**MARMARA UNIVERSITY**

**FACULTY OF ENGINEERING**

# Design and Development of a Prototype Forming Machine Producing Packaging from Recyclable Fibers

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**GRADUATION PROJECT REPORT**

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**by**

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YUSUF ALİ PANAVUR

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# ABSTRACT

The increasing environmental damage of plastic-based packaging materials and the increasing demand for sustainable packaging solutions have increased the interest in alternative materials. In this context, molded fiber technologies with recyclable and biodegradable properties are at the forefront in sustainable packaging solutions. This project aims to design a prototype of a small-scale forming machine for industrial packaging production from molded fibers.

As a result, this project aims to develop a packaging production technology that is applicable on an industrial scale, sustainable and economically advantageous. It is anticipated that the results will guide industrial companies in the transition to environmentally friendly packaging solutions.

# ABBREVIATIONS

**IMFA**: International Molded Fiber Association

**MPP**: Molded Pulp Packaging

# 1. INTRODUCTION

Recyclable fiber packaging production is an innovative and sustainable approach to manufacturing eco-friendly packaging solutions. It involves the use of renewable, natural, or recycled fibers, such as paper pulp, bagasse, bamboo, or other plant-based materials, to create packaging that is biodegradable, recyclable, and compostable. As the world faces increasing environmental challenges, such as plastic pollution and waste accumulation, recyclable fiber packaging offers an effective alternative that supports sustainability efforts across industries.

The production process begins with sourcing raw fibers, which are then pulped and converted into slurry. This slurry is molded into various shapes and sizes to form packaging products using advanced forming techniques. The versatility of recyclable fiber packaging enables its application in a wide range of industries, from food packaging (such as egg cartons, trays, and cups) to electronics, medical devices, and industrial packaging solutions.

This method of production is not only environmentally friendly but also offers significant benefits in terms of cost-effectiveness, reduced carbon footprint, and support for the circular economy. As the demand for sustainable packaging solutions continues to grow, recyclable fiber packaging production plays a crucial role in reducing dependence on single-use plastics and promoting a more sustainable packaging ecosystem. The development of automated systems for molding, drying, and finishing further enhances the efficiency and quality of recyclable fiber packaging, making it a viable and preferred solution for businesses aiming to meet environmental goals.

## 1.1 The History of Molded Pulp Packaging

Molded pulp packaging, also known as molded fiber packaging, has a history rooted in sustainable innovation and technological development. Its journey began in the early 20th century, with the first U.S. patent for a molded pulp process granted to Martin L. Keyes in 1903 [1]. This initial process involved pressing pulp slurry onto a mold and compressing it to remove excess water, creating durable shapes. Early applications were primarily for protective packaging, including egg cartons and industrial cushioning, due to the material's cost-effectiveness and shock-absorbing properties.

During the mid-20th century, molded pulp packaging gained wider recognition, particularly in the 1950s, when it became the preferred material for egg cartons [2]. This period saw technological advancements, including refinements in the manufacturing process by Italian engineer Enzo Michelin, who patented a method to enhance the strength and versatility of molded pulp products. These innovations paved the way for broader applications in industries beyond agriculture.

The late 20th century marked a turning point as environmental awareness grew. Molded pulp packaging was increasingly recognized as an eco-friendly alternative to plastics, aligning with the global push for sustainability. Industries such as electronics and medical devices adopted molded pulp for custom protective packaging, leveraging its lightweight, biodegradable, and recyclable qualities.

In the 21st century, molded pulp packaging has experienced significant growth, driven by the demand for sustainable and renewable solutions. Innovations in material sourcing, such as the use of bagasse, bamboo, and recycled paper, have expanded its applications. Advanced molding techniques, including thermoformed molded fiber, have improved the precision, strength, and aesthetic appeal of the products. Today, molded pulp is used in a wide range of industries, from consumer electronics and food service to shipping and logistics. Its biodegradability, recyclability, and adaptability have cemented its role as a key component in modern sustainable packaging.

Key references documenting this evolution include Martin L. Keyes' 1903 patent, reports from the International Molded Fiber Association, advancements by Enzo Michelin in the 1950s, and contemporary analyses of sustainable packaging trends. These sources highlight the historical and ongoing importance of molded pulp packaging as a versatile and environmentally friendly solution for global industries.

## 1.2 Sustainability

Molded pulp packaging is widely considered one of the most sustainable packaging solutions available today, offering numerous environmental benefits throughout its life cycle. Made primarily from recycled paper fibers, newspapers, and other plant-based materials such as bagasse or bamboo, molded pulp helps reduce the reliance on non-renewable raw materials, contributing to forest conservation and minimizing the carbon footprint associated with production. By using recycled paper, it also supports the circular economy by extending the life cycle of paper products, reducing the demand for virgin materials.

