

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES

DESIGN OF INJERA PROCESSING MACHINE

A Thesis Submitted to the Graduate School of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science

In

Mechanical Engineering (Mechanical Design)

By: Yesehak Tefera

Advisor: Dr.-Ing. Tamirat T.

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By

Yesehak Tefera

Submitted in accordance with the requirements for the degree

MASTER OF SCIENCE (M.Sc.)

Approved By Board of Directors

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I hear by declare that the research entitled “DESIGN OF INJERA PROCESSING MACHINE” is my own independent work, and has not been previously submitted to any other university in order to obtain a degree.

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Abstract

The present work emphasis in asserting a solution to the laborious Injera making system which are faced by most of the communities in and around Ethiopia. The main downside of the present existing Injera making processes is the source of power and energy consumption, tedious labor with little or no hygiene control and the production efficiency, which is predominantly because of the use of electric source or conventional fire wood for mitad and unskilled labors.

The proposed machines have been achieved by integrating the dough preparation and the baking operations to work simultaneously for continuous Injera production. The dough is prepared in a mixer container which are connected to a baking conveyor unto which the precise quantity of dough is squeezed on to the baking chamber through the conveyor. The baking conveyor are controlled to operate in-steps with controlled speed and appropriate delay for injera to bake, which is achieved by using a stepper motor with a control unit. The component design and the assembly has been done by CATIA and the real time simulation has been performed by ANSYS.

This machine is highly recommended to save energy, minimize individual energy bill per month and minimize operation costs of hotels and restaurants. Therefore, this injera baking machine saves labor, energy and it is hygienic.

Keywords: Mitad, Injera, Batter, Baking, Efficiency, PLC control system

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Nomenclatures

Q - Heat transferred in unit time

K - Thermal conductivity (W/m℃)

w_f - Total weight of cooked food in grams

h - convection heat transfer coefficient (W/m^2 ℃)

$\dot{Q}$ - heat flow (W)

$\frac{dT}{dX}$ - Temperature gradient in plane of heat transfer in the direction of heat flow (℃/m)

k - Thermal conductivity (W/m℃)

A - Area perpendicular to heat flow (m^2)

ΔT - Temperature difference between the fluid and the wall surface (℃)

σ - Stefan- Boltzmann constant

T_s - Body surface temperature (℃)

T_∞ - Surrounding or ambient temperature (℃)

ε - Emissivity of the surface

Q - Heat content in (kCal)

V - Flow rate of the substance in (m^3/hr)

ρ - Density of the flue gas in (kg/m^3)

C_p - Specific heat of the substance (kCal/kg℃)

C_w - is the heat capacity of water (kJ/kg.k)

m_i - Mass of the injera in (g)

h_{vap} - Heat of vaporization of water

$E_{utilized}$ - utilized energy in (kJ)

P - Power (kW)

T_1 - Hot flue gases temperature (℃)

T_2 - Teflon conveyor lower surface temperature (℃)

T_3 - Teflon conveyor upper surface temperature (℃)

Pr - Prattle number

Nu - Nusselt number

Ra - Raleigh number

g - Acceleration due to gravity (m/s^2)

α - Thermal diffusivity

υ - Kinematics viscosity

Chapter 1 Introduction

1.1 Background

Injera, a soft honey-comb structured flat bread, is one of the Ethiopian staple foods, mainly prepared from teff an indigenous cereal grain. It is a popular and nutritious food, with long shelf-life, distinct and preferred characteristics of texture and flavor, and simplest to prepare. Teff grain can be conserved for many years without any appreciable change or damage from insect pests, if vermin and moisture are excluded from storage bins. Injera has broad cultural implications for the Ethiopian society and there is always a need to hold on to it.

Injera is the most popular baked product in Ethiopia. It is fermented teff bread with a very sour taste and is the undisputed national bread of Ethiopia. The baked product is referred to by different names depending on the locality of production in Ethiopia. It is referred to as ‘budena’ in Oromigna, ‘taeta’ in Guragigna, and ‘solo’ in Walaytigna. The teff grains are prepared manually or mechanically and milled to flour which is subsequently used in the preparation of Injera.

Injera is eaten daily in virtually every household, and preparing it requires considerable time and resources. In Eritrea and Ethiopia, the bread is cooked on a large, black, hot clay plate called mitad in Amharic. This cooking method produces large amounts of smoke. Because of this cooking method, much of the area's limited fuel resources are wasted.

On the basis of production procedures three types of Injera are distinguishable: (i) thin Injera which results from mixing a portion of fermented teff paste with three parts of water and boiling to yield a product known as ‘absit’ which is, in turn, mixed with a portion of the original fermented flour (ii) thick Injera, which is reddish in color with a sweet taste, is a ‘teff’ paste that has undergone only minimal fermentation for 12-24 hours; (iii) komtata-type Injera, which is produced from over-fermented paste, and has a sour taste. The paste is baked or grilled to give a bread-like product. Yeasts are the major microorganisms involved in the fermentation of the sweet type of Injera.

Injera preparation usually takes two to three days; the teff is milled into powder then mixed in water along yeast. This mix is set aside at room temperature for 2 days so it ferments and raises.

During the second day it starts to give tangy aromas as the fermentation releases air bubbles; this is where the Injera's slight tangy taste comes from. After the fermentation process is finished the mix is cooked on 'Mitad'. A circular motion is used to achieve thin consistency. When the hot pan and the fermented teff contact each other, thousands of tiny air bubbles escape creating thousands of tiny eyes which is the familiar look of Injera.

It is no small challenge to remove the large, hot, thin Injera from the cooking surface without either tearing it or burning one's fingers. This challenge is further complicated when it is being prepared in a commercial establishment, catering to numerous diners, under substantial pressures of time and money. The repeated human hand contact, in a less than carefully run kitchen, can also be less than completely hygienic.

Fuels for cooking Injera or other traditional bread include, fuel wood, charcoal, dung, and other crop residues. In most developing countries like Ethiopia the household sector is the largest energy consumer. In Ethiopia the single largest demand for energy is for subsistence, which accounts for nearly 90% of the total energy consumption. This burden of subsistence is carried almost entirely by women. In villages, women have to spend more times in fuel collection. This heavy workload in the long run affects their health. This is because the energy expended is more than the intake of food to accomplish daily task. The burden of women taking care of the family gets worse when you include the time it takes to collect the wood using bare hand or primitive tools and carry it over long distances.

The urban poor have even a greater problem due to the scarcity of fuel and their incomes have not kept pace with rising cost. This group continues to rely on wood fuels, which are becoming very scarce. Recent news has shown that urban dwellers are collecting shrubs and leaves of trees or left over from tree cuttings making the soil open to erosion.

This is putting tremendous pressure on the family to maintain a subsistence living. Unless something is done soon in terms of alternative energy source or a new technological development in the near future, the country is putting itself in a dangerous situation in terms of sustaining the availability of wood or its derivative.

As discussed earlier biomass fuels such as wood and its derivatives are used widely in developing countries like Ethiopia, especially in rural and poor urban areas. This biomass is composed of complex organic maters, carbohydrates that contain carbon, nitrogen, oxygen and

other elements in trace amounts. Smoke emission from these domestic fuels is the major source of indoor pollution, especially in rural and poor urban communities.

This smoke contains pollutants and particulates that adversely affect the health of women. It is reported that these pollutants are the major causes of chronic bronchitis and lung diseases. This prolonged smoke exposure associated with biomass usage also has a huge long-term effect on eyesight of women and infants. Studies have shown that wood, charcoal and dung produced unacceptable levels of indoor air pollution during cooking and baking.

The wide spread practice of burning dung, burning crop residues for fuel, and deforestation for wood is undoubtedly increasing. Deforestation cannot be reduced without providing alternatives to the current way of cooking that also addresses related health issues. It is very important that whatever the alternatives are, they must provide better livelihood and sustained income generation to support the family. Otherwise the people will continue this relentless deforestation that endangers their life and the eco-system beyond repair.

Injera can be prepared from teff and other cereals like sorghum, barley, maize and wheat. The acceptance of such a substitute is only limited to certain areas. Cereals are bought from a nearby grain market, preparatory operations will be carried out by local women and the grain is ground into tine powder in a local flour mill.

The steps of injera production for white teff injera are listed as follows. [1]

First Teff flour is mixed with clean water in the ratio 1:2 (w/w) and 16 % of starter (ersho) by the weight of the flour and was kneaded. The resultant dough was allowed to ferment for 2 - 3 days at ambient temperature. After this primary fermentation, the surface water formed on the top of the dough was discarded. After the liquid is discarded a portion of the fermented dough is put into a boiling water by the ratio of 80 g dough to 200ml water (locally known as “absit”) After the absit was cooled to about 450C it was added into the main part of the dough. The batter was left covered for 2-3 hours for secondary fermentation. The main dough was thinned by adding water and stirred well. Finally, the batter is ready for baking which takes about 2-3 minutes.

In this paper the design considers the traditional injera preparation method and replaces it with modern industrial baking method by using the injera processing machine. Therefore, this paper focuses on studying the injera baking system and designing a suitable machine for baking injera for mass production.

1.2 Statement of the problem

The Injera baking tradition in Ethiopia is done manually by electric power that wastes more than 50% of the electric energy or by wood fuel that uses the traditional three stone stoves which takes longer time and relatively high amount of wood. This baking method is power wasting, laborious and it is not hygienic. [2]

Therefore, this design will introduce a mass production of injera that can greatly assist our local or foreign community in providing an Injera processing and baking machine that will ease the present injera baking system.

1.3 Objective of the research

General objectives

The aim of this research paper is to design Injera processing and baking machine which can be easily installed and operated wherever electric power is available. The automation ensures that the job is done faster, safer and skill independent for a mass production of injera. The target groups are institutions that have high demand of injera per day such as universities, hotels, injera exporters and supermarkets.

Specific objectives

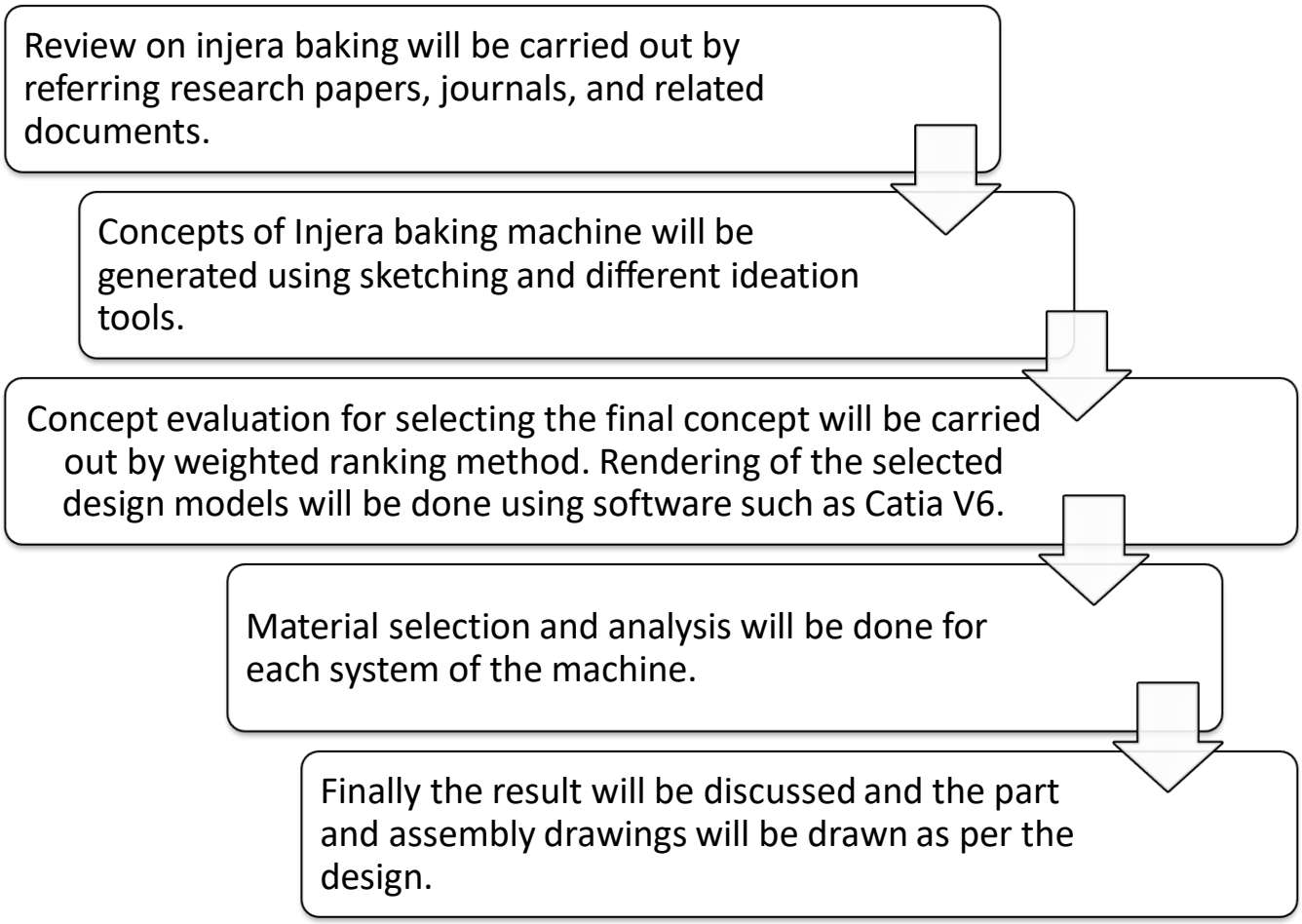
1) To discuss on the present and recent past situations of Injera processing & baking technologies and alternative practices in Ethiopia.
2) To identify different methods of Injera processing and baking and to select the more suitable design based on its efficiency that bakes injera in mass production in health and hygienic system.
3) To make design analysis for components that would be incorporated in the generalized system of the selected Injera processing and baking machine.
4) To determine the capacity of the designed Injera processing and baking machine.
5) To select the materials that is available, suitable and cheap for the fabrication of Injera processing and baking machine.
6) To analyze the financial feasibility of investment in manufacturing the Injera processing and baking machine for mass production.

1.4 Limitations

The major limitation of this paper is that the research is limited to the design and simulation analysis so further prototyping and testing could not be done due to lack of budget and the variation of the data on the injera possessing and baking is also the other limitation faced in this research.

1.5 Organization

This research will study the injera processing system and design an efficient machine that will solve the problems of Injera baking. The design includes selecting the best design concept for the machine, selecting different material for the machine, conducting the structural analysis by ANSYS software. The result of the research will be included in the report with the design paper, part drawing and assembly drawing which will be drawn by using Catia software.



Chapter 2 Literature Review

2.1 Previous works on injera processing machine

In this section we will review different designs of injera baking machines which have played a significant role in improving the present power wasting &laborious injera baking method.

The first reviewed research is the thesis paper on the Experimental Investigation on performance, characteristics and efficiency of electric injera baking pans ("Mitad"). The aim of this thesis work is to investigate the performance characteristics and efficiency of the electric baking pan ("mitad") experimentally and to prove the better efficiency of the improved "mitad". The average power consumptions of conventional and improved electric "mitads" were 12.86 kW/m^2 and 9.08 kW/m^2respectively. The improved electric "mitad" have an advantage over conventional electric "mitad" and it recommends to use the improved baking pans. [2]

The second reviewed research is the thesis paper on the Design and Manufacture of Laboratory Model for Solar powered Injera baking Oven.

The thesis research uses solar powered injera baking oven, so as to avoid the problems that are caused due to burning of fossil fuels and to assure the environmental sustainability. In the research a laboratory model for solar powered injera baking oven system is designed and manufactured; the laboratory model consists of the oil storage and heating tank, the piping and pumping system, the baking pan assembly, and supporting frame and legs as its main components. The system uses electrical heater to heat the heat transfer oil to the required temperature, and then the heated oil is pumped to the baking pan assembly to heat the pan surface and re-circulates in the system using an electrical driven pump. To protect heat loss; ash insulation system for the heat transfer oil gallery, the oil storage and heating tank and fiber glass insulation for the piping lines are used. The baking pan surface temperature in the experiment was measured and a temperature of about 215 ^oC on the pan surface was registered; so that it was possible to bake injera. But the baking cycle needs five minutes. [3]

The third reviewed research is the thesis paper on Heat transfer analysis during the process of injera baking by finite element method. Modeling and simulation of the heat transfer during the process of injera baking is done by mathematical models and finite element formulations. It studied the transient heat transfer analysis during injera baking process.

The research states that given the same thermal property (thermal conductivity, specific heat, and density) and power input, decreasing the thickness of a baking pan results a decrease in heat up time and idle time of the baking pan. Given the same thermal property and same pan thickness, decreasing power input results an increase in heat up time and idle time. And also, it shows that, heat up and idle time of a baking pan decreases as thermal conductivity increases, so a major improvement in efficiency will be obtained if baking pan thermal conductivity is improved. On the other hand, increase in specific heat capacity and density of baking pans increases the heat up time and idle time. [4]

The fourth reviewed research is injera baking machine invented by Yoseph Temesgen. This injera baking machine includes a polishing assembly, a batter application assembly, and deposition assembly. The polishing assembly includes a polishing pad which may be positioned over the cooking surface when the cooking surface is not in use. When engaged, the polishing assembly applies the rotating polishing pad to the cooking surface so as to clean it prior to applying injera batter to the cooking surface. The batter application assembly can also be positioned over the cooking surface with a drive to rotate a batter supply line reciprocating nozzle carrier so that the batter is poured onto the cooking surface along an inwardly spiral path so as to generate a uniform circular pour of batter. Finally, the deposition assembly utilizes a reciprocating conveyor equipped with a spatula and coordinated conveyor rollers so as to remove the cooked injera wafer from the cooking surface at cook completion time for cooling, while simultaneously discharging a previously cooled wafer generated by this fully automated, cyclic process. [5]

The fifth reviewed research is the Injera machine built by Dr. Wudneh Admassu a professor at University of Idaho and Chairman of Department of Chemical Engineering.

The machine can produce 500 unit per hour consistently and uniformly 24 hours a day using available electricity. Therefore, the Injera machine can easily be installed and operated wherever electric power is available. The Injera made using this technology has a shelf life of at least 5 to 7 days which is another improvement over the old way of making Injera which becomes moldy within 1 to 2 days of shelf life. [6]

The sixth reviewed research is a Double Sided Electric Injera Mitad by MDM engineering.

In this design, after pouring the batter on one of the two Mitad plates and allowing 15-20 seconds interval the unit is rotated 180^0 and the batter will be poured to the other mitad. This design can reduce baking energy and time by 50%. [7]



Figure 2-1 Double Sided Electric Injera Mitad

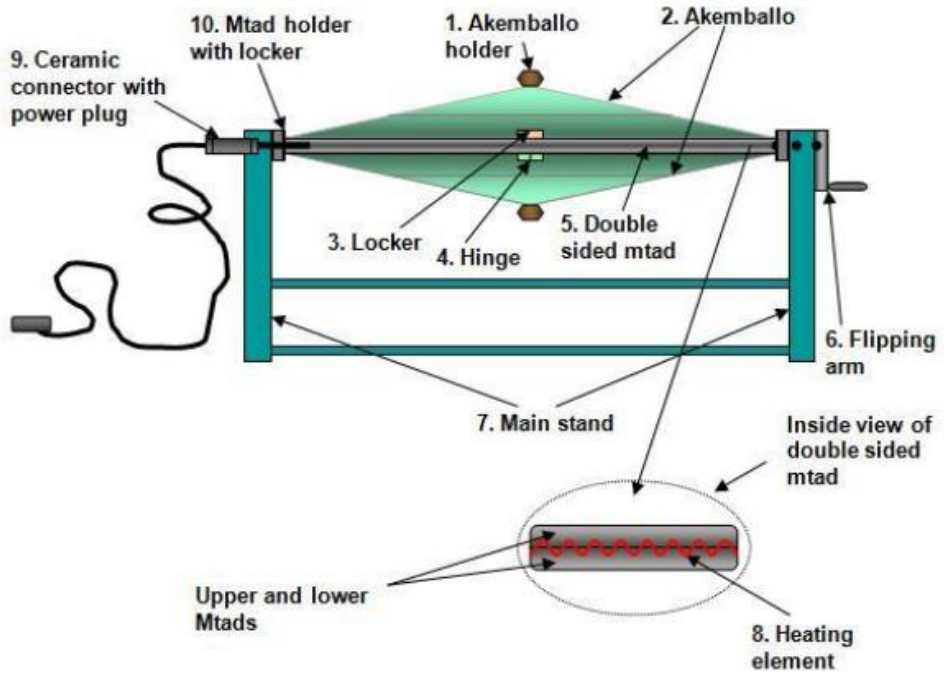


Figure 2-2 Drawing of Double sided Injera Baking Mitad

2.2 Major problems of the existing electric Injera Mitad

The existing electric Injera Mitad technology is believed to be in the market for many years. The performance efficiency is very lower and the product has not been standardized so far. The electric Injera Mitads are estimated to constitute about 60 % the power demand of a typical residential household. It is customary to see the dimming of light bulbs, lessening of power level and the high level of steam and heat generated while Injera is baked. Other electrical devices like stoves and water heaters will not be turned on once Mitads are in operation. Electric Injera Mitads contribute to the bulk of the electric power demand and consumption of a typical residential household and the nation.

The core problem of existing electric Injera Mitad is that it is energy inefficient. The causes of energy inefficiency are mainly attributed to the high amount of electrical energy needed to heat up to the set to temperature of about 200 – 250 ^{0}C required to bake Injera. This energy requirement is due to high heat load, heat losses, poor heat insulation, and the method of production of the Mitad.

