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# Design and Fabrication of a Distillation Apparatus for Traditional Alcohol Micro-distilleries

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# LETTER OF APPROVAL

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a project report entitled **"Design and Fabrication of a Distillation Apparatus for Traditional Alcohol Micro-distilleries"** submitted by **Sachin Saud, Sanjiv Pahari, Saroj Basnet, Madan Ghimire** in partial fulfillment of the requirements for the Bachelor's Degree in Mechanical Engineering.

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# ABSTRACT

Nepali traditional liquor ‘Raksi’ is a culturally significant alcoholic beverage predominantly composed of ethanol. Traditionally, it is prepared using crude distillation equipment, which are likely to induce inefficiency, inconsistent quality, and presence of poisonous impurities such as methanol and amyl alcohol. The project aimed at designing, developing, and testing an improved distillation equipment to enhance the recovery, safety, and consistency of the distillation operation. The enhanced design comprises reflux system, three bubble cap trays, continuous condensation system and real time concentration and volume measurement. Experimental findings showed an increased ethanol concentration from 61% upto 90% and recovery ratio from 0.22 to 0.75, while the content of amyl alcohol decreased from 116.9 g/100L to 70.7 g/100L. Methanol was absent in the distillate, further enhancing the quality and safety of the final product. The project successfully addressed the limitations of traditional distillation methods, providing a scalable and efficient solution for small-scale manufacturers. Future work can be focused on further optimizing the system for different feedstocks, integrating advanced control systems for automation, and exploring bioethanol blending.

Keywords: *fermentation, ethanol, batch distillation, reflux, bubble cap trays, amyl alcohol*

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# LIST OF ACRONYMS AND ABBREVIATIONS

**3D** :Three Dimensions
**AOAC** :Association of Official Analytical Chemists
**CAD** :Computer-Aided Design
**CFD** :Computational Fluid Dynamics
**CMO** :Constant Molal Overflow
**CNN** :Cable News Network
**DFTQC** :Department of Food Technology and Quality Control
**FTIR** :Fourier Transform Infrared Spectroscopy
**IR** :Infrared
**LMTD** :Logarithmic Mean Temperature Difference
**LPG** :Liquefied Petroleum Gas
**LVC** :Less Volatile Component
**ml** :Milliliter
**MVC** :More Volatile Component
**NTP** :Normal Temperature and Pressure
**Rs** :Rupees
**SG** :Specific Gravity
**SS** :Stainless Steel
**VLE** :Vapor-Liquid Equilibrium
**VOF** :Volume of Fluid

# CHAPTER 1: INTRODUCTION

## 1.1 Background

In many parts of the world, people have been making and enjoying drinks made from fermented grains for centuries, not just for fun, but also for cultural, nutritional, and even medicinal reasons. These drinks can have health benefits like helping with digestion or providing antioxidants. Although cereals lack certain essential components (such as amino acids), fermentation is a simple and cost-effective method to enhance their nutritional value, sensory characteristics, and functional properties [1]. The rice based alcoholic beverages are known to have provided several health-promoting benefits such as antioxidant, anti-hypertensive, anti-diabetes, and anti-cancer activities [2]. They also contain vitamins, minerals, proteins, organic acids, and other nutritional components. Beer, Chyang, Raksi, Sake, Bouza, Pito, and Burukutu are some of the cereal-based alcoholic beverages consumed around the world [3].

Raksi is a homemade traditional beverage which has been produced and drank since early century. It is a very strong drink that can be a little cloudy in color or clear as well which is made from millet (Kodo), rice and other grains. Raksi now ranks as 41st [4] most delicious drinks world wide, in CNN's list of the world's 50 most delicious drinks, has high commercial value in Nepali community and outside Nepal [5].

Figure 1.1: Traditional raksi distillation

The artisanal creation of Raksi involves a careful distillation process of fermented mash known as Jaand. Using Phonsi, a copper still vessel containing the fermented mash, alcohol vapor condenses when it touches a cooler surface. This process is precisely managed with the innovative Phonsi, Paini, Nani, and Bata setup (Figure 1.2 and Figure 1.1).

Alcoholic distillation relies on the different boiling points of alcohol (78.5°C) [2] and water (100°C) at NTP. When a liquid containing ethanol is heated between 78.5°C and 100°C, the resulting vapor, when condensed, will have a higher concentration of ethanol. This principle allows the separation and increase of alcohol content through controlled heating and condensation.

The distillation process is meticulously executed. During this process, water and other volatile substances evaporate and pass through the small openings of the paini. These vapors then condense on the cool surface of the bata, and the condensed liquid collects in the nani. To ensure the best results, the water in the bata is regularly replaced, particularly when its temperature surpasses 45°C[6]. It's important to note that as the frequency of water changes increases, the alcohol content in the final distillate tends to decrease.

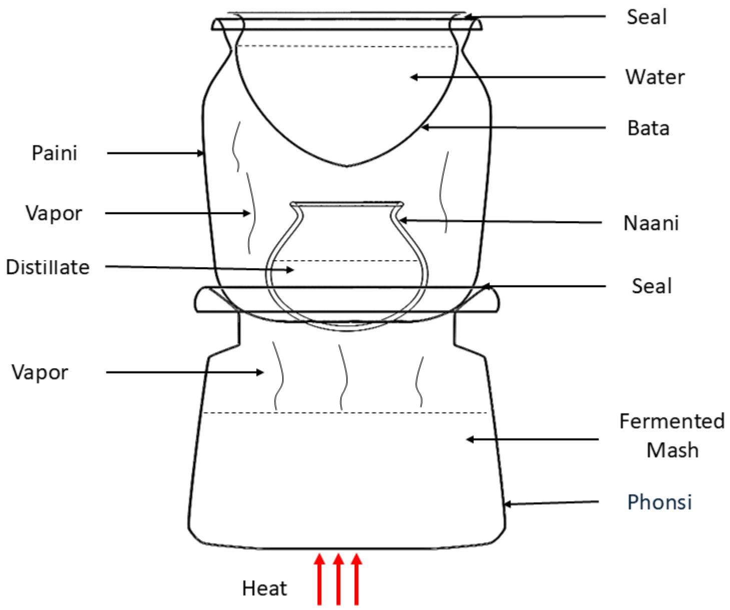


Figure 1.2: Traditional raksi distillation setup

In Nepal, making liquor without a license is not allowed under the Liquor Act, 2031[7]. Even if someone has a license, they must follow strict rules and conditions. However, under the act, people can make a small amount of alcohol or liquor for personal use without needing a permit.

The Nepalese government is also working on new laws to regulate the production, sale, and purchase of local raksi. They are even planning to brand and promote raksi as a unique local product.

### 1.1.1 International Market for Local Ethnic Alcohol

In the fiscal year, the Government of Nepal generated revenue of Rs. 30.41 billion from alcohol and Rs. 31 billion from beer sales [8]. Nepal can also benefit from the commercialization of its ethnic alcoholic beverages. Ethnic alcohols have a significant market presence around the globe, as evidenced by some of the well-known ethnic beverages from specific countries, as follows:

- **Soju (South Korea)**: The global soju market is estimated to reach approximately $7.6 billion by 2024, growing at a rate of 2.54% annually, fueled by demand from Asia and North America [9] [10].
- **Sake (Japan)**: The global sake market is valued at $9.76 billion in 2024 and is expected to grow to $12.02 billion by 2028, with a CAGR of 5.4 [11].
- **Baijiu (China)**: Baijiu remains the largest alcoholic drink category in China, with a market value around $40 billion globally [12].
- **Kesar Kasturi (India)**: While specific 2024 market data is sparse, Kesar Kasturi continues to grow in niche international markets, particularly in regions with significant Indian diaspora.

### 1.1.2 Types of Locally Produced Alcohol in Nepal

- **Aila**: A distilled alcohol used by the Newars, Madh by Tharus, and Daru in southern Nepal [13].
- **Raksi**: A general term for traditionally distilled alcohol.
- **Tongba**: The traditional, indigenous drink of the Limbu people and other Kirati communities, as well as many ethnic groups in Nepal. It is a home-brewed fermented beer, drunk by mixing with hot water. Native to eastern Nepal.
- **Chhaang**: A sweet-tasting, home-brewed beer primarily consumed by Sherpas. Known by different names in various communities: Ji by Tamangs, Thon by Newars, Phee by Thakalis, Jand by Gurungs and Kiratis, Muna by Majhis, and Janra by Tharus.
- **Tin Pani**: A traditional distilled alcohol made by changing the condensing water three times.
- **Arac**: A drink made from wheat or rice, used in medieval Nepal.
- **Thon**: A term used by Newars for a fermented drink.
- **Jaad**: Traditional, home-brewed beer.
- **Nigar**: A term used in eastern Nepal, similar to Jaad.

- **Mada**: Distilled spirits from the hilly and Himalayan regions of Eastern Rukum.

### 1.1.3 Alcohol Production by ethnicity

Alcohol plays a significant role in various rituals, especially those influenced by Tantric practices [14]. Some examples include:

- **Sherpas**: Alcohol is used extensively in Sherpa weddings and festivals. It is also given to new mothers as part of a ritual called Dejyang. In business settlements, alcohol is known as Chhongjyang.
- **Newars**: During the *Ha Thon* festival to worship Swyeta Bhairab, Samayabji and Aila are distributed as blessings. Alcohol is also part of the Sagan ritual, and it is typically served by women during gatherings and festivals (*Bhoj*).
- **Tharus**: Alcohol is offered to deities known as Deuryar during weddings. It is also part of the hair-cutting ritual in Falgun (February-March) to mark the ritual's initiation. Drinking and dancing are integral to Tharu culture.
- **Kirat**: In Kirat culture, a marriage proposal is only accepted if the groom sends alcohol on three occasions: Sodhani, Multheki, and Bhakah. Alcohol is used in various rituals and as an offering to gods and goddesses.
- **Tamang**: For Tamang marriages, the groom is expected to send 12 or 18 bottles of liquor to the bride's family, a practice called Chukunlah Pong. Alcohol is also offered during funeral rituals, and the daughter brings alcohol to serve the mourners.
- **Magar**: In the Magar community, after marriage, the couple must bring wine and a goat's leg to the bride's home, known as Duran.
- **Gurung**: Similar to the Kirat community, the Gurung marriage begins when the groom sends alcohol to the bride's family. Alcohol is also offered during funeral ceremonies.

**Mercaptans**, also known as *thiols*, are organic compounds containing a sulfur-hydrogen (-SH) group attached to a carbon atom (R-SH). The *R* group can be an alkyl or aryl group, making mercaptans a broad class of compounds. They are known for their strong, often unpleasant odor, which can be compared to that of rotten cabbage or garlic. **Examples**: *methyl mercaptan* ($CH_3SH$), *ethyl mercaptan* ($C_2H_5SH$), and *butyl mercaptan* ($C_4H_9SH$).

In distillation processes, mercaptans can be a byproduct of fermentation and may contaminate the final product. Their presence in alcohol distillation is undesirable due to their foul odor and potential toxicity. Removing mercaptans is essential for improving the quality of the distilled product.

**Amyl alcohol**, also known as *pentanol*, is a type of alcohol with the chemical formula $\mathbf{C_5H_{11}OH}$. It exists in several isomeric forms, but the most common one is *1-amyl alcohol*. It is a colorless liquid with a strong, unpleasant odor. Amyl alcohol is typically found in small quantities in the fermentation process of alcohol.

## 1.2 Problem Statement

Traditional distillation processes commonly used in Nepal suffer from several significant issues, including leakage, low production yield, inconsistent product quality (both in quantity and concentration), and chemical contamination from substances such as amyl alcohol, methanol and mercaptan compounds. Additionally, these processes lack the proper separation of the distillate into its key components: the head, heart, and tail fractions. These shortcomings not only reduce the efficiency and safety of the distillation process but also compromise the quality of the final product.

## 1.3 Objectives

### 1.3.1 Main Objective

The main objective is to analyze the traditional Nepali alcohol distillation process, identify its inefficiencies, and subsequently design and fabricate an improved distillation apparatus to enhance the overall efficiency, yield, and quality of the distilled product.

### 1.3.2 Secondary Objectives

1. Identify areas for improvement in the traditional design that contributes to inefficiencies and fabricate the improved and optimal design of the distiller.
2. To increase the purity of ethanol using stage-wise batch separation distillation column.
3. To minimize the amount of methanol and amyl alcohol content in the product.

## 1.4 Scope of the Project

1. The study of the existing batch distillation system paves the way for further research and optimization in previously overlooked areas of batch distillation systems.
2. The modified distillation system will economically support local producers, restaurant and entrepreneurs by increasing production rates.

3. Investigate the potential of bioethanol production and its blending for sustainable energy applications.
4. The optimized system can be utilized in distillation of different other products like water, perfume and spirit.

## 1.5 Feasibility Analysis

### 1.5.1 Economic Feasibility

The economic feasibility of the project is evaluated by considering several key factors, including costs based on the apparatus, sensors, and other equipment. We found that it can be built within a price range of Rs. 52,000. The energy operation cost is supposed to be around Rs. 265 for one cycle. Although the price may change with design changes, the enhanced efficiency will support local alcohol producers, and help reduce production time and effort.

### 1.5.2 Technical Feasibility

The distillation system can be built smoothly because the necessary sensors and raw materials are easily available. Using simulation tools like ANSYS makes the project more feasible, as it helps analyze and optimize the design. These tools allow for detailed modeling, improving our understanding of how the system works. Engineers test the design to ensure it meets key requirements, such as ethanol production, energy efficiency, and reliability. If any technical issues come up during development, they are fixed through design improvements and troubleshooting.

### 1.5.3 Operational Feasibility

The project demonstrates strong operational feasibility through its practical implementation approach. The distillation system features a simplified design that scales down industrial distillation principles to a compact batch micro-distillery format.

## 1.6 System Requirements

### 1.6.1 Hardware Requirements

- Aluminum tape, Temperature Sensors
- Power Source (LP Gas, Stove)
- Cooling System (Pipe, Pump, Connectors, Ball Valve)
- Battery, Potentiometer
- Beaker, Alcoholmeter, Measuring Cylinder

- Stopwatch
- Gaskets
- Nuts, Bolts, Washers

### 1.6.2 Software Requirements

- SOLIDWORKS: Design the structre of existing distiller and model the improved final structure.
- ANSYS: Simulate flow of vapor inside the distillation column.
- MATLAB: Calculate reflux ratio, condenser length, power, ethanol, and water vaporization rate.

# CHAPTER 2: LITERATURE REVIEW

In the central and eastern Himalayas, traditionally people use a cake called Murcha (Yeast), a white to cream coloured starter culture cake to ferment a variety of substrates, including the seeds of finger millet (Kodo; Scientific name: *Eleusine coracana*) , maize, rice, wheat, bajra, sweet potato, ginger or even Rhododendron flower petals to produce sweet-sour alcoholic drinks called Jaand [15].

Common traditional homebrewed alcoholic beverages found in Nepal are of two major types, distilled liquors(local raksi) and non-distilled fermented beverages(Jaand, Chhyang, Tongba) from grains, fruits, and sugar. In Nepal, people enjoy a local brew, mash called Jaand. This drink is made by fermenting different grains. It is then transformed into a stronger alcoholic drink called Raksi, which is like a clear, unaged brandy. To make Raksi, fermented mash is distilled in a pot still, concentrating the alcohol. So, Jaand is the base, and Raksi is the stronger alcoholic beverage derived from it [16].
A cross-sectional study conducted across 16 districts of Nepal analyzed 284 samples of traditionally homebrewed alcoholic beverages to assess ethanol concentrations. The study categorized the samples into distilled (e.g., local raksi) and non-distilled (e.g., Jand, Chhyang, Tumba) types. Results showed that distilled beverages had a median ethanol concentration of 14.0% (IQR: 10.0–19.0%), ranging from 3% to 40%, whereas non-distilled beverages had a median of 5.2% (IQR: 3.5–9.8%), with concentrations ranging from 1% to 18.9% [17]. In a study conducted in Chandannath, Jumla, methanol was detected in 2 out of 4 traditionally fermented alcoholic beverage samples. Specifically, local raksi (sample-2) contained 10.050 ppm of methanol, while local apple cider (sample-4) contained 13.721 ppm. Despite the presence of methanol, the concentrations were below toxic levels, highlighting the need for broader quantification efforts to ensure consumer safety [18]. Contamination by chemical substances including amyl alcohol, methanol, and mercaptan compounds has been reported [2].

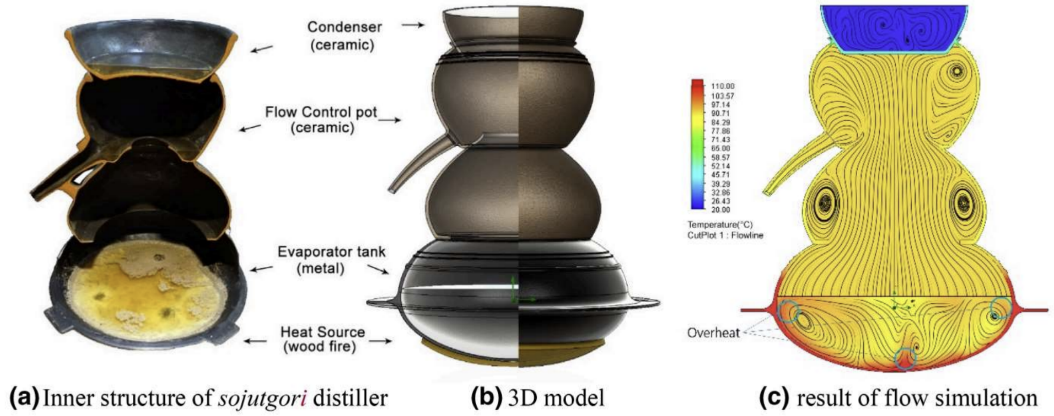
The distillate is categorized into different *paani* levels based on how many times the condensing water is changed before taking out the distillate from the collector. The different *paani* levels and their properties are as follows:

- ***Ek Paani***: *Ek Paani* refers to the alcohol prepared by changing the condensing water only once. The alcohol produced generally has a higher concentration of ethanol and stronger flavors.

- ***Dui Paani***: *Dui Paani* refers to the alcohol prepared by changing the condensing water twice. The alcohol produced has a lower ethanol concentration than *Ek Paani*.
- ***Teen Paani***: *Teen Paani* refers to the alcohol prepared by changing the condensing water thrice. The alcohol produced has a lower ethanol concentration than *Dui Paani* and much less flavor.
- ***Chaar Paani***: *Chaar Paani* refers to the alcohol prepared by changing the condensing water four times. The alcohol produced has a lower ethanol concentration than *Teen Paani* and much less flavor. At this stage, the beverage is much dilated than *Ek Paani*.
- ***Paanch Paani***: *Paanch Paani* refers to the alcohol prepared by changing the condensing water five times. The alcohol produced has a very low ethanol concentration. The drink is often prepared for those who prefer a much-diluted drink.

This goes upto *Nau Paani*, water changed 9 times. As we go up, the ethanol concentration decreases and the volume of distillate obtained increases, and also the the distillate becomes more cloudy.

There are several kind of traditional beverage produced in different locations in the world. They vary from each other according to their taste, odor, source of raw material, and process. Mostly these traditional beverages differ from each other according to the production process which is mainly contributed by the structure and efficiency of the production process. There are only a few studies done on the process of production of these kinds of traditional beverages which creates the situation of difficulty in promotion and growth of such valuable drinks. The preparation of the Raksi resembles one of the popular Korean traditional drinks '*Soju*' which is manufactured in '*Sojutgori*'. A research has been done to investigate the relationship between the form and composition of the Korean traditional distiller, *sojutgori* (Figure 2.1), which has retained its historical integrity despite evolving market demands [19]. Temperature fluctuations and fluid velocity impact the formation of vortices during distillation, and controlling these vortices can reduce residence time dispersion of ethanol particles, boost outlet flow speed, and effectively discharge vaporized ethanol particles. The research proposed innovative design modifications (Figure 2.3) that enhanced distillation efficiency. This research has been the key inspiration for our project.



**(a)** Inner structure of *sojutgori* distiller **(b)** 3D model **(c)** result of flow simulation

Figure 2.1: Inner Structure and Analysis result of the Korean traditional distiller *sojutgori*
(Adapted from [19])

Figure 2.2: Final model of *sojutgori*
(Adapted from [19])

The conventional production of Raksi involves rudimentary distillation techniques that are often energy-inefficient and yield inconsistent concentration. During distillation, water and alcohol vapors are carefully separated. Heat causes them to evaporate, rising through the paini's small holes. These vapors then cool against the bata's cold surface, turning back into liquid and collecting in the nani. To keep things efficient, the bata's water is regularly changed, especially when it gets hot (over 45°C)[6]. Interestingly, the more often the water is changed, the less alcohol ends up in the final product.

Distillation is a method for separating two or more liquid compounds on the basis of boiling-point differences. The boiling point of a mixture is a function of the vapor pressures of the various components in the liquid mixture. As a liquid is heated, its kinetic energy increases; more molecules move into the gaseous state, thereby increasing the vapor pressure. Therefore, the prediction on column efficiency to separate the ethanol from the mixtures relies on the fact that mass and heat transfer between the liquid and vapor phases [19]. In addition to it unstable temperature control and cooling structures lead to strong undesirable flavors, including raw material odor, wake odor, and burnt odor. It has been noted that the temperature distribution in the fermented wash, influenced by the direct fire heating method and the distiller's design and materials, affects the process [20]. Research is ongoing to assess how different heat sources and the structural properties impact distillation efficiency. Numerous studies suggest that computational fluid dynamics is a valuable tool for these investigations [21].

Bubble cap trays are well-studied and reliable distillation internals, particularly effective at handling low liquid loads where few alternatives exist. Their design ensures stable vapor-liquid contact through risers and caps, making them suitable for efficient separation even under varying operating conditions [22].

Multistage binary batch distillation is a separation process that involves multiple equilibrium stages to enhance the separation of a binary mixture in a batch operation. A single equilibrium stage often fails to achieve both the desired distillate purity and sufficiently low bottoms concentration [23] . To enhance separation, a distillation column is positioned above the re-boiler.

In multistage distillation, the distillate ($x_D$) and bottoms ($x_W$) compositions do not maintain equilibrium. Consequently, the Rayleigh equation cannot be directly solved without establishing a functional relationship between $x_D$ and $x_W$. This correlation is determined through stage-by-stage mass balance calculations. Assuming minimal holdup in trays, the condenser, and the accumulator, a dynamic mass and energy balance can be applied to stage $j$ and the column's top section, simplifying to:

**Input = Output**

Since accumulation effects are negligible outside the reboiler, the following equations describe system behavior at any time $t$:

$$V_{j+1} = L_j + D \tag{2.1}$$

$$V_{j+1} y_{j+1} = L_j x_j + D x_D \tag{2.2}$$

$$Q_c + V_{j+1} H_{j+1} = L_j h_j + D h_D \tag{2.3}$$

where:

- $V$, $L$, and $D$ are the vapor, liquid, and distillate molar flow rates (mol/s)
- $y_j$ and $x_j$ represent the vapor and liquid mole fractions at stage $j$
- $H_j$ and $h_j$ denote the vapor and liquid specific enthalpies (J/mol)
- $Q_c$ is the condenser heat duty (W)

These equations resemble those used for the rectifying section in continuous distillation, with the key distinction that they account for time-dependent behavior. Assuming constant molal overflow (CMO), vapor and liquid flow rates remain uniform across all stages, rendering the energy balance unnecessary.

$$y_{j+1} = \frac{L}{V}x_j + \left(1 - \frac{L}{V}\right)x_D \tag{2.4}$$

At any given moment, the equations plots as a straight line on a y-x diagram, where the slope is given by $\frac{L}{V}$ and the intersection with the $y = x$ line occurs at $x_D$. Since batch distillation involves variations in either $x_D$ or $\frac{L}{V}$ over time, the operating line continuously shifts throughout the process.

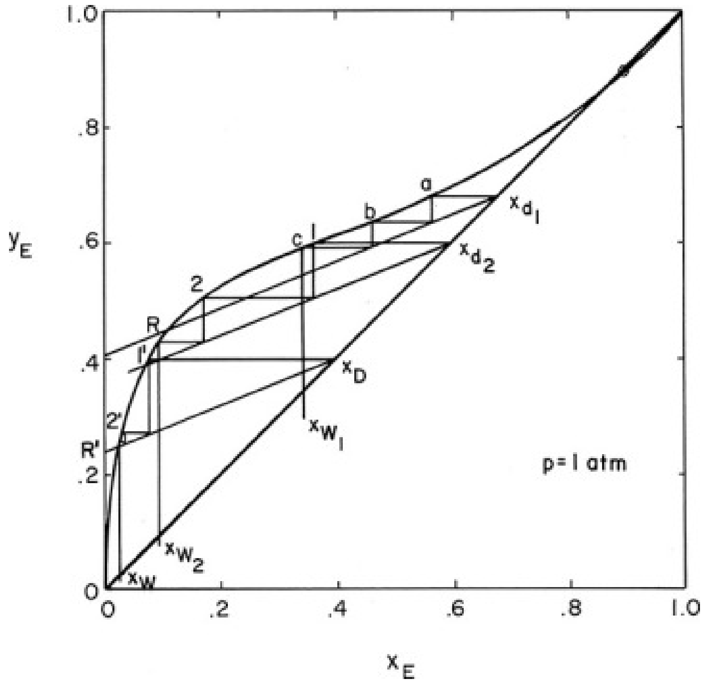


Figure 2.3: McCabe-Thiele diagram for multistage batch distillation with constant L/D (Adapted from [23])

A common approach in batch distillation is to maintain a constant reflux ratio while allowing $x_D$ to change. This method aligns with a simple batch operation where $x_D$ varies over time. In this situation, reyleigh equation is used to find the amount of residue and average purity of distillate collected for different range of instantaneous purity.

$$\ln\left(\frac{W_i}{W_f}\right) = \int_{X_{wf}}^{X_{wi}} \frac{X_d}{X_d - X_\omega} \tag{2.5}$$

The mass balance for a batch distillation process is given by:

The average distillate composition is given by:

$$X_{d,\text{avg}} = \frac{W_i X_{Wi} - W_f X_{Wf}}{W_i - W_f} \tag{2.6}$$

where:

- $W_i$ = Initial amount of liquid
- $W_f$ = Final amount of liquid
- $X_{Wi}$ = Initial mole fraction
- $X_{Wf}$ = Final mole fraction

The relationship between $x_D$ and $x_W$ is determined through a stage-by-stage McCabe-Thiele analysis. The operating equation is plotted on a McCabe-Thiele diagram for multiple $x_D$ values. By stepping off the specified number of equilibrium stages along each operating line starting from $x_D$, the corresponding $x_W$ value can be found.

The McCabe-Thiele analysis provides $x_W$ values for different $x_D$ values, enabling the calculation of $\frac{1}{(x_D - x_W)}$. The integral can be evaluated using numerical methods, such as Simpson's rule , or through graphical integration. Once $x_W$ values are established for several $x_D$ values, the standard batch distillation procedure applies. The final distillate composition $W_{\text{final}}$ is derived from the average distillate composition $x_{D_{\text{avg}}}$, and the total distillate $D_{\text{total}}$. If $x_{D_{\text{avg}}}$ is predefined, an iterative trial-and-error approach is required.

### Two Common Modes of Operation

- **Constant Distillate Composition** ($x_D$)
  - The reflux ratio changes over time.
  - This mode is more challenging to implement as it requires a composition sensor with rapid response capabilities.
- **Constant Reflux Ratio** ($R$)
  - This mode is equivalent to maintaining a constant distillate rate.
  - The distillate composition varies over time.

