MARMARA UNIVERSITY
FACULTY OF ENGINEERING

DESIGN AND DEVELOPMENT OF A PROTOTYPE FORMING MACHINE PRODUCING PACKAGING FROM RECYCLABLE FIBERS

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by

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ABSTRACT

Molded pulp products made from recyclable and biodegradable fibers are becoming increasingly popular due to the increasing need for ecologically friendly packaging solutions. Molded pulp has received significant interest from various industries in response to the urgent need to replace traditional plastic-based packaging with more environmentally friendly options due to its low environmental impact, affordability, and end-of-life single-of-life. However, the high initial cost and space requirements of traditional manufacturing systems often prevent widespread adoption.

The goal of this project was to design and build a small and convenient prototype machine that can convert recycled paper and agricultural waste into molded pulp packaging. A mixing tank, a pulp collection basin, and a pneumatic forming system are integrated into the mechanical design process optimized for affordability, ease of maintenance, and low environmental impact. SolidWorks was used for CAD modeling and simulations that accounted for real-world variables such as fiber concentration, vacuum pressure, and slurry flow dynamics.

The final prototype is a modular and scalable solution designed for flexible manufacturing, academic research, and rapid prototyping. It offers the flexibility to test a variety of fiber types, die geometries and process configurations, acting as a valuable intermediary between laboratory-scale experiments and full industrial application. This research contributes significantly to sustainable product development and demonstrates an option for eco-innovative packaging solutions by promoting the recycling of wastepaper and agricultural by-products within a circular production framework.

ABBREVIATIONS

AC: Alternating Current

CAD: Computer-Aided Design

DC: Direct Current

EPS: Expanded Polystyrene

HDPE: High-Density Polyethylene

IEC: International Electrotechnical Commission

IMFA: International Molded Fiber Association

IP: Ingress Protection (e.g., IP55)

MFP: Molded Fiber Product

PE: Polyethylene

PP: Polypropylene

PS: Polystyrene

PU: Polyurethane

PVC-U: Unplasticized Polyvinyl Chloride

RPM: Revolutions Per Minute

TDH: Total Dynamic Head

UCF: (Bearing Code) – Unit Cast Flange (used in UCF204)

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1. INTRODUCTION

The rising worldwide environmental concerns about material degradation along with plastic pollution have driven industries to adopt more sustainable choices. Packaging represents a major resource-intensive industry which makes it the primary focus for sustainable innovations. Molded pulp packaging has become a practical solution because it uses recycled paper materials together with other cellulose fibers. The packaging solution uses post-consumer waste and creates minimal long-term environmental damage which supports sustainability targets specified by the United Nations and European Green Deal.

Despite the environmental benefits, molded pulp packaging has technical challenges in design flexibility, surface quality and production efficiency. Conventional systems are often big, expensive or dependent on mature infrastructure that may not be feasible for small scale or local production. To address these limitations, there is a growing need for affordable, compact and adaptable forming machines that can produce molded pulp packaging with acceptable mechanical and aesthetic properties – especially from recyclable fibers. Design and prototyping of such machines supports material circularity and decentralized production for small businesses, startups and academic research environments.

The aim of this study is to design and develop a prototype forming machine capable of producing packaging materials from recyclable fibers such as used paper or agricultural residues. The research encompasses the mechanical design of the machine structure, the development of a forming mechanism using pneumatic and linear motion systems, and the integration of process parameters such as fiber concentration and vacuum pressure. CAD modeling and simulations were carried out using SolidWorks, providing visual and structural insights throughout the design process. The final prototype was evaluated in terms of functionality, repeatability, and compatibility with different types of recyclable pulp materials.

In addition, from both an engineering and environmental perspective there is utility in the project because from an engineering perspective, part of the project involves limiting machine constraints including cost, space, and assembling parts into components. From an environmental perspective, the valorization of waste fibers as products rather than waste contributes to a more sustainable product horizon. This project has applicability for crates, trays, electronics packaging, and even custom protective inserts for fragile items.

The creation of a high-quality, low-cost, compact forming machine for recyclable fiber packaging addresses both industrial and environmental needs, while encouraging new innovative uses for sustainable lightweight manufactured products. It contributes to the growing literature of eco-sensitive product design and knowledge on molding fiber production systems for future studies.

This prototype, in contrast to numerous extant laboratory-scale designs, prioritizes modularity and real-world usability, with the intention of facilitating both research and small-scale commercial implementation.

2. LITERATURE REVIEW

2.1 History of Molded Pulp Packaging

In the mid-1800s, with the mass distribution of newspapers and books, the prices for paper-related products dropped, and thus new applications emerged. The first appearance of a method for making molded products from wood pulp dates to 1890 [1].

First created as an economical and environmentally friendly substitute for wood and metal containers, molded pulp was especially useful for packing delicate goods like lightbulbs and glass bottles. Egg cartoons are among the first instances of its application; their low production costs and protective qualities made them popular.

The first patent for a machine for making pulp products was registered in 1903 by Martin L. Keyes, from Cambridge, Massachusetts [2]. Molded pulp was soon after used as packaging for eggs, designed and produced by the Canadian inventor Joseph Coyle, however the production machinery was not developed 3 until after the First World War. The shape of the package varied, and consequently the invention was applied to all sorts of fragile items, including light bulbs and fruit. The patent for this multi-use package was registered in 1920 [3]. Since then, the implementation of molded pulp products slowly increased, examples of other patented applications being a folding spoon for medicine, a pastry holder and packaging for a handset telephone (1940) [4].

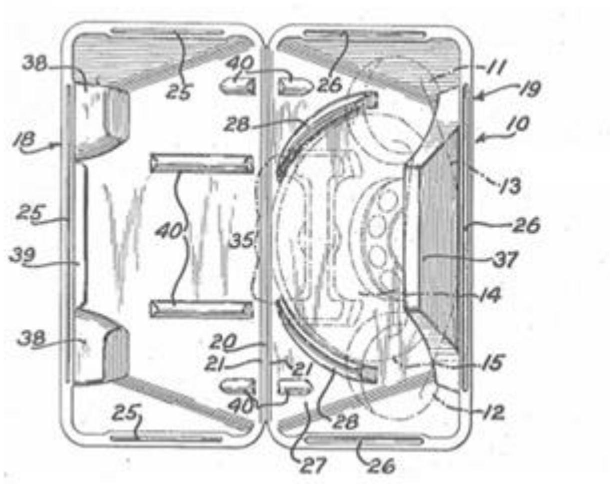


Figure 1:Molded Pulp Packaging for handset telephone, patented in 1940 by S. Price [5]

The late 1980s saw a change in the situation. The molded pulp business began creating fresh, creative solutions in those years as people began to worry about the items they bought and their effects on the environment. Especially after World War II, demand for packaging solutions that are both functional and environmentally friendly has increased. Increased environmental awareness and regulatory pressures to reduce plastic use have renewed interest in molded pulp packaging. Innovations in material formulation, drying methods, and automation technologies have further increased the performance and scalability of molded pulp production. Today, molded pulp packaging is recognized not only for its ecological advantages, but also for its adaptability to meet the evolving demands of modern packaging design.

2.2 Molded Pulp Product Classes

Based on the production process, surface quality, and intended use, molded pulp packaging is typically divided into four major groups. Molded pulp can be utilized in a variety of industries since each class meets distinct functional and aesthetic needs.

Thick-Wall

Based on the manufacturing technique and material quality, molded pulp products can be divided into different classes, according to the International Molded Fiber Association (IMFA). The first is referred to as a "thick wall" since it is composed of kraft and recycled paper and often has a wall thickness of 5 to 10 mm.

An aqueous suspension of fiber in a vat is where the process begins. Fibers (as well as any additional additives) are drawn toward a screen surface by applying vacuum while a porous mold is placed inside the vat. After that, the mold is removed from the vat while the moist molded product is still within. After that, the molded pulp product is taken out of the mold and allowed to dry in an oven. During shipping, thick-wall materials are mostly used as support packing for large, non-fragile commodities like furniture and auto parts.

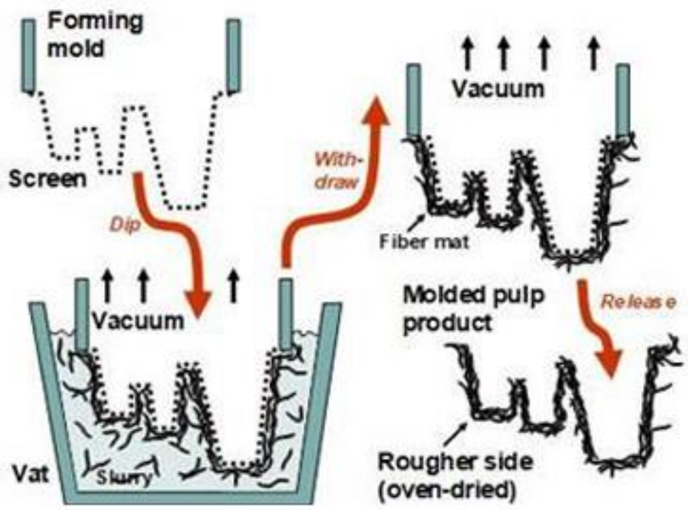


Figure 2:Schematic illustration of thick-wall process for molded pulp production [6]

Transfer Molded

Transfer molded is the term for the second variety. These have superior dimensional precision, comparatively flat surfaces on both sides, and thinner walls that range from 3 to 5 mm. Usually, these serve as egg trays. This is the most used type, especially for items like egg trays, drink carriers and electrical equipment packaging. This class strikes a balance between material efficiency and structural integrity, making it suitable for high-volume production.

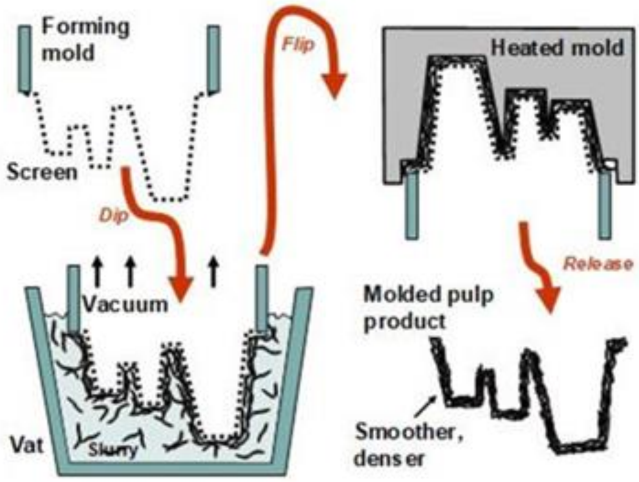


Figure 3:Schematic illustration of transfer molded process [6]

Such products start the process in a manner similar to that of thick wall. On the other hand, for transfer molded products, the mold is moved to press against an opposing surface that takes on the desired shape of the product while the damp molded object is still attached. The transfer mold surface is heated. The fact that transfer molded products are often smoother on the inside and exterior sets them apart from thick-wall molded pulp products.

Thermoformed (Thin-Wall)

The third kind, referred to as "thermoformed" or "thin-wall," is the most current method. These goods have smooth, hard surfaces, good dimensional precision, and thicknesses between 2 and 4 mm. In order to press, densify, and dry the first-formed product, this kind of product uses heated molds. These products can be used in place of thermoformed plastic products.

Processed (Post-Processed)

These products go through extra processes following the original molding, like coating, printing, trimming or additives. When certain performance or aesthetic qualities are needed, such as in retail packaging or custom inserts, processed pulp is usually utilized.

Manufacturers can choose the best kind of molded pulp for their design objectives by classifying it into these groups, considering variables like cost, environmental impact, and durability.

2.3 Advantages and Disadvantages of Molded pulp Packaging

Advantages:

- Environmental Sustainability: Molded pulp is biodegradable and compostable since it is mainly composed of recycled paper or other cellulose fibers. Compared to plastic, it uses less water and energy during production, which lessens its overall environmental impact.
- Cost-Effective for High Volumes: Cost-Effective for Large Volumes: Molded pulp may be manufactured at a reasonable scale once the first tooling is in place. It provides an effective trade-off between cost and performance, particularly for standardized products like drink carriers or egg trays.
- Good Cushioning and Protection: Molded pulp's structure allows it to

effectively absorb shocks and vibrations, making it appropriate for packaging delicate products in a protected manner.

- Customizable and Versatile: Molded pulp can be formed into intricate geometries to meet particular product specifications using contemporary mold-making techniques. Additionally, it can be coated or treated for improved surface finish or water resistance.
- Regulatory Compliance: Strict laws governing single-use plastics are currently enforced by numerous governments and organizations. Molded pulp offers a legal substitute that supports brand sustainability objectives and environmental regulations.

Disadvantages:

- Surface Finish and Aesthetics: If additional processing, such as coating or trimming, is not carried out, the rather coarse texture of typical molded pulp might not be appropriate for presentations of high-end objects.
- Limited Water Resistance: In humid areas, molded pulp may lose its structural integrity due to moisture absorption if it is not coated.
- Longer Cycle and Drying Times: In general, molded pulp production takes longer than plastic injection molding, especially when thick walls are involved or natural drying is used.
- Tooling Complexity for Fine Details: While basic shapes may be made rapidly, designs that call for high precision or fine details might necessitate more complex molds and additional finishing steps, increasing the overall cost and duration.

2.4 Application of Molded Pulp Packaging

From being a specialized solution, molded pulp packaging is now a material that is widely used in many different industries. Due in large part to its environmental benefits and the rising demand for sustainable products by consumers, it finds use in everything from consumer electronics to food packaging.

Food and Beverage Industry: The food industry has one of the oldest and most reliable applications for molded pulp, especially in the packaging of eggs, fruits, and drinks. Additionally, molded pulp is being utilized more and more in cup trays and takeout food containers, particularly in quick-service restaurants that want to use less plastic.

Figure 4:Food-Related Molded Fiber Products [8]

Electronics and Consumer Goods: Expanded polystyrene (EPS) and plastic foams are being replaced with molded pulp for internal packaging in several electronics manufacturers. It may be made to fit parts like cell phones, routers, and accessories snugly and offers dependable protection while in transit.

Figure 5:Electronic Packaging Products

Healthcare and Medical Supplies: Kidney trays, bedpans, and other sanitary containers are disposable medical devices made of molded pulp. These products facilitate hygienic disposal procedures in hospitals and care centers by being securely burned or composted after use.

Figure 6:Healthcare and Medical Supplies Molded Pulp Packaging

Industrial Packaging: Automotive and industrial components are protected with heavy-duty molded pulp packaging. It is appropriate for moving hardware and machine parts due to its resilience to shocks and vibrations, particularly in logistics where sustainability is an issue.

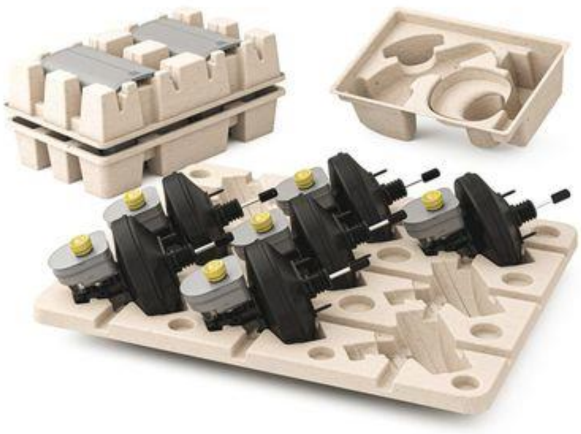


Figure 7:Industrial Molded Pulp Packaging

2.5 Production Process

Several steps are involved in the creation of molded pulp packaging, which turns natural fibers or recycled paper into three-dimensional packaging elements. Although the precise procedure may differ based on the kind of product and the manufacturing environment, it often includes the following basic steps:

Pulp Preparation:

The pulping step of the process starts with a hydropulper creating a slurry out of recycled paper, cardboard, or virgin fibers and water. In order to remove contaminants like staples, inks, and plastic residues, this combination is then screened. This pulp is ready for molding and has consistency like wet porridge.

Forming:

After being cleaned, the pulp is moved to a forming station and formed into the required shape. A perforated mold is immersed in the pulp slurry in standard transfer molding systems. The fibers are drawn onto the mold surface by vacuum suction, forming a wet-fiber structure. The fiber mat assumes the shape of the mold as the extra water drains away.

Pressing (Optional):

A pressing stage is added to products that need a smoother surface or a denser structure, such thermoformed pulp. In order to improve surface smoothness and dimensional accuracy, the wet preform is sandwiched between heated molds that compress and partially dry it.

Drying:

Drying the molded components is necessary to lower the moisture content and solidify the structure. The drying step follows the forming process. Two fundamental methodologies can be identified: plain and precision molding (or thermoforming). In a plain molding process, products are dried in an industrial oven without restraint. In a thermoforming process instead, heat is applied via the surfaces of two matching halves of a mold in which the part is pressed [14].

Products made via plain molding fall into the categories of thick wall and transfer molded in plain molding process. Plain molding production systems are usually designed for large volumes with a high level of automation [15].

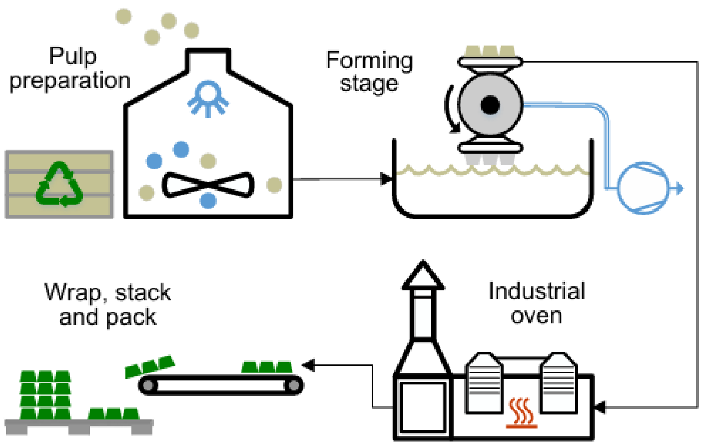


Figure 8:Typical process chain of a plain molding process [16]

In another process, During the drying process, the parts are pressed, making the products denser, smoother, and more precise than their “free-dried” counterparts [15].

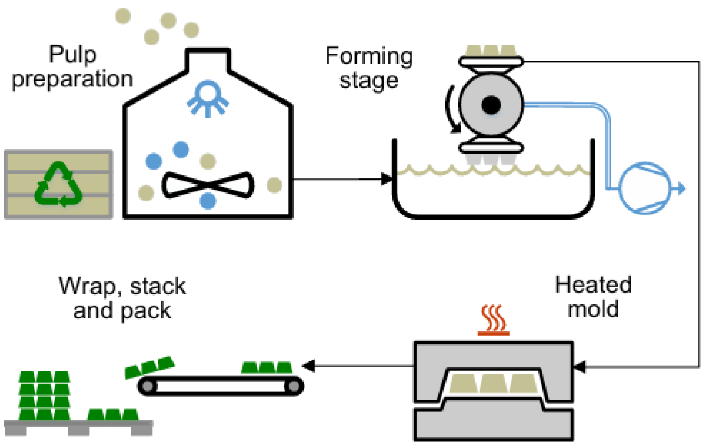


Figure 9:Typical process chain of a precision molding or thermoforming process [16]

Trimming and Post-Processing:

After drying, the molded items' edges are frequently rough and may need to be trimmed for practical or aesthetic reasons. Depending on the intended use, additional treatments like printing, embossing, surface coating (for moisture resistance), or assembly (e.g., gluing numerous sections) may be applied.

To maximize production efficiency, reduce waste, and maintain consistent quality, each of these processes needs to be closely monitored. Molded pulp is becoming more and more competitive with traditional plastic packaging as technical developments continue to improve each step, particularly in automation and drying.

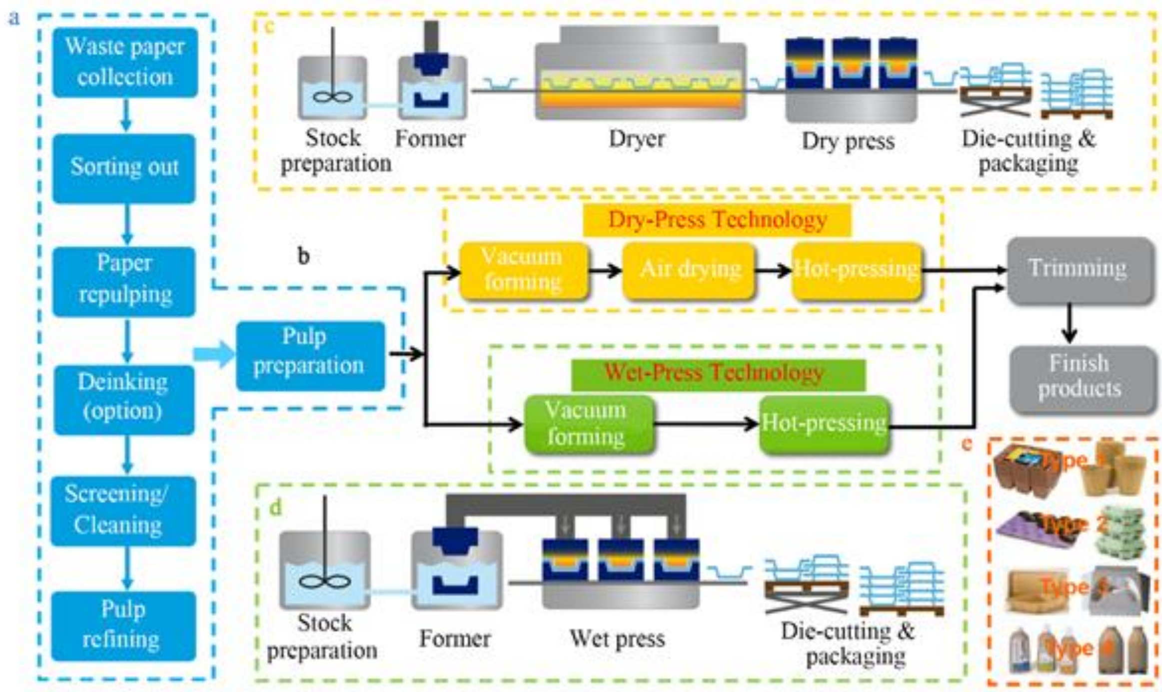


Figure 10:Schematic illustration of general process of manufacturing various types of molded pulp products [8]

Fig. 10 shows a schematic illustration of the general process of producing a wide variety of MFPs. Fig.10a and Fig.10b show pulp preparation and molding process, respectively. Fig.10c and Fig.10d show dry-press technology (plain molding) and wet-press technology (thermoforming), respectively. Fig.10e shows the molded pulp products.

