

Palestine Polytechnic University



College of Engineering and Technology Mechanical Engineering Department

Line Production of Compressed Wood (MDF)

Project Team

Adam Aljbour

Baraa ballot

Odi humeadat

Osaid horainy

Project Supervisor

Dr. Hussein Amro

Hebron – Palestine

2018-2019

Palestine Polytechnic University
Collage of Engineering
Mechanical Engineering Department
Hebron – Palestine

Line Production of Compressed Wood (MDF)

Project Team:

Adam Aljbour

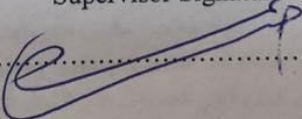
Baraa Ballot

Odi Humedat

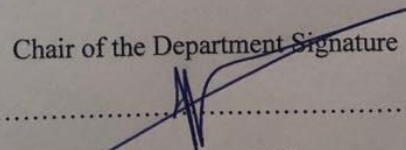
Osaid Horainy

Submitted to the Collage of Engineering
In partial fulfillment of the requirements for the
Bachelor degree in Mechanical Engineering.

Supervisor Signature


.....

Chair of the Department Signature


.....

September-2019

Abstract

According to the high prices of imported wood panels (which uses in furniture), the increasing of waste wood (which not being recycled properly) and using unregularly ways of cutting trees annually to produce panels (which causes bad effect on environment), all these problems was a motivate to find some solutions such as building a local project produces wood panels can compete the global product in terms like quality and specifications. Thus, this project aims at designing a machine that works to produce a wood panels by recycling the waste of wood, with dimensions (2.44m long , 1.22m width , 0.016m thickness) standard , these panels are to be used in furniture production. The project also aims to reduce the large amount of imported wood panels and provides a large proportion of the human needs of the wood.

The prototype contains a three main parts: mixer, hydraulic press and oven, with experiments as follows, adding the materials (waste wood and adhesive) to the mixer to be mixed and made it a flexible material, then the material obtained from the mixing process was pressed by a hydraulic press to get the final shape, and finally the panel was placed in the oven to make it a dried panel. Already A product has been produced.

المخلص

نظرا لارتفاع أسعار الألواح الخشبية المستوردة (التي تستخدم في الأثاث) ، زيادة نفايات الأخشاب (التي لا يتم إعادة تدويرها بشكل صحيح) و استخدام طرق غير منتظمة لقطع الأشجار سنويًا لإنتاج الألواح (التي تسبب تأثيرًا سيئًا على البيئة)، كانت كل هذه المشكلات الحافز لإيجاد بعض الحلول مثل بناء مشروع محلي ينتج الألواح الخشبية يمكن أن تنافس المنتج العالمي من حيث الجودة والمواصفات. وبالتالي ، يهدف هذا المشروع إلى تصميم آلة تعمل على إنتاج ألواح خشبية من خلال إعادة توفير نفايات الخشب ، بأبعاد (2.44 م طولاً ، 1.22 م عرض ، سمك 0.016 م) ، ستستخدم هذه الألواح في الصناعة مثل صناعة أثاث المنزل ، ويهدف أيضا الى التقليل من كمية الأخشاب المستوردة وتوفر نسبة كبيرة من الاحتياجات البشرية للخشب.

يحتوي النموذج الأولي الذي تم تصنيعه على ثلاثة أجزاء رئيسية: خلاط ، مكبس هيدروليكي وفرن. تم إجراء التجارب على النحو التالي ، إضافة المواد (نفايات الخشب والمواد اللاصقة) إلى الخلاط ليتم خلطها وجعلها مادة مرنة ، ثم تم ضغط المواد التي تم الحصول عليها من عملية الخلط بواسطة مكبس هيدروليكي للحصول على الشكل النهائي، و أخيراً تم وضع اللوح في الفرن لجعله لوح مجفف. بالفعل تم إنتاج منتج.

List of Contents:

| | |
|---|----|
| Abstract | 3 |
| CHAPTER 1 | 8 |
| 1.1. Overview: | 9 |
| 1.2. Problem Statement: | 9 |
| 1.3. Recognition of the Need: | 9 |
| 1.4. Conceptual Design:..... | 10 |
| 1.5. Objectives:..... | 11 |
| 1.6. literature Review: | 11 |
| 1.7. Time Schedule: | 12 |
| 1.8. The budget: | 12 |
| 1.9. Chapter Conclusions:..... | 13 |
| CHAPTER 2 | 14 |
| 2.1. Introduction:..... | 15 |
| 2.2. The Mixer: | 16 |
| 2.2.1. Parts of Mixer: | 16 |
| 2.3. Hydraulic Press: | 17 |
| 2.4. The Oven: | 18 |
| 2.4.1. Wood Drying:..... | 18 |
| 2.4.2. The System: | 19 |
| 2.4.3. Problems in Wood Drying: | 19 |
| 2.4.4. The Experiments:..... | 19 |
| CHAPTER 3 | 21 |
| 3.1 Introduction:..... | 22 |
| 3.2. Proposal System Description and Specifications:..... | 22 |
| 3.3. Mechanical Design: | 23 |
| 3.3.1. Mixer Machine: | 23 |
| 3.3.1.1. Area Calculations for Mixing Tank:..... | 25 |
| 3.3.1.2 Volume Calculations for Mixing Tank:..... | 26 |
| 3.3.1.3 Mixture Ribbon:..... | 27 |
| 3.3.2. The table:..... | 28 |
| 3.3.3. The Mold Dimensions:..... | 29 |
| 3.3.4. Mixture Drive:..... | 30 |
| 3.4. The Oven : | 33 |

| | | |
|--------------------------|-------------------------------|----|
| 3.4.1. | The Volume of the Oven: | 33 |
| 3.4.2. | The Walls of Oven: | 34 |
| 3.4.3. | The Power Consumption : | 34 |
| 3.4.3.1. | Thermal Energy : | 35 |
| 3.4.3.2. | The Electrical Energy : | 37 |
| 3.4.4. | Air Heating Process:..... | 38 |
| CHAPTER 4 | | 40 |
| 4.1 | Introduction:..... | 41 |
| 4.2 | Motor Calculations: | 41 |
| 4.3 | Switches:..... | 43 |
| 4.4 | Contactors: | 43 |
| 4.5 | Sensors: | 44 |
| 4.6 | Invertor:..... | 46 |
| 4.7 | Cylinders:..... | 46 |
| CHAPTER 5 | | 47 |
| 5.1. | Introduction:..... | 48 |
| 5.2. | PLC Characteristic: | 48 |
| 5.3. | System Programming: | 48 |
| 5.4. | Project Prototype: | 49 |
| 5.5. | Prototype Running On:..... | 50 |
| 5.6. | Total cost of prototype:..... | 50 |
| 5.7. | Experimental Result: | 51 |
| 5.8. | Recommendations: | 51 |
| CHAPTER 6 | | 52 |
| 6.1. | System basics: | 53 |
| 6.2. | Parts and Descriptions:..... | 53 |
| 6.3. | Main features: | 54 |
| 6.4. | Electrical circuit: | 54 |
| 6.5. | Operation and setting: | 55 |
| 6.6. | Check and maintenance : | 56 |
| 6.7. | Safety:..... | 56 |
| Appendix | | 57 |
| Uncategorized References | | 66 |

List of Figures:

| | |
|---|----|
| Figure 1. 1: The system design | 10 |
| Figure 1. 2: The conceptual design..... | 10 |
| Figure 2. 1: The machine design..... | 15 |
| Figure 2. 2: The mixer | 16 |
| Figure 2. 3: Hydraulic press design..... | 17 |
| Figure 2. 4: The oven | 18 |
| Figure 2. 5: The Experiments | 20 |
| Figure 3. 1: Machine design | 23 |
| Figure 3. 2: The mixer dimensions | 24 |
| Figure 3. 3: Mixing Tank | 25 |
| Figure 3. 4: Ribbon Blender | 27 |
| Figure 3. 5: The table dimensions | 28 |
| Figure 3. 6: curve of acceleration and speed by time | 31 |
| Figure 3. 7: free body diagram | 31 |
| Figure 3. 8: The oven dimensions..... | 33 |
| Figure 3. 9: The drying process..... | 34 |
| Figure 3. 10: Fan data sheet | 38 |
| Figure 3. 11: Psychrometric chart of air heating process..... | 39 |
| Figure 4.1: Mixing Motor..... | 41 |
| Figure 4.2: Overload | 42 |
| Figure 4.3: Switches..... | 43 |
| Figure 4.4: Contactor..... | 44 |
| Figure 4.5: Limit switches..... | 44 |
| Figure 4.6: Ultrasonic sensor | 45 |
| Figure 4.7: Thermocouple sensor..... | 46 |
| Figure 4.8: Invertor | 46 |
| Figure 5. 1: Final Project Prototype..... | 49 |
| Figure 6. 1: Control circuit..... | 54 |
| Figure 6.2: Power Circuit | 55 |
| figure A. 1: State Graph | 59 |
| figure A. 2: PLC Code | 65 |

List of Tables:

| | |
|---|----|
| Table 1.1: Time Schedule | 12 |
| Table 1.2: The total profit..... | 12 |
| Table 1.3; The total cost | 13 |
| Table 4.1 : Motor table | 42 |
| Table 5. 1: Total Cost Of Prototype | 50 |
| Table 6.1: Parts and Description | 53 |
| Table A. 1: PLC Characteristic: | 57 |
| Table A. 2: PLC characteristic | 58 |

CHAPTER 1

Introduction

- 1.1. Overview**
- 1.2. Problem Statement**
- 1.3. Recognition of the Need**
- 1.4. Conceptual Design**
- 1.5. Objectives**
- 1.6. literature Review**
- 1.7. Time Schedule**
- 1.8. The Budget**
- 1.9. Chapter Conclusions**

1.1. Overview:

The evolution of industry and resources consumption revolution has decreased in some resources like wood which is a great motivation to find alternative solutions.

One of these important resources is wood, There is so many of companies that consuming the wood with very large quantities per year that causes high import price of wood and make some problems of buying it. That was a big reason to make a project exploits the waste wood to produce a wood industrial panels with high specifications. That's had good benefits like avoid importing wood panels and paying high cost for it, avoid throwing the waste wood in dump.

After several researches about wood industry we realized there is a lot of (1,200,000) panels consumed in Hebron per a year and the waste of them is 110 tone per a year.

Notes: the dimension of standard panel is (2440 long, 1220 width, and 16 thicknesses) in mm.[1]

1.2. Problem Statement:

In this world, there are large quantities of waste wood and bad ways of recycling, the most of the people drop the waste wood in the dump, the increasing of cut wood caused bad effect on environment, the high cost of imported wood panel.

1.3. Recognition of the Need:

Notice that, the local market need a local wood panel product instead of importing it from other countries.

To reduce the importing of wood panels:

- 1) High specifications for local product.
- 2) A good price for local market.
- 3) A Mechanical electrical system without using a human hand.
- 4) Support the national economy.
- 5) Exploit the waste wood in recycling.

1.4. Conceptual Design:

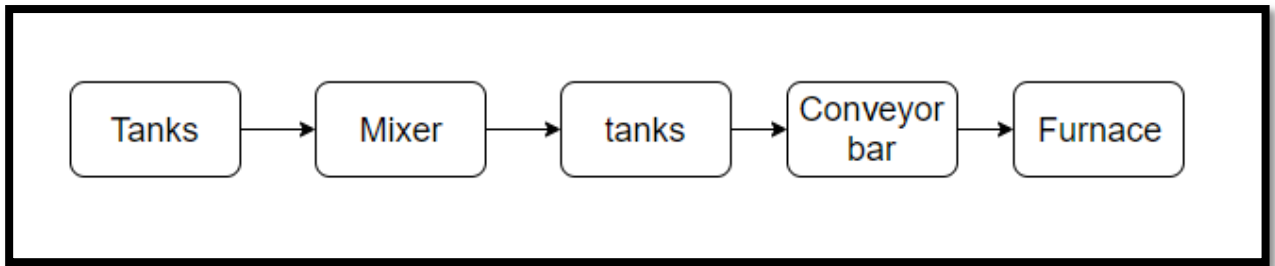


Figure 1. 1: The system design

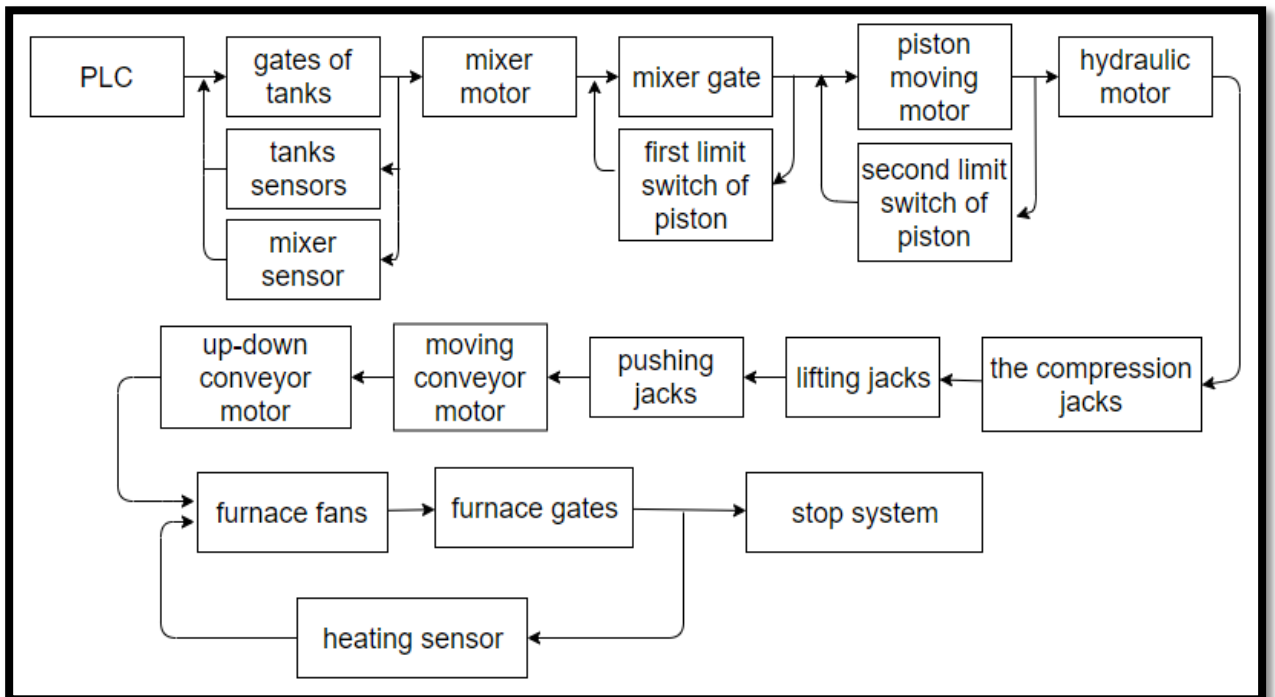


Figure 1. 2: The conceptual design

The production line process begins when the addition materials (waste wood and adhesive) goes to the tanks ,the (PLC) system will turn on to make a control for opening and closing tanks gates (signals come from sensors), which means that the quantity of materials reached to the required level then added to the mixer. There will be a sensor(signal for mixer motor to run) when all materials get in mixing tank, when the materials become a flexible one material the motor of mixer will turn off, after that the gate of the mixing tank will be opened to put the material inside the mold. There will be a plate moving right and left to make the material equal in all area of the mold then the mold will move until reaches under hydraulic press (by using a pinion and gear system). After the pressing process finish, the panel will lifted up (by using jacks exists under the mold) and transport it to oven (by a conveyor belt) for drying process. There will be a Sensors (for controlling) to determine the temperature.

