSED CUP: -28°C (-18.4°F).

**Flammable Limits:** LOWER: 2.5% UPPER: 15.1%

**Products of Combustion:** These products are carbon oxides (CO, CO<sub>2</sub>).

**Fire Hazards in Presence of Various Substances:** Flammable in presence of open flames and sparks.

**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.

**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:** Not available.

**Special Remarks on Explosion Hazards:** Not available.

**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. Eliminate all ignition sources.

### Section 7: Handling and Storage

**Precautions:**

Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapour/spray. 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.

**Storage:**

Flammable materials should be stored in a separate safety storage cabinet or room. Keep away from heat. Keep away from sources of ignition. Keep container tightly closed. Keep in a cool, well-ventilated place. Ground all equipment containing material. A refrigerated room would be preferable for materials with a flash point lower than 37.8°C (100°F).

### 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:** Not available.

### Section 9: Physical and Chemical Properties

**Physical state and appearance:** Liquid.

**Odor:** Characteristic. (Strong.)

**Taste:** Not available.

**Molecular Weight:** 88.15 g/mole

**Color:** Clear Colorless.

**pH (1% soln/water):** Not available.

**Boiling Point:** 55.2°C (131.4°F)

**Melting Point:** -109°C (-164.2°F)

**Critical Temperature:** Not available.

**Specific Gravity:** 0.7405 (Water = 1)

**Vapor Pressure:** 245 mm of Hg (@ 20°C)

**Vapor Density:** 3.1 (Air = 1)

**Volatility:** 100% (v/v).

**Odor Threshold:** Not available.

**Water/Oil Dist. Coeff.:** Not available.

**Ionicity (in Water):** Not available.

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

**Solubility:**

Soluble in methanol, diethyl ether. Partially soluble in cold water.

#### Section 10: Stability and Reactivity Data

**Stability:** The product is stable.

**Instability Temperature:** Not available.

**Conditions of Instability:** Not available.

**Incompatibility with various substances:** Not available.

**Corrosivity:** Non-corrosive in presence of glass.

**Special Remarks on Reactivity:** Not available.

**Special Remarks on Corrosivity:** Not available.

**Polymerization:** No.

#### Section 11: Toxicological Information

**Routes of Entry:** Dermal contact. Eye contact. Inhalation. Ingestion.

**Toxicity to Animals:**

WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE. Acute oral toxicity (LD50): 4000 mg/kg [Rat]. Acute toxicity of the vapor (LC50): 23576 ppm 4 hour(s) [Rat].

**Chronic Effects on Humans:** The substance is toxic to lungs, the nervous system, mucous membranes.

**Other Toxic Effects on Humans:**

Extremely hazardous in case of ingestion. Very hazardous in case of skin contact (irritant), of inhalation. Hazardous in case of skin contact (permeator).

**Special Remarks on Toxicity to Animals:** Not available.

**Special Remarks on Chronic Effects on Humans:** Not available.

**Special Remarks on other Toxic Effects on Humans:** Not available.

#### 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 more toxic.

**Special Remarks on the Products of Biodegradation:** Not available.

#### Section 13: Disposal Considerations

**Waste Disposal:**

#### Section 14: Transport Information

**DOT Classification:** Class 3: Flammable liquid.  
**Identification :** Methyl tert-butyl ether : UN2398 PG: II  
**Special Provisions for Transport:** Not available.

### Section 15: Other Regulatory Information

**Federal and State Regulations:**

Pennsylvania RTK: Methyl tert-butyl ether Massachusetts RTK: Methyl tert-butyl ether TSCA 8(b) inventory: Methyl tert-butyl ether SARA 313 toxic chemical notification and release reporting: Methyl tert-butyl ether CERCLA: Hazardous substances.: Methyl tert-butyl ether