The heat loss at the bottom of the clay plate in a form of radiation constitutes the major portion of the heat lost from the Mitad. Heat insulation is commonly made using either of Pumice, Sandstone, Gypsum and mixture of soil. The thermal conductivity of Pumice and Sandstone, Gypsum is relatively high. Besides, these materials add weight or heat load to the Mitad. Heat insulants like Fiber glass have very low thermal conductivity and weigh much less.

Due to the conduction of heat from the clay plate to the support ring and then to the enclosure and convection heat transfer, heat is lost at the side of the Mitad. The lifting cover stays closed for over 50% of the baking cycle and gets heated up. It will be heated up to a level it can't be touched with bare hands. Heat is lost to the surrounding through radiation, convection and conduction from the lifting cover.

The clay plate of electric Injera Mitad is made from sand and clay. The traditional manner in which it is produced makes the plate require more heat energy. The clay plate is produced in rural areas in a traditional way. Sand and clay are mixed in under surface pit using hand and legs. There is no defined or accurate measurement as to the proportions of the sand, clay and water either by weight or by volume. Many clay plates got broken or are rejected when brought to the market due to the traditional way of mix proportions, preparation and firing. Disproportional mix of clay and sand results in different level of heat requirement of the clay plate. The Specific heat of Sand and clay are different and heat added depends on the mass of

the sand and the clay. The mixture of sand clay and water is considered to be adequate by the feeling on the bare leg. The mix cannot be judged accurately by the feeling on the leg. This results in inadequate mixing thereby reduce the bonding expected from the sand and clay. The final sizing of clay plate is not precise. Thickness of plates is not uniform across the plate diameter. These results in the difference in the depth of grooves made while placing of the heating element there by inducing different level of heat response from the plate. After the mix is baked and dried it is fired on an open-air using cow dung as a fire source. When cow dung is burnt away completely the clay plate is considered fired. Because of the prevailing wind, the fire intensity and duration, the firing process is not perfect. There are under firing or over firing instances. This has got an impact on how the clay plate responds to an added heat and its mechanical strength. As a result, the mass and the strength of the clay plates produced differ from producer to producer. The heat required for the Mitad depends on the heat load.

No temperature regulating devices are installed on the electric Mitad to control overheating. While baking Injera, over heat and under heat conditions are managed through observation and the effects on the Injera baked. Unnecessary wastage of energy occurs while the over and under heat cases are managed. Different sizes of electric Injera Mitad are produced. Size ranges from 40 cm diameter to 60 cm diameter. There is different level of power requirement for the different sizes of the clay plates. As size increases heat requirement increases. However, similar sizes of heating elements are used for clay plate sizes starting from 56 cm to 60 cm resulting in high or low heat responses. Two pieces of the 0.9 mm diameter electrical heating element (resistor) locally wound are commonly used per Mitad for sizes from 56 cm to 60 cm diameter.

Resistances are mostly wound locally and the value per resistor depends on the length and diameter winded. As electrical power equals the square of voltage divided by resistance, slight change in the value of resistance changes the power demand. Hence, the electrical Mitads currently produced in the country do not have equal and uniform power rating, even within the products of the same producer. Resistor is placed in spirally made grooves at the bottom side of the clay plate in the case of the single clay type. After the resistor is placed, the groove is sealed with Gypsum material. There is no uniformity or accepted standard adhered to in fixing the clay plate thickness and the size and depth of the grooves. Deep groove leads to overheating as the resistor will be closer to the baking surface whereas shallow groove makes the clay plate unresponsive to the heat applied.

The energy inefficiency problems on the existing electric Injera Mitad have imposed two effects: The sets have been excessively rated to high power capacity. This placed immense pressure on the use of the product in residential households and electrical generating and distribution networks, and the energy demand of the country. Frequent interruptions of power especially during religious holidays depict the intensive and concurrent use of electric Injera Mitad. The bill of consumers is high and energy consumption at national level has become excessive.

2.3 Control System for the baking conveyor

PLC is an industrial control computer, which uses programmable memory to store instructions and to execute logic, sequence, timing, counting, and calculus functions, and input and output via digital or analog, so as to control plant machinery or production processes.

With the rapid development of the microprocessor, computer and digital communication technologies, computer control has been widely used in all industrial fields. Modern society requires the industry to respond quickly to market demand and produce small-volume, multi-species, multi-standard, low-cost and high-quality products. The programmable controller is to respond to this need. Microprocessor is a general industrial control device. Programming controller not only can realize logic control over a variety of pre-programmed programs, it also has advantages of being freely programmable, automatic diagnosis, versatility, small size and high reliability.

The PLC has its origin in the motor manufacturing industries. Manufacturing processes were partially automated by the use of rigid control circuits, electrical, hydraulic, pneumatic. It was found that whenever change had made, the system had to be rewired or reconfigured. The use of wiring of boards on which could connections could be changed by unplugging them and changing them around followed. With the development of microcomputers, it was realized that if the computer could switch things on or off and respond to a pattern of inputs, then the changes could be made by simply reprogramming the computer and so the PLC was born. PLC is an industrial computer control system that continuously monitors the state of input devices and makes decisions based upon a custom program to control the state of output devices. Almost any production line, machine function, or process can be greatly enhanced using this type of control system. However, the biggest benefit in using a PLC is the ability to change and replicate the operation or process while collecting and communicating vital information.

In application design of PLC systems, PLC application system was first designed, namely, according to requirement of controlled object's function and process, identifying system's work to be done and required conditions. Then analyze functions of PLC application system, namely through the analysis of systems function, providing the PLC control system structural form, the type of control signal, volume, system sizing, layout. Finally, according to conclusion based on the results of the system analysis, determine the specific configuration of model and system of the PLC. Therefore, the PLC control system is suitable for controlling the temperature, the conveyor speed and the other components of the injera baking machine.

2.4 Teflon conveyor belt for baking surface

Polytetrafluoroethylene (Teflon) coated conveyor belting is a small but important segment of the lightweight belting market. Teflon belts have a service temperature of 500 F. With proper belt design, higher temperatures are possible. Many Teflon coated belts are used to process foods. Teflon is very inert. It will not react with or contaminate the product being conveyed.

Teflon belts are very slippery. All Teflon coated fiberglass belts are coated on both faces. This leads to a belt that slides easily on the machine's support structure. It also means that the product being conveyed slides easily and is easily removed from the belt at the exit of the process which makes it suitable to bake injera continuously on the baking machine.

Chapter 3 Analytical methods, Conditions and Design

3.1. Conceptual design

This is a system of selecting good alternatives among many model solutions for a particular problem. There are different types of design matrices that are used to make systematic decisions on choosing best alternatives of given two or more alternative designs. The design matrix method is selected so that to help reach at the best decision.

