TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS

Fabrication of Modified Distillation Apparatus by CFD Analysis of Distillation Process of Traditional Nepali Alcohol ‘Raksi’

By:
Sachin Saud (077BME031)
Sanjiv Pahari (077BME035)
Saroj Basnet (077BME037)
Madan Ghimire (077BME050)

A PROJECT PROPOSAL TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE BACHELOR’S DEGREE IN MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
LALITPUR, NEPAL

June, 2024

ABSTRACT

Nepali traditional alcohol ‘Raksi’, is a culturally significant alcoholic beverage which is primarily composed of ethanol. The beverage is still produced using traditional distillation apparatus which often leads to inefficiencies and inconsistent quality. This project aims to analyze the distillation characteristics of Raksi using Computational Fluid Dynamics (CFD) and to fabricate an improved distillation design to enhance efficiency. By simulating the internal fluid flow and heat transfer dynamics during the distillation process, the key areas for optimization will be identified. The refined design will include reflux and other enhancements in the heating and condensation stages to increase ethanol recovery, reduce methanol content and produce consistent concentration.

Keywords: fermentation, ethanol, distillation, CFD

ACKNOWLEDGEMENT

We are profoundly grateful to the Department of Mechanical and Aerospace Engineering for granting us the invaluable opportunity and platform to undertake this project. Our sincere and heartfelt gratitude goes to Dr. Sudip Bhattarai, Associate Professor Bishwo Prasanna Amatya, Assistant Professor Laxman Motra, Assistant Professor Neeraj Adhikari, and Assistant Professor Kamal Darlami for their unwavering support, insightful ideas, and meticulous evaluation of our project title.

We are especially thankful to Sasa Twa restaurant and Mr. Min Kumar, who has been involved in making Newari drink ‘Aila’ for a long time. His generosity in providing us access to his Aila production distillery and his willingness to share the detail of history and production process of traditional alcohol.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

CFD	Computational Fluid Dynamics
CNN	Cable News Network
^oC	Celsius
CAD	Computer Aided Design
kW	KiloWatt
kg	Kilogram
VOF	Volume of Fluid
3D	Three Dimensions
Rs	Rupees

CHAPTER 1: INTRODUCTION

1.1 Background

Varieties of cereal-based fermented beverages are consumed worldwide, which are used for nutritional as well as medicinal purposes (as antiseptic and analgesic). Although cereals are deficient in some basic components (e.g. essential aminoacids), fermentation may be the most simple and economical way of improving their nutritional value, sensory properties, and functional qualities [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 [1] 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 utensil

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 , Figure 1.1).

Alcoholic distillation relies on the different boiling points of alcohol (78.5°C)[2] and water (100°C). When a liquid with 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 strengthening 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
(Adapted from [7])

In Nepal, nobody is allowed to produce liquor without obtaining the license and even a person who has obtained the license shall not produce liquor except in accordance with the terms and conditions specified in the license in 'Liquor Act, 2031'. But, it is not necessary to obtain a permit under the act to make a specified quantity of alcohol or liquor for private use. Nepal government is also planning to make laws related to production, selling, buying of Local raksi. And also they are working on for branding it.

1.2 Problem Statement

Traditional distillation processes prevalent in Nepal are labor-intensive, energy-inefficient, doesn't have pressure and temperature control. The traditional distillation process is afflicted by heat loss; resulting in high energy consumption, low production yield, inconsistent quantity and concentration, and chemical contamination by Methanol and Mercaptan Compound [2]. There is no separation of head, heart and tail of distillation.

1.3 Objectives

1.3.1 Primary Objective

The primary objective is to conduct a comprehensive analysis of the distillation characteristics of traditional Nepali Raksi through Computational Fluid Dynamics (CFD) simulations and subsequently develop and fabricate an optimized distillation apparatus to enhance the overall efficiency of the process.

1.3.2 Secondary Objective

1. Analysis of vapor flow, heat transfer, and temperature distribution within a traditional Raksi distillation setup by using CFD.

2. To optimize the discharge rate of the ethanol by mitigating issue of heat loss, temperature and pressure control.

3. Identify areas for improvement in the traditional design that contributes to inefficiencies and fabricate the improved and optimal design of the distiller.

4. To minimize the amount of methanol content in the product.

1.4 Scope of the Project

1. Study of the existing distillation system opens the door for further research and optimization in distillation system.