3. MECHANICAL DESIGN

3.1 General Design Approach

Our primary objective in developing the paper pulp forming machine prototype was to design a system that enables the rapid, economical, and practical production and testing of pulp-based products intended for future mass production. Rather than replicating the scale or complexity of full industrial systems, our approach focused on creating a compact, accessible, and cost-effective alternative that retains the core functional principles of large-scale equipment.

The prototype was envisioned as a bridge between laboratory-scale experimentation and industrial-scale manufacturing—providing a reliable platform for testing various pulp formulations, processing parameters, and mold geometries without the spatial, financial, or operational constraints of commercial machinery. To this end, the design emphasizes modularity, ease of use, and portability. Each subsystem was carefully designed to occupy minimal space while maintaining mechanical robustness and process efficiency.

Furthermore, the machine's simplified structure allows operators and researchers to quickly adapt the process to different material inputs or product designs, supporting iterative development cycles. Its user-friendly layout and straightforward maintenance requirements make it well-suited for use in educational environments, R&D facilities, and small production workshops. Ultimately, this prototype serves as a scalable foundation upon which more advanced or automated systems can be developed, offering an essential testbed for innovation in the field of pulp-based product manufacturing.

3.2 Working Principle

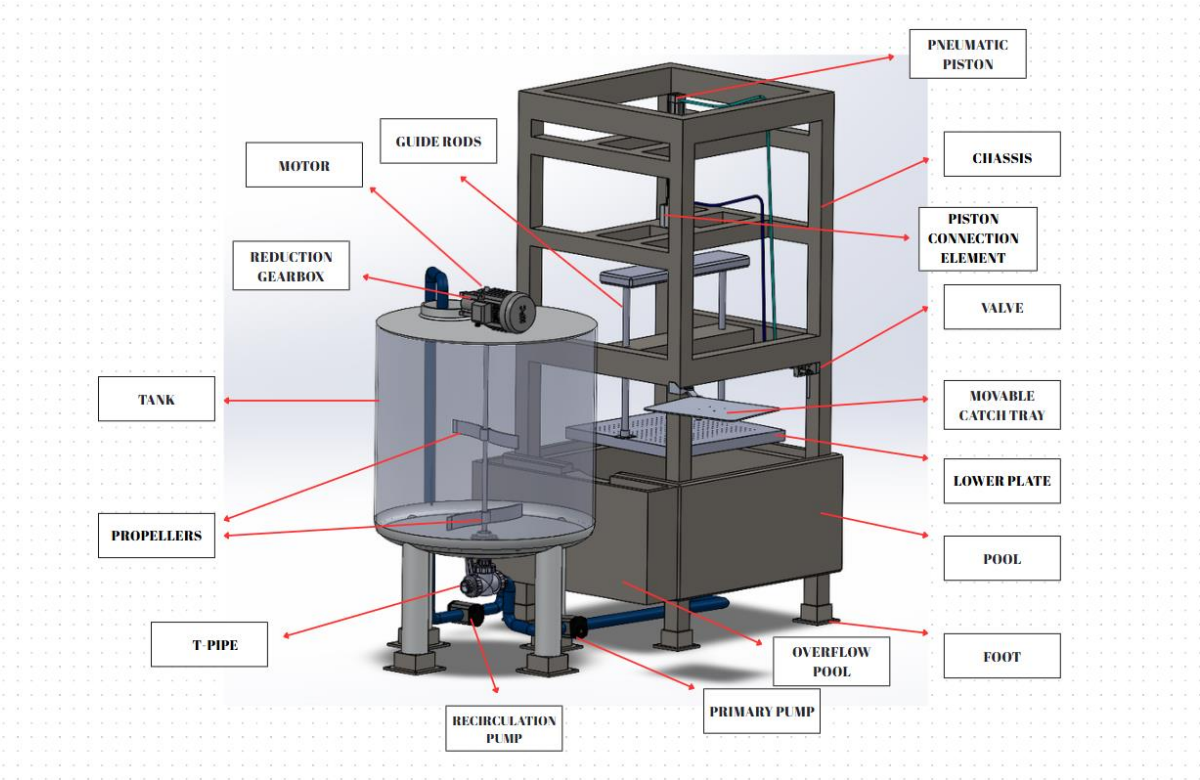
The machine is fundamentally composed of two primary sections: the mixing tank and the settling basin, each of which integrates multiple subsystems to carry out the pulp-forming process. Paper waste is first fed into the mixing tank through an inlet located at its top. Simultaneously, water is added to create a slurry of cellulose fibers. Agitation is provided by an electric motor mounted above the tank, which drives a set of impeller blades via a reduction gearbox. The gearbox reduces the impeller speed to protect the delicate cellulose fibers from shear damage while ensuring thorough mixing and uniform fiber dispersion.

Once a homogeneous pulp consistency is achieved, the slurry exits the tank through a T-shaped outlet pipe at its base. A centrifugal pump forces the pulp into the adjacent settling basin, while the additional branch of the T-pipe remains available for rapid tank drainage during cleaning or emergency shutdowns. As the basin fills, excess pulp recirculates: when the fluid level reaches a preset height, a secondary pump returns a portion of the mixture back to the mixing tank. This continuous recirculation stabilizes the slurry level in both vessels, preserves consistent fiber concentration, and prevents localized settling.

The dewatering and sheet-forming stage occurs within the settling basin itself. A lower platen—often referred to as the mold tray—submerges into the pulp under the action of a pneumatically driven piston attached to the machine’s frame. Guide rods ensure the platen descends vertically without tilting. Once in position, the lower platen’s perforated surface draws the fiber mat through vacuum, removing water and leaving a coherent sheet adhered to the tray. The upper plate then descends and switches to a blowing mode, gently releasing the formed sample from the lower mold onto its surface. Finally, the platen assemblies retract, and the finished paper-pulp sheet is ready for removal.

Throughout this cycle, pneumatic valves control the timing and pressure of the piston stroke, while manual and automatic interlocks manage slurry transfer, vacuum application, and platen actuation. A movable catch tray mounted on the frame further enhances operational flexibility, collecting any residual liquid or small solids during maintenance or special testing procedures. Together, these coordinated subsystems enable rapid prototyping of paper-pulp sheets with minimal footprint, straightforward operation, and swift turnaround between test runs.

3.3 Parts & Functions



The components that make up the system and their basic features are listed in the table below.

Part	Function
Mixing Tank	Hosts the paper-water slurry; provides containment for initial fiber dispersion and agitation.
Impeller & Reduction Gearbox	Agitates the slurry gently: the gearbox reduces motor speed to protect fibers, while the impeller ensures uniform mixing and prevents clumping.
T-Shaped Outlet Pipe	Directs mixed pulp out of the tank into the settling basin; second branch allows rapid tank drainage during cleaning or emergency shut-off.
Primary Pump	Transfers homogenized pulp from the mixing tank to the settling basin under controlled flow and pressure.
Settling Basin	Acts as a buffer and pre-dewatering vessel where gravity separates excess water and entrained air from the fiber network.
Recirculation Pump	Returns a portion of the overflowed pulp from the basin back to the mixing tank, maintaining a constant slurry level and fiber

Part	Function
	concentration in both vessels.
Lower Platen (Mold Tray)	Submerges into the pulp under vacuum to draw out residual water, forming a coherent fiber mat on its perforated surface.
Pneumatic Piston & Valves	Drives vertical motion of the lower platen; valves control pneumatic pressure, timing of descent/ascent, and ensure synchronized operation.
Guide Rods	Maintain precise, tilt-free linear movement of the platen assembly during immersion and retraction.
Upper Plate	Lowers onto the formed sheet in blowing mode to gently separate the dewatered pulp mat from the lower platen, then retracts to release the finished sheet.
Movable Catch Tray	Mounted on the frame beneath the basin/platen region to collect any residual liquid or solids during maintenance, special tests, or spill events.
Machine Frame & Antivibration Feet	Provides rigid support for all modules; feet isolate vibrations, ensure stability, and allow leveling on uneven floors.
Control Panel & Interlocks	Orchestrates sequence timing (mixing, pumping, vacuum, platen actuation) and incorporates safety interlocks for emergency stops and manual overrides.

Before proceeding with the detailed component-based design explanation, it should be noted that the system has been divided into two primary mechanical subassemblies during the design process: (1) the pulp tank and (2) the pulp collection pool (reservoir).

3.4 Design Details of Pulp Tank

This section focuses on the structural design of the tank and its lower mechanical components. Each component, including the tank body, the agitator shaft and blades, the motor and gearbox unit, the riser plate, the bottom bearing, and the flow control valve, is examined individually with relevant visual representations.

The associated figures below illustrate the overall layout and key elements of the tank assembly.

3.4.1 Tank

The tank used in this project is an industrial-purpose, leg-supported, bottom-connected storage/mixing system designed for processing and agitating paper pulp. The design of the tank was developed by considering both process requirements and manufacturability criteria.

The tank has an approximate **diameter of 1000 mm** and a **height of 1060 mm**. The first 950 mm of the structure is cylindrical, while the bottom section ends in a slightly sloped geometry to reduce sedimentation. The total volume of the tank is approximately **753 liters**, but it is recommended to operate it at **80% capacity** to ensure optimal processing, yielding an **effective working volume of around 600 liters**. The gently sloped base helps minimize volume loss.

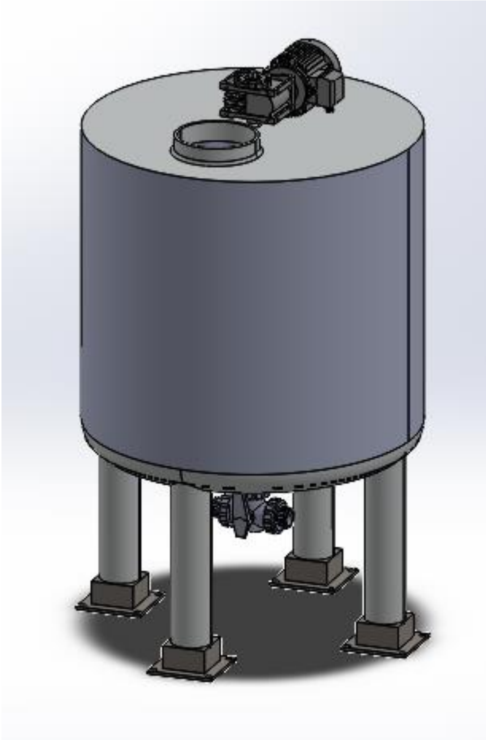


Figure 11: CAD Model of the Pulp Mixing Tank

Design Features:

- **Structure:**
  The tank body is designed with a uniform wall thickness of **10 mm**. The material of choice is plastic (e.g., **PE, PP, or HDPE**), ensuring a **low-cost and corrosion-resistant** structure.

- **Legs and Elevation:**
  The tank stands **480 mm above the ground on four support legs**. These legs are designed with **flanged mounting holes** to allow secure attachment to the ground.

- **Bottom Outlet System:**
  At the bottom center of the tank, an outlet hole is connected to a **three-way T-type valve**. This valve enables:
    - One line to direct flow back to the pulp pool,
    - The other line to be used for **cleaning and drainage.**

- **Top Inlets:**
    - A **central shaft entry hole** is placed at the top center for the agitator shaft.
    - A **Ø250 mm diameter opening** is also designed on the top surface for **pulp feeding**. Through this opening, excess pulp returning from the pool during the process is reintroduced into the tank.

- **Sealing and Hygiene:**
  Sealing is ensured by **using gaskets at the valve and flanged connection surfaces**. No separate drain plug is used for cleaning; this function is directly handled via the **three-way valve**.

All dimensions were hand-drawn, taking into account current manufacturing capabilities. In the final stage, a **commercially available plastic tank** will be selected for use, and a model with the closest geometry will be chosen for assembly planning. Therefore, in later phases, the cost, **lead time, and compatibility** of the selected commercial tank will also be analyzed.

3.4.2 Agitator

The agitator used in the system is designed to ensure the homogeneous distribution of the paper pulp inside the tank and to prevent fiber sedimentation. The agitator structure is a simple yet effective mechanical solution, optimized to operate at low speed without disrupting the flow pattern.

The agitator consists of a **shaft with a diameter of Ø20 mm and a length of 1150 mm**. The shaft is rotated by a **motor–gearbox unit** mounted at the top of the tank, while its lower end is supported by a **bearing housing** to prevent oscillations and axial misalignment.

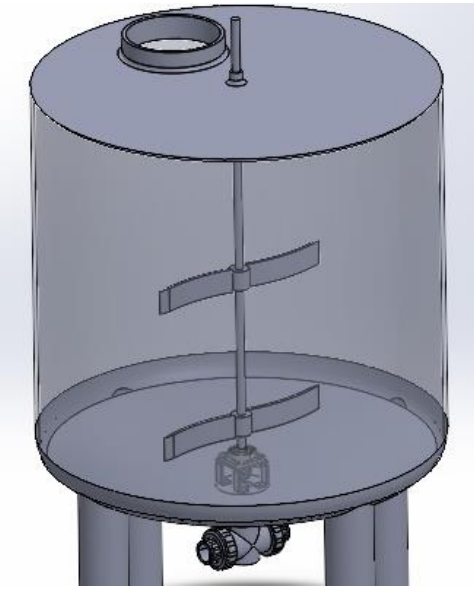


Figure 12: CAD Model of the Agitator

Blade Configuration:

- The agitator shaft is equipped with **four blades**.
- The blades are positioned **perpendicular to the shaft axis** and extend up to **250 mm from the shaft center**, resulting in a **total agitation diameter of 500 mm.**
- This diameter covers approximately **50% of the tank's internal diameter**, enabling efficient flow and mixing.
- The blades are arranged at **two levels:**
  - **Lower level**: near the bottom of the tank
  - **Middle level:** at the mid-point of the shaft

Design Features:

- The blades are not sharp-edged but are designed with **rounded corners and blunted edges** to avoid generating high shear forces.
- This design allows:
  - **Preservation of fiber integrity,**

- **Prevention of mechanical damage to the pulp,**
- **Smooth and balanced flow** during mixing.

Mounting Diagram and Connections:

- The agitator shaft is inserted into **a horizontal output port aligned with the gearbox output shaft.**
- The shaft is fitted into the gearbox coupling and secured with a **setscrew (grub screw).**
- The lower end of the shaft is supported by a **bearing housing**, which eliminates both **axial misalignment and shaft wobble.**

Material Selection:

Table 1: Material Selection for Agitator

Component	**Material**	**Rationale**
Shaft	Stainless steel (AISI 304)	Corrosion-resistant, machinable
Blades	AISI 304 / 316 or PVC plates	Smooth-surfaced material that does not damage pulp
Fasteners & pins	A2 stainless steel	Hygienic and easy to clean

3.4.3 Bearing Housing

To ensure axial stability, eliminate oscillation, and allow shaft-centered rotation during operation, a **flanged bearing housing** is used to support the agitator shaft. For this purpose, a widely available and industry-standard **UCF204 series four-bolt flange bearing** has been selected.

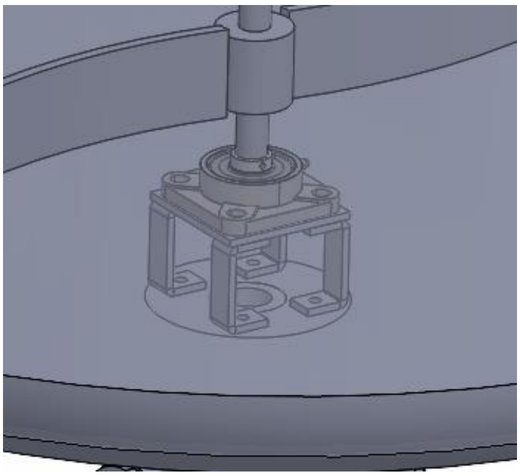


Figure 13: CAD Model of the Bearing Housing and Riser Plate

Technical Specifications:

Table 2: Technical Specifications of Bearing Housing

Specification	Value
Model	UCF204
Housing Type	Square flange (4-bolt)
Housing Material	Cast grey iron (GG20–25)
Shaft Compatibility	Ø20 mm (fully compatible with shaft)
Bearing Type	Self-lubricating ball bearing (UC204)
Mounting Type	Flange-mounted to base or plate
Shaft Locking Method	2 setscrews (grub screws)
Operating Temperature	–20°C to +100°C (suitable for process)

Function in the System:

- The bearing is positioned near the **lower end of the agitator shaft**.
- It keeps the shaft **axially aligned** and prevents **wobble during rotation**.
- It reduces **vibration** and balances the **load transferred to the motor–gearbox assembly**.
- Thanks to its **flanged structure**, it can be directly mounted onto a custom **support stand or riser plate**.
- Elevating the bearing with a plate also provides **space for piping and valve connections** beneath the system.

Mounting:

- In the **SolidWorks model**, the bearing housing is mounted onto a **metal riser plate**.
- It is fixed in place using **four bolts through the flange holes**, ensuring ease of installation.
- The shaft inserted into the bearing is secured with **setscrews**, preventing axial slip.

Compatibility and Availability:

- UCF204 series bearings are **commonly available** from both domestic and international suppliers.
- They are **low-cost, durable**, and **easy to maintain**.
- Since they are **directly compatible with the 20 mm shaft diameter**, they can be seamlessly integrated into the system.

3.4.4 Riser Plate

While the agitator shaft positioned under the tank is driven by a motor–gearbox unit, its lower end is supported by a **UCF204 bearing housing**. However, the pulp outlet and valve connection hole located at the **center-bottom** of the tank prevent the bearing from being mounted close to the ground level. Therefore, a **custom riser plate** was designed to elevate the bearing housing appropriately.

Specifications:

Table 3: Specifications of Riser Plate

Specification	Value
Plate Type	Sheet metal plate (with four support legs)
Top Surface Area	90 mm × 90 mm
Plate Thickness	5 mm
Material	Stainless steel (AISI 304) or galvanized steel
Total Height (with legs)	65 mm
Mounting	Four bolt holes for UCF204 flange bearing

Function:

- The plate raises the bearing housing by approximately 65 mm.
- This elevation ensures that the Ø48 mm discharge port under the tank remains unobstructed, allowing smooth fluid drainage.
- It maintains precise alignment between the shaft axis and the bearing axis, preventing misalignment.
- The bearing housing is secured to the plate via four bolts at the flange.

Manufacturing and Assembly:

- The part can be produced by **CNC machining.**
- The plate is mounted to the tank using **four M8 bolts** through its legs.
- The bearing housing is fixed onto the plate via **four bolted connection points**.
- Adequate **clearance is provided beneath the plate** for outlet piping and valve connections.

Suitability and Functionality:

The structural form of the riser plate is developed to both **preserve shaft–bearing alignment** and **avoid physical interference** with the discharge line. The **5 mm-thick stainless steel sheet** ensures sufficient rigidity to bear the loads transmitted from the agitator and the bearing. The use of **four support legs** not only provides the necessary elevation but also **enhances the system's stability**, minimizing vibration and oscillation.

This design achieves the **required durability and performance** levels expected in low-speed rotating systems. Thanks to its **simple geometry**, the plate is easy to manufacture and maintain and can be **replaced with similar commercial alternatives** if needed. Furthermore, the use of **AISI 304 stainless steel** offers excellent resistance to **moisture and chemical exposure**, ensuring long-term reliability in industrial environments.

3.4.5 Flow Control Component (3-Way Valve System)

In the system, a **multi-directional flow control solution** is required at the **central bottom outlet** of the tank (Ø48 mm), allowing the outlet to serve both for **pulp discharge** and **cleaning purposes**. For this reason, a **T-port 3-way valve system** is integrated into the outlet.

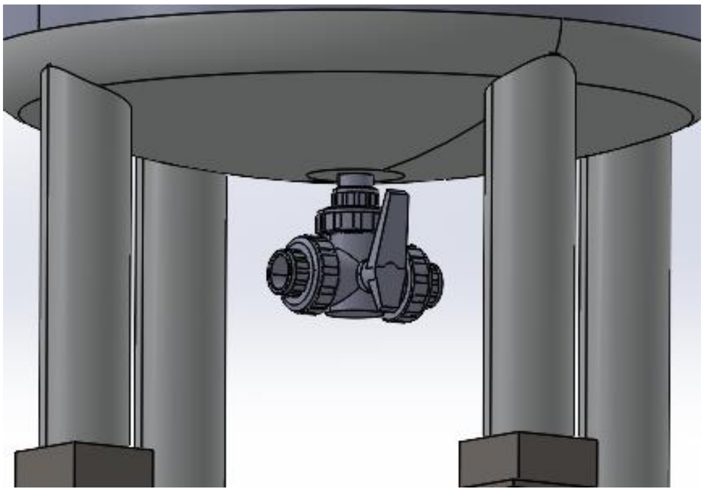


Figure 14: CAD Model of the T-Port 3-Way Valve System

Selected Component:

- **Model:** CEPEX or Europress PVC-U 3-Way T-Port Ball Valve (DN50)
- **Body:** PVC-U plastic, resistant to chemicals
- **Connection:** Flanged or threaded adapter versions
- **Inner Diameter:** Approximately 48–50 mm
- **Operating Temperature:** 0–60°C (suitable for water-based processes)
- **Mechanism:** Manual rotary lever for flow direction control

This valve is a **functional component** that manages two different outlet lines from a single inlet. It enables both **pulp transfer to the process pool** and **drainage or cleaning of the tank**. The chosen valve design features a **fixed T-shaped internal flow path**, and direction control is performed manually using a **rotary handle**.