1.5. Objectives:

The main objective is how to exploit the large quantities of waste wood to produce a standard wood panels (compressed wood MDF) with global and high specifications. The sub-objectives are:

- 1) Reducing of import wood panels used in furniture through recycling of waste wood.
- 2) Preserving the environment and reduce waste wood.
- 3) Reducing the irregular habits in cutting wood.

1.6. literature Review:

Reference [2] show the adhesive systems used today in the European industries of particleboard, medium density fiberboard (MDF) and oriented strand board (OSB) are discussed. The structure of particleboard, MDF and OSB markets in Europe in relation to the types of adhesives and product specifications are presented as well.

Reference [3] show the panel products industry like medium density fiberboard (MDF) and described it as engineered wood product and show the history of compressed wood industry development and manufacturing . The mold products industry for panels .

Reference [4] show a method and a System for producing a pressed-wood composite product from a prepared, pre-assembly mat having opposed facial expanses, and including, plywood sheets, lumber pieces, and Wood components, the system of cyclic compression and cyclic heating.

Reference [5] is dedicated to the analysis of the drying processes and the energy consumption. In order to evaluate the main energetic processes that consume the most energy, the energy consumption of each individual drying process with and without air recirculation was modelled.

This project differs from other projects in some parts such as the compressor mechanism a hydraulic press will be used while the rest of the systems use the rotating process, in the drying process there are many systems of drying processes in factories, such as the collection of the process of pressure and drying at one stage Or in a separate oven, but

here an external oven system will be used. The main objective of the project is profit, so a wood panel will be produced to compete with the imported product in terms of specifications, quality, price and the same dimensions.

1.7. Time Schedule:

Table 1.1: Time Schedule

| Tasks/ Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|
| Selecting project title | | | | | | | | | | | | | | | | |
| Collection data and information on the subject of the project | | | | | | | | | | | | | | | | |
| Identify function and task | | | | | | | | | | | | | | | | |
| Design and analysis | | | | | | | | | | | | | | | | |
| Documentation | | | | | | | | | | | | | | | | |

1.8. The budget:

Table (1.2) shows the total profit for one cycle(which means 5 days to produce 100 panel):

Table 1.2: The total profit

| Tools and devices | Items | Item price(₪) | Total price(₪) |
|---|---------|---------------|----------------|
| Waste wood | 20 | 20 | -400 |
| Adhesive | 20 | 25 | -500 |
| motors electricity | 330 KWh | 0.8 | -230 |
| Additional costs (machines,workers, Electricity...) | - | 200 | -1000 |
| Fuel (dry wood) | 400 Kg | 1 | -400 |
| Fans electricity | 52 KWh | 0.8 | -42 |
| Product sale | 100 | 70 | +7000 |
| Total profit | | | 4428 ₪ |

Table (1.3) shows the total cost of project:

Table 1.3; The total cost

| Tools and devices | Items | Item price(\$) | Total price(\$) |
|--------------------------|--------------|-----------------------|------------------------|
| Stainless steel | - | - | 4000 |
| Motor | 3 | 200 | 600 |
| Hydraulic motor & pump | 1 | 1000 | 1000 |
| Hydraulic jacks | 4 | 300 | 1200 |
| Air compressor | 1 | 2000 | 2000 |
| Pneumatic piston | 5 | 54 | 270 |
| Aluminum | - | - | 3000 |
| PLC | 2 | 400 | 800 |
| Contactors | 4 | 20 | 80 |
| Sensors | 9 | 10 | 90 |
| Fans | 3 | 230 | 690 |
| Electrical wires | 50 meter | 2/meter | 100 |
| Industrial cost | | | 4000 |
| Total cost | | | 16030 \$ |

1.9. Chapter Conclusions:

This project will solve many problems such as consuming a lot of money to buy imported wood panels and the problem of throwing wood waste into the environment... etc. After studying the budget, this project will generate good profits and create a good job opportunity.

CHAPTER 2

The system

- 2.1. Introduction**
- 2.2. The Mixer**
 - 2.2.1. Parts of Mixer**
- 2.3. Hydraulic Press**
- 2.4. The Oven**
 - 2.4.1. Wood Drying**
 - 2.4.2. The System**
 - 2.4.3. Problems in Wood Drying**
 - 2.4.4. The Experiments**

2.1. Introduction:

This chapter shows the general stages in the system the new technology of recycling waste wood with a full automated system. The proposed machine is shown in figure (2.1).

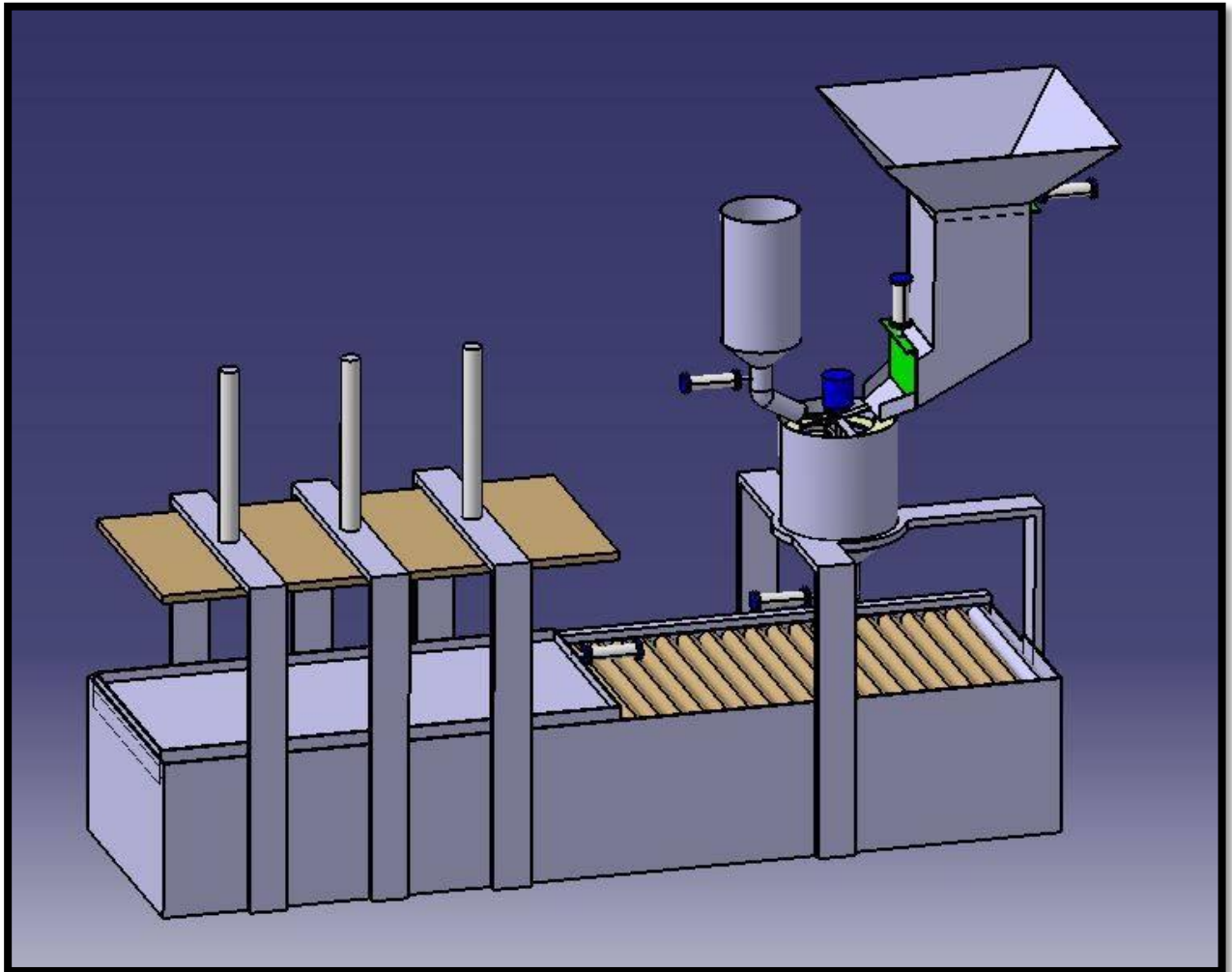


Figure 2. 1: The machine design

In order to draw an image in our minds about how the machine works and how the manufacturing stages pass through it to get the final product, we divided the stage of the production into three general stages, these stages are:

- 1) Mixer
- 2) Hydraulic press
- 3) The oven

2.2. The Mixer:

In order to obtain a high quality product. At this stage, the system mixes the waste of wood and additional materials (adhesive) in the tank mixing by using a ribbon blender with ratio (2 kg of waste wood :1 kg of adhesive) by trial. The ribbon blender is controlled by an electric motor located above the tank, as shown in figure (2.2).

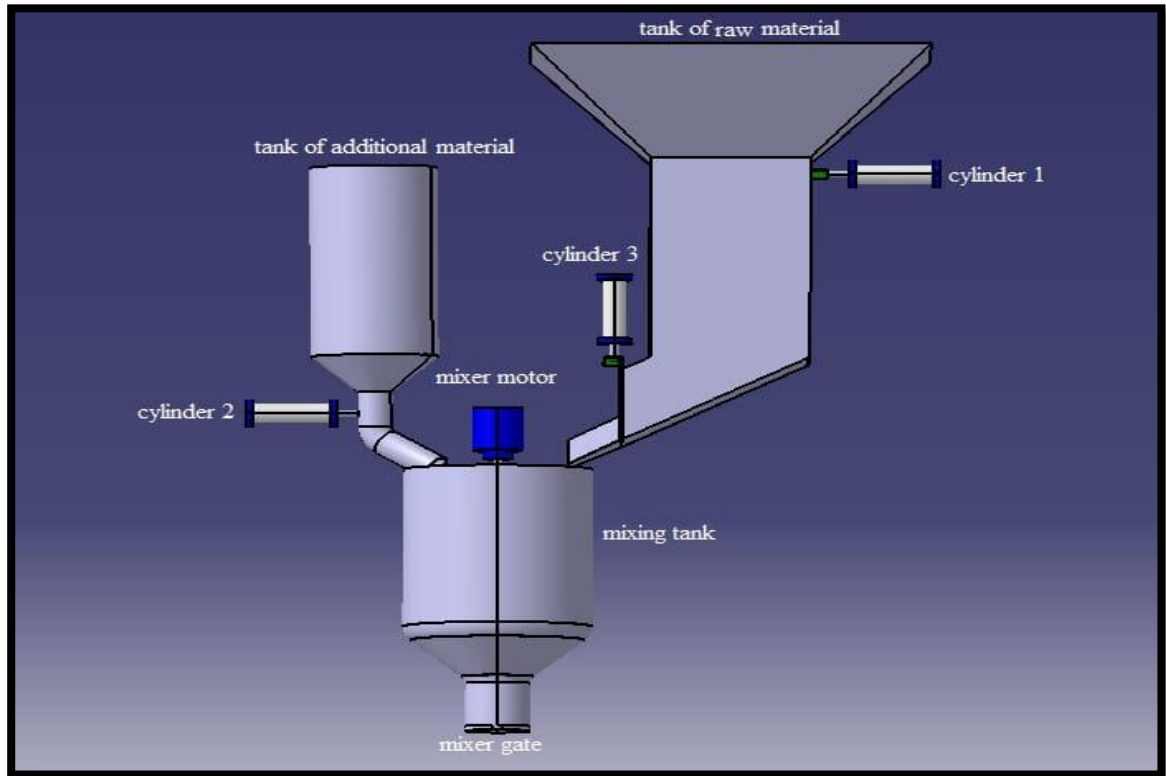


Figure 2. 2: The mixer

2.2.1. Parts of Mixer:

1) Mixing tank :

This part is a stainless steel container with a cylindrical design to facilitate the mixing process. We chose this type to resist the high weights of the mix. This steel should be smooth to avoid the adhesion of the mixture with the sides of the mixer.

This part contains an electrical operated rod installed in the centre and at the end of this rod there is a ribbon blender and this rod is operated by an electric motor located above the tank.

2) Ribbon blender:

The mixing elements consist of a center driveshaft and the actual component that provide the mixing action. This component is ribbon blender. The ribbon blender is used for mixing the waste of the wood in the tank. The mixing process will be according to specific amount for all material and according to some laws in order to get a good percentage of materials without the use of estimate in the mixing process.

3) Tank of additional material :

This part is a tank containing very strong adhesive materials dedicated to the process is relatively with wood waste to be mixed in the mixer. These materials are used to make wood particles more strength and hardness.

2.3. Hydraulic Press:

The second stage of the project is using a hydraulic press to compress the resulting mixture on a rigid table having a moving mold and There will be a plate moving right and left to make the material equal in all area of the mold. The hydraulic press will compress the wood panel to produce the wood panel form with global specifications and standard dimensions .The hydraulic press and the table shown in figure (2.3)