**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. R38- Irritating to skin. R41- Risk of serious damage to eyes.

**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.

**Created:** 10/10/2005 08:23 PM

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# POTASSIUM CARBONATE



Health	2
Fire	0
Reactivity	1
Personal Protection	E

## Material Safety Data Sheet Potassium carbonate, anhydrous MSDS

### Section 1: Chemical Product and Company Identification

<b>Product Name:</b> Potassium carbonate, anhydrous	<b>Contact Information:</b>
<b>Catalog Codes:</b> SLP4780, SLP1951, SLP3760, SLP5575	Sciencelab.com, Inc. 14025 Smith Rd. Houston, Texas 77396
<b>CAS#:</b> 584-08-7	US Sales: 1-800-901-7247 International Sales: 1-281-441-4400
<b>RETECS:</b> TS7750000	Order Online: <a href="http://ScienceLab.com">ScienceLab.com</a>
<b>TSCA:</b> TSCA 8(b) inventory: Potassium carbonate, anhydrous	<b>CHEMTREC (24HR Emergency Telephone), call:</b> 1-800-424-9300
<b>CI#:</b> Not available.	<b>International CHEMTREC, call:</b> 1-703-527-3887
<b>Synonym:</b> Salt of Tartar	<b>For non-emergency assistance, call:</b> 1-281-441-4400
<b>Chemical Name:</b> Potassium Carbonate	
<b>Chemical Formula:</b> K <sub>2</sub> CO <sub>3</sub>	

### Section 2: Composition and Information on Ingredients

#### Composition:

Name	CAS #	% by Weight
Potassium carbonate, anhydrous	584.08-7	100

**Toxicological Data on Ingredients:** Potassium carbonate, anhydrous: ORAL (LD50): Acute: 1870 mg/kg [Rat].

### Section 3: Hazards Identification

#### Potential Acute Health Effects:

Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of eye contact (corrosive).

#### Potential Chronic Health Effects:

CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance is toxic to mucous membranes. The substance may be toxic to skin, eyes. 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. 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. 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.

**Serious Inhalation:** Not available.

**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:** Not applicable.

**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.

**Fire Fighting Media and Instructions:** Not applicable.

**Special Remarks on Fire Hazards:** Not available.

**Special Remarks on Explosion Hazards:** Not available.

### Section 6: Accidental Release Measures

**Small Spill:**

Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

**Large Spill:**

Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system.

### Section 7: Handling and Storage

**Precautions:**

Keep container dry. Do not ingest. Do not breathe dust. 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, metals, acids.

**Storage:**

Hygroscopic. Keep container tightly closed. Keep container in a cool, well-ventilated area. Do not store above 25°C (77°F).

### 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. Lab coat. 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. 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:** Not available.

### Section 9: Physical and Chemical Properties

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

**Odor:** Odorless.

**Taste:** Not available.

**Molecular Weight:** 138.21 g/mole

**Color:** White.

**pH (1% soln/water):** Not available.

**Boiling Point:** Decomposes.

**Melting Point:** 891°C (1635.8°F)

**Critical Temperature:** Not available.

**Specific Gravity:** 2.29 (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:** Soluble in cold water.

### Section 10: Stability and Reactivity Data

**Stability:** The product is stable.  
**Instability Temperature:** Not available.  
**Conditions of Instability:** Dust generation, moist air, water, incompatible materials  
**Incompatibility with various substances:**  
Reactive with oxidizing agents, metals, acids. Slightly reactive to reactive with moisture.  
**Corrosivity:** Non-corrosive in presence of glass.  
**Special Remarks on Reactivity:**  
Hygroscopic. Reacts with water to evolve heat. Incompatible with KCO, chlorine trifluoride, calcium oxide, and magnesium.  
**Special Remarks on Corrosivity:** Not available.  
**Polymerization:** Will not occur.

### Section 11: Toxicological Information

**Routes of Entry:** Eye contact. Inhalation. Ingestion.  
**Toxicity to Animals:** Acute oral toxicity (LD50): 1870 mg/kg [Rat].  
**Chronic Effects on Humans:**  
Causes damage to the following organs: mucous membranes. May cause damage to the following organs: skin, eyes.  
**Other Toxic Effects on Humans:**  
Hazardous in case of skin contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of eye contact (corrosive).  
**Special Remarks on Toxicity to Animals:** Not available.  
**Special Remarks on Chronic Effects on Humans:** Not available.  
**Special Remarks on other Toxic Effects on Humans:**  
Acute Potential Health Effects: Skin: Causes severe skin irritation. Eyes: It is severely irritating to the eyes and its mucous membranes. It may cause corneal injury. It may cause burns and loss of vision. It may cause permanent damage. The amount of tissue damage depends on the length of contact. Ingestion: It causes gastrointestinal irritation with nausea, vomiting, abdominal pain, swollen glottis, increased respiration, and possible burns to the lips, tongue, oral mucosa, hypopharynx, stomach, or esophagus. It may affect the cardiovascular system(circulatory collapse), urinary system, and metabolism. Inhalation: Causes respiratory tract and mucous membrane irritation. Exposure can cause coughing, chest pains, and difficulty breathing (dyspnea).