2. The modified distillation system will economically support local producers and entrepreneurs by increasing production rates.

3. 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 26,500. The energy operation cost is supposed to be around Rs. 265 for one cycle. Although the price may change or increase with design changes, the enhanced efficiency will support local alcohol producers, and help reduce production time and effort.

1.5.2 Technical Feasibility

The availability of sensors and raw materials provides technical viability for the smooth development of the distillation system. The project's technical feasibility is enhanced by the availability of simulation tools such as ANSYS, which aids in design analysis and optimization. The program enables detailed modeling and analysis of the distillation process, resulting in a better understanding of system behavior and performance. Engineering evaluations are performed to ensure that the proposed design meets performance specifications such as ethanol yield, energy efficiency, and dependability. Any technical challenges encountered during the development process are addressed through iterative design improvements and troubleshooting.

1.5.3 Operational Feasibility

The project's operational feasibility is determined by its practicality and ease of implementation. The distillation system's design will have a simplistic design, with not many changes to the size of the apparatus and the installation of a few sensor systems that will ensure simple operation similar to the previous design.

1.6 System Requirements (For Development/Implementation)

1.6.1 Hardware Requirements

- Temperature Sensors: Thermocouples or temperature probes for monitoring temperature changes.

- Pressure Sensors: For monitoring pressure inside kit.

- Power Source: To provide electricity for the sensors and kit.

- Cooling System
- Collection System
- Microcontroller
- Alcohol Meter (Hydrometer)

1.6.2 Software Requirements

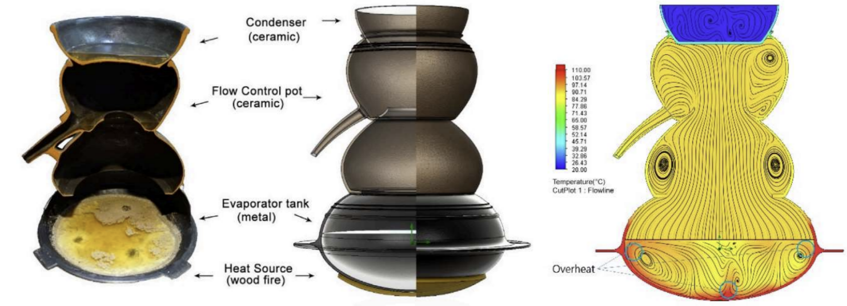
- SOLIDWORKS: To design the structre of existing distiller and to model the improved final structure.
- ANSYS: To simluate the flow of ethanol-water vapor inside the distillation chamber.
- MATLAB: To simulate the condensation (phase change process).

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) (Eleusine coracana Gaertn), maize, rice, wheat, bajra, sweet potato, ginger or even Rhododendron flower petals to produce sweet-sour alcoholic drinks, called jaand [8].

Common traditional homebrewed alcoholic beverages found in Nepal are of two major types, distilled liquors(local raksi) and non-distilled fermented beverages(Jand, Chhyang, Tongba) from grains, fruits, and sugar. In Nepal, people enjoy a local brew called Jand. This drink is made by fermenting different grains. Jand is then transformed into a stronger alcoholic drink called Raksi. Raksi is like a clear, unaged brandy. To make Raksi, Jand is distilled in a pot still, concentrating the alcohol. So, Jand is the base, and Raksi is the stronger alcoholic beverage derived from it [9]. Homebrewed alcohol is typically around 14 % ethanol (between 10 % and 19 %). Distilled versions are stronger (3 % to 40%) than non-distilled (1% to 18.9%) [10].

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 [11]. 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 2.2) 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 [11])

Figure 2.2: Final model of *sojutgori*
(Adapted from [11])

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. Recent advancements in computational fluid dynamics and modern fabrication methods provide opportunities to analyze and enhance these traditional processes.

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 [11]. 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 [12]. 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 [13].

The Navier-Stokes equations mathematically characterize transport phenomena like fluid motion and mass transfer [14]. Derived from mass, momentum, and energy balances, these equations are a set of partial differential equations. However, they possess analytical solutions only for straightforward scenarios. CFD consists of the use of powerful computers and numeric methods to solve the transport equations in fluid systems. CFD has been widely used for the modelling and improvement of different process equipment, such as fermenter [15], heat exchanger [16] and distillation system [11], where important achievements have been reached. The multi-phase models that can apply in the distillation column are volume of fluid (VOF), mixture and Eulerian models. The VOF model can be applied to simulate the multi-phase flow for gas-liquid flow [17, 18].