The valve body is made of **PVC-U (unplasticized polyvinyl chloride)**, a material known for its **chemical and mechanical resistance**, particularly in water-based pulp systems. PVC-U is lightweight, cost-effective, and corrosion-resistant—making it ideal for this application.

The valve's **internal diameter** is selected to match the **Ø48 mm outlet of the tank**, and the **flanged connection option** facilitates easy mounting. With the **T-port flow configuration**, the operator can:

- Direct pulp straight to the pool,
- Switch to an alternate line for tank cleaning,
- Or leave both outlets open simultaneously, depending on the need.

This configuration **simplifies process control**, minimizes operator intervention, and improves the **overall hygiene standard** of the system.

During the design phase, care was taken to model the valve in accordance with **widely available DN50-class products** from brands such as **CEPEX, Europress, and Georg Fischer**, ensuring compatibility with standard industrial components.

3.4.6 Drive Unit (Motor–Gearbox System)

The mixing of the pulp inside the tank is driven by an electric motor mounted at the top of the system, integrated with a gearbox. This assembly ensures low-speed yet sufficiently high-torque operation through the mixer shaft.

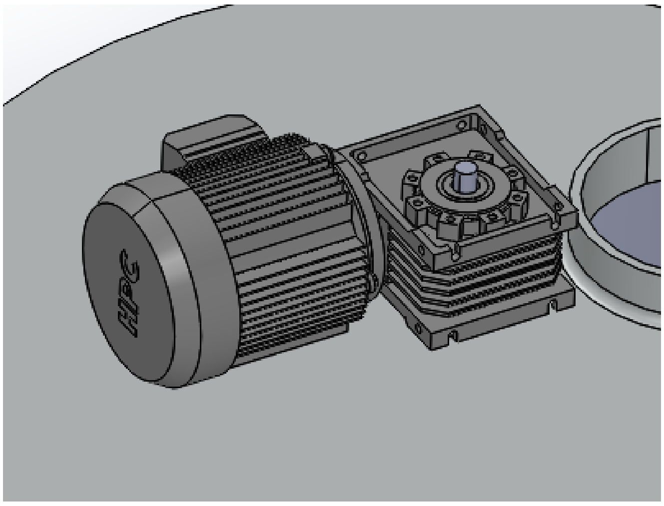


Figure 15: CAD Model of the Motor-Gearbox System

Based on the calculations made during the design process and the requirements of the process, a maximum operating speed of 80 revolutions per minute (rpm) for the mixer was deemed suitable. This low rotational speed is crucial for maintaining the structure of the fibrous and semi-fluid pulp, minimizing excessive turbulence, and preventing sedimentation.

Accordingly, the selected motor–gearbox system is the **HPC Power Transmission CHM63-20-90S4** model. Manufactured according to IEC standards by a reliable producer, the key technical specifications of the unit are as follows:

Table 4: Specifications of Motor-Gearbox

Specification	**Value**
Brand / Model	HPC Power Transmission – CHM63-20-90S4
Power	0.75 kW (1 HP)
Motor Type	4-pole, 3-phase asynchronous motor
Nominal Speed	1400 rpm
Gear Ratio	20:1 (worm gearbox)
Output Speed	70 rpm (in line with design requirements)
Output Shaft Diameter	Ø20 mm (directly compatible with mixer shaft)
Housing	Cast aluminum, fan-cooled, IP55 rated
Mounting Type	Flanged – horizontal axis mounting

The motor and gearbox are mounted on a support platform positioned above the tank. The gearbox's output shaft is aligned directly with the mixer shaft, allowing torque transmission through a direct shaft fit. This configuration provides a compact drive solution without the need for a coupling.

Compatibility and Availability

The CHM63-20-90S4 motor–gearbox unit is widely available in both Turkey and Europe. All necessary technical documentation, CAD models, and mounting accessories can be directly obtained from the manufacturer or authorized distributors. This accessibility offers a significant advantage in transitioning from design to production.

3.4.7 Fluid Transfer System – Pump Configuration

In the designed pulp processing system, two separate pumps are utilized to ensure continuous fluid circulation between the **tank** and the **process pool**:

a) Tank-to-Pool Pump:
This pump is located at the bottom outlet of the main tank. Its primary function is to **transfer processed pulp from the tank to the pool** during regular operation. The pump is mounted slightly below the tank to ensure gravitational assistance during startup and minimize priming issues.

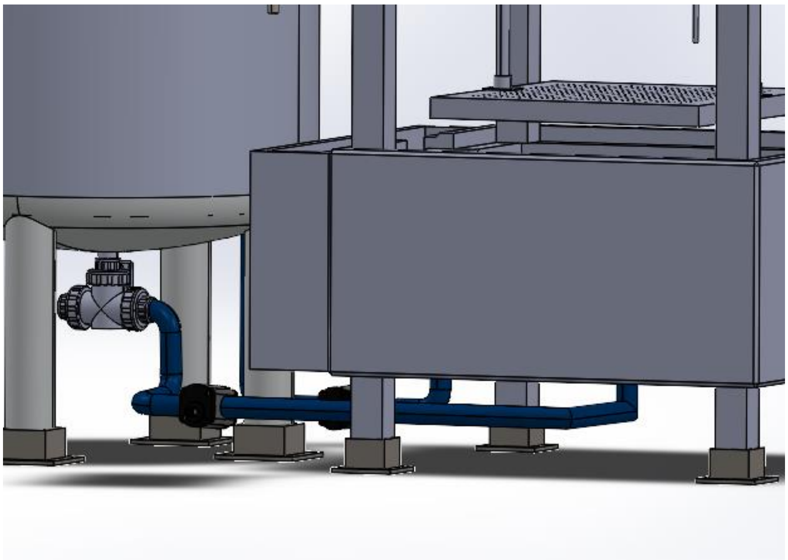


Figure 16: Tank-to-Pool Pump

The flow path includes:

- A vertical drop of approximately 100 mm,
- Followed by several horizontal and curved pipe sections (total length ~1.5 m),
- Terminating into the lower part of the pool wall.

Since the piping layout involves **five 90° elbows** and a total length of **~2.0 m** with Ø50 mm diameter pipes, the pump must overcome moderate friction and minimal static head pressure.

b) Pool-to-Tank Pump:
This second pump is located at the bottom of the pool and is responsible for **returning excess pulp back to the tank**, especially when overflow or re-processing is needed. The return flow enters the tank from the **top inlet (Ø250 mm)**.

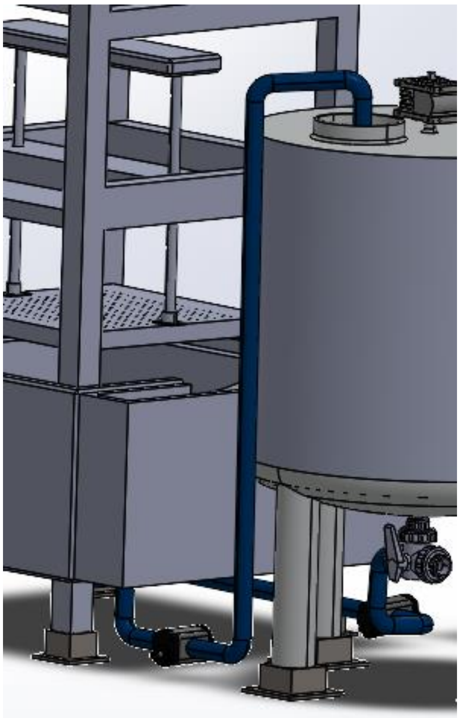


Figure 17: Pool-to-Tank Pump

The flow route includes:

- A vertical lift of approximately 1500 mm,
- Several horizontal and elbow sections (total length ~2.2 m),
- A final discharge into the top opening of the tank.

This return pump operates against a significantly higher **static head and flow resistance**, due to the vertical lift and piping complexity.

Pump Selection:
For initial prototyping, **two identical centrifugal pumps** were selected to simplify integration and maintenance. While their **final specifications are discussed in the component selection section**, the selected models offer:

- Adequate flow rate ($Q \approx 1.0\ m^3/h$),
- Ability to handle semi-viscous fluids (paper pulp with suspended fibers),
- Compatibility with Ø50 mm piping and socket fittings.

Note: Detailed hydraulic calculations and justification for pump sizing are provided in Calculations, while procurement, cost, and sourcing considerations are addressed in Component Selection.

This dual-pump configuration ensures a **closed-loop circulation** between the tank and the pool, supporting both **continuous processing and overflow recovery** without manual intervention.

3.5 Design Details of Pulp Pool and Forming Assembly

3.5.1 Chassis

The chassis serves as the main structural backbone of the machine, supporting all mechanical subsystems while ensuring alignment, rigidity, and operational stability. It was designed to withstand dynamic loads during mixing, pumping, and pneumatic operations, while also providing a modular and easily maintainable framework. The geometry and material selection reflect a balance between structural strength, ease of fabrication, and compatibility with industrial environments.

Design Features:

- Constructed from 80 × 80 mm square steel profiles, offering high load capacity and torsional stiffness.
- Total height of the frame, including leveling feet, is 2430 mm.
- Four vertical corner columns form the primary load paths and are connected by horizontal crossbeams to enhance structural rigidity.
- Crossbeams are positioned at key heights to support major subsystems such as the mixing tank, the pulp collection pool (reservoir), and pneumatic components.
- The design allows for modular mounting and alignment of components, facilitating assembly, maintenance, and future expansion.
- The frame includes adjustable anti-vibration feet to ensure stability on uneven surfaces and reduce operational noise.

3.5.2 The Pulp Collection Pool (Reservoir)

The pulp collection pool (reservoir) plays a key role in the circulation and stabilization of the pulp slurry within the system. It is composed of two interconnected sections: the main pool, where the pulp is collected and later processed, and an adjacent overflow pool, which helps regulate the liquid level and redirect excess pulp back into the cycle. The structural design of both components ensures smooth flow behavior, efficient slurry management, and compatibility with the machine’s pneumatic forming system.

Design Features:

- The **main pool** is designed with internal dimensions of **900 × 900 mm** and a depth of **400 mm**, providing sufficient volume for pulp accumulation and vacuum operations.
- At the very **center of the pool's bottom**, there is a **50 mm diameter inlet** through which the pulp is delivered.
- The **region surrounding the inlet is curved**, specifically shaped to prevent the accumulation or sedimentation of fibers in the corners, thus promoting continuous circulation.
- The **overflow pool** is positioned directly next to the main pool and measures **140 × 1020 mm**. It is mounted **90 mm higher** than the main pool to enable controlled overflow when the pulp level exceeds a certain height.
- A **50 mm outlet** is located at the bottom of the overflow pool, allowing excess slurry to be pumped back to the mixing tank, maintaining a closed-loop system.
- When assembled as a unit, the **total footprint of the two connected pools** is **1300 × 1100 mm**, ensuring compact integration into the overall machine structure.
- The entire reservoir assembly is mounted on a **supporting frame** that elevates it **200 mm above ground level**, allowing space for plumbing, drainage, and cleaning access beneath the unit.

This two-stage reservoir system ensures a consistent working level in the pulp chamber, facilitates recirculation, and prepares the medium for the vacuum forming process with minimal manual intervention.

Table 5: Specifications of Pools

Component	Length (mm)	Width (mm)	Height (mm)	Inlet/Outlet Ø (mm)	Material	Special Features
Main Pool	900	900	400	Inlet: 50	AISI 304 Stainless Steel	Curved bottom around inlet to reduce sedimentation
Overflow Pool	1020	140	490 *(400 + 90)*	Outlet: 50	AISI 304 Stainless Steel	Positioned 90 mm above main pool for controlled overflow
Assembly (Total)	1300	1100	–	–	–	Combined as one structural unit on shared support frame

3.5.3 Pneumatic Piston

Figure 18: Festo – DSNU Series Pneumatic Piston

The pneumatic piston is the primary actuator responsible for generating vertical motion within the system. It enables the precise up-and-down movement of the lower platen (tray), which is submerged into the pulp during the vacuum forming process and then retracted after dewatering is complete. The controlled linear motion of the piston ensures repeatability, consistency, and synchronization with other subsystems such as the vacuum module and upper plate.

The piston is mounted vertically on the structural chassis using a custom connection bracket, which secures it firmly while allowing axial alignment with the moving tray. This configuration allows the platen to move smoothly and without lateral deviation. In order to maintain stable motion during the stroke, guide rods are placed symmetrically alongside the piston to prevent any tilting or vibration that could affect the forming process.

Design Features & Technical Specifications – Pneumatic Piston:

Table 6: Specifications of Pneumatic Piston

Parameter	Specification
Function	Provides vertical motion for the lower platen (tray)
Mounting Orientation	Vertical, fixed to the chassis via custom bracket
Stroke Length	400 mm
Piston Diameter	50 mm
Operating Pressure Range	2 – 8 bar (recommended: 6 bar for consistent motion)
Material (Cylinder Body)	Anodized aluminum
Piston Rod Material	Stainless steel
Manufacturer / Model	Festo – DSNU Series (ISO standard profile)
Position Control	Optional magnetic sensor slot for stroke monitoring
Support System	Supported by guide rods to ensure stable linear travel

3.5.4 Piston Connection Bracket

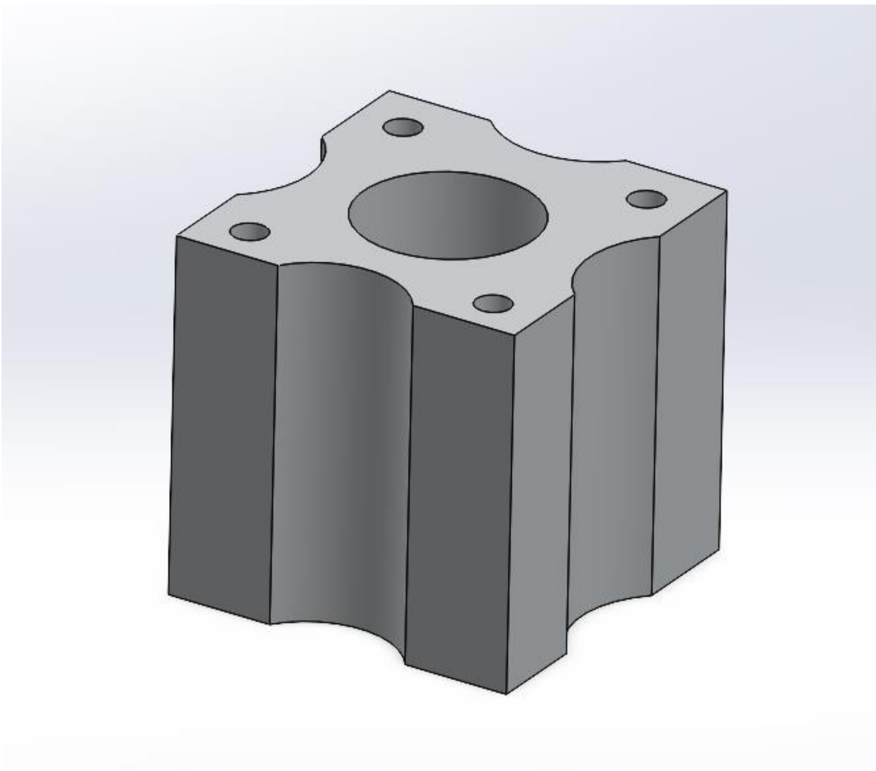


Figure 19: CAD Model of the Piston Connection Bracket

The piston mounting bracket serves as the mechanical interface between the pneumatic piston and the machine chassis. It ensures the piston is securely positioned in a perfectly vertical orientation, providing stable and accurate axial motion for the lower platen. Its geometry and material are carefully selected to handle the dynamic loads generated during the piston's stroke, while also allowing straightforward assembly and maintenance.

The bracket is fabricated as a rigid square plate with a central bore, allowing the piston rod to pass through without obstruction. It includes four precisely located mounting holes at the corners, enabling firm attachment to both the chassis and the piston body using high-strength fasteners. This configuration ensures that the piston remains properly aligned during operation, preventing lateral deflection or vibration.

Design Features & Technical Specifications – Piston Mounting Bracket:

Table 7: Specifications of Piston Mounting Bracket

Parameter	Specification
Dimensions	100 × 100 mm
Height (Thickness)	100 mm
Central Bore Diameter	50 mm
Mounting Holes	4 holes at the corners for bolt connection to chassis and piston body
Material	S355 Structural Steel (Chosen for high strength and weldability)
Mounting Method	Bolted directly to the chassis and piston flange using M8 or M10 bolts
Function	Provides rigid and accurate positioning of the pneumatic piston

3.5.5 Guide Piston Mechanism

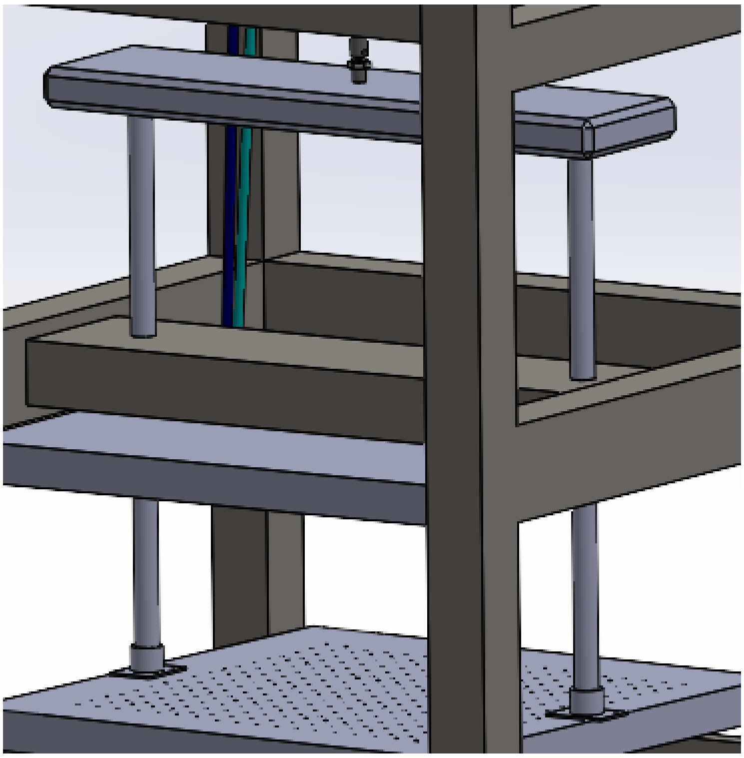


Figure 20: CAD Model of the Guide Piston Mechanism

The guide piston mechanism was developed to ensure that the vertical motion provided by the main pneumatic piston is evenly transferred to both ends of the lower platen (tray). In early design iterations, two separate pneumatic pistons were positioned on either side of the tray to provide synchronized movement. However, this dual-piston configuration introduced system complexity and potential synchronization issues, such as timing delays and uneven force distribution—common challenges in multi-actuator pneumatic systems.

To simplify the design and improve operational reliability, the system was redesigned to utilize a single central pneumatic piston. The guide piston mechanism functions as a mechanical linkage that distributes the motion of this central piston symmetrically to both ends of the tray. As a result, the tray maintains a level orientation throughout its vertical movement, eliminating the risk of tilting or uneven compression during the forming process.

This component is mounted horizontally and acts as a rigid bridge connecting both ends of the lower platen. Two small pneumatic assist cylinders are also integrated onto its surface, positioned 640 mm apart, to help stabilize and fine-tune the motion if needed.

Design Features & Technical Specifications – Guide Piston Mechanism:

Table 8: Specifications of Guide Piston Mechanism

Parameter	Specification
Function	Distributes the vertical motion from a single piston evenly to both tray ends
Previous Design	Dual-piston configuration (abandoned due to synchronization issues)
Final Design	Central piston + guide mechanism for simplified, balanced actuation

Parameter	Specification
Length	800 mm
Width	200 mm
Thickness	50 mm
Material	Aluminum 6082-T6 (lightweight, strong, corrosion-resistant)
Mounting	Connected directly to the lower platen and the central piston output
Key Advantage	Ensures smooth, level movement without tilting or asymmetry

3.5.6 Pneumatic Control Valve

Figure 21: Festo VUVG-L10-B52-T-M7-1P3 Valve

The pneumatic control valve is a critical component that governs the actuation of the main pneumatic piston responsible for the vertical movement of the lower platen. The selected valve model—Festo VUVG series—is a compact, high-performance solenoid valve designed for precise and reliable control of double-acting pneumatic actuators.

In our system, this valve regulates the extension and retraction cycles of the piston, enabling timed and consistent movement during the forming process. The valve is mounted on the front face of the chassis in an easily accessible location, allowing the operator to quickly perform manual overrides, diagnostics, or maintenance if needed. Its installation position was chosen for both ergonomic operation and simplified pneumatic line routing.

The valve is electrically controlled via the central control unit, which sequences its operation in coordination with the vacuum module and other subsystems. It plays a key role in ensuring that the piston responds swiftly and symmetrically, contributing to the system's overall stability and repeatability.

Design Features & Technical Specifications – Pneumatic Control Valve:

Table 9: Specifications of Pneumatic Control Valve

Parameter	Specification
Component Type	5/2-way single solenoid valve
Model	Festo VUVG-L10-B52-T-M7-1P3
Function	Controls extension and retraction of the main pneumatic piston
Mounting Location	Front face of the chassis (operator-accessible)
Control Signal	24V DC via centralized control panel
Pneumatic Ports	M7 thread, suitable for 4–6 mm tubing
Operating Pressure Range	2–8 bar
Manual Override	Integrated push-button for emergency/manual actuation
Response Time	Fast switching for accurate piston positioning
Additional Features	Compact size, DIN-rail mountable, low power consumption

3.5.7 Vacuum Plates

The forming process of the molded fiber packaging system is centered around a dual vacuum table mechanism and a rotating transfer tray. This sub-system enables the controlled extraction and transfer of the pulp material from the process pool to the drying stage.