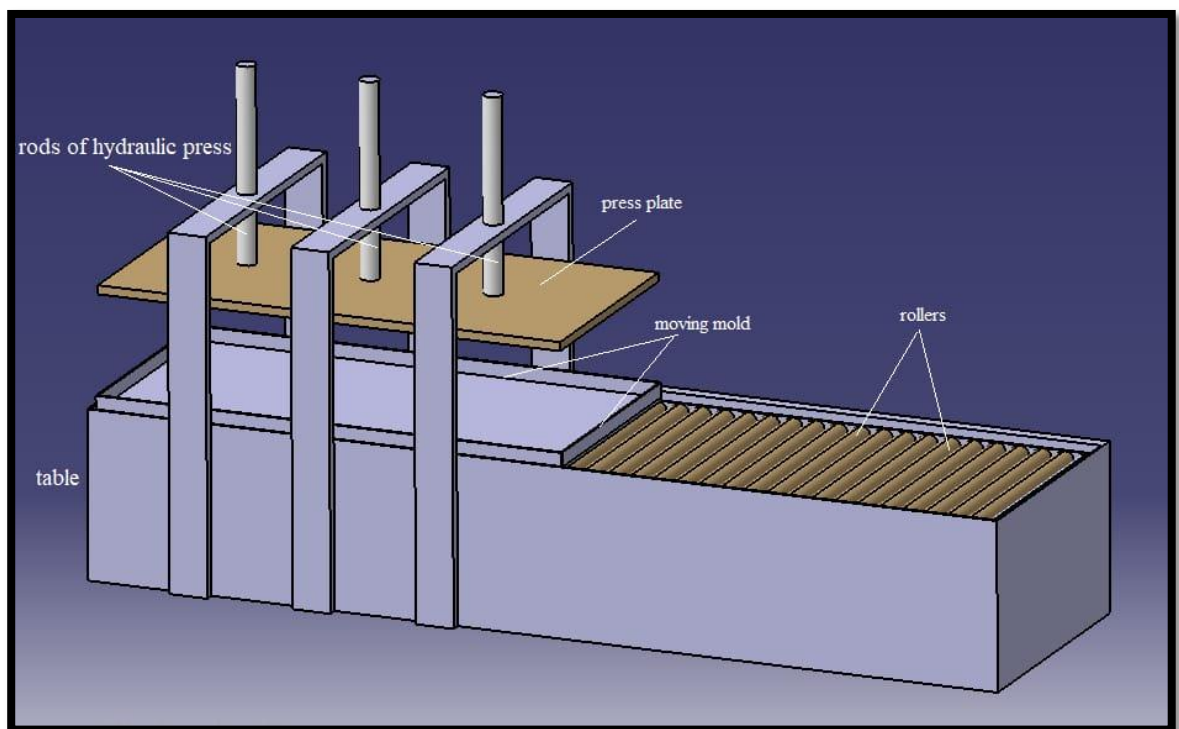


Figure 2. 3: Hydraulic press design

2.4. The Oven:

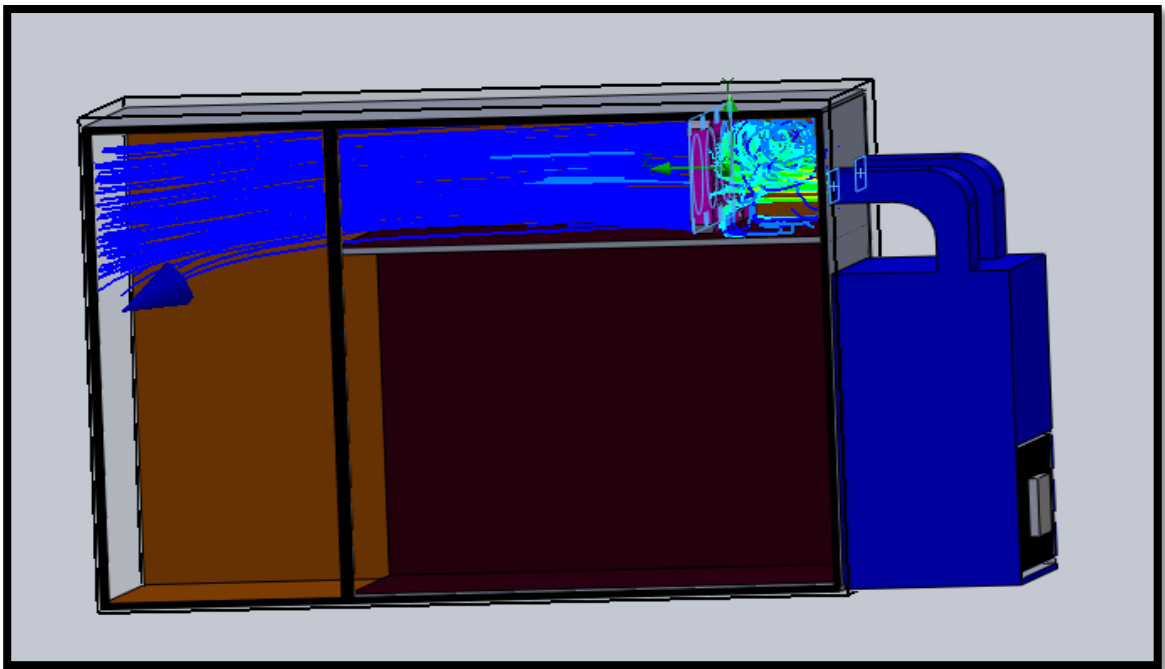


Figure 2. 4: The oven

As shown in figure (2.4).After removing the wood panel from the pressing process, the moisture content of the wood panel will be high reaches to 50%(by trial). Therefore, we need to reduce this ratio to reach the equivalent moisture content ranging from 8% to 12%. [6].

2.4.1. Wood Drying:

Some important reasons to dry wood include:

- 1) Reduced shipping costs. Dry wood weighs less (drying may reduce its weight by one-half or more). It is more profitable to transport wood than water
- 2) Less likelihood of stain or decay during transit, storage, and use.
- 3) Reduced susceptibility to insect damage.
- 4) Increased strength. As wood dries below 30% Moisture Content, most strength properties increase.
- 5) Better finishing. Paints and finishes adhere better to seasoned wood.
- 6) Better heat insulation. Dry wood is a better thermal insulator than wet wood.

2.4.2. The System:

The construction of a thermal oven designed to withstand a high temperature reaches to 160 °F(65 c°) [6], the oven contains of room where the burning of fuel, such as wood to heat the air and enter the air inside the oven and there are also several fans used to move the air inside the oven to make sure that the temperature in all parts of the oven is equal.

Air circulations through the wood can develop by natural convection. Warm, dry air enters the sides and top of the wood panel. As the dry air moves over the wood, it evaporates the moisture from the surfaces.

2.4.3. Problems in Wood Drying:

There are some negative aspects to drying wood, including:

- 1) The great amount of energy that must be expended to dry the water out of wood.
- 2) The possibility of drying defects. As wood dries, it shrinks in several dimensions. If wood is not correctly dried, the dimensional changes will cause drying defects.

2.4.4. The Experiments:

We did some experiments on this project, to know some information's for the calculations like thermal energy(The expected energy consumption to remove the desired amount of water from the wood fibers during processing) and moisture content to produce best panels the best result was 2 kg of waste wood and 1 kg of adhesive and you can see the results in the figure (2.5) below.



Figure 2. 5: The Experiments

CHAPTER 3

Mechanical Parts

- 3.1. Introduction**
- 3.2. Proposal System Description and Specifications**
- 3.3. Mechanical Design**
 - 3.3.1. Mixer Machine**
 - 3.3.1.1. Area Calculations for Mixing Tank**
 - 3.3.1.2. Volume Calculations for Mixing Tank**
 - 3.3.1.3. Mixture Ribbon**
 - 3.3.2. The table**
 - 3.3.3. The Mold Dimensions**
 - 3.3.4. Mixture Drive**
- 3.4. The Oven**
 - 3.4.1. the Volume of The Oven**
 - 3.4.2. The Walls of Oven**
 - 3.4.3. The Power Consumption**
 - 3.4.3.1. Thermal Energy**
 - 3.4.3.2. The Electrical Energy**
 - 3.4.4. Air Heating Process**

3.1. Introduction:

The process of production start with collecting operation of waste wood in a tank then moving to the mixer relatively with the adhesive to be mixed and became a flexible material and put it in the mold. The mold will move to reach under the hydraulic press; the material will compressed to obtain the required dimensions. The panel will extract and placed in the oven to dry it. Thus produces the wood panel.

Since the machine used for preservation of the environment and in order to maintain the product, most of the machine parts are made of steel, and in order to obtain a good and simple design a set of parameters must be considered, these parameters are related to the machine itself such as: safety, portability, cost, design simplicity, availability, work space, on the other hand, the design must be able to produce efficient suitable for user related into the international standard.

3.2. Proposal System Description and Specifications:

The first step in mechanical design is to know the whole operation of the system and to know how the machine is bind as shown in figure (3.1).

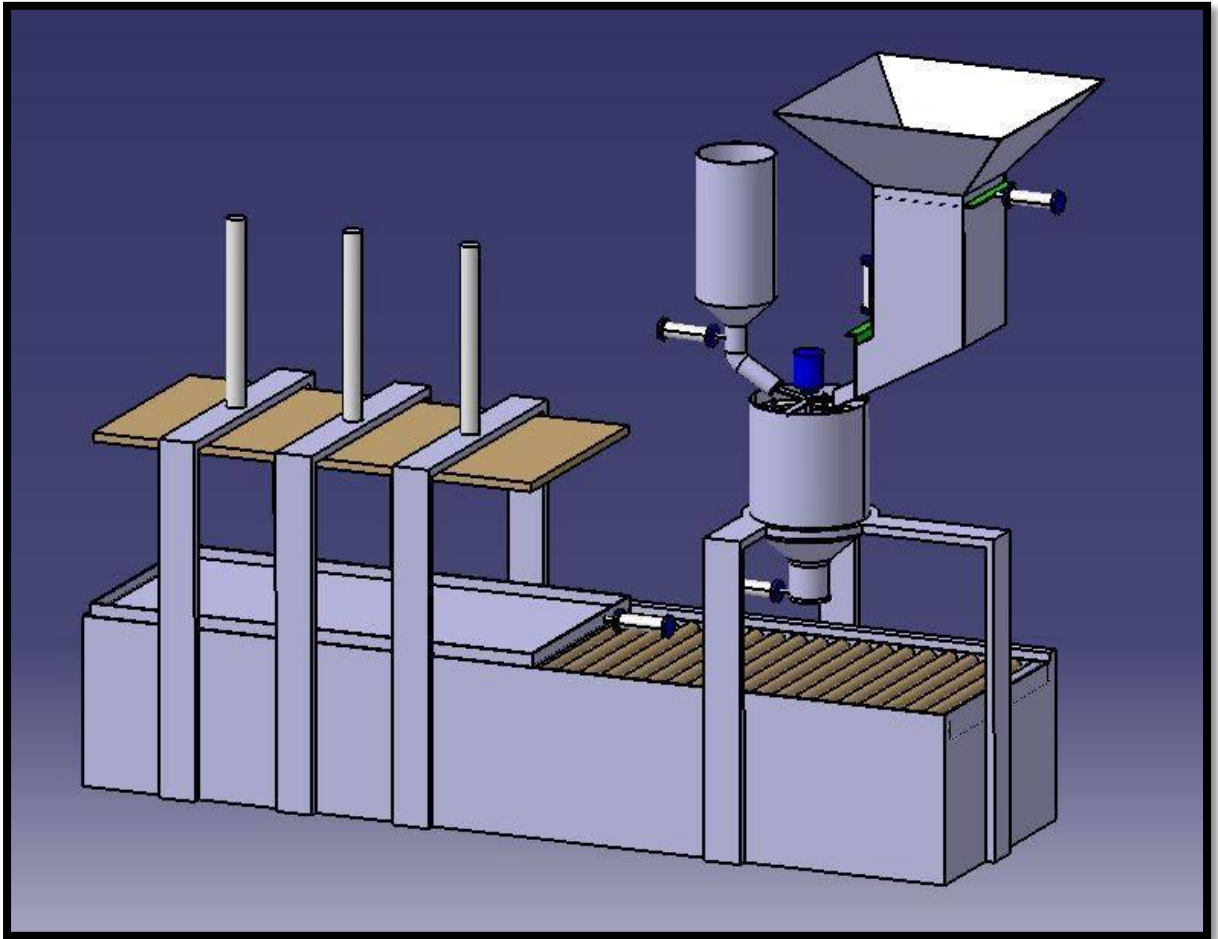


Figure 3. 1: Machine design

3.3. Mechanical Design:

In this section each block will be explained in details, the used material for most parts in this machine is stainless steel (1020).

3.3.1. Mixer Machine:

The first step in the operation start in this tank as shown in figure (3.2) which is designed to hold the mixture

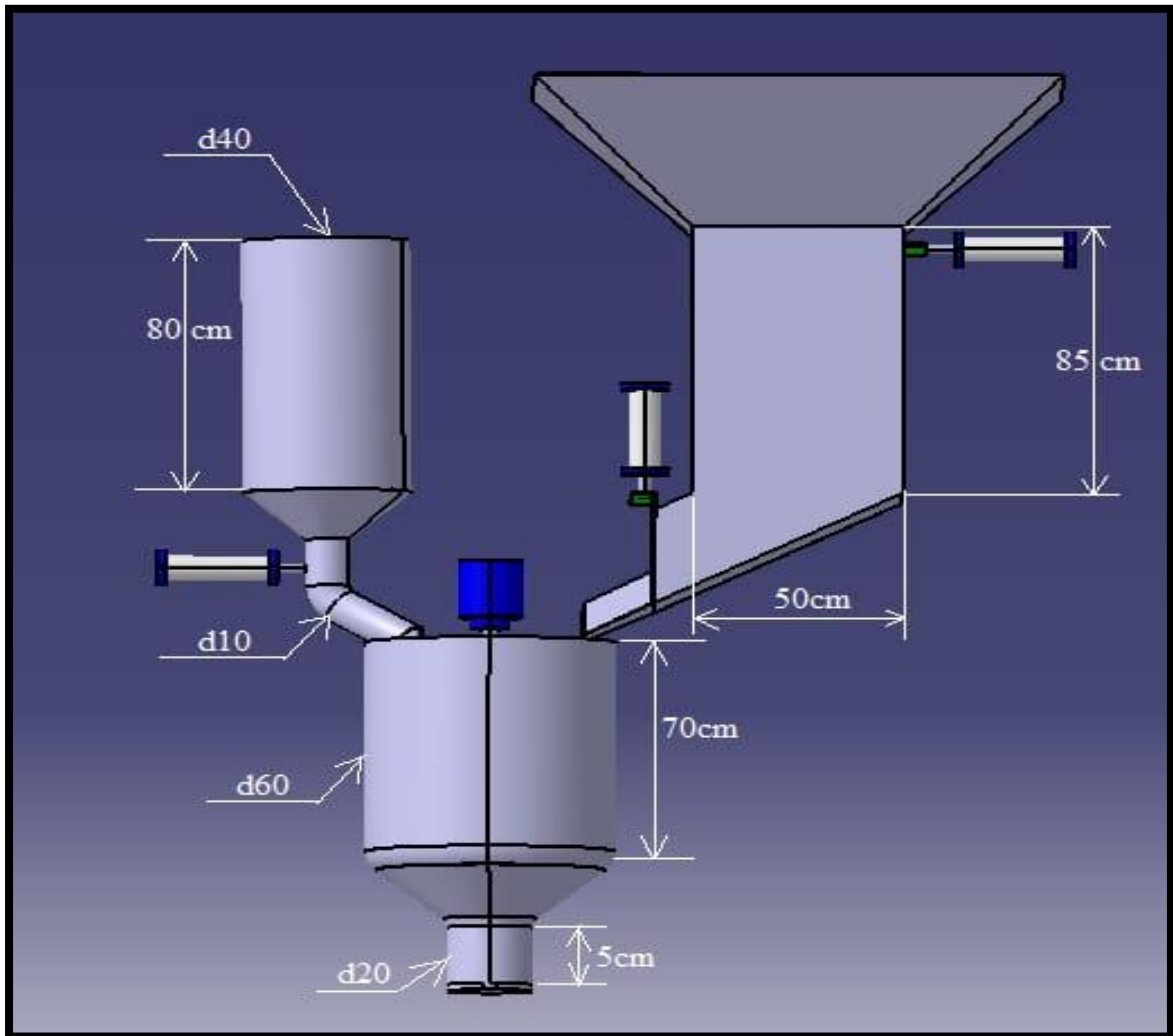


Figure 3. 2: The mixer dimensions

Through the experiment found that the density of the mixture before pressing is equal 177.6 kg/m³, finished product measurements (standard):

$$\text{Density} = 770 \text{ kg/m}^3$$

$$\text{Volume} = 0.048 \text{ m}^3$$

$$\text{Mass} = 37 \text{ kg}$$

$$\text{Mixture volume} = \frac{\text{mixture mass}}{\text{mixture density}} = 0.208 \text{ m}^3 \quad (3.1)$$