Singh [19] studied a design and prediction of concentration and temperature distribution for Benzene-Toluene system using two-phase Eulerian framework. In this study a mixture model was developed to give the predictions of the amount of alcohol produced per day. In a Structured Packed Distillation Column, the average relative error between CFD predictions and experimental data is 20.3 % for dry pressure drop, 23% for irrigated pressure drop, and 9.15% for mass transfer efficiency. These results demonstrate a good agreement, proving that CFD is a reliable, cost-effective, and suitable technique for designing and optimizing separation processes [20]. In the numerical Analysis of an Ethanol-Water Distillation, the distillation system initially operates in an unsteady state. However, after 35 seconds [11], it transitions to a steady state.

This research seeks to investigate how the traditional Nepali raksi distiller works, with its unchanged shape and material due to historical and market factors, affects distillation efficiency. Using CFD, the study aims to correlate the design aspects with distillation efficiency. Ultimately, the goal is to suggest a novel design that enhances the distillation process based on the findings.

CHAPTER 3: METHODOLOGY

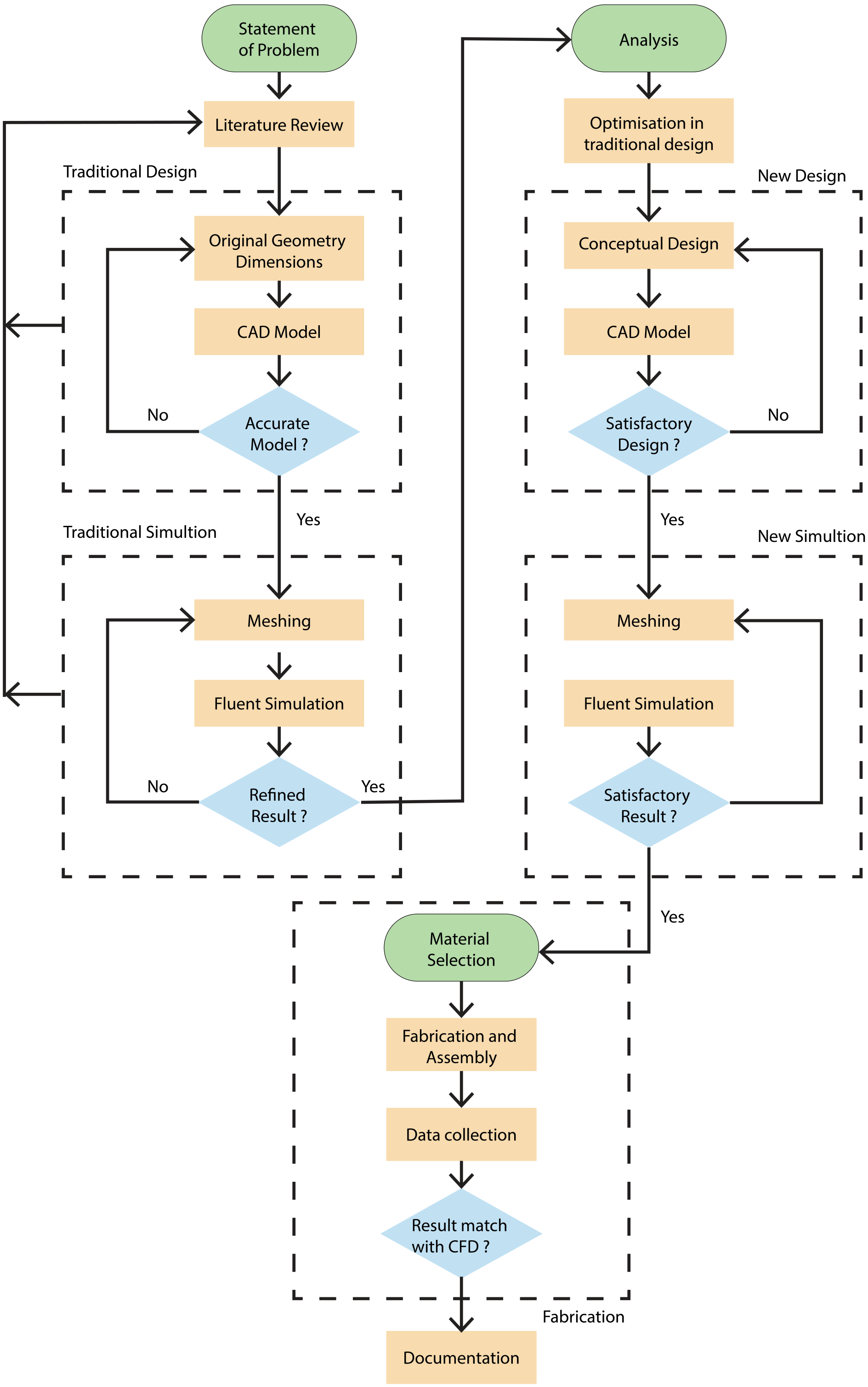


Figure 3.1: Methodology Flowchart

3.1 Study of working of existing traditional distiller

A number of visits will be carried out to the location where the raksi are being made using a traditional distiller. The questionnaire will be carried out to understand the facts and belief in working on the traditional distillation process.

3.2 Design and simulation of traditional distiller

3.2.1 Geometry and CAD Modeling

Exact dimensions of the structure of the existing distiller will be extracted through the average of the data collected during the visit to different locations, shops and museums while studying the working of the existing traditional Raksi distiller. During this we must have the accurate data of material used, method of heat employed with rough temperature measurement of the vessel, pressure inside the distiller, discharge rate. Based on these dimensions, 3D CAD Model (Figure 3.6) of the traditional distiller will be developed using SolidWork CAD Software 2023(Dassault System). It must be an exact model with no difference in types of material and process used to manufacture it.