One of the key sustainability features of molded pulp is its biodegradability. Unlike plastic or styrofoam, which can persist in the environment for centuries, molded pulp breaks down naturally over time, making it an excellent choice for reducing long-term waste. Additionally, it can be composted, further reducing its environmental impact. Molded pulp is also highly recyclable, allowing it to be reused in the production of new pulp packaging, which reduces waste and the need for new raw materials, conserving resources and energy in the process.

The production of molded pulp packaging generally requires less energy compared to plastic or foam packaging, with the use of recycled paper further reducing the carbon footprint. This efficient manufacturing process, along with the lightweight nature of molded pulp, also lowers transportation-related emissions, contributing to its overall sustainability. Despite being environmentally friendly, molded pulp packaging offers excellent protection for products, cushioning fragile items and reducing the need for replacements, which helps minimize waste across the supply chain.

Supporting the principles of a circular economy, molded pulp packaging is both recyclable and biodegradable, helping to keep materials in use longer while reducing waste. As demand for eco-friendly packaging continues to rise, molded pulp serves as a viable alternative to single-use plastics, providing a sustainable solution that addresses both environmental and economic concerns.

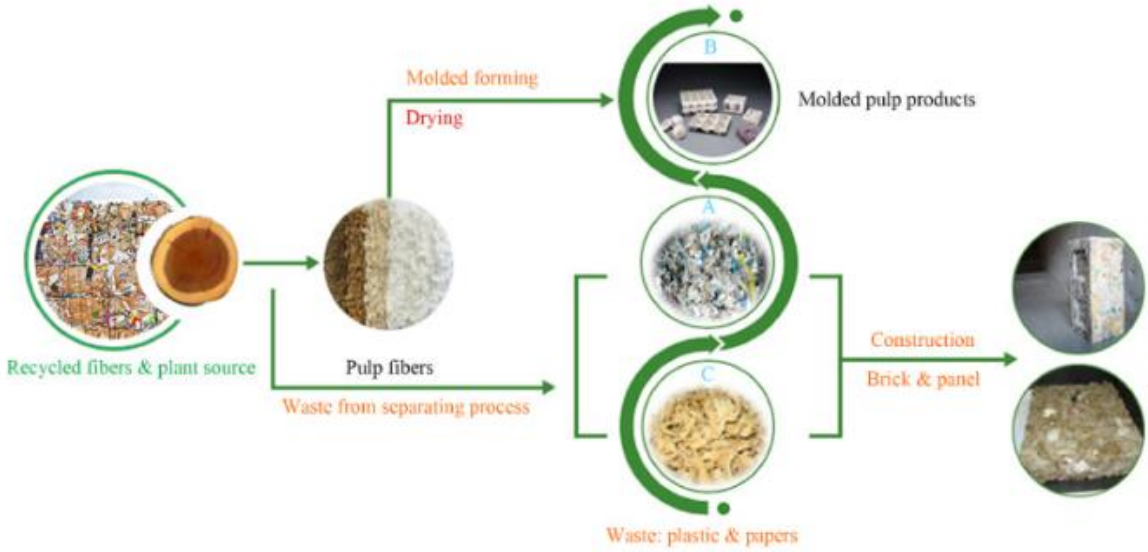


Figure 1 Integrated molded fiber product manufacturing process using recycled fibers as fiber sources

## 1.3 Pulp Molding Raw Materials

### 1.3.1 Bagasse Pulp

Bagasse pulp is a good raw material for pulp molding products. Production of pulp molding dining box tableware products using bagasse fiber.

### 1.3.2 Bamboo Pulp

Bamboo pulp is a very good raw material for pulp molding (plant fiber molding) products. Bamboo fiber belongs to the medium and long fiber group, and its properties are between coniferous trees (needle bush) and broad-leaved trees.

### 1.3.3 Wheat Straw Pulp

Wheat straw pulp, divided into mechanism fiber wheat pulp, chemical mechanical wheat pulp and chemical wheat pulp.

### 1.3.4 Reed Pulp

Reed pulp, mainly chemical reed pulp and chemical mechanical reed pulp.

### 1.3.5 Palm Pulp

Palm pulp is also a good raw material for molded pulp products. Palm pulp is mostly the true color (original color) pulp.