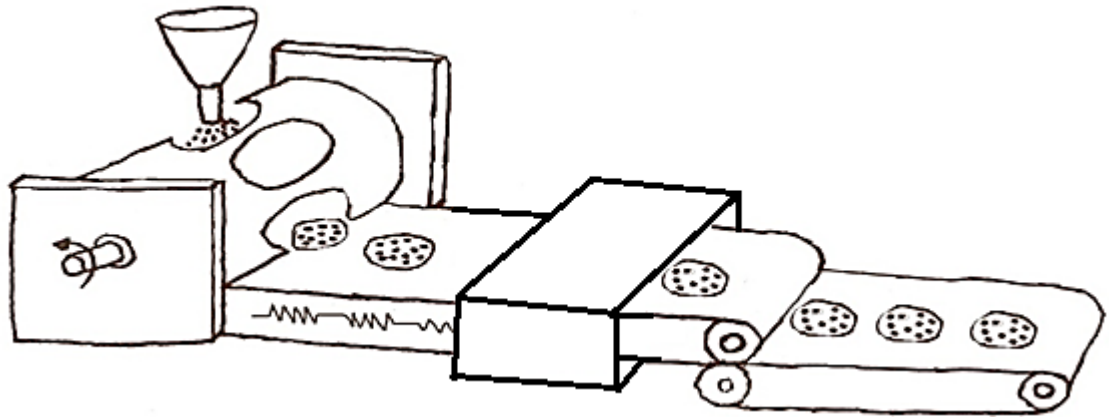


Figure 3-1 Baking design concept 1

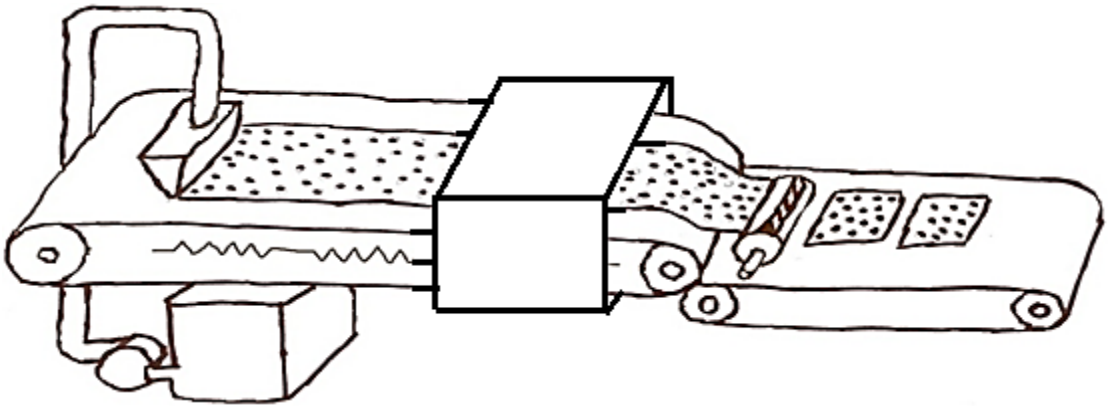


Figure 3-2 Baking design concept 2

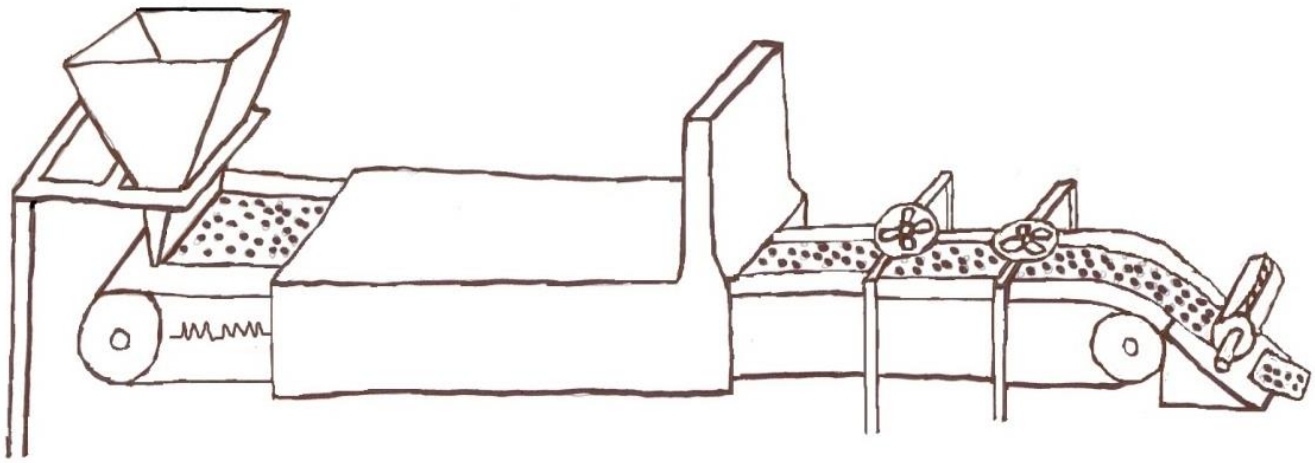


Figure 3-3 Baking design concept 3

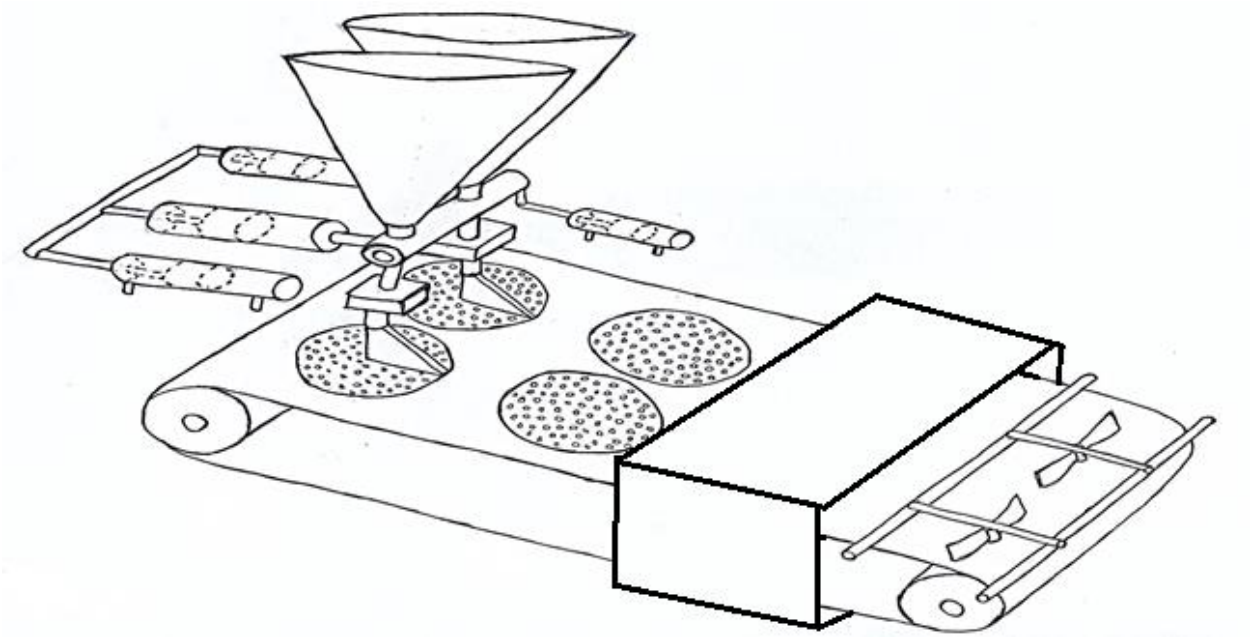


Figure 3-4 Baking design concept 4

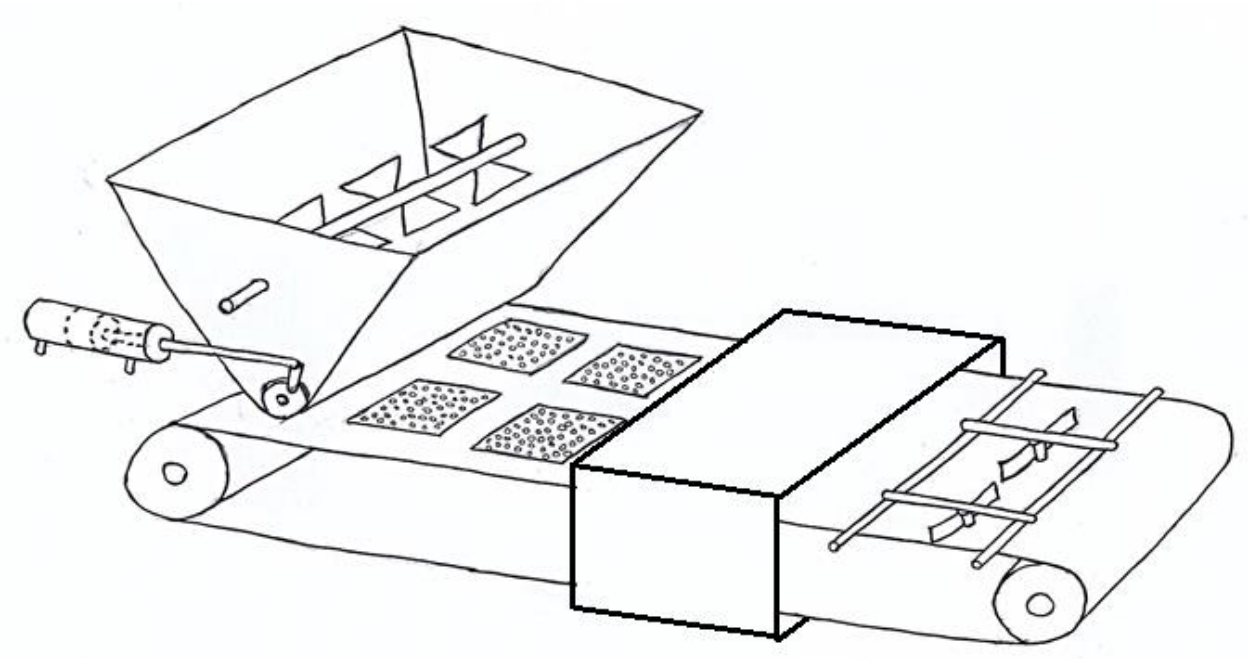


Figure 3-5 Baking design concept 5

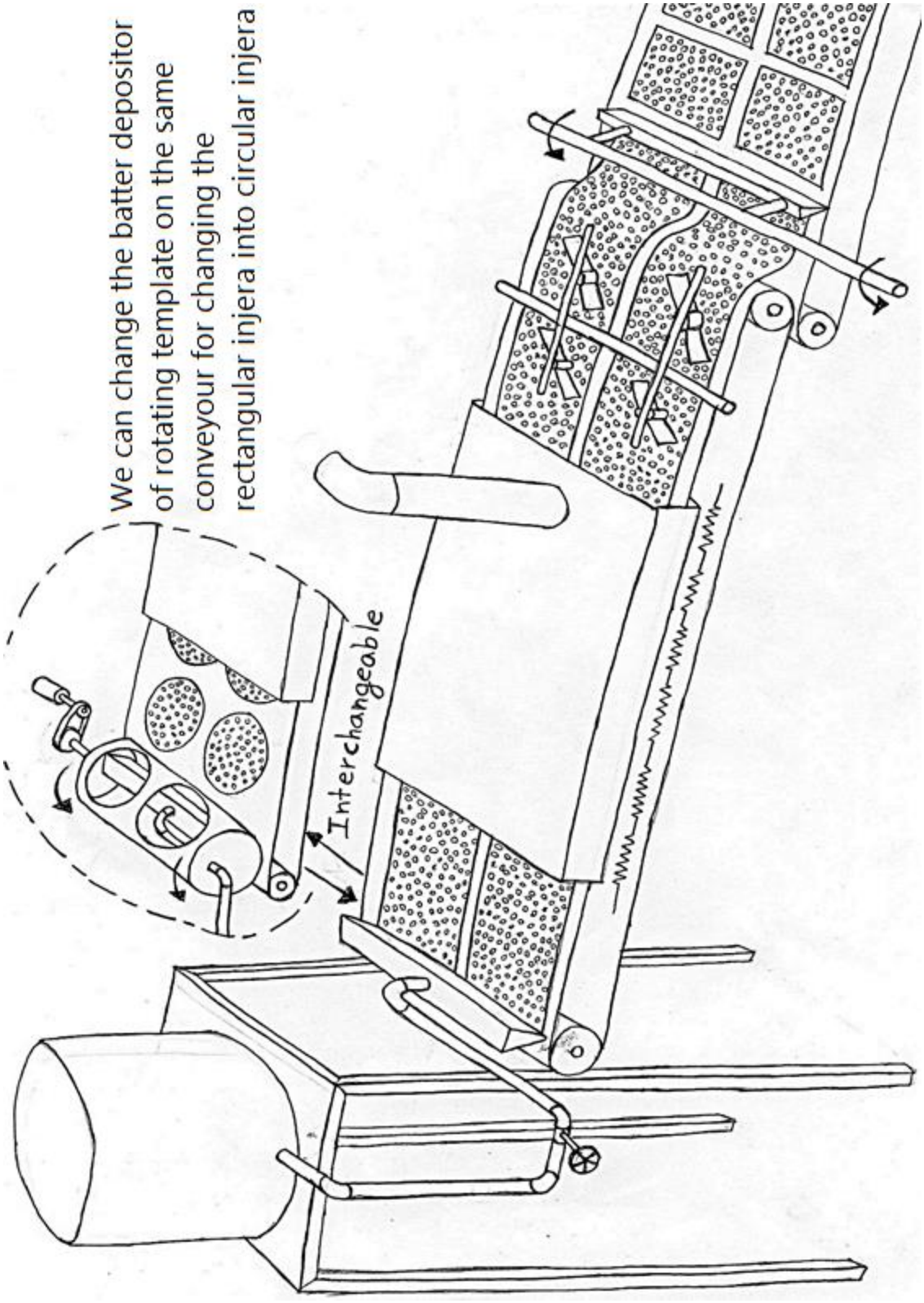


Figure 3-6 Baking design concept 6

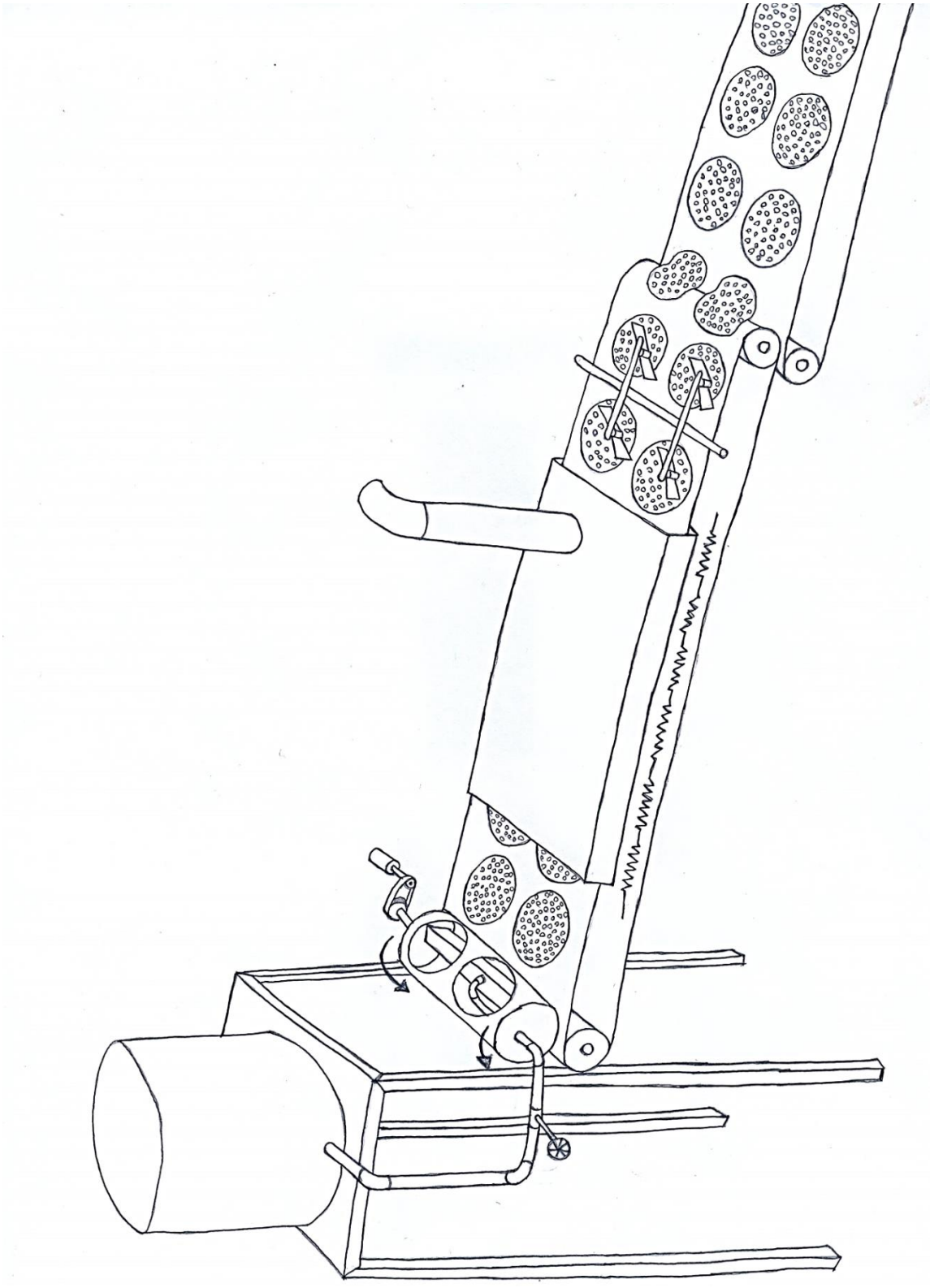


Figure 3-7 Baking design concept 6

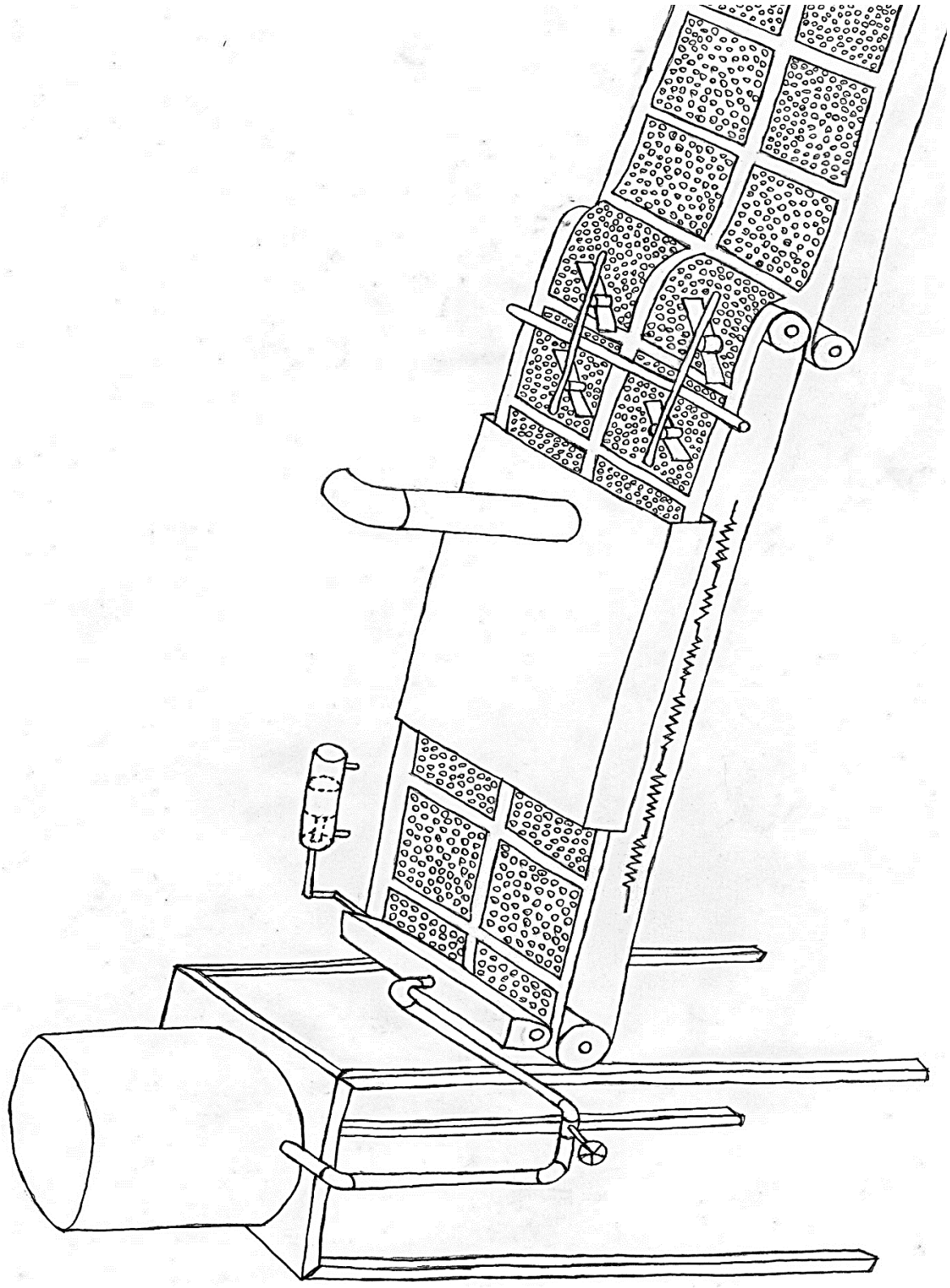


Figure 3-8 Baking design concept 6

Table 3-1 Ranking for design concept selection of Injera Baking machine

Therefore concept 6 is the selected injera baking design concept.

№	Criteria	Weight	Concepts											
			1		2		3		4		5		6	
			%	W	%	W	%	W	%	W	%	W	%	W
10	O. Capacity	0.182	62	11.284	75	13.65	79	14.37	77	14.014	80	14.56	82	14.924
8	O. Safety	0.164	64	10.496	65	10.66	68	11.15	70	11.48	76	12.464	80	13.12
9	Simplicity	0.127	62	7.874	65	8.255	71	9.017	73	9.271	76	9.652	79	10.033
4	Ease of O.	0.109	63	6.867	67	7.303	81	8.829	80	8.72	84	9.156	85	9.265
2	M. Cost	0.109	67	7.303	71	7.739	78	8.502	82	8.938	85	9.265	84	9.156
1	M. Cost	0.073	60	4.38	65	4.745	69	5.037	72	5.256	74	5.402	76	5.548
6	M.	0.073	66	4.818	66	4.818	68	4.964	71	5.183	65	4.745	71	5.183
7	Durability	0.073	65	4.745	75	5.475	79	5.767	80	5.84	84	6.132	81	5.913
11	Efficiency	0.054	62	3.348	69	3.726	80	4.32	82	4.428	75	4.05	78	4.212
3	Ease of A.	0.018	60	1.08	62	1.116	60	1.08	65	1.17	61	1.098	68	1.224
5	Easy of A.	0.018	59	1.062	65	1.17	63	1.134	72	1.296	61	1.098	71	1.278
		Sum		63.257		68.657		74.18		75.596		77.622		79.856
		Rank		6^{th}		5^{th}		4^{th}		3^{rd}		2^{nd}		1^{st}

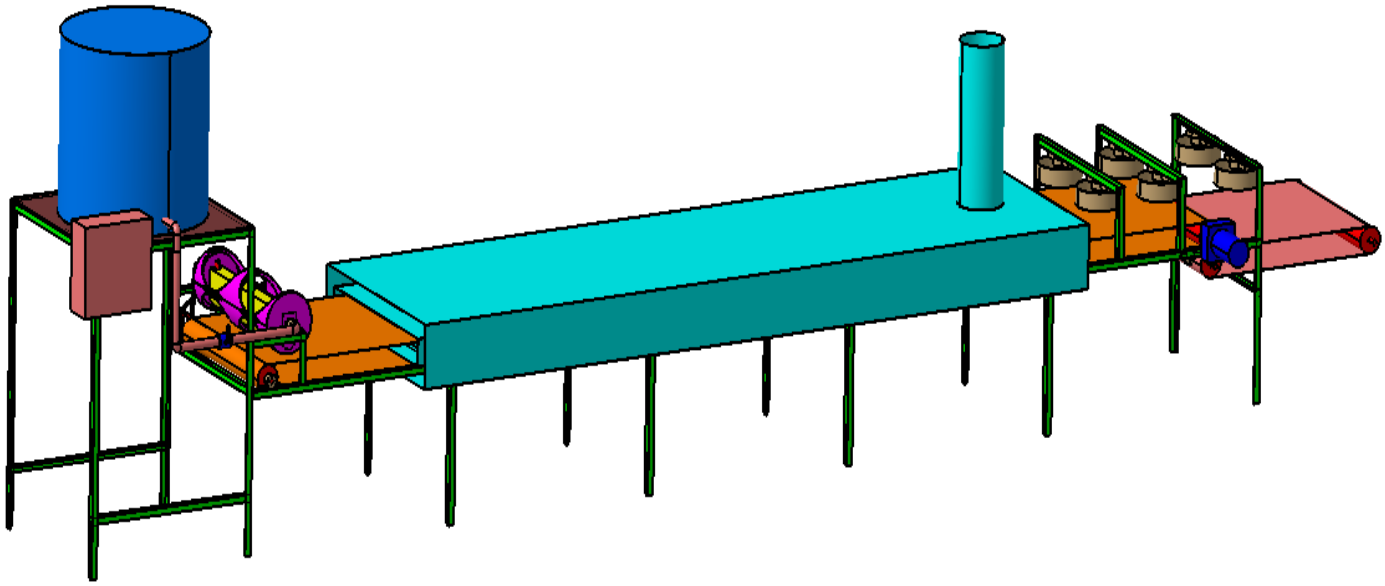


Figure 3-9 Selected baking design concept 3D model

To bake the circular injera the batter is deposited on the conveyor belt through the rotating cylinder while the remaining batter in the rotating cylinder will be pumped back into the depositor.

To bake the square (rectangular) injera the batter is deposited directly on the conveyor belt and the cutting process can be done before baking by clothing and opening the actuator while depositing or after baking by the rotary cutting mechanism.

The baking process starts by pumping the batter into the reservoir on the top. When the conveyor belt is heated to the baking temperature the depositor locking mechanism is opened and the injera batter is poured on the conveyor belt continuously. For some time, the injera passes through the oven where it is heated by the heater which is placed between the conveyor belts.

At the end of the baking process the injera will pass through a fan and it is allowed to cool for some time while it is on the same conveyor. After the baking process the cooling conveyor will receive the injera and more cooling will take place.

Since the machines for mixing, fermenting, cooling, cutting, rolling and packing are available in the market they can be selected according to the design concepts. But in this paper, we will focus on the detail design of the injera baking machine.

3.2 Embodiment design

3.2.1 Structural analysis of the frame

The model of the frame is designed by Catia software. This model is imported to ANSYS software for structural analysis. The ANSYS result for the static structural analysis is shown below.

The frame length is selected by considering the time it takes for the injera to be baked along the moving conveyor. Whereas the height of the conveyor is as per the standards of ergonomic heights.

Weight of batter container

Lower part volume; $V_A = A \times h$

$= \pi(0.5m)^2 x\ 1m$

$= 0.7854\ m^3$

Density of batter =1175 kg/m^3 [2]