Figure 3.2: Phonsi

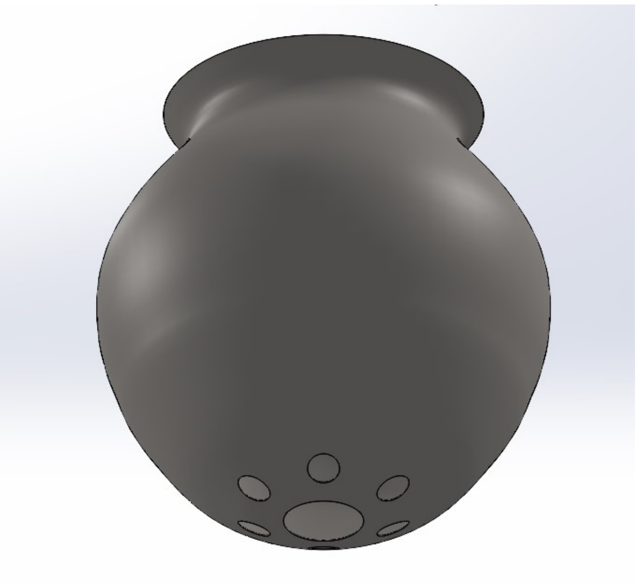


Figure 3.3: Paini

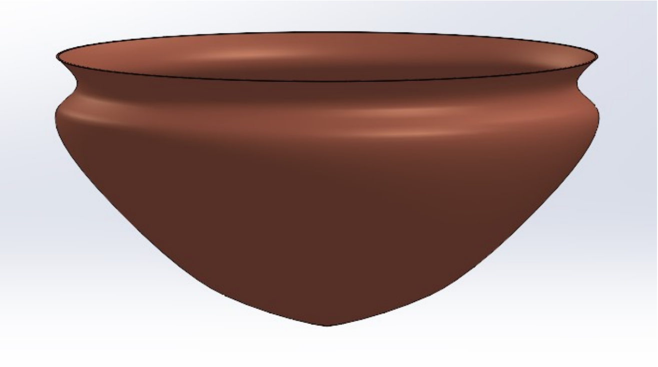


Figure 3.4: Bata

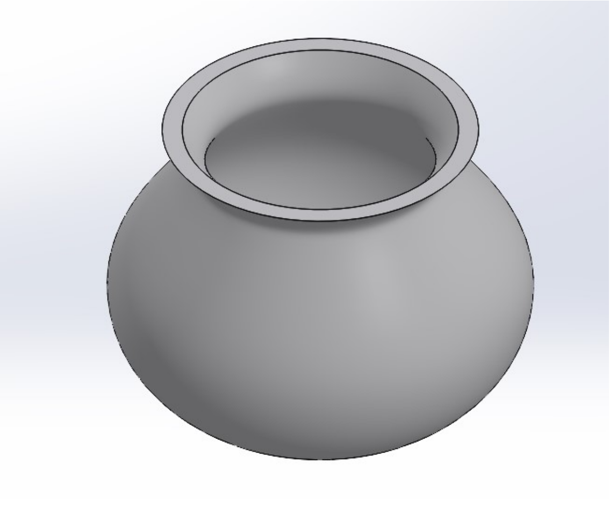


Figure 3.5: Nani

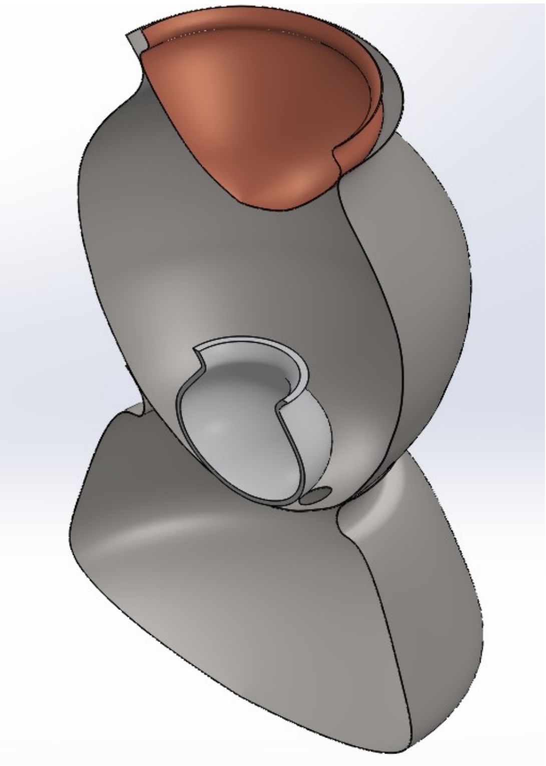


Figure 3.6: Assembled components

3.2.2 Fluent simulation

The exact geometry designed in Solidworks should be imported in Ansys Software to mesh it appropriately considering need of higher accuracy region which should have finer mesh. When utilising Ansys Fluent to see the simulation, we will be using pressure-based solver for steady-state analysis in first phase and same process will be carried out for the transient state if we result are not satisfactory. Each fluid region will be analysed as single phase liquid separately for tormented jaand and in liquid phase and the ethanol vapor in in gas phase.

After enabling the necessary models following conditions will be used:

- Equations: Energy equation, momentum equation
- Material: vapor (ethanol-water mixture) inside copper vessel
- Thermal properties: temperature and pressure, discharge rate, viscosity,
- Boundry conditions: inlet mass flow rate based on the amount of extracted ethanol measured on the surface of fermented wash, and also by the outlet volume flow

rate of ethanol vapor [21].

- Wall conditions: no slip, temperature, or heat flux.

After setting up the solver the simulation will be initialized with the hybrid initialization method and the simulation will be run. The CFD simulation will be conducted in the following three steps to get different results:

- In the first step, the temperature change caused by the energy that fermented wash received from the heat source and the flow and speed of fluid inside the liquid will be tracked [21]. The fermented wash area will be set as one sub-fluid area, and suitable point goals for tracking temperatures were set at the centers of three-dimensionally evenly distributed grids. The number of goals that satisfy the condition of 78°C at which ethanol vaporizes will be coupled with the inlet mass flow boundary condition of the fermented wash surface.

- In the second step, the fluid flow of the ethanol vapor will be observed based on the inlet mass flow in the fluid area of fermented jand. To implement the re condensation effect of ethanol vapor due to heat loss at the outer boundary, suitable number of surface goals will be set in the direction of height on the bulkhead comprising the gas area. Then the ethanol vapor loss will be calculated by setting the outlet volume flow boundary condition in the area where the vessel temperature decreased to 75°C or lower. The changes in streamlines, speed, and temperature inside the fluid area will be accumulated, and the flow of fluid in the gas area will be analyzed continuously according to the time dimension [21].

- In the last step, the residence time, speed, and emission of individual particles were checked by floating objects assumed to be The ethanol vapor particles in the fluid flow over time, which was obtained in the second step using the particle study module [21].

In order to find out the existing discharge efficiency of the ethanol, condensation of the ethanol vapor will be simulated sing Volume of Fluid(VOF) method.

