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The Design and Construction of A Pulp Molding Machine

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***Abstract*:- The conversion of fibrous wastes into useful packaging materials has become imperative to effectively manage the vast amount of waste paper and paper products. A laboratory sized machine was developed to mold pulp slurry into a bowl by suction. The processes included collection of waste papers, sorting to grades, cleaning, refining, molding and drying. The machine comprises of the mold, counter mold, slurry vat and lowering mechanism. The machine works on the suction principle with a pulp slurry consistency of about 5%.**

Keywords: Molding machine, Slurry vat, Counter mold, Pulp consistency

INTRODUCTION

The invention of paper and paper products is one of the most important inventions by man due to its versatility and indispensability in the daily life of man. The worldwide paper and paper output was one of man's most adaptable consumer items, and its consumption in 2017 amounted to about 419.7 million tons. (Garside, 2019). In the 2018 figure of 67.4 million tons, or 23.1 percent of the overall output of MSW, the American Forest & Paper Association calculated the total production of paper and paper boards in municipality's solid wastes. The recovery rate of about 46 million tons, the greatest of which was compared to other materials in the MSW, in 2018 was 68.2 percent (EPA, 2018).

Recycling is the transformation of trash into new usable resources that could or may not be similar to the waste raw material (Kolajo *et al.*, 2020). It has been discovered that recycling paper products has been good to the environment by reducing emissions of greenhouse gasses, saving forests, reducing operating costs and protecting the environment from air and water pollution which occurs in the manufacture of virgin pulp. Paper fibers' physiochemical characteristics, such as durability and flexibility (Berg *et al.*, 2018); have allowed them to be fashioned into a range of goods utilized in significant fields such as education, sanitation, security, and communication (EPN, 2018). Recycled paper and paper products are raw materials in making several products ranging from egg packaging trays and wall panels, to the production of cellulose fibers and nanocrystals, production of film of biopolymer and the making of biofuels (Raut *et al.*, 2012; Zihare and Blumberga, 2017; Ozola et al., 2019). The processes involved in paper recycling can be loosely grouped into collection, sorting into grades, cleaning, hydro-pulping, refining and molding.
The construction of the molding machine is aimed at delivering an economically viable and environmentally option. The cost and sophistication of recycling equipment were a key restriction to the recycling of waste papers locally. Recycling technology has grown through time and has been challenging to accept, particularly for local users who are finding it tough to keep pace with developing technologies, necessitating the need for a low cost alternative.

THEORETICAL CONSIDERATIONS

Pulp recycling consists of a series of processes which can be roughly divided into: (1) Pulp slurring (2) Pulp beating/refining (3) Paper formation (4) Surface treatment/finishing. These steps of manufacturing are preceded by the collection and storage of waste paper. This includes wastes paper and paper products from government offices, educational institutions, business centers and printing houses. Sorting is done according to grade and cleaned. These two processes are achieved manually. However, for the other production steps, the specialized machines and their functions are as discussed below:
Pulp Slurring: For separating and treating pulp fibers, several machines have been developed. Some of these work on the principle that the fibers will separate from each other if submitted to rapidly rotating machine parts, as well as by the method of passing them under heavy rolls that bear down on a base plate. The machines working by this principle are known as hydro-pulpers.
Pulp Beating/ Refining: This process is achieved by the use of the agitator tank. This is a cylindrical vessel equipped with an agitating impeller. There are different designs in which the impeller can be loaded either horizontally through the rear or vertically from the top. The impeller keeps the mixture in continuous movement and prevents settling of the paper content of the slurry. This is necessary to avoid coagulation of the stock, and secondly to achieve an even distribution of the mixture. The consistency of the stock can also be further reduced by the action of the impeller in the agitator tank.
Pulp Molding: In the conventional manufacture of pulp moldings, aqueous pulp slurry is applied to a shaped mold and the water in the slurry is drawn through the mold, leaving a shaped mat of pulp fibers on the mold. The molding is then removed from the mold, usually by use of a correspondingly shaped transfer tool, and the molding is dried. The shaped mold conventionally comprises of wire mesh in a support, the water being drawn under vacuum through the mesh. The wire mesh has to be bent to the exact shape required, and then supported on an underlying member, with water flow channels to conduct away

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the water strained out of the deposited pulp. The pulp molding process is achieved with the use of vacuum pump driven by an electric motor.