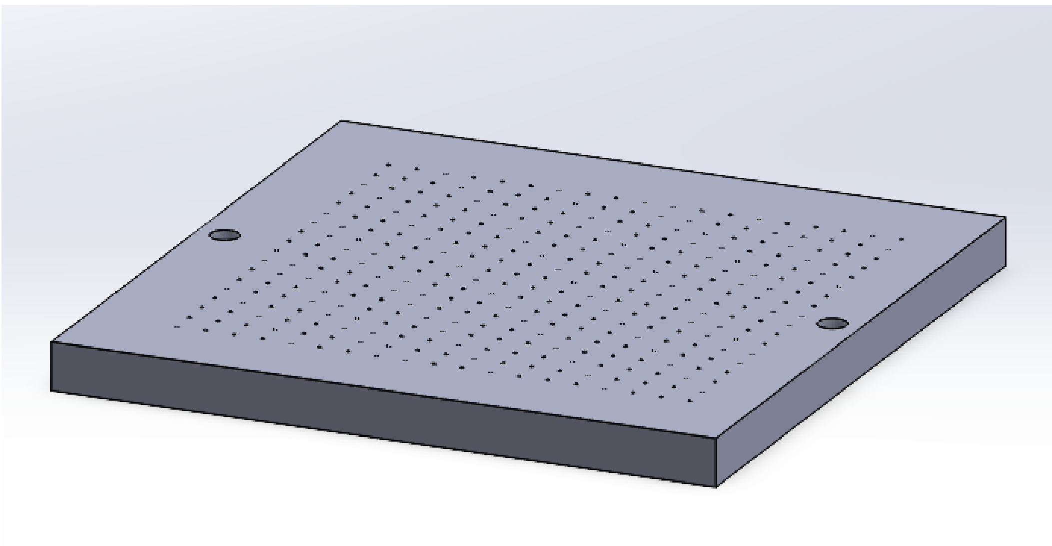


Figure 22: CAD Model of the Lower Plate

a) Bottom Vacuum Table (Moving Plate)

- **Function:**
  The bottom table is submerged into the pulp pool during the forming phase. Using a vacuum system, it draws pulp fibers through the mold surface, forming a thin fiber layer.

- **Operation:**
  Once the pulp is collected, the bottom table rises upward to press against the upper vacuum table for drying and transfer.

- **Dimensions:**
  Width × Length: 700 mm × 700 mm
  Thickness: 50 mm

- **Material:**
  Aluminum is chosen for its lightweight, machinability, and corrosion resistance.

b) Top Vacuum Table (Fixed Plate)

- **Function:**
  The upper table remains stationary and performs two roles:
    - It receives the pulp from the bottom plate via vacuum-assisted adhesion,
    - It later releases the semi-formed pulp by blowing compressed air downward.

- **Dimensions:**
  Same as bottom: 700 mm × 700 mm, 50 mm thickness.

- **Vacuum and Pressure Ports:**
  Integrated channels allow both vacuum suction and compressed air ejection as needed.

3.5.8 Movable Tray

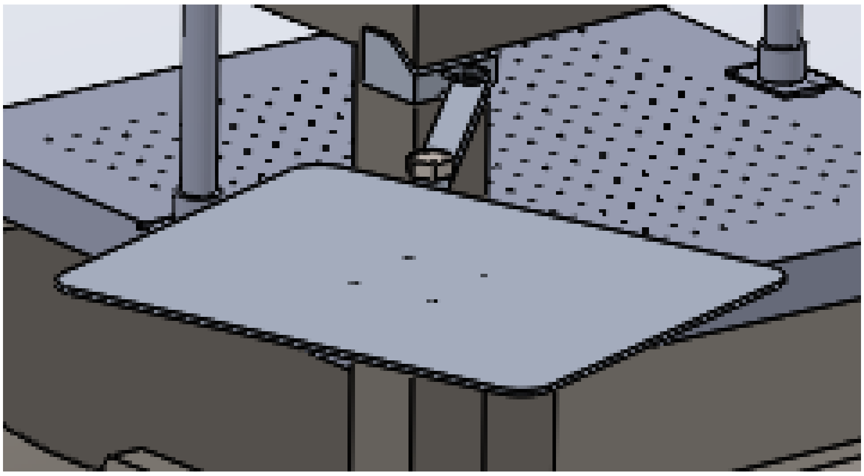


Figure 23: CAD Model of the Movable Tray

- **Function:**
  A rotating aluminum tray mounted on a horizontal axis arm, responsible for receiving the formed pulp from the upper table and transporting it to the drying section.

- **Operation:**
  After the top table finishes the forming stage, the tray rotates underneath it. Then, using air-blow, the fiber mat is transferred to the tray surface.

- **Dimensions:**
  - Width × Length: 500 mm × 400 mm
  - Thickness: 5 mm

- **Features:**
  - Mounted on a pivot system for controlled rotation,
  - Light enough for pneumatic or stepper-driven actuation,
  - Surface texture optimized for temporary pulp adhesion.

Note: Material selection, manufacturability constraints, and component sourcing for the vacuum plates and rotary tray are discussed in Component Selection and Cost Analysis.

3.5.9 Auxiliary Fluid Power Components – Vacuum and Compressed Air Systems

The system incorporates **two vacuum sources** and **two compressed air lines**, each serving different stages of the forming cycle.

a) Lower Forming Tray – Vacuum and Blow

- **Vacuum Operation:**
  When the lower tray is submerged into the pulp pool, a vacuum is applied to extract water and pull the pulp onto the perforated surface.

- **Compressed Air Operation:**
  After the lower tray is lifted, compressed air is introduced from underneath to push the semi-formed pulp upwards toward the upper tray for final shaping.

b) Upper Forming Tray – Vacuum and Blow

- **Vacuum Operation:**
  The upper tray receives the upward-propelled pulp and applies suction to hold the shape firmly.

- **Compressed Air Operation:**
  At the end of the process, a burst of air is applied to **release the final part onto a rotating tray** underneath for manual retrieval or drying.

The system details, technical specifications, final model selections for the vacuum pump and air compressor are further detailed in P&ID, Component Selection and Cost Analysis.

4. CALCULATIONS

4.1 Speed, Force, and Torque Calculations

The agitator used in the system is driven by a low-speed, high-torque motor–gearbox assembly. In this section, the torque at the motor output is calculated, and the adequacy of the mechanical force required by the system is evaluated.

4.1.1 Motor–Gearbox Configuration

The selected motor is a standard four-pole three-phase asynchronous motor, which operates at approximately 1400 rpm under a 50 Hz power supply. Due to the low-speed requirement, this motor is coupled with a worm gear reducer that provides a 20:1 reduction ratio.

Target rotational speed:

To ensure proper mixing of the paper pulp without damaging its structure, the maximum target rotational speed is:

n = 80 rpm (maximum)

A low rpm is preferred because excessive turbulence can damage the fibers, reduce product quality, and cause foaming.

Motor speed:

The speed of a standard four-pole asynchronous motor operating at 50 Hz:

$$n_{motor} = 1400 \text{ rpm}$$

Gear reduction ratio:

To achieve the desired output speed:

$$n_{agitator} = \frac{n_{motor}}{Reduction\ ratio} = \frac{1400}{20} = 70\ rpm$$

The speed at the gearbox output is approximately 70 rpm. This speed allows the agitator to distribute the pulp homogeneously inside the tank without spinning too fast. It is specifically chosen to maintain the fibrous structure of the pulp, minimize foaming, and prevent sedimentation.

4.1.2 Torque Calculation

The relationship between the mechanical power of the motor and the torque at the gearbox output is given by the following equation:

$$T = \frac{P \cdot 60}{2\pi \cdot n}$$

Where:

- **T**: Torque (Nm)
- **P**: Motor output power (W)

- **n**: Gearbox output speed (rpm)

Using the given values:

- **P = 0.75 kW = 750 W**
- **n = 70 rpm**

$$T = \frac{750 \cdot 60}{2\pi \cdot 70} \approx 102.5Nm$$

This result represents the theoretical torque transferred to the agitator at the gearbox output.

Adequacy Assessment

The calculated torque of **102.5 Nm** is sufficient for the agitator system, which uses a **20 mm diameter shaft** and a **dual-blade mixer with a 500 mm radius**. The system is optimized to operate at low rotational speeds. Therefore, high moment of inertia values are not expected, and the system is unlikely to be subjected to stress under sudden loads.

Moreover, the self-locking feature of the worm gear reducer prevents the agitator from continuing to rotate due to its own weight when the system is stopped. This eliminates the need for an additional braking mechanism.

4.2 Head Loss and Flow Calculation

4.2.1 Head Loss and Flow Calculation for Pump 1 (Tank to Pool)

In the designed system, the first pump transfers the paper pulp mixture from the bottom of the tank to the collection pool. The fluid follows a relatively short path primarily in the horizontal direction, with an initial 100 mm vertical descent. The piping is constructed using 50 mm outer diameter pipes (≈ 47–48 mm inner diameter assumed), and the layout includes multiple bends, as illustrated below:

- 1 vertical segment of 100 mm downward
- 3 horizontal segments totaling 1430 mm (100 + 975 + 355 mm)
- 5 pipe elbows with 90° angle and 25 mm bend radius

Step 1: Estimating Total Pipe Length

Each elbow adds approximately $\frac{\pi}{2} \cdot r$ to the total length, which is:

$$L_{elbows} = 5 \cdot \frac{\pi}{2} \cdot 25\,mm \approx 196.35\,mm$$

Thus, total equivalent pipe length is:

$$L_{total} = 100 + 100 + 975 + 355 + 196.35 = 1726.35mm \approx 1.73m$$

Step 2: Assumed Flow Rate

Since the system does not require continuous high-speed flow, and given the viscosity and density of the pulp, a moderate flow rate of 1 m^3/h (≈ 16.7 L/min or 0.000278 m^3/s) is assumed for calculation purposes.

Step 3: Velocity Calculation

The inner diameter of the pipe is approximated as 47 mm → radius ≈ 0.0235 m

Cross-sectional area:

$$A = \pi r^2 = \pi \cdot (0.0235)^2 \approx 1.73 \times 10^{-3} m^2$$

Fluid velocity:

$$v = \frac{Q}{A} = \frac{0.000278}{1.73 \times 10^{-3}} \approx 0.141\, m/s$$

Step 4: Frictional Head Loss Calculation

The Darcy-Weisbach equation is used to estimate head loss due to pipe friction:

$$h_f = f \cdot \frac{L}{D} \cdot \frac{v^2}{2g}$$

Where:
f = friction factor (assumed 0.035 for viscous pulp)
L = 1.73 m
D = 0.047 m
v = 0.141 m/s
g = 9.81 m/s^2

$$h_f = 0.035 \cdot \frac{1.73}{0.047} \cdot \frac{(0.041)^2}{2(9.81)} \approx 0.002\, m$$

Frictional losses are negligible due to low speed and short distance.

Step 5: Total Dynamic Head (TDH)

The system has an initial 100 mm vertical drop, which may create a siphon effect. To ensure conservative design, a minimal static head of 0.5 m is assumed to account for possible flow resistance and level differences:

$$TDH = h_{static} + h_f = 0.5 + 0.002 \approx 0.5\, m$$

Result:

The pump for this line must provide:

- Minimum head: ≈ 0.5 m
- Flow rate: 1 m^3/h
- Media: viscous paper pulp with fibrous content

This configuration indicates the need for a low-head, low-speed pump capable of handling viscous media with suspended solids. Recommended types include:

- Flexible impeller pumps

- Low-speed centrifugal pumps
- Lobe or peristaltic pumps (if hygiene is a priority)

4.2.2 Head Loss and Flow Calculation for Pump 2 (Pool to Tank)

The second pump in the system is responsible for transferring excess pulp mixture from the bottom of the collection pool back to the upper inlet of the tank. The flow direction in this case requires a vertical elevation gain, making head pressure more critical for pump selection.

The fluid travels through a 50 mm diameter pipe and passes through four 90° elbows with a bend radius of 25 mm. The segments and geometry are summarized as follows:

- 1 vertical drop: 100 mm downward
- 1 horizontal segment: 300 mm
- 1 vertical rise: 1500 mm
- 1 final horizontal segment: 200 mm
- 4 elbows, each 90° with 25 mm bend radius

Step 1: Estimating Total Pipe Length

Each elbow adds arc length calculated by $s = r \cdot \theta = 25 \cdot \frac{\pi}{2} \approx 39.27\ mm$

$$L_{elbows} = 4 \cdot 39.27 \approx 157.08\ mm$$

$$L_{straight} = 100 + 300 + 1500 + 200 = 2100\ mm$$

$$L_{total} = 2100 + 157.08 = 2257.08\ mm \approx 2.26\ m$$

Step 2: Assumed Flow Rate

To maintain consistency with Pump 1 and provide low-speed, gentle transfer of the pulp mixture, a volumetric flow rate of 1 m^3/h (0.000278 m^3/s) is assumed.

Step 3: Velocity Calculation

Using the same pipe cross-sectional area as in Pump 1:

- Pipe inner diameter: ≈ 47 mm → radius ≈ 0.0235 m
- Cross-sectional area:

$$A = \pi r^2 = \pi \cdot (0.0235)^2 \approx 1.73 \times 10^{-3} m^2$$

$$v = \frac{Q}{A} = \frac{0.000278}{1.73 \times 10^{-3}} \approx 0.141\ m/s$$

Step 4: Frictional Head Loss

Darcy-Weisbach equation is applied:

$$h_f = f \cdot \frac{L}{D} \cdot \frac{v^2}{2g}$$

Where:
f = friction factor (assumed 0.035 for viscous pulp)
L = 2.26 m (total length)
D = 0.047 m (pipe inner diameter)
v = 0.141 m/s
g = 9.81 m/s²

$$h_f = 0.035 \cdot \frac{2.26}{0.047} \cdot \frac{(0.041)^2}{2(9.81)} \approx 0.002\, m$$

Step 5: Static Head

The pump needs to overcome a net vertical rise of approximately 1400 mm (1500 mm upward minus 100 mm initial drop):

$$h_{static} = 1.4\, m$$

Step 6: Total Dynamic Head (TDH)

$$TDH = h_{static} + h_f = 1.4 + 0.002 \approx 1.402\, m$$

Summary

- Flow rate (Q): 1 m³/h
- Total dynamic head (TDH): ≈ 1.4 m
- Fluid: Viscous pulp with fibrous content
- Pipe size: Ø50 mm (outer diameter)

This scenario requires a pump capable of delivering low flow at a modest elevation gain, while being resistant to fiber blockage and compatible with pulp-based materials.

5. COMPONENT SELECTION

5.1 Component Selection for Chassis Frame

The chassis frame is built from 80 × 80 mm square steel profiles, chosen for their balance of strength, availability, and ease of fabrication. This simple, modular structure supports all subsystems with minimal material waste and straightforward assembly.

5.1.1 Manufacturability and Cost Criteria

- **Material & Profile:** 80 × 80 × 3 mm S235JR mild steel profiles—commonly stocked by Turkish steel service centers—require only straight cuts and standard MIG welding.
- **Cutting & Welding:** All profile lengths are laser-cut or band-sawed to size; joints are welded with simple fillets, avoiding complex fixturing.
- **Labor & Overhead:** A typical small-shop labor rate (~200 TRY/hour) and an estimated 8 hours of cutting, welding, and finishing work keep fabrication costs reasonable.
- **Surface Protection:** A basic zinc-plated finish is applied in-house to guard against corrosion, avoiding the higher cost of powder coating.

Cost Item	Quantity / Unit	Unit Cost (TRY)	Subtotal (TRY)
Steel profiles (15 m)	20 TRY / m	20	300
Cutting & Welding labor	8 hours @ 200 TRY/hr	200 / hour	1 600
Gusset plates & hardware	Assorted bolts & gussets	—	500
Anti-vibration feet (4)	100 TRY / each	100	400
Estimated Total			**2800 TRY**

5.1.2 Supply and Use of Standard Components

- **Steel Profiles:** Sourced from major Turkish distributors (e.g., Erdemir Service Centers), ensuring rapid delivery and certified material properties.
- **Fasteners & Gusset Plates:** Standard M10 bolts, nuts, and pre-cut gusset kits available from hardware suppliers (e.g., Sürmeli, Özgün).
- **Anti-Vibration Feet:** Catalog items from industrial parts vendors; no custom machining required, simplifying replacement and maintenance.
- **Finishing Materials:** Zinc plating chemicals and blasting media procured locally to maintain low per-unit costs.

5.2 Selection of the Pneumatic Piston

In choosing the pneumatic cylinder that drives the lower platen, our emphasis was on reliable performance, straightforward installation, and cost-effective sourcing within Turkish market conditions. The selected ISO-standard profile cylinder delivers the required 400 mm stroke and 50 mm bore, while remaining compatible with commonly available fittings and mounting hardware.

5.2.1 Manufacturability and Cost Criteria

- **Standardization:** An off-the-shelf 50 × 400 mm pneumatic cylinder (Festo DSNU-50-400) was chosen to avoid custom machining and ensure dimensional accuracy.
- **Installation Simplicity:** The cylinder's flat mounting surfaces and single-piece profile eliminate the need for precision brackets beyond a simple plate, reducing assembly time.

5.2.2 Supply and Use of Standard Components

- **Cylinder:** Sourced from Festo Türkiye or equivalent local distributor—model DSNU-50-400-PS with adjustable cushioning.
- **Mounting Bracket:** Simple 100 × 100 × 100 mm S355 steel plate with central bore, procured from local steel service center; requires only drilling and deburring.
- **Pneumatic Fittings & Tubing:** Push-in fittings (M7 or ¼″) and 6 mm PU tubing are standard items available from multiple pneumatic suppliers.
- **Fasteners:** M8 and M10 bolts and locknuts, zinc-plated, purchased in bulk for spares and maintenance.

5.2.3 Cost Breakdown - Pneumatic Piston Assembly

Table 10: Cost Analysis for Pneumatic Piston Assembly

Cost Item	**Quantity / Unit**	**Unit Cost (TRY)**	**Subtotal (TRY)**
Pneumatic cylinder (50×400)	1	1 500	1 500
Mounting bracket (100×100×100)	1	300	300
Push-in fittings (4 pcs)	4	50	200
PU tubing (6 mm × 20 m)	1	100	100
Assembly labor	2 hours @ 200 TRY/hr	200/hr	400
Estimated Total			**2 500 TRY**

5.3 Component Selection for the Pneumatic Control Valve

In specifying the control valve for the main pneumatic actuator, priority was given to ease of integration, reliable performance, and use of an ISO-standard, off-the-shelf solution that requires minimal customization.

5.3.1 Manufacturability and Installation Criteria

- **Standard Module:** The Festo VUVG series 5/2-way single-solenoid valve was selected for its compact envelope and standardized porting (M7 thread), eliminating the need for custom manifolds or adaptors.
- **Mounting Ease:** The valve's DIN-rail mounting option and integrated push-in fitting ports allow for rapid installation on the front chassis panel, with no special tools beyond common hex keys and tubing cutters.
- **Electrical Interface:** A 24 V DC solenoid coil with built-in LED indicator simplifies wiring diagnostics; the valve connects directly to the machine's control panel via a pre-terminated cable harness.
- **Maintenance Access:** Its front-facing location on the chassis ensures that manual override, visual inspection, and replacement can be performed without disassembling adjacent subsystems.

5.3.2 Supply and Use of Standard Components

- **Valve Unit:** Festo VUVG-L10-B52-T-M7-1P3 (5/2-way, single solenoid)
- **Mounting Hardware:** DIN-rail clip, M5 panel screws, and rubber vibration dampers (all catalog items)
- **Pneumatic Fittings:** Push-in M7 to 6 mm PU tubing connectors
- **Electrical Accessories:** 24 V DC cable harness with M8 connector and ferrules

5.3.3 Cost Breakdown – Pneumatic Control Valve Assembly

Table 11: Cost Analysis for Pneumatic Control Valve Assembly

Cost Item	Quantity	Unit Cost (TRY)	Subtotal (TRY)
Festo VUVG-L10-B52-T-M7 Valve	1	1 200	1 200
DIN-rail mounting kit	1	100	100
Push-in fittings (M7 → 6 mm)	4	50	200
Cable harness & connector kit	1	150	150
Installation labor	1 hour	200/hr	200
Estimated Total			**1 850 TRY**

5.4 Pump Selection Based on Hydraulic Calculations and Application Constraints

In the designed molded pulp forming system, two independent pumps are required to transport pulp slurry between the tank and the pool. Pump 1 is responsible for transferring the processed pulp from the bottom outlet of the tank to the pool. Pump 2 circulates the overflowed pulp back from the pool to the top inlet of the tank. Both pumps serve different positions in the system and operate under different hydraulic conditions, thus requiring appropriate selection based on calculated performance requirements, fluid characteristics, and practical integration constraints.

5.4.1 Pump 1 – Tank to Pool Transfer

- **Design Criteria:**
- **Total Dynamic Head (TDH):** ~0.5 m
- **Flow Rate:** 1 m^3/h

- **Piping:** Ø50 mm outer diameter (assumed Ø47 mm ID)
- **Fluid:** Viscous paper pulp with fibrous content
- **Constraints:** Low-pressure, gentle and clog-free transport, compact base mounting

Selected Pump: Sailflo FP32-24 Flexible Impeller Pump

- Max flow capacity: 20 L/min (1.2 m^3/h)
- Max head: 3.0 m
- Voltage: 24 V DC
- Construction: Nitrile rubber impeller, corrosion-resistant plastic body
- Price: ~₺3,363 (Hepsiburada, June 2025)

Figure 24: Sailflo FP32-24 flexible pump

This pump was selected due to its compatibility with low-head applications and its gentle pumping action. The flexible impeller design ensures minimal shear on the fibrous slurry, reducing the risk of pulp structure degradation. Its compact size and DC operation make it ideal for integration into the base of the tank structure. Although its maximum flow rate slightly exceeds the requirement, flow can be adjusted using throttling or duty cycling.