Related governing equation which are useful for simulation:

The continuity equation for the mixture is

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \tag{3.1}$$

The mass-averaged velocity, $\mathbf{u}$, for a mixture is defined as:

$$\mathbf{u} = \frac{\sum_i \rho_i \mathbf{u}_i}{\sum_i \rho_i} \tag{3.2}$$

Mixture density:

$$\rho = \sum_i \rho_i \alpha_i \tag{3.3}$$

The momentum equation for the mixture can be obtained by summing the individual momentum equations for all phases:

$$\sum_i \left(\frac{\partial (\rho_i \mathbf{u}_i)}{\partial t} + \nabla \cdot (\rho_i \mathbf{u}_i \mathbf{u}_i) \right) = \sum_i (-\nabla p_i + \rho_i \mathbf{g} + \mathbf{f}_i) \tag{3.4}$$

The mass fraction for any phase:

$$Y_i = \frac{\rho_i}{\rho} \tag{3.5}$$

where, ρ_i = Fluid density for phase i.

$\mathbf{u}_i$= Fluid velocity for phase i.

g= acceleration due to gravity.

$\mathbf{f}_i$= forces acting on the i-th phase

3.3 Analysis of the result of simulation

Fire points above 100°C must be noted down if detected in the CFD analysis of the digitalized Raksi distiller model. Since the shape of the distiller is curvy, strong vortices is expected to be observed at the top and bottom around the center. These vortex that occurs in the movement path of vaporized ethanol interferes with the discharge of ethanol particles and increases the residence time of particles, which acts as an obstacle to the acquisition of homogenous alcoholic liquors[21]. Similarly temperature spread of fermented jaand is known to induce the carbonization of organic compounds in the fermented wash and to cause the simultaneous vaporization of water and carbonation component with ethanol [21]. This problem is expected to be mitigated by the end of the new optimized design.

3.4 Design and fabrication of optimized distiller

After analyzing the result of the CFD simulation of the traditional distiller with several post-processing, different changes will be made. The new design will also be modeled in SolidWorks 2024. Fabrication being an equally crucial part of the project will be done in proper manufacturing techniques. On the basis of the new CAD design first the suitable material will be selected. Then lower and upper optimized part will be manufactured through rolling. The condenser will be manufactured through the same process but it might have a better design for faster condensation. Different temperature and pressure sensors will be added into the design. The new design is expected to have the following optimization:

- A stable and air tight structure
- Increase the efficiency and discharge rate of the ethanol production.
- High convection rate inside the distiller.
- Least heat loss into the surrounding through the wall.
- Temperature and pressure controlling feature.
- Refined distillation by the use of reflux ring.

3.5 Simulation and testing of the new design

The new design will be simulated in Ansys fluent similar to the old design and similar properties and the result will be analyzed to make sure the problem was solved. After fabrication, experimental testing of the new design will be carried out. The result from testing will be compared ti the result of the simulation after several post-processing. If the results do not match the simulated result, the fabrication process will be done again with required improved and testing will be repeated until the observed inefficiency are not reduced.

3.6 Documentation

When the results of testing are satisfactory documentation process begins. After proper references and plagiarism testing final draft of the project report will be prepared.

CHAPTER 4: EXPECTED OUTCOME

4.1 Implications and Significance

After the project concludes, the anticipated results are as follows:

- A modified distillation system for the production of *Raksi* that reduces time and energy consumption.

- An integrated system that continuously monitors and displays real-time temperature and pressure parameters of the distillation process.

- Comparative analysis of vapor flow, heat transfer, and temperature distribution in both a traditional *Raksi* distillation setup and a newly modified design.

The new design will be suitable for both the local and the commercial producers. The project will also contribute to enhancements in various other distillation processes.

4.2 Budget Analysis

For our project, a substantial portion of the budget will be dedicated to fabricating the distillation apparatus and procuring essential electronic components. A comprehensive breakdown of the cost estimation is outlined in the table provided below:

Table 4.1: Budget Breakdown

Component	**Quantity**	**Rate (Rs)**	**Total Cost (Rs)**
Copper	–	10000	10000
Copper bubble cap tray	2	5000	5000
Heater	1	3000	3000
Temperature sensor	1	1600	1600
Pressure sensor	1	1800	1800
Pressure relief valve	1	1600	1600
Water pump	1	1200	1200
Hydrometer	1	700	700
Microcontroller (Arduino UNO)	1	1600	1600
Millet	12kg	330	4000
Yeast	5	20	100
Laboratory testing	–	4000	4000
Fabrication	–	10000	10000
Others	–	–	5000
Total	–	–	**49600**

Note: The figures provided are estimates and subject to change based on market fluctuations and project requirements.