3.3.1.1. Area Calculations for Mixing Tank:

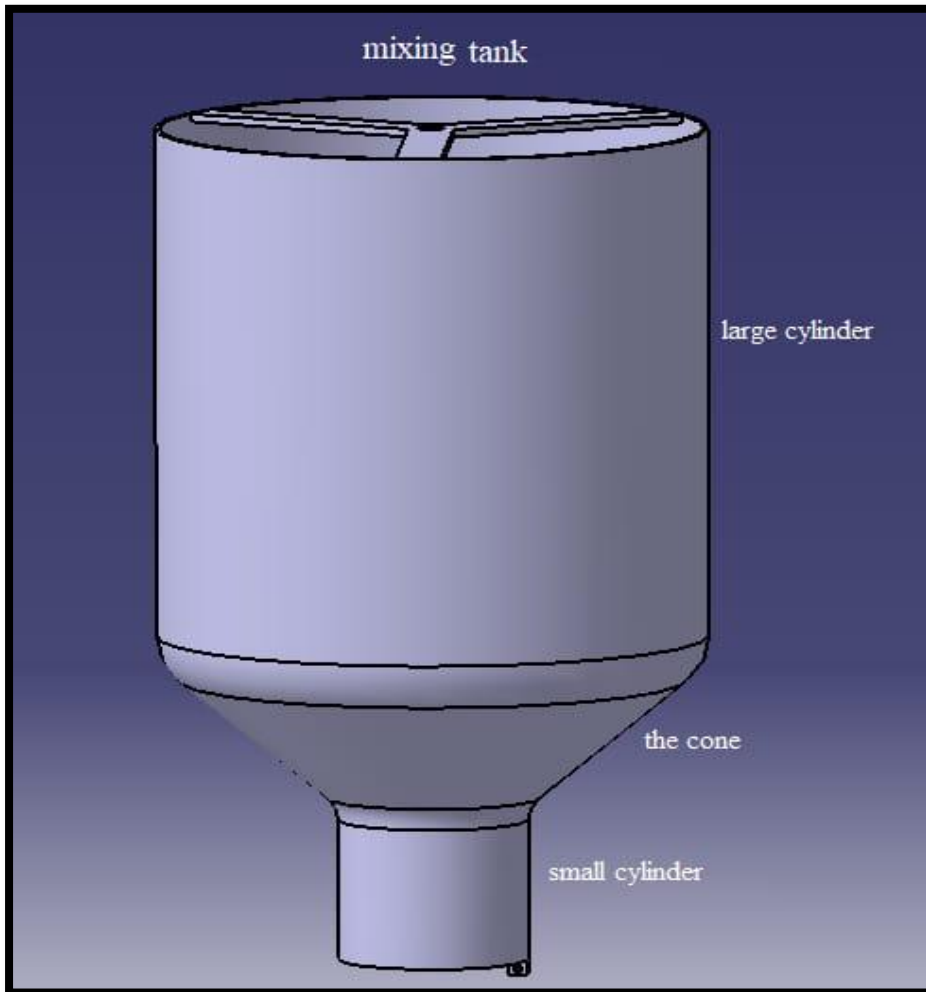


Figure 3. 3: Mixing Tank

➤ The large cylinder area (A_1):

$$A_1 = 2\pi r_1 h_1 = 1.319 \text{ m}^2 \quad (3.2)$$

Where:

r_1 : the radius of cylinder (0.3 m).

h_1 : the height of cylinder (0.7 m).

A_1 : Area (m^2)

➤ The cone area (A_2):

$$A_2 = \pi s(R-r) = 0.387 \text{ m}^2 \quad (3.3)$$

Where:

s: the length of the slash (0.352 m).

R: the radius of large Circle (0.3 m).

r: the radius of small circle (0.05 m).

A_2 : area (m^2).

➤ The small cylinder area (A_3):

$$A_3 = 2\pi r_2 h_2 + \pi r_2^2 = 0.0219 \text{ m}^2 \quad (3.4)$$

Where:

r_2 : The radius of small cylinder (0.05m)

h_2 : The height of small cylinder (0.05 m)

A_3 : area (m^2)

➤ The total area is the area of the mixer:

$$A_{Total} = A_1 + A_2 + A_3 = 1.728 \text{ m}^2 \quad (3.5)$$

3.3.1.2 Volume Calculations for Mixing Tank:

➤ The large cylinder volume (V_1):

$$V_1 = \pi r_1^2 h_1 = 0.208 \text{ m}^3 \quad (3.6)$$

➤ The cone volume (V_2):

$$V_2 = \frac{1}{3} \pi h (r^2 + Rr + R^2) = 0.0279 \text{ m}^3 \quad (3.7)$$

- The small cylinder volume (V_3):

$$V_3 = \pi r_2^2 h_2 = 0.000393 \text{ m}^3 \quad (3.8)$$

- The total volume is the volume of the mixer:

$$V_{\text{Total}} = V_1 + V_2 + V_3 = 0.236 \text{ m}^3 \quad (3.9)$$

3.3.1.3 Mixture Ribbon:

The ribbon blender is a vertical styled helical blade mixer. That ribbon blender is of highly efficient and versatile mixing machine designed to homogeneously mix dry process, thorough mixing is accomplished by continuously moving the process media from the center to both ends of the container and in reverse direction. Which diameter area estimated about 60 cm, and consumes a 440 voltage and a current of (2A) and it will turn in speed of (60 rev/min). as shown in figure (3.4).

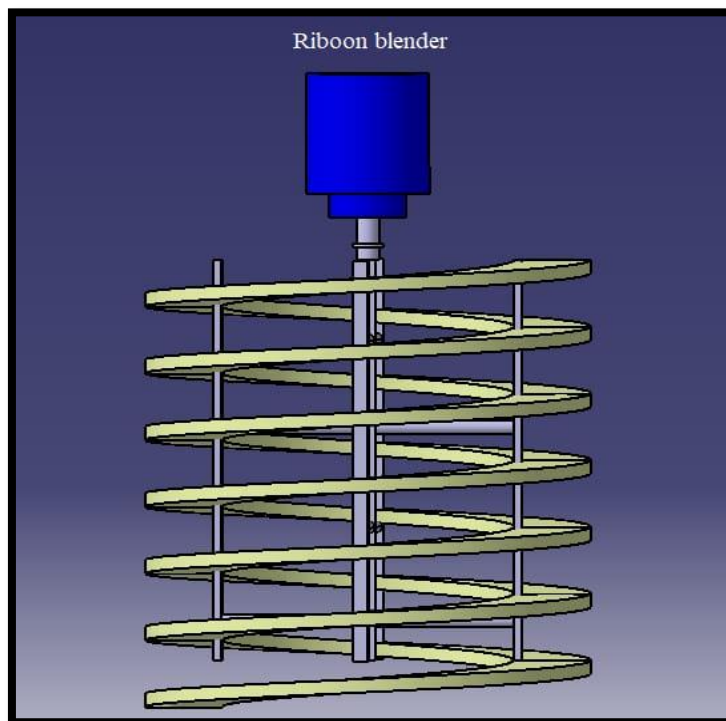


Figure 3. 4: Ribbon Blender

3.3.2. The table:

This table will be designed to have the ability of a forward and backward movement, In the beginning the mold will be filled with the mixture of the mixer then move horizontally until it reaches under the hydraulic press for compression process, so the dimensions must be appropriate for this process so as not to find any problem.as shown in figure (3.5)

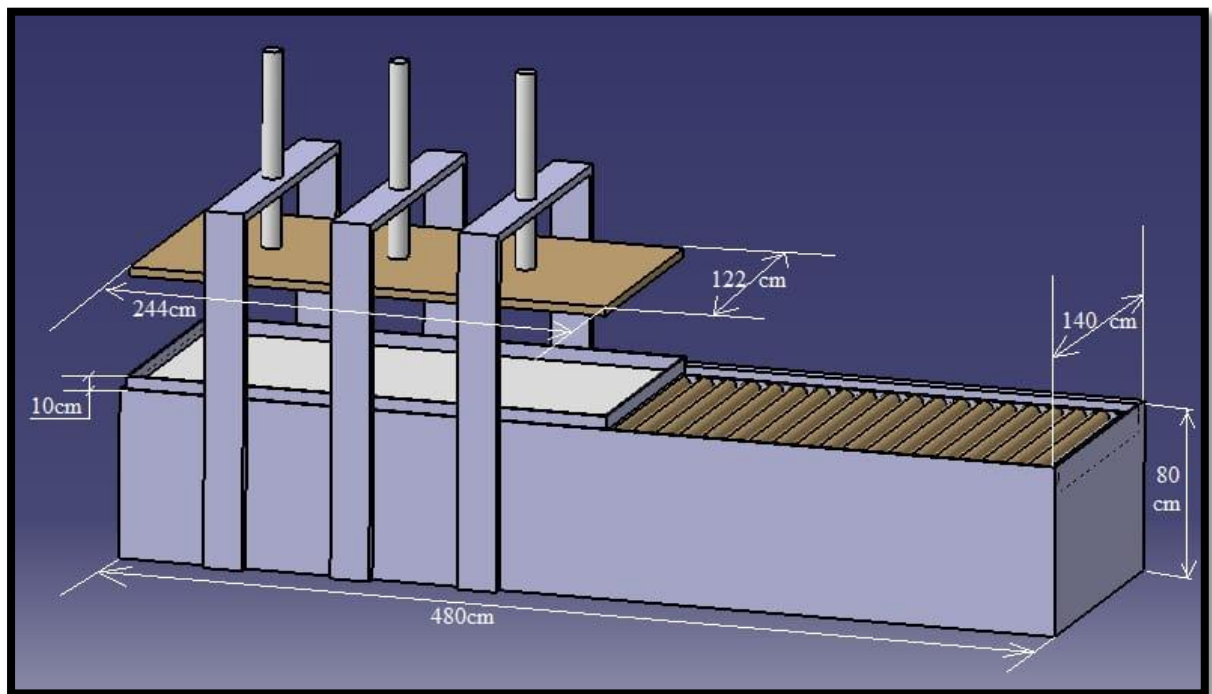


Figure 3. 5: The table dimensions

The table dimensions:

➤ Width:

Width=the width of the mold+ walls thickness (3.10)

Width = 1.4 m

- Length:

The length of the table is the distance between the edge of the table and center of the mixer and radius of the mixer and the distance between the mixer and the hydraulic press and the length of the mold.

$$\text{Length} = 4.8 \text{ m}$$

- The height is 0.8 m
- The edges height is 0.05 m

3.3.3. The Mold Dimensions:

- Length : Length of the board + thickness of the edges = 2.44 m + 0.012 m = 2.452 m

- Width: 1.22 m + 0.012 m = 1.232 m

- The height: $\frac{\text{Mixture volume}}{\text{length} \times \text{width}} = 0.07 \text{ m}$ (3.11)

- High wall mold = 0.07 + 0.03 = 0.1 m

- Mold area:

$$\text{Area} = 6.123 \text{ m}^2$$

- Mold volume:

$$\text{Volume} = 0.208 \text{ m}^3$$

3.3.4. Mixture Drive:

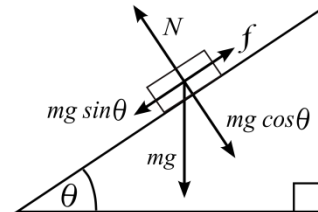
(330/220)V AC motor. That used to run the mixer; the motor will be connected with inverter to control the speed of motor and make the speed of blades slow to give high torque.

In order to choose the suitable motor to rotate the internal blades ,there are two points.

➤ Blades Torque (T)(static)

$$T = f \times r \rightarrow f = m g \cos(\theta)$$

$$\begin{aligned} T_b &= m g \cos(\theta) \times r \\ &= 36.96 \times 9.81 \times \cos(7.2) \times 0.29 \\ &= 104.32 \text{ N.m} \end{aligned}$$



Where:

m: mass of mixture.

θ : angle between blade and horizontal line.

r: radius of blade.

T_b : Blades Torque.

The torque required to move the blades must be higher than the blade torque value (T_b) so choose torque (T) equal (120 N.m).

➤ Power consumption (P)

$$P = T \times \omega = 753.6 \text{ W} \tag{3.12}$$

Where:

ω : angular velocity (rpm)

➤ Blades Torque (T)(dynamic)

As shown in figure (3.6) the relation between speed acceleration and time:

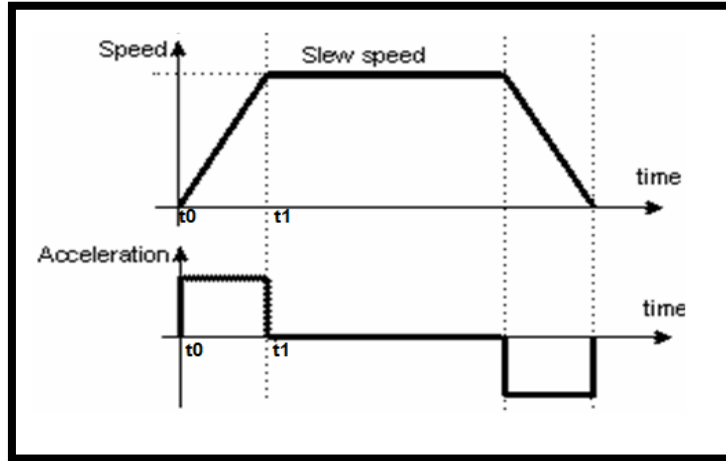


Figure 3. 6: curve of acceleration and speed by time

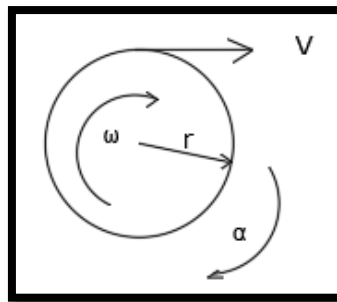


Figure 3. 7: free body diagram

➤ The Acceleration:

$$\omega = \frac{v_{max}}{r_{max}}, \quad r = \frac{Ds}{2}$$

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{\omega_1 - \omega_0}{t_1 - t_0}, \quad \omega_0 = 0, \quad t_0 = 0$$

$$\alpha = \frac{\omega_{max}}{t_1} , \quad \ddot{\theta} = \frac{\omega_{max}}{t_1} \quad (3.13)$$

$$\ddot{\theta} = \frac{\omega_{max}}{t_1} = 0.104 \frac{\text{rad}}{\text{s}^2}$$

Where:

$\ddot{\theta}$: The acceleration of the motor.

t_1 : The time required for motor to reach high speed. (1 min)

➤ Mass moment of inertia (I) :

1) For shaft:

$$I_s = \frac{1}{2} m \cdot R^2 = 0.00056 \text{ kg.m}^2$$

Where:

M: the mass of shaft (5 kg)

r: radius of shaft (0.015 m)

2) For helical :

$$I_H = \frac{1}{2} m (R_o^2 + R_i^2) = 0.601 \text{ kg.m}^2$$

3) For material :

$$I_m = \frac{1}{2} m R^2 = 1.665 \text{ kg.m}^2$$

$$4) \sum I = 2.266 \text{ kg.m}^2$$

➤ Newton's second law for rotating :

$$\sum T = \sum I * \ddot{\theta} = 0.236 \text{ N.m} \quad (3.14)$$

Where:

T: The torque (N.m)

I: mass moment of inertia (kg.m²)

$\ddot{\theta}$: Acceleration (0.104 $\frac{\text{rad}}{\text{s}^2}$)

3.4.The Oven :

The oven designed to contain 100 panels in each cycle, and the temperature in is between (100°F_160°F) [6] if the temperature exceeds this value the panel will shrink and damage so the oven will be at 150 °F shown in figure (3.8):