5.4.2 Pump 2 – Pool to Tank Circulation

Design Criteria:

- **Flow rate (Q):** 1 m^3/h
- **Total Dynamic Head (TDH):** ~1.4 m
- **Fluid:** Fibrous slurry, containing solid particles
- **Pipe diameter:** Ø50 mm
- **Constraints:** Must handle vertical lift and suspended solids without clogging

Selected Pump: Einhell GC-DP 9035 N Submersible Dirty Water Pump

- **Max flow:** 18,000 L/h (18 m^3/h)

- **Max head:** 9.0 m
- **Particle tolerance:** up to 35 mm
- **Power supply**: 230 V AC, 900 W
- **Housing:** Stainless steel
- **Price:** ~₺3,356 (Amazon Turkey / Hepsiburada, June 2025)

Figure 25: Einhell GC-DP 9035 N product

This solids-handling submersible pump is designed for wastewater and slurry applications. Its ability to tolerate large particles makes it highly suitable for pulp systems with potential fiber clumps. Although its maximum flow rate is significantly higher than required, flow can be throttled to match the 1 m³/h target.

Summary Table

Table 12: Specifications of Pumps

Parameter	Pump 1 – Tank to Pool	Pump 2 – Pool to Tank
Required Flow Rate	1 m³/h	1 m³/h
Total Head	~0.5 m	~1.4 m
Fluid Type	Fibrous, low-viscosity pulp	Fibrous slurry with solids
Pump Type	Flexible impeller (DC)	Dirty water submersible (AC)
Power Supply	24 V DC	230 V AC
Control Method	Throttling / cycling	Throttling

5.4.3 Cost Summary

Neither of the selected pumps are custom-fabricated; both are **off-the-shelf, commercially available** products. This greatly simplifies procurement and shortens lead time. The flexible impeller pump (Pump 1) has a compact design that fits directly under the tank and can be integrated with basic throttling control. The submersible pump (Pump 2) is designed for direct immersion into the slurry pool, requiring minimal mounting infrastructure.

In terms of cost, both pumps fall within the budget expectations for pilot-scale systems. As of June 2025:

Table 13: Cost Analysis for Pumps

Pump	Model	Qty	Unit Price (TRY)	Total (TRY)
Flexible Impeller Pump	Sailflo FP32-24	1	3,363	3,363
Dirty Water Submersible Pump	Einhell GC-DP 9035 N	1	3,356	3,356
Total				**6,719**

Note: Prices reflect market listings as of June 2025 and may vary by supplier.
The choice of standard, widely used components avoids the need for high-precision machining or specialized materials, contributing to the project's overall manufacturability.

5.4.4 Supply and Use of Standard Components

Both selected pumps are standard products readily available in the Turkish market via major online retailers such as Hepsiburada and Amazon Turkey. This ensures supply chain stability and allows for **easy replacement or scaling** in future iterations of the system.

By using **standard fittings and widely used pipe diameters (Ø50 mm)**, the pumps are compatible with other process components such as valves, tanks, and piping networks. This not only simplifies integration but also enables **low-cost maintenance** and part interchangeability.

The motor specifications (24 V DC for Pump 1, 230 V AC for Pump 2) align with available power sources in typical laboratory or industrial test environments, further confirming their compatibility with standard infrastructure.

5.5 Component Selection for Tank

The ideal tank for this design is a **750 L, leg-supported, cone-bottom HDPE mixing tank** with a bottom outlet ready for integration with a three-way valve. Such a tank matches the process need for ~600 L effective volume, 10 mm wall thickness (HDPE/PP), a sloped base to prevent sedimentation, and ~480 mm leg clearance for the agitator and valve.

A suitable candidate from a Turkish manufacturer is the **750 L HDPE Cone-Bottom Mixing Tank with Steel Frame** from Barat Endüstriyel Plastik. It offers:

- **Diameter:** ~950 mm; **Height:** ~1500 mm
- **Capacity:** 750 L total (≈ 600 L working at 80%)
- **Base:** Sloped cone with centre outlet flange
- **Support:** Steel-frame legs (≈ 480 mm clearance)
- **Material:** UV-stabilized HDPE with PP/steel flanges

5.5.1 Manufacturability and Cost Criteria

Barat’s 750 L HDPE tank is manufactured using **rotational molding** or **welded plate**

assembly, both cost-effective and scalable. It includes:

- Precision cone geometry to ensure fluid drainage
- Pre-fitted flanges for agitator shaft and valve installation
- Frame legs facilitating forklift handling and sub-components (motor, valve) clearance

Estimated Cost:

– **₺25,000–35,000** (based on similar 1000 L polypropylene models; actual quote required)

This price is significantly lower than custom stainless steel tanks, offers faster lead times (4–6 weeks), and supports standard HDPE fabrication methods.

5.5.2 Supply and Use of Standard Components

Supplier: Barat Endüstriyel Plastik

- Offers **custom polypropylene/HDPE mixing tanks** in sizes 500 L, 1000 L, etc.
- Supports cone-bottom and leg-supported configurations
- Equipment includes standard flanged connections (PP with glass-fiber reinforcement), compatible with shaft seals and valves

Product Listing (Model Estimate): 750 L Cone-Bottom Mixing Tank

- **Capacity:** 750 L total
- **Material:** HDPE/PP, UV-resistant
- **Flanges:** Center cone outlet, side top ports
- **Support Frame:** Steel legs (~480 mm clearance)
- **Estimated Price:** ₺30,000 (with labor and flanges)

5.6 Component Selection for Agitator

The agitator was designed to ensure uniform mixing of paper pulp and to minimize the risk of fiber sedimentation during operation. Based on the tank geometry (1000 mm diameter, 1060 mm height), a vertical agitator shaft with two levels of blades was determined to be optimal.

Technical Specifications:

- **Shaft diameter:** 20 mm
- **Shaft length:** 1150 mm
- **Rotation speed:** Max 80 rpm (low shear operation)
- **Blade extension:** 250 mm per side (500 mm total agitation diameter = 50% of tank ID)
- **Blade levels:**
    - Lower: near the bottom (≈ 100 mm above base)
    - Middle: midpoint of shaft (≈ 550–600 mm height)

This configuration provides sufficient turbulence for mixing without disrupting the slurry's fiber structure. The vertical alignment of the shaft, with top-mounted drive and bottom-supported bearing housing, ensures minimal wobble and smooth operation even at continuous use.

5.6.1 Manufacturability and Cost Criteria

The agitator components were selected to prioritize **low-cost fabrication**, **chemical resistance**, and **mechanical reliability**:

- The shaft and blades were modeled for **machinability** and **easy assembly**, requiring basic turning and welding operations.
- The blade geometry is intentionally simple (flat bar or sheet profiles) and mounted via through-holes or welding.
- The design avoids complex geometries, ensuring fabrication with standard tools.

Estimated Costs (2025, Türkiye):

Table 14: Estimated Cost of Agitator (2025, Türkiye):

Component	Material	Unit Cost (TRY)	Notes
Shaft (20×1150 mm)	AISI 304 SS	~₺450-650	CNC turned or round bar stock
Blades (4 pcs)	AISI 304	~₺300-500	3 mm thickness, laser-cut
Fasteners + pins	A2 SS	~₺100	Allen pins or grub screws
Total	–	**~₺850-1250**	Full agitator build estimate

5.6.2 Supply and Use of Standard Components

To simplify maintenance and ensure interchangeability, all parts were selected from **standard mechanical components** available on the Turkish market:

- The **shaft** was made from **AISI 304 stainless steel**, a widely available corrosion-resistant material compatible with wet pulp environments.
- **Flat blades** were made either from stainless steel (for durability) or rigid PVC sheets (for lower cost and fiber protection).

These components are easily sourced from mechanical suppliers such as KMS, Makelsan, or online industrial vendors.

5.7 Component Selection for Bearing Housing and Riser Plate

To ensure stable operation of the agitator shaft and minimize vibrations during mixing, a support mechanism was implemented at the lower end of the shaft. The selected component is a **UCF204 pillow block bearing**, which provides both radial and axial alignment. However, due to the tank’s central bottom outlet, the bearing could not be mounted directly at the tank floor.

Figure 26: UCF204 pillow block bearing

The selected UCF204 unit is widely available in Türkiye through platforms such as **Hepsiburada**, making it easily replaceable and scalable. Key specs:

- **Product:** EXHOO UCF204 pillow block bearing,
- **Bore diameter:** 20 mm
- **Body size:** 90 × 90 mm
- **Mounting holes:** 11 mm
- **Material:** Cast iron housing with pre-lubricated bearing
- **Price:** ₺123 (June 2025)

To address this, a **90 × 90 × 5 mm square steel mounting plate**, elevated by four legs to a height of **60 mm**, was designed and placed beneath the tank. This elevation serves two purposes:

- Ensures mechanical clearance for the pulp discharge outlet and the three-way valve,
- Provides a fixed surface to mount the bearing housing securely.

Together, the bearing and elevated plate form a robust substructure that allows the agitator shaft to rotate smoothly while avoiding contact with the discharge system and resisting torsional vibrations.

5.7.1 Manufacturability and Cost Criteria

Both components in the shaft support system were selected for ease of manufacturing, affordability, and compatibility with standard fabrication methods:

- The **UCF204 bearing unit** is a readily available component commonly used in rotating machinery. It requires no custom machining and comes with a 4-bolt flange base for direct mounting.
- The **mounting plate** was designed as a simple 90 × 90 mm steel plate, **5 mm thick**, fabricated using laser or plasma cutting. Four short legs (each ~60 mm) were welded or bolted underneath the plate to elevate the bearing.

These features allow for easy assembly and integration without the need for complex machining or specialized parts.

Estimated Costs (June 2025, Türkiye):

Table 15: Estimated Cost of Agitator Bearing

Component	Unit Cost (TRY)	Notes
UCF204 Bearing Block	₺123	Standard cast housing with 20 mm bore
Steel Plate + Legs	~₺300–₺500	ST37 or AISI 304, includes welding/fastening
Total Assembly	**~₺423–₺623**	Shaft support system cost

5.7.2 Supply and Use of Standard Components

All elements of the agitator shaft support system are off-the-shelf or easily fabricated parts:

- The selected **UCF204** bearing unit was purchased via the Turkish online marketplace Hepsiburada.
- The **90 × 90 mm mounting plate** can be cut from standard ST37 or AISI 304 stainless steel sheets using CNC or laser cutting services.
- The **elevation legs** may be manufactured from short sections of steel tubing or square bar stock, welded or bolted to the plate depending on structural needs.

These choices ensure:

- **Low production cost**,
- **Fast lead times**,
- **Compatibility with other standard components**,
- And **easy replacement or scaling** during future iterations.

5.8 Component Selection for the Agitator Drive Unit (Motor-Gearbox)

The drive system of the agitator was determined based on the mechanical requirements of the pulp mixing process. A maximum agitator shaft speed of **80 rpm** was selected to ensure gentle mixing, minimize fiber damage, and avoid excessive turbulence in the semi-fluid paper pulp.

To achieve this, the selected unit is a **combined electric motor and worm gearbox**. The required output torque and reduced speed are obtained using a 20:1 gear reduction ratio.

Figure 27: Selected Drive Unit (Motor-Gearbox)

Selected Unit:

- **Model:** HPC Power Transmission – CHM63-20-90S4
- **Motor speed (nominal):** 1400 rpm (4-pole, 50 Hz)
- **Gear ratio:** 20:1
- **Calculated output speed:** 1400 / 20 = 70 rpm
- **Shaft compatibility:** Output shaft Ø20 mm (direct fit with mixer shaft)

This configuration provides direct torque transmission from motor to shaft without needing an additional coupling or adapter.

5.8.1 Manufacturability and Cost Criteria

The selected drive unit — **HPC Power Transmission CHM63-20-90L4** — is a commercially available integrated motor–gearbox system, offering a compact, efficient, and low-maintenance solution for the agitator mechanism. The use of a **worm gearbox with a 20:1 ratio** enables direct reduction from the motor's nominal speed of 1400 rpm to a suitable agitator shaft speed of **70 rpm**.

This model is compatible with IEC standards and offers excellent reliability for industrial-scale mixing operations.

Market Pricing (June 2025):

Table 16: Agitator Drive Unit (Motor-Gearbox) Market Pricing (June 2025)

Specification	Value
Model	CHM63-20-90L4
Motor Type	4-pole, 3-phase asynchronous motor
Power	1.50 kW
Nominal Speed	1400 rpm
Gear Ratio	20:1
Output Speed	~70 rpm
Output Torque	164 Nm
Output Shaft Diameter	Ø20 mm
Service Factor	0.8
Price (without VAT/shipping)	**538.97 EUR** (≈ ₺24.644, June 2025)

This price was obtained from a European industrial supplier. Depending on tax, customs, and shipping, the total landed cost in Türkiye may vary between **₺20,000–25,000**.

5.8.2 Supply and Use of Standard Components

The CHM63-20-90L4 unit was sourced from HPC Europe's official website, which provides full access to technical documentation, CAD models, and installation guides. This gearbox–motor assembly is compatible with IEC standards and features: **Interchangeability** with other IEC-compatible gearboxes and motors

- **Ease of integration** with CAD models, assembly layouts, and electrical systems
- **Direct shaft connection**: 20 mm output shaft couples directly with the agitator shaft, eliminating the need for an additional coupling
- **Horizontal flange mounting (B5 or B14 type)** simplifies installation on a fixed platform above the tank

5.9 Component Selection for Flow Control Component - 3-Way Valve at Tank Bottom

To enable both **pulp transfer to the process pool** and **cleaning/discharge functions** from a single outlet, a **3-way flow control valve** is required at the bottom center of the tank. The outlet pipe diameter is approximately Ø48 mm, corresponding to **DN50 nominal pipe size**.

The selected valve must support:

- Manual operation (no automation required),
- Resistance to water-based pulp mixture and slight pressure changes,
- Compatibility with threaded connections for ease of installation.

Therefore, a **T-port 3-way ball valve** with a full-bore flow design and stainless steel body was considered optimal for long-term durability and chemical compatibility.

5.9.1 Manufacturability and Cost Criteria

While premium industrial valves (e.g., Danfoss rotary actuated 3-way valves) are available, they are often prohibitively expensive (₺10,000+). Instead, a **cost-effective stainless steel 3-way valve** option was selected.

Figure 28: Stainless Steel 3-Way Threaded Ball Valve

Selected Alternative:

- **Product Name:** Stainless Steel 3-Way Threaded Ball Valve
- **Connection Type:** G-threaded ends (compatible with pipe fittings)
- **Material:** 304 Stainless Steel
- **Configuration:** T-Port, Full Bore

- **Bore Size:** 2" (≈ DN50)
- **Control:** Manual rotary handle
- **Seal Material:** PTFE
- **Operating Pressure:** ≤ 1000 PSI
- **Temperature Range:** –20°C to +180°C
- **Supplier:** Alibaba

Price Analysis:

Table 17: Price Analysis for 3-Way Valve at Tank Bottom

Component	Source	Unit Price (USD)	Unit Price (TRY)	Estimated Landed Cost (TRY)
Stainless Steel 3-Way Ball Valve	Alibaba (China)	**$15.00–$35.00**	~₺595–₺1,388	~₺600–₺1,250 (with tax & shipping)

Total Estimated Cost : ~₺1195-2638

This makes the stainless-steel option up to 90% more affordable than premium European alternatives while still delivering high chemical resistance and mechanical strength.

5.9.2 Supply and Use of Standard Components

- **Supplier Platform:** Alibaba (direct-from-manufacturer or distributor)
- **Material Compliance:** AISI 304 stainless steel—suitable for food-grade and corrosive environments

- **Installation Flexibility:** Threaded ends (female BSP or G-type) enable:
    - Easy integration with existing pipework
    - No welding or flanging required

- **T-Port Configuration:** Offers three operational modes:
    - Direct flow from tank to pool
    - Flow redirection to drain for cleaning
    - Simultaneous open state (optional)

These valves are widely used in semi-industrial and pilot-scale setups due to:
- Mechanical simplicity,
- Ease of cleaning,
- Durability in wet and fibrous environments.

5.10 Component Selection Based on System Requirements of Vacuum Tables and Movable Tray

To carry out the fiber molding and transfer processes, the system requires three essential mechanical components:
- **Two vacuum tables (top and bottom)** for pulp extraction and transfer,
- **One rotary tray platform** for intermediate handling and drying preparation.

The selection of these components was guided by:

- Dimensional compatibility with the forming molds,
- Resistance to corrosion and mechanical wear in a wet pulp environment,
- Lightweight structure for ease of actuation and movement.

Due to their size, simplicity, and customizable features, **machined aluminum plates** were selected for both vacuum tables and the rotary tray.

5.10.1 Manufacturability and Cost Criteria

a) Vacuum Tables (Top & Bottom)

Table 18: Specifications of Vacuum Tables

Feature	Specification
Dimensions	700 mm × 700 mm × 50 mm (each)
Material	Aluminum 5083 or 6061
Process	CNC milling or waterjet cutting
Integration	Embedded vacuum channels and ports
Estimated Unit Cost	~₺1,800–2,500 per plate (machined aluminum)

Aluminum was chosen due to its:

- **Excellent machinability**,
- **Corrosion resistance** in moist pulp environments,
- **High strength-to-weight ratio** for fast actuation.

Locally, such plates can be custom-cut by aluminum sheet fabricators or CNC workshops. Off-the-shelf options for this size and channeling do not exist; thus, **custom manufacturing is required**.

b) Movable Tray

Table 19: Specifications of Movable Tray

Feature	Specification
Dimensions	500 mm × 400 mm × 5 mm
Material	Aluminum sheet (Grade 5083)
Actuation Type	Pivoting on mechanical shaft or stepper arm
Surface Treatment	Polished or coated to prevent sticking
Estimated Unit Cost	~₺300–₺600 (cut and shaped aluminum tray)

The tray was designed to be:

- **Lightweight**, to minimize torque demand,

- **Durable**, despite frequent movement and air-blow interaction,
- **Easy to clean**, through smooth surface finish.

5.10.2 Supply and Use of Standard Components

While the trays and tables themselves are **custom-fabricated**, all peripheral components (vacuum connectors, pipe adapters, mounting shafts, fasteners) are **standard market parts**, available from:

- Local aluminum sheet suppliers (e.g., aluminyumburada.com),
- CNC service providers and waterjet cutters,
- Pneumatic fitting vendors (for vacuum/air channels).

This design choice **maximizes modularity and serviceability**, allowing easy maintenance and cost-efficient replacements.

5.11 Component Selection for Vacuum Pump and Compressor

a) Vacuum Pump for Forming Tables

- **Technical Criteria:**
  - Vacuum pressure: ≥ −0.85 bar
  - Flow rate: ≥ 100 m^3/h
  - Oil-free operation for hygiene and low maintenance

b) Air Compressor

- **Technical Criteria:**
  - Pressure: 6–8 bar
  - Tank volume: ≥ 50 L
  - Quiet operation, single-phase (220V)

5.11.1 Manufacturability and Cost Criteria

Figure 29: Vacuum Pump-Becker VT4.10

Figure 30: Air Compressor-Makita MAC610

Table 20: Estimated Costs for Vacuum Pump and Compressor

Component	Model	Estimated Cost (TRY)
Vacuum Pump	Becker VT4.10	₺18,000–₺22,000
Compressor	Makita MAC610	₺5,500–₺6,500

Together, these components contribute to automation and product quality while maintaining affordable sourcing.

5.11.2 Supply and Use of Standard Components

Table 21: Supply and Use of Vacuum Pump and Compressor

Feature	Becker VT4.10	Makita MAC610
Availability	Official Becker distributors (TR + EU)	Toolnation, Makita dealers
Compliance	CE marked, industry-standard	CE marked, DIY & semi-pro applications
Maintenance	Filter cleaning, no oil refill needed	Oil-free, silent, minimal upkeep
Integration Ease	Compact, mountable to side cabinet	Plug-and-play, mobile format

These components were selected based on **performance-to-cost ratio**, compatibility with other subsystems (valves, trays, and PLCs), and easy access to aftersales support and spare parts in Turkey.

Note: Supplier links are provided in Appendix E.

5.12 General Cost Summary Table

Component	Estimated Unit Cost (TRY)	Cost Range
Pneumatic System		
– Chassis (Frame)	₺2,800	Fixed
– Pneumatic Piston	₺2,500	Fixed
– Pneumatic Control Valve	₺1,850	Fixed
Subtotal (Pneumatic)	–	**₺7,150**
Tank System		
– Tank (Plastic, ~750 L)	–	**₺25,000–₺35,000**
– Agitator (Shaft + Blades)	–	**₺850–₺1,250**
– Bearing & Plate	–	**₺423–₺623**
– Motor + Gearbox (HPC)	–	**₺24,644**
– 3-Way Valve	–	**₺1,195–₺2,638**
Tray System		
– Vacuum Tables (x2)	–	**₺1,850–₺2,500**
– Movable Tray	–	**₺300–₺600**
Airflow System		
– Vacuum Pump (Becker VT4.10)	–	**₺18,000–₺22,000**
– Air Compressor (Makita MAC610)	–	**₺5,500–₺6,500**

Estimated Total System Cost:

- **Minimum Estimate:** ~₺84,912
- **Maximum Estimate:** ~₺102,905

Note: Prices include only primary hardware. Shipping, VAT, electronic control panel, assembly labor, and safety equipment are not included.

5.12.1 Cost Evaluation Commentary

The system has been developed using both industrial and semi-professional components to balance **cost**, **functionality**, and **availability**. The most cost-intensive elements include the **plastic tank**, **motor-gearbox system**, and **vacuum equipment**, which account for nearly 60% of the overall hardware budget.

- By choosing **PVC, HDPE, and PE-based plastic components**, structural corrosion risk is minimized, and total weight is reduced.
- **Using standard parts** such as the UCF204 bearing, DN50 ball valves, and AISI 304 materials ensures easy manufacturability and low lead times.
- The **vacuum and compressed air components** are critical not just for

actuation but for forming efficiency and quality, and were selected for reliability and quiet operation.
- Where applicable, **consumer-grade products with industrial-grade performance** (e.g., Makita MAC610) were used to minimize costs without compromising process effectiveness.