METHODOLOGY

The molding technology employed is one where the slurry containing fiber and water is sucked onto the mold with the assistance of the vacuum pump. The mold is next leveled and fastened into the counter mold. The vacuum pump suction action is transferred to the counter-mold in which, while still sucking water from the product, the molded product is received. When the suction is blocked, the product is dried to the required moisture level to prevent collapse, the product is then withdrawn from the counter mold. The pulp molding machinery components may be split into two main and auxiliary components. The main components of the machine are the counter mold, slurry vat, the mold and other auxiliary parts such as the frame, lowering mechanism and the vacuum pump and electric motor.

DESIGN DETAILS

(a) The Mold: The pulp molding shape is determined by this template. It comprises of a metal sheet material produced according to the required shape of the molded product and is based on a metal sheet. The sieve material is further covered with a cloth material to prevent the entry of fibers into the mold. For the model design, which is a tray is of a rectangular cross-section, having a dimension of 50mm by 75mm (inverted base part), extending to 75mm by 100mm. The plate carrying the mold is of dimension 150mm by 175mm, leaving a clearance of 37.5mm on either side of the mold. This clearance was necessary for easy fixture of the mold with the pulp molding into the counter-mold.

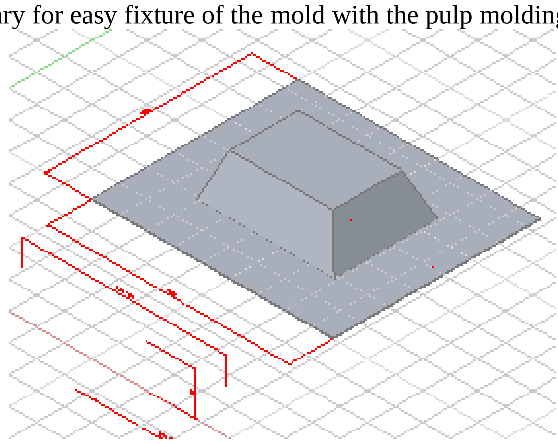


Figure 1: An Isometric View of the Mold

(b) The Counter Mold: This can also be referred to as an intermediate transfer tool. The function of the counter mold is to release the molded product into the drying chamber easily. The usage of the vacuum system also achieves this. The counter mold is an inverted rectangular box, having a surface of the desired shape of the molded product, made from the same material with which the mold was formed. This surface is further coated with foam (a flow-able material). The essence of this is to enhance easy detaching of the molded product without fracture of the molded parts. The vacuum chamber of the counter-mold has the same cross-sectional dimension as the mold plate, i.e. 150mm by 175mm (recommended), and having a height of 50mm. it also has a hole bored at the centre, having a diameter of 12.5mm, fixed with a pipe of same diameter to hold the pressure hose from the vacuum pump.

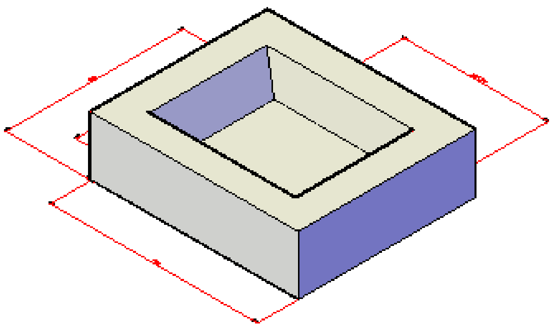


Figure 2: An Isometric View of the Counter mold

(c) Pulp slurry vat: This is used as the pulp slurry container for molding. It is the foundation of the pulp forming machine. The vat is a rectangular opened container with an ability to bear a somewhat thick fluid under atmospheric pressure. It is sufficiently stiff to resist the shaken up stock. The level of consistency is also expected to be about 5%. Consistency is determined by:

$$C = \frac{WF}{TW} \times 100 \qquad - - - \quad (TAPPI, 1988)$$

Where,

C = Pulp consistency (%); WF = Weight of solid fiber; TW = Total weight of the slurry

