Design of a Manually Operated Paper-Recycling Machine

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Abstract

A manually operated paper-recycling machine was designed and fabricated. This was done to enable waste paper conversion into useful product. The fabricated plant consists of six major component units that include the disc refiner, the hydropulper, the head box, the felt conveyor, the driers and the rollers. From the results of experimental analysis carried out on the study, it was discovered that for every 0.1kg of used paper fed into the refiner, about 7000ml of water is required to defibre it, and about 0.2 kg of starch adhesive is required. The calculated volume of the refiner, hydropulper and head box is 11795.62cm^3, 62930.47cm^3 and 60979.096cm^3 respectively. The fabricated machine is capable of producing 7.6 kg of recycled paper from 10 kg of used paper.

Keywords

Paper recycling, Design, Fabrication, Waste, Conversion, Defibre

Introduction

Paper is one of the most important products ever invented by man. Widespread use of a written language would not have been possible without some cheap and practical material to write on. The invention of paper means that more people would be educated because more books would be printed and distributed. Industry would grow because all the plans, blueprints, records and formulae it uses would be written down and saved, together with the printing press, paper provided an extremely important way to communicate knowledge.

The primary source of raw material for production of paper is vegetable fibers, obtained mainly from plants. To ensure that the forest is not depleted of these woods, there is need to provide alternative source of raw materials, this therefore leads to the invention of the process of recycling.

Recycling, which is the extraction and recovery of valuable materials from scrap or other discarded materials, is employed to supplement the production of paper. The designing and fabricating of a used paper recycling plant is therefore a welcome development as it will ensure that the source of raw material for paper production is multiplied and also waste paper that could have constituted into wastes are recycled for various productive purposes.

Designing a manually operated paper recycling plant ensures that a cheap and non-complex method of production of paper product is guaranteed. This is the objective of this paper.

Methodology and design calculation

Description of the Recycling Plant

The designed of a waste paper recycling plant included the determination of the volume of the refiner, hydropulper and head box and also the selection of a convenient material for the construction of the individual units. The bulk of the parts of the plant were fabricated using mild steel, this is because it is the easiest to be joined among all other metals. It is a very versatile metal, necessitating its use by many industries for fabrication of process unit equipment. Apart from its versatility, it is also very cheap and readily available compared to other metals. Some basic properties of mild steel that enhance these qualities include (Howard E. B., Timothy L. G., 1985, Metal Handbook):

- Tensile strength: 430KN/mm;
- Yield stress: 230KN/mm;
- Percentage longatum: 20%;
- Tensile modulus: 210KN/mm^3
- Hardness: 130APLS.

Unit Design

The Disc Refiner

The unit consists of three main parts: a hopper for charging in the pulp slurry, a screw type conveyor for moving the slurry to the treating element blade and a treating element.

Volume of hopper is a frustum of a pyramid and the volume is given by V = Ah/3, where V is volume, A is area of base of pyramid, and h is height of pyramid.

- Using similar triangle theorem, height:

$$\frac{h}{8}=\frac{H}{30}, H = h + 29, \frac{h}{8}=\frac{h+29}{30}, 30h = 8h + 232, h = \frac{232}{22}, h = 10.545 \text{ cm}$$

- Total volume of pyramid V_p: $V_p = (1/3)(300)^2\cdot(10.545 + 29) = 11863.5 \text{ cm}^3$
- Volume of truncated pyramid: $V_S = (1/3)\cdot Ah = (1/3)\cdot 8\cdot 8\cdot 10.545 = 224.96 \text{ cm}^3$
- Volume of cylinder enclosing shaft: $V_C = \pi r^2 h$, r = 2.5, h = 8cm then $V_C = 157.08\text{cm}^3$
- Total volume of hopper refiner is $V = (V_p - V_s) + V_c$ and then: V = (11863.5 - 224.96) + 157.080 = 11795.62cm^3

The Hydropulper

This is an open cylindrical vessel incorporating one bladed rotating element that serves both to circulate the slurry and to separate the fibre from each other. It makes the paper source become disintegrated, transformed and well blended into fibre slurry. This unit is operated manually. It follows:

- Volume of Hydropulper, V_r it result from its mass and density. Using a scale up factor of 10 (for the whole plant) mass of pulp slurry leaving hydropulper, mass is 7.14675·10 = 71.46750 Kg = 71467.5 g; Density of pulp is 1.172 g/cm^3, then volume of pulp slurry V_C is 60979.096 cm^3. Total Volume of Hydropulper: Vr = Vc + 0.32 Vc = 1.032Vc, and replacing the numeric values: $V_r = 60979.096 + 0.032\ (60979.096) = 62930.427\text{cm}^3$;
- Diameter of Hydropulper (a cylindrical vessel) it result from volume of cylinder $V = \pi r^2 h$, where height of 50 cm is used i.e. h = 50 cm;
- Radius of circular cylinder: $r^2 = V/\pi h$; $r = \sqrt{\frac{V}{\pi h}} = \sqrt{\frac{62930.43}{\pi \cdot 50}} = \sqrt{400.628} = 20.016$ cm.
- Diameter of cylinder D = 2r = 2·20.016 = 40.032 cm.
- The total surface area of cylinder A: $A = 2\pi r(h+r) = 2\pi\cdot 20.016(50+20.06) = 8805.51 \text{ cm}^3$

- Circumference of cylinder, C: $C = 2\pi r = 2\pi \cdot 20.016 = 125.764$ cm.