  - Easier to implement due to the availability of fast-responding flow sensors.
- **Optimal Control**
  - Both the reflux ratio and distillate composition vary over time.
  - The goal is to maximize the amount of distillate, minimize operation time, or maximize profit.

This research seeks to investigate the operational principles and limitations of traditional Nepali alcohol distillers, which are commonly used in rural and household settings. By thoroughly analyzing their design, materials, and distillation performance, the study aims to identify key areas for improvement and propose a novel, efficient distillation system that enhances alcohol yield, purity, and safety while remaining accessible and affordable for local producers.

# CHAPTER 3: METHODOLOGY

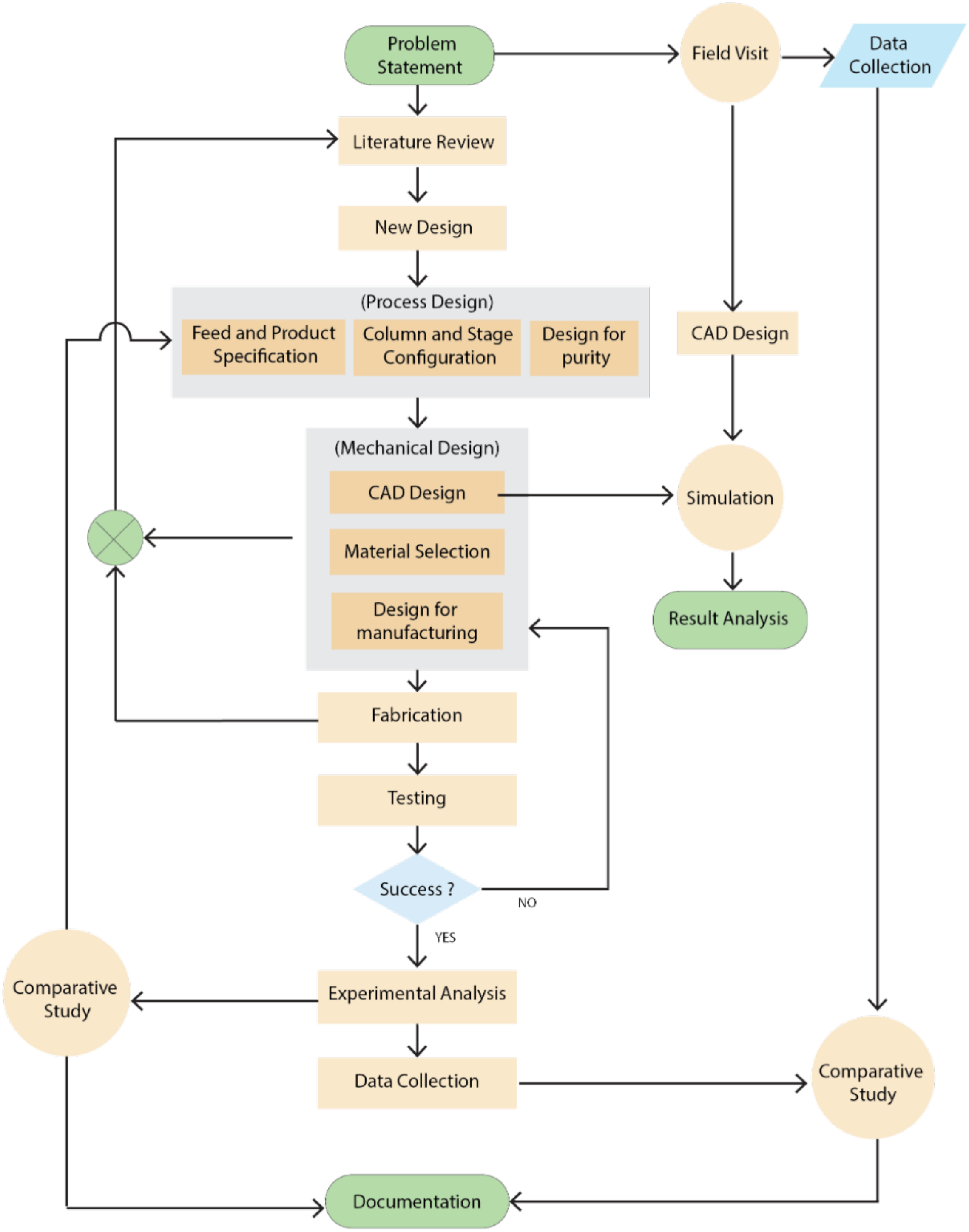


Figure 3.1: Methodology Flowchart

## 3.1 Flowchart Explanation

**Problem Statement:** Define the issue that needs to be addressed.
**Field Visit & Data Collection:** Gather necessary information through observations and research.
**Literature Review:** Study existing research to understand current solutions.
**New Design:** Propose a new conceptual design.
**Process Design:**

- **Feed and Product Specification:** Defining input and output parameters.
- **Column and Stage Configuration:** Setting up process units.
- **Design for Purity:** Ensuring product quality.

**Mechanical Design:**

- **CAD Design:** Creating 3D models.
- **Material Selection:** Choosing appropriate materials.
- **Design for Manufacturing:** Ensuring manufacturability.

**Simulation & Result Analysis:** Testing the design virtually.
**Fabrication & Testing:** Building and evaluating the physical prototype.
**Success Check:**

- **If NO:** Revise the design and repeat testing.
- **If YES:** Proceed to experimental analysis.

**Experimental Analysis & Data Collection:** Validate performance.
**Comparative Study:** Compare with existing solutions.
**Documentation:** Report the findings and conclusions.

## 3.2 Study of working principle of existing traditional distiller

During our visit to a local alcohol production facility, we observed and recorded various parameters critical to the distillation process. We meticulously measured the dimensions of the equipment used, ensuring accurate assessment of their size and surface areas. Additionally, we monitored temperatures at multiple key points, including the external surface temperature of the utensils and the internal temperature of the liquid contained within them. To enhance measurement accuracy, we utilized both a conventional thermometer and a thermal gun, allowing us to compare readings and account for potential deviations.

Furthermore, we recorded the temperature variations of the cooling water in the condenser, as well as the molasses and distillate at different process stages. These observations provided valuable insights into the complex dynamics of alcohol distillation, emphasizing the role of heat transfer, cooling mechanisms, and overall system efficiency.

## 3.3 Parameters Analyzed During the Field Study

1. **Batch Processing Time measurements:** Evaluating the time required for each concentration batch to complete the distillation cycle.
2. **Temperature Profiling:** Systematic measurement and comparison of temperatures at different stages, including external utensil surfaces, liquid contents, and condenser cooling water.
3. **Water Levels in Traditional Distillation Systems:** Assessing the impact of varying water levels on process efficiency and product yield.
4. **Previous Liquid Composition Report Analysis:** Reviewing and analyzing past reports on liquid composition to understand variations in raw material properties and their influence on distillation performance.

## 3.4 Schematic Diagram

### 3.4.1 General Industrial Distillation System

A general industrial distillation column consists of multiple trays or packing material to enhance the separation of components. The primary components of this column include:

- **Rectifying Section**: The upper part of the column where vapor rises and becomes enriched in the more volatile component.
- **Feed Entry**: The location where the liquid mixture is introduced.
- **Reboiler**: Provides heat at the bottom to generate vapor.
- **Condenser**: Cools the vapor at the top, converting it into a liquid.
- **Reflux Drum**: Stores part of the condensed liquid, which is returned to the column to improve separation.
- **Distillate**: The purified product collected at the top of the column.

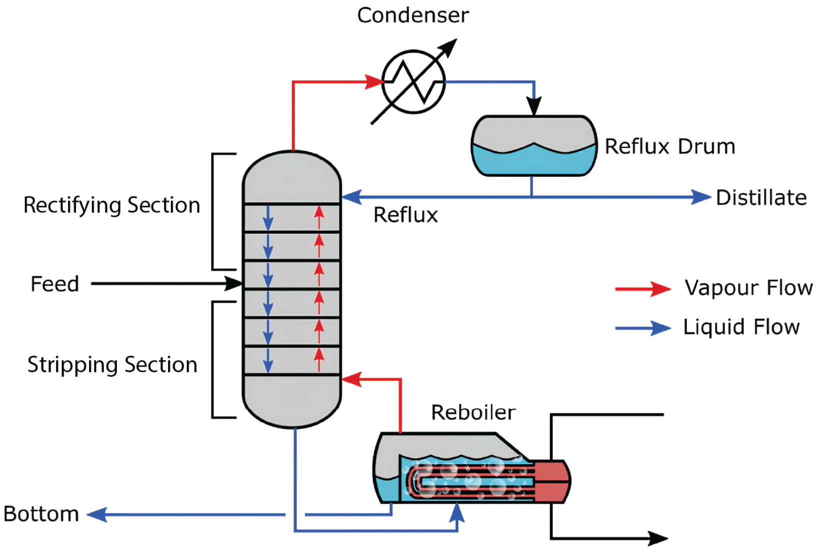


Figure 3.2: General Industrial Distillation Column

The working principle of an industrial distillation column is based on continuous operation, where the feed continuously enters, and the separated components exit from the top and bottom.

### 3.4.2 Distillation System for Micro Distillery

A micro distillery column operates similarly but is designed for small-scale batch distillation. Key differences include:

- **Boiler**: Heats the feed directly to generate vapors.
- **Reflux Condenser**: A smaller condenser that returns part of the vapor as liquid to improve efficiency.
- **Main Condenser**: Cools the final distillate before collection.
- **Coolant System**: Uses a water cooled system to condense vapors efficiently.

This type of distillation is more suited for craft distilleries, laboratories, and small-scale ethanol production.

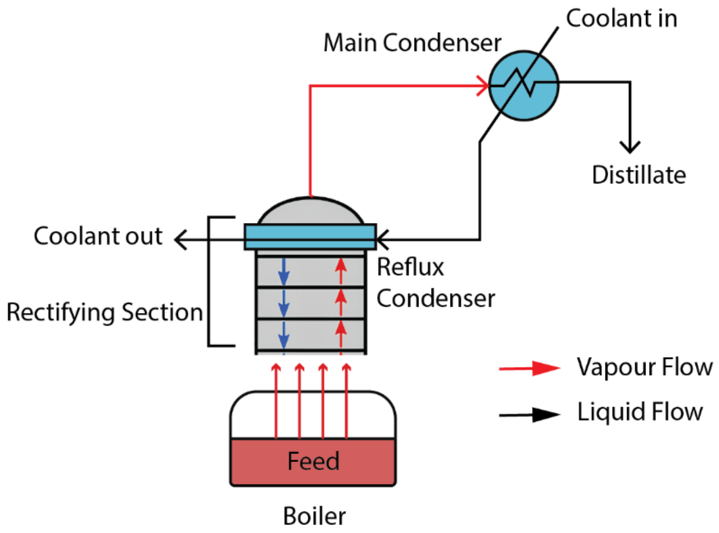


Figure 3.3: Distillation Column for Micro Distillery

## 3.5 Process design

As discussed above in the literature review section, a typical strategy in batch distillation involves keeping the reflux ratio constant while allowing $x_D$ to fluctuate over time. This approach aligns with a basic batch operation where $x_D$ changes as distillation progresses. The relationship between $x_D$ and $x_W$ is established through a stage-by-stage McCabe-Thiele analysis. The operating equation is represented on a McCabe-Thiele diagram for various $x_D$ values. By successively stepping through the required number of equilibrium stages along each operating line, starting from $x_D$, the corresponding $x_W$ can be determined. Reversely for a fixed reflux ratio number trays can be calculated for different input purity tracing back the operating line on the diagram.

### 3.5.1 Number of stages ($N$):

Number of trays can be calculated using Fenske equation. It uses the dsired purity, inital concentration in mixture to calculate number of trays required.

The Fenske equation is given by:

$$N_{\min} = \frac{\log\left(\frac{x_d(1-x_w)}{x_w(1-x_d)}\right)}{\log\alpha} \tag{3.1}$$

where:

- $N_{\min}$ = Minimum number of theoretical equilibrium stages

- $x_D$ = Mole fraction of the more volatile component (MVC) in the distillate
- $x_W$ = Mole fraction of the MVC in the bottoms (residue)
- $\alpha$ = Relative volatility of MVC to less volatile component (LVC)

It is the number of minimum theoretical equilibrium stages.

### 3.5.2 Number of Trays

$$\text{Number of trays } (N) = N_{\text{th}} - \text{(Reflux condenser)} - \text{(Still pot)} \tag{3.2}$$

### 3.5.3 Initial Purity for different number of trays:

After calculating number of stages we choose a reflux ratio as per our requirement or choose optimum relfux ratio and then calculate the purity for different number of trays for same reflux ratio. Fore example, if initial concentration is $X_{wi} = 20\%$ and we fix a reflux ratio(R) to 2.7 then we can calculate the purity for different number of trays using mecheb- Thele Method for specific pressure. (for now lets take **Pressure** ($P$): 0.89 atm)

Table 3.1: Stage vs Purity

| **No. of Stages** | **Initial Purity** |
|---|---|
| 7 | 80% |
| 5 | 70% |
| 4 | 50% |
| 3 | 35% |
| 2 | 25% |
| 1 | 23% (just still pot / Flash Batch Distillation) |

We can choose the stages as per our purity requirement.

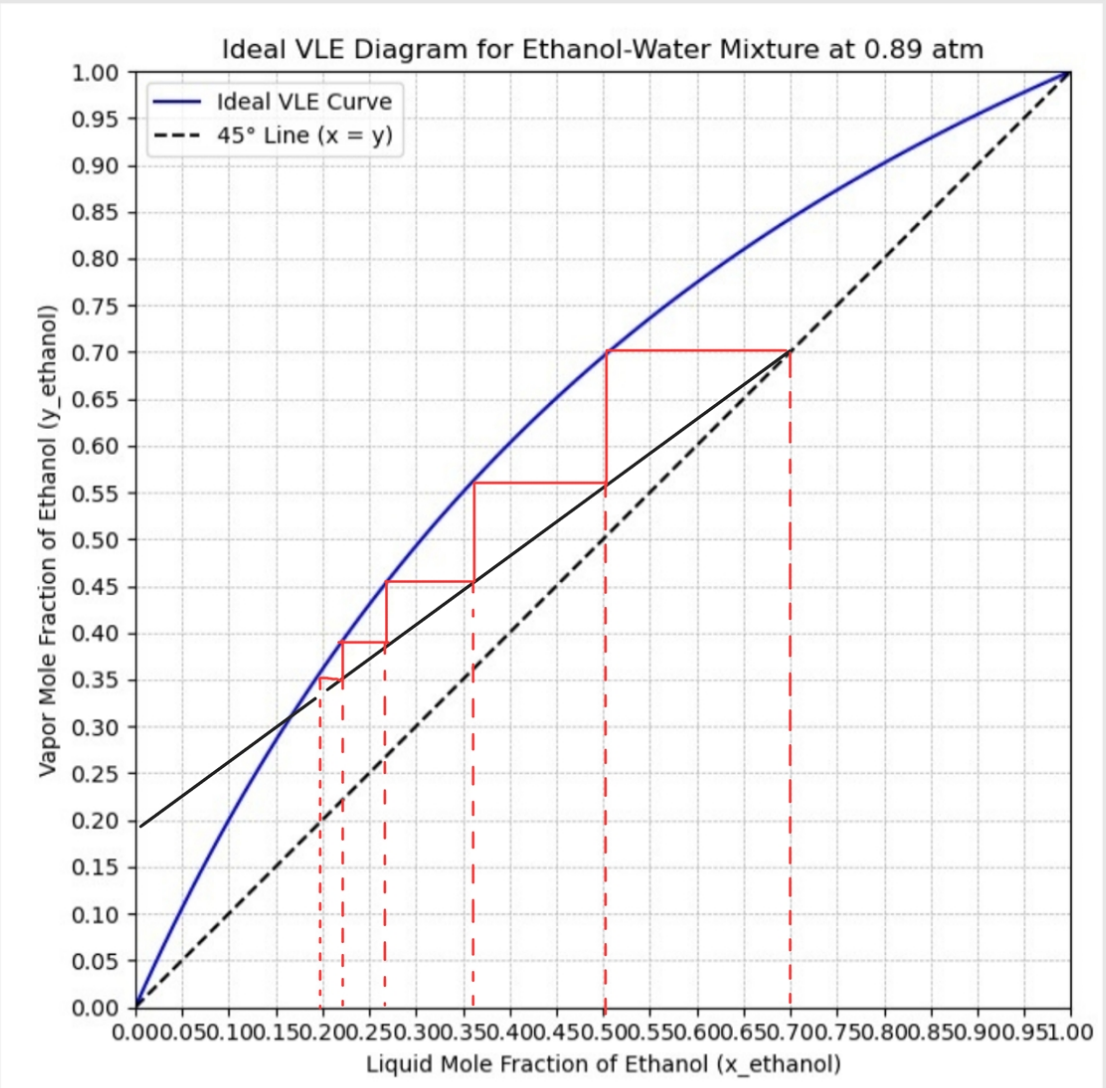


Figure 3.4: Ideal VLE Diagram for Ethanol-Water

### 3.5.4 Column Height and Tray Spacing

During the design of the distillation column, we generally have the limitation of the total height. So, the spacing between the tray depends upon the total height and can be calculated by the following equation.

Depending on the height of the column, calculate the spacing between the trays:

$$\text{Tray Spacing} = \frac{\text{Height}}{N} \tag{3.3}$$

### 3.5.5 Selection of stage tray

The tray used for the stages is the bubble cap tray which has the Murphree efficiency of 60% - 80% (for low to moderate vapor and liquid flow rates).

Murphree Efficiency Formula

$$EM = \frac{y_{n+1} - y_n}{y^* - y_n} \times 100 \tag{3.4}$$

### 3.5.6 Diameter of the column:

For a quick estimation of the distillation column diameter, use the following empirical formula based on vapor load:

$$D = K \times \sqrt{\frac{V}{\rho_V}} \tag{3.5}$$

Where:

- $D$ = Column diameter (m)
- $V$ = Vapor flow rate (m³/s)
- $\rho_V$ = Vapor density (kg/m³)
- $K$ = Empirical constant (depends on tray type, typically 0.5 - 1.0)

Large diameter is not preferable in distillation column.

## 3.6 Thermodynamic and Mechanical design

### 3.6.1 Boiling point calculation

At an elevation of 1350 meters [24] (Kathmandu Valley), the boiling points of water and ethanol are calculated using the Clausius-Clapeyron equation:

$$T_b = \left( \frac{1}{\frac{1}{T_{b,\text{sea}}} - (\frac{R}{L_v}) \ln(\frac{P}{P_0})} \right) - 273.15 \quad {}^\circ\text{C} \tag{3.6}$$

where;

- $T_b$ is the boiling point ($^\circ C$),
- $P$ is the atmospheric pressure at altitude, $P_0 = 101325$ Pa (sea-level pressure),
- $R = 8.314$ J/(mol·K) (universal gas constant), and
- $L_v = 2260 \times 10^3$ J/kg (latent heat of vaporization of water) and $L_v = 838 \times 10^3$ J/kg for ethanol.

Based on this, the boiling point of water is found to be $95.65^\circ C$, while that of ethanol is $74.22^\circ C$.

### 3.6.2 Reflux Ratio

**Assumptions**

The following assumptions were made in the derivation of the heat balance equation and reflux ratio:

- The system operates at steady state, meaning there are no changes in temperature, or flow rates over time.
- Heat losses to the surroundings are negligible.
- The specific heat capacity of water ($S_w$) and the latent heat of vaporization of water ($L_v$) are constant.
- The distillate is a binary mixture of ethanol and water, and their properties (e.g., density, specific heat) are constant.
- The temperature difference ($\Delta T$) across the reflux condenser is uniform.
- The volumetric flow rates of the water and the distillate are constant.

**Heat Balance Equation**

The heat released by the condensation of vapour in the top column is equal to the heat absorbed by the reflux water. This can be expressed as:

$$\dot{m}_{\text{condensed}} \cdot L_{mix} = \dot{m}_{\text{water}} \cdot S_w \cdot \Delta T \tag{3.7}$$

Where:

- $\dot{m}_{\text{condensed}}$: Mass of liquid condensed in reflux (kg/s) .
- $L_{mix}$: Latent heat of vaporization of the the mixture (J/kg).
- $\dot{m}_{\text{water}}$: Mass flow rate of reflux water (kg/s).
- $S_w$: Specific heat capacity of water (4184 J/kg·K).
- $\Delta T$: Reflux condenser's water's temperature difference ($T_{\text{out}} - T_{\text{in}}$) in °C.

The reflux ratio $R$ is derived from the heat balance equation. It is given by:

$$R = \frac{\dot{m}_{\text{water}} \cdot S_w \cdot (T_{\text{out}} - T_{\text{in}})}{\dot{V}_{\text{dist}} \cdot (C_{\text{ethanol}} \cdot L_{\text{ethanol}} \cdot \rho_{\text{ethanol}} + \rho_{\text{water}} \cdot (1 - C_{\text{ethanol}}) \cdot L_{\text{water}})} \tag{3.8}$$

where:

- $\dot{m}_{\text{water}}$ is the mass flow rate of cooling water (kg/s),
- $T_{\text{out}}$ is the outlet temperature of cooling water (°C),
- $T_{\text{in}}$ is the inlet temperature of cooling water (°C),
- $\dot{V}_{\text{dist}}$ is the volumetric flow rate of the distillate (m³/s),

- $C_{\text{ethanol}}$ is the concentration of ethanol in the distillate (%),
- $L_{\text{ethanol}}$ is the latent heat of vaporization of ethanol (J/kg),
- $\rho_{\text{ethanol}}$ is the density of ethanol (kg/m³),
- $\rho_{\text{water}}$ is the density of water (kg/m³),
- $L_{\text{water}}$ is the latent heat of vaporization of water (J/kg).

### 3.6.3 Design of Condenser

The condenser is designed based on thermodynamic balancing to achieve the desired condensation results. For a binary vapor mixture of ethanol and water condensing inside the tube with counterflow cooling water outside, the required length of the heat exchanger is calculated using the following approach.

### Key Equations and Parameters

1. **Heat Transfer Equation**: The total heat released by the vapour, $Q$, consists of two components:

- Heat released during phase change (latent heat).
- Heat released to decrease the temperature (sensible heat).

Mathematically, this is expressed as:

$$Q = Q_{\text{phase change}} + Q_{\text{sensible}}$$

$$\begin{aligned} Q = {} & V_{\text{vapour}} \left( C_{\text{ethanol}} \rho_{\text{ethanol}} L_{\text{ethanol}} + (1 - C_{\text{ethanol}}) \rho_{\text{water}} L_{\text{water}} \right) \\ & + V_{\text{vapour}} \left( C_{\text{ethanol}} \rho_{\text{ethanol}} S_{\text{ethanol}} + (1 - C_{\text{ethanol}}) \rho_{\text{water}} S_{\text{water}} \right) \Delta T \end{aligned} \tag{3.9}$$

where:

- $V_{\text{vapour}}$ = Volumetric flow rate of vapor (m$^3$/s).
- $C_{\text{ethanol}}$ = Concentration of ethanol(v/v).
- $\rho_{\text{ethanol}}$ = Density of ethanol (kg/m$^3$).
- $\rho_{\text{water}}$ = Density of water (kg/m$^3$).
- $L_{\text{ethanol}}$ = Latent heat of vaporization of ethanol (J/kg).
- $L_{\text{water}}$ = Latent heat of vaporization of water (J/kg).
- $S_{\text{ethanol}}$ = Specific heat of ethanol (J/kg·K).
- $S_{\text{water}}$ = Specific heat of water (J/kg·K).
- $\Delta T = T_{\text{vapour, in}} - T_{\text{vapour, out}}$ = Temperature difference (K).

2. **Log Mean Temperature Difference (LMTD)**: The LMTD is calculated as:

$$\Delta T_{\text{lm}} = \frac{(T_{\text{vapor,in}} - T_{\text{water,out}}) - (T_{\text{vapor,out}} - T_{\text{water,in}})}{\ln\left(\frac{T_{\text{vapor,in}} - T_{\text{water,out}}}{T_{\text{vapor,out}} - T_{\text{water,in}}}\right)} \tag{3.10}$$

where the assumed values are:

- $T_{\text{vapor,in}}$ = Initial condensation temperature of the vapor mixture (°C)
- $T_{\text{vapor,out}}$ = Final condensation temperature of the vapor mixture (°C)
- $T_{\text{water,in}}$ = Inlet temperature of cooling water (°C)
- $T_{\text{water,out}}$ = Outlet temperature of cooling water (°C)

3. **Length of the Heat Exchanger**: The length $L$ of the heat exchanger is calculated as:

$$L = \frac{Q}{U \pi D_s \Delta T_{\text{lm}}} \tag{3.11}$$

where:

- $U$ = Overall heat transfer coefficient (W/m$^2$·K).
- $D_s = \frac{D_{\text{inner}} + D_{\text{outer}}}{2}$ = Average diameter of the heat exchanger (m)
- $D_{\text{inner,outer}}$ inch = Outer diameter of the inner pipe (m)
- $D_{\text{outer,inner}}$ inches = Inner diameter of the outer pipe(m)

4. **Condenser Water Flow Rate**: The water flow rate is calculated as:

$$\text{Water flow rate} = \frac{1000 \times 60 \times Q}{S_{\text{water}} \times (T_{\text{water,out}} - T_{\text{water,in}})} \tag{3.12}$$

**Assumptions**

- The vapor mixture has constant concentration and flow rate.
- No significant heat loss to the surroundings.
- The properties of ethanol, water, and the vapor mixture are constant throughout the process.
- Condensation of the vapor mixture follows a weighted latent heat approach.

5. **Power Supplied for Heating**: The power supplied to the container is calculated as (in kW):

$$P = \frac{(V_e \rho_e s_e + V_w \rho_w s_w)(T_2 - T_1)}{\eta * t * 1000} \tag{3.13}$$

Where:

- $V_e$ = ethanol's volume = $\frac{C_{\text{ethanol}}}{100} \cdot V_{\text{initial}}$
- $V_w$ = water's volume = $V_{\text{initial}} - V_e$
- $\rho_e, \rho_w$: densities of ethanol and water (kg/m$^3$)
- $s_e, s_w$: specific heats of ethanol and water (J/kg°C)
- $T_1$: initial temperature
- $T_2$: final temperature
- $t$: Time to reach boiling point in seconds (from 0 to $t$)
- $\eta$ = 45% : efficiency of stove

**Assumptions:**

- Constant specific heats ($s_e$ and $s_w$) are assumed for both ethanol and water over the entire temperature range ($T_1$ to $T_2$).
- The ethanol and water are perfectly mixed and heat up uniformly.
- Heat loss from the container is neglected.
- The process is assumed to be 45% efficient, meaning only 45% of the supplied power goes into heating the system.

## 3.7 Testing

After fabrication, experimental testing of the new design was carried out. The test result was compared with the theoretical result. The following tests were performed. Four controlled distillation trials were conducted to assess the efficiency and purity of the distillate under varying time and heating conditions. Each batch was subjected to distinct temperature settings and operational configurations. The distillation process was divided into two collection phases, and ethanol concentration was measured using an alcoholmeter to evaluate separation efficiency.

- **Batch-1:** 8 liters of initial mash was taken and the container was heated for 120 minutes. Observations were focused on separation efficiency, yield, and purity stability over time.

- **Batch-2:** 4 liter of initial mash was taken and the test was run for 45 minutes. The impact of time duration on ethanol purity and yield was analyzed.

- **Batch-3:** 4 liter of initial mash was taken and the test was run for 25 minutes. Observations were centered on the balance between rapid distillation and purity due to reduced separation time.

- **Batch-4:** 3.6 liter of initial mash was taken and distillation was conducted without bubble cap trays to evaluate the role of internal separation stages. The test was run for 45 minutes. Comparative analysis was performed against Batch-2 to determine the impact of column configuration on distillate purity and efficiency.