WF = 150g; Water used = 2000g; TW = (100 + 2000)g = 2100g

The consistency is therefore put at 5%.

Calculating the vat thickness, the allowable stress of steel metal (σ_{all}) is given as 165MPa.

Assume the vat to be of circular cross-section, the circumference is assumed to be outside the perimeter of the vat. The radius of the circle obtained = 186mm. (Figure 3).

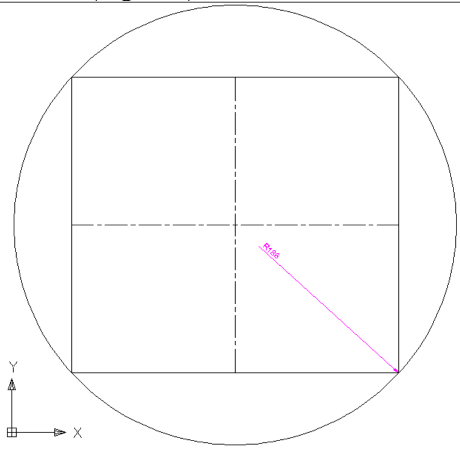


Figure 3: Assumed circumference of the pulp vat

To determine the yield strength of a thin walled cylinder bearing fluid under atmospheric pressure,

$$\sigma_{yield} = \frac{Pr}{t} \qquad - \quad - \quad - \quad (Ryder, 2004)(II)$$

Where,

r= 186mm, P = atmospheric pressure, t = thickness,

$P\ (\ell gh) = (1000 \times 9.81\ \times 0.2) N/m^2\ =\ 1962 N/m^2$ (ℓ = 1000kg/m^3 , g = 9.81m/s^2 , h = 200mm)

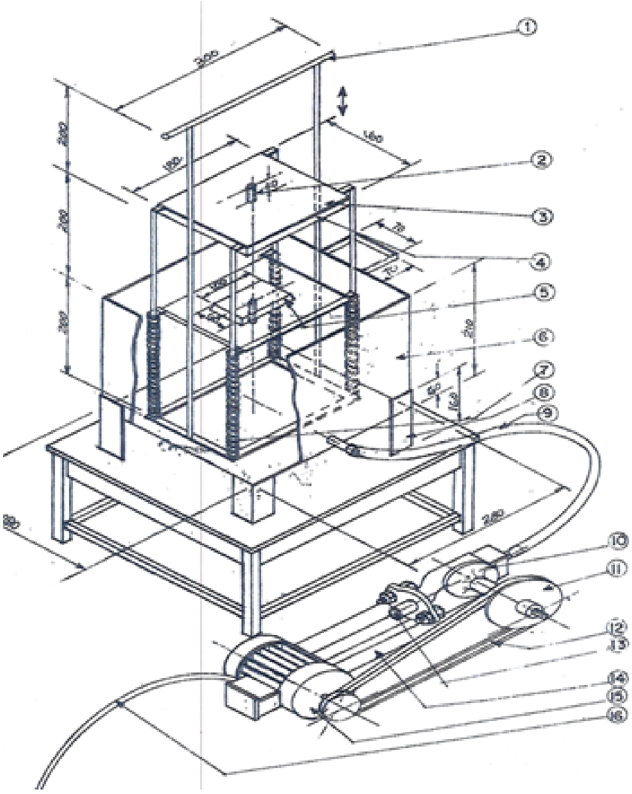
Taking the yield stress σyield as 250MPa, and a factor safety of 4,