### 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:** Not a DOT controlled material (United States).

**Identification:** Not applicable.

**Special Provisions for Transport:** Not applicable.

#### Section 15: Other Regulatory Information

**Federal and State Regulations:** TSCA 8(b) inventory: Potassium carbonate, anhydrous

**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-2B: Material causing other toxic effects (TOXIC). CLASS E: Corrosive solid.

**DSCL (EEC):**

R22- Harmful if swallowed. R37/38- Irritating to respiratory system and skin. R41- Risk of serious damage to eyes. S2- Keep out of the reach of children. 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. S46- If swallowed, seek medical advice immediately and show this container or label.

**HMS (U.S.A.):**

**Health Hazard:** 2

**Fire Hazard:** 0

**Reactivity:** 1

**Personal Protection:** E

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

**Health:** 2

**Flammability:** 0

**Reactivity:** 0

**Specific hazard:**

**Protective Equipment:**

Gloves. Lab coat. 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.

**Created:** 10/10/2005 11:40 AM

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

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# SODIUM BICARBONATE



Health	1
Fire	0
Reactivity	0
Personal Protection	E

## Material Safety Data Sheet Sodium bicarbonate MSDS

Section 1: Chemical Product and Company Identification	
<b>Product Name:</b> Sodium bicarbonate	<b>Contact Information:</b>
<b>Catalog Codes:</b> SLS3241, SLS2446, SLS3868	Sciencelab.com, Inc.
<b>CAS#:</b> 144-55-8	14025 Smith Rd.
<b>RTECS:</b> VZ0950000	Houston, Texas 77396
<b>TSCA:</b> TSCA 8(b) inventory: Sodium bicarbonate	US Sales: 1-800-901-7247
<b>Cl#:</b> Not available.	International Sales: 1-281-441-4400
<b>Synonym:</b> Baking Soda; Bicarbonate of soda; Sodium acid carbonate; Monosodium carbonate; Sodium hydrogen carbonate; Carbonic acid monosodium salt	Order Online: <a href="http://Sciencelab.com">Sciencelab.com</a>
<b>Chemical Name:</b> Sodium Bicarbonate	CHEMTREC (24HR Emergency Telephone), call: 1-800-424-9300
<b>Chemical Formula:</b> NaHCO <sub>3</sub>	International CHEMTREC, call: 1-703-527-3887
	For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients		
<b>Composition:</b>		
<b>Name</b>	<b>CAS #</b>	<b>% by Weight</b>
Sodium bicarbonate	144-55-8	100
<b>Toxicological Data on Ingredients:</b> Not applicable.		

Section 3: Hazards Identification
<b>Potential Acute Health Effects:</b> Slightly hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.
<b>Potential Chronic Health Effects:</b> CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. Repeated or prolonged exposure is not known to aggravate medical condition.

Section 4: First Aid Measures
<b>Eye Contact:</b> 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 if irritation occurs.

**Skin Contact:**

Wash with soap and water. Cover the irritated skin with an emollient. Get medical attention if irritation develops. Cold water may be used.

**Serious Skin Contact:** Not available.

**Inhalation:**

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

**Serious Inhalation:** Not available.

**Ingestion:**

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 if symptoms appear.

**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:** Not applicable.

**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.

**Fire Fighting Media and Instructions:** Not applicable.

**Special Remarks on Fire Hazards:** When heated to decomposition it emits acrid smoke and irritating fumes.

**Special Remarks on Explosion Hazards:** Not available.

**Section 6: Accidental Release Measures****Small Spill:**

Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

**Large Spill:**

Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system.

**Section 7: Handling and Storage****Precautions:**

Do not ingest. Do not breathe dust. If ingested, seek medical advice immediately and show the container or the label. Keep away from incompatibles such as acids.

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

**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:** Safety glasses. Lab coat. 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. 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:** Not available.