## 1.4 Advantage of Molded Pulp Packaging

- Manufactured from recycled materials, such as paperboard and newsprint, molded pulp is both biodegradable and recyclable, making it an eco-friendly alternative to traditional plastic packaging.
- It has a lower carbon footprint compared to plastic packaging.
- The use of inexpensive raw materials and efficient production processes contributes to the affordability of molded pulp packaging. Its lightweight nature also helps reduce shipping costs.
- Molded pulp provides excellent bracing, blocking, and cushioning protection for various products. It remains effective under extreme temperatures and can be made water-resistant with additives.
- Since multiple production can be done in a single mold, it offers a cost advantage in high volume production.
- The material can be molded into complex 3D shapes with rounded corners, allowing for tailored packaging solutions that meet specific product requirements.

## 1.5 Classification of Molded Pulp Packaging

Molded pulp describes a three-dimensional package that has been classified in different ways in the past years. The criteria used were based on the product density, on the production process and on the fabrication method [1].

According to the International Molded Fiber Association (IMFA) [2], molded pulp products can be categorized in various groups based on the manufacturing process and quality of materials.

**1.5.1 Thick Wall :** Manufactured using an open mold and then oven dried. Typical wall thickness ranges from 5 mm to 10 mm. The surface in contact with the mold is relatively smooth, while the other side is very rough. The raw material is typically Kraft paper mixed with recycled paper. They are usually used as support packaging for non-fragile, heavy items (e.g. furniture and vehicle parts).

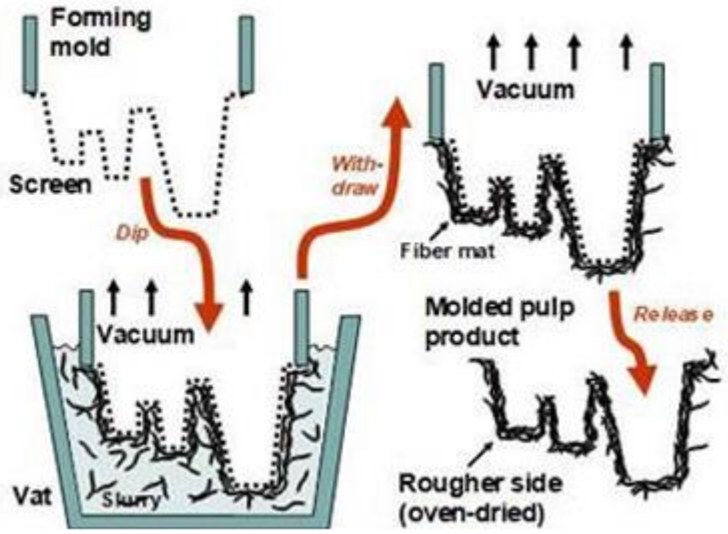


Figure 2 Schematic illustration of thick-wall process for molded pulp production

**1.5.2 Transfer Molded :** Products in this category have thinner walls, 3 mm to 5 mm. They are manufactured using both a forming mold and a transfer or take-off mold. The result is a product with relatively smooth surfaces on both sides and better dimensional accuracy. The formed product is dried in a heated oven. The raw material commonly used is recycled newspaper. Typical examples are egg trays and packaging for electronic equipment.

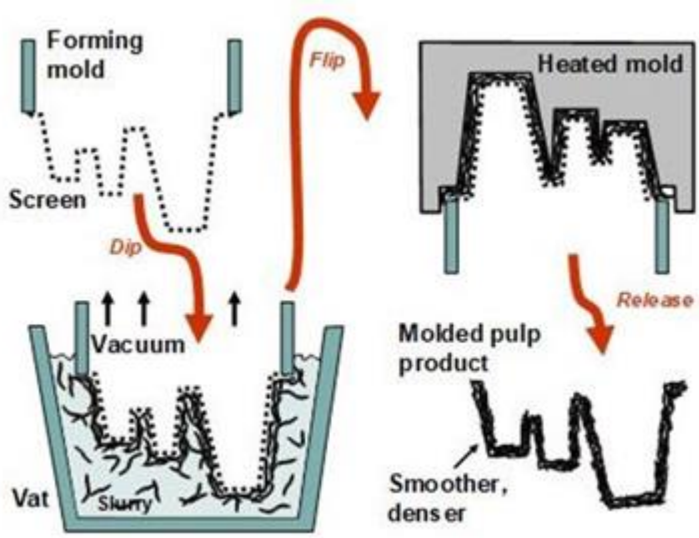

Figure 3 Schematic illustration of transfer molded process

**1.5.3 Thermoformed (Thin-wall) :** This is the most recent approach. The initial formed product is captured in heated molds where it is pressed, densified and dried. No oven curing is needed. This process produces high quality thin-walled items (from 2 mm to 4 mm), with good dimensional accuracy, and smooth, rigid surfaces. The result resembles the appearance of thermoformed plastic items

**1.5.4 Processed :** This refers to MPP that require some further or special treatment, for instance additional printing, coatings or additives [2].