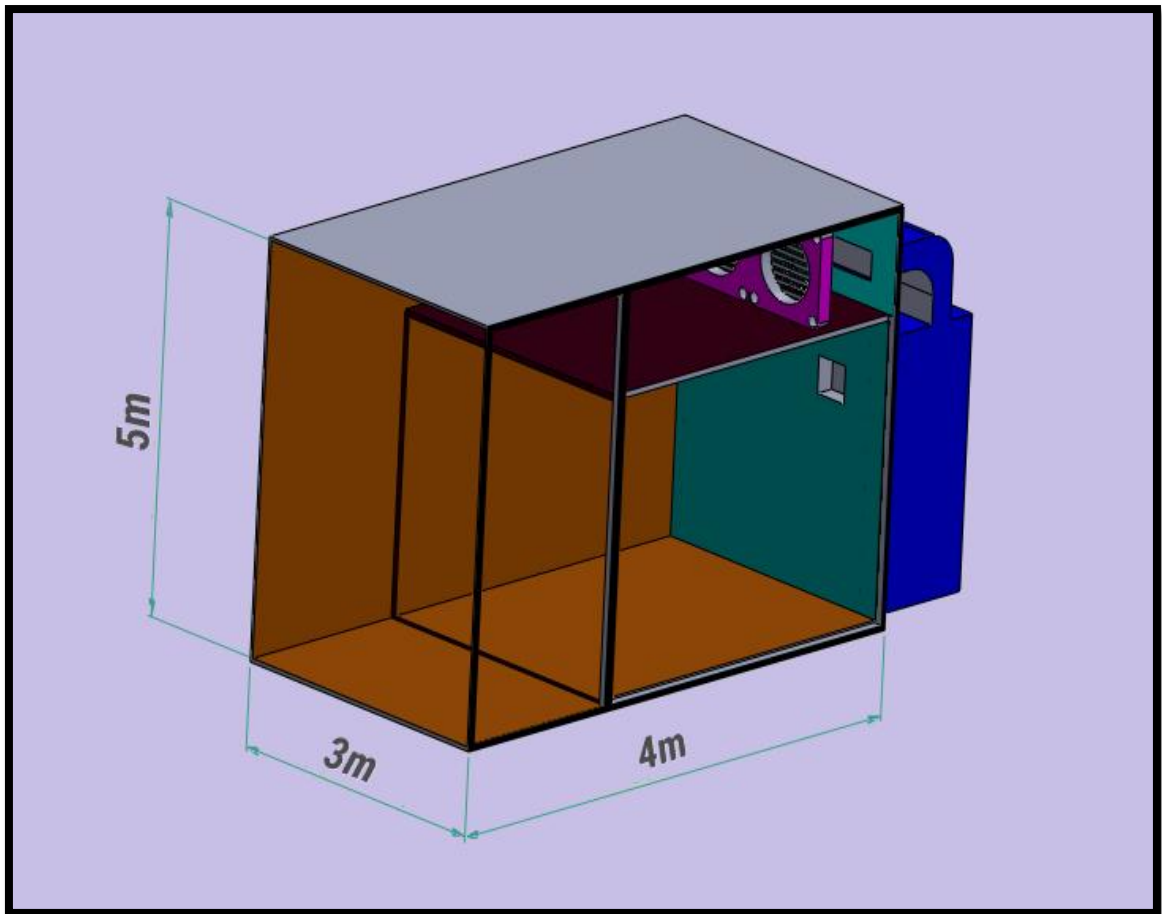


Figure 3. 8: The oven dimensions

3.4.1. The Volume of the Oven:

$$V=L*W*H =60m^3 \tag{3.15}$$

Where:

V: the volume of the oven (m^3)

L: the length of the oven (4m)

W: the width of the oven (3m)

H: the height of the oven (5m)

3.4.2. The Walls of Oven:

The walls of the oven are designed to contain three layers two of them is aluminum and insulation layer between of them, the walls of the oven have a thickness (15_20 cm) .[4]

3.4.3. The Power Consumption :

The energy for the production of MDF results from sources of electricity and fire of wood. Electrical power is used all over the manufacturing process in order to operate equipment inside the oven, such as fan motors. The thermal energy is generated by provides hot air to the process that comes from wood burning. The system shown in figure (3.9).

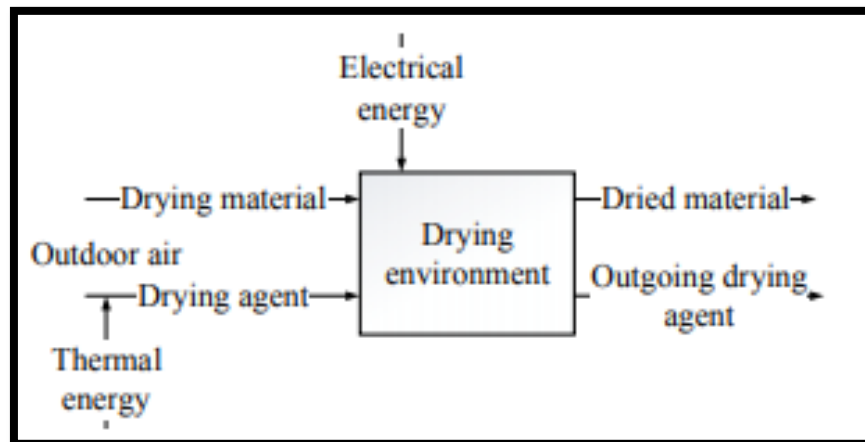


Figure 3. 9: The drying process

3.4.3.1. Thermal Energy :

➤ Moisture content :

To calculate the thermal energy, first we must calculate the initial moisture content (MC) in the wood panel after press process.[6]

$$\%MC = \frac{WBD - WAD}{WAD} * 100\% = 50\% \quad (3.16)$$

Where:

WBD: weight before drying (3 kg by trial)

WAD: weight after drying (2 kg by trial)

The expected energy consumption to remove the desired amount of water from the wood fibers during processing. The average Moisture Content (MC) of wood material coming into the mill in this study was 50%(by trial) on an oven-dry weight basis. The targeted MC for the dried material was 8_12% [6]. The MC of the MDF finished was approximately 12% on an oven-dry.

➤ the time:

Second, we must calculate the time consumed in drying operation, the rate at which wood dries depends upon a number of factors, the most important factors the temperature, the dimensions of the wood panel, and the relative humidity. So any change in these factors the time will change so the value of the time is important:

$$t = \frac{L^n}{a + bp_{sat}(T)} \ln\left(\frac{M - M_e}{M_0 - M_e}\right) = 5.6 \text{ days (135 hours)} \dots\dots [5, 7] \quad (3.17)$$

Where:

t: the time of dry operation (days)

L: the thickness of the panel (0.64 inches)

n: constant (1.52)

a: constant (0.0575)

b: constant (0.00142)

$P_{\text{sat}}(T)$: the saturation vapor pressure of water at temperature T (192 mmhg at 150 °F)

M: initial moisture content (50%)

M_0 : finally moisture content (12%)

M_e : moisture content of the wood at equilibrium (11%)

➤ The heat consumption:

The amount of heat needed to evaporate the moisture from the material is

$$Q = F(M - M_0)[r_o - (C_{pw} - C_{pv})T]t = 7796471.4 \text{ kJ} \dots\dots[8] \quad (3.18)$$

Where:

Q: The amount of heat needed to evaporate the moisture from the material (kJ)

F: material flow rate (0.1 ton/hour=100 kg/hour)

r_o : latent heat of water (2260 kJ/kg)

C_{pw} : specific heat of water (kJ/kg K)

C_{pv} : specific heat of water vapor (kJ/kg K)

T: the temperature (338 k)

t: the time (135 hours)

➤ the amount of fuel (wood) :

The amount of fuel wood needed to give the oven this amount of energy:

The calorific value (The amount of energy produced by the complete combustion of a material or fuel. Measured in units of energy per amount of material. KJ/Kg) of wood dry is 19.9 MJ/Kg. [9]

$$A = \frac{Q}{CV} = 391.78 \text{ kg} \quad (3.19)$$

Where:

A: the amount of fuel wood (Kg)

CV: the calorific value (KJ/Kg)

3.4.3.2. The Electrical Energy :

The electrical energy in oven system is expressed by the fan motors, but first we must choose the type of the fan, the size and how much fans we need. We can calculate the size and type required by calculate the size of the oven and measure the flow rate from this equation:

$$\text{The flow rate needed for the oven volume} = 4230 \text{ m}^3/\text{hour} \dots [10] \quad (3.20)$$

So the fan must reach this flow rate but this flow is too high ,it need many fans in the oven to circulation operation , we decide to choose fan in type of Axial Plate Fan, 315mm,as shown in figure (3.10) the Data sheet of this fan :

| Specifications | |
|---------------------------|-----------------------|
| Attribute | Value |
| Fan Type | Axial Plate Fan |
| Air Flow | 0.43m ³ /s |
| Fan Speed | 1400rpm |
| AC or DC Operation | AC |
| Blade Diameter | 315mm |
| Bearing Type | Ball |
| Power Consumption | 130W |
| Noise Level | 49dB(A) |
| Maximum Current | 590mA |
| Supply Voltage | 220 — 240 V ac |
| Dimensions | 430 x 430 x 168mm |
| Depth | 168mm |
| Height | 430mm |
| Width | 430mm |
| Dimensions Height x Width | 430 x 430mm |

Figure 3. 10: Fan data sheet

From data sheet this fan can give 0.43 m³/s (1548 m³/h), three of this fan work.

The power consumption= 3*130 = 390 W

3.4.4. Air Heating Process:

Assume that the process start at point (A) having a temperature and relative humidity of outside air then make a sensible heating until the temperature reach to 150°F at point (B) after that the water in the wood panel start evaporation , the relative humidity in the air will increase gradually until the end of wood drying operation at point (C). We can't know point (C) in the chart without make an experiment. The process shown in figure (3.11).

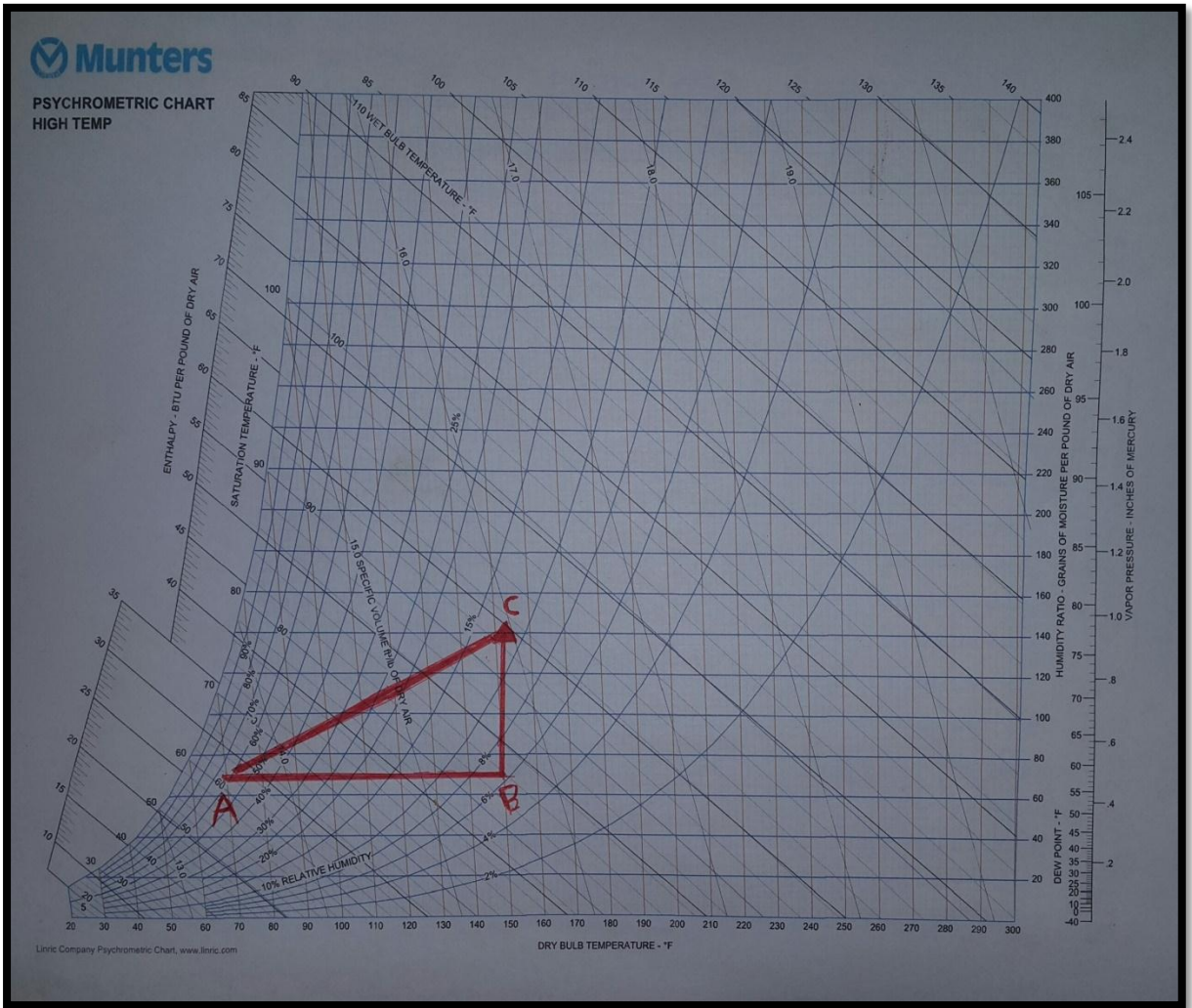


Figure 3. 11: Psychrometric chart of air heating process

CHAPTER 4

Electrical parts

- 4.1 Introduction**
- 4.2 Motor Calculations**
- 4.3 Switches**
- 4.4 Contactors**
- 4.5 Sensors**
- 4.6 Invertor**
- 4.7 Cylinders**

4.1 Introduction:

This chapter contains the electrical component specifications (motor, sensor, and overload), power & control circuit, and protection.

4.2 Motor Calculations:

Mixing motor:

The mixing motor was obtained 753.6 W by equation $P= T \times \omega$.



Figure 4.1: Mixing Motor

Table 4. 1: Motor table

| Motor Table | |
|----------------|-----------------|
| Max current | 2.5 A |
| Input power | 1 Kw |
| Voltage | 380\220 V |
| Cos (ϕ) | 0.66 |
| Phase speed | 3 phase pole 50 |
| Speed | 1400 rpm |

To protect the motors we used overload switches and it defined as overload relays are intended to protect motors against excessive heating due to prolonged motor over currents up to and including locked motor currents. Protection of the motor due to short circuits or grounds is a function of circuit breakers, or motor short-circuit protectors. In this project we used one Overload. As shown in figure (4.2).



Figure 4.2: Overload

4.3 Switches:

The emergence switch is used to stop the machine immediately when something wrong happened with the machine as shown in figure 4.3.a. The start pushbutton switch are used to turn on the project as shown in figure(4.3)b The stop pushbutton switch used to turn off the project as shown in figure(4.3)c.

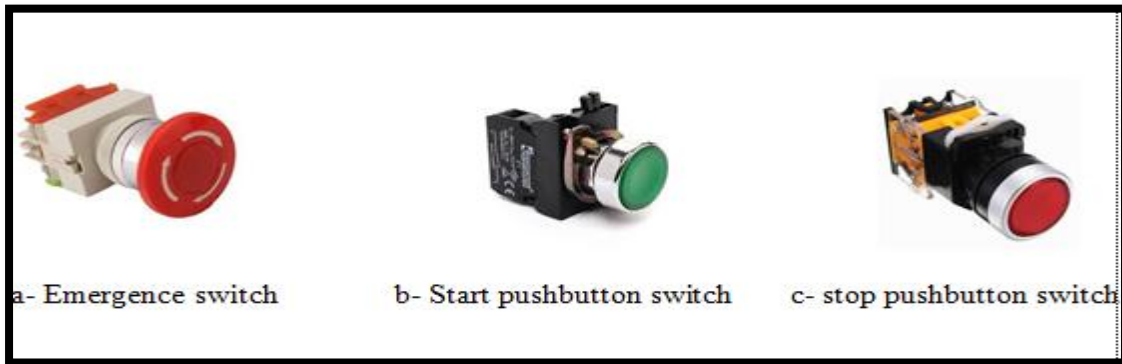


Figure 4.3: Switches

4.4 Contactors:

A contactor is an electrically controlled switch used for switching a power circuit similar to a relay except with higher current ratings.