**Section 9: Physical and Chemical Properties**

**Physical state and appearance:** Solid.

**Odor:** Odorless.

**Taste:** Saline. Alkaline.

**Molecular Weight:** 84.01g/mole

**Color:** White.

**pH (1% soln/water):** Not available.

**Boiling Point:** Not available.

**Melting Point:** Not available.

**Critical Temperature:** Not available.

**Specific Gravity:** Density: 2.159 (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:**

Soluble in cold water. Slightly soluble in alcohol. Solubility in Water: 6.4, 7.6, 8.7, 10.0, 11.3, 12.7, 14.2, 16.5, 19.1 g/100 solution at 0, 10, 20, 30, 40, 50, 60, 80, and 100 deg. C, respectively. Solubility in Water: 6.9, 8.2, 9.6, 11.1, 12.7, 14.5, 16.5, 19.7, and 23.6 g/100g water at 0, 10, 20, 30, 40, 50, 60, 80, 100 deg. C, respectively.

**Section 10: Stability and Reactivity Data**

**Stability:** The product is stable.

**Instability Temperature:** Not available.

**Conditions of Instability:** Incompatible materials, Moisture. Stable in dry air, but slowly decomposes in moist air.

**Incompatibility with various substances:** Reactive with acids.

**Corrosivity:** Non-corrosive in presence of glass.

**Special Remarks on Reactivity:**

Reacts with acids to form carbon dioxide. Dangerous reaction with monoammonium phosphate or a sodium-potassium alloy.

**Special Remarks on Corrosivity:** Not available.

**Polymerization:** Will not occur.

### Section 11: Toxicological Information

**Routes of Entry:** Inhalation. Ingestion.

**Toxicity to Animals:** Acute oral toxicity (LD50): 3360 mg/kg [Mouse].

**Chronic Effects on Humans:** Not available.

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

**Special Remarks on Toxicity to Animals:** Not available.

**Special Remarks on Chronic Effects on Humans:**

Sodium Bicarbonate as produced genetic effects in rats (unscheduled DNA synthesis). However, no effects have been found in humans.

**Special Remarks on other Toxic Effects on Humans:**

**Acute Potential Health Effects:** Skin: May cause mild skin irritation. Eyes: May cause mild eye irritation. Inhalation: May cause respiratory tract irritation. Symptoms may include coughing and sneezing. Ingestion: Symptoms of overexposure to Sodium Bicarbonate include thirst, abdominal pain, gastroenteritis, and inflammation of the digestive tract. **Chronic Potential Health Effects:** Skin: Repeated or prolonged skin contact may cause irritation, drying or cracking of the skin. Ingestion and Inhalation: Chronic toxicity usually occurs within 4 to 10 days following ingestion of very large amounts. Repeated or prolonged ingestion or inhalation of large amounts may cause metabolic abnormalities, and sodium retention. Metabolic abnormalities such as acidosis, hypernatremia, hypochloremia, alkalosis, hypocalcemia, or sodium retention may affect the blood, kidneys, respiration (cyanosis, apnea secondary to metabolic acidosis or pulmonary edema), and cardiovascular system (tachycardia, hypotension). Severe toxicity may also affect behavior/central nervous system/nervous system. Neurological changes may result from metabolic abnormalities. These may include fatigue, irritability, dizziness, mental confusion, paresthesia, seizures, tetany, cerebral edema. **Medical Conditions Aggravated by Exposure:** Persons with pre-existing skin conditions might have increased sensitivity. Predisposing conditions that contribute to a mild alkali syndrome include, renal disease, dehydration, and electrolyte imbalance, hypertension, sarcoidosis, congestive heart failure, edema, or other sodium retaining conditions.

### 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:** Not a DOT controlled material (United States).

**Identification:** Not applicable.

**Special Provisions for Transport:** Not applicable.

#### Section 15: Other Regulatory Information

**Federal and State Regulations:** TSCA 8(b) inventory: Sodium bicarbonate

**Other Regulations:** Not available.

**Other Classifications:**

**WHMIS (Canada):** Not controlled under WHMIS (Canada).

**DSCL (EEC):**

This product is not classified according to the EU regulations. Not applicable.

**HMS (U.S.A.):**

**Health Hazard:** 1

**Fire Hazard:** 0

**Reactivity:** 0

**Personal Protection:** E

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

**Health:** 1

**Flammability:** 0

**Reactivity:** 0

**Specific hazard:**

**Protective Equipment:**

Gloves. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Safety glasses.

#### Section 16: Other Information

**References:** Not available.

**Other Special Considerations:** Not available.

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