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Development of Wastepaper Recycling Machine

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ABSTRACT

Waste paper recycling involves reprocessing of used papers in order to produce a new one without using the initial raw material (tree), there by preserving the trees and natural vegetation. Paper production increases deforestation and disposal contribute to environmental loitering and hazards. This study aimed to develop a waste paper recycling machine. The waste paper recycling machine which comprises of digester and pulper units was designed using SolidWorks. The parameters of the digester (volume of slurry and mechanical power agitation) and that of the pulper (pulper volume, rotor power, rotor tip speed, open area ratio, total open area, flow rate through screen and required open area for target flow) were carried out using design calculations. The machine components were fabricated using mild steel and assembled. The evaluation of the recycling paper machine was carried out on the digester and the pulper by loading the machine with waste paper of mass of (20, 40, 60, 80 and 100 kg) and (10,20,30,40 and 50 kg); consistency (3, 4 and 5 %) and (3, 4 and 5 %) and retention time (1 and 2 hr.) and (1,2, and 3 hr.) respectively. The volume of pulp from the digester and pulper were recorded. The digester slurry volume and mechanical power agitation are 0.283 m^3 and 0.42 Kw respectively. The pulper volume, rotor power, rotor tip speed, open area ratio, total open area, flow rate through screen and required open area for target flow are 0.339 m^3,1.28 Kw, 848.34 m/s, 2, 150 mm^2, 0.0508 m/s and 0.150 m^2 respectively. The output volume at the digester are (0.62, 1.30, 2.00, 2.62 and 3.30 m^3) at 1hr and 3% consistency; (0.50, 1.00, 1.50, 2.00 and 2.50 m^3) at 1 hr. and 4% consistency; (0.40, 0.80, 1.20, 1.60 and 2.00 m^3) at 1 hr. and 5% consistency; (1.33, 2.66, 4.00, 5.33 and 6.66 m^3) at 2 hr. and 3% consistency; (1.00, 2.00, 3.00, 4.00 and 5.00 m^3) at 2 hr. and 4% consistency; (0.80, 1.60, 2.40, 3.20 and 4.00 m^3) at 2 hr. and 5% consistency. Output volume at the pulper are (0.33, 0.66, 1.00, 1.33 and 1.66 m^3) at 1 hr. and 3% consistency; (0.25, 0.50, 0.75, 1.00 and 1.25 m^3) at 1 hr. and 4%; (0.20, 0.40, 0.60, 0.80 and 1.00 m^3) at 1 hr. and 5% consistency; (0.66, 1.33, 2.00, 2.66 and 3.33 m^3) at 2hr. and 3% consistency; (0.50, 1.00, 1.50, 2.00 and 2.50 m^3) at 2hr. and 4% consistency; (0.40, 0.80, 1.20, 1.60 and 2.00 m^3) at 2hr. and 5% consistency; (1.00, 2.00, 3.00, 4.00 and 5.00 m^3) at 3hr, and 3% consistency; (0.75, 1.50, 2.25, 3.00 and 3.75 m^3) at 3hr. and 5% consistency; (0.60, 1.20, 1.80, 2.40 and 3.00 m^3) at 3hr. and 5% consistency. The paper recycling machine was produced having a maximum output at 3% consistency for both digester and pulper at 3hours retention time. Its application will be of benefit in all institutions and organization for recycling of waste paper

Keywords: Waste Paper, Recycling, Waste Management, Waste Paper Recycling Machine, Digester, Pulp, Pulper Machine

Aims Research Journal Reference Format:
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1. INTRODUCTION

The rapid growth of offices and businesses has led to significant increase in paper waste generation, contributing to environmental pollution and waste management challenges (Babalola, 2018; Ogwueleka, 2019).