Mass of batter = density of batter$*$ volume of batter

$= 1175\ kg/m^3 * 0.7854\ m^3$

=922.84 kg

Weight = (922.84 Kg) *$(9.8m/s^2)$

= 9043.8N

Properties of the selected material: -

Structural steel

Density 7850 kg/m^3

Dimension: 40 x 40 x 4 mm

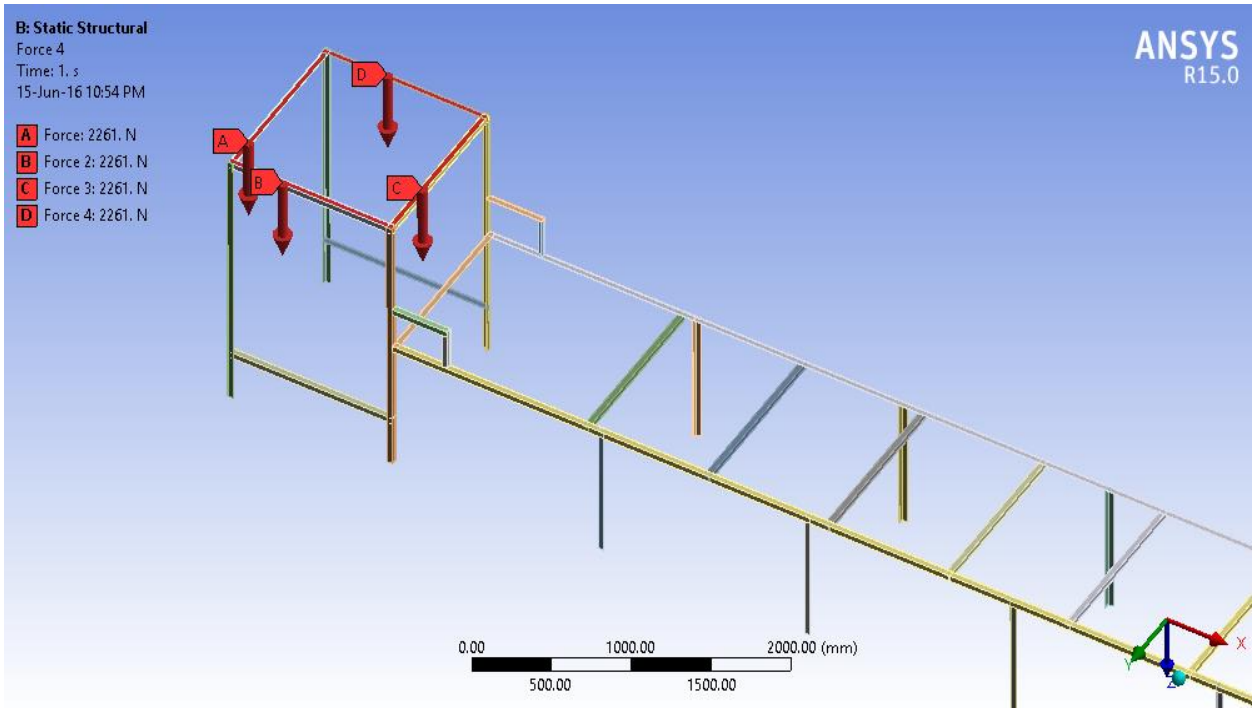


Figure 3-10 Load distribution

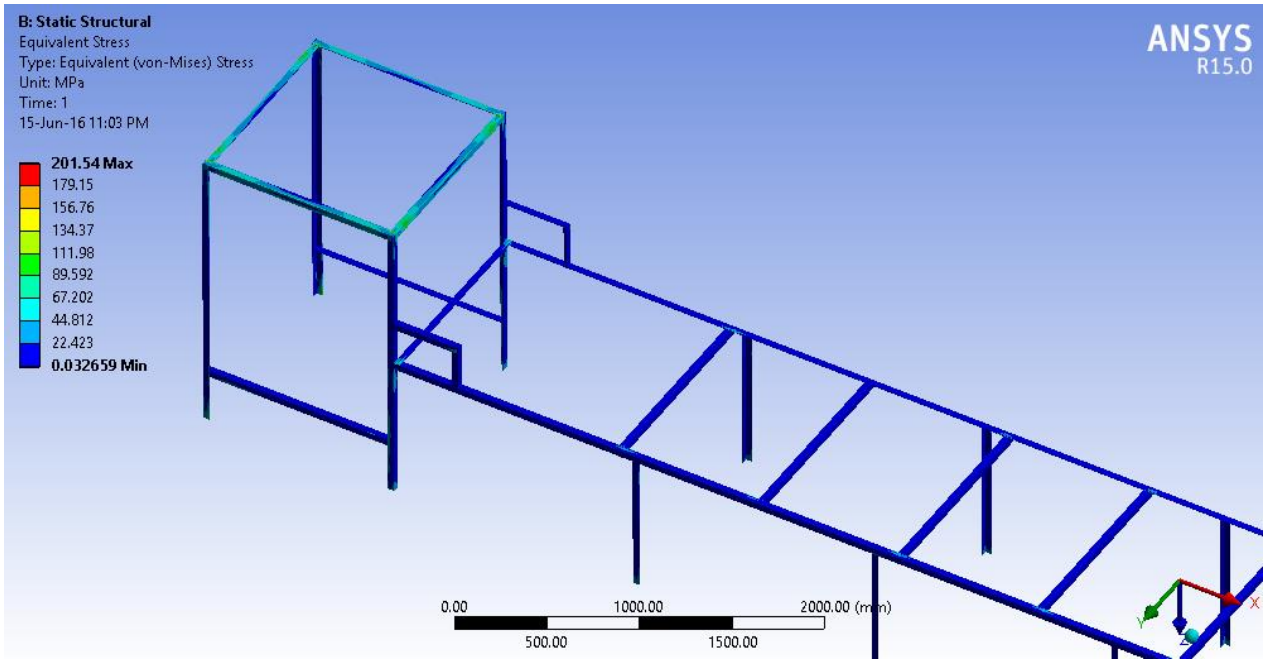


Figure 3-11 equivalent stress

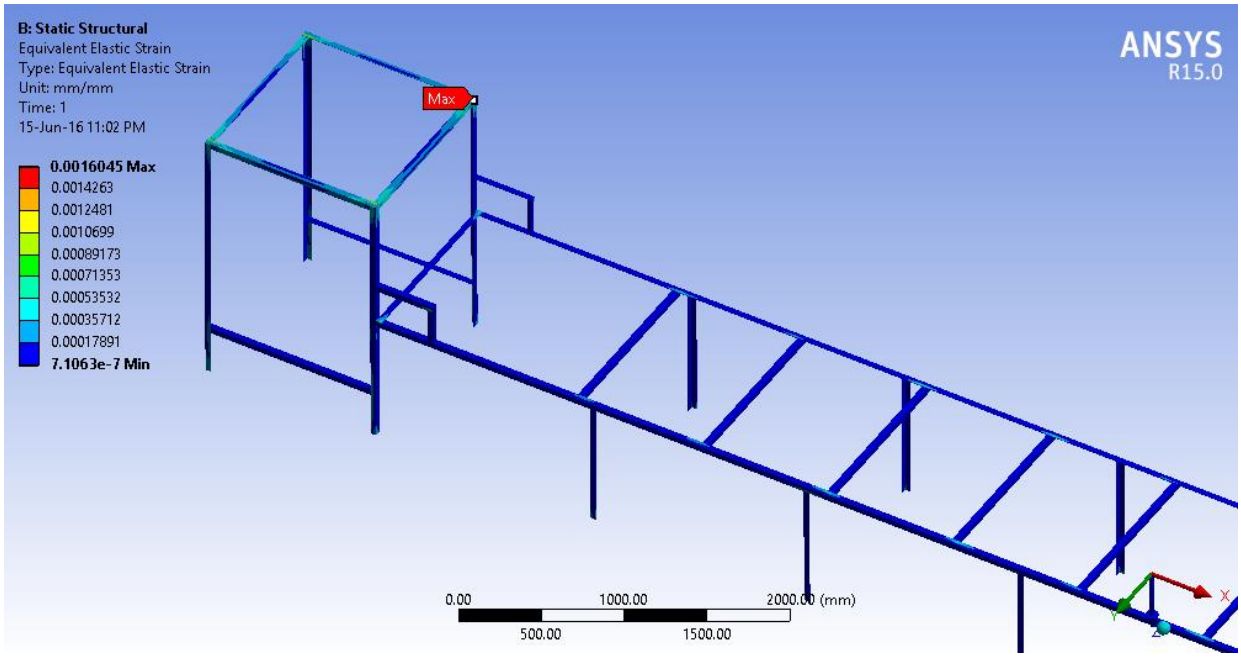


Figure 3-12 equivalent elastic strain

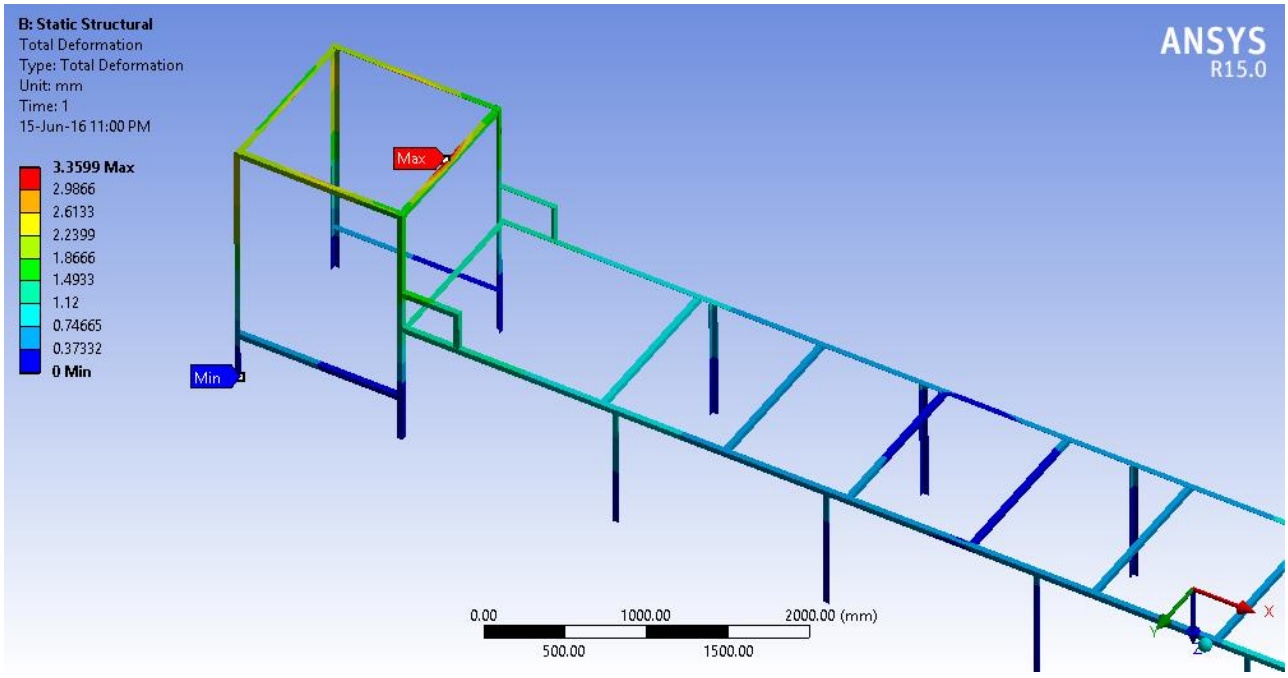


Figure 3-13 Total deformation

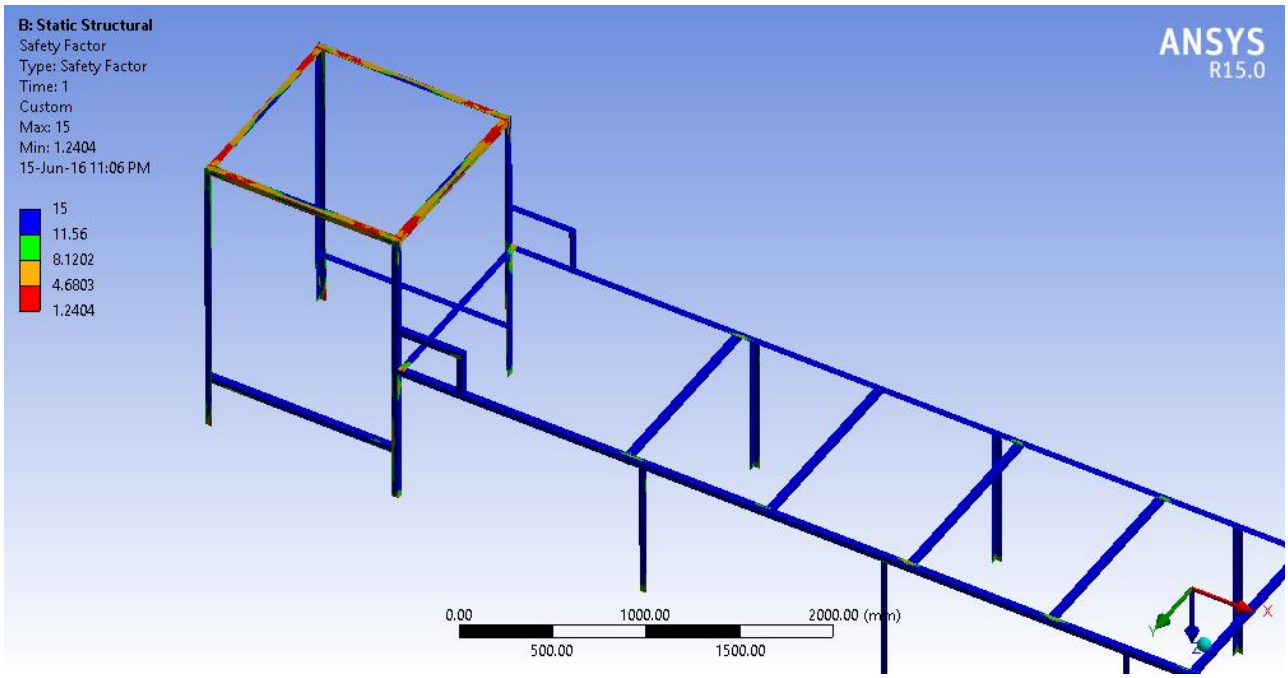


Figure 3-14 Safety factor

As we can see from the above results, the frame structure is safe to carry the load. The deformation shown by the ANSYS result is negligible.

3.2.2 Motor selection

Most rotary electromechanical systems have a need to accelerate, run at a constant speed, and decelerate. To move any mechanical system with contacting elements, friction, damping, and any external loading must be overcome by the motor. When accelerating, additional torque must be applied to overcome inertia. While decelerating, friction and damping apply a negative torque and assist the motor with deceleration. Motor sizing starts with a first pass estimation of all loading and a simple move profile defining the worst-case acceleration and velocity requirements. The most common type of general-purpose motors found in industrial motor systems are squirrel cage induction motors. These motors are generally referred to as "general-purpose motors." The squirrel cage name is derived from the shape of the motor's rotor, which is shaped like a cylinder constructed from bars and rings, and which resembles a hamster's cage.

To optimize system efficiency, it is important to select the appropriate motor to meet the needs of the application. For more detailed information, the National Electrical Manufacturers Association (NEMA) Motor Generator Section maintains standards for squirrel cage induction, NEMA Standards Publication MG 1–2010.

Motor specification

The nameplate of a motor provides important information necessary for selection and application. Below is the nameplate of a sample 15 horsepower AC motor. Specifications are given for the load and operating conditions as well as motor protection and efficiency.

AC motors are designed to operate at standard voltages and Frequencies. This motor is designed for use on 230 VAC 60Hz and 200VAC 50Hz. Full load current for this motor is 38 amps (60Hz) and 44 amps (50Hz).

Base speed is the nameplate speed, given in RPM, where the motor develops rated horsepower at rated voltage and frequency. It is an Indication of how fast the output shaft will turn the connected equipment when fully loaded with proper voltage and frequency applied.

The base speed of this motor is 1780 RPM (60Hz) and 1475 RPM (50Hz). It is known that the synchronous speed of a 4-pole motor is 1800 RPM. When fully loaded there will be 1.1% slip. If the connected equipment is operating at less than full load, the output speed (RPM) will be slightly higher than name plate.

$$\%\, Slip = (1800 - 1780)\, x\, 100\% \,/\, 1800 \quad \%\, Slip \;=\; 1.1$$

A motor designed to operate at its nameplate horsepower rating has a service factor of 1.0. This means the motor can operate at 100% of its rated horsepower. Some applications may require a motor to exceed the rated horsepower.

In these cases, a motor with a service factor of 1.15 can be specified. The service factor is a multiplier that may be applied to the rated power. A 1.15 service factor motor can be operated 15% higher than the motor's nameplate horsepower. The 15 HP motor with a 1.15 service factor, for example, can be operated at 22.5 HP. It should be noted that any motor operating continuously at a service factor greater than 1 will have a reduced life expectancy compared to operating it at its rated horsepower.

In addition, performance characteristics, such as full load RPM and full load current, will be affected.

Procedure for selection:

1. Check speed ratio of the gear head
2. Calculate the required torque
3. Select motor (ORIENTAL or SIEMENS catalogue)
4. Calculate the starting torques
5. Check moment of load inertia

Based on the above procedures,

1. Determining the gear ratio

Speed at the gear head output shaft, $N_G = \frac{V \times 60}{\pi \times D} = \frac{110 \pm 11 \times 60}{\pi \times 120} = 17.5 \pm 1.75\ rev/min$

Where Belt speed = 110 mm/sec

Because the rated speed for a 4-pole motor at 60 Hz is 1450 to 1550 rev/min, the gear ratio is calculated as follows:

Gear ratio, $i = \frac{1450 \sim 1550}{N_G} = \frac{1450 \sim 1550}{17.5 \pm 1.75} = 82.85 \sim 88.57$

This gives as a gear ratio $i = 85$

2. Calculate the required torque T_M

Friction coefficient of sliding surface F is calculated as follows:

Where total mass of belt and load, m_1 Kg which is mass of belt + injera = 5.5 Kg

$$F = F_A + m \cdot g\ (sin\ \theta + \mu \cdot cos\ \theta)$$
$$F = 0 + 5.5 \times 9.807(\sin 0 + 0.8 \cdot \cos 0)$$
$$F = 43.15\ N$$

Take η = 0.9 for between rebar and rollers

Where diameter of the roller (D) = 120 mm

$$Load\ torque, T_L = \frac{FD}{2\eta} = \frac{43.15 \times 0.12}{2 \times 0.9}$$

$$= 2.876\ Nm$$

Taking safety factor of 2

$$T_L = 2.876 \times 2 = 5.752\ Nm$$

Here, **5IK60GE-AW2U** and **5GE50SA** are tentatively selected as the motor and gearhead respectively, by referring to the "Gear motor – of oriental motor general catalogue.

Convert this load torque to a value on the motor output shaft to obtain the required torqueT_M, as follows: taking gear efficiency $\eta_G = 0.66$

$$Starting\ torque\ , \quad T_m = \frac{T_L}{i \times \eta_G} = \frac{5.752}{85 \times 0.66}$$

$$= 0.1025\ Nm\ [102.5\ mN.m]$$

Since the starting torque of the 5IK60GE-AW2U motor is 320 mN·m, this is greater than the required torque of 102.5mN·m

3. Checking moment of load inertia

Inertia of belt and load,

$$J_{m1} = m_l \left(\frac{D}{2}\right) 2$$

$$= 5.5\ Kg \times (0.06)^2$$

$$= 0.0198\ Kgm^2$$

Inertia of roller,

Where mass of roller diameter is 1.5 kg

$$J_{m2} = \left(\frac{1}{8}\right) m_r D^2$$

$$= \left(\frac{1}{8}\right) \times 1.5 \times (0.12)^2$$

$$= 0.0027\ Kgm^2$$

$$J = Jm1 + 2Jm2$$

$$= 0.0198 + 2 \times 0.0027$$

$$= 0.0252\ \text{kg}m^2$$

Form the above calculation we have:

Power rated = 2.5 KW at 50 Hz

$n_{rated} = 1465\ rpm$

$T_{rated} = 5.752\ Nm$

Mounting = horizontal

3.2.3 Controller Selection for the baking system

In temperature control applications a set-point is the target value at which a controller attempts to maintain the process variable. This can be achieved by adjusting its control output power (the correcting variable). Controllers have a local set-point and sometimes remote or other alternative set-points. Set-point values are limited by the instrument input range and any other environmental or equipment limits.

These days to control the temperature of various baking systems programmable controllers are used. A programmable temperature controller can be configured with multiple set-points that are sequenced with preset timing criteria. In its simplest form this can be one profile made up of multiple segments.

Heat-up, soak, and cool-down times are critical elements to consider for selecting the correct equipment. Heat-up time is the time that the equipment takes to increase from room temperature to the desired amount for baking or other function. Soak time refers to that time when the product has reached the desired process temperature for the desired length of time.

A programmable controller can be programmed to remain at temperature for a specified period of time, then cool-down to complete the cycle. For many applications, the soak cycle begins once the time specified for the heat-up cycle has been completed. When more precise control is necessary and it is important that the soak time does not begin until the product has reached its temperature, a guaranteed Soak option can be utilized. In this method, the controller does not start timing the soak cycle until a thermocouple embedded on the product, or in the airstream, senses that the set point temperature has been reached.

Since cooling can be thought of as removal of heat, product considerations for cool-down rates are similar to those for heat-up rates. Typically, oven cool-down is achieved by exhausting heated air from the oven. A corresponding flow of cooler, ambient air will enter the oven to replace the warm exhausted air. If the cool-down rate requires no control, the only need is to size the exhaust fan large enough to remove the necessary amount of heat in the required time.

If the cool-down rate is to be controlled, it can be accomplished in two ways:

A. Exhaust dampers are opened to the maximum position, and the heaters supply enough heat to keep the temperature from dropping too rapidly.

B. Modulating dampers can be controlled by the programmable controller. The dampers will modulate in order to maintain a controlled cooling rate. Consider that the initial investment cost of this option is greater, but operating costs will be lower due to a more energy efficient system.

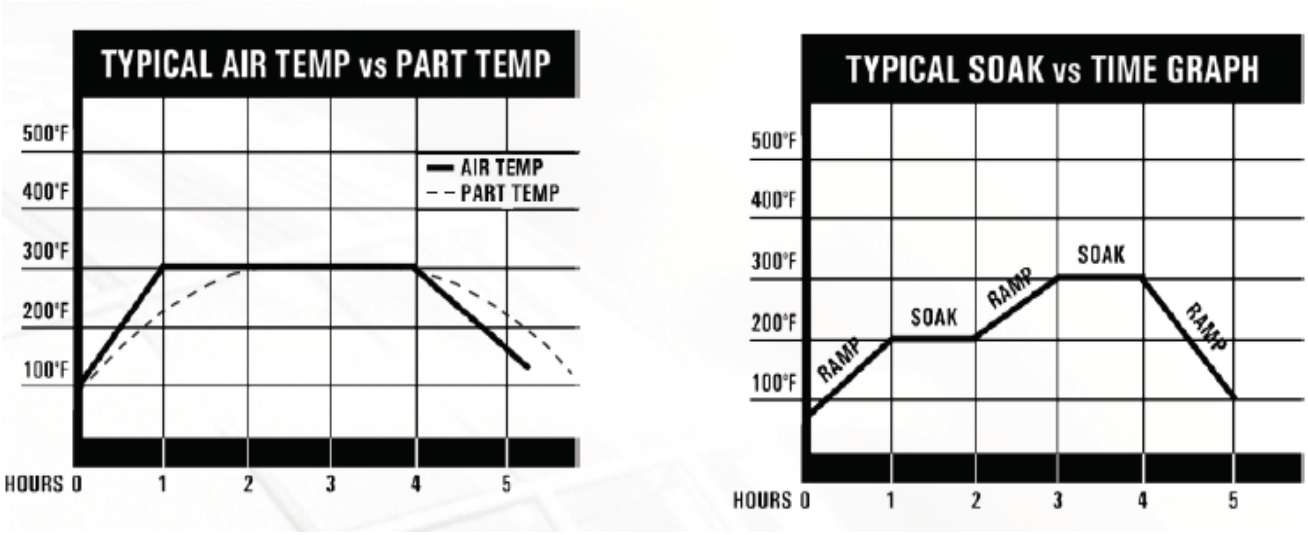


Figure 3-15: Different Segments of programmable temperature controller

In a programmable temperature controller, the programs are also referred to as profiles and recipes. There are a number of programmable temperature controllers available which can store multiple 'recipes' allowing the programmable controller to be used for a variety of processes, for example baking of edible products, heat treatment of metals and composites. With some instruments it is possible to set the programs (profile, recipe) to be joined and/or repeated. The complexity of the temperature control process will dictate how sophisticated the programmable controller needs to be.

When choosing a programmable controller, the number of segments and programs that the process and application needs will be your first concern. These ranges widely between instruments, for example in the West Control Solutions product offering the PMA KS 40-1 includes a basic programmer function which allows up to 4 segments with 1 program however the new Pro-EC44 dual loop temperature controller from West allows up 255 segments and 64 programs [18].

Other options to consider when choosing a programmable temperature controller include:

Human Machine Interface and Displays: This is particularly important if you will be expecting users to make regular profile selections via the menu interface. A text display can make the selection process much easier and minimize errors.

Outputs and Event Options: Programmable temperature controllers will vary in the number of outputs available and how these are used. In addition to main control and alarms, outputs are often assigned as profile events and are activated for associated control whilst specific segments are running. Again, the process will dictate your requirements here.

Remote Input: This can allow remote program selection as well as remote run, hold and reset options.

Real Time Clock: This is not commonly available on programmable controllers but it is a very useful if your process needs to work in real-time.

Data Logging: As one would assume, a programmable temperature controller with a built-in data logger allows important process data to be logged and stored for later analysis. This can be a key requirement to meet some industry regulations or where a process audit trail is required. You may also require this data to be available on a PC, if so you will need to consider communications option or a USB port.

Heating Element selection

Heat can be transferred to any process by natural convection, forced convection or by radiant heat sources. Natural convection heating can be very fast, but may not be as uniform as forced convection. There are many issues that must be considered when selecting industrial equipment, including: the quantity of material to be processed, the uniformity, size and shape of the products, the temperature tolerance that is permissible, whether the product or process lends itself to be batch or continuous in-line processing.

There are many ways of heating the continuous Teflon conveyer. Many industries use: electrical heaters or combustion heating systems that use fuels or natural gases. Most of the time industries that produce edible products like bread and biscuits use electrical heaters because they provide a clean and leakage free heating mechanism. Because of these reason electrical resistors are used to heat the Teflon conveyer.

Indirect resistance heating involves passing line alternating current through low resistance heating elements. The resistance to the current flow generates heat in the coil; and the heat is transferred to the baking Teflon by convection.

The whole process of heating the Teflon conveyer lies up on giving the right amount of current to the resistance heating element. The supplied electrical power is converted to heat energy and it is used to heat the Teflon conveyer.

$$P = I^2R = \frac{V}{I}$$

The most widely used heating element resistance is the Ni-Cr resistance. This heating resistance type is selected because [17]: It has high melting point $1400^0\text{C} - 2550^0C$ and it doesn't oxidize at high temperature.

It doesn't expand when heated and the temperature increases only by 10% between its room temperature and its maximum temperature limit.

Temperature Sensor Selection

There are different types of temperature sensors that can be used in different industrial environment. These temperature sensors are constructed to withstand certain amount of temperature. The following table describes the different type of sensors and their temperature sensing range.

Table 3-2: Temperature Sensor Types [16]

THERMOCOUPLE	RTD	THERMISTOR	SEMICONDUCTOR
widest Range: –184ºCto+2300ºC	Range: –200ºCto+850ºC	Range: 0ºCto+100ºC	Range: –55ºCto+150ºC
High Accuracy and Repeatability	Fair Linearity	Poor Linearity	Linearity:1ºC Accuracy:1ºC
Needs Cold Junction Compensation	Requires Excitation	Requires Excitation	Requires Excitation
Low-Voltage Output	Low-cost	High Sensitivity	10mV/K,20mV/K, or1µA/K Typical

Table 3-3: Common Thermocouple Sensors [16]

JUNCTION MATERIALS	TYPICAL USEFUL RANGE (ºC)	NOMINAL SENSITIVITY	ANSI DESIGNATION
Platinum (6%)/Rhodium-Platinum (30%)/Rhodium	38 to 1800	7.7	B
Tungsten (5%)/Rhenium - Tungsten (26%)/Rhenium	0 to 2300	16	C
Chromel-Constantan	0 to 982	76	E
Iron-Constantan	0 to 760	55	J
Chromel-Alumel	–184 to 1260	39	K
Platinum (13%)/Rhodium-Platinum	0 to 1593	11.7	R
Platinum (10%)/Rhodium-Platinum	0to1538	10,4	S
Copper-Constantan	–184to400	45	T

For baking injera by using Teflon continuous conveyor the Copper and Constantan alloy thermocouple temperature sensor is selected because of its high accuracy, repeatability and the desired temperature range that is required. The Thermocouple sensor is placed on the Teflon conveyer and will sense the conveyer temperature. The temperature control of the Teflon continuous time oven is described by the figure 3-16 shown below.

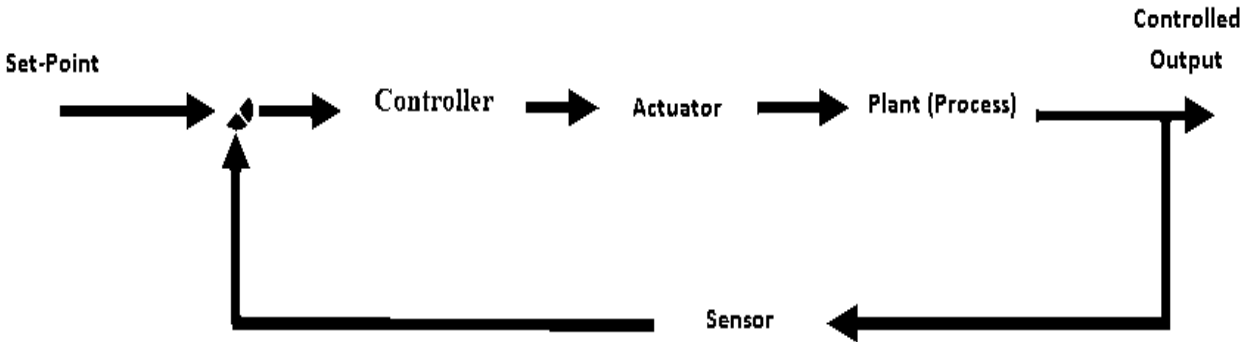


Figure 3-96 Automatic Controller Setup for Temperature Control

3.2.4 Heat transfer analysis

Heat transfer, also known as heat flow, heat exchange, or transfer of thermal energy is the movement of heat from one place to another. When an object is at a different temperature from its surroundings, heat transfer occurs so that the body and the surroundings reach the same temperature at thermal equilibrium. Such spontaneous heat transfer always occurs from a region of high temperature to another region of lower temperature. There are three basic modes of heat transfer mechanisms conduction, convection and radiation.