Each experimental setup provided critical insights into the relationship between heating intensity, separation efficiency, and ethanol purity, helping to establish optimal distillation parameters.

## 3.8 pH and Ethanol Content Measurement

### 3.8.1 pH Test Method

The pH test method is a procedure used to measure the *hydrogen ion concentration* in a solution, which determines its acidity or alkalinity. This is typically performed using standardized methods such as:

- **AOAC 18th Edition 27.1.19:** A method specified by the *Association of Official Analytical Chemists (AOAC)* that provides accurate and consistent pH measurements.
- **Procedure:**
  1. A calibrated pH meter is used for measurement.
  2. The sample is brought to room temperature for accuracy.
  3. The pH value is recorded directly from the meter.

### 3.8.2 Specific Gravity Method

The **Specific Gravity Method** is a procedure used to determine the *concentration of ethanol* in a liquid by comparing the density of the liquid to the density of water. Specific gravity (SG) is the ratio of the density of a sample to the density of water at a specified temperature.

$$SG = \frac{\text{Density of the sample at 15°C}}{\text{Density of water at 15°C}}$$

- **Procedure:**
  1. The liquid sample is taken and its density is measured at a controlled

temperature (typically 15°C).

2. A hydrometer or digital density meter is commonly used for this measurement.
3. The specific gravity value is then converted to ethanol concentration (%V/V) using standard reference tables.

### 3.8.3 Calculation of Produced Ethanol Volume

**Volume of Ethanol**

$$\text{Volume of ethanol} = \text{Total alcohol (L)} \times \left(\frac{\text{Ethanol percentage}}{100}\right)$$

**Moles of Ethanol**

$$\text{Mass of ethanol} = V_{\text{ethanol}}\,(L) \times \text{Density of ethanol (g/L)}$$

The molecular formula of ethanol is:

$$\mathrm{C_2H_5OH}$$

Where:

- **C** represents carbon
- **H** represents hydrogen
- **O** represents oxygen

Then, we calculate the moles of ethanol using the molar mass of ethanol (46.07 g/mol):

$$n_{\text{ethanol}} = \frac{\text{Mass of ethanol (g)}}{\text{Molar mass of ethanol (g/mol)}}$$

## 3.9 FTIR Test

FTIR (Fourier Transform Infrared) spectroscopy works by passing infrared light through a sample, where specific molecular bonds absorb light at characteristic wavelengths. The resulting spectrum is analyzed to identify and quantify compounds like ethanol, based on absorption peaks corresponding to functional groups and bond vibrations in the sample.

The results of the IR spectra are summarized in the table below, which shows the functional groups, their corresponding wavenumber ranges, and their significance.

Table 3.2: FTIR Functional Group and Wavenumber Ranges

| **Functional Group** | **Wavenumber ($cm^{-1}$)** | **Significance** |
|---|---|---|
| O-H Stretching (Broad peak) | 3200 - 3600 | Presence of water, ethanol, and methanol |
| C-H Stretching | 2800 - 3000 | Presence of ethanol and methanol |
| C-O Stretching (Ethanol) | 1050 - 1100 | Specific to ethanol |
| C-O Stretching (Methanol) | $\sim$1030 | More specific to methanol |
| O-H Bending (Water signature) | 1600 - 1650 | Stronger for water presence |

## 3.10 Food Safety Test

The Department of Food Technology and Quality Control (DFTQC) conduced tests on the samples to quantify the amounts of methanol, ethanol, and higher alcohols. Based on the results, the samples will be evaluated to determine whether they are safe for human consumption.

The analysis will focus on:

- Quantifying the concentration of methanol, which is toxic and must be within permissible limits.
- Measuring the ethanol content to ensure it meets the required standards for consumable products.
- Identifying and quantifying higher alcohols, which can affect the flavor and safety of the product.

**Test Methods:**

- **Ethanol Content:** USP - 38 Method no. 611, 2015
- **Methyl Alcohol:** AOAC Official Method, 22nd Edition 2022; 972.11
- **Higher Alcohol as Amyl Alcohol:** AOAC Official Method, 22nd Edition 2022; 968.09

The results of these tests will determine whether the samples are edible and compliant with food safety regulations.

## 3.11 Comparative Economic Analysis

**Ferment Cost**

The cost of the fermented mass is Rs. 500 per 20 liters.

Cost per 1000 ml = 0.025 Rs/ml $\times 1000\,\text{ml} =$ Rs 25 per 1000 ml

**LPG Cost**

LPG gas costs Rs. 1,910 per cylinder (as of March 2025) for a 14.2 kg cylinder. At full flame the conventional burner has consumption rate of 0.3 kg/h.

$$\text{Total Time} = \frac{\text{Total Gas}}{\text{Burner Consumption Rate}} = \frac{14.2\,\text{kg}}{0.3\,\text{kg/h}} = 47.33\,\text{hours}$$

$$\text{Cost per Hour} = \frac{\text{Total Cost}}{\text{Total Time}} = \frac{1910\,\text{Rs}}{47.33\,\text{hours}} \approx 40.36\,\text{Rs/hour}$$

$$\text{Cost per Minute} = \frac{40.36\,\text{Rs}}{60} \approx 0.67\,\text{Rs/min}$$

**Alcohol per 1000 mL of Ferment (mL):**

$$\text{Alcohol per 1000 mL of Ferment} = \frac{\text{Alcohol Produced (mL)}}{\text{Fermented Mass Used (mL)}} \times 1000$$

**Alcohol per Rs. 1 of Ferment (mL):**

$$\text{Alcohol per Rs. 1 of Ferment} = \frac{\text{Alcohol Produced (mL)}}{\text{Fermented Mass Used (mL)} \times \text{Ferment Cost (Rs.)}}$$

**Alcohol per Rs. 1 of LPG (ml):**

$$\text{Alcohol per Rs. 1 of LPG} = \frac{\text{Alcohol Produced (mL)}}{\text{Fuel Rate (Rs. / min)} \times \text{Total Time (min)}}$$

**Total Ferment Cost (Rs.):**

$$\text{Total Ferment Cost} = \text{Ferment Cost(Rs. / mL)} \times \text{Fermented Mass Used (mL)}$$

**Total Gas Cost (Rs.):**

$$\text{Total Gas Cost} = \text{LPG Cost (Rs. / min)} \times \text{Gas Consumed (min)}$$

**Total Cost (Rs.):**

$$\text{Total Cost} = \text{Total Ferment Cost} + \text{Total Gas Cost}$$

**Total Cost per 100 mL Alcohol (Rs.):**

$$\text{Total Cost per 100 mL Alcohol} = \frac{\text{Total Cost (Rs.)}}{\text{Alcohol Produced (mL)}} \times 100$$

## 3.12 Documentation

Once the testing results are found to be satisfactory, the documentation phase begins. This involves compiling all relevant data, analysis, and findings in a structured format. Proper referencing is carried out to acknowledge all sources used throughout the project. Additionally, plagiarism checks are performed to ensure originality and academic integrity. After these steps, the final project report is submitted.

# CHAPTER 4: RESULTS AND DISCUSSION

## 4.1 Field Visit and Data Collection

We visited two local distillation sites (**Site A** and **Site B**) for data collection on the production of *Ek Paani* Alcohol. During our visit to these local alcohol distilleries, we observed and measured various parameters involved in the distillation process, including distillation time and condensation water change time. We recorded the dimensions of the utensils used, ensuring precise measurements of their size and surface areas. Temperature measurements were taken at different points: the surface temperature of the utensils, the inner temperature of the liquid, and the temperature of the cooling water in the condenser. Additionally, the temperatures of the ferment and distillate at certain stages were measured.

The produced distillate sample from the two distillation sites were recorded as follows: Production from site A has been named '**Traditional 1 Paani (A)**' and from site B as '**Traditional 1 Paani (B)**'.

### 4.1.1 Liquid Composition Analysis

An alcoholmeter was used to measure the alcohol concentration of the produced distillate at the site.

Table 4.1: Production Data for *Ek Paani* Alcohol

| **Batch** | **Ferment Used (ml)** | **Collected Distillate (ml)** | **Production Time (mins)** | **Alcohol Conc. (%V/V)** | **Alcohol Produced (ml)** |
|---|---|---|---|---|---|
| Traditional 1 Paani (A) | 28,000 | 2,200 | 25 | 57 | 1,254 |
| Traditional 1 Paani (B) | 20,000 | 1,500 | 25 | 61.3 | 919.5 |

We had access to the ethanol contents of various *Paani Alcohol* samples produced at Site A, as documented in the test report from the Government of Nepal, Ministry of Industry, Nepal Bureau of Standards and Metrology, Food Laboratory. These test reports could be used as references for analyzing the ethanol concentration and quality of the produced alcohol.

Table 4.2: pH Value and Ethanol Content of Various *Paani* Levels

| **Paani** | **Parameters** | **Unit** | **Test Method** | **Observed Values** |
|---|---|---|---|---|
| Ek Paani | pH<br>Ethanol at 15°C | -<br>%V/V | AOAC 18th Edition 27.1.19<br>Specific Gravity Method | 4.1<br>56.14 |
| Dui Paani | pH<br>Ethanol at 15°C | -<br>%V/V | AOAC 18th Edition 27.1.19<br>Specific Gravity Method | 3.6<br>48.94 |
| Teen Paani | pH<br>Ethanol at 15°C | -<br>%V/V | AOAC 18th Edition 27.1.19<br>Specific Gravity Method | 3.6<br>44.35 |
| Chaar Paani | pH<br>Ethanol at 15°C | -<br>%V/V | AOAC 18th Edition 27.1.19<br>Specific Gravity Method | 4.2<br>37.16 |
| Paanch Paani | pH<br>Ethanol at 15°C | -<br>%V/V | AOAC 18th Edition 27.1.19<br>Specific Gravity Method | 3.9<br>4.62 |

### 4.1.2 Temperature Measurement

Both the standard alcohol thermometer and the thermal gun were used to take temperature measurements of different aspects of the distillation setup.

Table 4.3: Temperature Measurement Data

| **Category** | **Average Temperature Range (A)** | **Average Temperature Range (B)** | **Measurement Device** | **Time Interval (A)** | **Time Interval (B)** |
|---|---|---|---|---|---|
| Gas Temperature | 365.29°C | 361.50°C | Thermal gun | 25 min | 25 min |
| Bata's Water Initial Temp | 1st batch: 22°C | 1st batch: 25°C | Alcohol Thermometer | 15 min | 15 min |
| | 2nd batch: 22°C | 2nd batch: 26°C | Alcohol Thermometer | 10 min | 10 min |
| Bata's Water Final Temp | 1st batch: 48°C | 1st batch: 44.5°C | Alcohol Thermometer | 15 min | 15 min |
| | 2nd batch: 48°C | 2nd batch: 44°C | Alcohol Thermometer | 10 min | 10 min |
| *Paini* | 48°C | 51°C | Thermal gun | - | - |
| *Nani* | 72°C | 68°C | Thermal gun | - | - |
| Distillate | 73°C | 76.5°C | Alcohol Thermometer | - | - |
| Mash | 70°C | 66.2°C | Alcohol Thermometer | - | - |
| *Phonsi* | 91.25°C | 88°C | Thermal gun | - | - |

Table 4.4: Fig: Error margins for temperature measurement devices

| **Instrument** | **Error Margin/Deviation** | **Details** |
|---|---|---|
| Alcohol Thermometer | $\pm 2°C$ | Deviations that could occur due to parallax error, direct sunlight, or rapid temperature changes. |
| Thermal Gun | $\pm 5°C$ | The thermal gun had temperature deviations of around $5°C$ when compared with the standard measurement alcohol thermometer. |

## 4.2 Analysis of traditional distillation process and apparatus

### Limitation and inefficiencies in traditional distillers

Based on the collected responses and our analysis, traditional distillers exhibit several limitations and inefficiencies:

1. **Lack of Air Tightness:** The traditional apparatus is not air-tight.
2. **Less recovery ratio** The traditional apparatus has less recovery ratio. Most of the ethanol goes wasted.
3. **Non-continuous condensation process:** The water of the condenser needs to be changed manually between the production.
4. **Heat Loss:** Heat Loss due to lack of insulation of column.
5. **Low Purity:** The ethanol concentration is low.
6. **Manual Temperature Control:** Temperature control is done entirely manually, relying on instinct rather than precise instrumentation.
7. **Labor-Intensive Operations:** The manual processes, such as changing condensation water and collecting distillate by removing pots, increase the labor intensity of the operation.

These limitations highlight the need for modernizing distillation equipment and processes, emphasizing automation, better energy utilization, and precise monitoring tools to enhance productivity and reduce labor dependency.

## 4.3 CAD modeling of traditional utensils

The dimensions of the utensils were measured and designed in Solidworks 2024. All dimensions are in inch.

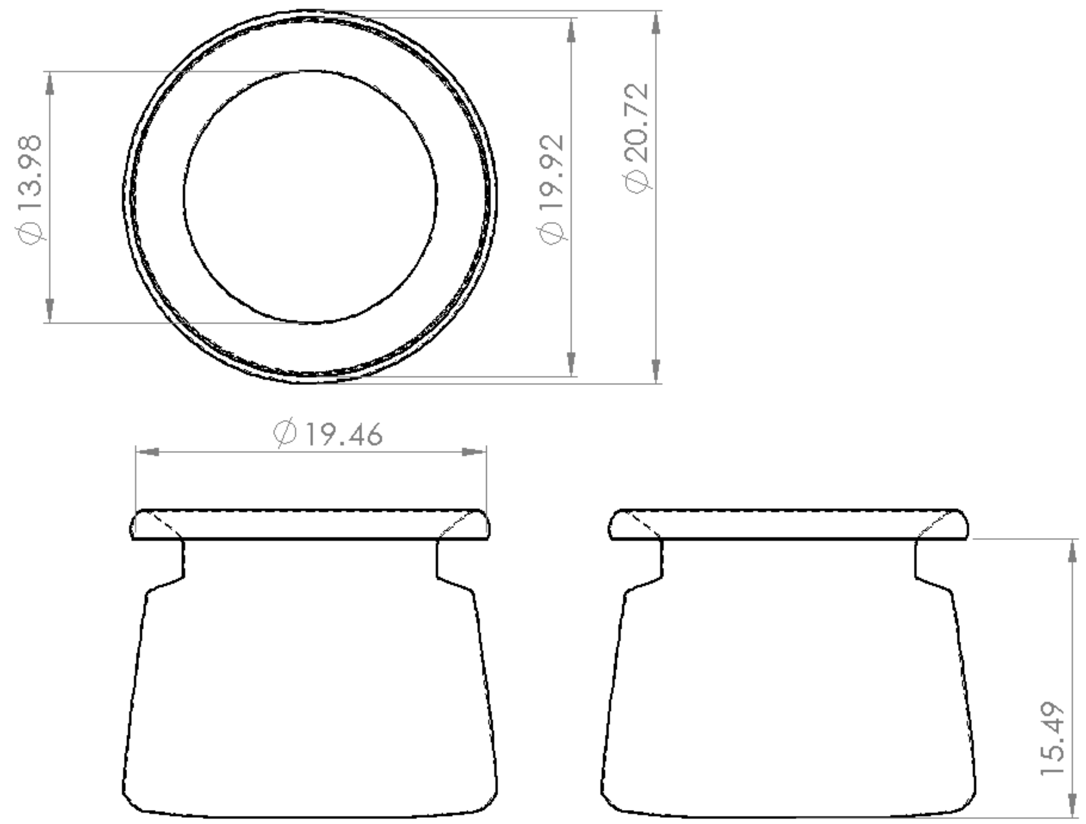


Figure 4.1: Orthographic view of Phonsi

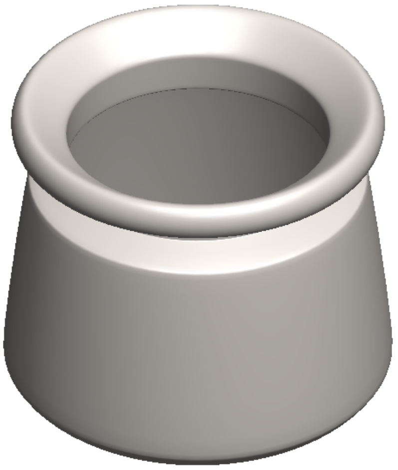


Figure 4.2: Isometric view of Phonsi (Mash Container)

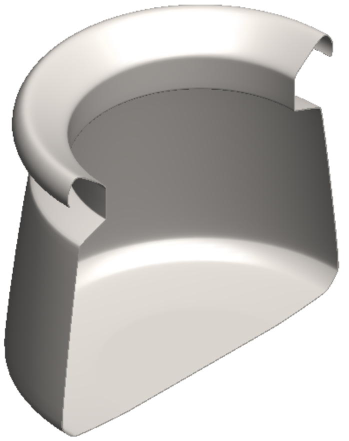


Figure 4.3: Section view of Phonsi

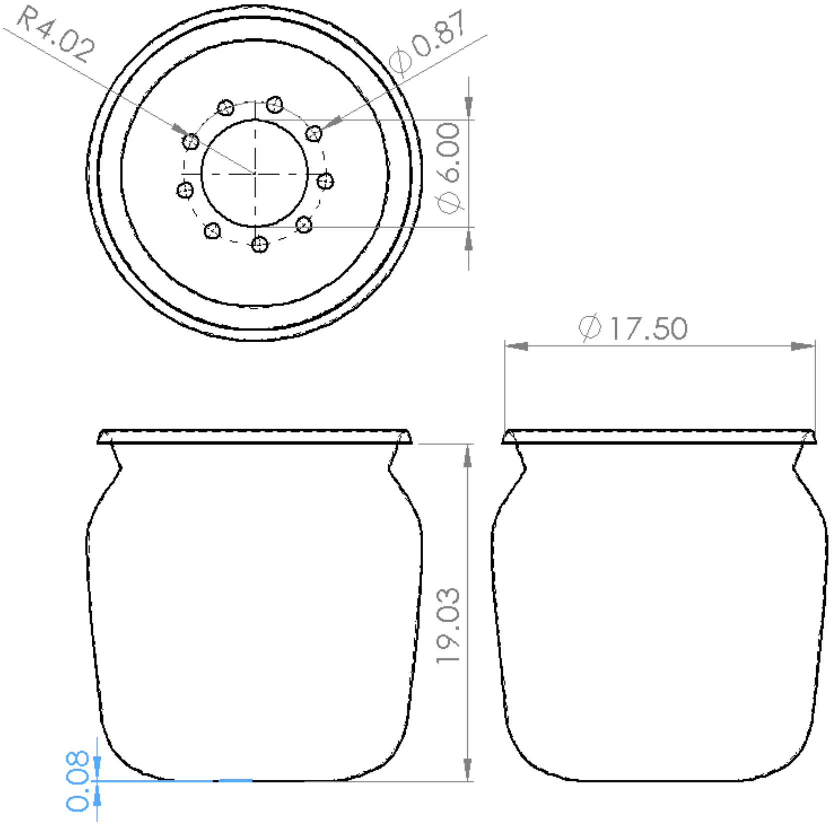


Figure 4.4: Orthographic view of Paini

Figure 4.5: Isometric view of Paini (Column)

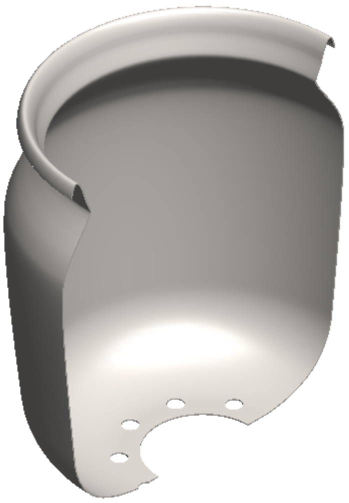


Figure 4.6: Section view of Paini

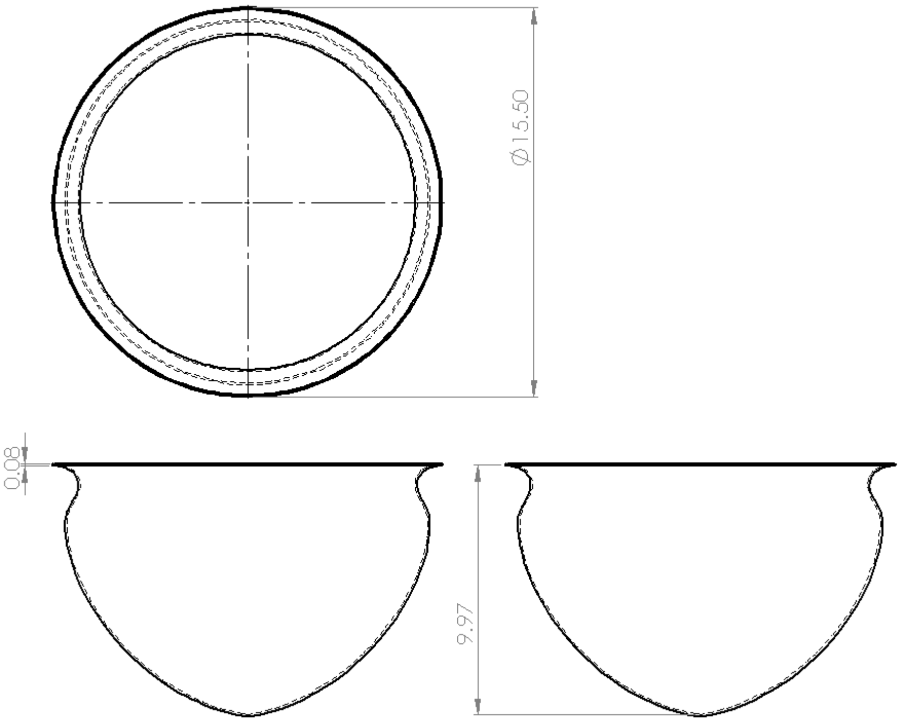


Figure 4.7: Orthographic view of Bata

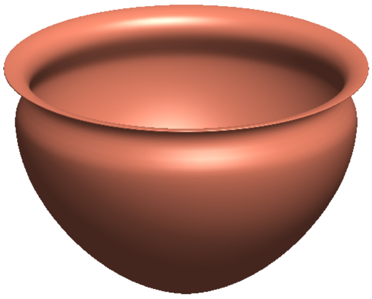


Figure 4.8: Isometric view of Bata (Condenser)

Figure 4.9: Isometric view of Nani (Distillate Collector)

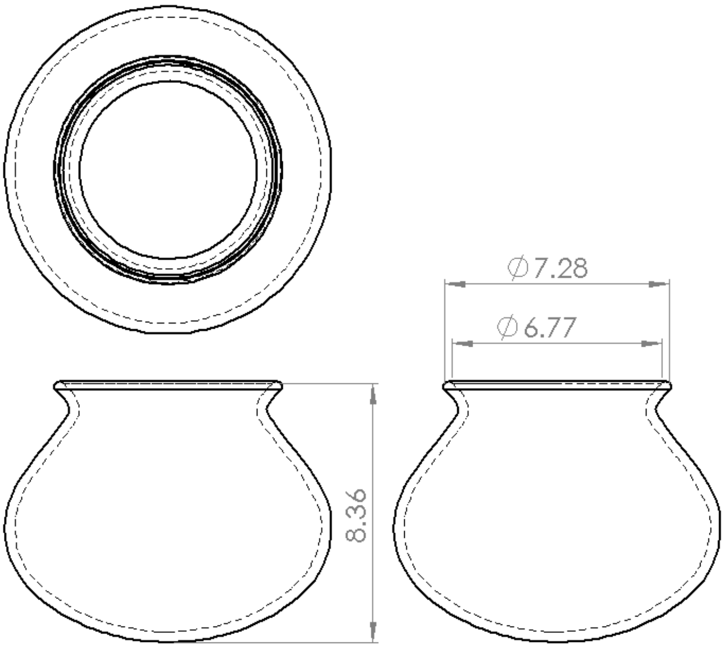


Figure 4.10: Orthographic view of Nani

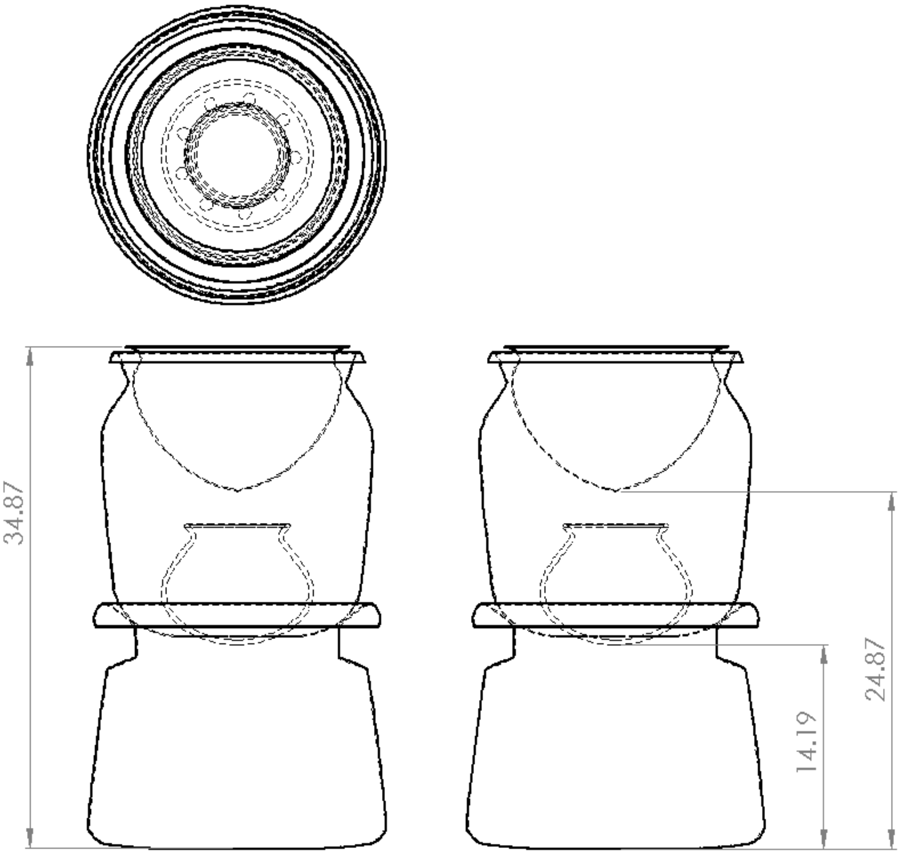


Figure 4.11: Orthographic view of Assembled Design

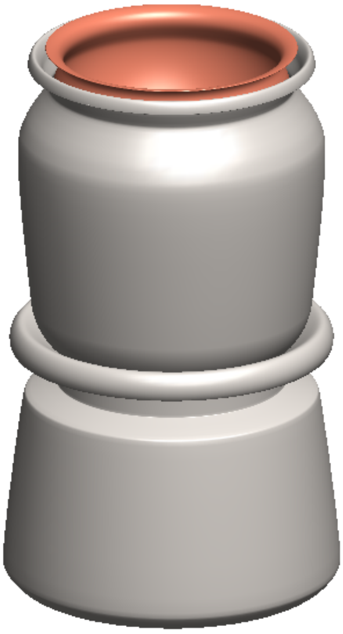


Figure 4.12: Isometric view of Assembled Design

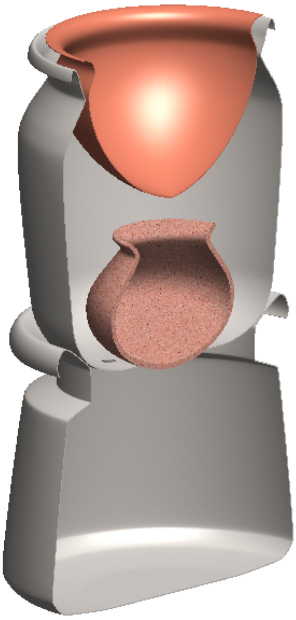


Figure 4.13: Sectional view of Assembled Design

## 4.4 CFD Analysis of Traditional Distiller

The CAD model of the traditional distiller, designed in SolidWorks, was imported and simulated using ANSYS Workbench 2024R1 Fluid Flow (Fluent). The following boundary conditions were applied:

- Inlet temperature: 375 K
- Inlet velocity: 1 m/s
- Condenser temperature: 290 K
- Gravity: -9.81 $m/s^2$ along the Y-axis
- Fluid components: Water, water vapor, and air

The simulation results are presented below.