## 1.6 Applications of Molded Pulp Packaging

Molded pulp packaging is a versatile and eco-friendly solution widely used across various industries. In the food sector, it is commonly used for egg cartons, food trays, and disposable tableware such as plates, bowls, cups, and containers, all of which are valued for their sustainability and compostability [3]. In consumer electronics, molded pulp serves as protective inserts for delicate items like laptops, smartphones, and tablets, providing shock absorption and secure holding, while also being used for organizing smaller components like cables and chargers. The medical and healthcare industries benefit from molded pulp in the form of sterile trays for medical instruments and single-use products like bedpans and kidney trays, which are hygienic and disposable.

For industrial packaging, molded pulp offers excellent cushioning for heavy or fragile goods during shipping and is also used for corner protectors and edge guards for items like glass, ceramics, or furniture. In retail, it enhances the presentation of consumer goods by being used in gift boxes, cosmetic packaging, and display trays, adding a premium and sustainable touch. Agricultural applications include biodegradable seed trays suitable for planting directly into the ground and packaging for fruits, vegetables, and flowers to ensure their protection during transport and storage.

The beverage industry utilizes molded pulp for bottle carriers, ensuring secure transport for wine, beer, and juice bottles, as well as cup carriers frequently seen in coffee shops and fast-food outlets. E-commerce and shipping sectors rely on molded pulp for protective packaging to securely cushion fragile items, with custom inserts designed to hold products in place during transit. In the automotive industry, molded pulp is used to package and protect car parts, such as lights and engines, ensuring they remain undamaged during shipment.

As a sustainable alternative, molded pulp is increasingly replacing single-use plastics across various applications, meeting the growing demand for environmentally friendly packaging solutions. Its adaptability, cost-effectiveness, and environmental benefits make molded pulp packaging an essential component in numerous industries, aligning functionality with sustainability goals.

# 2. WORKING PRINCIPLE OF THE FORMING MACHINE

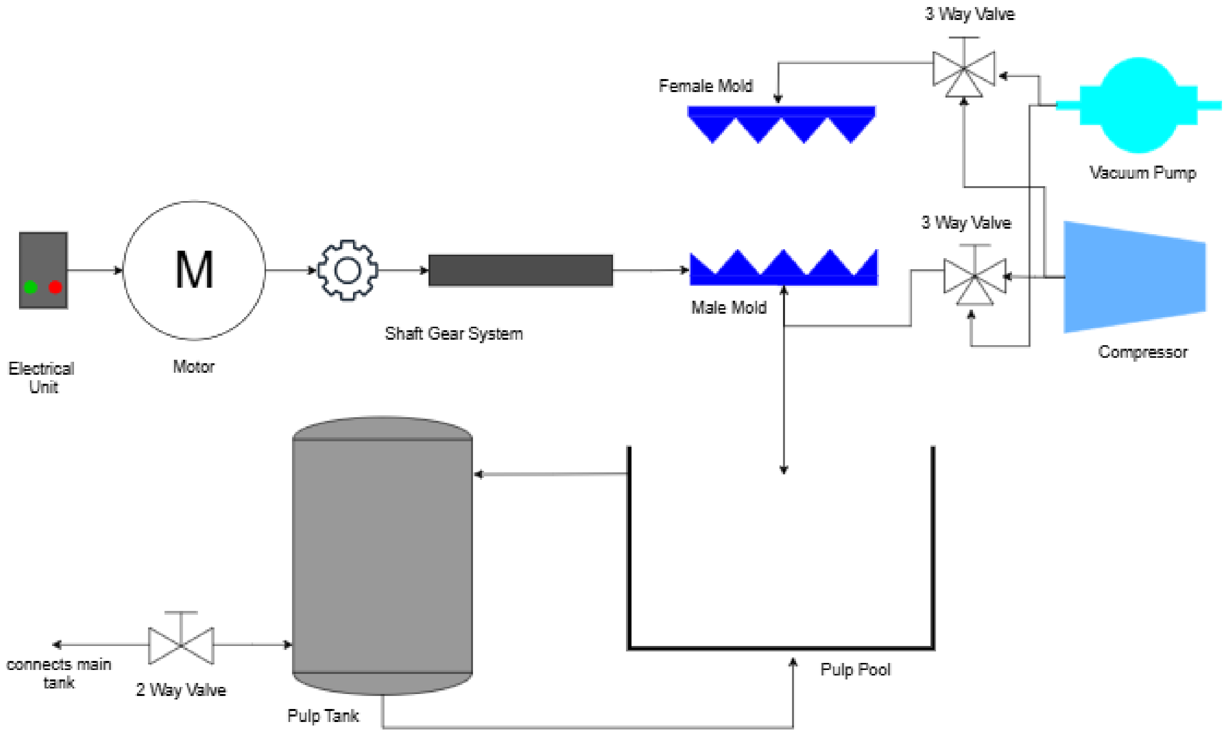


Figure 4 Piping and Instrumentation Diagram (P&ID) of Forming Machine

This P&ID diagram shows the main components of the designed forming machine and their interconnections. The system is designed to form the raw material into the desired shape by passing it through a molding process. The main components are detailed below:

## 2.1 Components of the System

- **Electrical Unit:** It controls the opening and closing of the motor using the on/off button on it.
- **Motor:** The motor converts electrical energy into mechanical motion and transmits power to the shaft and gear mechanism.

- **Shaft Gear System:** It produces rotary motion by connecting to the motor output shaft. It enables the molds to work with linear motion in the mechanical system.
- **Male Mold:** The movable mold moves up and down, entering and exiting the pool. It takes the pulp from the pool using vacuum and transfers it to the female mold by applying pressure.
- **Female Mold:** The fixed mold takes the pulp from the male mold using vacuum and shapes it, then deposits the shaped material into trays using pressure.
- **3 Way Valves:** 3-way valves direct the air and vacuum flow, connected to the upper and lower molds. In vacuum mode, the pulp is drawn into the mold, in compressed air mode, the product is separated from the mold.
- **Vacuum Pump:** It ensures that the pulp material sticks to the mold. It supports the removal of excess water, thus increasing the consistency of the material.
- **Compressor:** It provides positive pressure and performs the separation process from the mold. It helps to remove the product remaining in the mold without damage.
- **Pulp Tank:** It is the tank where the paper pulp liquid is located and transfers the pulp to the pool. There is also a connection at the top of the pool to prevent the liquid from overflowing from the pool.
- **Pulp Pool:** It is a pulp pool that contains the pulp liquid coming from the tank. The male mold goes in and out of this pool.
- **2 Way Valve:** It allows controlling the transfer of paper pulp liquid from the main tank in the factory to the pulp tank.

## 2.2 Working Principle

The pulp liquid in the tank is filled into the pool. When the motor is manually operated, the male mold moves and enters the pool via the gear and shaft set. At this time, the vacuum valve is open and the male mold collects the pulp on it.

Then the motor is started again and the male mold starts to move up. As soon as it connects with the female mold, the compressed air valve for the male mold opens and the vacuum valve for the female mold is activated. Thus, the male mold transfers the pulp to the female mold.

Then the male mold is separated from the female mold. Then the compressed air valve of the female mold opens and the shaped pulp is transferred to the tray.

# 3. MACHINE DESIGN

The design of the forming machine is shown below. The components that make up the machine are illustrated.