A contactor is controlled by a circuit which has a much lower power level than the switched circuit.

Contactors come in many forms with varying capacities and features. Unlike a circuit breaker, a contractor is not intended to interrupt a short circuit current. Contactors range from those having a breaking current of several amperes to thousands of amperes and 24 V DC to many kilovolts. The physical size of contactors ranges from a device small enough to pick up with one hand to large devices approximately a meter (yard) on a side. Contactors are used to control electric motors, lighting, heating, capacitor banks, thermal evaporators, and other electrical loads.

In this project we used two contactors, first contactor for a mixer motor and second contactor for conveyer motor.



Figure 4.4: Contactor

4.5 Sensors:

1) Limit switch:

Limit switch is a Switch operated by the motion of a cylinder part or presence an object, they are used for control of a sequence of the cylinder, interlocks, or to count objects passing a point in project there are five limit switches as showing in figure (4.5).



Figure 4.5: Limit switches

2) Ultrasonic sensor:

This sensor works to transmit sound waves through an outlet (Trig) and after the collision waves with the body reflected and are received through the port (Echo) and through the time between sending waves and reception time is calculated distance through the following equation:

$$\text{Distance} = (\text{time} * \text{speed}) / 2$$

In this project there are two ultrasonic sensors used as shown in figure (4.6)



Figure 4.6: Ultrasonic sensor

3) Thermocouple sensor:

Is an electric piece used in measuring temperature, for this type of measurement pieces is very important in the measurement of high temperature value and features of this sensor low manufacturing cost and strong design and ease of use. As shown in figure (4.7).

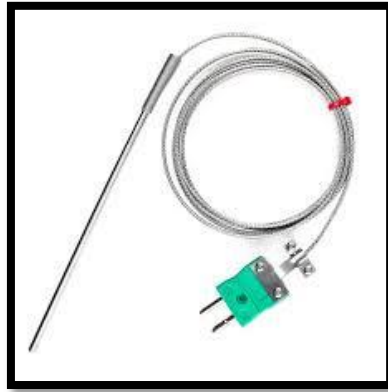


Figure 4.7: Thermocouple sensor

4.6 Invertor:

Is a device whose primary function is to convert the DC power current to 220/380 AC to operate the equipment and control motor speed. As shown in figure (4.8).



Figure 4.8: Invertor

4.7 Cylinders:

In this project we used nine cylinders, Three of these cylinders are used to control the movement of tanks gates, one to control the mixer gate, three are used to press the material into the mold, two are used to lift the board from the mold and the last one is used to push the board and transfer to the conveyor, controlled by nine electrical control valve.

CHAPTER 5

Control and Prototyping

- 5.1. Introduction:**
- 5.2. PLC Characteristic:**
- 5.3. System Programming**
- 5.4. Project Prototype**
- 5.5. Prototype Running On**
- 5.6. Total cost of prototype**
- 5.7. Experimental Result**
- 5.8. Recommendations**

5.1. Introduction:

As mentioned ,the operation of line production will be full automated in serial orders by using PLC (programming logic controller). This program added some specifications like automated running and occupational safety. This chapter provides experimental result and, some recommendations from the work team for this project.

5.2. PLC Characteristic:

Programmable Logic Controller (PLC) is a digital computer used for automation of electromechanical process, such as control of machinery on factory assembly lines, PLCs are used in many industries and machine. Unlike general-purpose computers, the PLC is designed for multiple inputs and output arrangements. extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery backed up or non- volatile memory.

A PLC is an example of a hard real time system since output results must be produced in response to input conditions within a limited time otherwise unintended operation will result. In our controlling design it is desirable to use a PLC with 13 input and 11 outputs mention, It can be operated on 24 volt. The used PLC is Twido base controller 24VDC with 13 inputs and 11 outputs.

5.3. System Programming:

The program of the system has been done of three stages: define outputs and inputs of the system with symbols, programmatic expression for system parts and movements by SFC, transfer SFC to PLC program

1. Inputs and outputs definition:
Put symbols to definition inputs (switches, sensors, limit switches) (Appendix, table A.2). And outputs (motors, cylinders) (Appendix, table A.1).
2. Building SFC:
Coordinate movement of system parts sequentially by SFC (Appendix, figure A.1)

3. PLC program:

After making SFC, transfers it to ladder program then upload the code to PLC (Appendix, figure A.2).

5.4. Project Prototype:

The figure (5.1) shows the prototype that was made and it consists of three main parts: mixer, hydraulic press and oven. The prototype is one to ten in the real project which means every centimeter in prototype equal ten centimeters in real project.



Figure 5. 1: Final Project Prototype

5.5. Prototype Running On:

The operation starts with adding the materials (adhesive and waste wood) manually to the mixer, then with pressing on the button (on) the operation will start with mixing the material to become a flexible material in around three minutes, after ending this time the gate of the mixer will be opened automatically, then the material will fall in the mold in around ten seconds, when the mixer gate opened, the timer will start counting until fifteen seconds. After that the mold will start moving to be under the hydraulic press and when it reaches, the sensor will give a signal to the motors of the mold to turn off. The hydraulic press will press the material manually after this operation ends. Taking the panel to the oven manually to be a dried panel.

5.6. Total cost of prototype:

Table 5. 1: Total Cost Of Prototype

| | | |
|-------------------|------------------------------------|-------------|
| 1 | Metal structure | Table 61000 |
| 2 | Gears and bearings | 200 |
| 3 | DC motors | 300 |
| 4 | Coupler | 150 |
| 5 | Switches, wires and limit switches | 100 |
| 6 | Relays | 100 |
| 7 | PLC Twido | 1500 |
| 8 | Temperature controller | 100 |
| 9 | Cylinder | 150 |
| 10 | Finishing | 250 |
| Total cost | | 3850 |

5.7. Experimental Result:

We made some experiments on the project, the results:

Adding of the materials (adhesive and carpentry) was manually , after that the mixing stage has been started in the tank and took a three minute which produce a flexible product ready for pressing , the tank was open after this point to put flexible material in the mold and transfer it below the hydraulic press to press the material and produce the panel after that we put this panel in the oven for drying , the results was good as we wished. Already A product has been produced.

5.8. Recommendations:

- 1.** Study the possibility of using a compress rollers instead of hydraulic press to increase production quantity.
- 2.** Improve the project through of adding a crusher to get a large quantities of raw materials.
- 3.** To study the possibility of HMI programming of this project.
- 4.** Studying the possibility of dry the product through of pressing stage.

CHAPTER 6

Manual User

- 6.1. System basics**
- 6.2. Parts and Descriptions**
- 6.3. Main features**
- 6.4. Electrical circuit**
- 6.5. Operation and setting**
- 6.6. Check and maintenance**
- 6.7. Safety**

6.1. System basics:

This system is designed to recycle waste wood to produce wood panels with dimensions of 1.6 * 122 * 244 cm suitable for industrial use and wood production.

6.2. Parts and Descriptions:

Table 6.1: Parts and Description

| # | Part | Description |
|-----|------------------------|--|
| 1 | Mixer | Mixer and waste of wood and adhesive |
| 1.1 | Waste wood tank | 25 * 50 * 50 |
| 1.2 | Adhesive tank | Cylindrical design with D40 |
| 1.3 | Mixer tank | Stainless steel cylindrical design with D60 |
| 1.4 | Mixture ribbon | Vertical styled helical blade mixer |
| 2 | Table | Moving mold horizontally between mixer and hydraulic press |
| 2.1 | Mold | Contains a fixed part and moving part to bring out the wood panels |
| 2.2 | Rollers | Facilitate mold movement |
| 2.3 | Hydraulic press | Hydraulic jacks press and remove wood panels in mold |
| 3 | Oven | Dries 100 panels in each production cycle |
| 4 | PLC | Twido base controller 24V DC |
| 5 | Temperature controller | 220V AC |

6.3. Main features:

- 1) medium size ,heavy weight
- 2) fully automatic system
- 3) mass production line and short cycle time
- 4) easy installation
- 5) easy maintenance

6.4. Electrical circuit:

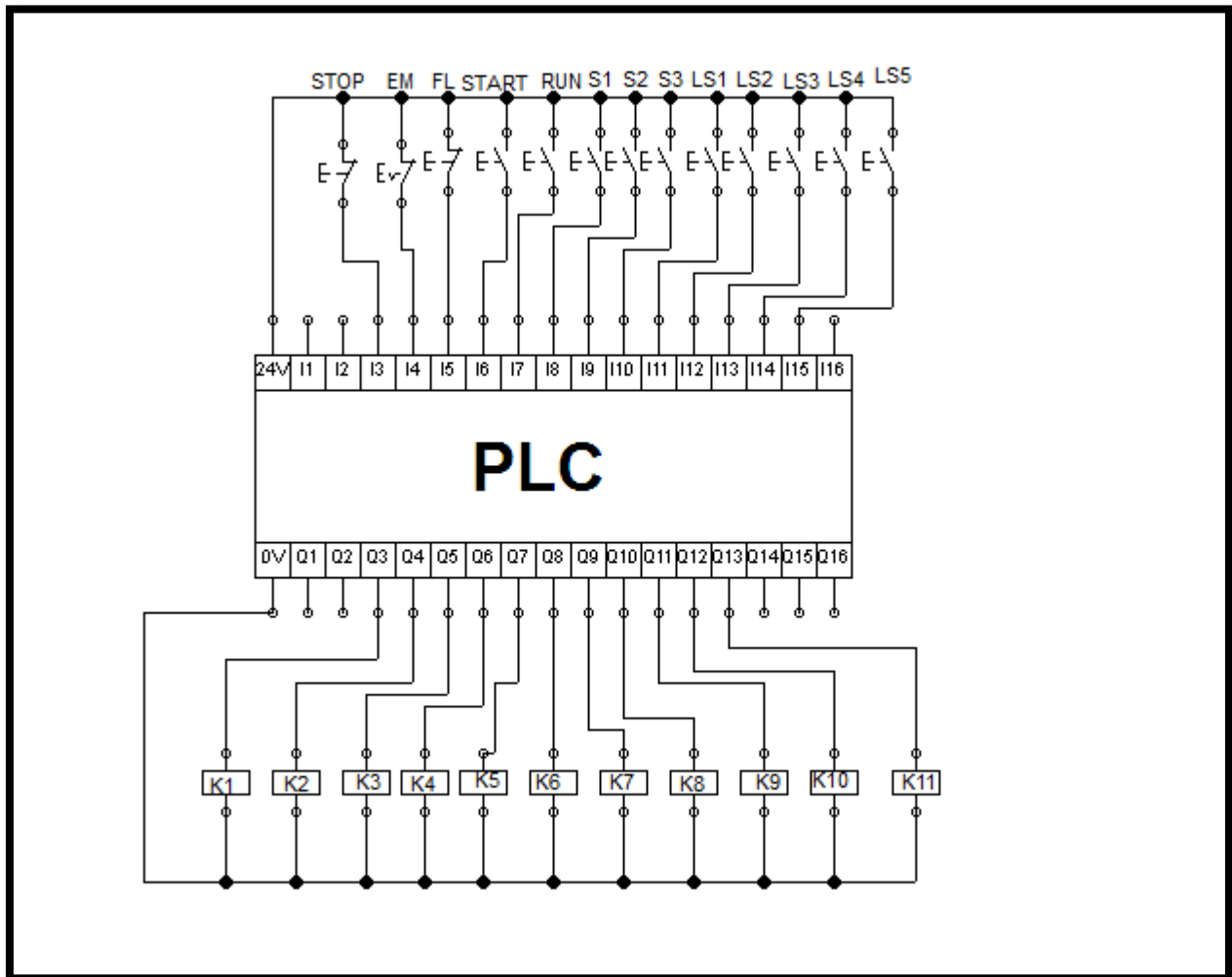


Figure 6. 1: Control circuit

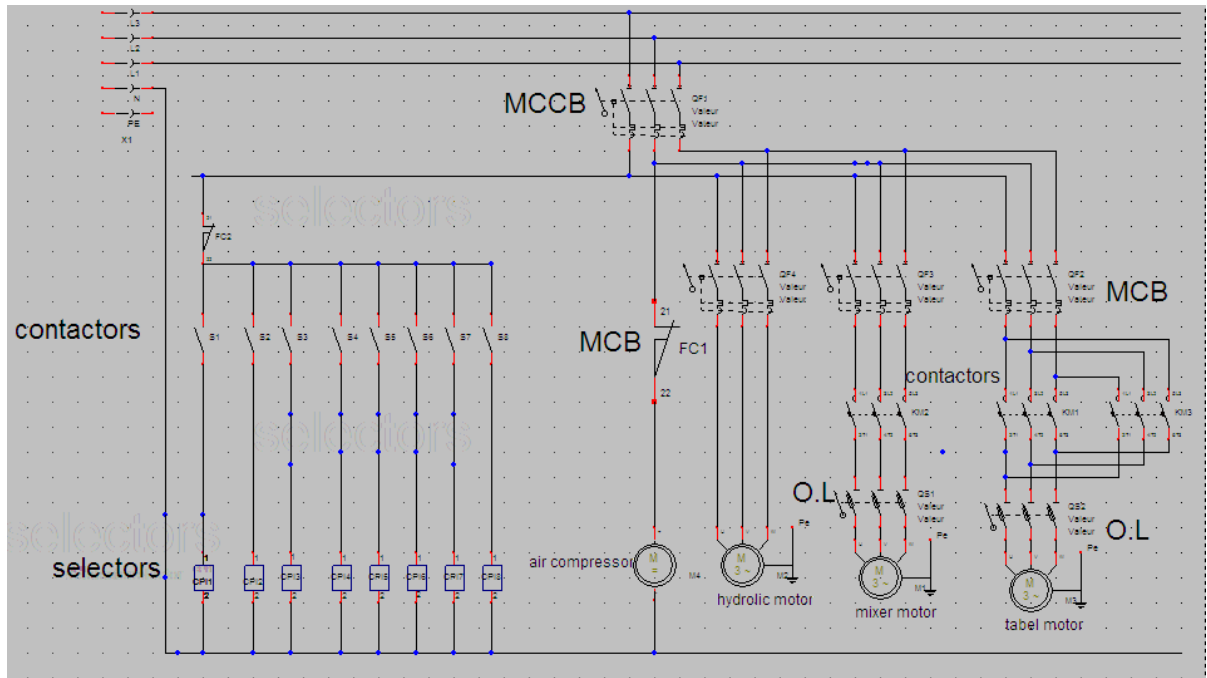


Figure 6.2: Power Circuit

6.5. Operation and setting:

Note: Electrical cables are connected to the clutch

- 1) Lifting the main and secondary electrical bases
- 2) make sure that the electric current reaches the production line and the compressor air and hydraulic motor
- 3) make sure that the controller (PLC) is working through the exist of power light
- 4) make sure that the materials are in place (waste wood in the tank of waste wood and adhesive in the tank of adhesive)
- 5) Press "start" button to start the process of the system, then the system will run automatically from A to Z.
- 6) To stop the process at any time press "stop" button.
- 7) If any danger or not normal states happened, press "emergency" button immediately to move the system to the most safety conditions.
- 8) If the process stopped for any reason press "Run" button to complete the operation from the stop point.