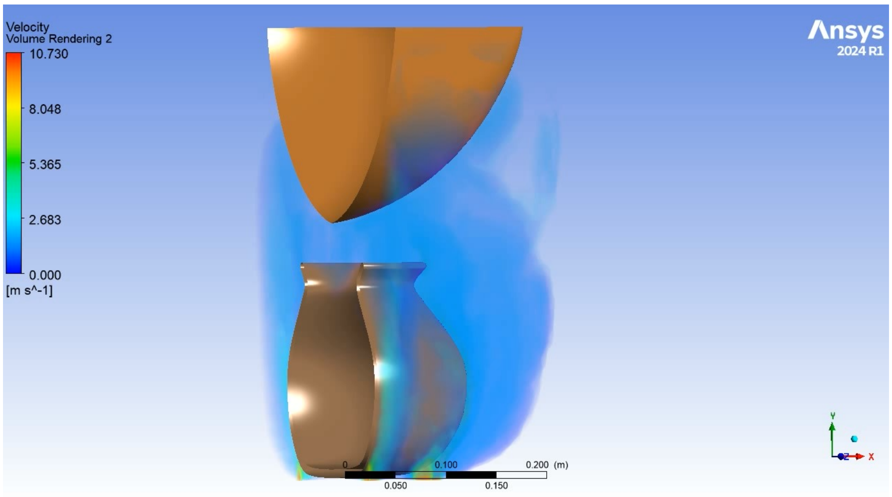


Figure 4.14: Velocity Distribution

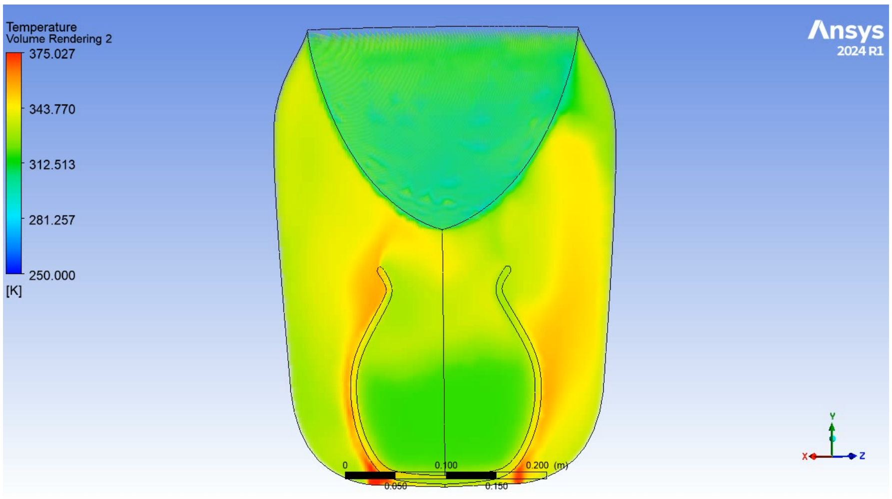


Figure 4.15: Temperature Distribution

### 4.4.1 Results from CFD Analysis

Based on the provided figures (**Figure 4.14: Velocity Distribution** and **Figure 4.15: Temperature Distribution**), the following results can be inferred:

**Velocity Distribution (Figure 4.14)**

- The velocity distribution within the distiller shows variations in flow patterns, indicating areas of high and low velocity.
- High-velocity regions are likely near the inlet or areas with minimal obstructions, while low-velocity regions may occur near the condenser or in areas with complex geometries.
- Uneven velocity distribution can lead to inefficiencies in vapor flow, potentially causing incomplete distillation or energy losses.

**Temperature Distribution (Figure 4.15)**

- The temperature distribution reveals gradients within the distiller, with higher temperatures near the heat source (inlet) and lower temperatures near the condenser.
- The temperature gradient is critical for effective condensation and separation of ethanol from other components.
- Inefficient temperature distribution may result in poor condensation, leading to reduced ethanol purity or energy wastage.

## 4.5 Process design

### 4.5.1 Calculation results of distillation column parameters

**Initial mixture** ($W_i$)= 4000 ml
**Initial Concentration** ($X_{wi}$):20% = 0.2
**Desired Concentration** ($X_D$): 80% = 0.8
**Desired residue after distillation**($X_w$)= 0.10
**Pressure** ($P$): 0.89 atm

Using the Fenske equation ( 3.1), the minimum number of theoretical stages comes out to be:

$$N_{\min} \approx 4.22$$

So We use 5 theoretical stages,
**Number of trays** ($N$):

$$N = 5 - (\text{Reflux Condenser} + \text{Still Pot}) = 3$$

We select reflux ratio as:
**Reflux ratio** ($R$) = 2.7

### 4.5.2 Initial Purity for different number of trays:

If initial concentration is 20 % and we fix a reflux ratio to 2.7 then we can calculate the purity for different number of trays using the Mecheb-Thele method:

For $R = 2.7$
$X_{wi} = 20\%$

| **No. of Stages** | **Initial Purity** |
|---|---|
| 7 | 80% |
| 5 | 70% |
| 4 | 50% |
| 3 | 35% |
| 2 | 25% |
| 1 | 23% (just still pot Flash Batch Distillation) |

*** We choose $N_{th} = 5$ due to height limitation**

Number of trays:

$$\begin{aligned}\text{Number of trays} &= N_{th} - 1 \text{ (Reflux condenser)} - 1 \text{ (Still pot)} \\ &= 5 - 1 - 1 = 3\end{aligned}$$

### 4.5.3 Column Height

**Column Height and Tray Spacing**
For micro distilleries we approximate the height of the total apparatus height as 75 cm depending on the space available in their business.

Depending on the height of the column only (excluding container and reflux section), calculating the spacing between the trays:

$$\text{Tray Spacing} = \frac{\text{Height}}{N} = \frac{40}{3} = 13.33\,\text{cm}$$

### 4.5.4 Selection of stage tray

The tray used for the stages is the bubble cap tray which has the Murphree efficiency of 60% - 80% (for low to moderate vapor and liquid flow rates).

### 4.5.5 Diameter of the column:

Since large diameter is not preferable in distillation column, we select:
Diamter (D)= 7.6 cm

### 4.5.6 Final parameters for the design

Number of stages/ trays= 3
Reflux ratio= 2.7(Can be varied in need of different batch)
Height of the column= 40 cm
Diameter of the column= 7.62 cm (3 in)
Tray spacing= 13.33cm

## 4.6 Design of Condenser

For a binary vapor mixture of ethanol and water condensing inside the tube with counterflow cooling water outside, the required length of the heat exchanger is calculated using the following values.

- $V_{\text{vapour}} = 1500\,\text{ml}$ per 15 miutes
- $C_{\text{ethanol}} = 40\%$
- $\rho_{\text{ethanol}} = 789$ kg/m$^3$.
- $\rho_{\text{water}} = 1000$ kg/m$^3$.
- $L_{\text{ethanol}} = 838000$ J/kg.
- $L_{\text{water}} = 2260000$ J/kg.
- $S_{\text{ethanol}} = 2440$ J/kg·K.
- $S_{\text{water}} = 4184$ J/kg·K.
- $T_{\text{vapor,in}} = 96$ °C
- $T_{\text{vapor,out}} = 36.1$ °C
- $T_{\text{water,in}} = 18.3$ °C
- $T_{\text{water,out}} = 25$ °C
- $U = 1000$ W/m$^2$·K. (assumed minimum, [25])
- $D_{\text{inner,outer}} = 0.75\,\text{inch}$
- $D_{\text{outer,inner}} = 3\,\text{inches}$

  *Note: 1 inch = 0.0254 meter*

From the equation (3.9), the total heat released by the vapour, $Q$ = 3028.3 J
From equation (3.10), LMTD = 38.454 °C
From the equation (3.11), the length of the heat exchanger = 20.722 inches
From the equation (3.12), the condenser water flow rate = 6482 ml per minute

**Final Design Specifications:** The final design specifications, based on calculations and practical considerations, are summarized in Table 4.5.

Table 4.5: Final Design Specifications

| Parameter | Calculated Value | Final Design Value |
|---|---|---|
| Length of Condenser | 20.722 inches | 24 inches |
| Water Flow Rate | 6482 ml per minute | 10000 ml per minute |

**Justification**

- The condenser length was increased from 20.722 inches to 24 inches to provide a factor of safety of 1.16 and ensure sufficient heat transfer area.
- A pump with a flow rate of 10 liters per minute was selected, which exceeds the calculated requirement of 6482 ml per minute. The adjustable flow rate allows for precise control of the cooling process.

## 4.7 CAD Modeling of New Design

Using all the mathematically calculated parameters and dimensions a new design for the distillation column was designed using SolidWorks 2024. All dimensions are in inches.

### 4.7.1 Base container Design

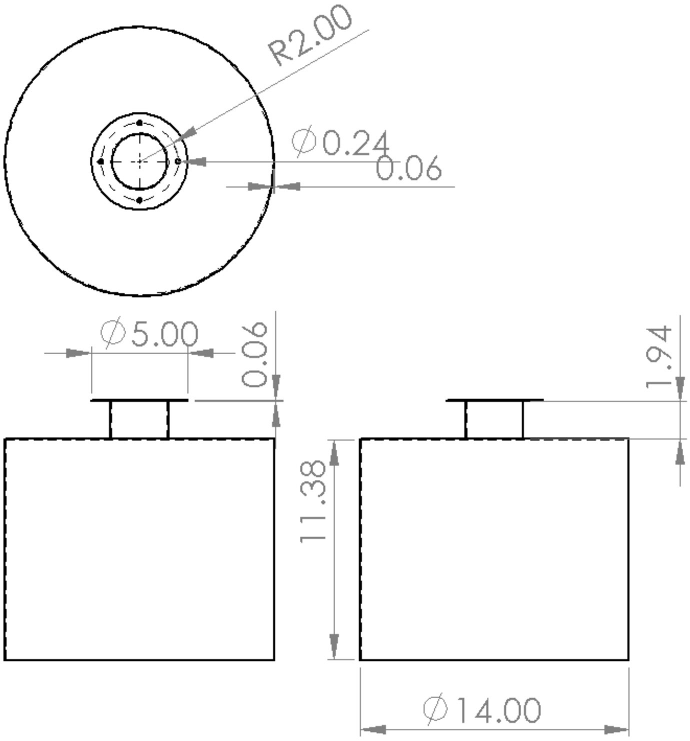


Figure 4.16: Orthographic view of Base container

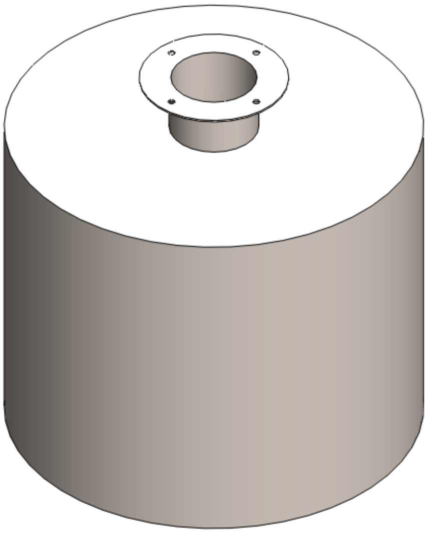


Figure 4.17: Isometric view of Base container

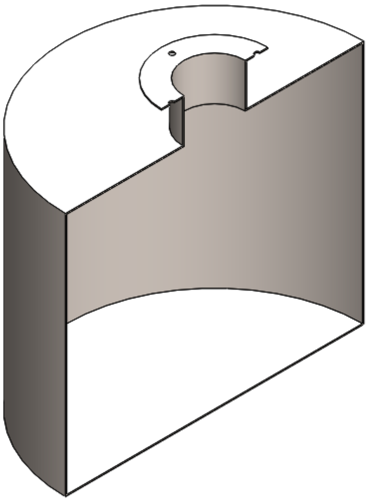


Figure 4.18: Section view of base container

### 4.7.2 Stage tray

1. **Bubble Cap**

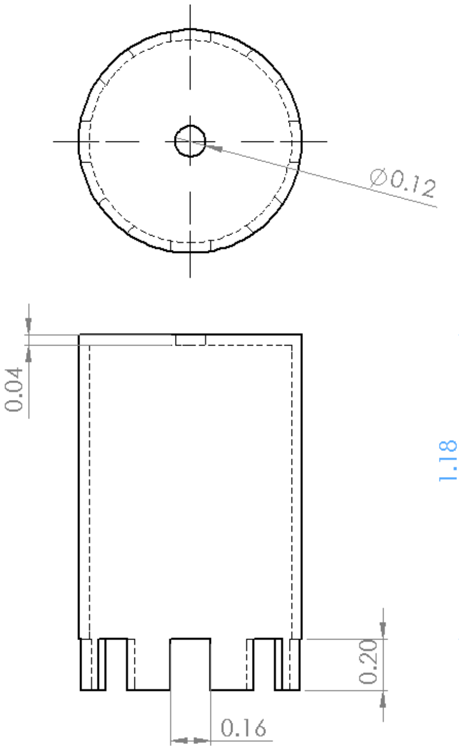


Figure 4.19: Orthographic view of Bubble Cap

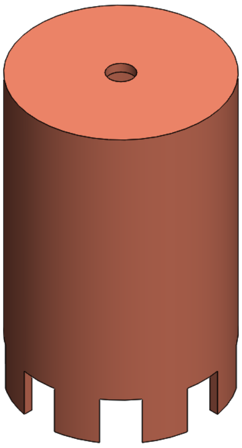


Figure 4.20: Isometric view of Base Bubble cap

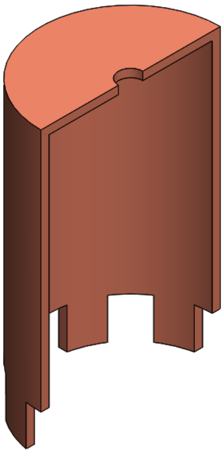


Figure 4.21: Section view of Bubble Cap

2. **Raiser**

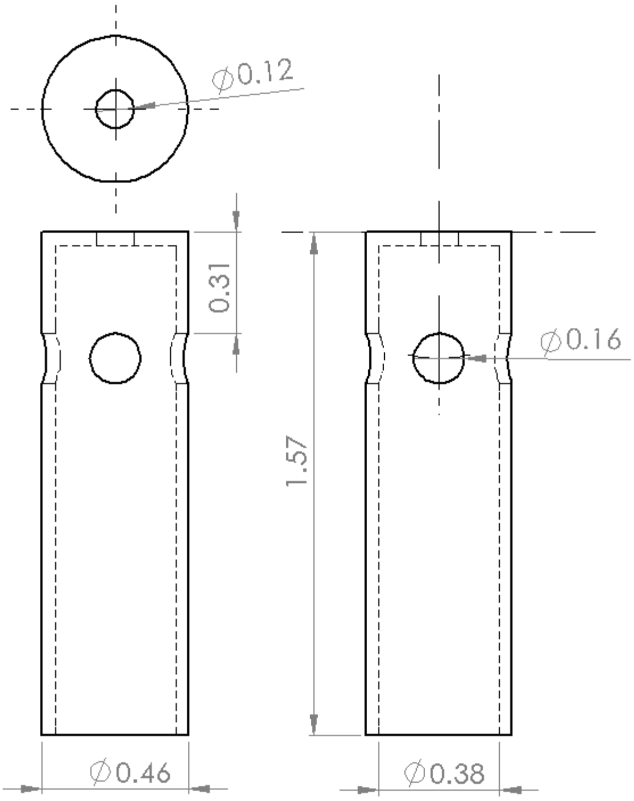


Figure 4.22: Orthographic view of Raiser

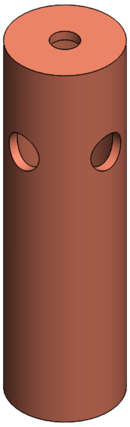


Figure 4.23: Isometric view of Raiser

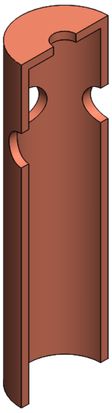


Figure 4.24: Section view of Raiser

3. **Downcomer**

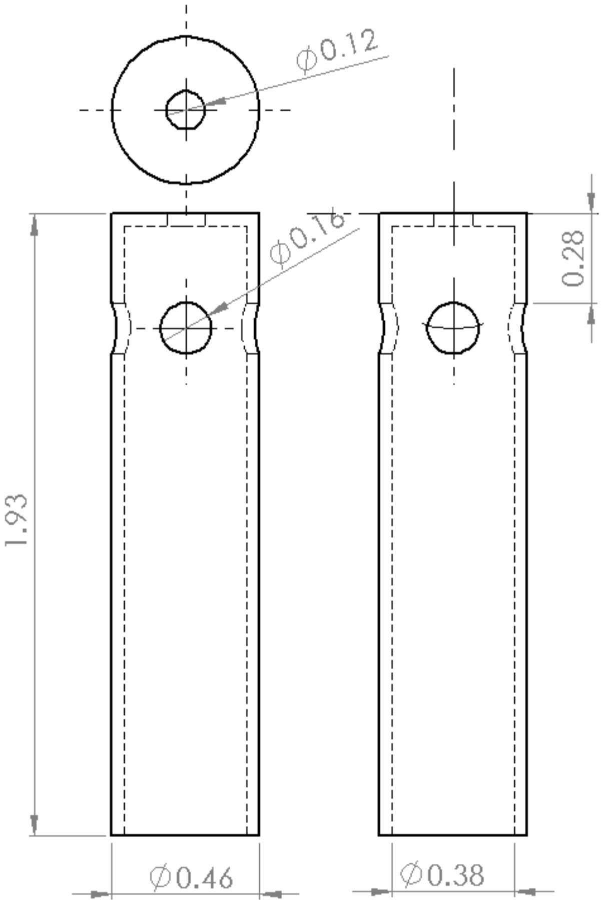


Figure 4.25: Orthographic view of Downcomer

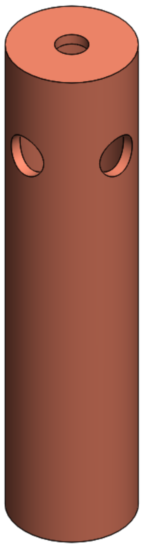


Figure 4.26: Isometric view of Downcomer

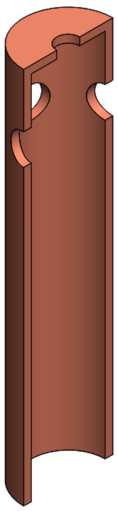


Figure 4.27: Section view of Downcomer

4. **Copper Plate**

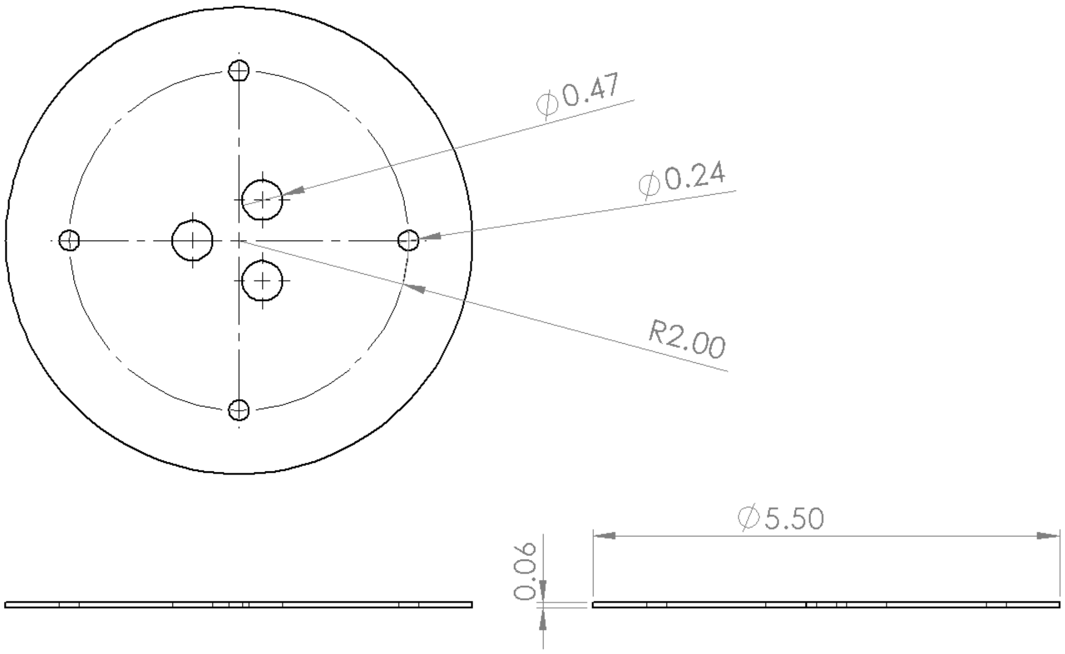


Figure 4.28: Orthographic view of Copper Tray

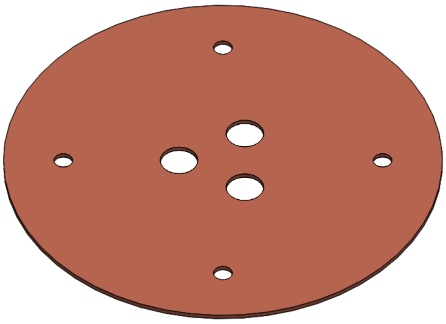


Figure 4.29: Isometric view of Stage Tray

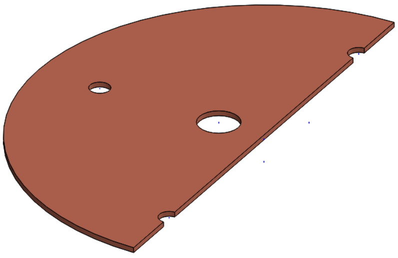


Figure 4.30: Section view of Stage Tray

### 5. Assembly of Stage Tray

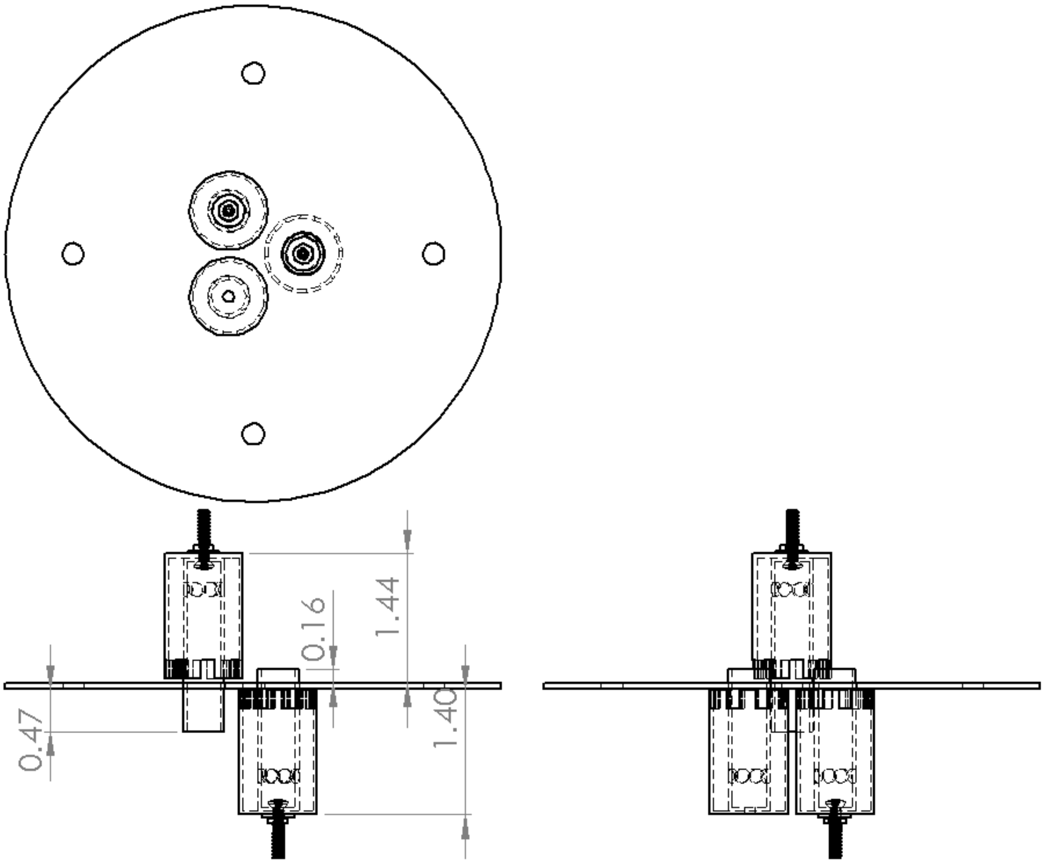


Figure 4.31: Orthographic view of Stage Tray

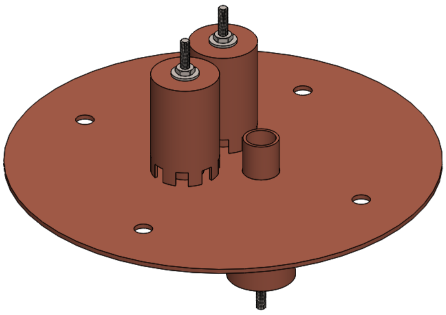


Figure 4.32: Isometric view of Stage Tray

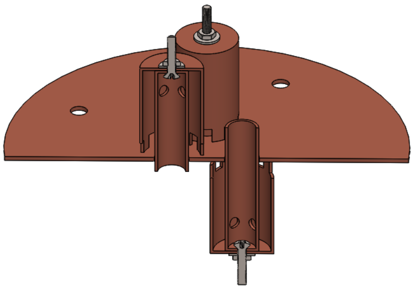


Figure 4.33: Section view of Stage Tray

### 4.7.3 Column Stage

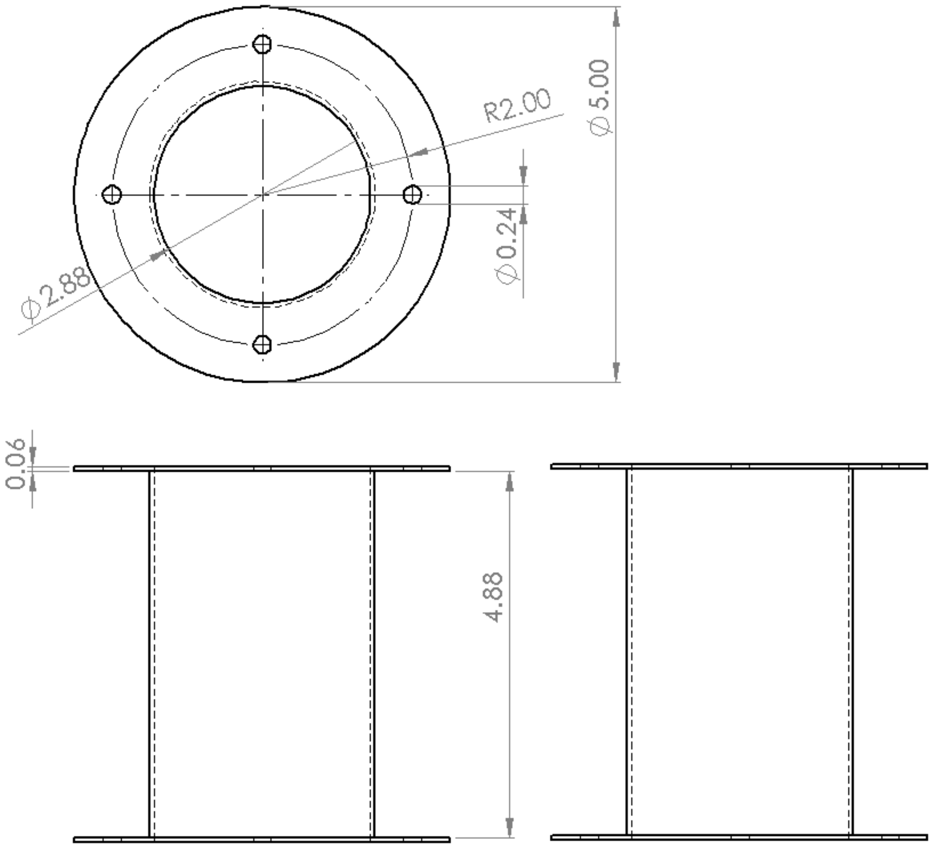


Figure 4.34: Orthographic view of Column

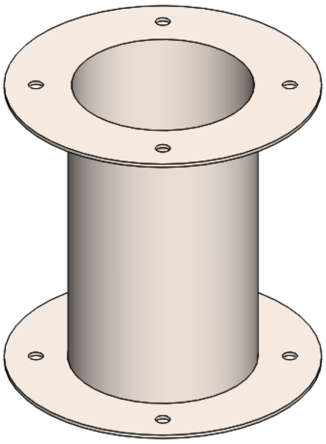


Figure 4.35: Isometric view of Column Stage

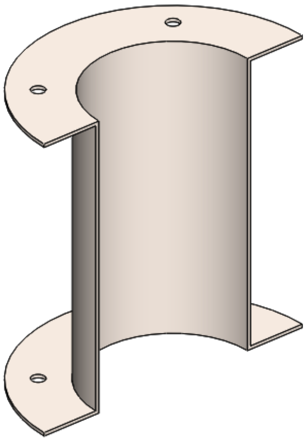


Figure 4.36: Section view of Column Stage

### 4.7.4 Gasket

Four different sized gaskets were made.