This approach enables scalability while ensuring sufficient robustness for a pilot production environment.

6. P&ID

P&ID stands for Piping and Instrumentation Diagram. It is a detailed technical drawing that shows the piping layout, pneumatic and hydraulic lines, valves, actuators, and instrumentation used in a system. A P&ID is an important document in automation and control engineering because it helps visualize how the components are connected and how the system works.

In a P&ID, each component is represented by a standard symbol. It includes connections between pneumatic actuators, solenoid valves, air filters, compressors, and control devices. It does not show the physical placement of components but rather focuses on how they are logically and functionally connected.

6.1 Purpose of Actuators:

The main purpose of this project is to automate the vertical motion of telescopic pneumatic actuator using compressed air. This actuator is designed to move up and down as part of an automated system. In the mechanical setup, the actuator lift a tray containing a plate from inside a tank and move it upward toward the upper plate. This motion needs to be precise and repeatable, which is why a fully automated pneumatic control system is used.

The system is modelled and simulated using FluidSIM software to visualize the operation and ensure proper function before building the physical circuit.

To achieve automation, the system uses a combination of pneumatic components and an electronic control circuit. The pneumatic circuit is powered by compressed air and controls the actuators using directional control valves and solenoid valves. The electronic part includes relays and limit switches, which send control signals to the solenoid valves, allowing the actuators to move in a controlled cycle.

This project demonstrates how pneumatic automation can be used in practical applications such as mold handling systems, where timing, reliability, and smooth motion are essential.

6.2 Actuators Pneumatic Diagram:

In this project, I used a single double-acting pneumatic telescopic actuator to create a continuous up-and-down motion in an automated system. In the mechanical design, the telescopic actuator was selected and modelled using the FluidSIM software. This actuator can extend and retract in multiple stages, allowing for a longer stroke in a compact space. While it is possible to use two actuators instead of one, using two actuators causes pressure losses in the piping. As a result, the two actuators may not move simultaneously at the same speed or level. This can lead to vibrations and instability in the system.

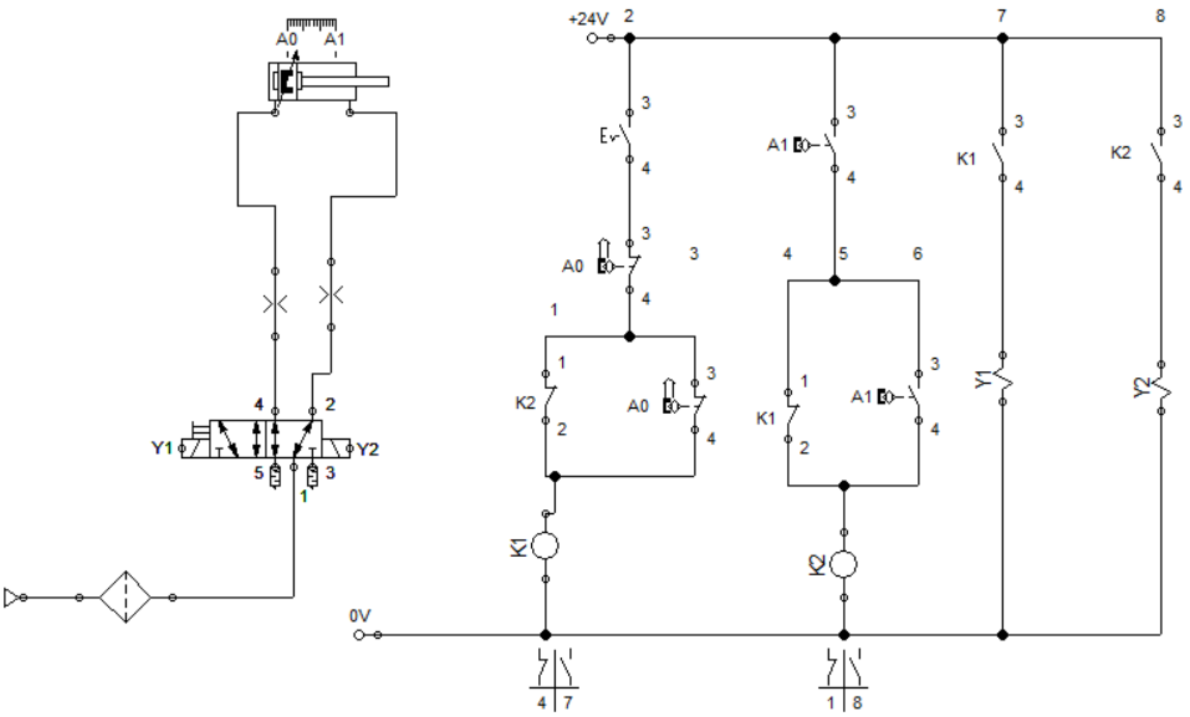


Figure 31

The basic working principle of the pneumatic circuit is as follows:

Compressed air is produced by a compressor. This air is then delivered into the system through air pipes. Before reaching the actuator, the air first passes through an air filter unit. The purpose of this filter is to remove any dust, dirt, or moisture from the air to protect the components in the circuit. Clean air ensures safe and reliable operation.

After filtration, the air reaches a 5/2-way directional control valve, which is controlled both manually and automatically using solenoid valves (Y_1 and Y_2). These solenoids receive electrical signals from the control circuit. When Y_1 is energized, the directional valve changes position and allows the air to flow to one side of the actuator, causing it to extend. When Y_2 is energized, the valve shifts to the other position, and the air is redirected, causing the actuator to retract.

Thanks to this configuration, the pneumatic system allows for fully automatic back-and-forth movement of the telescopic actuator. The precise control of the actuator motion is made possible by the combined use of directional valves and solenoids. In the image above, we can see how the electrical wiring and pneumatic piping are arranged during the simulation. This setup shows the flow of current in the control circuit and the direction of compressed air through the pneumatic lines while the system is operating in the simulation software.

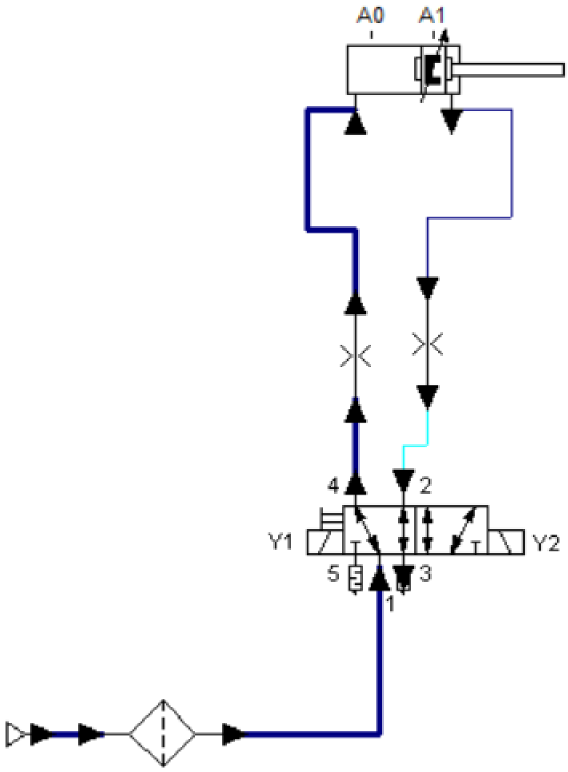


Figure 32

In the image above, we can see how the pneumatic piping are arranged during the simulation. This setup shows the flow of current in the control circuit and the direction of compressed air through the pneumatic lines while the system is operating in the simulation software.

6.3 Electrical Control System

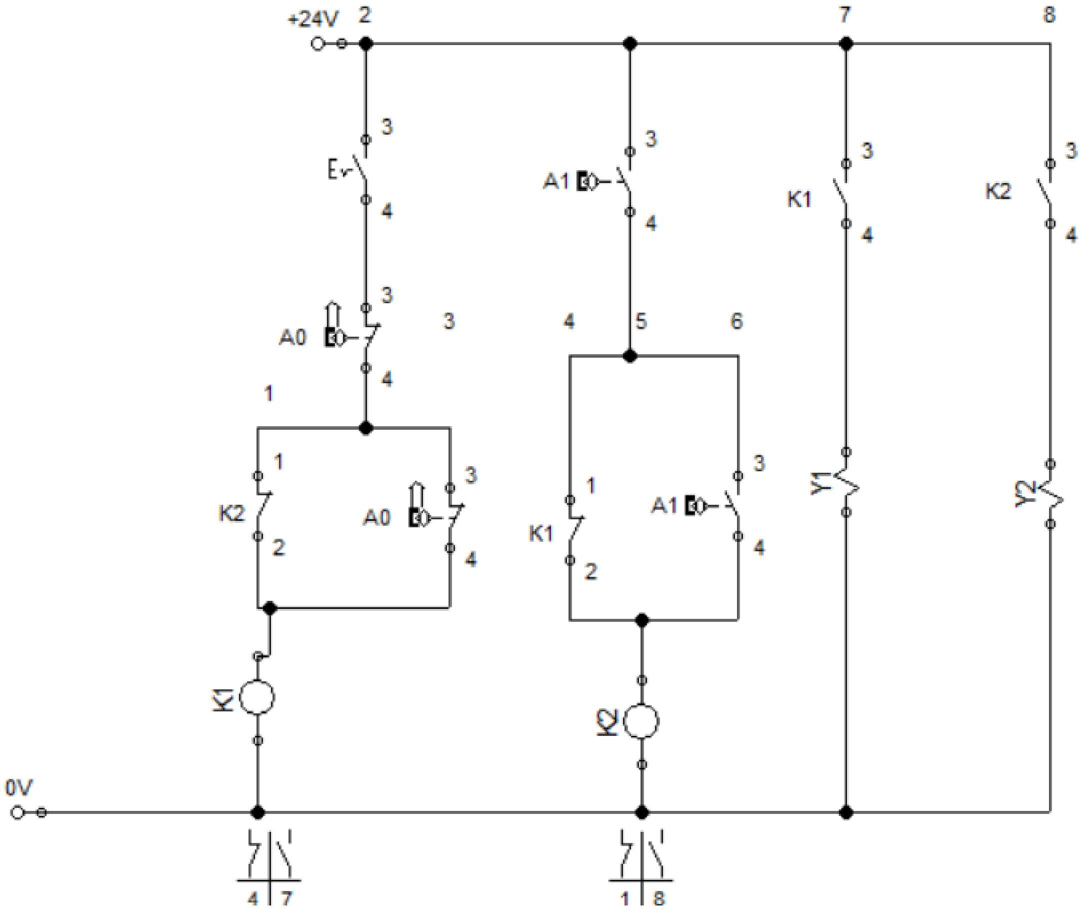


Figure 33

The electrical control system in this project is designed to operate the pneumatic actuators in a fully automated cycle. The system begins with a manually operated switch, which provides the initial signal to start the sequence. Once the switch is pressed, an electrical signal is sent to the relay circuit, triggering the first step of the motion.

The directional control valve, which regulates the flow of compressed air to the cylinders, is operated by two solenoid coils (Y_1 and Y_2). These solenoids receive control signals from the relay modules (K_1 and K_2). When a solenoid is energized, it shifts the valve to one of its two positions, directing air either to extend or retract the cylinder.

To achieve continuous automatic motion, the system uses position feedback from the actuators. The fully extended and fully retracted positions of the cylinder are detected by limit switches, labelled A0 and A1, respectively. These switches are strategically placed to sense when the actuator reaches the end of its stroke.

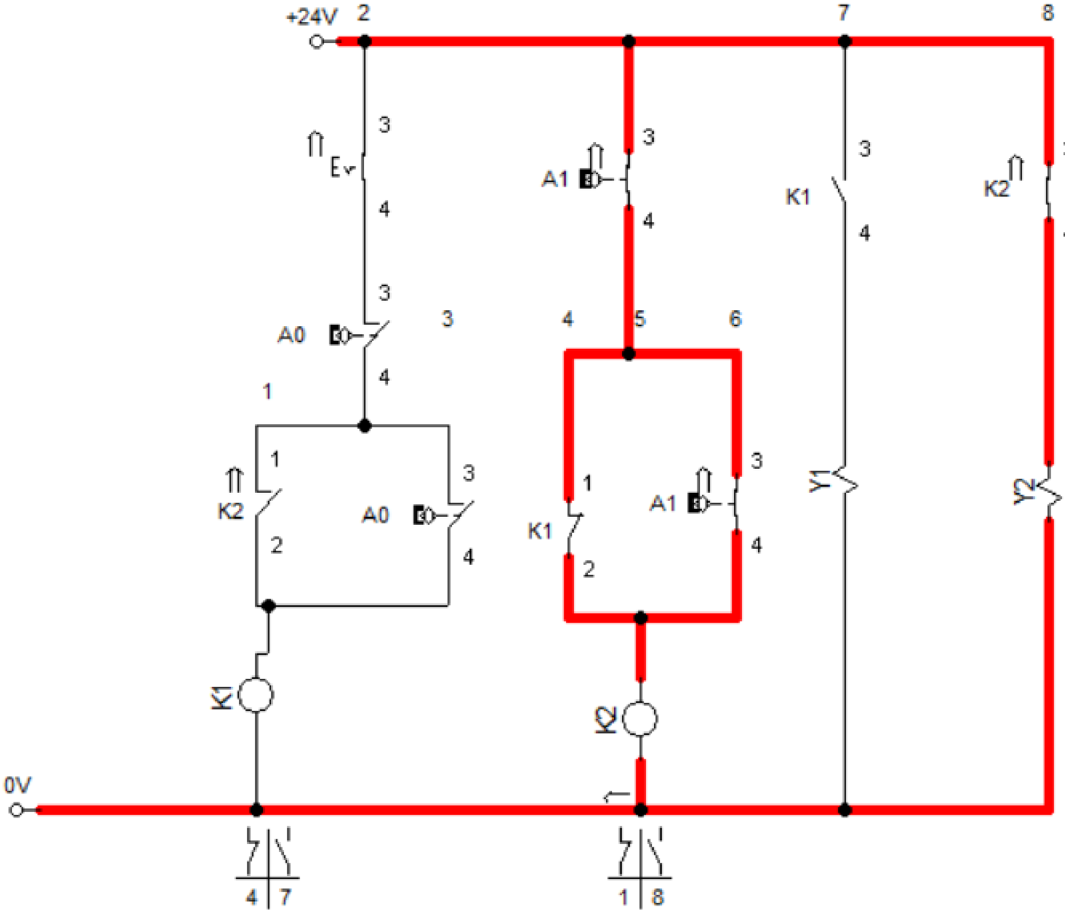


Figure 34

Here is how the control sequence works:

1. The operator presses the manual switch, which energizes Relay K_1.
2. Relay K_1 activates Solenoid Y_1, which shifts the 5/2 directional valve, allowing air to extend the cylinder.
3. When the actuator reaches its maximum extended position, Limit Switch A_1 is triggered.
4. A_1 sends a signal to activate Relay K_2, which energizes Solenoid Y_2.
5. Solenoid Y_2 switches the directional valve to the opposite position, causing the actuator to retract.
6. When the actuator is fully retracted, Limit Switch A_0 is triggered.
7. A_0 resets the cycle by reactivating Relay K_1, and the loop continues automatically.

The use of relays ensures proper isolation between the control logic and the power required to operate the solenoid valves. This configuration also allows for safe switching and protection of electrical components.

Thanks to this setup, the pneumatic actuators can perform repeated up-and-down motion without continuous manual input. The system is therefore ideal for applications requiring repetitive, reliable, and automated mechanical movement.

6.4 Component List and Descriptions

Below is a detailed list of the components used in the pneumatic and electrical control system, along with their functions:

1) **Double-Acting Telescopic Cylinder:**
These actuators are responsible for the vertical motion required in the system. Their telescopic structure allows for extended stroke lengths within a compact space. They operate using compressed air and are capable of both extension and retraction.

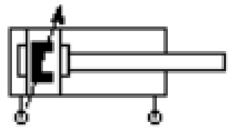


Figure 35

2) **5/2-Way Directional Control Valve:**
This valve directs the flow of compressed air to either side of the cylinders. It has five ports and two positions and is essential for controlling the extension and retraction cycles. The valve is actuated by solenoid coils.

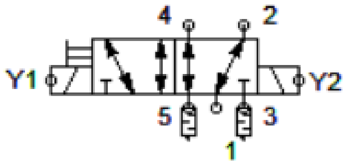


Figure 36

3) **Relays (K1 and K2):**
Electromechanical switches used to control the solenoid valves. Each relay is activated by input signals from sensors or limit switches and serves to isolate and manage the power sent to the solenoids.

Figure 37

4) **Air Filter-Regulator Unit:**
This unit cleans the compressed air by removing contaminants such as dust and moisture. It also ensures the air pressure is kept at a safe and optimal level for system operation.

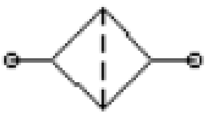


Figure 38

5) **Compressor:**
Provides the system with the necessary compressed air. It is the primary source of energy for all pneumatic functions in the circuit.

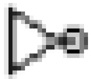


Figure 39

6) Limit Switches (A0 and A1)
Positioned to detect the end positions of the actuator stroke. They provide feedback signals to the relays, enabling the control logic to proceed to the next phase of operation.

Figure 40

6.5 Purpose of Vacuum and Pressure

This pneumatic system is designed to automate the transfer of material from a lower plate located inside a tank to an upper molding plate by using compressed air and vacuum technology. The system operates with a telescopic pneumatic actuator that moves vertically, enabling the lower plate to rise and align with the upper plate during the process.

At the beginning of the cycle, the lower plate creates vacuum pressure to draw material from the surrounding environment while submerged in the tank. Once the material is collected, the actuator lifts the lower plate upward. When the two plates are properly aligned, the system switches the vacuum and pressure conditions: vacuum is applied to the upper plate to hold the material in place, while positive air pressure is applied to the lower plate to release the material into the mold on the upper plate. This controlled transfer ensures precise placement of the material into the mold cavity.

The entire operation is designed to function in an automated cycle, improving production speed and consistency while reducing the need for manual handling. This system is particularly useful in applications such as industrial molding and forming, where material must be transferred and positioned accurately within a mold.

6.6 Vacuum and Pressure Pneumatic Diagram

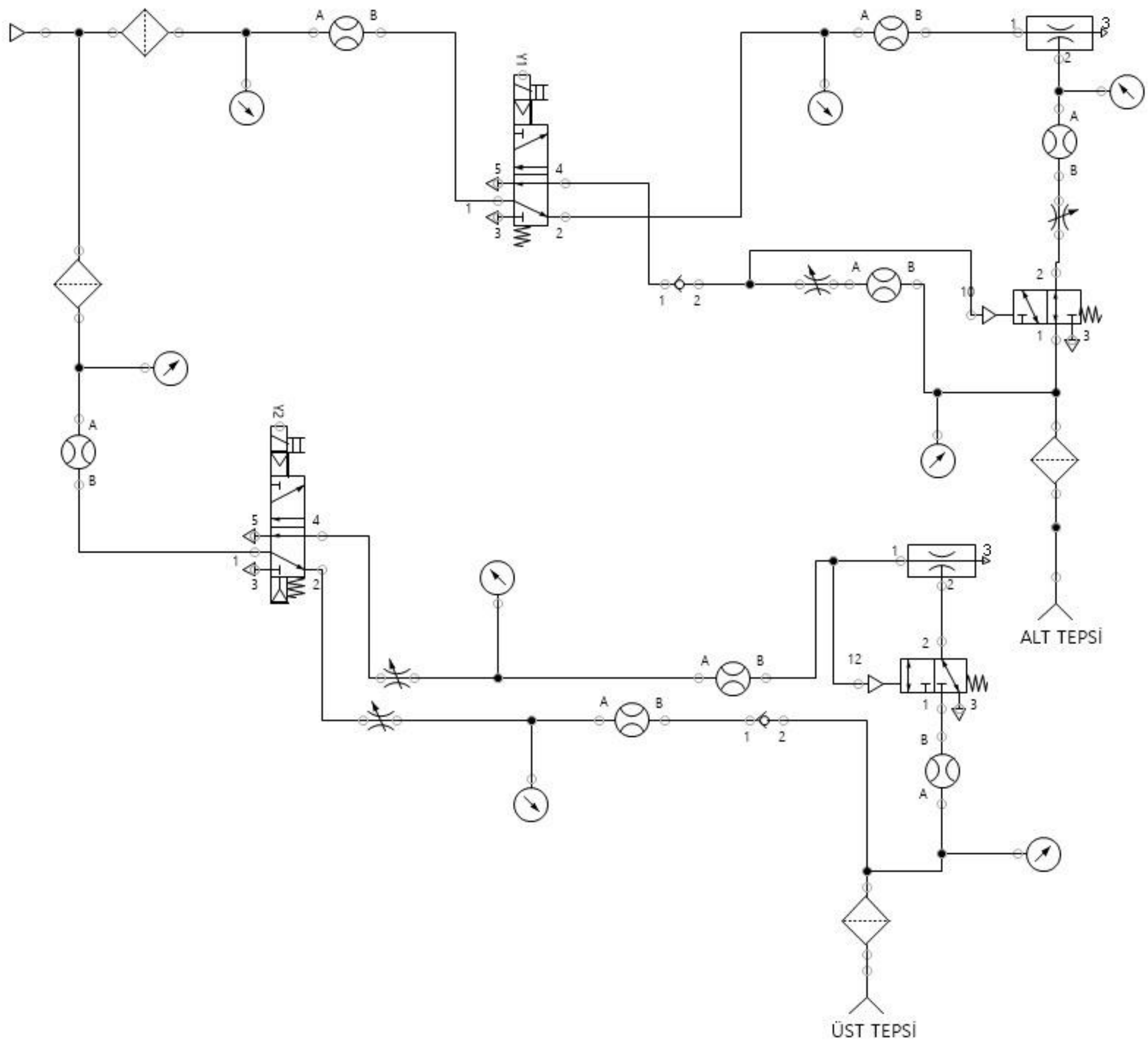


Figure 41

The vacuum system in this project plays a critical role in transferring the material from the lower plate to the upper molding plate. The process begins with compressed air supplied from a compressor. This air first passes through a filter to eliminate any dust or particles, ensuring that only clean air enters the pneumatic system. The filtered air is then directed through a 5/2 directional control valve, which is operated by a solenoid coil. This valve determines the direction of airflow based on the control signal from the electronic circuit.