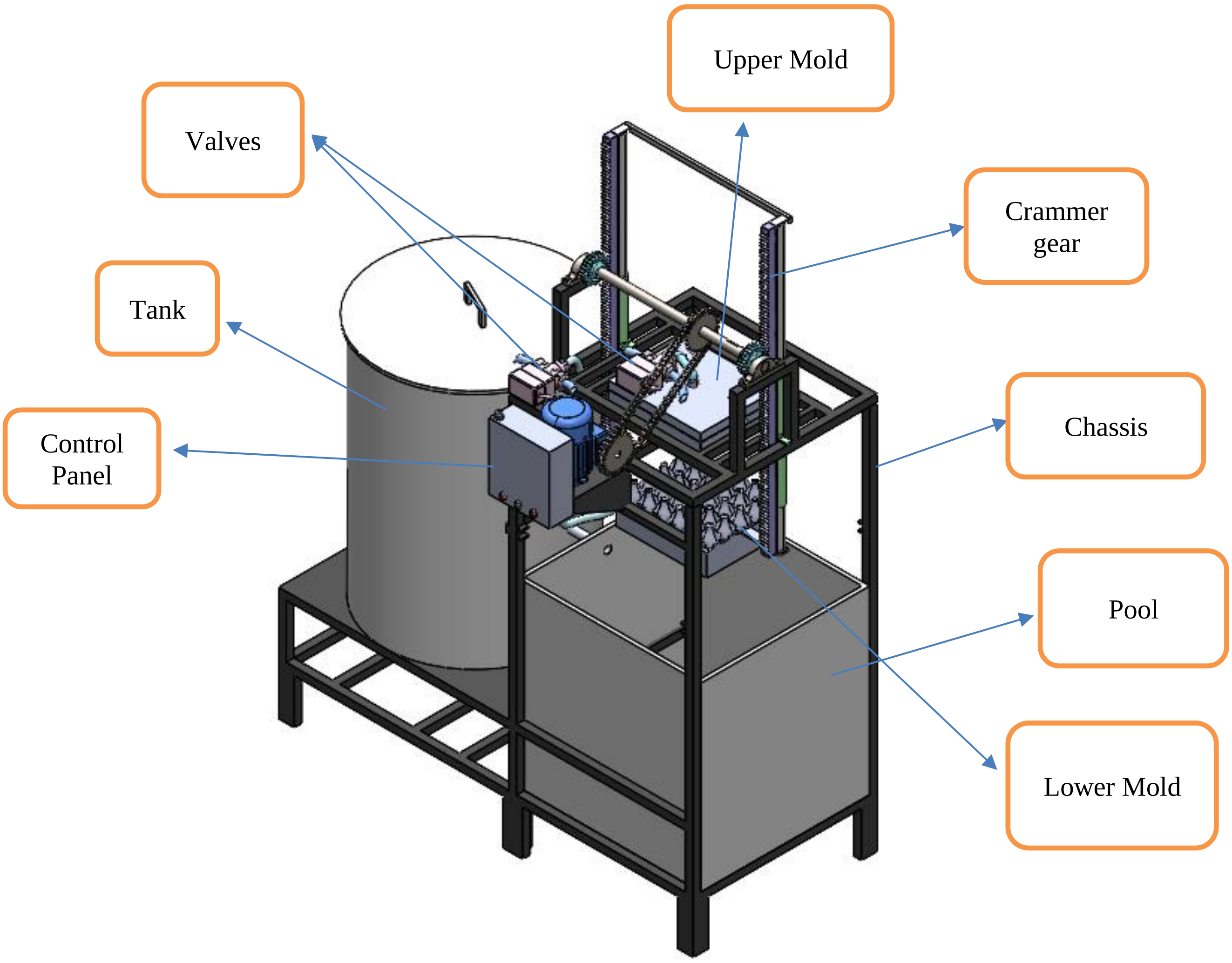


Figure 5 Forming machine design and main components

The upper mold is fixed to the frame, while the lower mold can be moved using the motor and rack-and-pinion system, controlled via the control panel. The connection and operation of the motor and gear systems are detailed below.

A three-way valve is integrated into both the upper and lower molds. These valves are connected to the vacuum and compressor tanks, allowing control from the control panel. This setup enables the selection of which mold will be connected to the vacuum or compressor.

The main pulp tank is connected to the forming tank, allowing pulp slurry to be transferred via a pump. Inside the forming tank, a distribution surface ensures the even spread of the slurry. To prevent overflow, a return pipe is installed to redirect excess slurry back to the main tank.

The machine frame is reinforced with structural supports to withstand the machine's weight. Additionally, linear guides are incorporated on the frame, allowing for the placement of a tray or sheet between the upper and lower molds