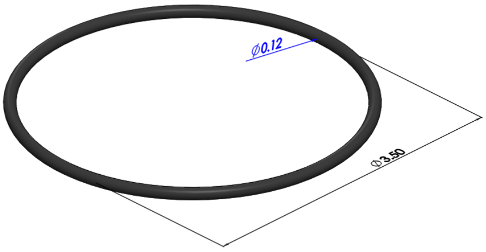


Figure 4.37: Isometric view of Inner Gasket

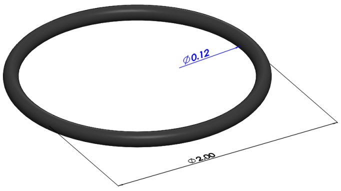


Figure 4.38: Isometric view of Inner Gasket at Condenser

### 4.7.5 Real Time Concentration and Volume measurement

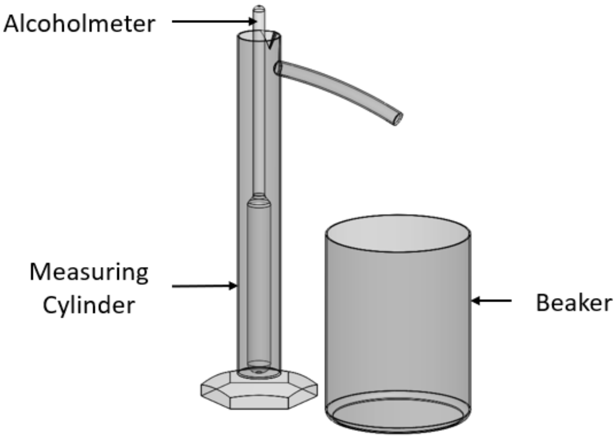


Figure 4.39: Isometric view of Alcoholmeter and Beaker

### 4.7.6 Main Condenser

It is the condenser placed after the distillation column for the complete condensation of the separated vapor.

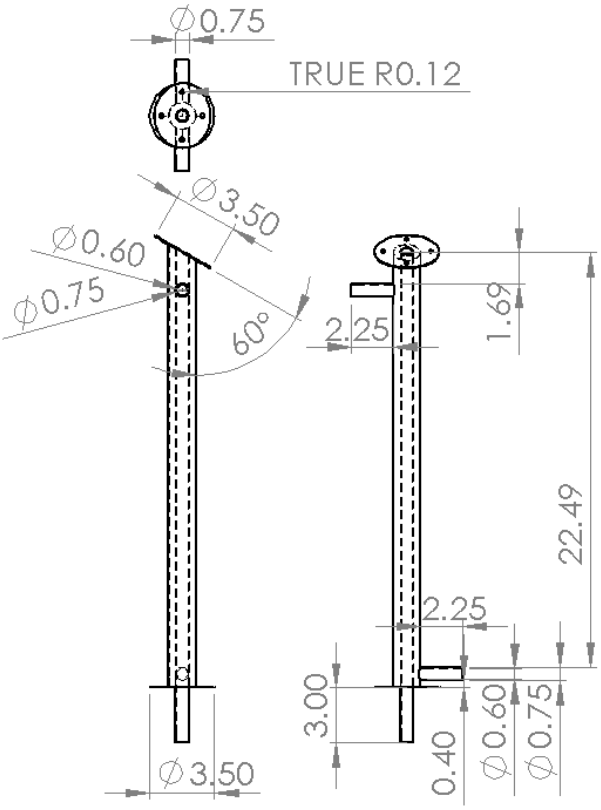


Figure 4.40: Orthographic view of Main Condenser

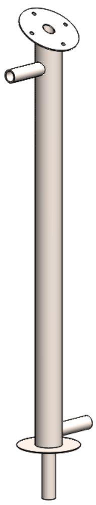


Figure 4.41: Isometric view of Main Condenser

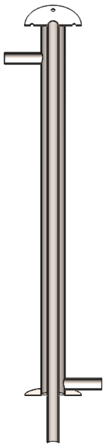


Figure 4.42: Section view of Main Condenser

### 4.7.7 Reflux Condenser

It is the condenser placed on around the top stage column but is an operated after the main distillation process in the cycle. This condenser is designed in such a way that it matches the reflux ratio calculated as per the desired distillation design.

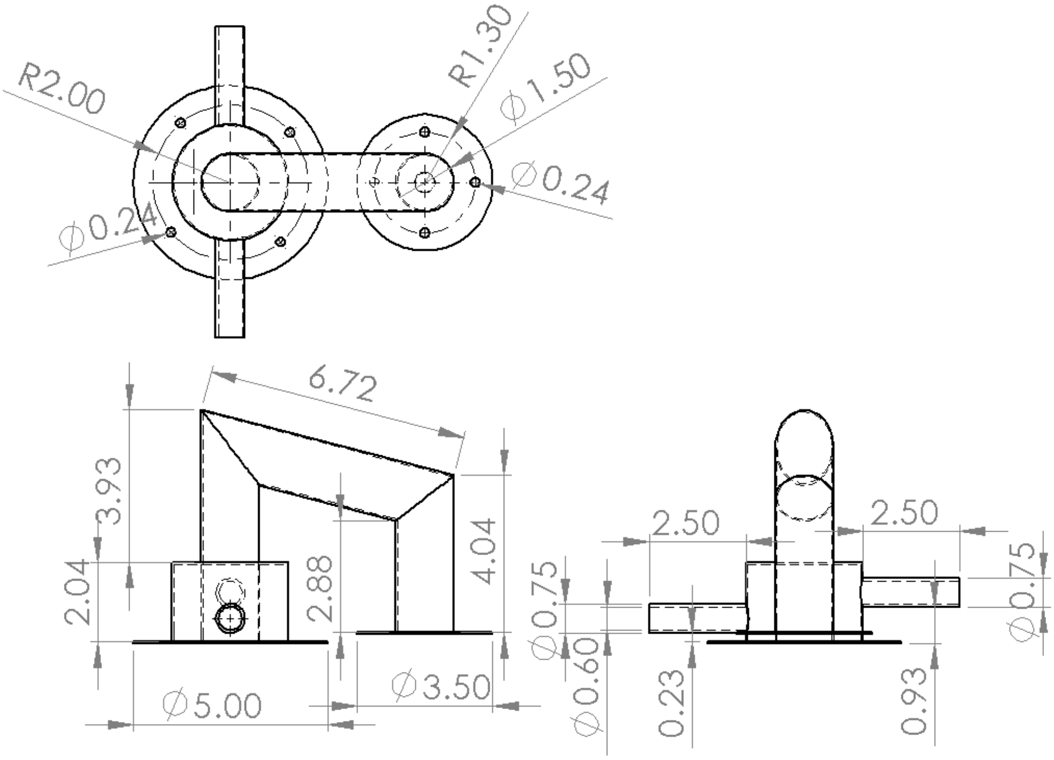


Figure 4.43: Orthographic view of Reflux Condenser

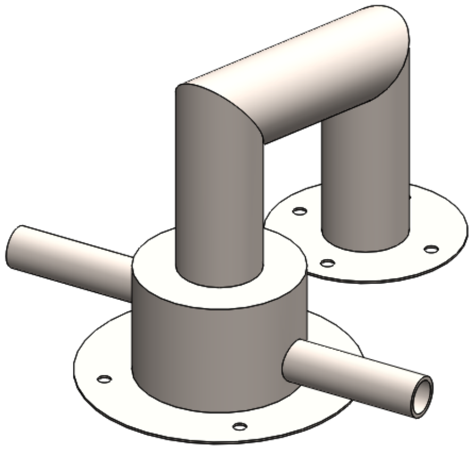


Figure 4.44: Isometric view of Reflux Condenser

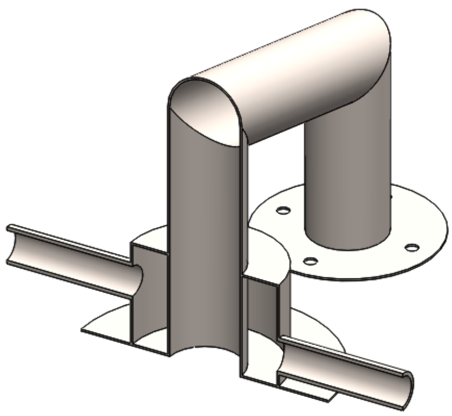


Figure 4.45: Section view of Reflux Condenser

### 4.7.8 Complete assembly

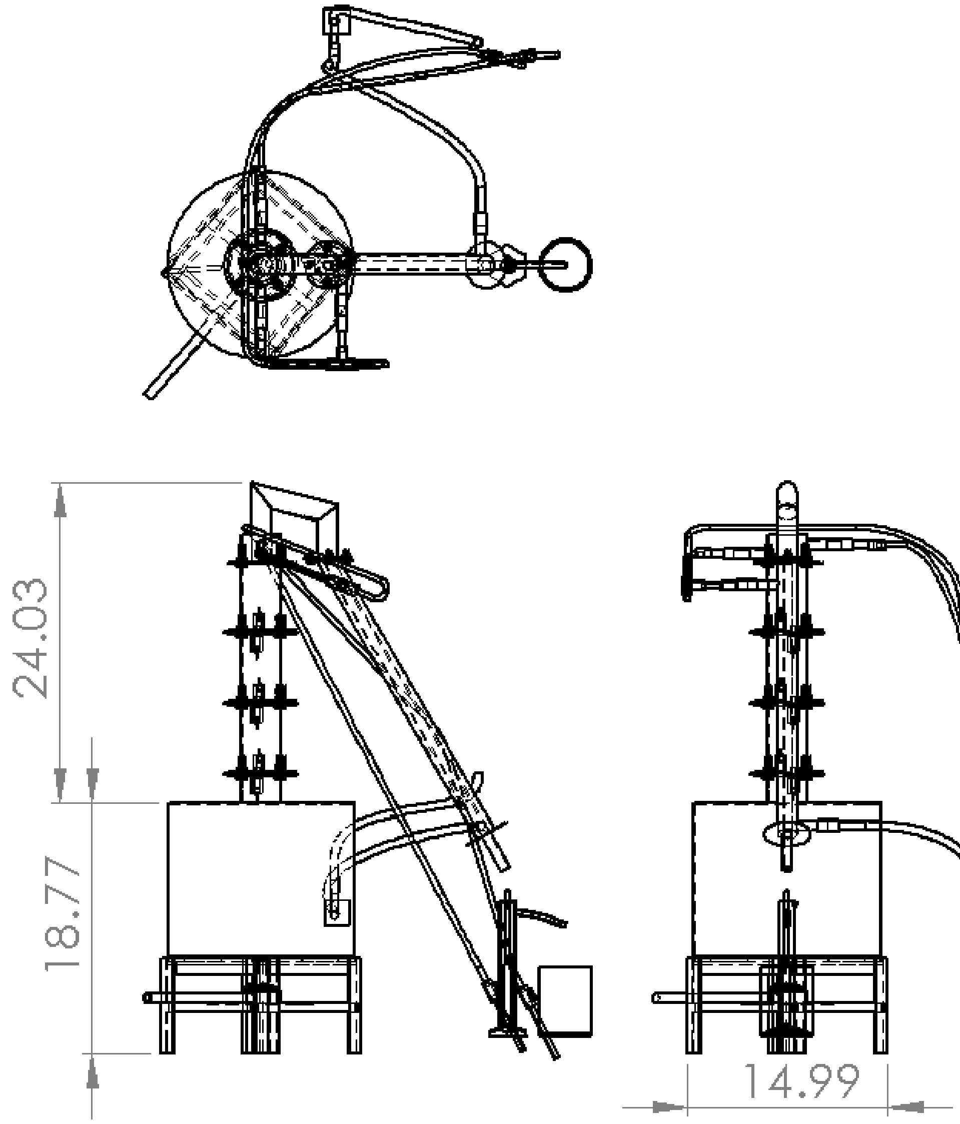


Figure 4.46: Orthographic view of Full Assembly

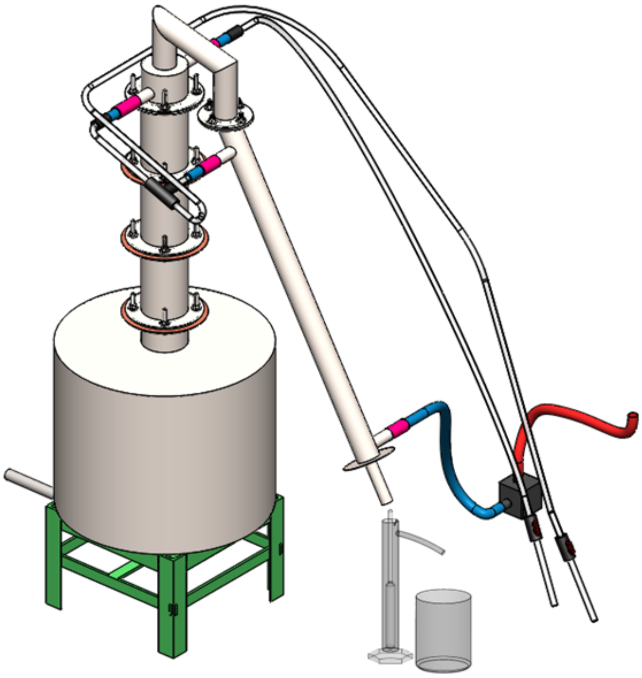


Figure 4.47: Isometric view of Distillation Apparatus

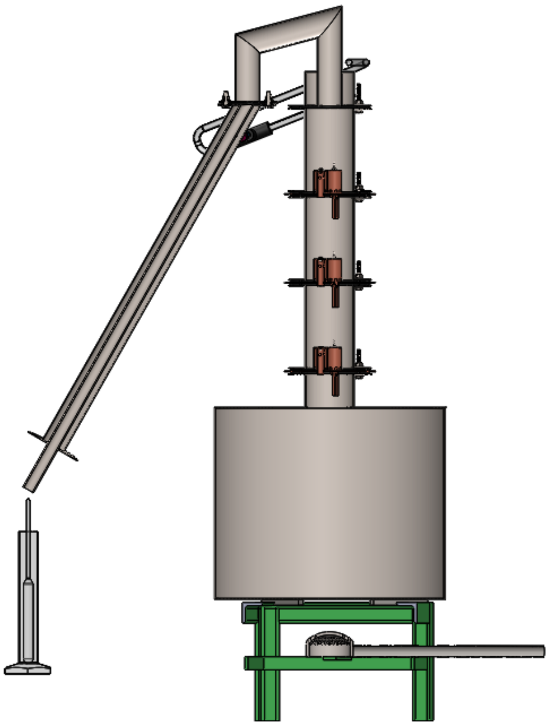


Figure 4.48: Section view of Distillation Column

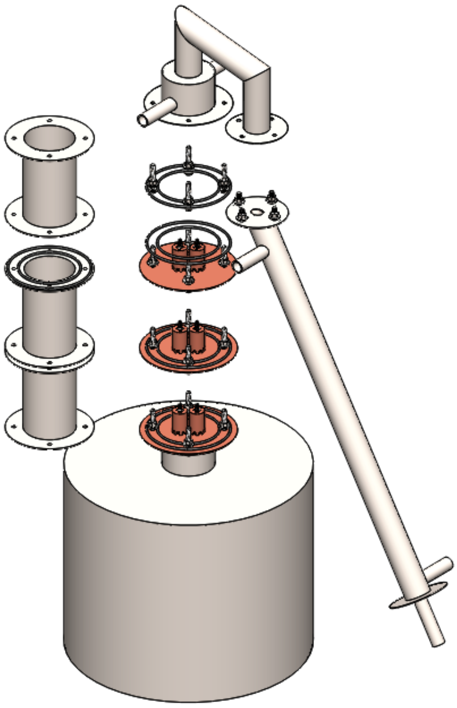


Figure 4.49: Exploded view of Distillation Apparatus

## 4.8 Flow visualization in Distillation Column

The following simulation were done in ANSYS 2024R1

### 4.8.1 Pressure Contour of Distillation Column

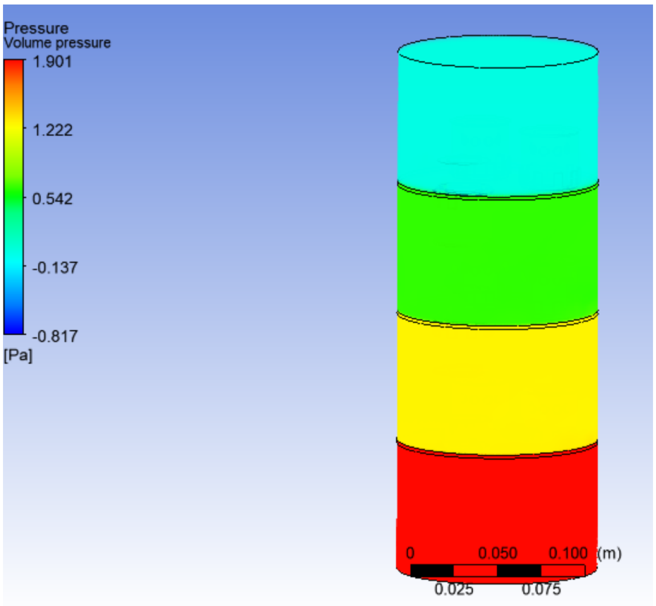


Figure 4.50: Pressure Contour

- **Pressure Gradient:** The pressure contour shows a gradual decrease in pressure from the bottom (red) to the top (cyan/blue). Higher pressure at the bottom is due to vapor generation, while lower pressure at the top aids condensation.
- **Pressure Distribution:** The uniform distribution of pressure across the column height indicates a smooth vapor flow, which is crucial for effective mass transfer between liquid and vapor phases.
- **Operational Insight:** The pressure contour helps identify potential issues like blockages, disturbances, or uneven pressure drops that may cause problems.
- **Design Validation:** The smooth pressure gradient ensures the column is designed correctly, with properly spaced trays or packing elements functioning as expected.

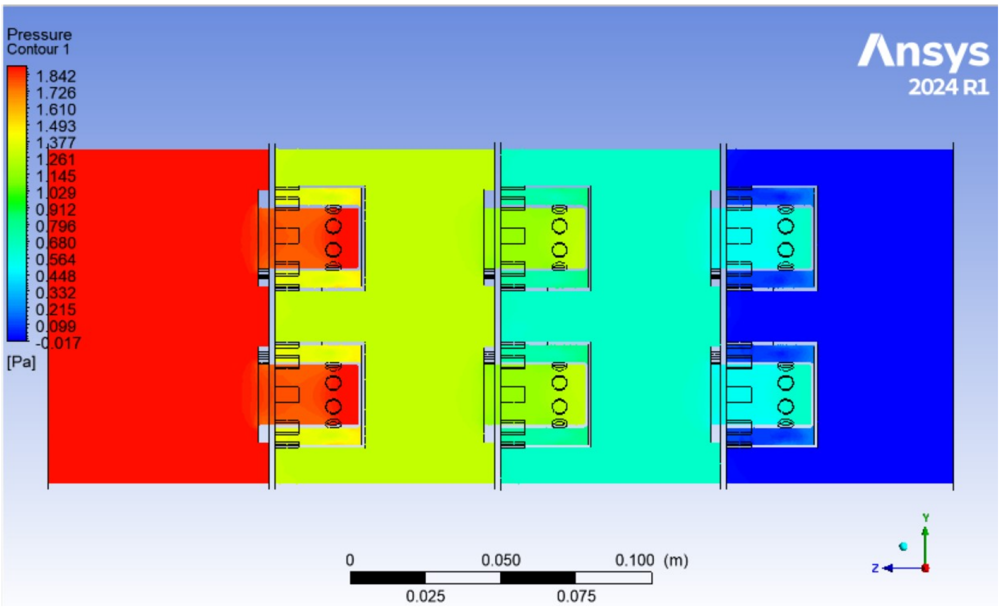


Figure 4.51: 2D Pressure Contour

### Benefits of Pressure Contour Analysis

- **Ensures Uniform Vapor Flow:** Consistent pressure gradients ensure even vapor movement, improving separation.
- **Troubleshooting:** Reveals defects like pressure drops due to clogging or faulty internals.
- **Enhances Design Validation:** Confirms the column operates as per specifications, reducing failure risks.

### 4.8.2 Velocity Contour of Distillation Column

The red parts have higher velocity and blue parts have minimal velocity.

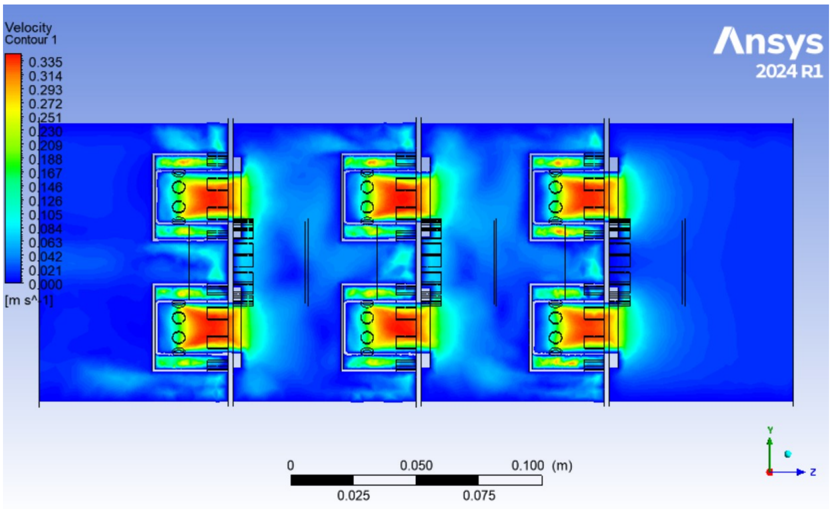


Figure 4.52: 2D Velocity contour

## 4.9 Material Selection

Material selection plays a crucial role in the performance, durability, and efficiency of the distillation column. The choice of appropriate materials ensures reliability, resistance to corrosion, and cost-effectiveness while maintaining operational safety. For this project, the following materials have been carefully selected based on their properties and suitability for the working environment:

### 4.9.1 Column and Container: Stainless Steel (SS304)

- **Reason for Selection:** SS304 is chosen for its chemical resistance, food safety, and high durability in contact with ethanol, water, and high temperature.
- **Properties:**
  - Excellent corrosion resistance
  - Non-reactive and food-safe
  - High strength and heat resistance

### 4.9.2 Stage Trays (Bubble Cap Trays): Copper

The stage tray, including the riser, bubble cap, and downcomer, is constructed using copper to enhance mass transfer efficiency, thermal conductivity, and resistance to chemical degradation.

- **Reason for Selection:** Copper is preferred in trays due to its ability to react with sulfur compounds and improve distillate quality.
- **Properties:**
  - High thermal conductivity for efficient heat transfer

  - Excellent corrosion resistance, particularly in alcohol-based environments
  - Malleable and easy to fabricate, ensuring precision in component design
  - Promotes catalytic effects that improve the distillation process efficiency

### 4.9.3 Fasteners (Nut and Bolts): Mild Steel

- **Reason for Selection:** Mild steel fasteners are strong and affordable, suitable for securing structural and non-pressurized joints.
- **Properties:**
  - Good mechanical strength
  - Low cost and high availability

### 4.9.4 Condenser: Stainless Steel (SS304)

- **Reason for Selection:** Stainless Steel SS304 is used in the condenser due to its corrosion resistance, food safety, and decent thermal conductivity for effective heat exchange in distillation.
- **Properties:**
  - Moderate thermal conductivity: ˜16.2 W/m·K
  - Excellent corrosion resistance in alcohol-rich and wet environments
  - Non-reactive with ethanol, ensuring purity and safety
  - Sufficient mechanical strength to withstand water pressure and weight.

### 4.9.5 Sealing Gaskets: Silicone Rubber (Pressure Cooker Gaskets)

- **Reason for Selection:** It is chemically inert and can withstand high temperatures and pressures.
- **Properties:**
  - High-temperature resistance (up to 250°C).
  - Flexible and durable, maintaining elasticity over time.
  - Non-toxic and food-safe.
  - Resistant to ethanol and water, making it suitable for distillation.