Conduction Heat Transfer Mechanism

Transfer of energy between objects in physical contact is the transfer of heat from a hot side to a cooler side through a dividing medium. The hot side heats the molecules in the dividing medium and causes them to move rapidly, heating the adjacent molecules until the cool side is heated. The transfer of heat stops when the temperature of the hot side equals that of the cool side

Conduction through a plane wall: The details of conduction are quite complicated but for engineering purposes may be handled by a simple equation, usually called Fourier's equation. For the steady flow of across a plane wall with the surfaces at temperatures of T_1 and T_2 where T_1 is greater than T_2; the heat flow Q per unit area A; (the heat flux) is:

$$\frac{Q}{A} = K\left\{\frac{T_1 - T_2}{X_1 - X_2}\right\} = K\frac{\Delta T}{\Delta X}$$

$$\dot{Q} = -KA\,\frac{dT}{dX}$$

Where: $\dot{Q}$ - Is the heat flow (W)

$\frac{dT}{dX}$- Temperature gradient in plane of heat transfer in the direction of heat flow ($℃/m$)

k- Thermal conductivity ($W/m℃$)

A – Area perpendicular to heat flow (m^2)

The negative sign in the equation is provideed to account for the fact that heat is conducted from a high temperature to a low temperature, so that (dT/dx) inherently negative; therefore the double negative indicates a positive flow of heat in the direction of decreasing temperature.

Convection Heat Transfer Mechanism

Convection is transfer of energy between an object and its environment, due to fluid motion. Convection can be forced convection in which the flow is caused by a pump or a fan or it may be natural convection in which the flow is caused by density differences due to differences in temperature. It is found that the heat flux is approximately proportional to the temperature difference between the wall and the bulk of the fluid.

$$\frac{Q}{A} \propto (T_f - T_s)$$

This causes to define a constant proportionality called "convection heat transfer coefficient" denoted by, h

$$\frac{Q}{A} = h(T_f - T_s)$$

Thus the rate of convection heat transfer is given by [23].

$$\dot{Q} = hA(T_f - T_s)$$

Where: h -convection heat transfer coefficient (W/m^2 °C)

A - Surface area where convection takes place (m^2)

ΔT - Temperature difference between the fluid and the wall surface (°C)

Radiation Heat Transfer Mechanism

Transfer of energy from or to a body by the emission or absorption of electromagnetic radiation. All objects with a temperature above absolute zero radiate energy at a rate equal to their emissivity multiplied by the rate at which energy would radiate from them if they were a blackbody. According to Stefan–Boltzmann law, ideal radiators emit energy at a rate proportional to the fourth power of the absolute temperature. And the net rate of exchange of energy between two ideal radiators A and B related as; [24].

$$\dot{Q} = \sigma A\left({T_A}^4 - {T_B}^4\right)$$

Where: σ - Stefan- Boltzmann constant = $5.67x10^{-12} w/cm^2.k^4$

T_A - Temperature of body A (℃)

T_B - Temperature of body B (℃)

In many physical situations, we are interested in radiation heat transfer from the surface of an object to the surrounding uniform temperature. Thus, the net radiation from a non-black surface to the surrounding is given by [25].

$$\dot{Q} = \varepsilon\sigma A\left({T_s}^4 - {T_\infty}^4\right)$$

Where: T_s - Body surface temperature (℃)

T_∞ - Surrounding or ambient temperature (℃)

ε - Emissivity of the surface and has a value between 0 and 1, for a perfect reflector ε = 0 and for a perfect emitter a so called “black body”, ε = 1.

3.2.5 Optimum Temperature of the resistance heater coil for the baking conveyor

When a medium comes in contact with another, heat exchange will occur from one point of a medium to another whenever there is a temperature difference between the two. A distinguishing characteristic of conduction is that it takes place within the boundary of a medium, or across the boundary of a medium into another medium in contact with the first, without an appreciable displacement of the matter.

Heat conduction is important in stove top cooking, where heat is conducted from the heat source electric coils directly to the bottom side of the baking conveyor. Energy transfer from resistance coil heater to the Teflon baking conveyor was in the way of conduction heat transfer mechanism.

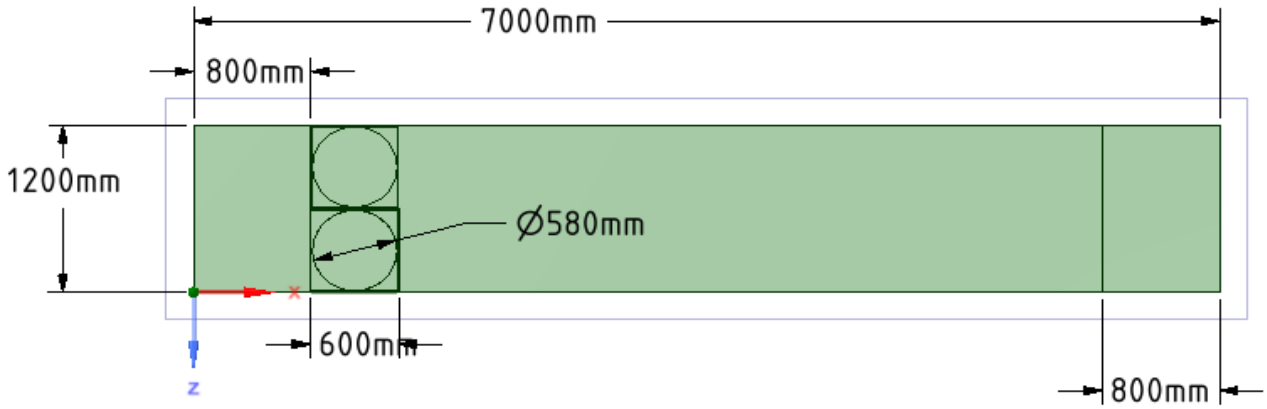


Figure 3-17: Top view of the baking conveyor

Thus, the rate of heat transfer from the resistance heater coil to baking conveyor surface can also be expressed as follows.

$$\dot{Q} = \frac{KA(T_b - T_u)}{t_c}$$

Where: T_b- baking conveyor bottom temperature (℃) (which is equivalent to the resistance heater coil temperature)

T_u- baking conveyor surface temperature = 200℃

t_c- Thickness of baking conveyor (Teflon) = 0.003m

K- Thermal conductivity of Baking conveyor (Teflon) = 0.25w/m.K

A- Area of the baking section of conveyor is calculated as follows;

$$A = L_b \times W$$

Where: L_b- the length of baking section of conveyor = 5.4m

W- The width of baking conveyor =1.2 m

$$A = L_b \times W = 5.4 \times 1.2 = 6.4\ m^2$$

Now the required resistance coil temperature can be calculated as:

$$\dot{Q} = \frac{KA\,(T_b - T_u)}{t_c}$$

$$T_b = \frac{\dot{Q} t_c}{KA} + T_u$$

$$= \frac{50.634 \times 0.003}{0.25 \times 6.4} + 473$$

$$T_b = 566.8\,K$$

3.2.6 Heat Loss Coefficients of the Injera Machine

Heat is lost in three directions of the bake ware; the side, the bottom and top directions of the baking machine. All the three modes of heat transfers, (conduction, radiation and convection) participate in the transfer of energy to the surrounding. During baking the bottom side of injera is heated by conduction from the top bake conveyor surface temperature and heat is given off from injera at the top surface to the surrounding by convection. So, the energy transferred to injera is accounted as the useful energy used to cook the product and is not considered as a loss.

Heat lost coefficients are the heat transfer coefficients at the three sides of the stove and the heat transfer to the product were not considered as a loss since this is the heat used to cook the product. The heat source to the bake ware (conveyor) is the current flow through Ni–Cr coil (or wire) that is placed at the bottom side of the bake ware. The bake ware gets heated due to the resistance to the flow of current through the heating element; what is termed as ohmic heating or joules heating.

1. **Surface heat transfer coefficient**

The surface heat transfer coefficient is influenced by the composition of the fluid, the nature and geometry of the surface, and on the hydrodynamics of the fluid moving past the surface. From the boundary conditions the heat transfer coefficient over the bake ware is the combined effect of the heat transfer coefficient due to convection and radiation.

$$h = h_c + h_r$$

Where h_c convective heat transfer coefficient in $(W/m^2.K)$, h_r radiation heat transfer coefficient $(W/m^2.K)$ and h is surface heat transfer coefficients in $(W/m^2.K)$. The convective heat transfer coefficient over the bake ware is given by:

$$h_c = Nu\frac{K}{L}$$

Where: - *Nu* is the Nusselt Number, *K* is the thermal conductivity of the fluid (w/m. k), *L* is the characteristic length (m).

1.1 Convective Heat Transfer Coefficient

In the determination of convective heat transfer coefficient, a dimensionless functional relationship derived using dimensional analysis between h_c and the relevant physical properties of the flow situation are used. The functional of this relationship is given by:

$$h_c = f(\rho, V, L, \mu, C_p, \Delta T, k, \beta, g)$$

Where ρ is Density of fluid (kg/m^3), V is Average fluid velocity (m/s), L is Characteristic length (m), μ is Dynamic viscosity $(N.s/m^2)$, C_p is Specific heat of fluid (J/kg. k), β is volumetric expansion coefficient (1/k), g is Gravitational acceleration (m/s^2). By performing a dimensional analysis on the above equation, the following functional relation can be derived:

$$\frac{h_c L}{k} = f\left(\frac{\rho VL}{\mu}, \frac{C_p\mu}{k}, \frac{\rho^2 g\beta L^3\Delta T}{\mu^2}, \frac{V^2}{C_p\Delta T}\right)$$

Where: $Ra = \frac{\rho VL}{\mu}$ is the Reynolds number, $Pr = \frac{C_p\mu}{k}$ is the Prandtle number,

Gr $=\frac{\rho^2 g\beta L^3\Delta T}{\mu^2}$ is the Grashof number and $\frac{V^2}{C_p\Delta T}$ is the Eckert number.

In natural convection, many correlations contain the product of the Grashof number and the Prandtle number; the product of the two is defined as the Rayleigh number:

$$Ra = Gr \times Pr$$

As the motion of fluid in free convection is caused by buoyancy force, for horizontal plates either from the plate or toward the plate, two situations should be distinguished.

1. Heat transfer occurs in the direction of gravitational force (lower surface heated upper surface cooled), and
2. Heat transfer against the direction of gravitational force (Upper surface heated lower surface cooled).

A general correlation between the Nusselt number and Rayleigh number is developed based on the above two cases as:

$$Nu = C(Gr \times Pr)^m$$

Where, m and C are constants. The value of the constants depends on geometry. Since heat transfer during injera baking is against the direction of gravitational force, only the second case is used for this study.

Fuji and imura (1972) proposed the following correlation for heat transfer to or from the horizontal plate with constant heat flux [19, 20, 21, and 22]:

$$Nu = 0.13(Gr \times Pr)^{\frac{1}{3}}, \quad for\ Gr \times Pr < 2 \times 10^8$$

$$Nu = 0.16(Gr \times Pr)^{\frac{1}{3}}, \quad for\ 2 \times 10^8 < Gr \times Pr < 2 \times 10^{11}$$

In these equations β is evaluated at $T_\infty + 0.25[T_s - T_\infty]$, and all other properties at $T_s - 0.25\ [T_s - T_\infty]$. T_s is the average wall temperature.

Correlations are also presented for flat surfaces without constant heat flux as [19, 20, 21, & 22]

$$Nu = 0.54(Gr \times Pr)^{\frac{1}{4}}, \quad for\ 10^4 < Gr \times Pr < 10^7$$

$$Nu = 0.15(Gr \times Pr)^{\frac{1}{3}}, \quad for\ 10^7 < Gr \times Pr < 10^{11}$$

To determine the convictive heat transfer coefficients of the bake ware air properties are first evaluated at the average film temperature. This is the average temperature between the bake conveyor top surface and the temperature of the environment.

$$T_S = \frac{T_s + T_\infty}{2} = \frac{473 + 293}{2} = 383\ K$$

The film temperature to evaluate the properties of air is

$$T_W = T_S + 0.25\,[T_s - T_\infty] = 383 + 0.25\,[473 - 293) = 360.5\,K]$$

Properties at the average film temperature:

$\rho = 0.996\ {}^{kg}/_{m^3}$, $C_p = 1010\ {}^{J}/_{kg.K}\ k = 30.5275 \times 10^{-3}\ {}^{W}/_{m.K}$

$\beta = 2.773 \times 10^{-3}\ K,$ $v = 2.216 \times 10^{-5}\ {}^{m^2}/_{S},$ $\mu = 2.1193 \times 10^{-5}\ {}^{Kg}/_{m.s}$

$g = 9.81\ {}^{m}/_{S^2},$ $\alpha = 3.131 \times 10^{-5}\ {}^{m^2}/_{S}\ Pr = 0.71$

The characteristic length for horizontal surface is calculated as $L = \frac{A_S}{P}$ where, A_S is the surface area and p is the perimeter of the baking conveyor [19, 21]. The dimensionless Grashof and Rayleigh numbers become:

$$Gr = \frac{g\beta L^3 \Delta T}{v^2} = \frac{9.81 \times 2.773 \times 10^{-3} \times (0.5122)^3 \times (383 - 293)}{(2.216 \times 10^{-5})^2}$$

$$= 6.70 \times 10^8$$

$$Ra = Gr \times Pr = 6.70 \times 10^8 \times 0.71 = 4.76 \times 10^8$$

Thus,

$$Nu = 0.16(Gr \times Pr)^{\frac{1}{3}} = 0.16(6.70 \times 10^8 \times 4.76 \times 10^8)^{\frac{1}{3}} = 124.91$$

The convective heat transfer coefficient becomes:

$$h_c = \frac{Nu\ K}{L} = \frac{124.91 \times 30.5275 \times 10^{-3}}{0.5122} = 7.44\ W/m^2.K$$

The radiative heat transfer coefficient at the surface of the baking pan is given by:

$$\mathrm{h_r} = \frac{\sigma\varepsilon(T_s^4 - T_\infty^2)}{(T_s - T_\infty)}$$

Where; σ is the Stefan Boltzmann constant $\left(5.67 * 10^{-8}\ {}^{W}/_{m^2K^4}\right)$,

and ε is the emissivity of the surface conveyor (0.91).

Therefore: $h_r = 0.91 \times 5.67 * 10^{-8}(473^2 + 293^2)(473 + 293)$

$$h_r = 12.47\ {}^{W}/_{m^2.K}$$

The surface heat transfer coefficient on the top surface of the baking pan will be:

$$h = h_c + h_r = 7.44 + 12.47 = 19.91\ {}^{W}/_{m^2.K}$$

1.2 Bottom Heat Transfer Coefficient

Heat is lost from the plate to the ambient, by conduction through the insulation to the plate casing and subsequently by convection and radiation from the bottom casing surface to the ambient:

$$U_b = \left[\frac{t_{in}}{k_{in}} + \frac{t_p}{k_p} + \frac{1}{h_b}\right]^{-1}$$

h_b- The total heat transfer coefficient on the bottom plate surface to the ambient air

t_{in}- Insulation thickness = 40 mm

k_{in}- Thermal conductivity of gypsum = 0.15w/m.K

t_p- Plate thickness = 3 mm

k_p- Thermal conductivity of plate = 40 w/m.k

And the total heat transfer coefficients from the bottom casing surface to the ambient is given as:

$$h_b = h_{c,b} + h_{r,b}$$

Where; $h_{r,b}$ is the bottom radiative heat transfer coefficient, It can be determined as by considering the bottom surface temperature is 55 ℃

$$h_{r,b} = \frac{\sigma\varepsilon\left({T_{s,b}}^4 - T_\infty^4\right)}{\left(T_{s,b} - T_\infty\right)} = \varepsilon_b\sigma\left({T_{s,b}}^2 + {T_\infty}^2\right)\left(T_{s,b} + T_\infty\right)$$

$$= 0.10 \times 5.67 * 10^{-8}((318)^2 + (293)^2)(318 + 293)$$

$$h_{r,b} = 0.648\ {}^{W}/_{m^2.K}$$

And, $h_{c,b}$ is the bottom convective heat transfer coefficient $= 11.8\ {}^{W}/_{m^2.K}$

$$h_b = h_{c,b} + h_{r,b} = 11.8 + 0.648 = 12.44\ {}^{W}/_{m^2.K}$$

Then the back-loss coefficient formula and its analytical value can be determined as:

$$U_b = \left[\frac{t_{in}}{k_{in}} + \frac{t_p}{k_p} + \frac{1}{h_b}\right]^{-1} = \left[\frac{0.04}{0.15} + \frac{0.003}{40} + \frac{1}{12.44}\right]^{-1}$$

$$U_b = 2.89\ {}^{W}/_{m^2.K}$$

1.3 Lateral or Edge Heat Transfer Coefficient

Energy lost from the lateral side of the baking pan casing may be taken to have similar value with the bottom side of the baking pan if the thickness and area of the edge insulation has the same to that of back (or bottom) insulation. But they have different thickness and area.

$$U_e = \left[\frac{t_{in}}{k_{in}} + 2\left(\frac{t_p}{k_p}\right) + \frac{1}{h_s}\right]^{-1}$$

$$= \left[\frac{0.04}{0.15} + 2\left(\frac{0.003}{40}\right) + \frac{1}{12.44}\right]^{-1}$$

$$U_e = 2.880\ {}^{W}/_{m^2.K}$$

3.2.7 Energy required for injera baking

Baking injera requires intensive energy and this energy can be defined as the energy necessary to raise the batter to a particular temperature, and evaporate the amount of water that is to be lost during the baking process. To measure the energy utilized in cooking injera, the initial mass of batter, and the total amount of injera produced from this batter were measured.

Thus, the mass of water vapor can be obtained by reducing the mass of the injera produced from the initial mass of batter. It is assumed that the energy utilized in cooking the injera is the energy required in raising the temperature of the batter from room temperature to the boiling point of water which is called sensible heat, plus the energy required to evaporate water which is called latent heat.

It is also assumed that the heat capacity of injera batter is the same as that of water in order to calculate the energy required to raise the batter temperature to boiling point [27]. Therefore, the utilized energy is:

$$E_{utilized} = m_{ba}C_w(T_{bo} - T_r) + (m_{ba} - m_i)h_{vap}$$

Where:

m_{ba} -is the mass of the batter expected for one injera= $400g$

T_{bo} - is the boiling temperature of water in Addis Ababa= 92℃

T_r - is the room temperature in the baking pan test room = 20℃

C_w- is the heat capacity of water = 4.187 kJ/kg.k

m_i - is the mass of the injera produced = 320g

h_{vap} - is the heat of vaporization of water = 2260 kJ/kg

$$E_{utilized} = 0.4kg \times 4.187kJ/kg.k \times (92 - 20)\,k + (0.4 - 0.32)\,kg \times 2260\,kJ/kg$$

$$E_{utilized} = 120.6\,KJ + 180.8kJ$$

$$E_{utilized} = 301.4\,kJ$$

During injera baking there are losses in the sides, bottom side of electric heater support, and conveyor, so considering the losses and assuming a safety factor of 1.4 the total energy required will be 301.4 kJ x 1.4 = 421.96 kJ.

The time taken for cooking of one injera is about 2 to 3 minutes taking 2.5 minutes; the power required for injera baking can be calculated as:

$$P = \frac{E_{utilized}}{\Delta t}$$

Where: P- the power required for baking one injera

$$\Delta t = 2.5mi \times 60sec = 150\,sec$$

Then; $P = \frac{421.96kJ}{150\ sec} = 2.813\ kW$

Since the overall length of baking(L_b) section of the Teflon conveyor was designed to bake **N** injera in lengthwise, and also it can be used to bake **2** injera along its width, Therefore, the total number of injera and the total amount of power required can be determined as:

$$L_b = N \times l_{for\ one\ injera}$$

Thus,

$$N = \frac{L_b}{l_{for\ one\ injera}} = \frac{5.4\ m}{0.6}$$

$$N = 9$$

Since the injera is baked in two rows on the Teflon conveyor belt the total number of injera that can be baked in 2.5 minute is 18 injera.

$$\text{Then, } P_{total} = 2N \times P$$

$$= 2 \times 9 \times 2.813\ kW$$

$$P_{total} = 50.634\ kW$$

3.2.8 Heat loss calculation

Heat loss from the cover oven of the Teflon baking conveyor

L – length of Cover = 5 m

t – thickness of cover = 0.001 m

w – width of the cover = 1.186 m

T_o- outer cover temperature $= 52$ ℃

T_i- internal cover temperature $= 100$ ℃

K- Thermal conductivity of Aluminum = 205 w/m.K

The heat transfer through the wall is considered to be at steady state.