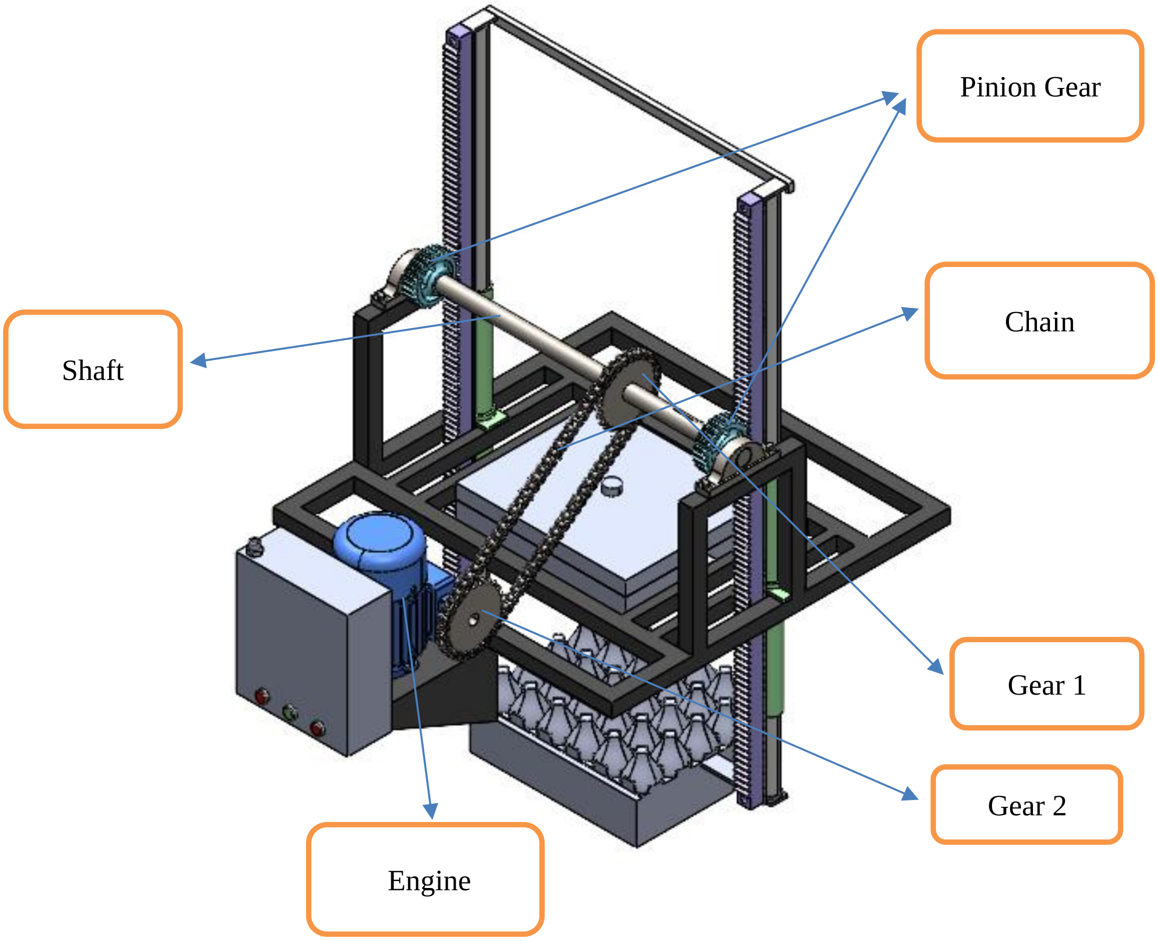


Figure 6 Shaft And Gear System

### 3.1 Shaft And Gear System

**Engine:** It is the main power source, connected to Gear 2, and controlled via the control panel.
**Gear 2:** Transmits torque from the motor to Gear 1 via a chain.
**Gear 1:** Rotates the shaft using the transmitted torque.
**Pinion Gear:** Rotates along with the shaft, moving the rack gear in a vertical direction.
**Crammer Gear:** Moves vertically with the torque received from the pinion gear, enabling the lower mold to be submerged into and lifted out of the tank. The crammer gears are connected to cylindrical rods, which are attached to the lower mold at the bottom. These rods are stabilized by linear guide rails mounted on the frame. The rods move smoothly by sliding within the rails, ensuring balanced and controlled motion

## 3.2 Material Selections

**Crammer**

Material chosen for crammer and pinion is AISI 8620 (Surface Hardened Carbon Steel) stell.

Features:

- Hardness up to 60 HRC can be achieved with surface hardening.
- Resistant to wear and impact.
- Widely used in gear production.

**Shaft**

Material chosen for shaft is AISI 4140 stell.

Features:

- High strength (900-1100 MPa)
- High fatigue strength and impact resistance
- Medium machinability
- Heat treatment: Induction hardening (50-55 HRC)

**Chassis**

Material chosen for chassis is AISI 304 stell.

Features

- Corrosion Resistance: Provides medium-level corrosion resistance. Suitable for general use and resistant to moisture and atmospheric conditions.
- Strength: Offers high strength and toughness. Its low carbon content prevents brittleness and cracking after processing.
- Machinability: High machinability and good performance at welding temperatures.
- Applications: Food processing machinery, indoor applications, equipment exposed to humid environments.

**Tank and Pool**

Material chosen for tank and pool is AISI 316 stell

Features

- Corrosion Resistance: Has much higher corrosion resistance than AISI 304. Extremely resistant to saltwater and acidic environments.

- Strength: High mechanical properties, but slightly less hardness than AISI 304.
- Chemical Resistance: Excellent resistance to acidic environments and chemical processes.
- Applications: Marine applications, chemical tanks, food and pharmaceutical industries.