## 4.10 Final Design of the Modified Apparatus for Micro Distillery

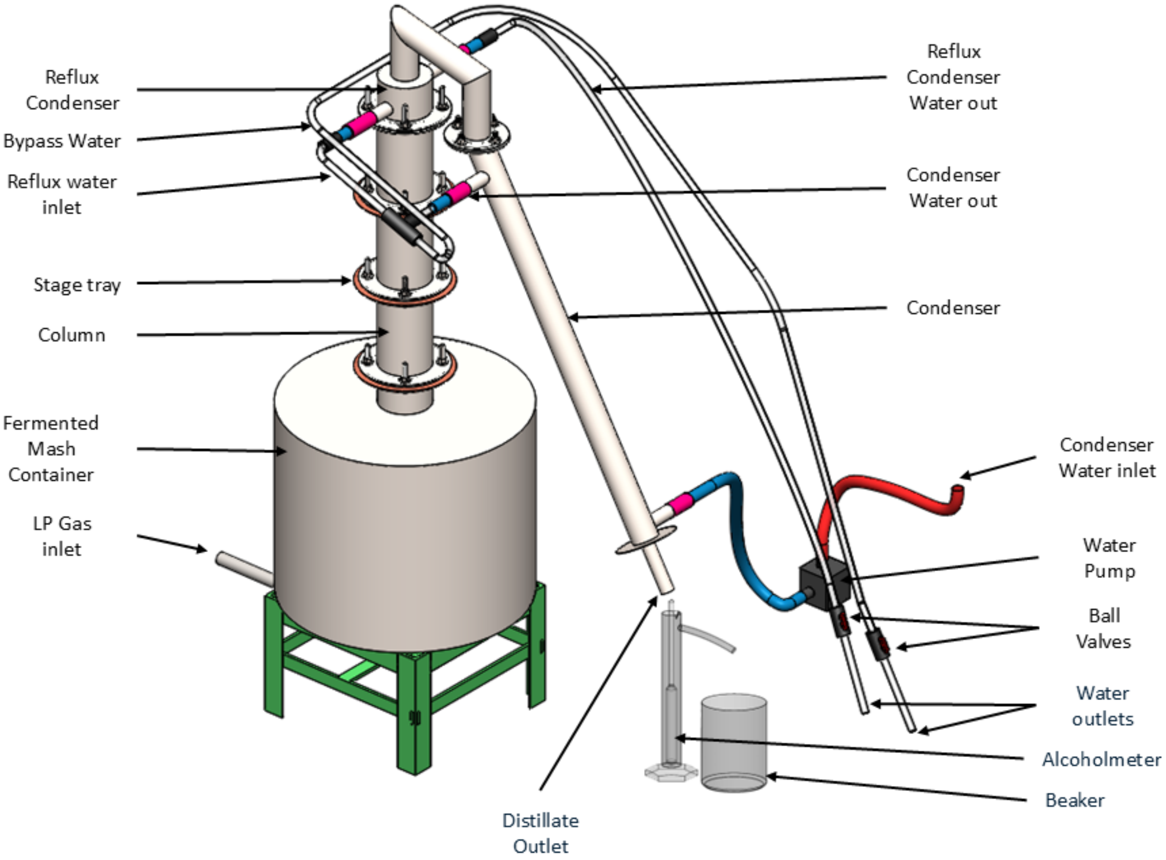


Figure 4.53: Detailed design

**Fermented Mash Container (Boiler)**

Contains the fermented mash (ethanol, water, impurities). Heated via LP Gas / Induction to evaporate ethanol (boiling point: 74.22°$C$).

**Distillation Column with Stage Trays**

Vapors rise into the column where fractional separation occurs. Heavier compounds (water, residues) condense and fall back. Ethanol-rich vapors continue to the reflux condenser.

**Reflux Condenser**

Cools part of the vapor, allowing high-boiling compounds to return to the column. Ensures higher purity alcohol is distilled.

**Main Condenser**

Vapors pass into the main condenser, where they are cooled using circulating water. The vapor condenses into liquid ethanol.

**Cooling Water Circulation System**

Water enters through inlets and exits via outlets. Pump and ball valves control water flow for efficient cooling.

**Distillate Outlet and Alcoholometer**

Condensed ethanol is collected through the distillate outlet. An alcoholometer measures the alcohol percentage.

## 4.11 Fabrication of Final Design

The distillation apparatus was made of 304 stainless steel, chosen for its durability and resistance to corrosion. The system was divided into different units: the heating unit, the distillation column, and the condenser unit. Copper plates were fabricated using brazing and placed inside the distillation column to enhance vapor-liquid interaction for improved separation efficiency. Gaskets were used between the plates and the column to prevent leakage and ensure an airtight system.

**Heating Container**

The heating container was used to heat the fermented mass, causing it to vaporize. Made of stainless steel, it ensured durability and resistance to high temperatures, making it suitable for continuous distillation processes. Additionally, the heating container was versatile, as it could be heated by both induction and LP gas, providing flexibility in the distillation process and ensuring consistent and controlled heating.

**Distillation Column**

The distillation column played a crucial role in separating components based on their boiling points. It consisted of copper trays that enhanced separation efficiency for vapor-liquid interaction.

Figure 4.55: Distillation Column

Figure 4.54: Heating Container

**Reflux Condenser**

Reflux was a key component used to improve the efficiency of distillation. It allowed a portion of the condensed vapor to return to the column, helping to refine and increase the purity of the final product.

**Main Condenser**

A long condenser was used to cool and condense the vapor back into liquid form. Its extended length increased the heat exchange efficiency, ensuring maximum condensation.

**Short Condenser**

The short condenser served the same purpose as the main condenser but was more compact. It was typically used in systems where space constraints existed.

Figure 4.56: Main Condenser

Figure 4.57: Short Condenser

Figure 4.58: Reflux Condenser

**Ball Valve**

The ball valve was used to regulate the flow of cooling water in the condenser system. It allowed precise control of liquid movement, ensuring optimal cooling efficiency.

**Water Pump**

The water pump was responsible for circulating cooling water through the condenser system. Proper circulation ensured effective condensation of ethanol vapors. The condenser section was designed with a continuous water circulation system, where it was connected to a 12V battery-powered motor with a flow rate of 10 L/min, ensuring efficient cooling of the vapors. A controller was integrated to regulate the water flow rate, optimizing the condensation process for better separation efficiency.

Figure 4.59: Ball Valve

Figure 4.60: Water Pump

**Copper Trays**

The copper trays were designed and fabricated with two raisers and one downcomer to ensure optimal flow and separation during the distillation process. Copper trays also played an essential role in removing sulfur compounds from the alcohol vapors, thereby improving the quality and taste of the final distillate.

Figure 4.61: Top View of Tray

Figure 4.62: Side View of Tray

Figure 4.63: Tray with Gasket

Figure 4.65: Gasket

Figure 4.64: Copper Trays

### Gasket

Gaskets were used to create airtight seals between the various parts of the distillation apparatus. They prevent vapor leaks. For this project, gaskets were custom-made to the required dimensions using pressure cooker gaskets, which are durable, heat-resistant, and readily available.

### Complete Assembly

Figure 4.66: Distillation Apparatus Naked Setup

Figure 4.67: Side View of Distillation Apparatus

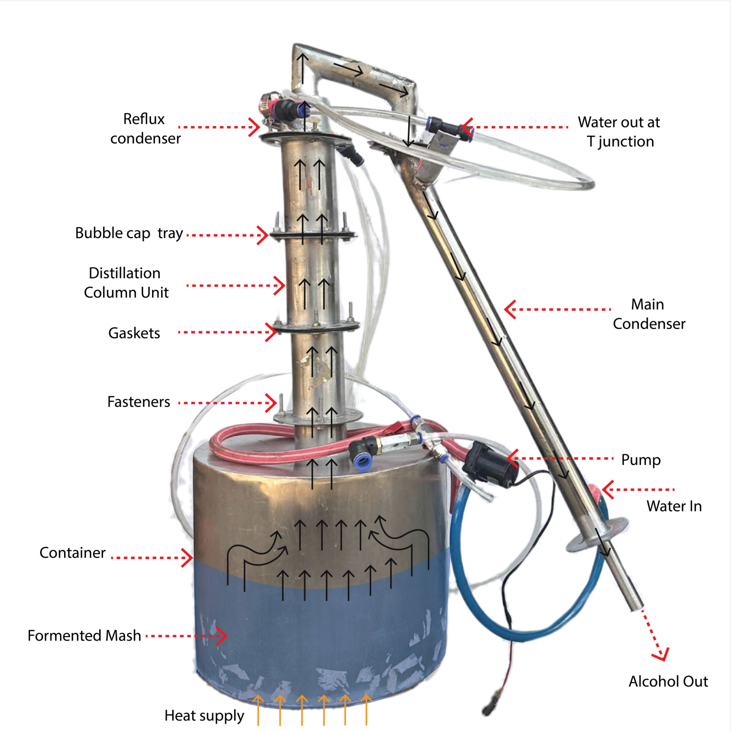


Figure 4.68: Front View of Distillation Apparatus

## 4.12 Experimental Setup

### 4.12.1 Feed Charging

The mash was shaken properly to ensure uniformity in composition. 8 liters of fermented mash was fed into the container for 1st batch. The specific gravity of the mash was recorded before heating. The initial alcohol content of the mash was determined using an alcoholmeter.

### 4.12.2 Device Assembly

The container and each of the other parts and components of the distiller were rinsed with distilled water to remove any impurities. The lower container was then connected to the column. The first gasket—internal—was placed on the flange of the container opening, followed by the second external gasket. Next, the first tray was positioned on top of the gasket to provide initial separation. The column was then assembled, ensuring a tight seal to minimize vapor loss. Each subsequent tray was stacked accordingly when used for tray-based tests.

The condenser was attached to the vapor outlet at the top of the column. The cooling water inlet and outlet were connected to the condenser to facilitate efficient condensation of the vaporized alcohol.

### 4.12.3 Piping

The distillation system was connected with stainless steel piping to ensure durability and minimize contamination. The steam output was directed through a controlled pathway to prevent pressure buildup. The joints were properly sealed with high temperature gaskets to prevent leaks. The reflux line was installed to allow partial condensation to return to the column, facilitating a controlled reflux ratio.

### 4.12.4 Condenser Initialization

To start the condenser, the pump was primed and activated to circulate the coolant. The coolant flow rate was initially set at 360 ml/min for 1st batch. The reflux ratio was adjusted by varying the cooling water flow rate and was continuously monitored.

### 4.12.5 Temperature Measurement

Thermocouples were placed at the following points:

- Bottom side of the container
- Above reflux

- Condenser inlet
- Condenser outlet
- Distillate outlet

Temperature readings were recorded at regular intervals using a data acquisition system to track the efficiency of heat transfer and phase separation.

### Temperature Reading Calibration

The temperature was measured by placing the thermocouple on the outer surface of the container, which could introduce errors in the readings. To address this, the temperature readings were calibrated for both the inside of the container and the outside wall of the container before conducting the tests.

Table 4.6: Temperature Calibration Inside and Outside Container

| **Time (minutes)** | **Inside Temperature (°C)** | **Outside Temperature (°C)** |
|---|---|---|
| 0.0 | 17.8 | 18.5 |
| 0.5 | 21.2 | 22.0 |
| 1.0 | 23.7 | 24.8 |
| 2.0 | 28.6 | 29.4 |
| 3.0 | 36.0 | 35.9 |
| 4.0 | 45.2 | 45.0 |
| 5.0 | 54.8 | 52.3 |
| 5.5 | 62.5 | 59.3 |
| 6.0 | 70.5 | 67.1 |
| 7.0 | 78.4 | 72.7 |
| 8.0 | 84.4 | 78.5 |
| 8.5 | 91.3 | 86.0 |
| 9.0 | 94.2 | 89.1 |
| 10.0 | 94.3 | 90.0 |
| 11.0 | 94.8 | 92.5 |
| 12.0 | 95.8 | 93.5 |
| 13.0 | 95.9 | 94.6 |
| 14.0 | 96.0 | 95.8 |
| 15.0 | 96.7 | 96.7 |
| 16.0 | 96.7 | 96.7 |

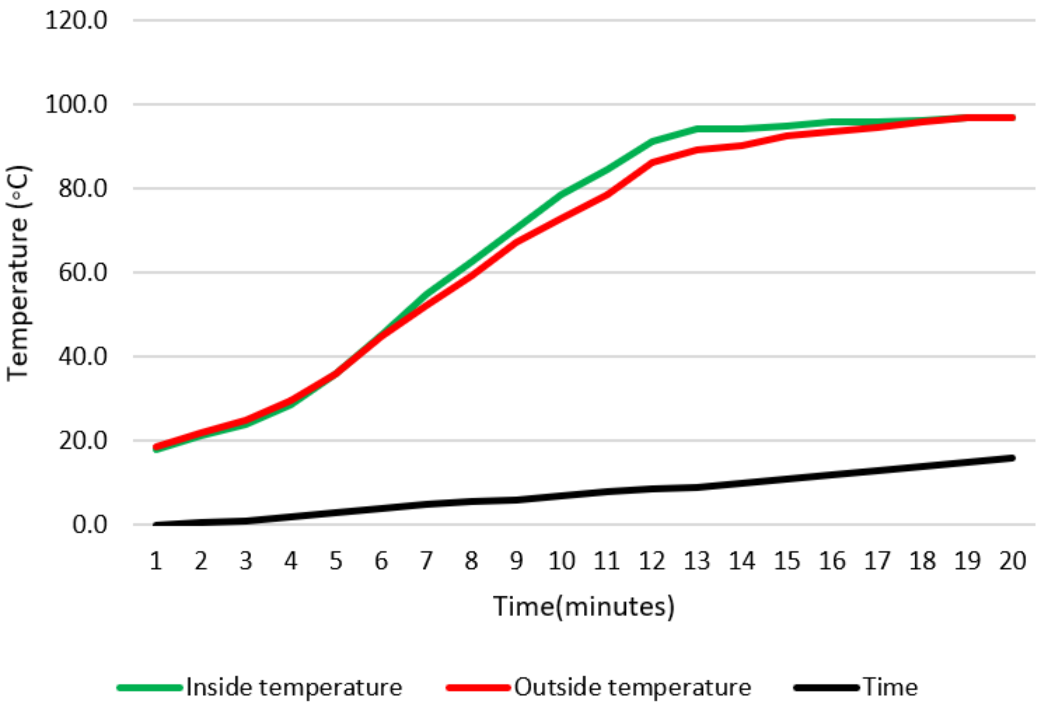


Figure 4.69: Temperature Inside Vs Outside Container

The data shows a slight variation in temperature during the heating phase. However, the temperatures coincide after the boiling point of water (95.65°C) is reached. This indicates that the system stabilizes at the boiling point of water, suggesting that the heat transfer process reaches equilibrium at this temperature.

### 4.12.6 Distillate Collector Setup and Concentration Measurement

The distillate was collected in a measuring cylinder equipped with an alcoholmeter to monitor the real-time alcohol concentration. The distillate then flowed directly into a beaker, where the real-time flow rate was observed and recorded. A timer was used to measure the elapsed time during the collection process.

Figure 4.70: Real-time Concentration and Flow Rate

## 4.13 Testing and Experimental Analysis

Four kinds of tests were carried out on the new distiller:

- Batch-1
- Batch-2
- Batch-3
- Batch-4

In the four batches, each batch was divided into two parts:

- The first part was collected during the initial given time period.
- The second part was collected separately during the final given time period.

The concentrations were measured by Alcoholmeter. The details of Part 1 for each of the four batches are provided below:

### 4.13.1 Batch-1

The initial 15 mL of the distillate (the ‘head’) was discarded to remove most of the methanol. The key observations included:

- Initial volume taken: **8 liters**
- Time taken to reach boiling point: **22 minutes**
- Power supplied: **3.905 kW** from Equation (3.13)
- Total time: **120 minutes**
- Rate of distillate collection: **10 ml/min**

- Reflux ratio: **3** from Equation ( 3.8)
- Alcohol concentration of distillate: **90%**

**Result:** Larger reflux ratio and longer duration heating provided better separation, yielding a higher alcohol concentration.

### 4.13.2 Batch-2

The distillation column was operated with the trays in place(later to compare with batch-4). The additional separation stages were expected to improve distillate purity. The initial 10 ml of distillate was discarded. Key observations:

- Initial volume taken: **4 liters**
- Time taken to reach boiling point: **10 minutes**
- Power supplied: **4.295 kW** from Equation(3.13)
- Total time: **45 minutes**
- Rate of distillate collection: **27 ml/min**
- Reflux ratio: **2.7** from Equation (3.8)
- Alcohol concentration of distillate: **68%**

**Result:** Due to the increased power of the stove (compared to Batch-1 in initial volume taken), more water was evaporated, which led to a decrease in the alcohol concentration.

### 4.13.3 Batch-3

The initial 20 ml of distillate was thrown away. The key observations included:

- Initial volume taken: **4 liters**
- Time taken to reach boiling point: **12 minutes**
- Power supplied: **3.579 kW** from Equation(3.13)
- Total time: **25 minutes**
- Rate of distillate collection: **45 ml/min**
- Reflux ratio: **0.79** from Equation (3.8)
- Alcohol concentration of distillate: **76%**

**Result:** Even if reflux ratio was low, due to shorter duration of the distillation process, lesser water was collected as ethanol has lower boiling point which causes more ethanol evaporation initially.

### 4.13.4 Batch-4

The Bubble Cap trays were removed, and the distillation was conducted without internal separation stages. The initial 10ml of distillate was thrown away. Key observations:

- Initial volume taken: **3.6 liters**
- Time taken to reach boiling point: **11 minutes**
- Power supplied: **3.514 kW** from Equation (3.13)
- Total time: **45 minutes**
- Rate of distillate collection: **23 ml/min**
- Reflux ratio: **1.55** from Equation (3.8)
- Alcohol concentration of distillate: **61%**

Table 4.7: Ethanol Concentration in Distillate Over Time(Batch-4)

| Time (mins) | Concentration (%) |
|---|---|
| 11 | 95 |
| 16 | 75 |
| 22 | 70 |
| 25 | 67 |
| 33 | 66 |
| 45 | 41 |
| 60 | 30 |

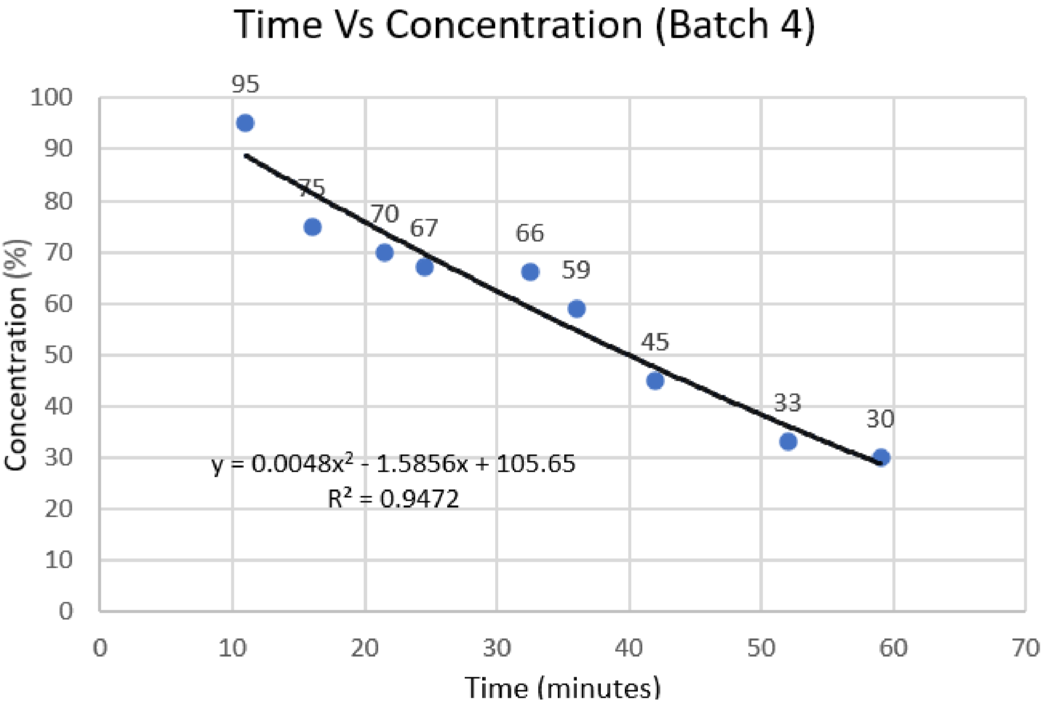


Figure 4.71: Temperature Inside Vs Outside Container

**Result:** Without trays, the alcohol concentration was lower, and the distillate contained visible impurities, requiring additional distillation cycles to achieve the desired purity. The table (4.7) and graph (Figure 4.71) show that the real time concentration decreases over time. Initially, more ethanol evaporates, leading to a higher concentration at the beginning of the process.

### 4.13.5 Distillate Samples

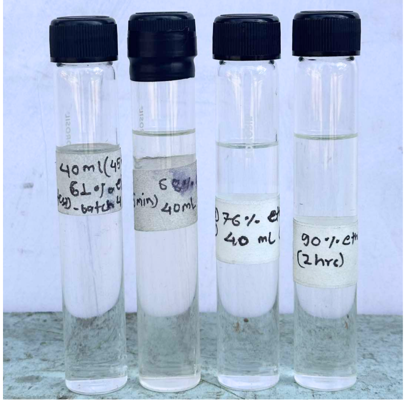


Figure 4.72: Samples of Alcohol Produced

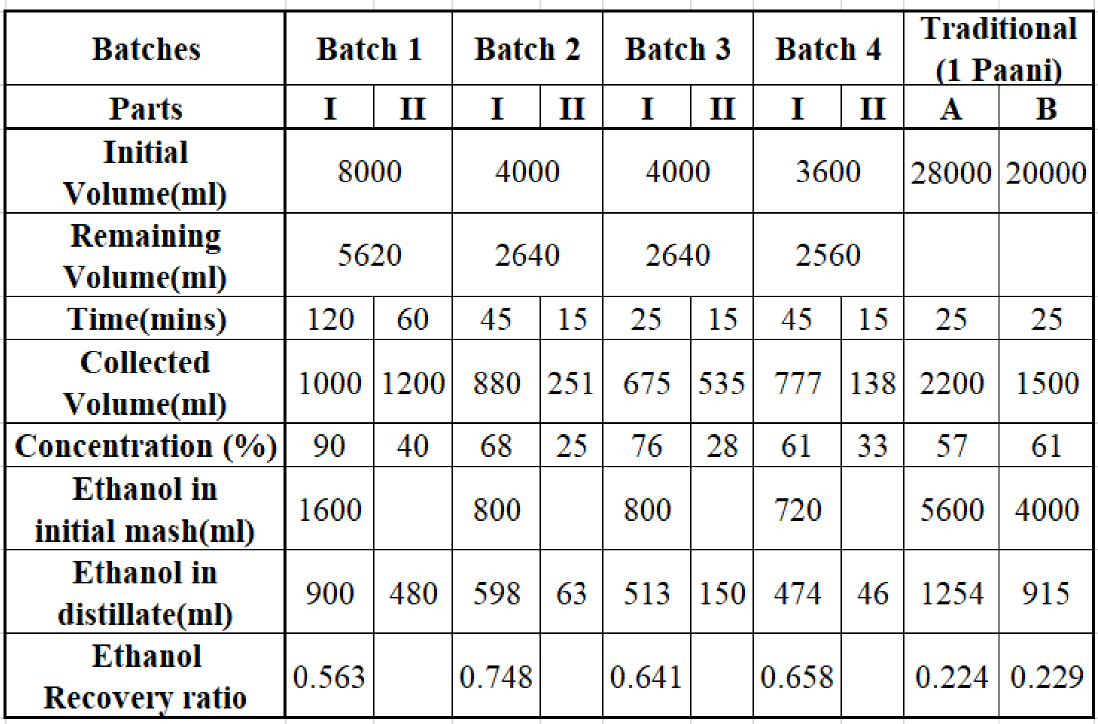
Figure 4.73: Collection of different Alcohol Batches

The alcohol batches were collected in bottles during the distillation process for storage. Samples from these batches were collected into borosilicate glass containers for further testing to determine their purity and other properties.

## 4.14 Comparative Analysis

The first to fourth batches were divided into two parts—Part 1 and Part 2—based on the initial and final minutes of collection, which were gathered separately. Additionally, traditional ‘1 paani A’ and ‘1 paani B’ were collected separately for different batches. All batches used the same initial mash with a 20 % ethanol (v/v) concentration.

Table 4.8: Comparative table for Different Batches and Traditional



| Batches | Batch 1 | | Batch 2 | | Batch 3 | | Batch 4 | | Traditional (1 Paani) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Parts | I | II | I | II | I | II | I | II | A | B |
| Initial Volume(ml) | 8000 | | 4000 | | 4000 | | 3600 | | 28000 | 20000 |
| Remaining Volume(ml) | 5620 | | 2640 | | 2640 | | 2560 | | | |
| Time(mins) | 120 | 60 | 45 | 15 | 25 | 15 | 45 | 15 | 25 | 25 |
| Collected Volume(ml) | 1000 | 1200 | 880 | 251 | 675 | 535 | 777 | 138 | 2200 | 1500 |
| Concentration (%) | 90 | 40 | 68 | 25 | 76 | 28 | 61 | 33 | 57 | 61 |
| Ethanol in initial mash(ml) | 1600 | | 800 | | 800 | | 720 | | 5600 | 4000 |
| Ethanol in distillate(ml) | 900 | 480 | 598 | 63 | 513 | 150 | 474 | 46 | 1254 | 915 |
| Ethanol Recovery ratio | 0.563 | | 0.748 | | 0.641 | | 0.658 | | 0.224 | 0.229 |

The traditional method takes slightly less time than Part 1 of the new distillation process. However, it results in a lower ethanol concentration and recovery ratio. In contrast, the new distillation method is more efficient, achieving higher ethanol recovery and concentration, making it a more effective extraction process overall.

Table 4.9: Concentration Determination from Alcoholmeter and Refractometer at 20°C

| Batch (Part I only) | Concentration (%) by Alcoholmeter | Refractive Index | Concentration (%) by Refractometer |
|---|---|---|---|
| Batch 1 | 90 | 1.3648 | 73.9 |
| Batch 2 | 68 | 1.3629 | 63.3 |
| Batch 3 | 76 | 1.3639 | 68.3 |
| Batch 4 | 61 | 1.3608 | 55.1 |
| Traditional 1 Paani (A) | 57 | 1.3604 | 53.7 |
| Traditional 1 Paani (B) | 61.3 | 1.3612 | 56.5 |

The alcohol concentration in different batches was tested using two tools: an alcoholometer and a refractometer. The alcoholometer gave direct readings, while the refractometer measured concentration based on the refractive index at 20°C, with tests done at the National Food Research Centre, NARC. The refractometer showed lower concentrations compared to the alcoholometer because, at high concentrations (above 50% alcohol), the refractive index curve flattens. This means that small changes in concentration cause only minor changes in refraction, making the refractometer less sensitive and less accurate at high alcohol levels. Despite this, both tools confirmed that the new distillation method produced higher ethanol concentrations and recovery rates than the traditional method, making it more effective.

### 4.14.1 FTIR Test

FTIR spectroscopy was performed on the different batches using the IRTracer-100 Fourier Transform Infrared Spectrophotometer. The test was conducted at the Central Department of Chemistry, Tribhuvan University to gather precise spectral data for each batch.

The FTIR spectra indicate that all the samples contain **methanol**, **ethanol**, and **water**. The presence of these compounds is confirmed by the characteristic peaks observed in the spectra, as detailed in the table above.

### 4.14.2 Food Safety Report

A sample of Batch 1 and Traditional 1 Paani (B) were sent to the Government of Nepal, Ministry of Agriculture and Livestock Development, Department of Food Technology and Quality Control, National Food and Feed Reference Laboratory for food safety testing. These batches were created from the same batch of fermented mash.

Table 4.10: Food Lab Test Results

| **Batch** | **Ethanol Concentration (%V/V)** | **Methyl Alcohol (mg/L) of Distilled Absolute Alcohol** | **Higher Alcohol as Amyl Alcohol (g/100 L of Distilled Absolute Alcohol)** |
|---|---|---|---|
| Batch 1 | 90.0 | Not Detected | 70.7 |
| Traditional 1 Paani (B) | 61.3 | Not Detected | 116.9 |

The measured ethanol content aligned closely with alcoholmeter readings, confirming consistency in concentration. Methanol was undetected in both samples, suggesting its absence or presence at levels below the detectable threshold. Additionally, a notable reduction in amyl alcohol content was observed in the new sample.

**Safety Recommendation:** Due to the distillate's high ethanol concentration, direct consumption is not advised. However, dilution to safe consumption levels (as per regulatory standards) renders it suitable for use.