In Nigeria, for instance, it is estimated that over 50% of municipal solid waste is composed of paper and cardboard materials (Agunwamba, 2017; Nwosu *et al.,* 2020). Traditional waste management practices, such as landfilling and incineration are not only ineffective but also pose environmental and health risks (Kumar *et al.*, 2020; EPA, 2020). One of the primary drivers for waste paper recycling is its environmental benefits. Studies have shown that recycling paper waste reduces the need for virgin fiber extraction, which helps conserve forests and biodiversity (Okafor *et al*, 2021). Additionally, recycling paper requires less energy and water compared to producing paper from raw materials, resulting in lower greenhouse gas emissions and reduced environmental pollution. By diverting paper waste from landfills, recycling also helps alleviate pressure on landfill capacity and reduces the emission of methane, a potent greenhouse gas generated during decomposition (Blair and Mataraarachchi, 2021).

Recycling paper waste can significantly reduce the environmental footprint of offices and business, conserve natural resources, and promote sustainable development (EPA, 2020; Guerrero *et al*., 2013). However, the lack of efficient and cost-effective recycling technologies has hindered the widespread adoption of paper recycling practices in Nigeria (Ogwueleka, 2019; Adekunle *et al*., 2019). Additionally, recycling paper waste reduces waste management costs for municipalities and businesses, leading to overall cost savings and improved efficiency in waste management systems (Dorosz *et al,* 2021). Waste paper recycling also has important social implications, particularly in terms of community engagement and empowerment. Recycling programs encourage public participation and environmental stewardship, fostering a sense of responsibility and ownership among citizens for waste management and resource conservation. Additionally, recycling initiatives create opportunities for community involvement, collaboration, and education, promoting awareness and understanding of sustainability issues and encouraging sustainable behaviors (Altassan, 2023).
Recycling of used papers does have a limitation. Every time when paper is recycled, the fibre becomes shorter, weaker and more brittle. In general, a waste paper can be recycled up to seven times before it is discarded (Vijay Kumar,2017).

Despite the numerous benefits of waste paper recycling, several challenges remain, including contamination of recycled paper streams, inadequate recycling infrastructure, and fluctuating market demand for recycled paper products. Addressing these challenges requires coordinated efforts from governments, businesses, and communities to invest in recycling infrastructure, improve collection and sorting systems, and promote market demand for recycled paper materials. Furthermore, innovations in recycling technologies and materials, as well as policy interventions and incentives, can help overcome barriers and unlock the full potential of waste paper recycling in achieving environmental sustainability and resource efficiency goals (Wilson, 2023).

2. METHODOLOGY

In order for waste paper to be reused, it needs to go through some recycling stages. These stages are shredding, digesting, pulping, sieving, washing and flotation, ink removal and bleaching, respectively. After these processes, the paper production process is started (Thompson, 2004).
The components of a paper recycling machine are: Shredding, Digester, Pulping and Screening, Pulp clearing and Deinking, Paper Machine web formation and drying and Finished Paper Units.

2.1 Design of Digester and Pulper Machine of waste paper recycling.

This research worked on the digester and the pulper machine that recycle waste paper into pulp. The Solid-work software was used to draw the digester and the pulper and the components of each system was design using standard formula.