4.3 Work Schedule

4.3.1 Work Scheduling

The tasks to be done in this project are listed below in tabular form (Table 4.2), along with the estimated time they may take to complete:

Table 4.2: Work Scheduling

Task	**Duration**
Literature Review	8 months
CAD model and Simulation	2 months
Order of materials	20 days
Fabrication	2 months
Testing and data collection	2 months
Documentation	9 months
Final report	20 days

4.3.2 Gantt Chart

The entire workflow and the whole timeline of the project is shown in the Gantt chart below:

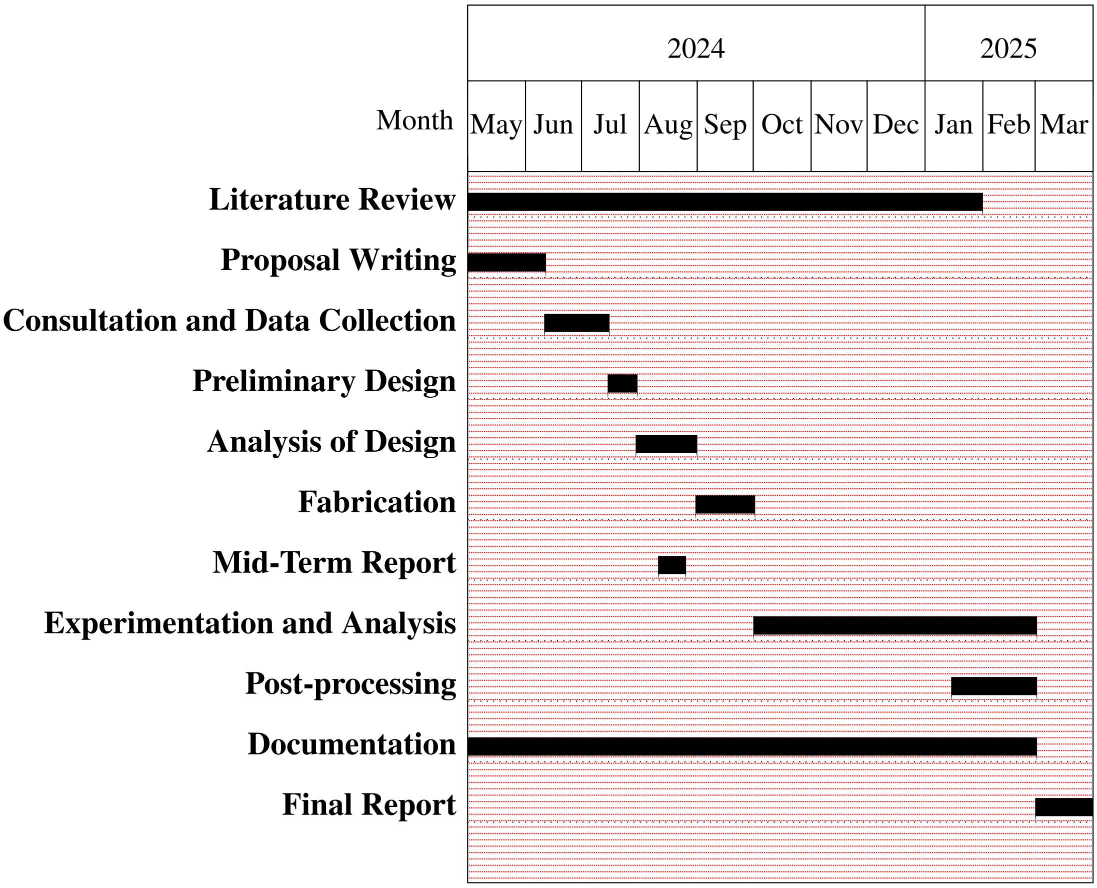


Figure 4.1: Project Timeline

REFERENCES

[1] A. Blandino, M. Al-Aseeri, S. Pandiella, D. Cantero, and C. Webb, “Cereal-based fermented foods and beverages,” *Food research international*, vol. 36, no. 6, pp. 527–543, 2003.

[2] V. Joshi, M. Bordiga, F. Cosme, L. Farina, R. S. Jackson, A. Lonvaud, A. M. Jordão, and C. Stockley, *Concise Encyclopedia of Science and Technology of Wine*. CRC Press, 2021.