## 4.15 Comparison of Theoretical and Experimental Analysis

### Compairision of 1 Pani from traditional distiller and Batch - 2 from new distiller:

**Initial mixture** ($W_i$)= 4000 ml
**Initial Concentration** ($X_{wi}$):20% = 0.25
**Desired Concentration** ($X_D$): 80% = 0.8
**Number of Theoretical Stages** (number of equilibrium stages) ($N_{th}$) = 5
**Number of trays** ($N$):

$$N = 5 - (\text{Reflux Condenser} + \text{Still Pot}) = 3$$

**Pressure** ($P$): 0.89 atm **Reflux ratio** ($R$) = 2.7

| Volume | Still Concentration | Distillate Concentration |
|---|---|---|
| $W_i = 4000$ ml | $X_{wi} = 0.18$ | $X_{di} = 0.95$ |
| $W_f = ?$ | $X_{wf} = ?$ | $X_{df} = 0.05$ |
| $D = ?$ | $X_{\text{avg}} = ?$ | |

**Slope of operating line:**

$$\frac{R}{R+1} = \frac{2.7}{2.7+1}$$
$$= \tan^{-1}(0.729)$$
$$= 36.11$$

**Rectifying Operating Line (ROL):**

$$y_{n+1} = \frac{R}{R+1} X_n + \frac{X_D}{R+1}$$

$$y_{n+1} = \frac{2.7}{2.7+1} X_n + \frac{X_D}{2.7+1}$$

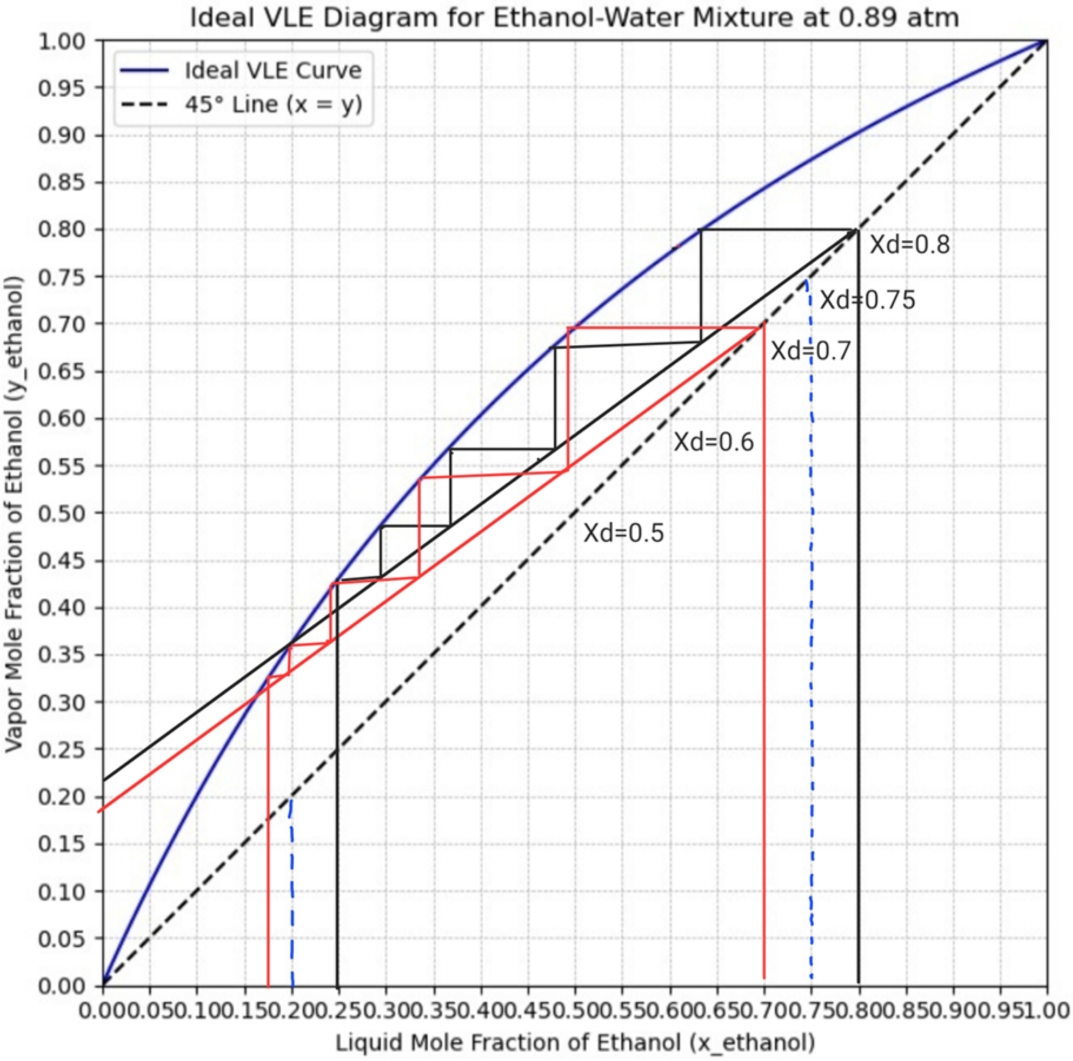


Figure 4.74: VLE Curve -McCabe-Thiele method

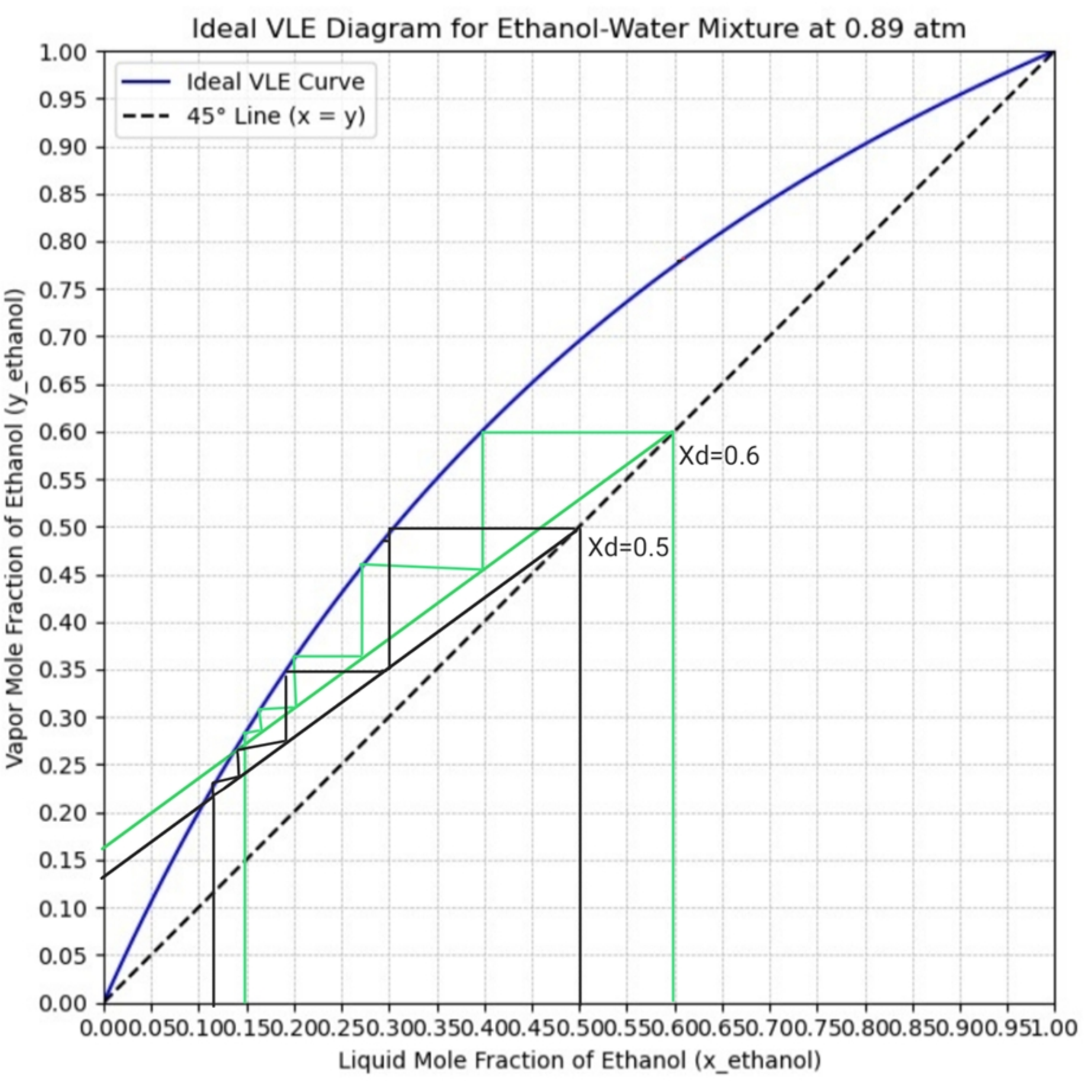


Figure 4.75: VLE Curve -McCabe-Thiele method

Generating table from above graph:

Table 4.11: Values of $X_d$, $X_w$, and $\frac{1}{X_d - X_w}$.

| $X_d$ | $X_w$ | $\frac{1}{X_d - X_w}$ |
|---|---|---|
| 0.9 | 0.36 | 1.851 |
| 0.8 | 0.24 | 1.818 |
| 0.75 | 0.205 | 1.834 |
| 0.7 | 0.16 | 1.851 |
| 0.6 | 0.15 | 2.220 |
| 0.5 | 0.10 | 2.500 |

- values for $X_d$=0.75 are calculated using interpolation.

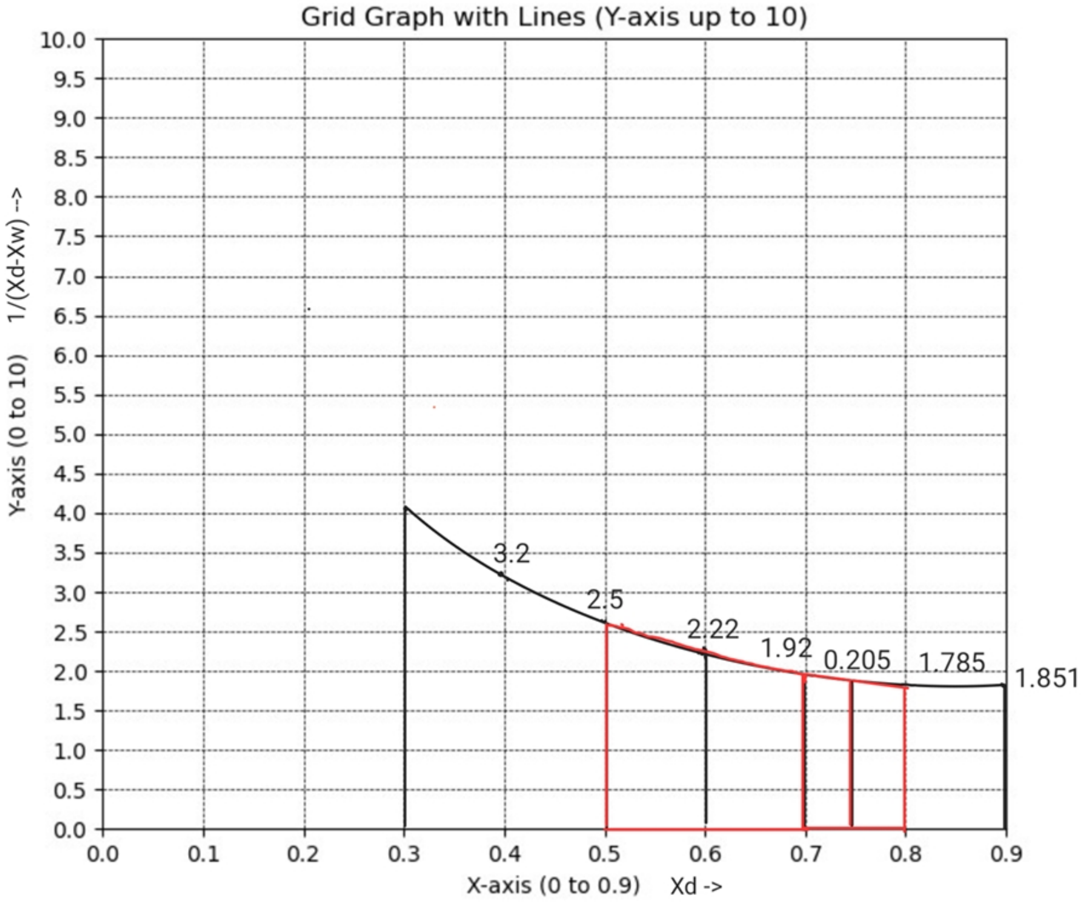


Figure 4.76: VLE Curve -McCabe-Thiele method

Using Rayleigh equation (Eqn 2.5):
To find right side of the equation, we add the area of each strip forming the trapizoid.

$$\int_{0.1}^{0.24} \frac{X_d}{X_d - X_\omega}$$

$$= \left(\frac{2.5+2.22}{2}\right) \times 0.1 + \left(\frac{2.22+1.92}{2}\right) \times 0.1 + \left(\frac{1.92+1.818}{2}\right) \times 0.1$$

$$= 0.628$$

$$\ln\left(\frac{w_i}{w_f}\right) = 0.628$$

$$w_f = \frac{4000}{1.873} = 2134.63 \text{ ml}$$

**Average Distillate Concentration**

$$X_{\text{avg}} = \frac{w_i X_i - w_f X_f}{w_i - w_f}$$

$$= \frac{4000 \times 0.25 - 2134.63 \times 0.10}{4000 - 2134.63} = 0.421$$

Cuts can be defined as the distillate quantities with different concentrations.

**First Cut** ($X_d = 0.8$ **to** $0.75$)
Using Rayleigh equation:

$$\ln\left(\frac{W_i}{W_f}\right) = \int_{0.20}^{0.24} \frac{X_d}{X_d - X_\omega} \qquad = \frac{1.8349 + 1.8182}{2} \times 0.05 = 0.091$$

$$W_f = 3652.6 \text{ ml}$$

**1st cut distillate** = 4000 - 3652.6 = 347.4 ml

$$X_{d_{avg}} = \frac{4000 \times 0.25 - 3652.6 \times 0.205}{4000 - 3652.6} = 0.723$$

**Second Cut** ($X_d = 0.75$ **to** $0.6$)

$$\frac{X_d}{X_d - X_w} = \frac{1.834 + 1.851}{2} \times 0.05 =$$

$$W_f = 3331.55 \text{ ml}$$

**2nd cut distillate** = 3652.6 - 3331.55 = 321.04 ml

$$X_{d_{avg}} = \frac{3652.6 \times 0.205 - 3331.55 \times 0.16}{321.04} = 0.67$$

**Conclusion:** Thus, in a similar fashion, different cuts of certain volumes as per calculation can be made. Or, we can get the overall distillate of overall concentration at the minimum distillate concentration.

The experimental results were compared with theoretical predictions using distillation equations and heat transfer models. The deviations observed were analyzed:

| **Parameter** | **Theoretical Result** | **Experimental Result(Batch 2** |
|---|---|---|
| Initial Volume (mL) | 4000 | 4000 |
| Initial Purity (%) | 20 | 20 |
| Distillate Purity (%) | 72.3 | 64 |

Table 4.12: Comparison of Theoretical and Experimental Results

The deviation from the theoretical values are due to following possible reasons:

- Heat source fluctuation
- Minor reflux variations affecting separation efficiency
- Variation in the boiling point due to impurities in the mash

In general, the experimental findings were close to theoretical predictions, validating the model with minor discrepancies. Adjustments in reflux ratio and heating rate could further improve accuracy in future trials.

## 4.16 Economic Analysis

From the distillation data, we observe significant variations in alcohol yield, efficiency, and cost effectiveness between traditional (Traditional 1 Paani A & B) and fabricated batch-based distillation (Batch 1–4).

Table 4.13: Comparison of Production Economics

| **Parameter** | **Trad 1 Paani (A)** | **Trad 1 Paani (B)** | **Batch 1** | **Batch 2** | **Batch 3** | **Batch 4** |
|---|---|---|---|---|---|---|
| Fermented Mass Used (mL) | 28000 | 20000 | 8000 | 4000 | 4000 | 3600 |
| Total time (min) | 25 | 25 | 120 | 45 | 25 | 45 |
| Distillate Produced (mL) | 2200 | 1500 | 1000 | 880 | 675 | 777 |
| Rate of distillate collection (mL/min) | 88 | 60 | 8.33 | 19.56 | 27 | 17.27 |
| Fuel Rate (Rs/min) | 0.67 | 0.67 | 0.22 | 0.67 | 0.67 | 0.67 |
| Alcohol Content (%) | 57 | 61.3 | 90 | 68 | 76 | 61 |
| Alcohol Produced (mL) | 1254 | 919.5 | 900 | 598.4 | 513 | 473.97 |
| Alcohol per 1000 mL of Ferment (mL) | 44.79 | 45.98 | 112.5 | 149.6 | 128.25 | 131.66 |
| Alcohol per Rs. 1 of Ferment (mL) | 1.79 | 1.84 | 4.5 | 5.98 | 5.13 | 5.27 |
| Alcohol per Rs. 1 of LPG (mL) | 74.87 | 54.90 | 34.09 | 19.85 | 30.63 | 15.72 |
| Total Ferment Cost (Rs) | 700 | 500 | 200 | 100 | 100 | 90 |
| Total Gas Cost (Rs) | 16.75 | 16.75 | 26.4 | 30.15 | 16.75 | 30.15 |
| Total Cost (Rs) | 716.75 | 516.75 | 226.4 | 130.15 | 116.75 | 120.15 |
| Total Cost per 100 mL Alcohol (Rs) | 57.16 | 56.20 | 25.16 | 21.75 | 22.76 | 25.35 |

### 4.16.1 Alcohol Yield per Fermented Mass

Traditional methods produced **44.79–45.98 mL** of alcohol per **1000 mL** of ferment. Batch distillation performed significantly better, yielding up to **149.6 mL per 1000 mL** in Batch 2, showing higher efficiency.

### 4.16.2 Cost Efficiency

In terms of **alcohol per Rs. 1 of ferment**, traditional methods yield around **1.79–1.84 mL**, whereas batch methods go up to **5.98 mL** (Batch 2), making batch distillation more cost-efficient. However, for **alcohol per Rs. 1 of LPG**, traditional methods appeared more fuel-efficient (**74.87 mL per Rs. 1 in Trad 1 Paani A**) compared to batch methods (**as low as 15.72 mL in Batch 4**). Since **20,000 mL of ferment has not been used in batch methods**, further testing is needed. If we extrapolate, batch distillation might actually prove **more fuel-efficient** than the current numbers suggest.

### 4.16.3 Total Cost per 100 mL Alcohol

Traditional method costed **Rs. 56.20–Rs. 57.16** per **100 mL of alcohol**, whereas batch methods have lower costs, ranging from **Rs. 21.75–Rs. 25.35**, making them more economical.

### 4.16.4 Economic Viability

- **Alcohol Yield per unit Ferment** is significantly higher (up to **226%** more alcohol) in fabricated method.
- **Production Cost per unit Alcohol** is significantly lower in fabricated method (approximately **60%** cheaper).
- **Fuel costs** seemed higher in fabricated method, but efficiency can improve with larger ferment volumes. Since batch methods did not utilize 20,000 mL of ferment as in traditional distillation, further testing is required to determine if efficiency can be improved with higher input volumes. Extrapolated data suggests that batch distillation could potentially become more fuel-efficient with optimized setups.

## 4.17 Budget Analysis

For our project, a substantial portion of the budget was dedicated to fabricating the distillation apparatus. A comprehensive breakdown of the cost is outlined in the table below:

Table 4.14: Cost Breakdown of the Project

| **Component** | **Quantity** | **Rate (Rs)** | **Total Cost (Rs)** |
|---|---|---|---|
| Steel & Fabrication | 1 | 35000 | 35000 |
| Pipes, connectors | 1 | 2550 | 2550 |
| Gaskets | 7 | 250 | 1750 |
| Copper (rod, plate) | 2 | 1000 | 2000 |
| Brazing, rod & flux | 1 | 800 | 800 |
| Aluminum Tape | 1 | 450 | 450 |
| Temperature sensor | 7 | 250 | 1750 |
| Water pump | 1 | 650 | 650 |
| Alcoholmeter | 1 | 750 | 750 |
| Glass bottle | 4 | 175 | 700 |
| Fermented mash | 1 | 500 | 500 |
| Laboratory testing | 2 | 2050 | 4100 |
| Miscellaneous | - | 1000 | 1000 |
| **Total** | - | - | **52000** |

## 4.18 Comparison Between New Distiller and Traditional Distiller

Traditional distiller and new apparatus were compared on the following basis:

- The final distiller ensures complete airtight operation, avoiding leakage.
- Continuous vapor condensation is achieved in the final distiller.
- The final design exhibits a higher recovery ratio compared to traditional systems.
- Traditional distillers lack real-time concentration measurement capability.
- The effective fractionation of head (mainly methanol), heart, and tail components is successfully implemented in the new distiller.
- Reflux control enables precise regulation of the distillate flow rate.

## 4.19 Flexibility of the Equipment

The apparatus is flexible for following reasons:

- The equipment follows the design for assembly.
- Number of trays and column unit can be increased or decreased as per required purity.
- Capacity of the container can be increased if needed.
- Condenser can be replaced with different kind and capacity if needed.
- Reflux ratio can be varied in certain proportion to maintain constant concentration.

## 4.20 Limitations

The limitations of this project include:

1. **Insufficient Water Supply**: The unavailability of enough water for the condenser affected the cooling efficiency and calculations of reflux ratio.
2. **Limited Batch Testing**: Only four small batches were tested during this phase, with only two undergoing laboratory analysis. Conducting additional tests would provide more consistent results and enable a deeper evaluation of the system's performance.
3. **Inaccurate Power Measurement**: The power of the gas stove could not be accurately measured, leading to inconsistencies in heat input.
4. **Inconsistent Water Flow Rate**: The inconsistent flow rate of the water pump caused variations in the reflux ratio, impacting the distillation process.
5. **Environmental Variability**: Fluctuations in ambient temperature introduced uncertainties in the performance analysis.

## 4.21 Problems Faced

The challenges encountered during the project were:

1. **Container Fabrication Issues:** During the fabrication of the base container, the middle portion curved inward due to the heat generated during welding. This deformation prevented the container from sitting flat on the induction stove, making it unsuitable for testing.
2. **Issue with Flange Thickness and Gasket Positioning:** We initially did not perform a stress or deformation analysis of the column flange, so a smaller thickness was used. Gaskets were placed only inside the nut bolts, which caused the outer part of the flange to deform when the nut bolts were tightened. Later, we added gaskets to the outer side as well, which helped distribute the stress more evenly.
3. **Water Leakage Issue:** Initial testing revealed leakage at connection points when straight connectors were bent during operation. This problem was resolved by replacing the straight connectors with L-shaped variants, which accommodated bending without compromising the seal, effectively eliminating the leakage.
4. **Tool Shortage:** Due to the unavailability of essential fabrication tools such as drill bits, we resorted to using welding to create holes for nut and bolt connections.
5. **Unavailability of Food-Grade Gaskets:** We were unable to find food-grade flat

silicone gaskets, which are essential for ensuring a safe and airtight seal.

6. **Heating Power:** We tried to heat the mash by induction heater, but induction heater didn’t have enough power. Later we used LP Gas stove.
7. **Workshop Limitations:** Insufficient workshop facilities caused delays in testing the system.
8. **Temperature Measurement Discrepancies:** During the visit to the alcohol producer, discrepancies were observed between the temperature readings from different devices, necessitating cross-verification and additional data collection.

# CHAPTER 5: CONCLUSION AND FUTURE ENHANCEMENT

## 5.1 Conclusion

Our redesigned distillation setup made a big difference in how Raksi is produced. Compared to the traditional system, the ethanol concentration in the final product went up from about 61% to as high as 90%, which means the alcohol was much purer. We also saw the recovery ratio jump from 0.22 to 0.75, a clear sign that more ethanol was being collected efficiently.

One of the major improvements was the drop in amyl alcohol content, from 116.9 g/100L to 70.7 g/100L, which helps make the drink smoother and safer. And most importantly, there was no trace of methanol in the distillate, which is a big safety win, especially since methanol can be very harmful.

These results show that our new design works well. It solves many of the problems found in the traditional process like leaks, waste, and inconsistent quality and offers a reliable and scalable option for local or small-scale producers. In the future, we hope to improve the system even more by adapting it for different raw materials and adding automation for better control and easier operation.

## 5.2 Scope for Future Enhancement

The following areas present potential avenues for future research and enhancements in the distillation system:

1. **Control System Improvements**:
    - Develop advanced control systems to automate and optimize the distillation process, ensuring more consistent product quality and energy efficiency.
    - Test the new distillation apparatus in real-world settings to gather comprehensive performance data and validate its effectiveness.
2. **Condenser Design Optimization**:
    - Optimize the condenser design to enhance heat transfer efficiency and reduce energy consumption.
    - Explore the use of advanced materials and coatings to improve corrosion

resistance and durability.

3. **CFD Simulations and Real-World Testing**:
    - Conduct additional CFD simulations to improve the accuracy of vapor formation and flow dynamics predictions.
    - Perform real-world testing to validate simulation results and ensure reliable system performance.
4. **Experimental Setup Advancements**:
    - Integrate more precise temperature sensors and flow meters to enhance data collection and analysis.
    - Improve fabrication tools and techniques to ensure higher-quality components.
5. **Experiments with Various Raw Materials**:
    - Conduct experiments with different types of molasses, agricultural waste, or other feedstocks to evaluate the scalability and versatility of the distillation system.
    - Investigate the impact of feedstock composition on bioethanol yield, purity, and production efficiency.
6. **Bioethanol Blending**:
    - Investigate the blending of bioethanol produced from this apparatus with conventional fuels to evaluate its potential as a sustainable energy source.
    - Study the effects of bioethanol blending on engine performance, emissions, and fuel efficiency.
    - Explore the production of bioethanol from various feedstocks, such as agricultural waste, algae, or lignocellulosic biomass, to improve sustainability and reduce production costs.
    - Analyze the economic and environmental benefits of bioethanol blending in comparison to traditional fossil fuels.
7. **Study in Entrepreneurial Aspect**: The improved distillation system presents a strong entrepreneurial opportunity, especially for small-scale liquor producers seeking to enhance product quality, safety, and efficiency. By offering a scalable and cost-effective solution, the system can support local entrepreneurship, promote safer alcohol production practices, and open avenues for commercialization of high-quality traditional liquors like Raksi. Further market studies and business model development could strengthen its commercial viability.

# REFERENCES

[1] Ana Blandino, ME Al-Aseeri, SS Pandiella, D Cantero, and C Webb. Cereal-based fermented foods and beverages. *Food research international*, 36(6):527–543, 2003.

[2] VK Joshi, Matteo Bordiga, Fernanda Cosme, Laura Farina, Ronald S Jackson, Aline Lonvaud, António Manuel Jordão, and Creina Stockley. *Concise Encyclopedia of Science and Technology of Wine*. CRC Press, 2021.

[3] Evance Pakuwal and PRAKASH Manandhar. Production of rice based alcoholic beverages and their quality evaluation. *J. Food Sci. Technol. Nepal*, 12:37–48, 2020.

[4] CNN Tim Cheung. World's 50 most delicious drinks, 2011.

[5] Roman Karki, Dhan Bahadur Karki, Pravin Ojha, Ranjan Shrestha, Prakriti Basnet, Sushma Maharjan, Utshah Manandhar, and Kabina Karki. Traditional fermentation practices and brewing dynamics of nepalese millet-based alcoholic beverages.

[6] DB Karki. *Improvement on Traditional Millet Fermentation Process and Its Brewing Quality Assessment*. Doctoral dissertation, Central Department of Food Technology, TU, Nepal, 2013.

[7] Government of Nepal. *Liquor Act, 2031*. 2031.

[8] ShareSansar. 84.75 billion revenue collected from cigarettes and alcohol, 2023. Accessed: 2024-12-16.