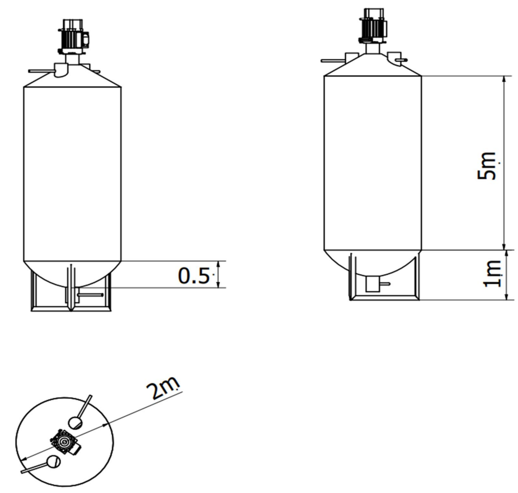

Figure 1: Orthographic projection of the digester

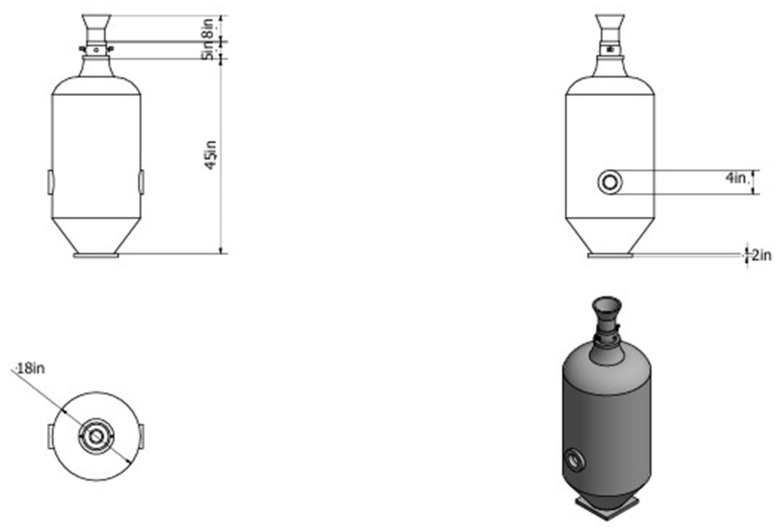

Figure 2: Orthographic and 3D drawing of a Pulper Machine

2.2 Process of paper recycling

The waste paper is shredded (depending on the type of paper shredding may be excluded); convert to pulp in a digester. The Pulp is separated to clean the fibres in a screening unit which beat and refine the fibres. It is then passed to a floating chamber where the slurry fibres are diluted to form a thin fibre slurry in suspended solution. It is also deinked in this chamber and made to pass through the headbox into a thin screen forming a web of fibres on a thin screen. The web is further press to increase the density of the material, dried to remove the remaining moisture through a roller press and released in paper tray.

2.3 Design Outline

The paper recycling machine consists of the following units:

1. Digester Unit
2. Pulp and Screening Unit

2.3.1 The digester Unit

The purpose of the digester is to separate the cellulose fibers from the lignin and other substances in the wood chips. The cellulose fibers are the main component of pulp, which is then refined and processed to make paper. Pulp digester, also called digester, is a huge container for chemical pulping and dissolved fiber steam sections. It is used to cook raw materials of paper pulp, such as grass, wood, boom etc.

2.3.2 Components of the Digester

The pulp digester is made of steel material inform of pressure cooker, with heating element and temperature regulator, values, gate, and pipes. Paper pulp digester is used to make chemical pulp. It cooks raw materials of papermaking (wood, grass, bamboo, paper etc.) to produce the pulp mainly containing the cellulose by chemical interaction with the cooking liquor.The types of pulp digester applied in the paper pulp making are the rotary and vertical digesters types of batching cooking digester. While the continuous digester also makes use of continuous tubular digester and vertical digester. Waste paper usually consists of 60-62 % cellulose, 4-12 % of hemicellulose, and1-18% of lignin (Zhou et al ., 2017).

The chips are fed into a large pressure cooker (digester), into which is added the appropriate chemicals (white liquor). The chips are then cooked (digested) with steam at specific temperatures (160-175 ℃.) long enough (Cooking usually lasts 5-6 hours) to separate the fibers and partially dissolve the lignin and other extractives. Colour is removed from the fibres using sodium hydrosulphate, a reductive bleach. Hydrogen peroxide is used to brighten the fibres and when disposed of it breaks down into water and oxygen. The heating process mainly refers to the indirect heating area of the tube heater. The liquid from the center flows through the tube and heats up and moves from the top to the bottom