The heat transfer through the top cover is can be determined as

$$Q = \frac{KA(T_1 - T_2)}{L}$$

= (205 w/m.K) (5 m x 1.186 m) (100 ℃ − 52 ℃)/5m

= 11.67 kW

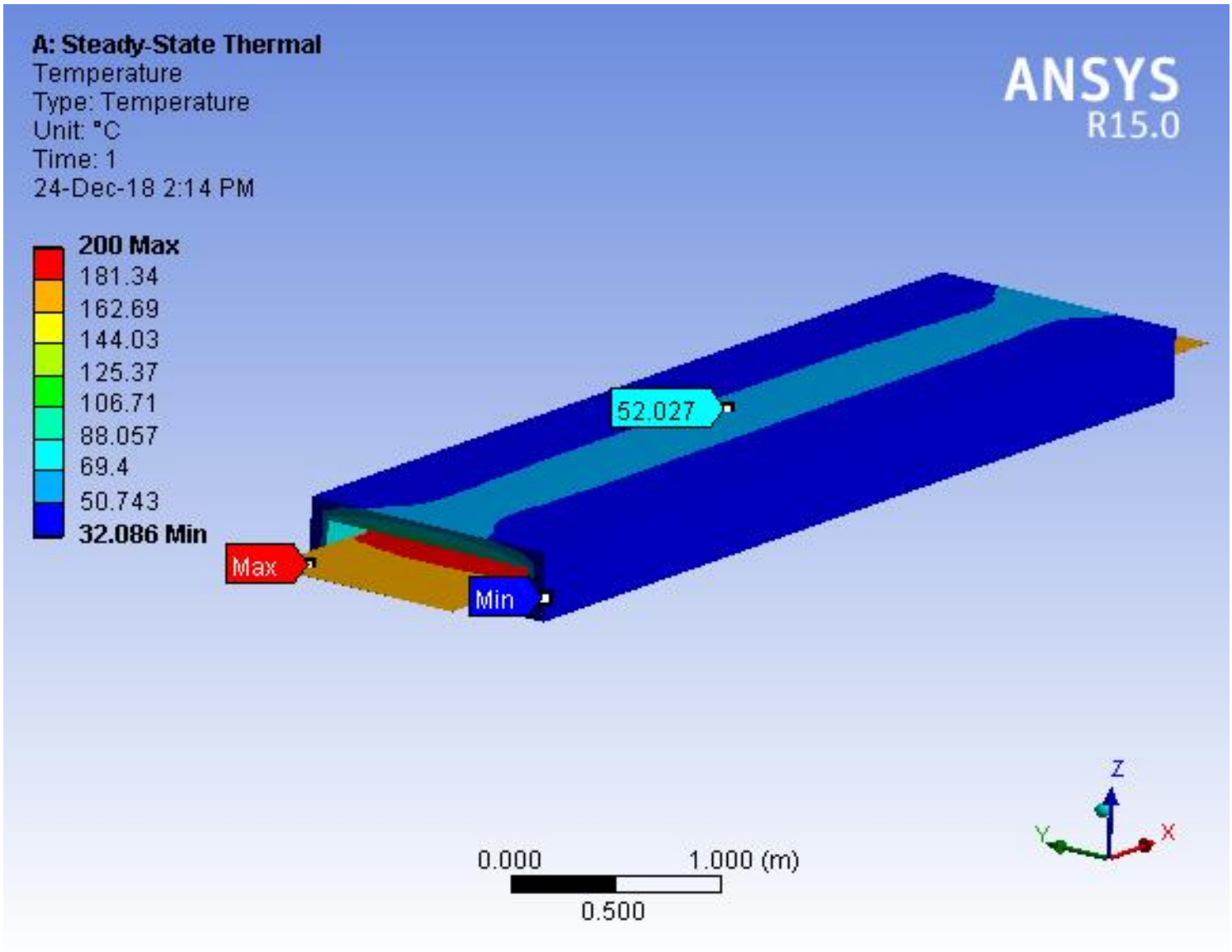


Figure 3-18: Baking conveyor thermal analysis by ANSYS

The heat loss from the side walls of the baking conveyor

L - length of the side walls = 5 m

h – height of the side walls = 0.154 m

t_i – thickness of inner sheet metal = 0.001 m

$t_{nsulation}$ – thickness of insulation foam = 0.01 m

t_o – thickness of outer sheet metal = 0.001 m

T_i- temperature of inner side of interior sheet metal $= 70$ ℃

T_o- temperature of outer surface of outer sheet metal $= 36$ ℃

$A_{total} = 2[L \times h]$

= 2 [5m x 0.154 m] = 1.54 m^2

The thermal resistance network for the heat transfer is through a three-layer plane wall of the internal wall and the external wall.

Thermal resistance of each layers can be determined as

$$R_1 = \frac{t_1}{K_{Al} A_{total}}$$

$$= \frac{0.001 \text{ m}}{\left(205 \frac{\text{w}}{\text{m}}.\text{K}\right)(1.54\ m^2)}$$

$= 3.16 \text{ x } 10^{-6} \text{ K/W}$

$$R_2 = \frac{t_{insulation}}{K_{insulation} A_{total}}$$

$$= \frac{0.01 \text{ m}}{\left(0.028 \frac{\text{w}}{\text{m}}.\text{K}\right)(1.54\ m^2)}$$

$= 0.23 \text{ K/W}$

$$R_3 = \frac{t_3}{K_{Al} A_{total}}$$

$$= \frac{0.001 \text{ m}}{\left(205 \frac{\text{w}}{\text{m}}.\text{K}\right)(1.54\ m^2)}$$

$$= 3.16 \text{ x } 10^{-6}\,\text{K/W}$$

$$R_{total} = R_1 + R_2 + R_3$$

$$= (3.16 \text{ x } 10^{-6}\,\text{K/W}) + (0.23\,\text{K/W}) + (3.16 \text{ x } 10^{-6}\,\text{K/W})$$

$$= 0.23\,\text{K/W}$$

The heat transfer for the side walls can be determined as

$$\text{Q} = \frac{(\text{T}_{\text{in}} - \text{T}_{\text{out}})}{\text{R}_{\text{total}}}$$

$$= (\,70\,℃ - 36\,℃\,) / (0.23\,\text{k/w})$$

$$= 147.8\,\text{W}$$

The heat loss for the bottom part of the baking oven

L - length of the bottom walls = 5 m

$t_{nsulation}$ – thickness of insulation foam = 0.01 m

T_i- temperature of inner side of the bottom cover $= 150$ ℃

T_o- temperature of outer side of the bottom cover $= 41$ ℃

$$\text{Q} = \frac{(\text{T}_{\text{in}} - \text{T}_{\text{out}})}{\text{R}_{\text{total}}}$$

$$= (\,150\,℃ - 41\,℃\,) / (0.23\,\text{k/w})$$

$$= 473\,\text{W}$$

$Q_{\text{total loss}} = Q_{\text{top loss}} + Q_{\text{side loss}} + Q_{\text{bottom loss}}$

$= 11.67\ \text{kW} + 147\ \text{W} + 473\ \text{W}$

$= 12.29\ \text{kW}$

For 12 heaters in the machine of diameter 50 cm

$Q_{\text{input}} = N_{\text{heaters}} \times P_{\text{for each heater}}$

$= 12 \times 2.813\ \text{kW}$

$= 24.813\ \text{kW}$

$Q_{\text{utilized}} = Q_{\text{input}} - Q_{\text{loass}}$

$= 24.813\ \text{kW} - 12.29\ \text{kW}$

$= 12.523\ \text{kW}$

$$\eta = \frac{Q_{utilized}}{Q_{input}}$$

$= 12.523\ \text{kW} / 24.813\ \text{kW}$

$= 50.46\ \%$

3.3 Cost Analysis

Table 3-4 Material cost

No.	Part Name	Qty	Unit cost (birr)	Total cost (birr)
1	Angle iron (40*40*6000)	8	500	4000
2	Sheet metal (1200*1200*4)	1	2000	2000
3	Sheet metal (Stainless steel) (2000*1000*1)	3	2500	7500
4	Sheet metal (Stainless steel) (2000*1000*2)	4	3000	12,000
5	¾" pipe (L = 2000)	1	1000	1000
6	¾" Gate valve	1	150	150
7	Oven Heaters	1	6000	6000
8	Foam insulation	1	3000	3000
9	Industrial oven control panels	1	4,000	4,000
10	Arduino Uno is a microcontroller board	1	800	800
11	Relay switch	8	300	2400
12	Teflon Conveyor belt	1	10,000	10,000
13	Conveyor rollers	2	400	800
14	Conveyor Gear Drive Motor	1	3500	3500
15	Bearing	6	90	540
16	Fan	6	400	2400
17	Fabrication			10,000
18	Other extra process charges			3000
Total				**73,090 Birr**

Chapter 4 Result and Discussion

To decrease the heat loss from the baking oven insulation is used on the baking oven covers. The foam insulation is selected in this design which is the common type of insulation in the baking industries. For the baking conveyor Teflon belt is selected for its resistance in high temperature. The Teflon coated belt is suitable to bake the injera because it will not react with or contaminate the product being conveyed.

The batter container has a volume of 0.7854 m^3 and it can contain 785.4 liters of injera batter. And the injera batter can be added in a given interval to the container. The total cost of the machine is 73,090 Birr**.** After considering the heat energy losses the efficiency achieved in this design is 50.46 %.

For the designed injera machine the PLC control system is selected with programmable memory to store instructions and to execute logic, sequence, timing, so as to control the baking conveyor speed and to control the temperature of the heaters.

The heat will be transferred to the injera by using natural convection heating mechanism through a continuous oven. The baking system controls the temperature of the Teflon conveyer to give the optimum amount of heat that is required by the injera to be baked. The Pro-EC44-Dual-Loop-Controller-300px is selected to control the temperature of the Teflon conveyer.

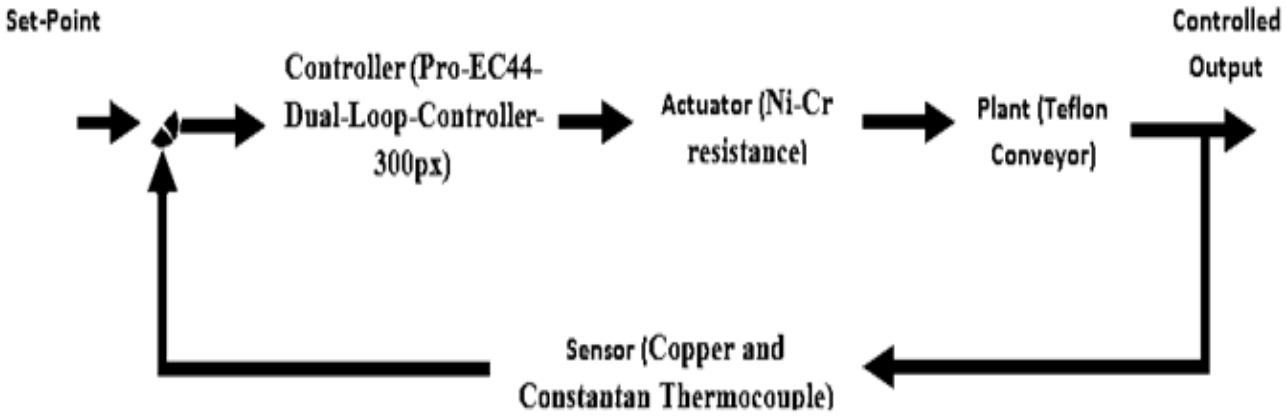
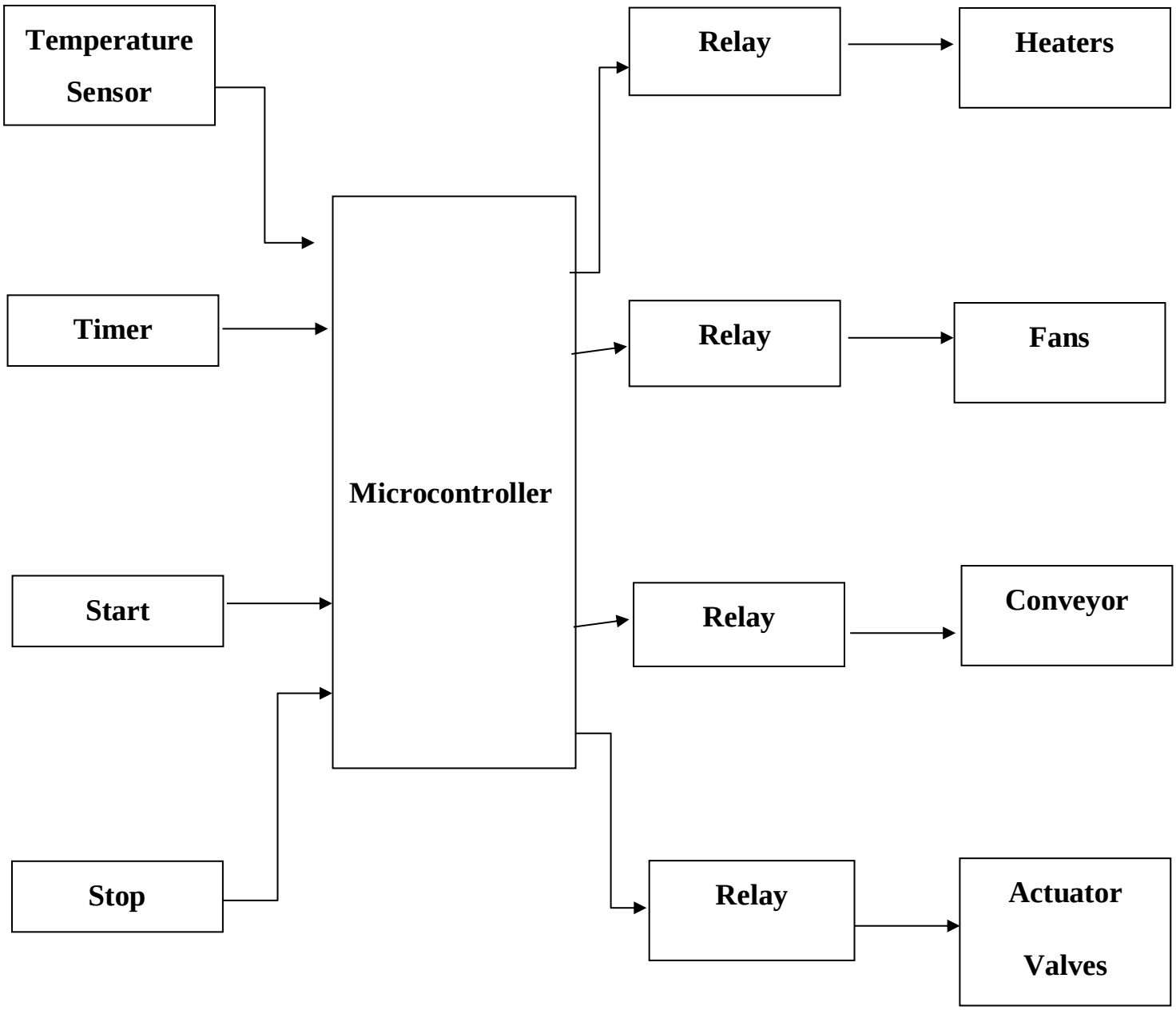
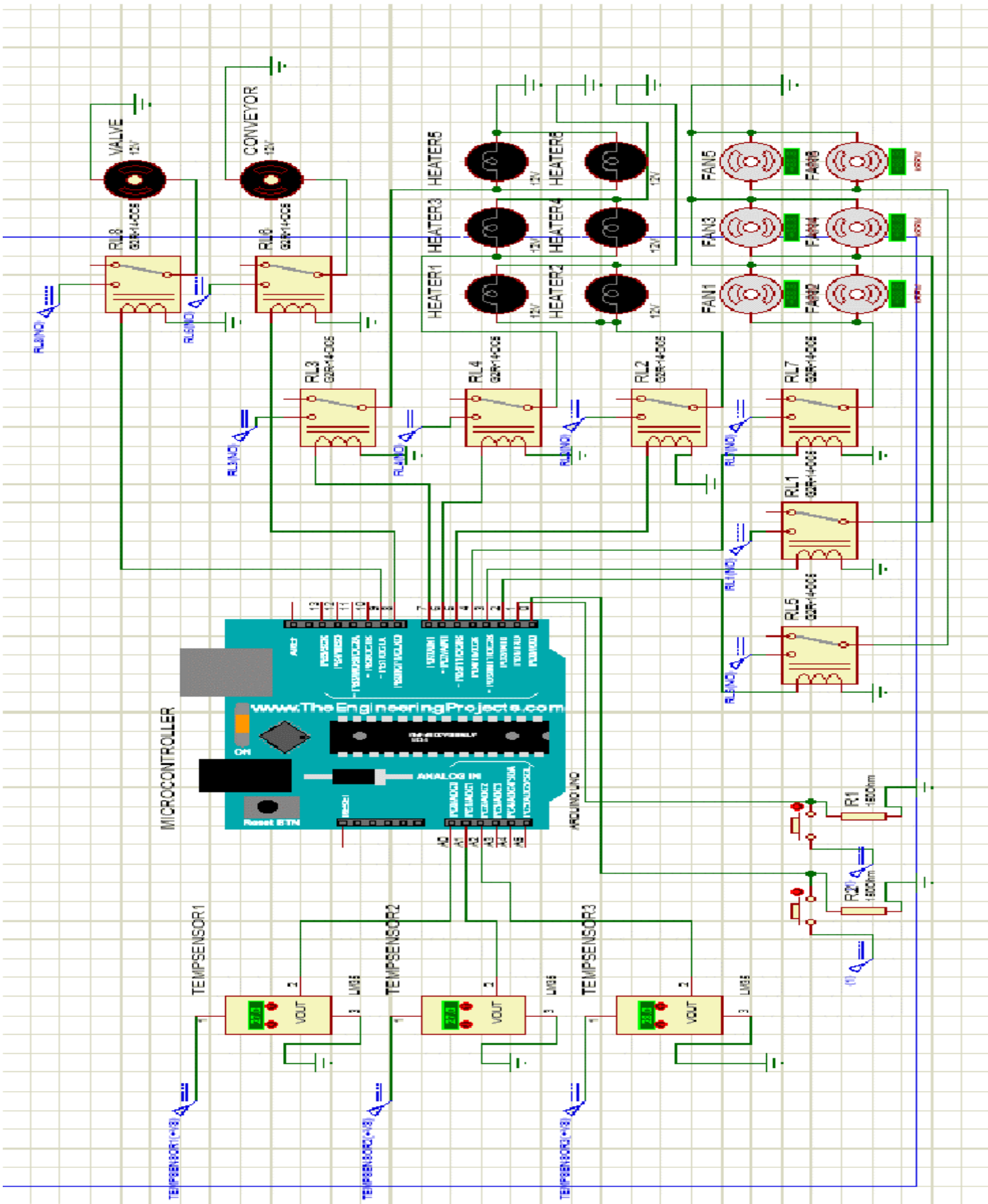


Figure 4-19: The complete temperature controller setup

In the baking system the heater, the fans, the actuator valves and the conveyor are controlled by the PLC control system as shown in the two diagrams below.




VALVE
CONVEYOR
HEATER1
HEATER2
HEATER3
HEATER4
HEATER5
HEATER6
FAN1
FAN2
FAN3
FAN4
FAN5
FAN6
RL1
RL2
RL3
RL4
RL5
RL6
RL7
RL8
MICROCONTROLLER
www.TheEngineeringProjects.com
ANALOG IN
Reset BTN
TEMPSENSOR1
TEMPSENSOR2
TEMPSENSOR3
VOUT
R1
R2

The existing injera Mitad design has many drawbacks. For example, the high resistance, inadequately sized electric wiring, and incorrectly adjusted combustion element; use of poor construction materials; poor insulation: dissipation of energy during the baking session is said to roughly range from 40 to 50 percent; lack of temperature control device such as a thermostat, encouraging loss of heat; and overall, sub-optimal and inefficient design and workmanship.

The result is loss of energy. Compared to a continuous baking process, one-at-a-time baking process is basically less efficient.

An automation of Injera baking process to produce reasonably priced Injera would help relieve the labor of daily cooking, while minimizing harmful air pollutants from use of biomass, wood or other similar fuels, frequently used as alternative fuels since power is unreliable, and undependable in the current electric situations.

In spite of high daily demand, currently, there are very few wholesale bakers and sellers of Injera. The few bakers supply primarily to restaurants, leading hotels, some supermarkets, universities, and other institutions.

Currently, the peak load demand is growing rapidly. Two major contributing factors are: industrial expansion and lifestyle changes such as more appliances in the home. The increased power demand overloads Ethiopian electric power corporation's existing power infrastructure, causing increased blackouts, low voltage, rotating load cracking. The lack of reliable power leads to increased utilization of alternatives, such as diesel power generation. Reduction of peak load demand will also reduce the high fuel costs of serving these peak demands.

At present, regular power shortages, in particular with the country's industrial sector suffers significant economic losses on a daily basis. It is therefore crucial that sound planning, supported by effective implementation and monitoring, are put in place on a priority basis. Use of well planned, proven measures such as demand-side management, power conservation and implementing energy efficiency programs, is recommended, must be included in power moderation strategies.

Chapter 5 Conclusion and Recommendation

5.1 Conclusion

The number of injera baked on the conveyor and the energy consumed in a specific time is the crucial factor for comparing the result with the present electric injera mitad. The injera baking machine can bake 18 injera in 2.5 minutes which means 432 injera in 1 hour with 50.634 kW. The saved labor force is also a big achievement in this injera baking technology. Therefore, the injera baking machine can make injera supplier companies very profitable by allowing them to provide injera to the community by reducing the labor and energy costs. The demand observation was conducted in the Debre Berehan University Students cafeteria kitchen. From the survey result the average number of injera baked in Debre Berhan University per day is up to 36,000 injera. This means 12,960,000 Injera per year. This number will increase as the number of students increase. Covering such large injera demand with the present fuel wood baking system is very expensive and its quality is very low. Due to the low energy efficiency of the existing electric Injera Mitad, there is a huge electrical energy consumption and power demand in the country. This indicates that majority of the conventional Mitads have low efficiency.