[9] Market Data Forecast. Soju market size, share, analysis & trends, 2032, 2024. Accessed: 2024-12-16.

[10] Grand View Research. Soju market size, share and growth analysis report, 2030, 2024. Accessed: 2024-12-16.

[11] Grand View Research. Sake market size, share and growth analysis report, 2024-2028, 2024. Accessed: 2024-12-16.

[12] Grand View Research. Baijiu market size, share and growth analysis report, 2024,

2024. Accessed: 2024-12-16.

[13] Jyoti Prakash Tamang. *Ethnic fermented foods and alcoholic beverages of Asia*, volume 409. Springer, 2016.

[14] Ramesh Raj Kunwor. Nepalese society: Liquor and culture. *Ancient Nepal*, 81:1–31, 1984.

[15] Jyoti Tamang, Prabir Sarkar, and Clifford Hesseltine. Traditional fermented foods and beverages of darjeeling and sikkim - a review. *Journal of the Science of Food and Agriculture*, 44:375 – 385, 01 1988.

[16] Achyut Mishra and Roman Karki. Rice products diversiàcation in context of nepalese culture.

[17] N Thapa, KK Aryal, M Paudel, R Puri, P Thapa, S Shrestha, and B Stray-Pedersen. Nepalese homebrewed alcoholic beverages: Types, ingredients, and ethanol concentration from a nation wide survey. *Journal of Nepal Health Research Council*, 13(29):59–65, 2015.

[18] Apurba Acharya, Sushma Kaphle, Bijay Aryal, and Arbin Shakya. Analysis of methanol content in different varieties of traditionally fermented alcohol found in chandannath municipality of jumla district, nepal. *Journal of Karnali Academy of Health Sciences*, 6:42–46, 12 2023.

[19] Taedong Kim and Taewon Seo. Numerical analysis of an ethanol-water distillation system using computational fluid dynamics (cfd). *Internationa Journal of Mechanical and Mechatronics Engineering (IJMME-IJENS)*, 14(04), 2014.

[20] BC Rankine. Formation of higher alcohols by wine yeasts, and relationship to taste thresholds. *Journal of the Science of Food and Agriculture*, 18(12):583–589, 1967.

[21] Zinedine Khatir, Joe Paton, Harvey Thompson, Nik Kapur, Vassili Toropov, Malcolm Lawes, and Daniel Kirk. Computational fluid dynamics (cfd) investigation of air flow and temperature distribution in a small scale bread-baking oven. *Applied Energy*, 89(1):89–96, 2012.

[22] Volker Engel. How to design and optimize bubble cap trays. *WelChem Process Technology*, (Part 2), 2020. Published in the IACPE Magazine, April 2020.

[23] Phillip C. Wankat. *Separation Process Engineering: Includes Mass Transfer Analysis*. Pearson, 4 edition, 2016.

[24] European Space Agency. Kathmandu valley elevation, 2024. Accessed: 2025-03-07.

[25] The Engineering ToolBox. Overall heat transfer coefficient: Definitions, values & applications. Online, 2003. Accessed: 9 March 2025.

# ANNEX

## ANNEX 1: Field Visit and Fabrication Photos

The following images were captured during the field visits and fabrication process. These photos document practical implementation steps, including on-site observations, component assembly, and workshop fabrication.

*F*ig. A1: Bata (Condenser)

*F*ig. A2: Nani (Distillate Collector)

Fig. A3: *Paini* (Condensation Chamber)

Fig. A4: Top view of *Paini*

Fig. A5: *Phonsi* (Mash Boiler)

Fig. A6: Measurement of condensing water temperature

Fig. A7: Measurement of mash temperature

Fig. A8: Collection of Distillate from *Naani*

Fig. A9: Volumetric Measurement of the distilled Alcohol

Fig. A10: Column Manufacturing

Fig. A11: Reflux Condenser manufacturering

Fig. A12: Copper Brazing for Bubble Caps

Fig. A13: Drilling of Bubble Caps

Fig. A14: Bubble Caps

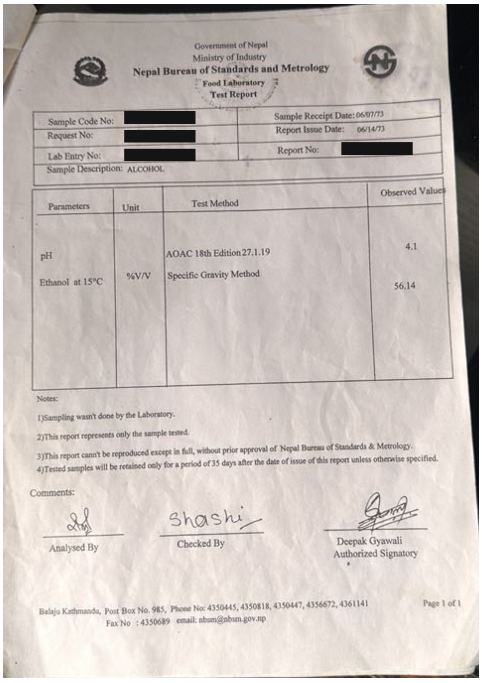
Fig. A15: Bubble Cap Tray after use

Fig. A16: Volumetric Measurement of remaining Fermented Mass

Fig. A17: Bubble Cap Tray after use

# ANNEX 2: Research Compliance Documentation

This annex contains supporting documentation related to research compliance, including lab test reports and testing equipment.


Government of Nepal
Ministry of Industry
**Nepal Bureau of Standards and Metrology**
**Food Laboratory**
**Test Report**

Sample Code No: [redacted]
Request No: [redacted]
Lab Entry No: [redacted]
Sample Description: ALCOHOL
Sample Receipt Date: 06/07/73
Report Issue Date: 06/14/73
Report No: [redacted]

| Parameters | Unit | Test Method | Observed Values |
|---|---|---|---|
| pH | | AOAC 18th Edition 27.1.19 | 4.1 |
| Ethanol at 15°C | %V/V | Specific Gravity Method | 56.14 |

Notes:

1)Sampling wasn't done by the Laboratory.

2)This report represents only the sample tested.

3)This report cann't be reproduced except in full, without prior approval of Nepal Bureau of Standards & Metrology.

4)Tested samples will be retained only for a period of 35 days after the date of issue of this report unless otherwise specified.

Comments:

Analysed By

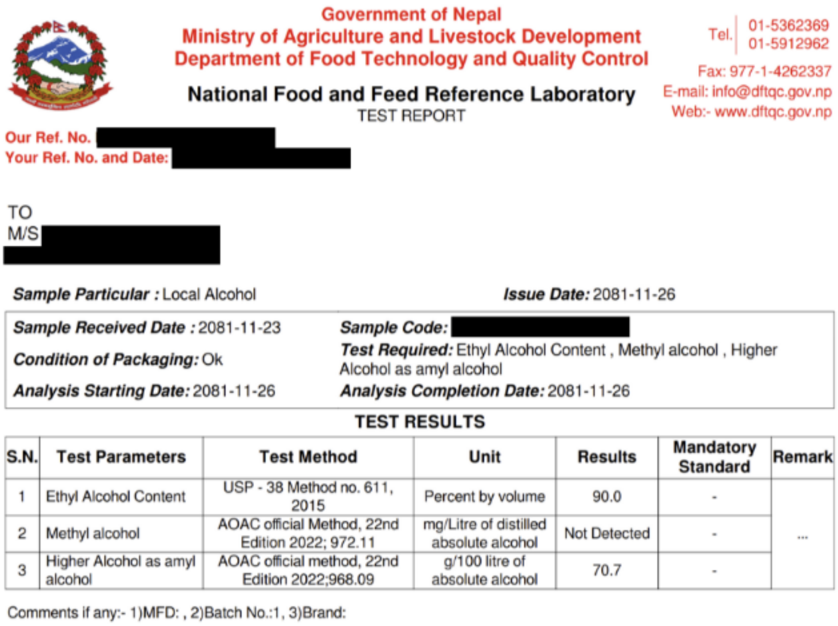
Shashi
Checked By

Deepak Gyawali
Authorized Signatory

Balaju Kathmandu, Post Box No. 985, Phone No: 4350445, 4350818, 4350447, 4356672, 4361141
Fax No : 4350689 email: nbsm@nbsm.gov.np
Page 1 of 1

Fig. A18: Test Report of *Ek Paani* Alcohol

Fig. A19: Testing Alcohol Concentration using Refractometer


Government of Nepal
Ministry of Agriculture and Livestock Development
Department of Food Technology and Quality Control
**National Food and Feed Reference Laboratory**
TEST REPORT

Tel. 01-5362369
01-5912962
Fax: 977-1-4262337
E-mail: info@dftqc.gov.np
Web:- www.dftqc.gov.np

**Our Ref. No.** [redacted]
**Your Ref. No. and Date:** [redacted]

TO
M/S [redacted]

***Sample Particular :*** Local Alcohol
***Issue Date:*** 2081-11-26

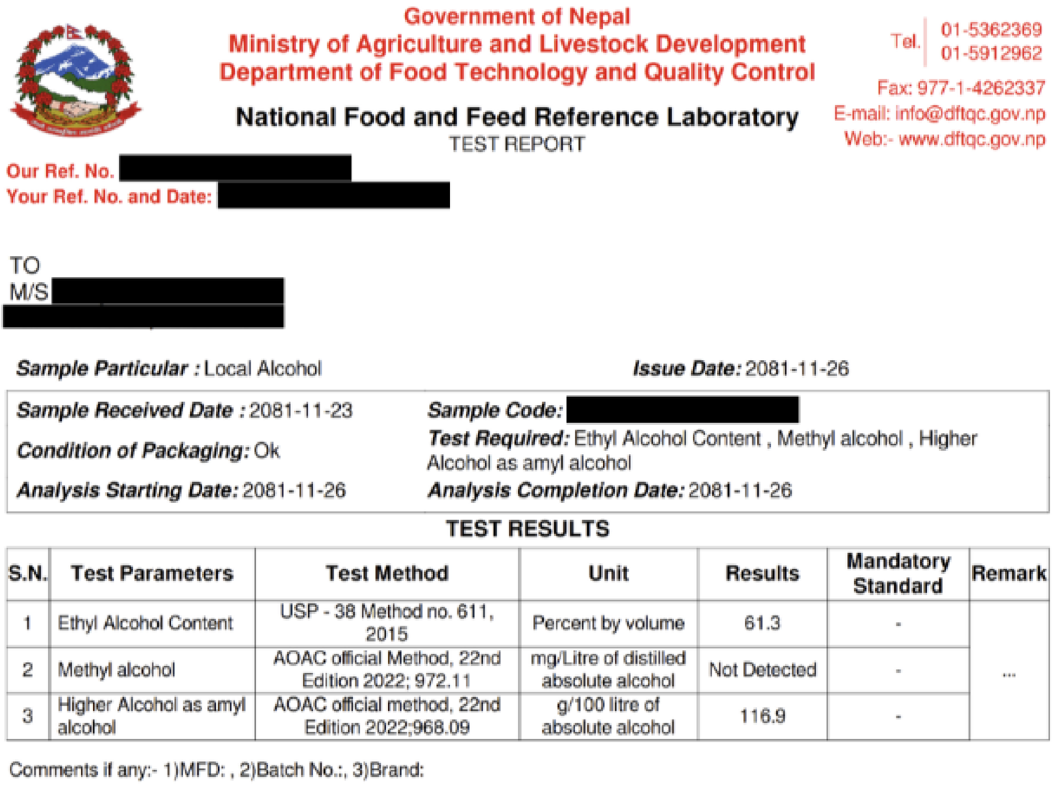
***Sample Received Date :*** 2081-11-23
***Condition of Packaging:*** Ok
***Analysis Starting Date:*** 2081-11-26
***Sample Code:*** [redacted]
***Test Required:*** Ethyl Alcohol Content , Methyl alcohol , Higher Alcohol as amyl alcohol
***Analysis Completion Date:*** 2081-11-26

**TEST RESULTS**

| S.N. | Test Parameters | Test Method | Unit | Results | Mandatory Standard | Remark |
|---|---|---|---|---|---|---|
| 1 | Ethyl Alcohol Content | USP - 38 Method no. 611, 2015 | Percent by volume | 90.0 | - | |
| 2 | Methyl alcohol | AOAC official Method, 22nd Edition 2022; 972.11 | mg/Litre of distilled absolute alcohol | Not Detected | - | ... |
| 3 | Higher Alcohol as amyl alcohol | AOAC official method, 22nd Edition 2022;968.09 | g/100 litre of absolute alcohol | 70.7 | - | |

Comments if any:- 1)MFD: , 2)Batch No.:1, 3)Brand:

Fig. A20: Lab report of Batch 1



Government of Nepal
Ministry of Agriculture and Livestock Development
Department of Food Technology and Quality Control

**National Food and Feed Reference Laboratory**
TEST REPORT

Tel. 01-5362369
01-5912962
Fax: 977-1-4262337
E-mail: info@dftqc.gov.np
Web:- www.dftqc.gov.np

Our Ref. No. [redacted]
Your Ref. No. and Date: [redacted]

TO
M/S [redacted]

***Sample Particular :*** Local Alcohol

***Issue Date:*** 2081-11-26

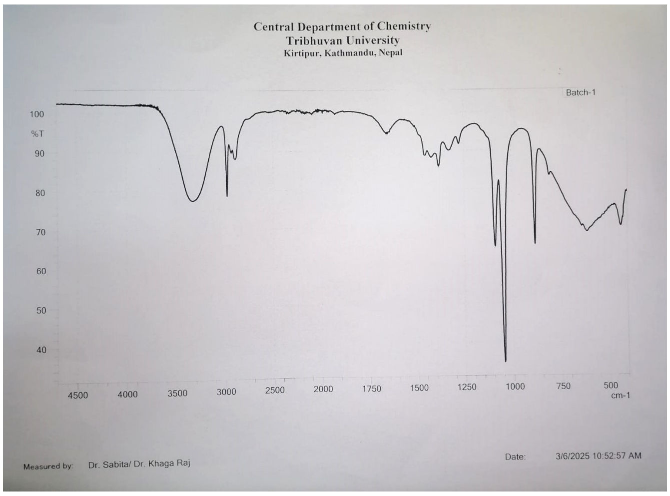
|  |  |
|---|---|
| ***Sample Received Date :*** 2081-11-23 | ***Sample Code:*** [redacted] |
| ***Condition of Packaging:*** Ok | ***Test Required:*** Ethyl Alcohol Content , Methyl alcohol , Higher Alcohol as amyl alcohol |
| ***Analysis Starting Date:*** 2081-11-26 | ***Analysis Completion Date:*** 2081-11-26 |

**TEST RESULTS**

| S.N. | Test Parameters | Test Method | Unit | Results | Mandatory Standard | Remark |
|---|---|---|---|---|---|---|
| 1 | Ethyl Alcohol Content | USP - 38 Method no. 611, 2015 | Percent by volume | 61.3 | - | ... |
| 2 | Methyl alcohol | AOAC official Method, 22nd Edition 2022; 972.11 | mg/Litre of distilled absolute alcohol | Not Detected | - |  |
| 3 | Higher Alcohol as amyl alcohol | AOAC official method, 22nd Edition 2022;968.09 | g/100 litre of absolute alcohol | 116.9 | - |  |

Comments if any:- 1)MFD: , 2)Batch No.:, 3)Brand:

Fig. A21: Lab report of Traditional 1 Paani (B)



Central Department of Chemistry
Tribhuvan University
Kirtipur, Kathmandu, Nepal

Measured by: Dr. Sabita/ Dr. Khaga Raj

Date: 3/6/2025 10:52:57 AM

Fig. A22: Batch-1: FTIR Spectra

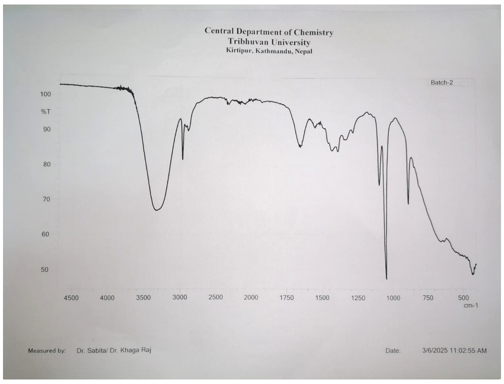


Fig. A23: Batch-2 FTIR Spectra

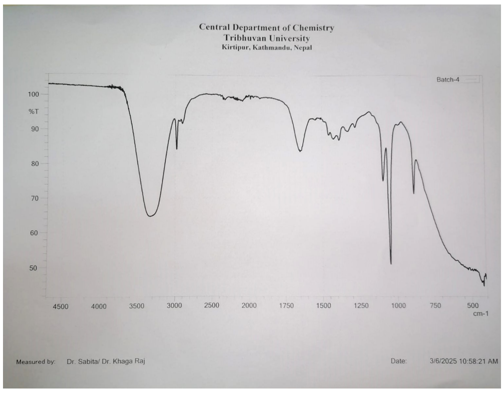


Fig. A24: Batch-4 FTIR Spectra

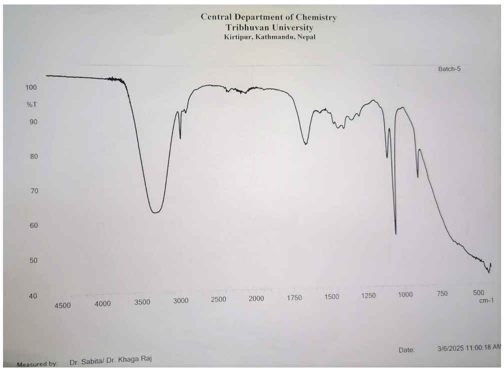


Fig. A25: Traditional 1 Paani FTIR Spectra

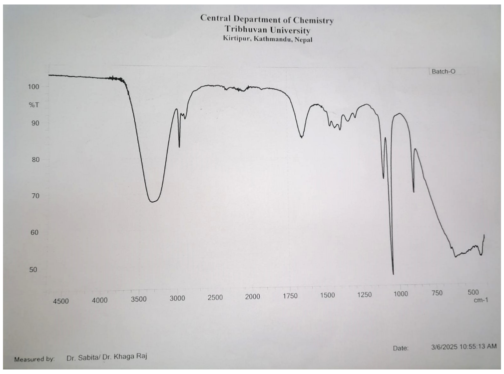


Fig. A26: Traditional 3 Paani FTIR Spectra

# ANNEX 3: MATLAB Codes

### 5.2.1 VLE Curve

```
%VLE Curve
% Constants
P_total = 0.89 * 760;  % Total pressure in mmHg

% Antoine equation coefficients
% log10(P) = A - B / (T + C), P in mmHg, T in  C
antoine_ethanol = [8.20417, 1642.89, 230.300];  % [A, B, C] for Eth
antoine_water = [8.07131, 1730.63, 233.426];    % [A, B, C] Water

% Temperature range (in  C )
T_range = linspace(78, 100, 100);

% Function to compute vapor pressure using Antoine equation
vapor_pressure = @(T, coeffs) 10.^(coeffs(1) - ...
    coeffs(2) ./ (T + coeffs(3)));

% Liquid phase mole fractions of ethanol
x_ethanol = linspace(0, 1, 100);
y_ethanol = zeros(size(x_ethanol));  % Initi. vapor phase mole frac

% Calculate VLE using Raoult's Law
for i = 1:length(x_ethanol)
    x1 = x_ethanol(i);

    % Calculate vapor pressures
    P_eth = vapor_pressure(T_range, antoine_ethanol);
    P_wat = vapor_pressure(T_range, antoine_water);

    % Calculate total pressure
    P_total_calc = x1 .* P_eth + (1 - x1) .* P_wat;

    % Calculate vapor phase mole fraction of ethanol
    y1 = (x1 .* P_eth) ./ (x1 .* P_eth + (1 - x1) .* P_wat);

    % Find the temperature index where total pressure     P_total
    [~, idx] = min(abs(P_total_calc - P_total));

    % Store the corresponding vapor mole fraction
    y_ethanol(i) = y1(idx);
end

% Plotting
figure;
```

```
plot(x_ethanol, y_ethanol, 'b-', 'LineWidth', 2); hold on;
plot([0, 1], [0, 1], 'k--', 'LineWidth', 1.5);  % 45-degree line

% Axis formatting
xticks(0:0.05:1);
yticks(0:0.05:1);
grid on;
xlabel('Liquid Mole Fraction of Ethanol (x_{ethanol})');
ylabel('Vapor Mole Fraction of Ethanol (y_{ethanol})');
title('Ideal VLE Diagram for Ethanol-Water Mixture at 0.89 atm');
legend('Ideal VLE Curve', '45   Line (x = y)', ...
    'Location', 'NorthWest');
axis([0 1 0 1]);
axis square;
```

Listing 5.1: VLE Curve

### 5.2.2 Boiling Point Calculation

```
% BPT calculation
clc; clear; format long;

% Constants
P1 = 101325;        % Atmospheric pressure at sea level (Pa)
g = 9.81;           % Acceleration due to gravity (m/s^2)
M_air = 28.97e-3;   % Molar mass of dry air (kg/mol)
R = 8.314;          % Universal gas constant (J/(mol K))
h = 1350;           % Elevation of Kathmandu (m)
T_298 = 298;        % Reference temp. for barometric formula (K)

% Barometric formula to calculate pressure at Kathmandu
exponent = -(g * M_air * h) / (R * T_298);
P2 = P1 * exp(exponent); % Atmospheric pressure at Kathmandu (Pa)

% Clausius-Clapeyron equation for ethanol
delta_Hvap_e = 38500;   % Enthalpy of vap. of eth (J/mol)
T1_e = 351.45; % bpt of ethanol at sea level (K, 78.3 C )

% Clausius-Clapeyron equation for water
delta_Hvap_w = 40700;   % Enthalpy of vap. of water (J/mol)
T1_w = 373.15;         % bpt of water at sea level (K, 100 C )

% Compute lhs of Clausius-Clapeyron equation (same for both)
lhs = log(P2 / P1);

% Compute boiling point for ethanol
inv_T2_e = (1 / T1_e) - (lhs * R) / delta_Hvap_e;
```

```
T2_e = 1 / inv_T2_e;
T2_Celsius_e = T2_e - 273.15;

% Compute boiling point for water
inv_T2_w = (1 / T1_w) - (lhs * R) / delta_Hvap_w;
T2_w = 1 / inv_T2_w;
T2_Celsius_w = T2_w - 273.15;

% Display results
fprintf(['The boiling point of ethanol at Kathmandu ' ...
    'is approximately %.2f C.\n'], T2_Celsius_e);
fprintf(['The boiling point of water at Kathmandu ' ...
    'is approximately %.2f C.\n'], T2_Celsius_w);
```

Listing 5.2: Boiling Point of Ethanol and Water

### 5.2.3 Condenser Design

```
% Condenser length calculation
clc; clear; close all;

rho_eth = 789;
rho_water = 1000;
T_in_vapour = 96;
T_out_vapour = 36.1;
T_in_water = 18.3;
T_out_water = 25;
dT1 = T_in_vapour - T_out_water;
dT2 = T_out_vapour - T_in_water;
dTlm = (dT1-dT2)/(log(dT1/dT2));

D_2 = 3*0.0254;
D_o = 0.75*0.0254;
D_i = D_o;
D_s = (D_2+D_o)/2;
A_s = pi*D_o^2/4;

L_ethanol = 838000;         % Latent heat of ethanol (J/kg)
L_water = 2260000;
S_water = 4184;
S_ethanol = 2440;
k_steel = 15;     % heat transfer coefficient of steel
C_ethanol = 40/100;

V_vapour = 1500/(15*60*1e6);
U = 1000;

```

```matlab
% Q = U*pi*D_s*L*dTlm;
% Q = m_wo*S_w*(T_out_water - T_in_water);
% Q = mL + MSdT
Q = V_vapour*(C_ethanol * rho_eth * L_ethanol + (1 - ...
    C_ethanol) * rho_water * L_water) + ...
    V_vapour * (C_ethanol * rho_eth * S_ethanol +  (1 - ...
    C_ethanol) * rho_water * S_water) * (T_in_vapour - T_out_vapour);

Length_cond = Q/(U*pi*D_s*dTlm);
water_flow_rate  = 1000*60*Q/(S_water*(T_out_water -...
T_in_water)); % ml per min

fprintf('Water flow rate = %0.3f ml per min\n',water_flow_rate);
fprintf('LMTD = %0.3f Celcius\n',dTlm);
fprintf('L = %0.3f inch \n',Length_cond/0.0254);
```

Listing 5.3: Condenser Design

### 5.2.4 Reflux Ratio Calculation

The values of water volume flow rate, distillate collection rate, temperatures, concentration, etc. were changed to calculate for different batches.

```matlab
% Reflux Ratio Batch 1
clc; clear;

% Given data
v_dot_water = 360/(60*1e6);
V_dot_dist = 1000/(98*60*1e6) ;
T_in = 31.8;                  % Inlet temperature ( C )
T_out = 48.4;                  % Outlet temperature ( C )
S_w = 4184;                 % Specific heat of water (J/kg C)
L_ethanol = 838000;         % Latent heat of ethanol (J/kg)
L_water = 2260000;          % Latent heat of water (J/kg)

% Given mixture properties
C_ethanol = 90/100;           % Ethanol composition by volume
rho_ethanol = 785;
rho_water = 1000;

m_dot_water = v_dot_water*rho_water;

% Calculate Reflux Ratio
R =  (m_dot_water * S_w * (T_out - ...
T_in)) / (V_dot_dist*(C_ethanol*L_ethanol*rho_ethanol+...
rho_water*(1-C_ethanol)*L_water));

```

```
% Display the result
fprintf('R = %.8f\n', R);
```

Listing 5.4: Reflux Ratio Calculation for Batch-1

### 5.2.5 MATLAB code for power calculation

In the following code, value of initial volume, time to reach boiling point were changed to calculate power for different batches.

```
% Power Calculation for Ethanol-Water Mixture Heating batch 4
clc; clear; close all;

%% System Parameters
V_initial = 3.6;                  % Total initial volume [L]
C_eth_jaad = 20;                % Ethanol concentration [%]
V_e_in = C_eth_jaad*V_initial/100;  % Ethanol volume [L]
V_w_in = V_initial - V_e_in;    % Water volume [L]

% Material Properties
density_ethanol = 0.789;        % Ethanol density [kg/L]
density_water = 0.995;          % Water density [kg/L]

s_ethanol = 2440;    % Ethanol specific heat [J/kg C]
s_water = 4186;      % Water specific heat [J/kg C]

% Thermal Conditions
initial_temp = 18;               % Initial temperature [ C ]
final_temp = 96;                 % Final temperature [ C ]
time_minutes = 11;               % Heating time [minutes]
time_seconds = time_minutes * 60; % Convert to [seconds]

%% Mass Calculations
mass_ethanol = V_e_in * density_ethanol;    % Ethanol mass [kg]
mass_water = V_w_in * density_water;        % Water mass [kg]

%% Heat Calculations
% Sensible heat required
Q_ethanol = mass_ethanol * s_ethanol * (final_temp - ...
    initial_temp); % [J]
Q_water = mass_water * s_water * (final_temp - ...
    initial_temp);       % [J]
Q_total = Q_ethanol + Q_water;  % Total heat required [J]

%% Power Calculations
P_ideal = Q_total / time_seconds; % Ideal power required [W]
efficiency = 0.45;         % System efficiency [%]
```

```
P_actual = 1e-3 * P_ideal / efficiency;

%% Results Display
fprintf(’Ideal power required (100%% efficiency): %.3f kW\n’, ...
    P_ideal/1000);
fprintf(’Actual power required (45%% efficiency): %.3f kW\n’, ...
    P_actual);
```

Listing 5.5: MATLAB code for power calculation