2.3.3 Design of a digester

The Main Components of digester are:

a) Digester Vessel (Pressure or Atmospheric type) which is made to be cylindrical shape made of stainless steel.
b) Agitator or Rotor: Provides mechanical mixing of paper pulp during digestion. It is driven by an electric motor with gearbox
c) Heating system: Provides the require steam or thermal energy for cooking the pulp. It consists of : Steam inlet valve , Pressure control valve, Steam trap and Condensate outlet
d) Dilution and Water inlet System: Supplies water to adjust pulp consistency before or after digestion. It consists of Flow control valve.
e) Discharge system: Allows removal of digested pulp to the next stage (washer, refiner, or storage chest) which includes: Bottom discharge valve and Outlet pipe

2.4 Typical Process Flow in the digester

Waster Paper + Water loaded into digester
Chemicals dosed → mixing begins
Steam supplied → temperature rises (90-160^{o}c)
Digestion for fixed time (30-120min)
Pulp discharged → washed and refined

2.4.1 Design Considerations of digester vessel

Material selection was based on availability, durability, cost, ease of operation and fabrication was considered. The following consideration was used in the design of digester vessel volume and mechanical properties: material throughout (mass/time),operating consistency (solids %), retention time (digestion time), geometrical configuration (cylindrical, conical), mechanical agitation and Pressure and temperature (for high-consistency or thermal pulping)

2.5 Design calculation for the components of a waste paper digester

The volume of the digester is giving in by

$$V = \frac{Q_{dry}}{pC_s}, t \qquad 1$$

Where:

V = require vessel volume (m^3)
Q_{dry} = dry paper flow rate (kg/h),
p =density of water/pulp slurry ≈ 1000kg/m^3
t= retention time (h)

The value of 1.2-1.5 is suggested for safety factor to account for foaming agitation, headspace.

2.5.1 Design for Mechanical Agitation Power

Pulper production require mixing to break down fibers. For a low consistency ration the power is

$$P = K.V \qquad 2$$

Where:

P = power in Kw,
V= slurry volume (m^3)
K= power coefficient ($\sim 1.5 - 3\ kW/m^3$ for low-consistency pulpers).

2.5.2 Design of Digester's thickness

ASME section VIII pressure vessel design equation was used and is giving as

$$t = \frac{P.D}{2.\sigma.E} \qquad 3$$

Where:

t = shell thickness (m)
P = internal pressure (Pa),
D = internal diameter (m),
σ = allowable stress (Pa)
E =weld efficiency (decimal e.g., 0.85)

For atmospheric vessels: P ≈ O

2.6 Pulp Preparation

Pulp and paper manufacturing process are sometimes split into pulp production and pulp process to final paper. The pulp is transported to the paper mill – in this case, pulp is dried and cut into bales. For an 'in-line' process, the pulp is cleaned, refined and purified in a 97% water mix containing both long and short cellulose fibres. In this section, contaminants are already removed from pulp, excluding ink. The pulper consists of screen, impeller attached to shaft, motor and pipe connections. Chemical are added to the pulp at this stage, namely: tetra-oxo-sulphate VI acid (H_2SO_4), chlorine and chlorine dioxide.

2.7 Basic Design formula for Volume

Let's assume:

M = dry feed mass flow (kg/h)
C = consistency
t_{res} = residence time in digester (hours)
p_{mix} = density of slurry (typically – 1000kg/m³ for dilute slurries)

then the required digester volume (V)

$$V = \frac{M}{C.\rho_{mix}} x\ t_{res} \qquad 4$$

2.8 Power Requirement of Rotor (P)

$$P = \frac{p.N^3.D^5.K}{\pi} \qquad 5$$

Where:

P = Power required (Watts)
p = Density of pulp slurry (kg/m³)
N = Rotational speed (rev/s)
D = Rotor diameter (m)
K = Dimensionless coefficient depending on rotor design
π = Efficiency or the system

2.9 Tip Speed (V.)

$$V_t = \ . D. N \qquad 6$$

Where:

V; = Tip speed of the rotor (m/s)
D = Diameter of rotor (m)
N = Rotational speed (rev/s)

Tip speed influences the shear force, which is crucial in disintegrating fibers without damaging them.