Note: When the system is running on, there are some signs explains the operation movements like green led lights when the system is running on, the yellow led lights when the system stop and the red led lights when the operation of press is running.

6.6. Check and maintenance :

Note: If any electrical component stops working, check the electrical cutter of that component.

- If any engine stops working, check the overload circuit breaker. If the cutter is disconnected, disconnect the power supply from the engine and look for the load and fix it then reconnect the power and start working
- In the case of giving the appropriate pressure for the jack, check the selector and if there is no problem in it make sure of work the hydraulic pressure engine or air compressor
- When making sure all electrical parts are working and there is no electrical fault, but the system does not work when you give the START command, make sure the controller (PLC) electrical connections (Power / Input / Output) If there is no defect, the problem is in the programming of the plc, so reprogram the plc the code is in figure(A.2).

6.7. Safety:

- 1) Do not use flammable gasses such as anesthetic gas ,oxygen or hydrogen ,or flammable liquid such as ethanol ,near the system because there is danger of explosion .
- 2) Make sure that the electrical source is proportional to the electrical characteristics of the production line
- 3) When maintaining or changing the used parts make sure that their characteristics appropriate to the original parts of the system and take down the cutter.
- 4) Replace damaged electrical cables with electrical cables with the same characteristics for fear of electric shock
- 5) Keep the production line away from any water source, especially the control panel because the system does not have a protection system against water, there is a risk of electric shock when exposed to water
- 6) If any problem is observed during the operation or scan, stop the process immediately and turn off the system
- 7) Before cleaning the system, turn it off and remove the power cable from the plug to avoid electric shock
- 8) To avoid damage to the system or electrical failure, do not remove the cable from the plug until the system is turned off

Appendix

Table A. 1: PLC Characteristic:

| Output | symbol | address | Logic allocation |
|----------------------|--------|---------|--|
| Gate A1 | GA1 | Q0.2 | Q0.2=1,open first gate of raw tank |
| Gate A2 | GA2 | Q0.3 | Q0.3=1,open second gate of raw tank |
| Gate B1 | GB1 | Q0.4 | Q0.4=1,open first gate of additional tank |
| Gate B2 | GB2 | Q0.5 | Q0.5=1,open second gate of additional tank |
| Gate C | GC | Q0.6 | Q0.6=1,open mixer gate |
| Mixer motor | M1 | Q0.7 | Q0.7=1,mixer motor on |
| Mold motor | M2 | Q0.8 | Q0.8=1,mold motor on at left direction |
| Mold motor direction | M2D | Q0.9 | Q0.9=1,mold motor on at right direction |
| Cylinder 1 | C1 | Q0.10 | Q0.10=1,press piston out |
| Cylinder 2 | C2 | Q0.11 | Q0.11=1,raise piston out |
| Cylinder 3 | C3 | Q0.12 | Q0.12=1, push piston out |

Table A. 2: PLC characteristic

| Input | Symbol | Address | Logic Allocation |
|--------------------------|--------|---------|---|
| Stop (NC) | Stop | I0.3 | I0.3=0,operation stop |
| Emergency switch (NC) | Emg | I0.4 | I0.4=0,turn off all processes |
| Over load (NC) | FL | I0.5 | I0.5=0,stop motors |
| Stars (NO) | Start | I0.6 | I0.6=1,operation start |
| Run (NO) | Run | I0.7 | I0.7=1, complete the stopped operation |
| Ultrasonic sensor 1 (NO) | S1 | I0.8 | I0.8=1,tank of additional material is full |
| Ultrasonic sensor 2 (NO) | S2 | I0.9 | I0.9=1,mixer tank is full I0.9=0,mixer tank is empty |
| Load sensor (NO) | S3 | I0.10 | I0.10=1,tank of raw material is full |
| Limit switch 1 (NO) | LS1 | I0.11 | I0.11=1, mold under mixer |
| Limit switch 2 (NO) | LS2 | I0.12 | I0.12=1,mold under press piston |
| Limit switch 3 (NO) | LS3 | I0.13 | I0.13=1,press piston is fully expansion |
| Limit switch 4 (NO) | LS4 | I0.14 | I0.14=1, raise piston is fully expansion |
| Limit switch 5 (NO) | LS5 | I0.15 | I0.15=1, push piston is fully expansion |

State graph:

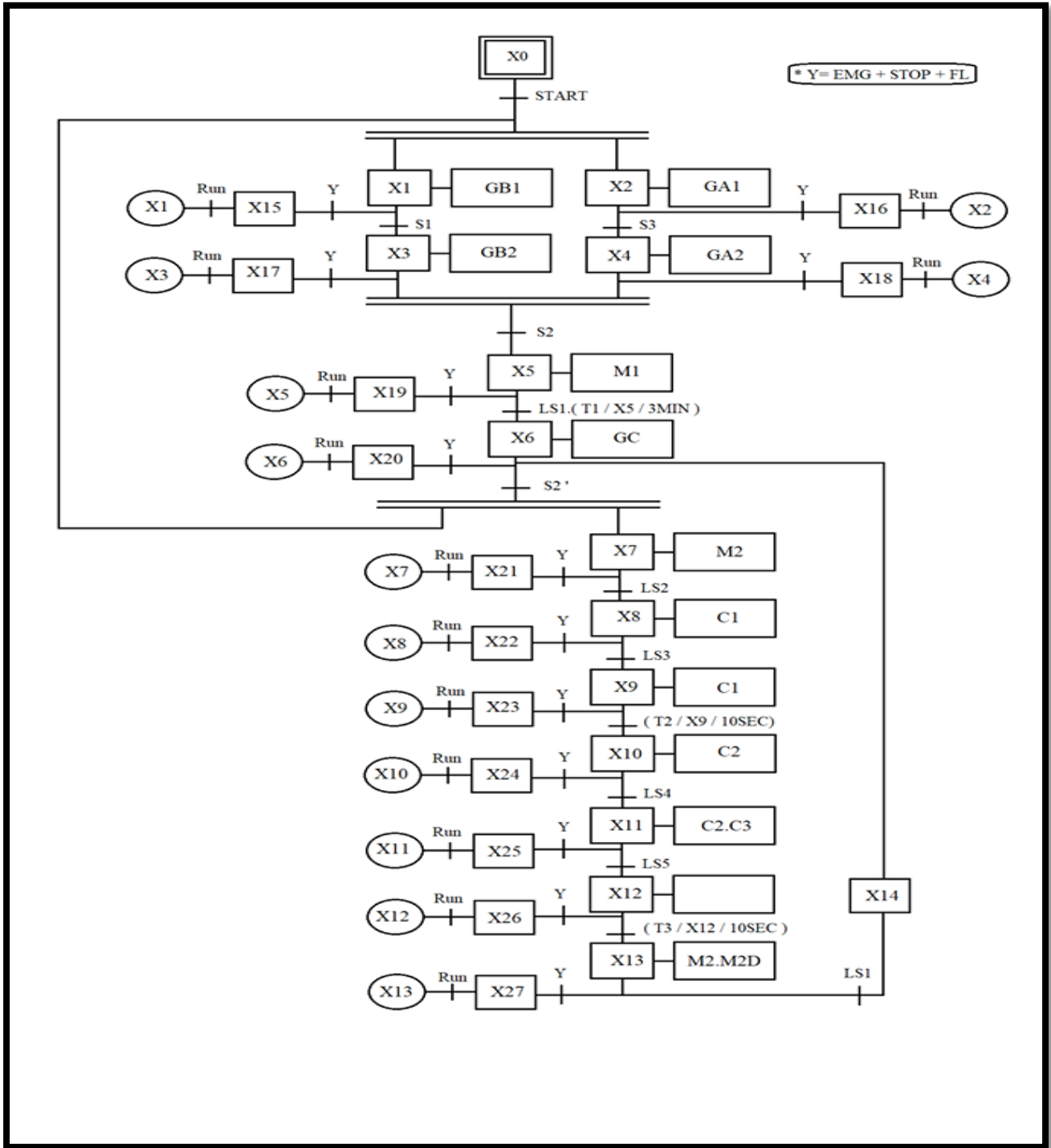
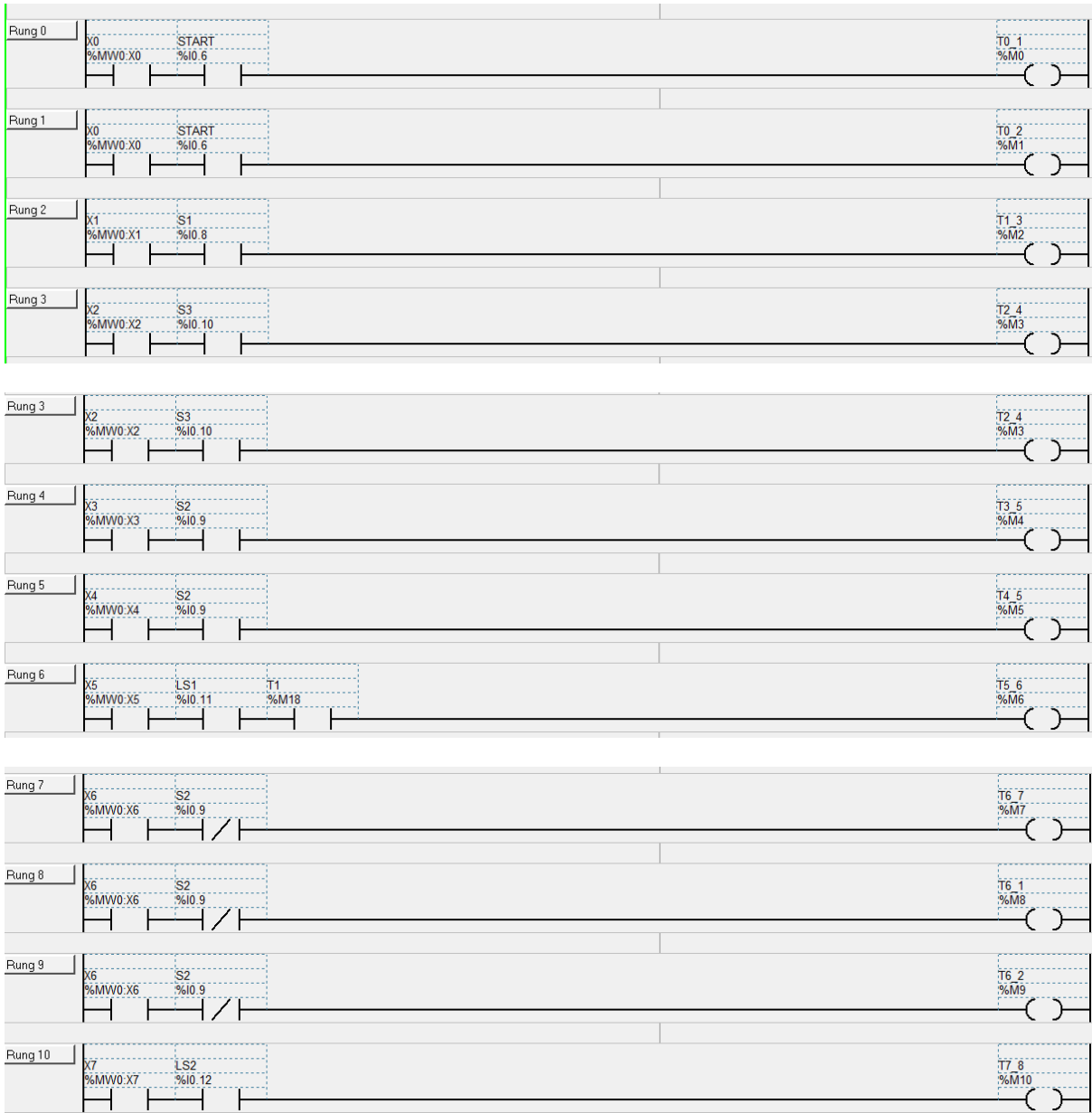
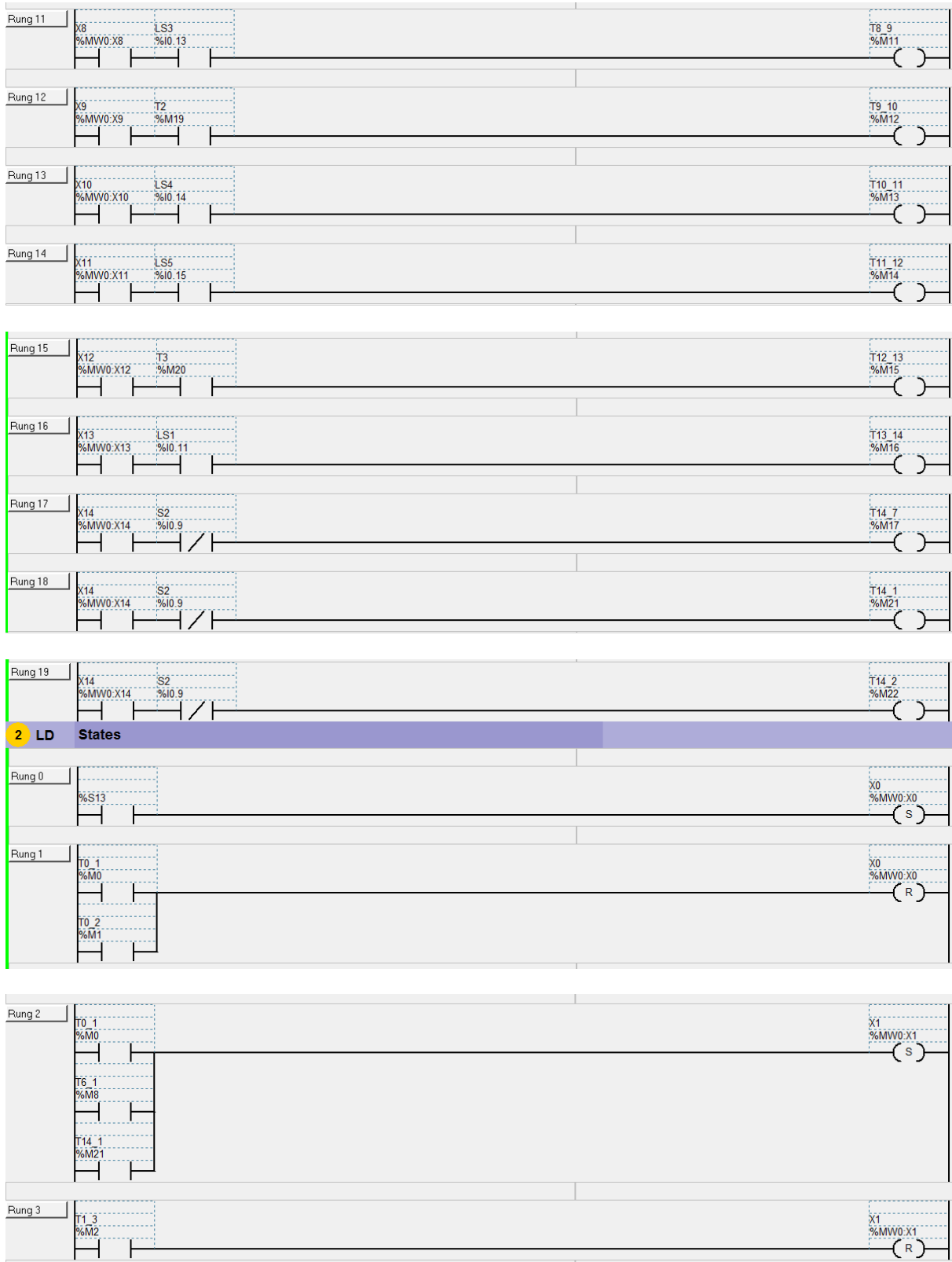
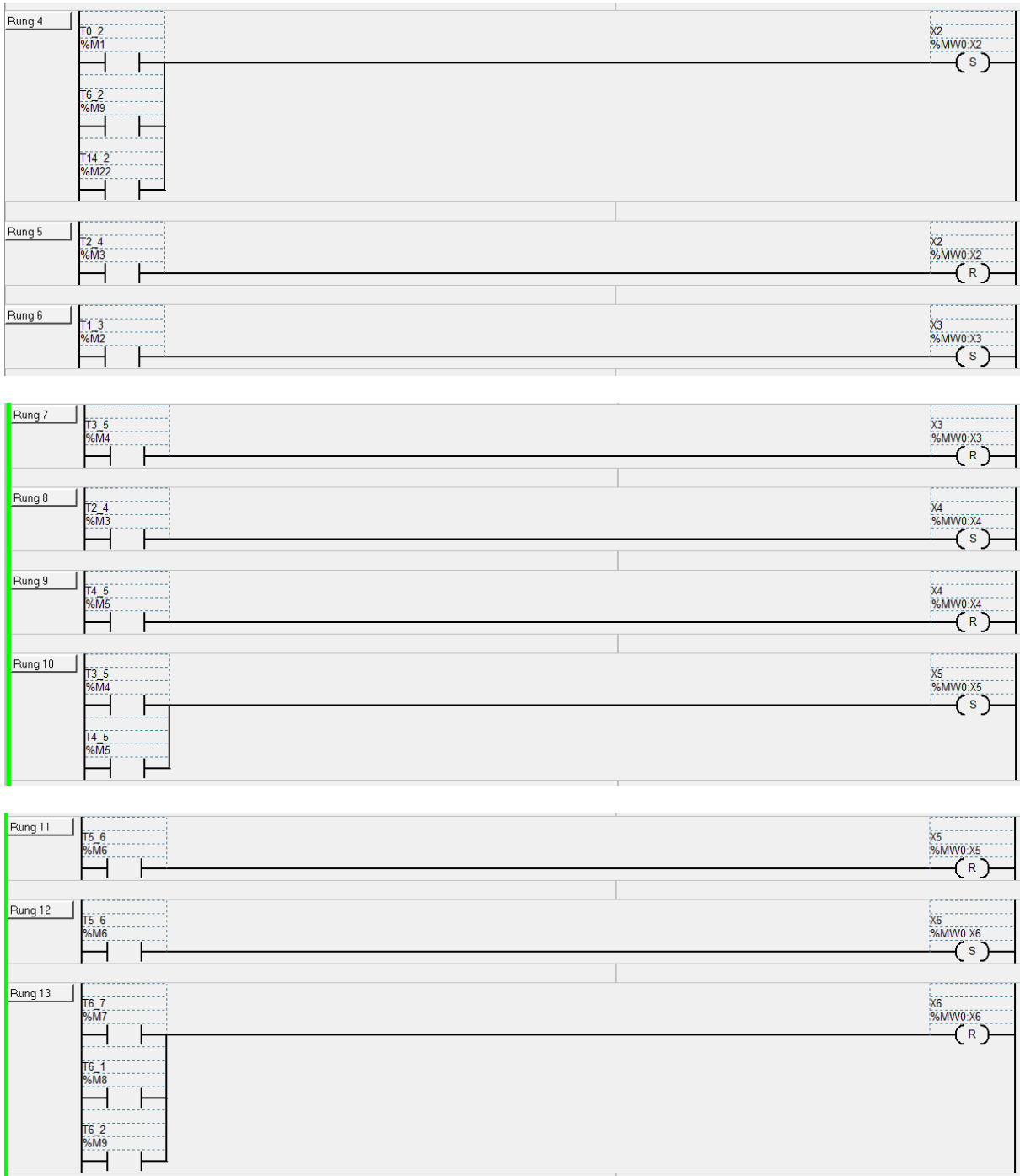