However, the demand for the product is growing at a high rate due to the rapid economic growth, the shortage of fire wood and biomass, and the huge electrification programs underway in the country. There is a huge power demand and energy consumption imposed on the electric generation and distribution infrastructure. There are many injera bakers and suppliers and few exporters. Most hotels and restaurants get supply of injera from individual bakers and recently established small scale enterprises. The interest of Injera bakers, suppliers and exporters is reduction on the cost of energy and better efficiency of newer products. They prefer efficient mass producing injera machines.

Injera baking is considered the most energy intensive activity in Ethiopia. The Injera electric baking mitad are highly energy inefficient. Also, the daily baking's power load becomes coincident with peak load requirements, thereby overloading the distribution system. Notwithstanding the above, the manufacturing of competitively-priced low-cost energy efficient Injera electric baking stoves is of paramount importance to cost-effectively manage peak load demand and reduce daily blackouts. Daily use of Mitad, with the most grid-connected households, in view of serious daily power supply shortfalls, adversely impacts the daily peak load demand.

The impact is especially severe on week days, given the timing of Mitad use mid-morning and mid-noon and the high-power needs. Compounding the situation is Mitad's design has not evolved in terms of energy efficiency. Cost reflective pricing is needed to lower power demand, eliminate wasteful energy use, and encourage use of energy efficiency measures.

Injera baking is the major component of household energy use in Ethiopia. It is estimated that over 50 percent of the overall households' energy consumption is for 'Injera' baking. For the urban poor households, and many rural Ethiopians, fuelwood is the major source of energy consumed. Many middle-income urban households also use biomass, given lack of reliability of power supply. However, there is no credible quantification of the extent of biomass used as fuel. Nevertheless, continued fuelwood supplies are unsustainable and wood fuel use has adverse health impacts, in addition to being environmentally degrading.

The design of the injera baking machine is used for an efficient injera baking mechanism. It is well known that the present injera mitad consumes high amount of energy and the baking system is a burden to the women. Since there is high degree of repeated human hand contact, in a less than carefully run kitchen, it is not hygienic. The removal of the baking injera is also one challenge due to the high temperature of the mitad and this will lead to the tearing of the injera and burning one's fingers.

Therefore, this design is dedicated to improve the injera baking technology by providing the injera baking system that will reduce the energy consumption and the labor force to increase the production rate. This machine is used mainly by injera providing companies to produce a large number of injera continuously. By this method many injera mitads can be replaced by one machine that has high production and energy efficiency.

5.2 Recommendation

This injera baking machine is specially recommended for the provision of injera to high community institutions such as military, university, hotels and etc. If we can use the injera baking machine we can minimize the energy bill, thereby it would minimize individual energy bill per month, improves individual economy and minimize operation costs of hotels and restaurants.

This machine is highly recommended to replace the wood fuels which are used to bake injera so that we can reduce deforestation and high waste of electricity.

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Appendix A

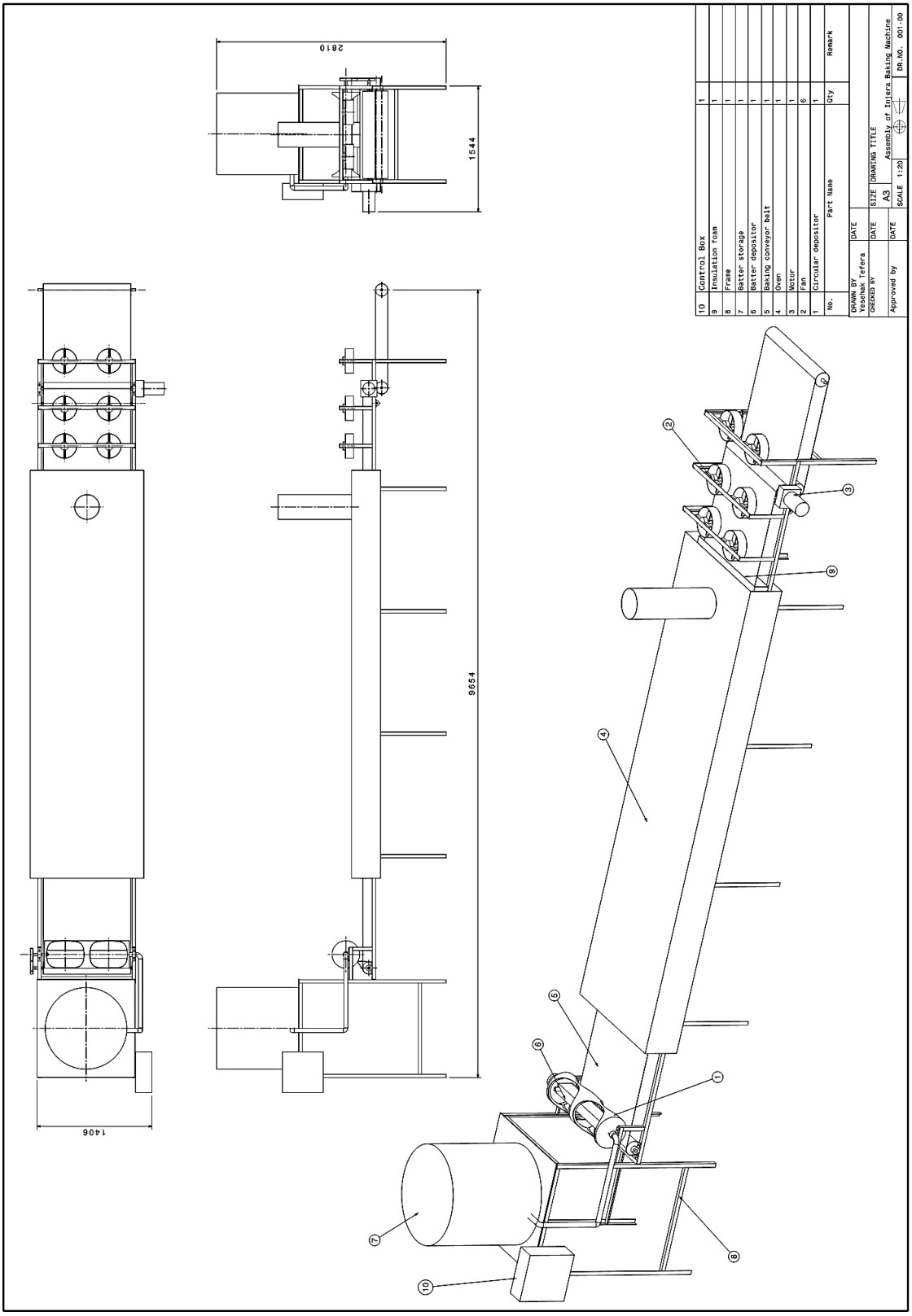
Traditional Injera baking currently taking place at Debre Berehan university baking 36,000 injera per day.

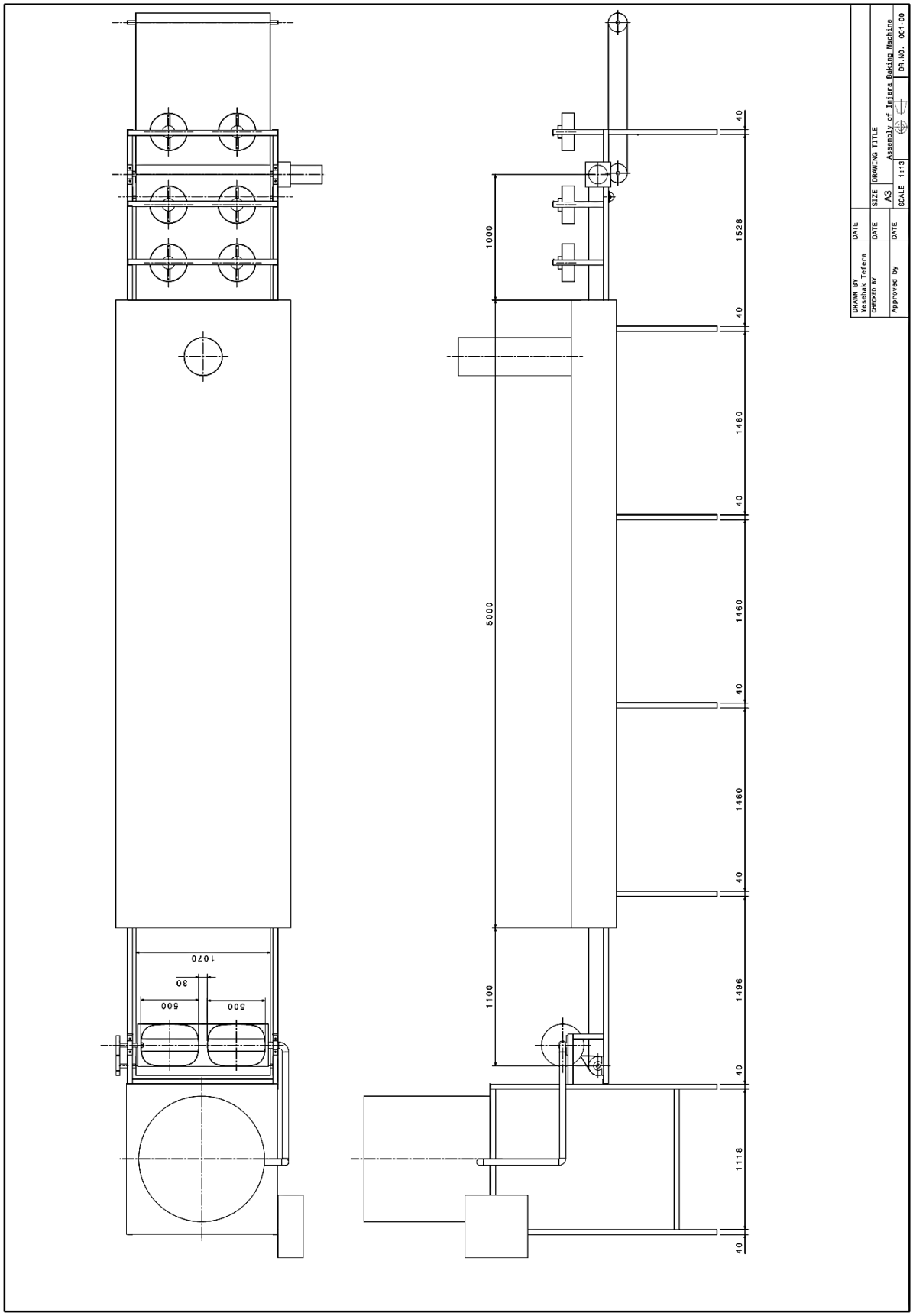


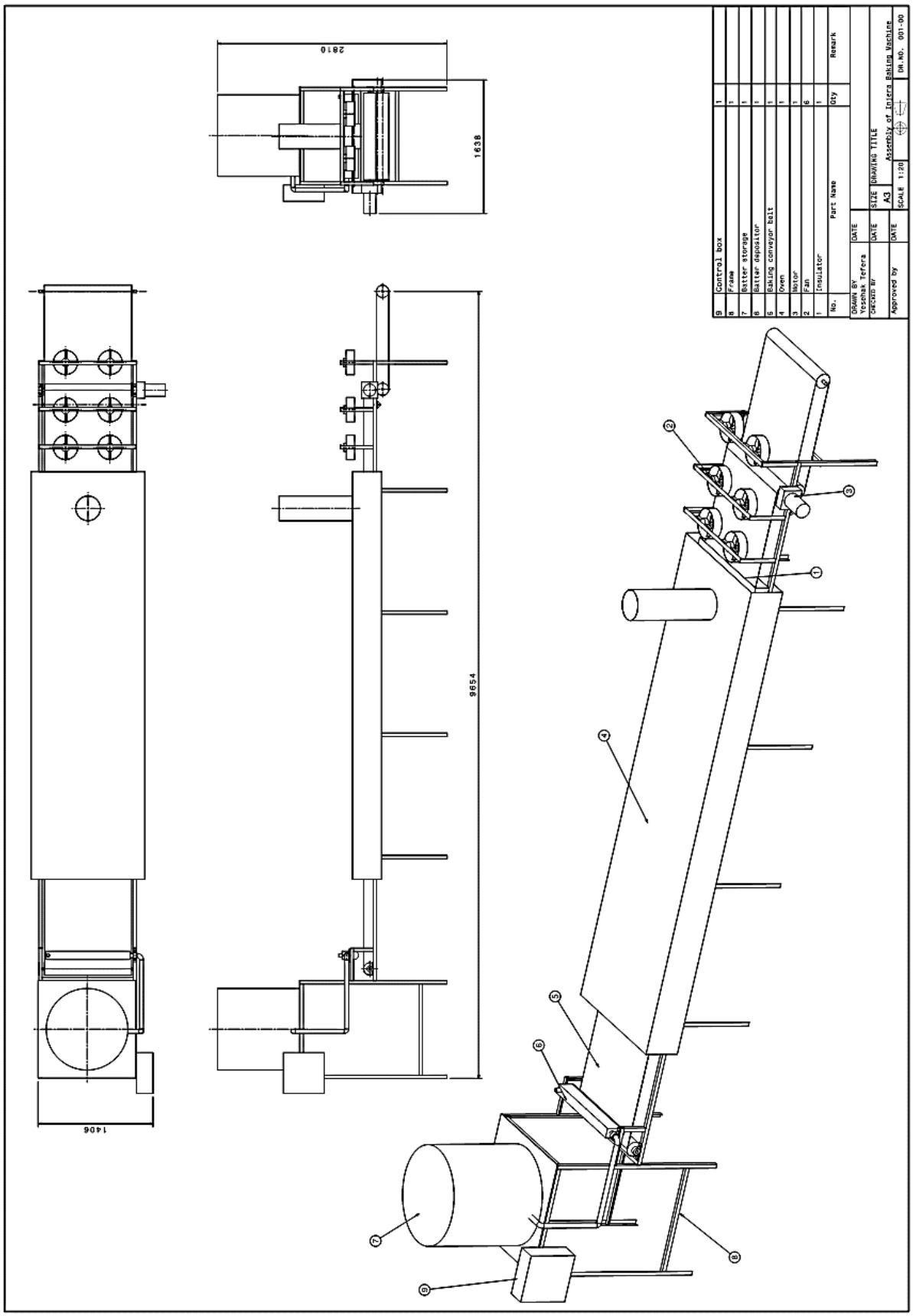


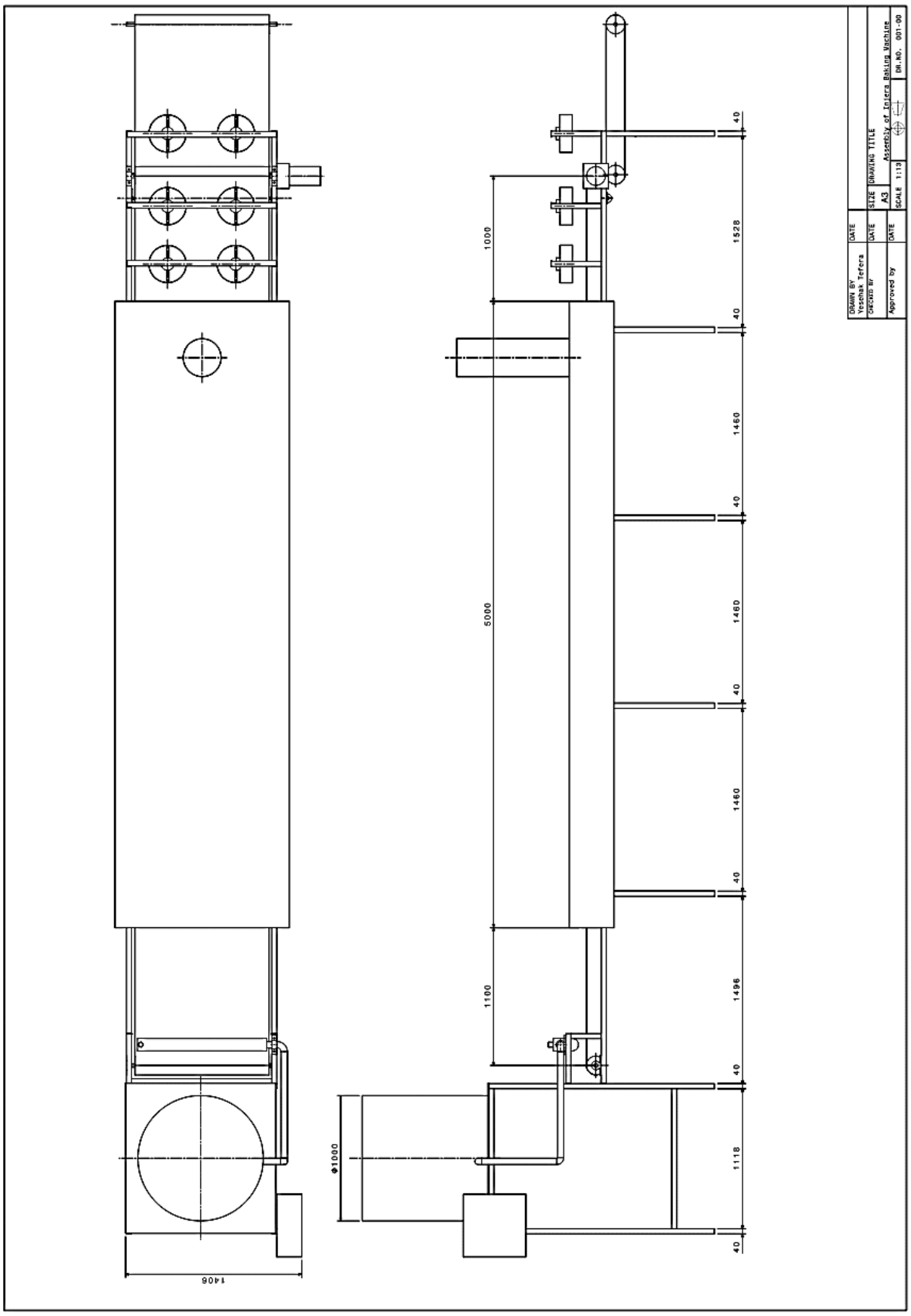
Appendix B

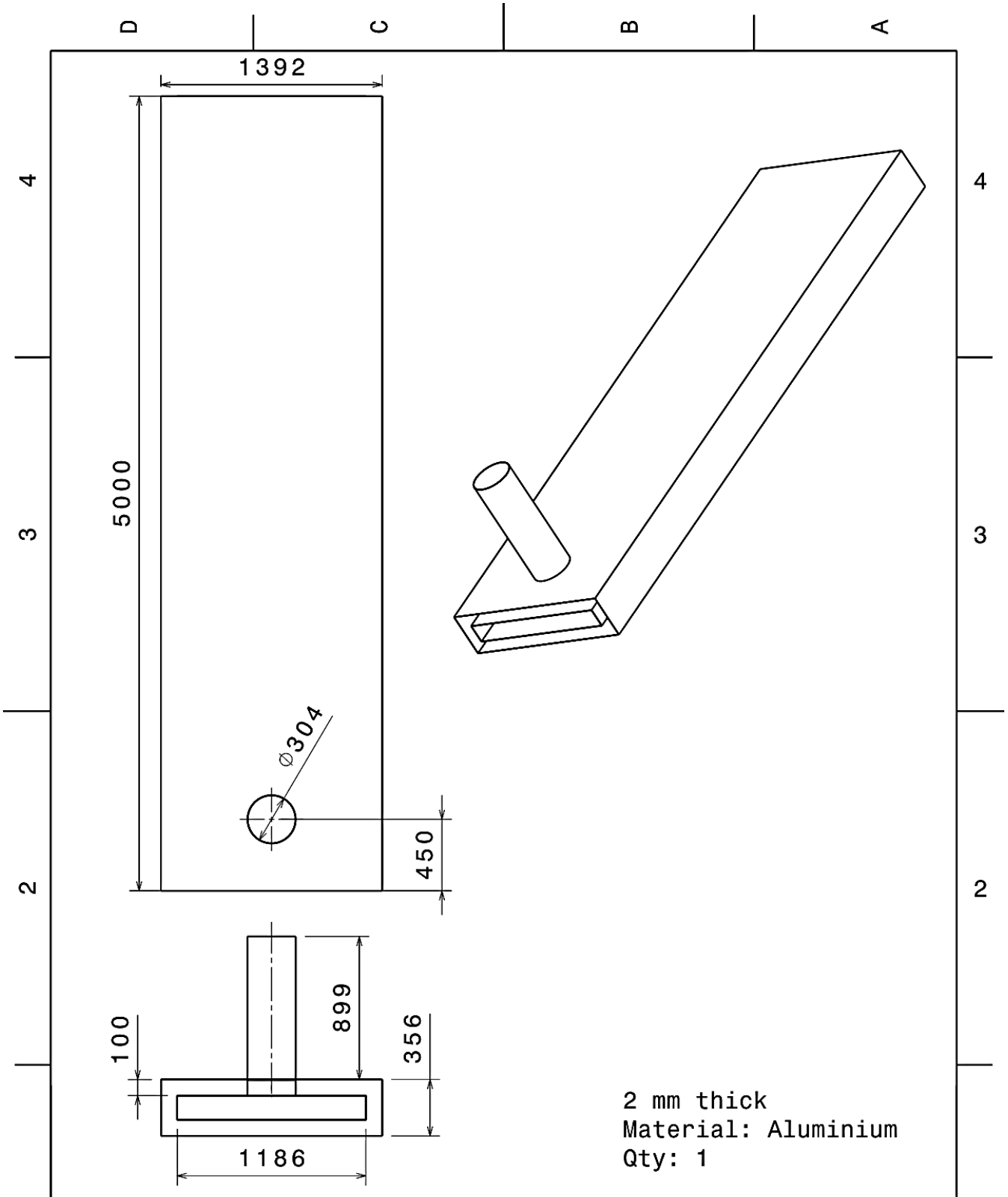
Part and Assembly drawing for both circular and square injera baking machine