After the directional control valve, the air passes through flow control valves. These valves allow adjustment of both pressure and flow rate, which is essential for achieving the desired vacuum level without damaging the material or disrupting the process. Once properly regulated, the air flows into the vacuum suction nozzles. In the first stage, these nozzles are connected to the lower plate, allowing vacuum to be created and enabling it to draw the material from within the tank.

In the next stage of the process, once the actuator lifts the lower plate and aligns it with the upper plate, vacuum needs to be applied to the upper plate, and positive air pressure must be applied to the lower plate. This ensures that the material is released from the lower plate and correctly transferred into the mold on the upper plate. The same sequence of operations is used here: filtered air passes through the solenoid-operated 5/2 valve, then through the flow controllers, and finally reaches the suction nozzle connected to the upper plate, providing the required vacuum. Simultaneously, the lower plate receives positive pressure.

Controlling the switching between vacuum and pressure at the right moment is a key requirement of this system. Both the upper and lower vacuum/pressure cycles need to be synchronized using a single control signal. To achieve this, a single solenoid valve was used to operate both directional valves. A simple electronic circuit was developed to energize this solenoid. Once the system is manually started via a push button, the circuit takes over and ensures that the vacuum and pressure states automatically alternate between the two plates in each cycle, thus enabling continuous automated operation.

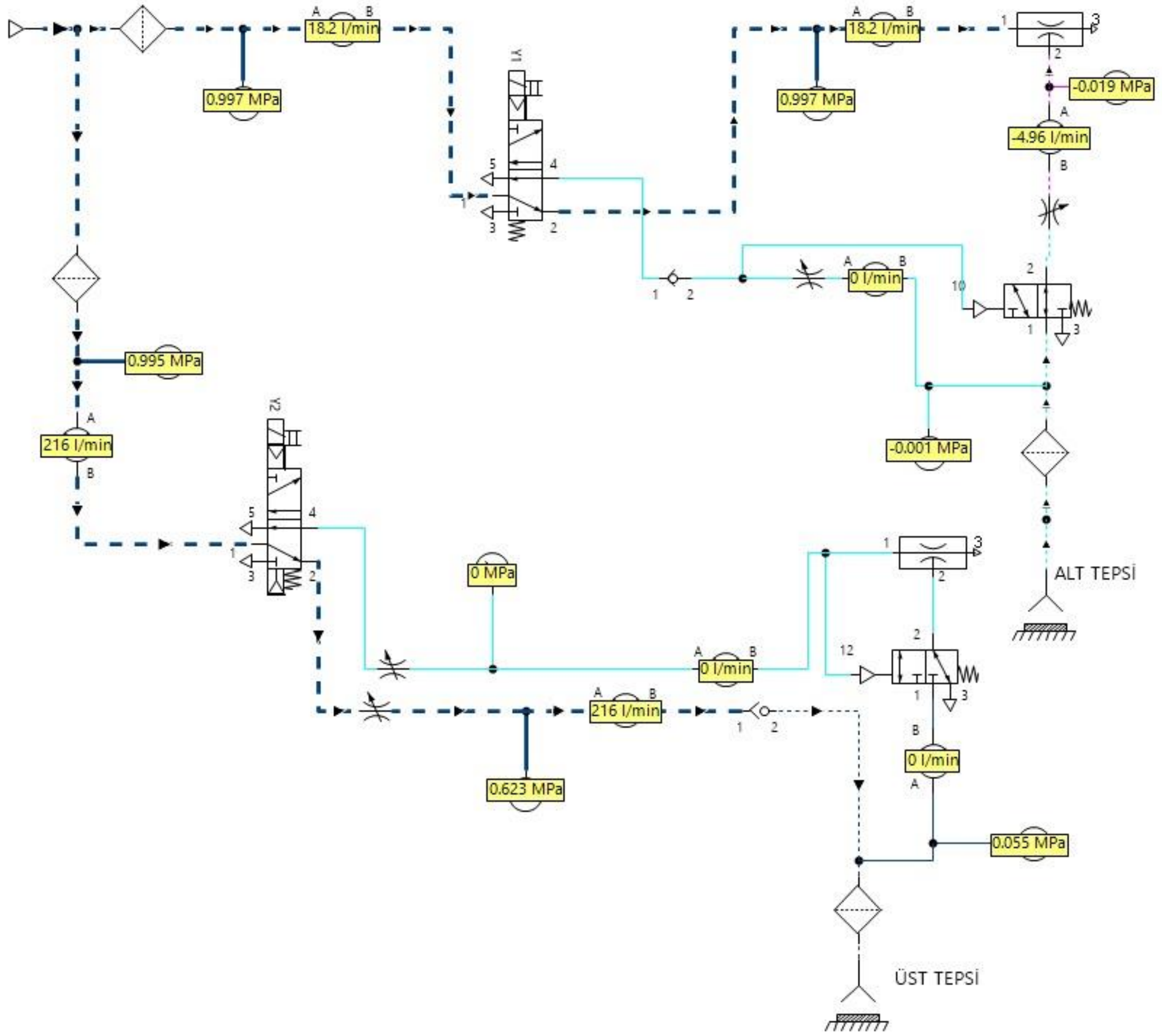


Figure 42

In the figure above, it is shown that vacuum is being applied to the lower plate. At the same time, the pressure and flow rate values can be monitored through the connected manometers and flowmeters, which are integrated into the system to ensure real-time observation and control of the pneumatic parameters.

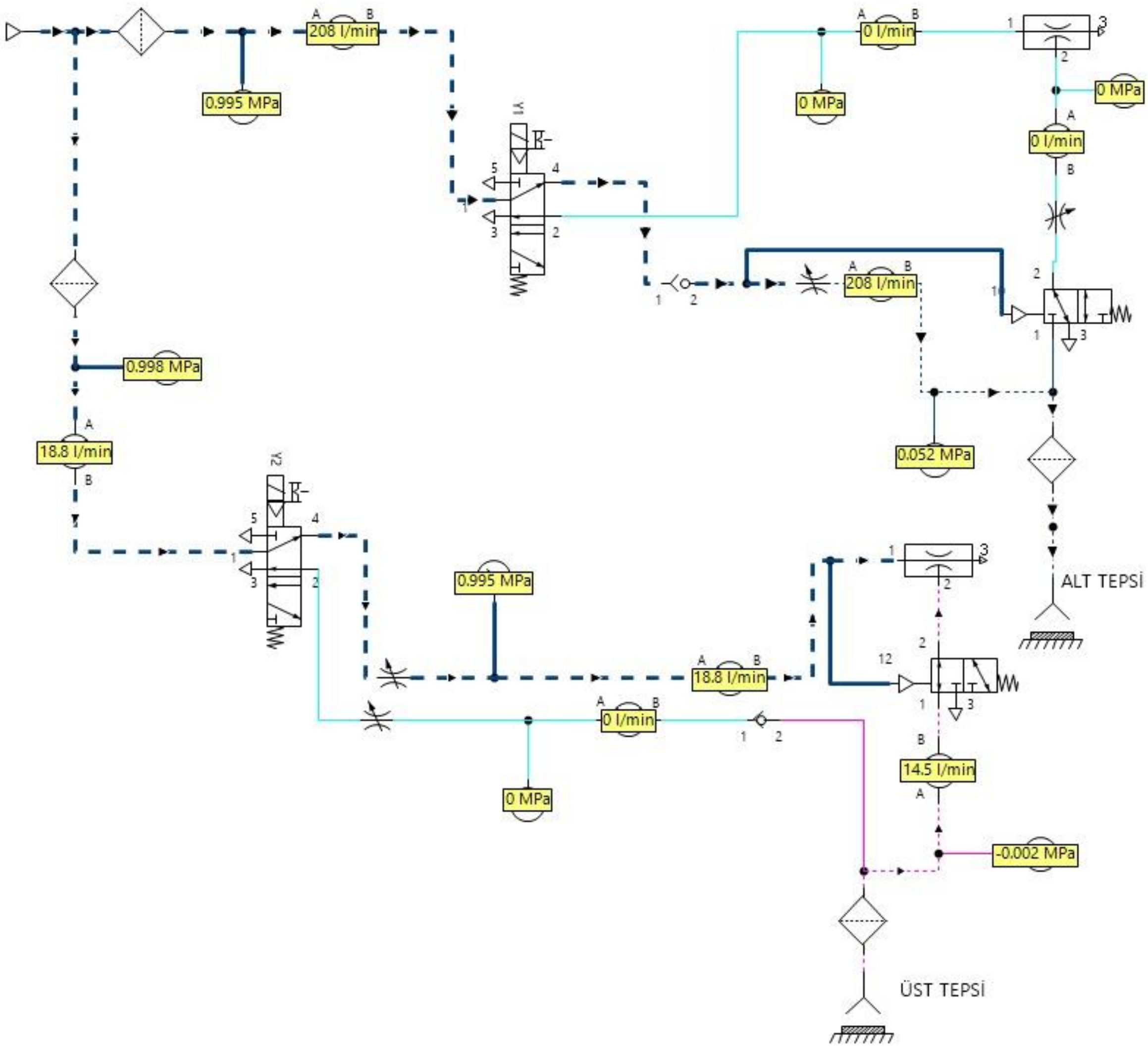


Figure 43

In the figure above, vacuum is applied to the upper plate. At the same time, both pressure and flow rate values can be observed through the manometer and flowmeter installed in the system, allowing for accurate monitoring and control of the pneumatic conditions during operation.

6.7 Electrical Control System

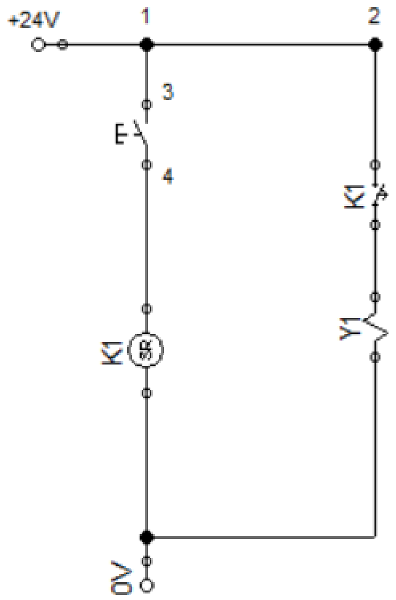


Figure 44

The switching between vacuum and pressure in the pneumatic system is managed by a simple electrical control circuit, which ensures the correct operation of the system during each cycle. This circuit is composed of a manually operated switch, a relay, and a solenoid valve.

The process starts when the manual switch (a push button) is pressed by the operator. This action sends an electrical signal to the relay, energizing it. Once the relay is activated, it closes its internal contacts and allows current to flow to the solenoid coil of the 5/2 directional control valve.

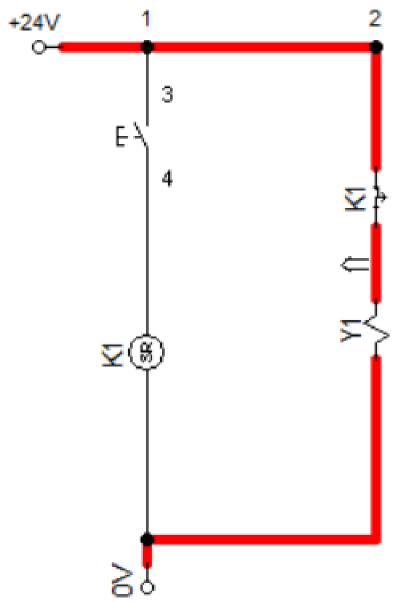


Figure 45

A relay with switch-off delay is a special type of relay that includes an internal timer. Thanks to this feature, the relay can continue conducting electricity for a specific duration even after the control signal is removed. This allows the circuit to be controlled with timing, ensuring more precise operation. In this system, the use of a delay relay helps maintain the solenoid activation for the required time, which is especially useful in applications that require time-based transitions between vacuum and pressure phases.

The energized solenoid shifts the valve, changing the direction of airflow within the pneumatic system. At this stage, vacuum is applied to the upper plate, while positive pressure is applied to the lower plate. This configuration ensures that the material is transferred from the lower plate into the mold on the upper plate.

The use of a single solenoid valve to control both vacuum and pressure switching simplifies the system and allows both operations to be handled with one electrical signal. Once the actuator completes its movement, a mechanical limit switch is triggered, which can reset or reverse the signal, allowing the system to return to its initial state and repeat the cycle.

This basic but effective control logic enables fully automated operation with minimal components, making the system easy to use, reliable, and cost-effective.

6.8 Component List and Descriptions

1) **Vacuum Suction Nozzle**
   The vacuum suction nozzle creates suction by generating a localized vacuum through the Venturi effect when compressed air flows through it. This low pressure at the nozzle tip allows it to pull and hold materials.

   In this system, the nozzle is mounted on both the lower and upper plates at different stages. First, the lower plate's nozzle creates a vacuum to draw material from the tank. Then, after lifting, the upper plate's nozzle holds the material while the lower plate applies positive pressure to release it.

   The nozzle's performance relies on properly controlled airflow using flow control valves to maintain the needed vacuum without harming the material or interrupting the process. It enables precise, contactless material transfer between plates.

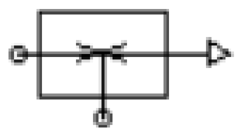


Figure 46

2) **Flowmeter**
   A flowmeter measures the flow rate or velocity of air or fluid within the system. It helps to monitor and control the flow to ensure the system operates efficiently and meets process requirements.

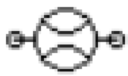


Figure 47

3) **Manometer**
   A manometer measures the pressure within pipes or tanks. It is used to verify that

the pressure remains within the desired range, ensuring safe and proper system operation.

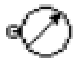


Figure 48

4) Relay (Switch-off Delay)

A relay with switch-off delay is a special type of relay that includes a built-in timer, allowing it to remain active for a set period of time after the control signal is turned off. This feature makes it possible to control devices based on time, ensuring they continue to operate for a specific duration even after the input is deactivated.

Commonly used in automation systems, this relay type helps achieve functions like delayed shutdowns in lighting, ventilation, or pneumatic applications, providing greater flexibility and precision in time-based control.

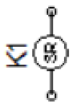


Figure 49

7. CONCLUSION

Within the scope of this project, a compact and low-cost prototyping machine capable of producing packaging from recyclable paper and cellulose-derived fibers was designed and developed. Increasing environmental awareness, the damage caused by plastic-based packaging to nature, and the widespread use of the concept of circular economy increase the need for alternative packaging technologies. In this context, molded paper packaging has become one of the prominent solutions in terms of sustainability. However, the fact that current production systems are generally large-scale, costly, and inaccessible to small businesses limits the widespread use of this technology. This project represents an innovative engineering solution that directly responds to this need.

The prototype system is designed to be modular and compact in terms of engineering and consists of three main sections: mixing tank, forming pool (pulp pool) and pneumatic forming system. The mixing tank in the system mixes paper waste with water to obtain a homogeneous pulp. The geared motor used at this stage performs the mixing process at low speed but high torque, ensuring that the fiber structure is mixed without damage. The system can be easily cleaned, and the process can be controlled thanks to the T-type 3-way valve integrated under the tank.

The dough shaping process takes place in a specially designed pool. In this section, the shaping process is carried out by means of a fixed mold table and a mold table that is moved up and down by a pneumatic piston. The pneumatic control system used during this process plays a critical role in terms of movement synchronization and repeatability. When the lower mold enters the pool, the vacuum system works and ensures that the fibers are collected on the mold surface. Then the lower mold moves upwards and connects with the upper mold. At this moment, the vacuum system works in the upper mold, the lower mold transfers the shaped product to the upper mold by blowing air. After the transfer process is completed, the lower mold and the upper mold are separated from each other. Then the formed product is taken by the upper mold blowing air and releasing it.

In the design process of the system, a comprehensive CAD modeling and analysis study was carried out using SolidWorks software. In this way, the placement, strength and functionality of each part were evaluated in a three-dimensional environment; possible errors were minimized before production. In addition, the basic components of the system, the motor, reducer, pump, pneumatic piston and vacuum systems were selected as standard components that are easily available in the market. This approach both shortens production time and reduces costs.

The operating principles and mechanical design process of the system were carefully planned. Constant fiber density was achieved in both the tank and the pool by providing continuous cyclic pulp flow; thus, product quality was stabilized. In addition, the return pump used in the system prevented waste by transferring excess pulp back to the mixing tank, thus increasing the efficiency of the system.

In addition to the engineering aspect of the project, its environmental impacts are also very important. Packaging production from recyclable materials directly contributes to the reduction of plastic consumption. In addition, the use of low-quality fibers such as agricultural waste makes it possible to evaluate waste with no economic value. In this respect, the project is an example of sustainable production systems and is considered an important step in the dissemination of environmentally friendly technologies.

The potential application areas of the project are quite wide. Especially for small businesses, local areas, university laboratories and newly established projects, such a system can be used for both education and production purposes. It is possible to produce with many production technologies such as electronic device packaging, egg boxes, fruit carrying trays, medical carrying containers. The use of molded packaging is increasing, especially in sectors that provide special design and sensitive protection. In this sense, the project is a prototype that can be directly adapted to the application.

However, some developments are needed to move the system from the current prototype level to the industrial level. First of all, increasing the level of automation will increase production speed and accuracy by reducing human intervention. In addition, the integration of the drying system is important for the product to reach its final form. The system, which currently focuses only on shaping, will become much more functional when completed with an integrated drying module. Issues such as energy consumption, processing time and material compatibility should also be addressed in detail in future studies.

In this context, future studies can be summarized as follows:

- Integration of the drying unit and optimization of drying time,
- Development of higher precision vacuum control systems,
- Improvement of the production line with PLC or microcontroller-based automation systems.

As a result, the prototype machine developed with this project offers a solution that is both technically functional and environmentally and economically sustainable. The project is not only an academic study, but also a highly applicable engineering solution that can be found in real life. The importance of such prototype systems is increasing in terms of increasing local production capacity, improving waste management and popularizing sustainable packaging solutions. This study provides a basis that will guide similar academic projects and industrial systems to be developed in the future.

8. REFERENCES

[1] [F. E. Keyes, "Method of molding pulp articles," US 424,003, 1890.]

[2] [M. L. Keyes, "Apparatus for making pulp articles," US 740,023, 1903.]

[3] [M. Koppelman and S. Cooper, "Packaging for fragile articles," US 1,429,207, 1922.]

[4] [S. Price and E. C. Sloan, "Package," US 2,217,455, 1940]

[5] [The History of Molded Fiber Packaging; a 20th Century Pulp Story Renee Wever and Diana Twede]

[6] [M. Debnath, R. Sarder, L. Pal, and M. A. Hubbe. Debnath et al. (2022). "Molded pulp packaging review," BioResources.]

[7] [https://www.moldedpulppackaging.com/pros-and-cons-of-molded-pulp-packaging/]

[8] [Molded fiber and pulp products as green and sustainable alternatives to plastics: A mini review Yanling Zhang, Chao Duan, Swetha Kumari Bokka, Zhibin He, Yonghao Ni]

[9] [https://pulp2pack.com/]

[10] [https://bonitopak.com/reyclable-molded-fiber-products-for-hair-dryer-packaging/]

[11] [http://vyoltech.com/]

[12] [https://neuindustries.com/what-is-moulded-pulp/]

[13] [https://www.tridas-tech.cz/en/]

[14] [Kit L. Yam, editor. The Wiley Encyclopedia of Packaging Technology. John Wiley & Sons, Inc., Hoboken, NJ, USA, sep 2009. ISBN 9780470541395. doi: 10.1002/9780470541395.]

[15] [Molded Pulp Products Manufacturing: Process Development, Characterization and Modeling, Mattia Didone]

[16] [M.Didone, P. Saxena, E. Brilhuis-Meijer, G. Tosello, G. Bissacco, T.C. Mcaloone, D.C.A. Pigosso, and T.J. Howard. Moulded Pulp Manufacturing: Overview and Prospects for the Process Technology. Packaging Technology and Science, 30(6), 2017. ISSN 10991522. doi: 10.1002/pts.2289.]