Blade Design for Hydropulper

The blade was designed in a way that it has more mixing effect than cutting. The diameter, D_a vary from 1/2.33 D_T to 1/3 D_T.

From the lower value, Blade diameter = 1/2.33 D_T, where D_T = 40.032 cm (diameter of tank), D_a= 1/2.33·40.032 (Diameter of blade) = 17.181cm.

It follows:

- Height of blade (H) from blade of cylinder: $H = 0.15\ D_T - 0.12 D_T$
- The lower value: $H_i = 0.12\ D_T = 0.12 \cdot 40.032 = 4.804$ cm.

The Head Box

This unit is made out of an 18" gauge flat sheet into a square tank. Its purpose is to ensure that a continuous flow of stock at constant velocity across the width of the machine is provided.

Its principal design involves the use of a single slice to develop a free jet of pulp that is then deposited onto the moving felt conveyor.

It has an inlet medium fitted with a 2" pipe socket that allows for a continuous flow of pulp slurry.

It follows:

- Volume of Head box, using a scale up factor of 10 (for the whole plant) result from mass of slurry leaving the hydropulper to the head box, equal to 7.14675·10 = 71.4675 Kg.
- The density of the pulp, 1.172 g/cm^3.
- Volume of the pulp slurry = $\frac{\text{mass}}{\text{density}} = \frac{71.4675}{1.172} = 60.979096 m^3$
- Volume of the headbox = 60979.096cm^3.
- Free jet area is length × breadth = 2.5 × 25.50 = 63.75 cm^2.
- Free jet displacement sheet area, A_{fj}, $A_{fj} = (a+b) \cdot J = (19.2+9) \cdot 25.5 = 71.91$ cm^2
- The total area of headbox slices covering top edge: $A_{hs} = (40.60 \cdot 4.00) \cdot 4 = 649.60$ cm^2
- Entrance area from the hydropulper to the headbox is of: Internal diameter = 4.00cm = Φ; External diameter = 6.00cm = Φ_{ex}, and then:

Internal area = $\frac{\pi \cdot (4.00)^2}{4} = 12.57cm^2$, External area = $\frac{\pi \cdot (6.00)^2}{4} = 28.77cm^2$

Felt Blanket Conveyor

The design of the felt is to serve three (3) main purposes:

1. A conveyor to assist the sheet through the manufacturing process;
2. A porous media to provide void volume and channels for effective water removal;
3. A texture cushion for passing moist sheet without crushing or significant marking.

As a tension band to maintain sheet felt ness and ultimate contact with followings:

- hot dry surface length of cylinder (50cm);
- radius of cylinder (7cm);
- circumference of cylinder ($2\pi r = 2\pi \cdot 7 = 43.99$cm);
- AB = 43.99/2 = CD = 21.99cm;
- Total length of felt: AB + CD +BC + DA = 21.99 + 21.99 +140 +140 = 323.98 cm.

The Dryers

This unit consists of two hollow cylinders designed in the form of a roller, an external mild steel metal cylinder and an internal ceramic cylinder.

The internal cylinder 7" in diameter is made of ceramic material. It is hollow in form and serves as the heating plate. The choice of a ceramic material for the heating plate is hinged on the fact that ceramic does not conduct electricity and is resistance to heat. Each heating plate consists of two heating elements, connected to electric mains outside. The external cylinder encloses the internal cylinder as a casing.

The external cylinder has:

- Diameter of roller = 14cm, therefore radius = 14/2 = 7 cm;
- Length of cylinder = 50 cm;
- Circumference of external cylinder = $2\pi r = 2\pi 7 = 43.98$ cm.

Therefore, circumference of cylinder is 43.98cm.

Internal cylinder has:

- Diameter of pipe = 8 cm;
- Length of ceramic pipe = 30 cm;
- Radius = 8/2 = 4 cm;

- Circumference of internal ceramic = $2\pi r = 2\pi \cdot 4 = 25.132$ cm.

Therefore, circumference of internal ceramic is 25.132 cm.

Since the other rolls have same dimension as the external cylinder of the dryer, therefore the circumference and diameter of all the six cylinders have equal values. The external cylinder of the dryer i.e. 43.98 cm = $4.398 \cdot 10^{-2}$ m.

Conclusions

The development of a manually operated used paper-recycling machine is much cheaper than the automated recycling industries worldwide. The fabricated machine can serve dual purposes, it can be manned permanently at a stationary position or it could be shifted from one place to another as the case may be.

One great advantage to be derived from the use of this machine is that the cost of running it is minimal compared to what it takes to run a full plant. The simplicity of operation of this machine ensures that no too much technical skill is needed to operate it.

When the machine is well maintained, its durability is guaranteed.

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