[3] E. Pakuwal and P. Manandhar, “Production of rice based alcoholic beverages and their quality evaluation,” *J. Food Sci. Technol. Nepal*, vol. 12, pp. 37–48, 2020.

[4] C. Tim Cheung. (2011) World’s 50 most delicious drinks. [Online]. Available: https://www.cnn.com/travel/article/most-delicious-drinks-world

[5] R. Karki, D. B. Karki, P. Ojha, R. Shrestha, P. Basnet, S. Maharjan, U. Manandhar, and K. Karki, “Traditional fermentation practices and brewing dynamics of nepalese millet-based alcoholic beverages.”

[6] D. Karki, “Improvement on traditional millet fermentation process and its brewing quality assessment,” Doctoral Dissertation, Central Department of Food Technology, TU, Nepal, 2013.

[7] G. Kharel, P. Acharya, and B. Rai, “Traditional foods of nepal,” *Highlight Publication Pvt Ltd*, 2010.

[8] J. Tamang, P. Sarkar, and C. Hesseltine, “Traditional fermented foods and beverages of darjeeling and sikkim - a review,” *Journal of the Science of Food and Agriculture*, vol. 44, pp. 375 – 385, 01 1988.

[9] A. Mishra and R. Karki, “Rice products diversiàcation in context of nepalese culture.”

[10] N. Thapa, K. 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*, vol. 13, no. 29, pp. 59–65, 2015.

[11] T. Kim and T. Seo, “Numerical analysis of an ethanol-water distillation system using computational fluid dynamics (cfd),” *Internationa Journal of Mechanical and Mechatronics Engineering (IJMME-IJENS)*, vol. 14, no. 04, 2014.

[12] B. Rankine, “Formation of higher alcohols by wine yeasts, and relationship to taste thresholds,” *Journal of the Science of Food and Agriculture*, vol. 18, no. 12, pp. 583–589, 1967.

[13] Z. Khatir, J. Paton, H. Thompson, N. Kapur, V. Toropov, M. Lawes, and D. Kirk, “Computational fluid dynamics (cfd) investigation of air flow and temperature distribution in a small scale bread-baking oven,” *Applied Energy*, vol. 89, no. 1, pp. 89–96, 2012.

[14] G. Fimbres-Weihs and D. Wiley, “Review of 3d cfd modeling of flow and mass transfer in narrow spacer-filled channels in membrane modules,” *Chemical Engineering and Processing: Process Intensification*, vol. 49, no. 7, pp. 759–781, 2010.

[15] P. Moilanen, M. Laakkonen, and J. Aittamaa, “Modelling fermenters with cfd,” in *Computer Aided Chemical Engineering*. Elsevier, 2005, vol. 20, pp. 709–714.

[16] M. M. A. Bhutta, N. Hayat, M. H. Bashir, A. R. Khan, K. N. Ahmad, and S. Khan, “Cfd applications in various heat exchangers design: A review,” *Applied Thermal Engineering*, vol. 32, pp. 1–12, 2012.

[17] J. Teleken, L. Werle, C. Marangoni, M. Quadri, and R. Machado, “Cfd simulation of multiphase flow in a sieve tray of a distillation column,” *Brazilian journal of petroleum and gas*, vol. 3, no. 3, 2009.

[18] M. R. Rahimi and H. Karimi, “Modeling distillation mass transfer efficiency,” *International Journal of Chemical and Environmental Engineering*, vol. 2, 2011.

[19] S. Singh, “Cfd simulations of benzene–toluene system over sieve tray,” *Inter. J. Eng. Sci. and Emerging Tech*, vol. 3, pp. 81–89, 2012.

[20] M. Haghshenas Fard, M. Zivdar, R. Rahimi, M. Nasr Esfahani, A. Afacan, K. Nandakumar, and K. Chuang, “Cfd simulation of mass transfer efficiency and pressure drop in a structured packed distillation column,” *Chemical Engineering & Technology: Industrial Chemistry-Plant Equipment-Process Engineering-Biotechnology*, vol. 30, no. 7, pp. 854–861, 2007.

[21] U.-s. Kim, J.-h. Kim, T.-W. Kim, and J.-h. Choi, “Analysis of distillation characteristics via cfd (computational fluid dynamics) of korean traditional ‘sojutgori’and study on structure for distillation efficiency enhancement,” *Food Science & Nutrition*, vol. 11, no. 1, pp. 590–598, 2023.