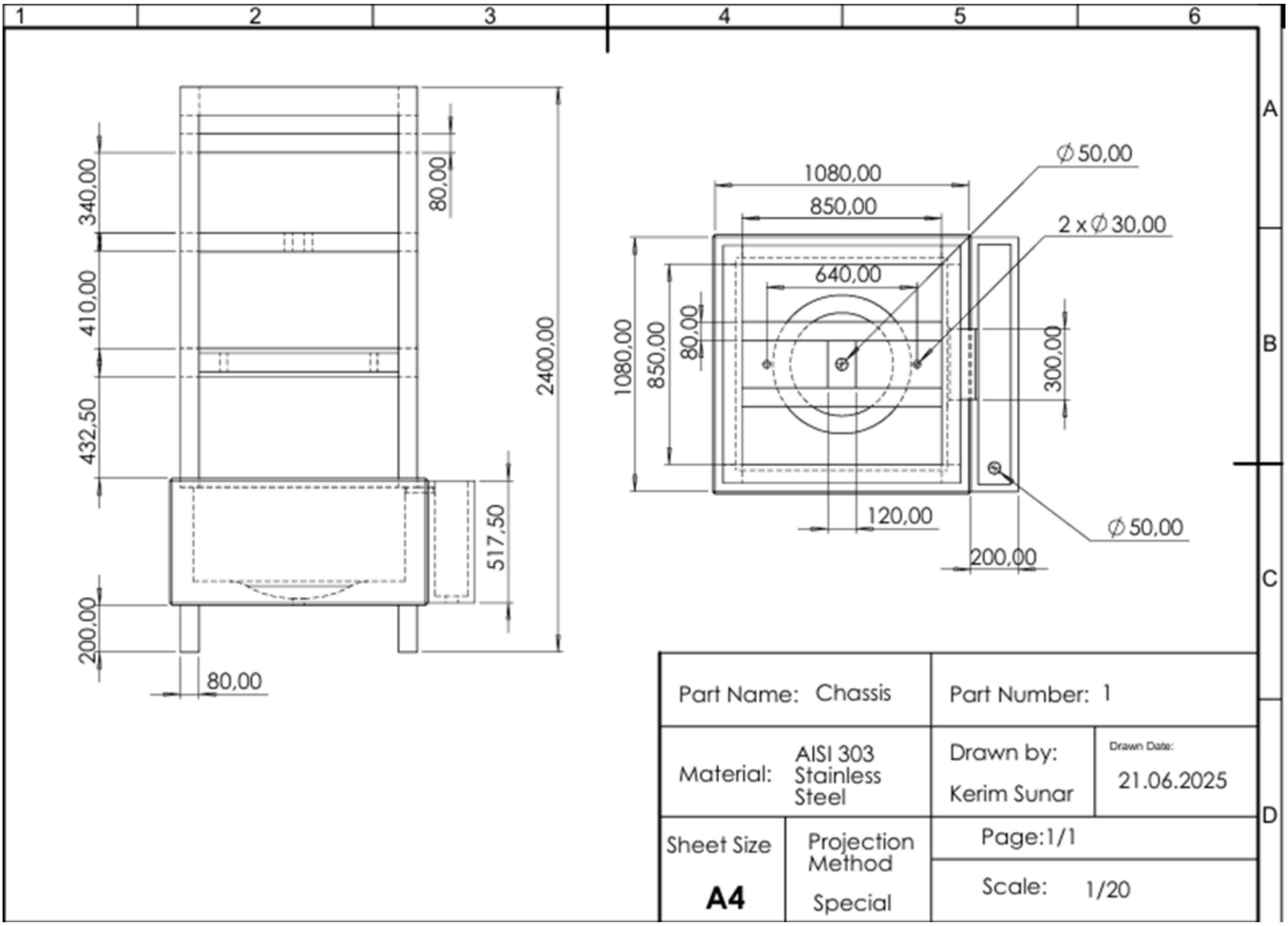
9. APPENDIX

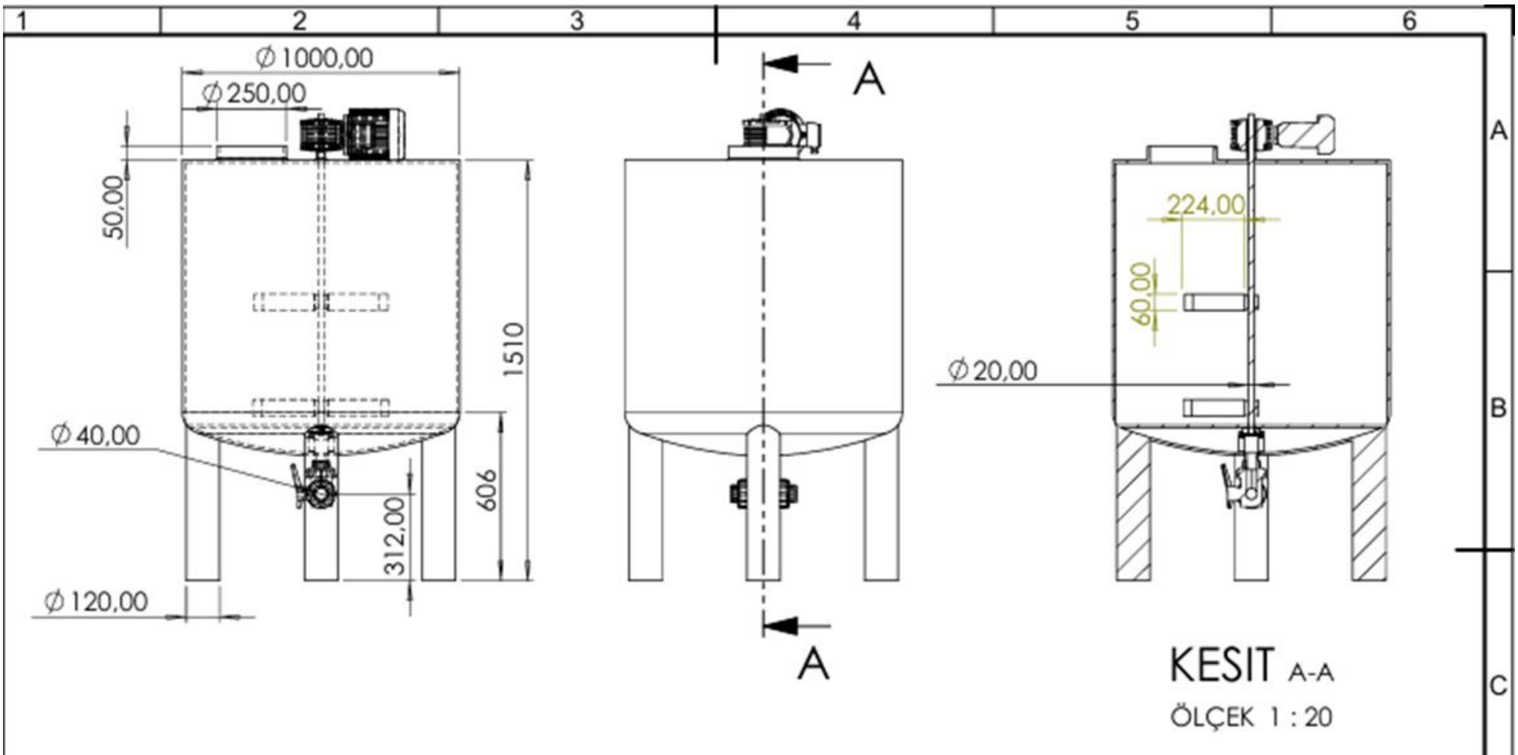
Table 22:Appendix E – Selected Components and Source Information

Component	Product Name / Type	Material / Key Specs	Source / URL
Agitator Motor + Gearbox	HPC CHM63-20-90L4	1.5 kW, 1400 rpm, 20:1 reduction, 70 rpm output, IP55	https://shop.hpceurope.com/an/produit.asp?prid=3086
Pulp Tank (Custom)	Cylindrical + sloped bottom, leg-supported	Plastic (PE/PP/HDPE), Ø1000 mm × 1060 mm, 753 L capacity	https://www.barat.com.tr/service/polietilen-hdpe-karistiricili-tank-imalati/
Agitator Bearing	UCF204 Square Flange Bearing Unit	Ø20 mm bore, cast housing, pre-lubricated	https://www.hepsiburada.com/exhoo-ucf-204-ucf204-yatakli-rulman-ic-cap-20mm-yatak-tipi-kare-pm-HBC00005X4ELO
Mixer Shaft and Blades	Custom-designed shaft and 4-blade system	Ø20 mm shaft, AISI 304, blade radius 250 mm	– (Designed in SolidWorks)
Riser Plate for Agitator Bearing	90×90×60 mm Raised Platform	Welded steel or aluminum sheet	– (Designed in SolidWorks)
3-Way Valve (Bottom Tank)	Stainless Steel 3-Way Threaded Ball Valve	T-port, DN50, SS304, PTFE seals, manual lever	https://www.alibaba.com/product-detail/Stainless-Steel-3way-Thread-Ball-Valve_1600091673828.html?spm=a2700.9099375.14.4.4cfe789a3mYfXq&s=p
Pump (Tank → Pool)	Centrifugal pump (to be finalized)	Approx. Q=1 m³/h, H=1.2 m, suitable for pulp slurries	https://www.hepsiburada.com/sailflo-fp32-24-24-volt-esnek-pervaneli-pompa-yag-su-ve-mazot-aktarim-flexibile-impeller-pm-HBC00006PV63X
Pump (Pool → Tank)	Centrifugal pump (to be finalized)	Approx. Q=1 m³/h, H=1.4 m, 1500 mm vertical lift	https://www.amazon.com.tr/dp/B07GSH61CZ/ref=nosim?th=1
Bottom Vacuum Table	Submersible fiber-forming vacuum plate	700×700×50 mm, aluminum, CNC milled, vacuum channeled	https://aluminyumburada.com/
Top Vacuum Table	Stationary vacuum/air-blow plate	700×700×50 mm, aluminum, vacuum + pressure	https://aluminyumburada.com/

Component	Product Name / Type	Material / Key Specs	Source / URL
		channels	
Rotary Tray	Fiber transfer tray with pivot system	500×400×5 mm, aluminum sheet, polished	https://aluminyumburada.com/
Pneumatic Piston	DSBC-50-400-D3-PPSA-N3	400mm stroke x 50 mm	https://www.festo.com/
Selenoid valf	VSNC-FTC-M52-M-G14-F19		https://www.festo.com/
Vacuum Pump	Becker VT4.10		https://beckervakumpompalari.com/tr/urunler/vakum-pompalar%C4%B1-ve-blowerlar/becker-vt4-10-kuru-tip-vakum-pompas%C4%B1-detail
Compressor	Makita MAC610		https://www.toolnation.com/makita-mac610-compressor-8-bar.html?srsltid=AfmBOopwqwiQAUOP9VQfZp2lCKOEuDtLahXaOSRjdVkpxEhxGRr86nVz

Technical Drawings





Part Name: Tank Assembly		Part Number: 2	
Material: PE, PP, HDPE		Drawn by: Kerim Sunar	Drawn Date: 21.06.2025
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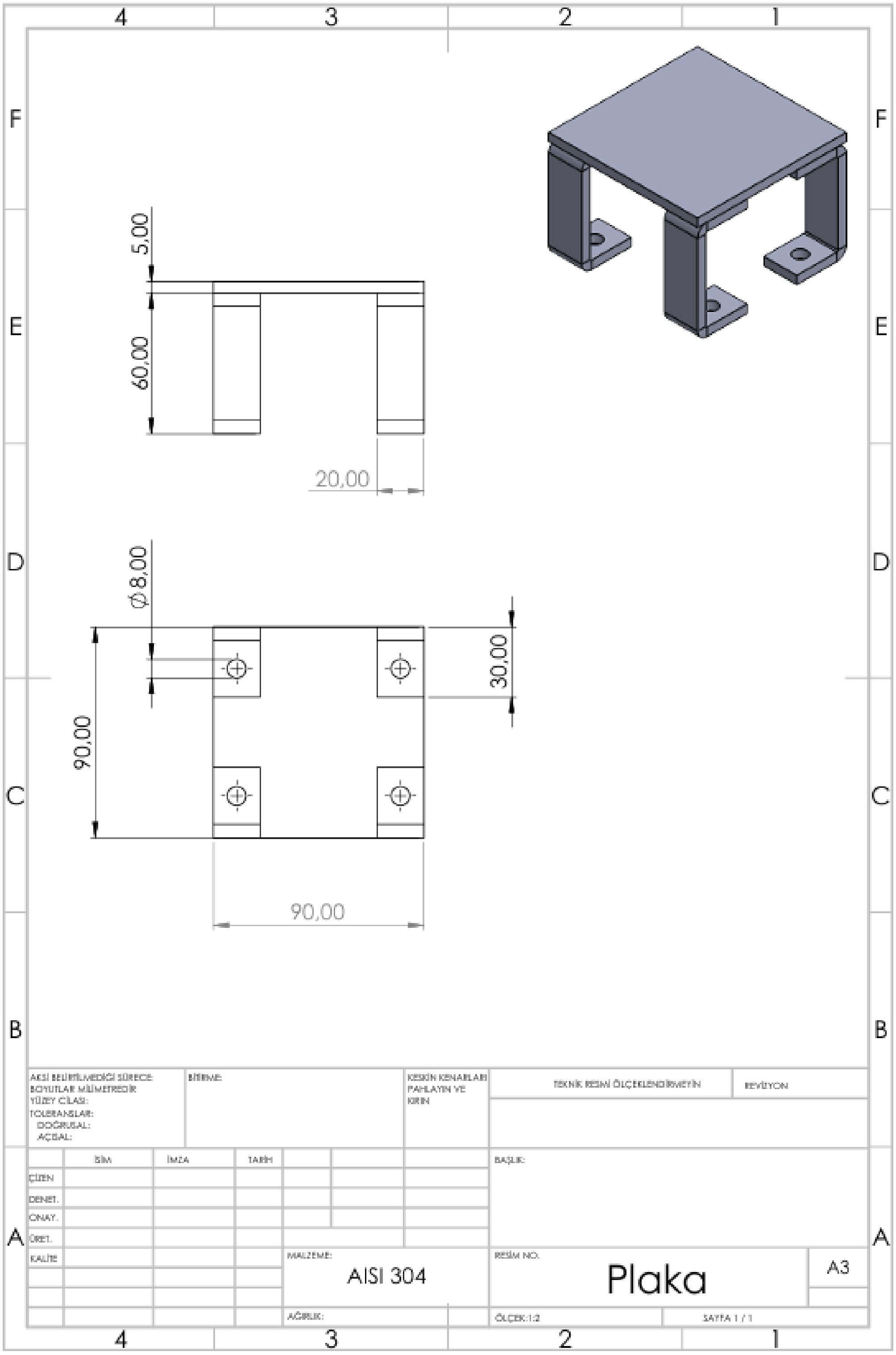
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BOYUTLAR MİLİMETREDİR
YÜZEY CİLASI:
TOLERANSLAR:
DOĞRUSAL:
AÇISAL:
BİTİRME:
KESKİN KENARLARI PAHLAYIN VE KIRIN
TEKNİK RESMİ ÖLÇEKLENDİRMEYİN
REVİZYON
İSİM
İMZA
TARİH
BAŞLIK:
ÇİZEN
DENET.
ONAY.
ÜRET.
KALİTE
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RESİM NO.
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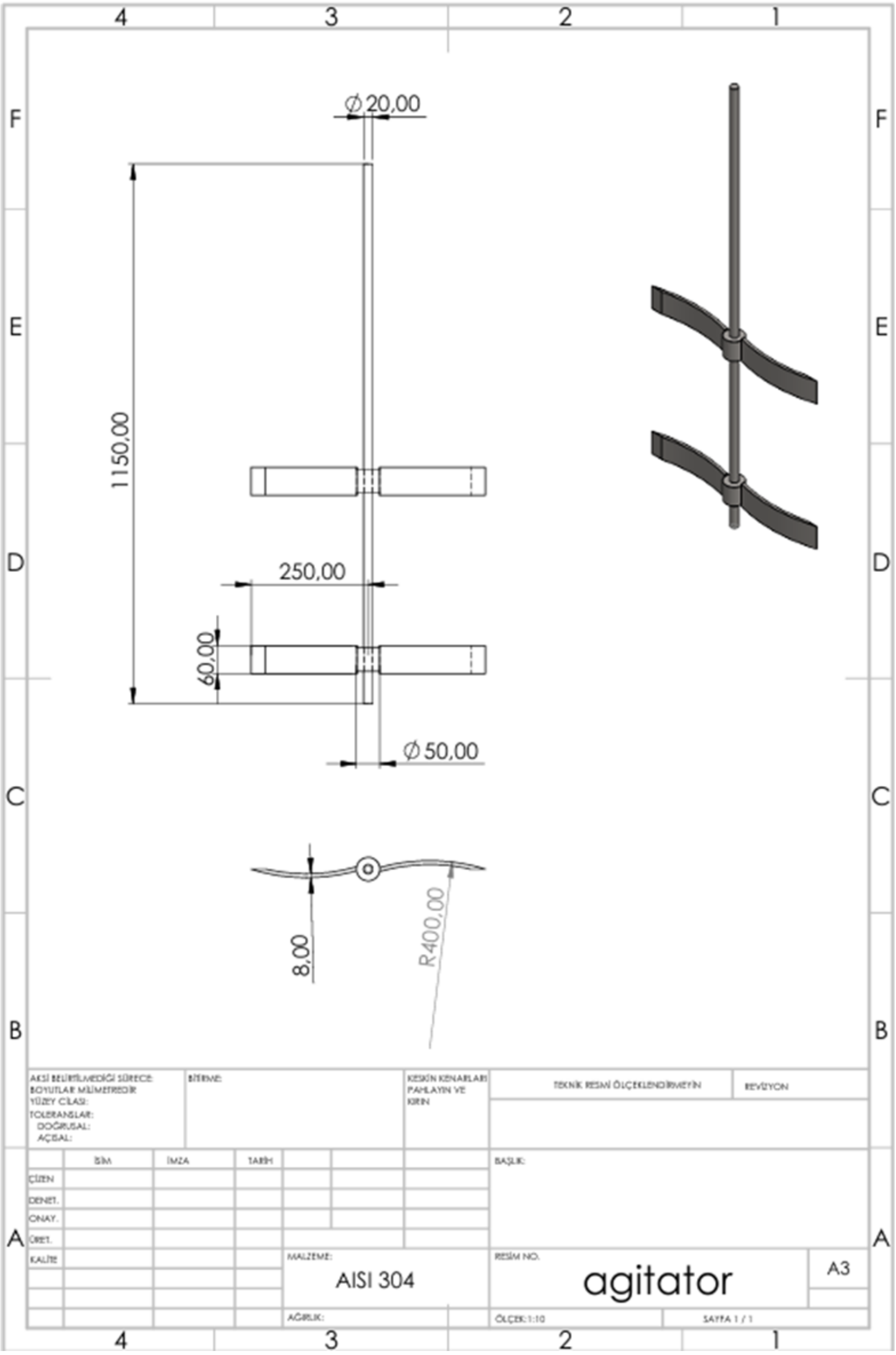

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Ø 50,00
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YÜZEY CİLASI:
TOLERANSLAR:
DOĞRUSAL:
AÇISAL:
BİTİRME:
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TEKNİK RESMİ ÖLÇEKLENDİRMEYİN
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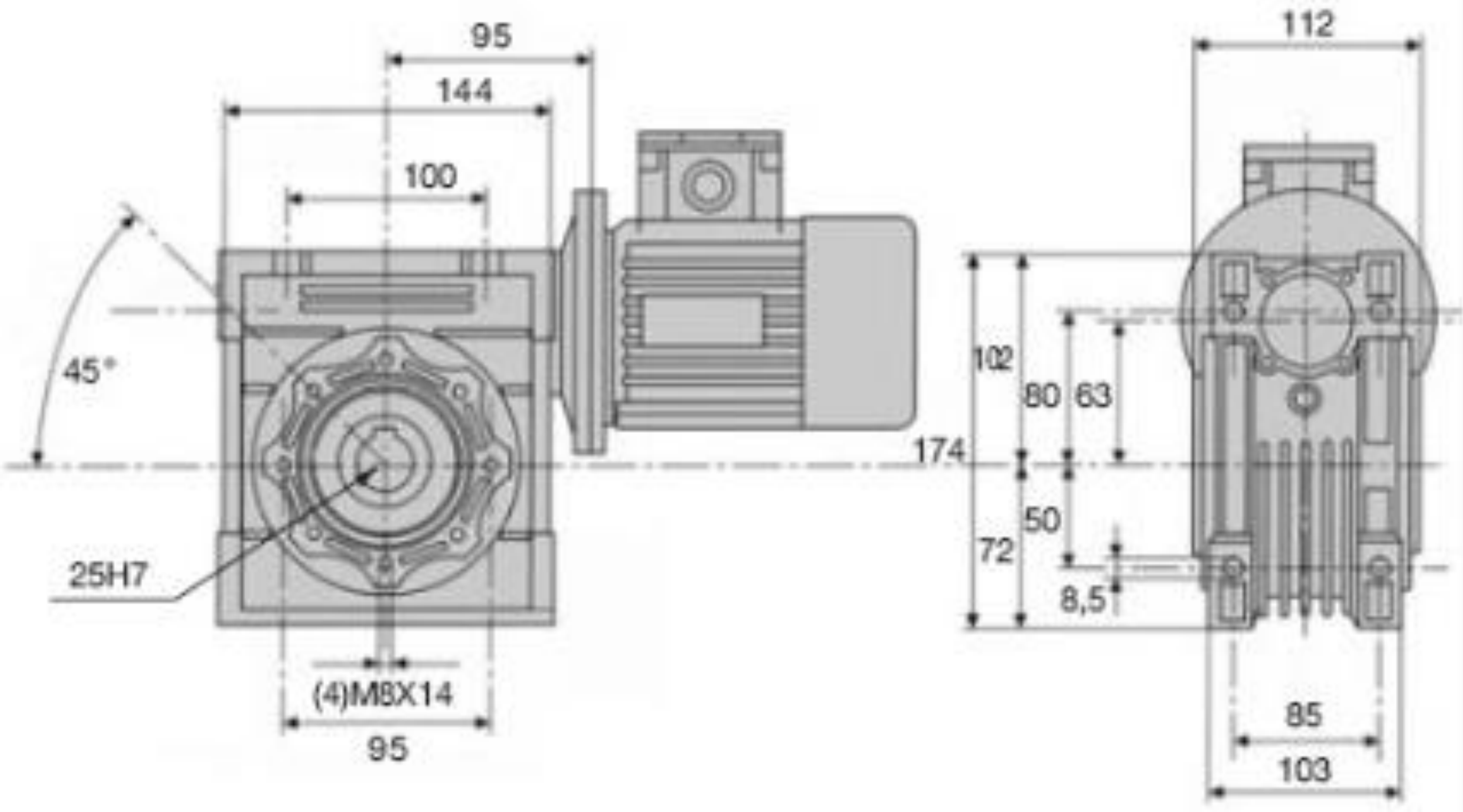
SAYFA 1 / 1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Datasheets of Selected Parts

https://shop.hpceurope.com/pdf/gbPDFauto/CHM63%2DMOT.pdf

https://www.festo.com/tr/tr/a/download-document/datasheet/8165588

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