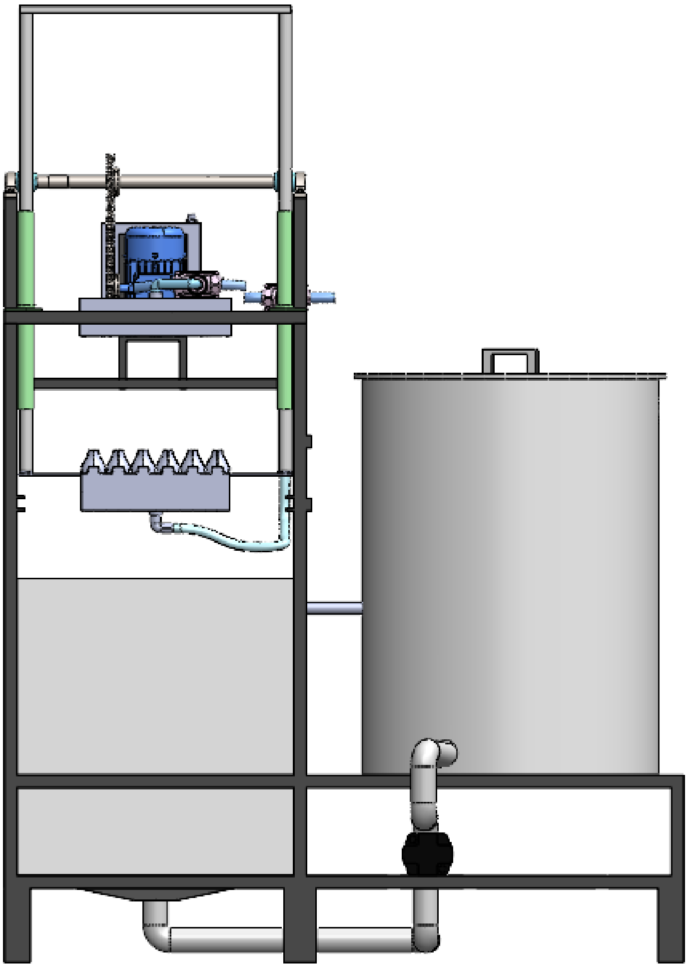

Figure 7 Front surface view of forming machine

# 4. CALCULATIONS AND MOTOR SELECTION

- The motor is directly connected to gear 2
- Gear 2 is connected to gear 1 by a chain.
- Gear 1 is connected to the shaft.
- The shaft is connected to the pinion.
- The pinion drives the crammer gear.

**Cramer load**

Transported mass (m) : 50 kg

Gravity acceleration (g) : 9.82 $m/s^2$

Required lift force :

$$F = m \times g = 50 \times 9.81 = 490.5\ N$$

**Pinion Gear (Gear That Moves the crammer) :**

Number of teeth ($z_p$) : 25

Diameter ($d_p$) : 81 mm = 0.081 m

**Gears no. 1 and 2 (chain – linked gears) :**

Number of teeth ($z_1 = z_2$) : 26

Outer diameter ($d_1 = d_2$) : 60 mm

Inner diameter : 50 mm

**Target Rotational Speeds**

Target speed of pinion gear : 20 rpm

Chain transmission ratio : $R_{chain} = \frac{z_2}{z_1} = \frac{26}{26} = 1$ ( So seed does not change)

Motor rotational speed : 20 rpm ( Because the chain ratio is 1:1 , the speed does not change)

**Torque Calculations**

First, let's find the torque that the pinion gear must create:

$$T_p = \frac{F \times d_p}{2} = \frac{490.5 \times 0.081}{2} = 19.85\ Nm$$

The torque that the shaft must produce to provide this torque to the pinion gear:

$$T_{shaft} = T_p = 19.85\ Nm$$

Because the pinion is directly connected to the shaft.

Since the gear ratio in the chain transmission is 1:1, the motor must also produce the same torque:

$$T_{shaft} = T_{engine} = 19.85\ Nm$$

**Engine Power Calculation**

Engine power is calculated from the following formula:

$$P_{engine} = \frac{T_{engine} \times \omega}{\eta}$$

$$\omega = \frac{2\pi \times 20}{60} = 2.904\ rad/s$$

Let's assume the system efficiency is 90%

$$P_{engine} = \frac{19.85 \times 2.094}{0.9} = 46.2\ W$$

## Motor Selection

Minimum torque required: ≈ 19.85 Nm
Minimum power required: ≈ 46.2 W (0.046 kW)
Rotation speed of the motor: 20 rpm

According to the calculations, the engine that meets the criteria, has small dimensions and low cost is BVA 20 NM Flat Shutter Engine.

# 5. CONCLUSION

This project was initiated in response to the growing environmental concerns associated with plastic-based packaging materials and the increasing demand for sustainable packaging solutions. The rising interest in alternative materials, particularly molded fiber technologies with recyclable and biodegradable properties, has positioned them at the forefront of sustainable packaging innovations.

This project laid the foundation for scalable, environmentally friendly packaging solutions that are expected to guide industrial companies in the transition to more sustainable packaging practices.

As a result, this project contributed to the development of a sustainable, economically advantageous and industrially applicable packaging production technology, providing valuable insights and practical solutions for the transition to environmentally friendly packaging solutions.

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