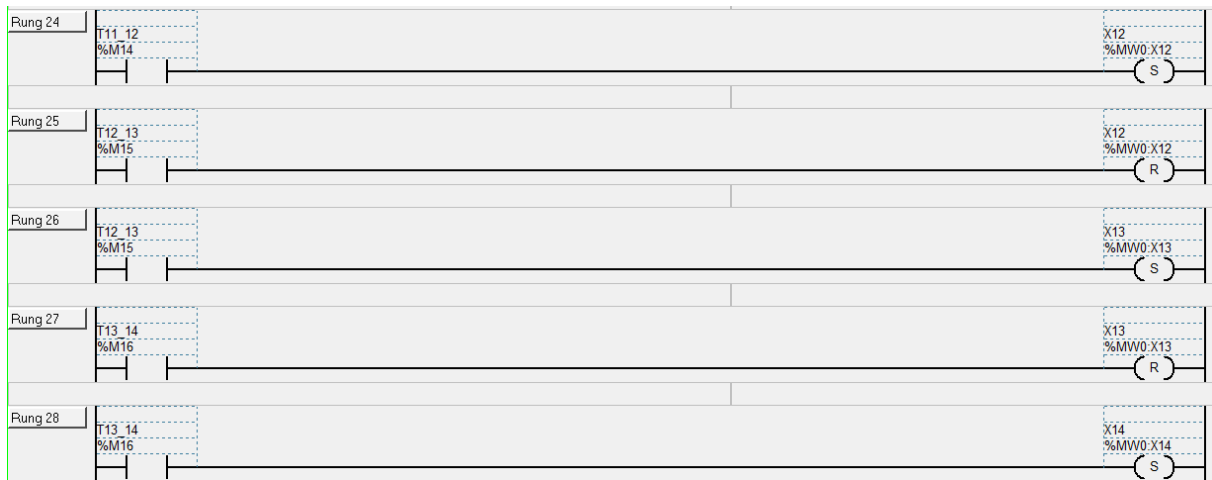
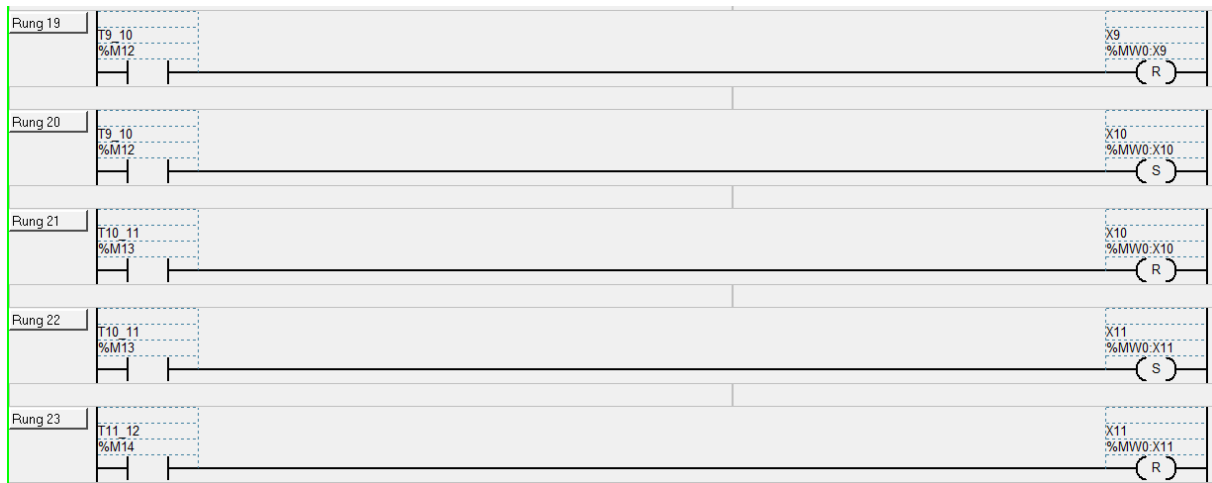
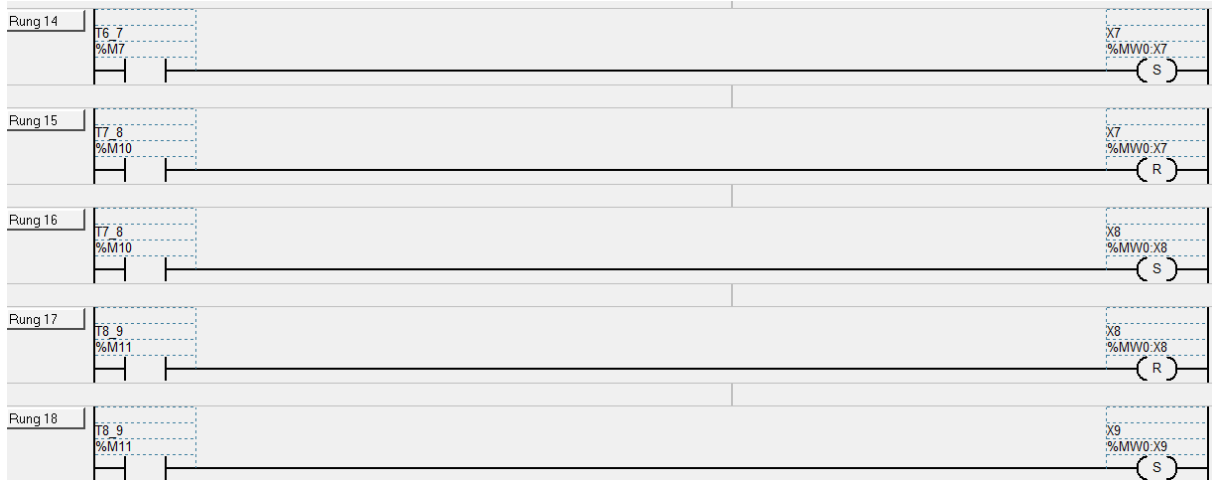
figure A. 1: State Graph

PLC Code:









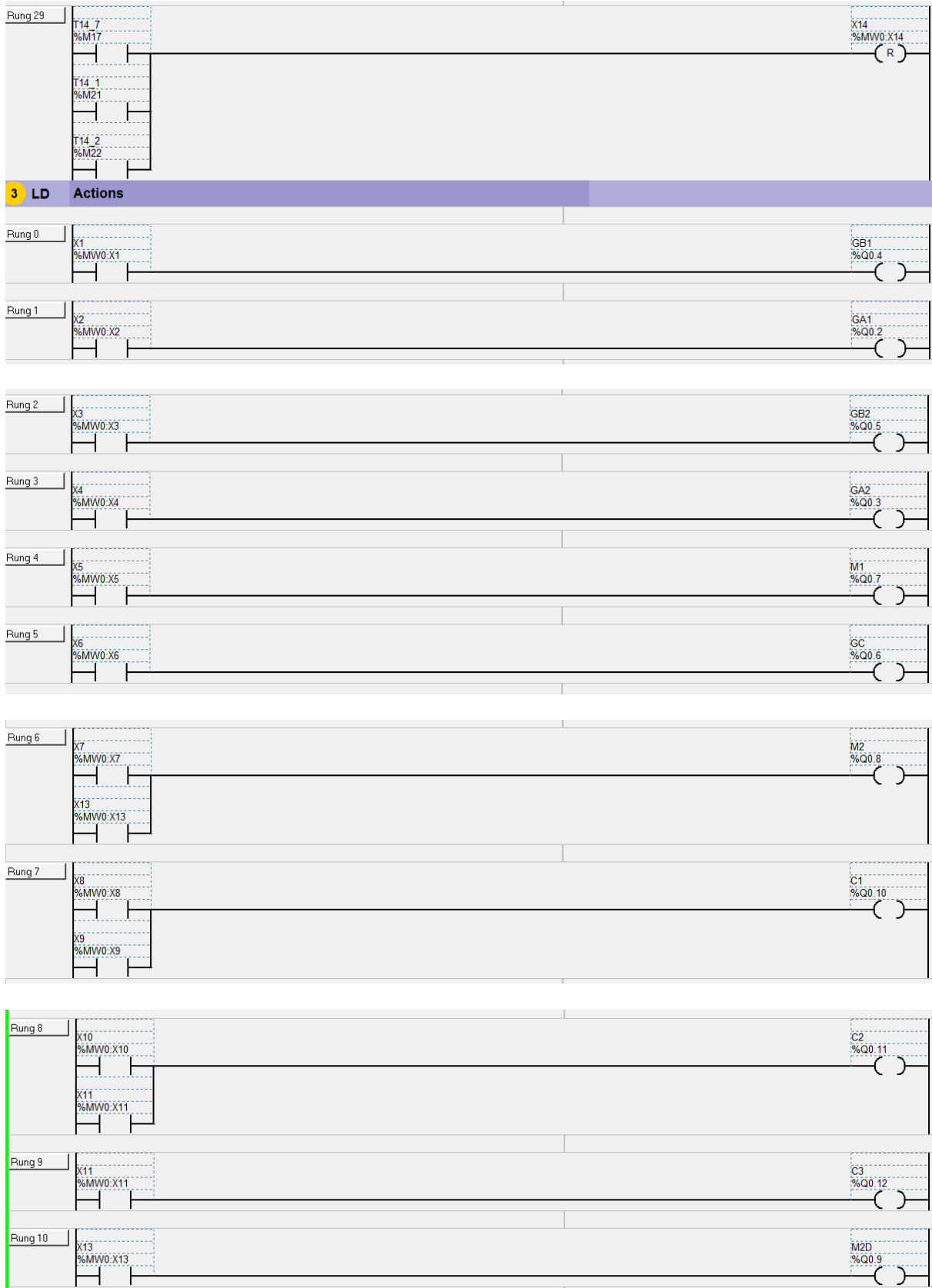




figure A. 2: PLC Code

Uncategorized References

1. Ganev, S., et al., *Mechanical properties of MDF as a function of density and moisture content*. Wood and fiber science, 2007. **37**(2): p. 314-326.
2. Mantanis, G.I., et al., *Adhesive systems used in the European particleboard, MDF and OSB industries*. Wood Material Science & Engineering, 2018. **13**(2): p. 104-116.
3. Maloney, T., *The family of wood composite materials*. Forest Products Journal, 1996. **46**(2): p. 19-26.
4. Klemarewski, A.M., *System and method for making compressed wood product*. 2001, Google Patents.
5. Vigants, E., et al. *Analysis of energy consumption for biomass drying process*. in *Proceedings of the 10th International Scientific and Practical Conference. Volume II*. 2015.
6. Reeb, J.E., *Drying wood*. 1992: Cooperative Extension Service, University of Kentucky, College of Agriculture.
7. Simpson, W.T. and J. Tschernitz, *Importance of thickness variation in kiln drying red oak lumber*. 1979.
8. Marouslis, Z., S. Mujumdar, and G. Saravacos, *Spreadsheetsaided dryer design*. *Handbook of Industrial Drying*. 2006, London: Taylor and Francis Group.
9. Telmo, C. and J. Lousada, *Heating values of wood pellets from different species*. Biomass and bioenergy, 2011. **35**(7): p. 2634-2639.
10. Piekarski, C.M., A.C. de Francisco, and L.M. da Luz, *Energy consumption in MDF production: Overview of use renewable and non-fossil energy sources in a Brazilian mill*. 2012, ICIEOM.