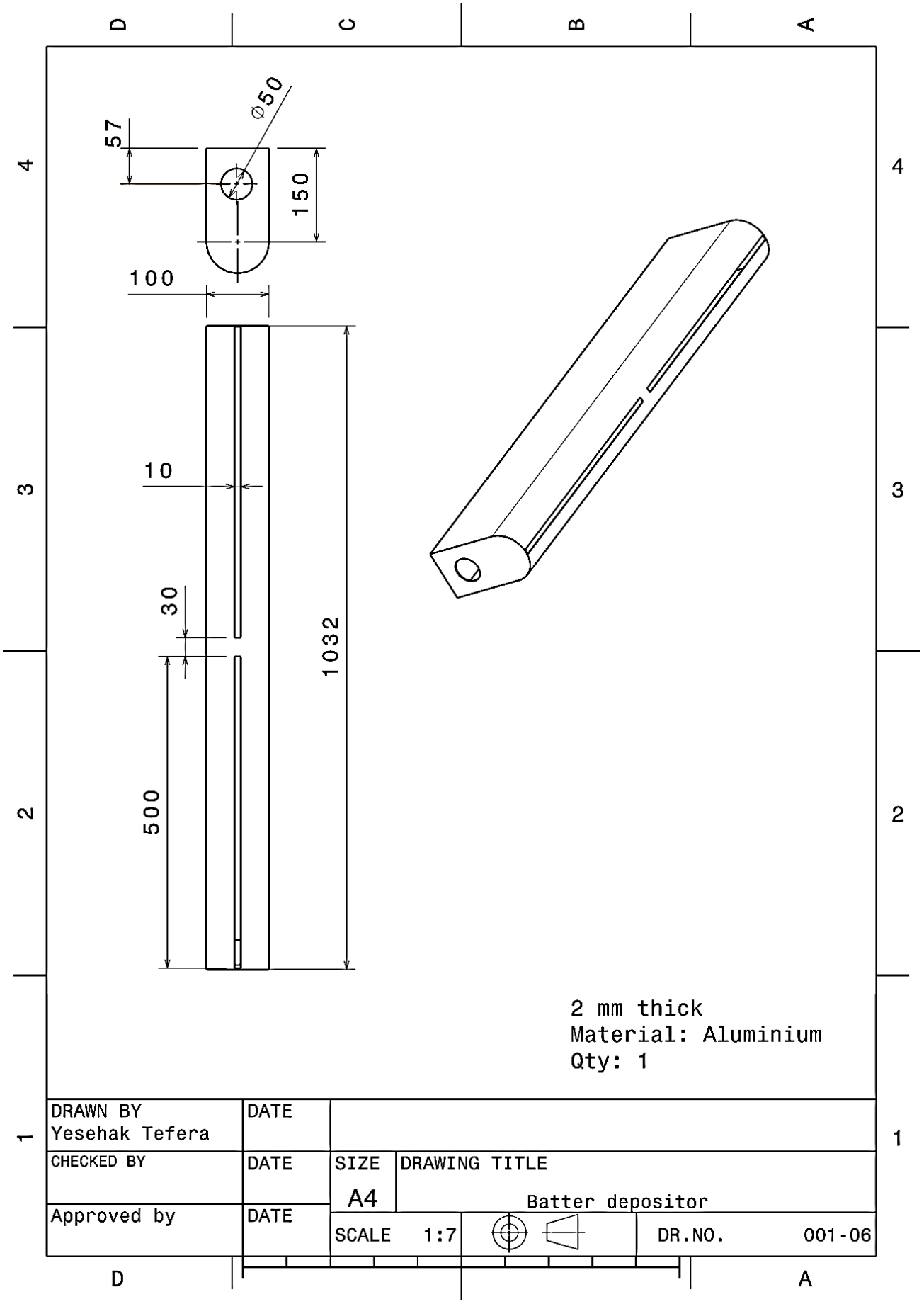


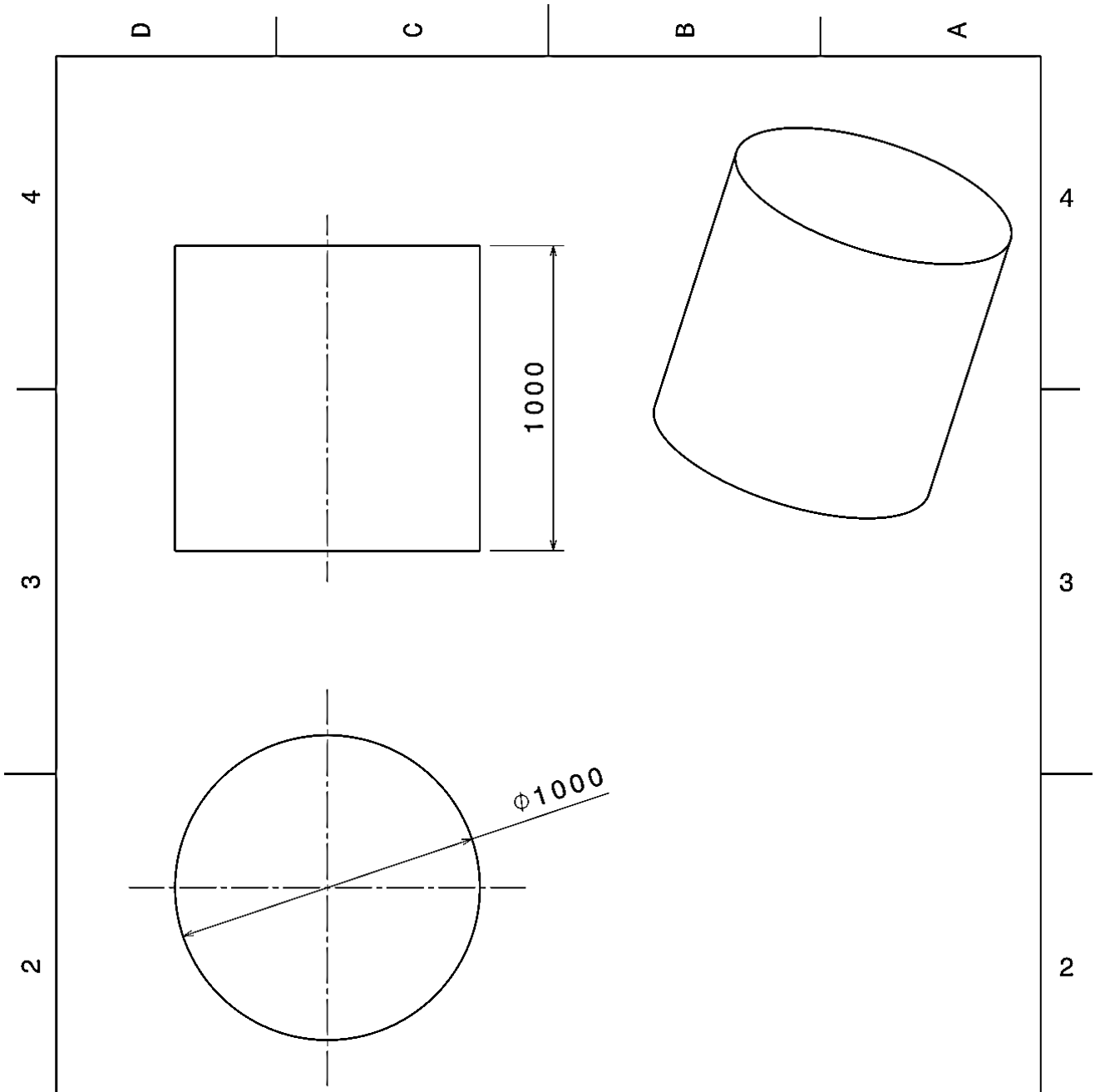

1070
30
500
500
1000
5000
1100
40
1528
40
1460
40
1460
40
1460
40
1496
40
1118
40
DRAWN BY
Yeshak Tefera
DATE
CHECKED BY
DATE
Approved by
DATE
SIZE
A3
DRAWING TITLE
Assembly of Injera Baking Machine
SCALE 1:13
DR.NO. 001-00


2810
1638
9654
1406
9 Control box 1
8 Frame 1
7 Batter storage 1
6 Batter depositor 1
5 Baking conveyor belt 1
4 Oven 1
3 Motor 1
2 Fan 6
1 Insulator 1
No. Part Name Qty Remark
DRAWN BY Yoseph Tefera DATE
CHECKED BY DATE
APPROVED BY DATE
SIZE A3
DRAWING TITLE
Assembly of Injera Baking Machine
SCALE 1:20
DR.NO. 001-00


DRAWN BY
Yeneak Tefera
DATE
CHECKED BY
DATE
Approved by
DATE
SIZE
A3
DRAWING TITLE
Assembly of Injera Baking Machine
SCALE 1:10
DR.NO. 001-00
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1498
1118

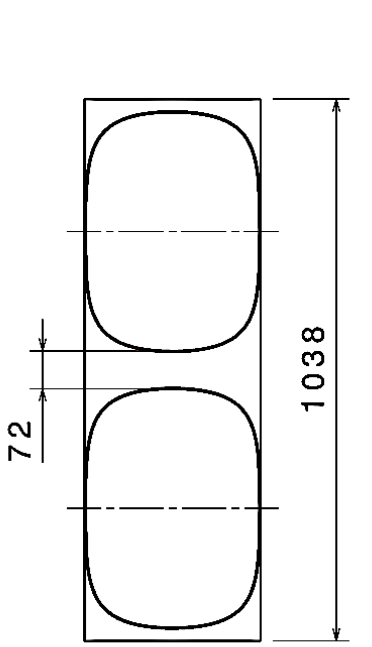

D
C
B
A
1392
5000
⌀304
450
899
356
100
1186
2 mm thick
Material: Aluminium
Qty: 1
DRAWN BY
Yesehak Tefera
DATE
CHECKED BY
DATE
Approved by
DATE
SIZE
A4
DRAWING TITLE
Oven hood
SCALE 1:30
DR.NO. 001-04

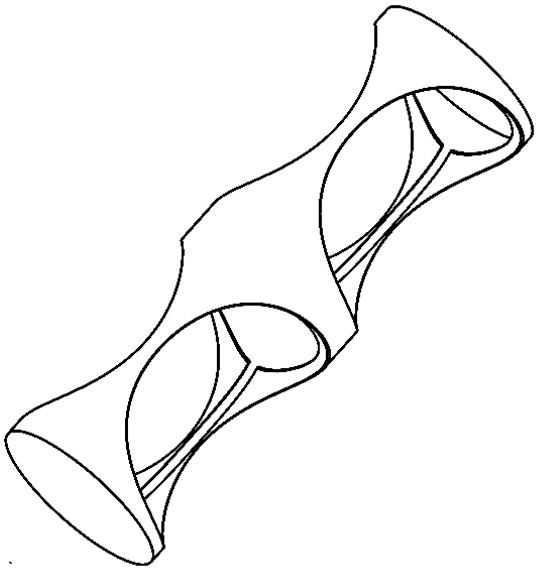

D
C
B
A
4
3
2
1
57
Ø50
150
100
10
30
1032
500
2 mm thick
Material: Aluminium
Qty: 1
DRAWN BY
Yesehak Tefera
DATE
CHECKED BY
DATE
Approved by
DATE
SIZE
A4
DRAWING TITLE
Batter depositor
SCALE 1:7
DR.NO. 001-06

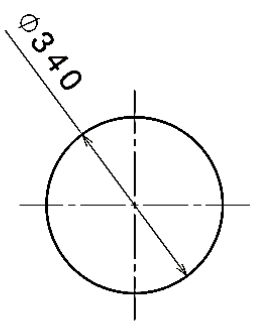


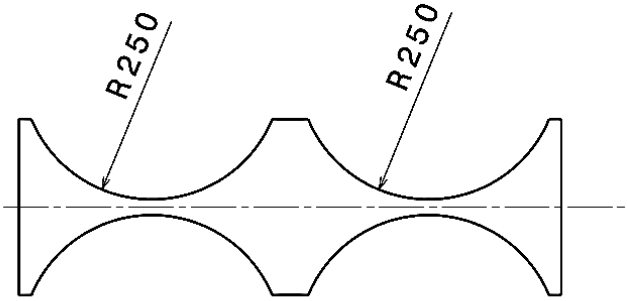
2 mm thick
Material: Aluminium
Qty: 1

DRAWN BY Yesehak Tefera	DATE		
CHECKED BY	DATE	SIZE A4	DRAWING TITLE Batter storage
Approved by	DATE	SCALE 1:17	DR.NO. 001-07



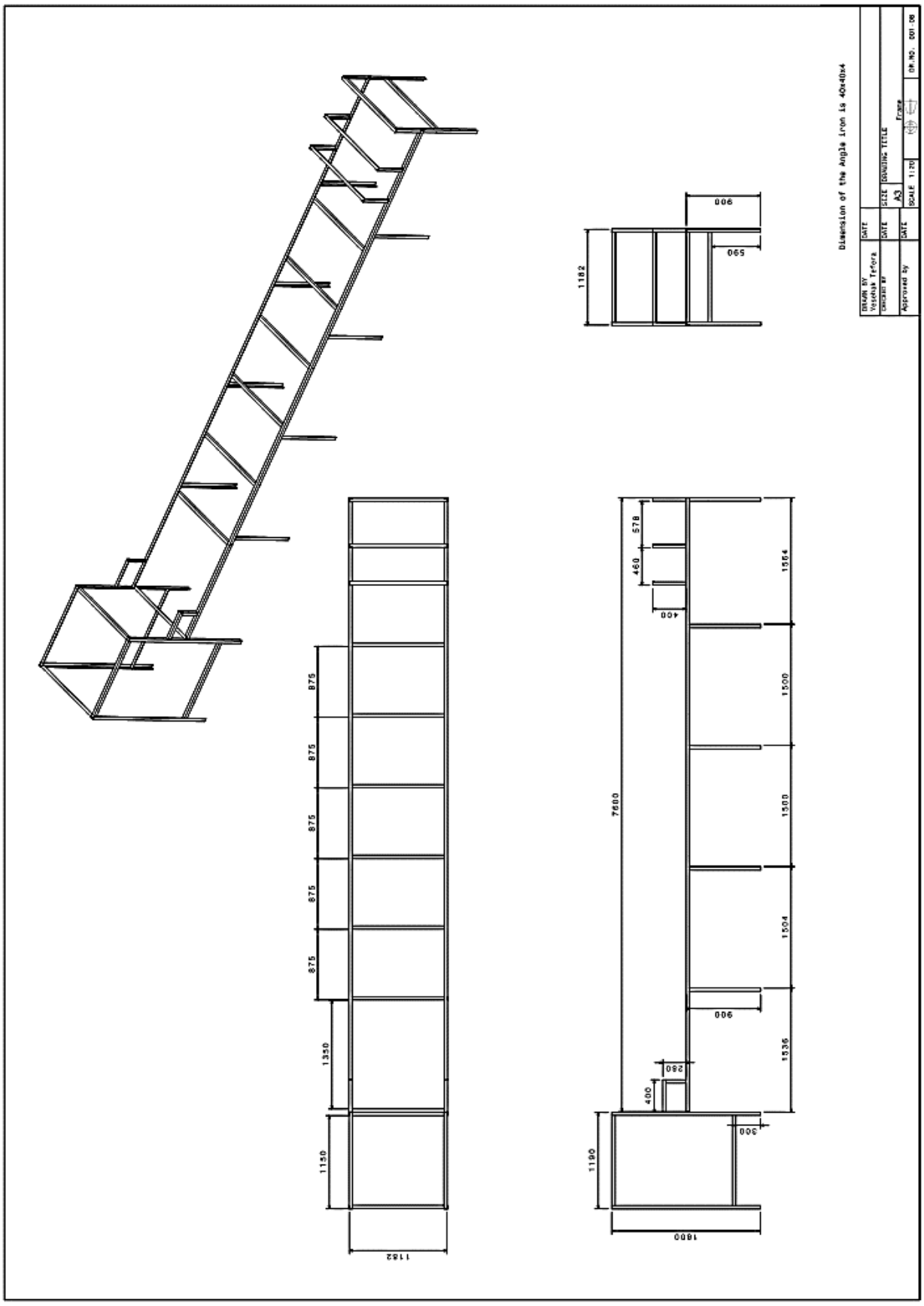


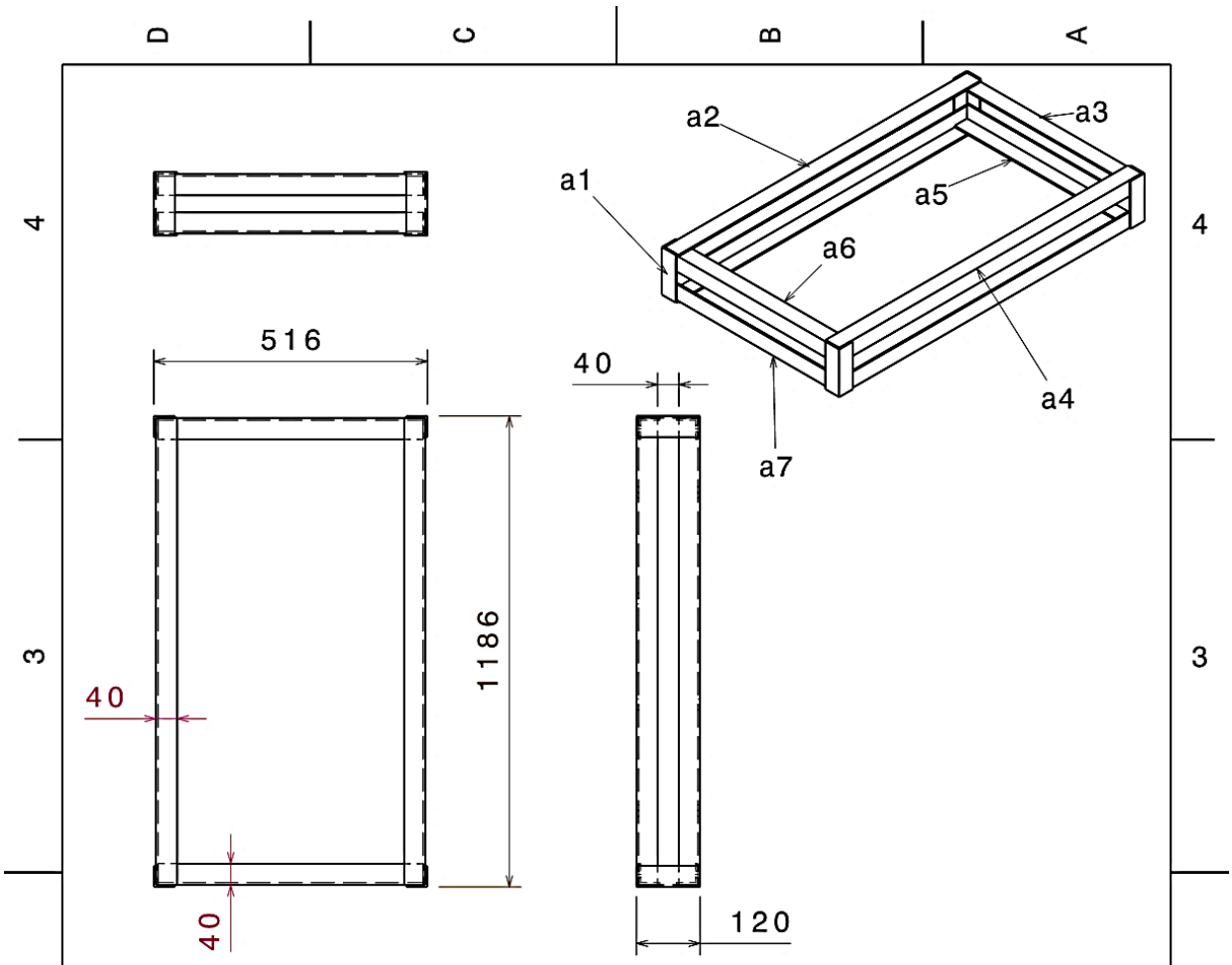




2 mm thick
Material: Aluminium
Qty: 1

DRAWN BY Yesehak Tefera	DATE		
CHECKED BY	DATE	SIZE A4	DRAWING TITLE Circular depositor
Approved by	DATE	SCALE 1:12	DR.NO. 001-09


Dimension of the Angle iron is 40x40x4
DRAWN BY
Yoseph Tefera
DATE
CHECKED BY
DATE
Approved by
DATE
SIZE
A3
DRAWING TITLE
Frame
SCALE 1:20
DR.NO. 001.00
900
590
1182
578
460
400
1564
1500
1500
1504
900
1536
7600
280
400
300
1190
1800
875
875
875
875
875
1350
1150
1182



Part No	Part Name	Qty	Material	Dimension
a7	Member 7	1	Angle iron	500x40x40x4
a6	Member 6	1	Angle iron	500x40x40x4
a5	Member 5	1	Angle iron	500x40x40x4
a4	Member 4	2	Angle iron	1186x40x40x4
a3	Member 3	1	Angle iron	500x40x40x4
a2	Member 2	2	Angle iron	1186x40x40x4
a1	Member 1	4	Angle iron	120x40x40x4

DRAWN BY Yesehak Tefera	DATE		
CHECKED BY	DATE	SIZE A4	DRAWING TITLE Thermal Resistor holder frame
Approved by	DATE	SCALE 1:11	DR.NO. 01-10