$$\sigma_{yield} = \frac{250}{4} = 62.5MPa \equiv 6.25 \times 10^7 N/m^2$$

$$t = \frac{Pr}{\sigma_{yield}} = 0.0058mm$$

- **(d) The lowering mechanism:** This conveys the mold from the counter mold to the pulp slurry vat. The mechanism itself contains four long poles that stretch from the slurry vat to the counter mold through the length. On each pipe on which the mold sits after the pulp molding is completed, 150mm helical springs are attached. To either side of the mold, two Ø7.5mm pipes are mounted on an overhead shaft. The top shaft is used to regulate the movements of the mold via physical pressure.
- **(e) The auxiliary tank:** This tank serves as the drain for the water molecules drawn with the pulp into the mold during the forming of the molded product. It also serves as the intermediate vacuum point before the mold itself or the counter mold. The main essence of this tank is to ensure that the water drawn from the slurry vat along with the pulp does not get into the vacuum pump. This is to protect the pump and electric motor and ensure a neater operation. The design of the auxiliary tank is determined by the consistency of the pulp slurry. This consistency gives the quantity of water that is expected to be drawn into the mold. However, any dimension of tank can be used, provided it is properly sealed to prevent loss of vacuum. Taking an average of 10 moldings per batch, the least volume requirement of the tank will be 0.006m^3.
- **(f) Electric motor:** The vacuum pump is driven by an induction motor single phase electrical engine. The electric motor ratings to be used rely on the vacuum pump indicated by the size of the pulp formation.
- **(g) Vacuum pump:** The vacuum pump used for the model design is a rotary-vane type vacuum pump. This is powered by the electric motor and it in turn creates the vacuum through which the pulp slurry is drawn and sticks to the mold. It is also essential in the removal of the molded product from the mold into the counter mold, and from the counter mold. The rotary-vane pump has lower vacuuming capacity than other types of pumps that may be available but is found suitable enough for the design of the laboratory machine

(h) Pump and Motor seat: This is the seat on which the electric motor and vacuum pump are tightened. The seat is also necessary to provide the proper alignment between the pump and motor pulleys and also to ensure the proper tensioning of the pulley belt. It consists of two angle bars of length 360mm each, cross-braced by metal angle bars of 60mm at both ends. The bracings are also designed to be placed at 90mm intervals along the length of the angle bars to provide more support and rigidity.



S/N	Description	Quantity
1	Lowering handle	1
2	Outlet to vacuum pump	1
3	Counter mold with vacuum chamber	1
4	Foam coating	1
5	Mold	1
6	Pulp slurry vat	1
7	Compression spring	4
8	Framing legs	4
9	Pressure hose	1
10	Vacuum pump	1
11	Pulley	1
12	Pulley belt	1
13	Discharge hose	1
14	Motor frame	1
15	Electric motor	1
16	Cable	1

Figure 4: Sectional view of the machine

RESULTS AND DISCUSSIONS

After the machinery was successfully manufactured, a performance test was carried out and the following observations and inferences were made:

- The machine was fabricated and a molded product was achieved (Figure 5).
- The pulp molding is of the same form as that of the mold and the counter mold, since the pulp slurry used in the assessment averages the sizes of the mold and counter mold.
- However, it was noticed that the process of molding progressed at a quicker pace when more dilution is achieved, i.e. lowering the consistency of the slurry.

CONCLUSIONS

On completion, it can be concluded that the treatment that the pulp slurry is subjected to prior to molding has a great impact on both the molded product and the molding process. Only pulp slurry that had been properly beaten is usable in the formation of products using the vacuum technology. The lower the consistency of the slurry, the easier the formation of the pulp molding. The size and capacity of the vacuum pump and the electric motor powering the pump should correspond to the size of the pulp molding to be formed. A safe overall conclusion is that the general objective of this research in molding a usable material from a mechanically disintegrated pulp has been achieved.

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Figure 5: The Molding machine and Molded Product

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