2.10 Flow Rate (Q) - Approximation for Axial Flow Impellers

$$Q = \emptyset. N. D^3 \qquad 7$$

Where:

Q = Flow rate (m³/s)
Ø = Flow coefficient (dimensionless, depends on blade shape and angle)

Reynolds Number (Re) for Rotor Flow

$$Re = \frac{P.D^2.N}{\mu} \qquad 8$$

Where:

μ = Dynamic viscosity of the pulp slurry

This helps determine the flow regime (laminar or turbulent), which impacts efficiency and effectiveness of fiber separation.

Shear Rate (γ) near the Rotor

$$\gamma = \frac{V_t}{\delta} \quad 9$$

Where:
δ = Boundary layer thickness or gap (m)

High shear rates help with fiber disintegration, but too high may damage fibers.

Specific Energy Consumption (SEC)

$$SEC = \frac{P.t}{m} \quad 10$$

Where:
SEC = Specific energy consumption (kWh/ton)
t = Time of operation (h)
m = Mass of pulp processed (tons)

2.11 Rotor Design Considerations:

Number of blades and their curvature affects the turbulence pattern. Clearance between rotor and screen plate (in drum or vertical pulpers). RPM is typically optimized to balance disintegration and energy use.

2.12 Estimating Torque Required by Pulper

$$T = \frac{P.60.100}{2\pi} \quad 11$$

Or derived from mechanical output needs (force, radius, etc.):

$$T = F.r \quad 12$$

Where: F = Tangential force applied by rotor (N)
r = Radius of the rotor shaft (m)

Gearbox Ratio Selection

The gearbox reduces the high-speed output from the motor to a usable low-speed, high-torque output:

$$I = \frac{N_{motor}}{N_{pulper}} \quad 13$$

Where: I = Gearbox ratio
N_{motor} = Motor RPM
N_{pulper} = Required RPM of pulper rotor

2.13 Motor Selection

Motor power should include a safety factor:

$$P_{motor} = \frac{P_{required}}{\eta} \text{ x SF} \quad 14$$

Where: η = Efficiency of gearbox (typically 0.9 to 0.95)
SF = Safety factor (typically 1.2 to 1.5 depending on load type)

2.14 Screen plate design

Designing the screen plate (either perforated or slotted) for a waste paper pulper machine involves several parameters that affect pulp quality, throughput, and energy consumption. Parameters in Screen Plate Design are:

Symbols	Description
A_0	Total open area of screen (m^2 or cm^2)
D	Diameter of perforation or width of slot (mm)
P	Pitch or center-to-center spacing between holes/slots (mm)
A_t	Total area of screen plate (m^2 or cm^2)
Ø	Open area ratio (dimensionless or %)
Q	Flow rate or capacity (m^3/h or L/min)
V	Flow velocity through openings (m/s)
N	Number of holes or slots

Open Area Ratio (for Perforated Plate)

$$Ø = \frac{A_0}{A_t} \quad 15$$

For circular holes:

$$Ø = \frac{\pi_D{}^2}{4P^2} \quad 16$$

Or for slotted plates (slots of width D and length L):

$$Ø = \frac{D.L}{P_x\,.P_y} \quad 17$$

Where: P_x = slot pitch in X-direction (lengthwise)
P_y = slot pitch in Y-direction (widthwise)

Total Open Area
For circular holes:

$$A_0 = N.\,\frac{\pi_D{}^2}{4} \quad 18$$

For slotted screens:

$$A_0 = N.\,D.\,L \quad 19$$

Where
N = Number of holes or slots

Flow Through Screen (Hydraulic Capacity)

Assuming laminar flow through the screen holes:

$$Q = A_0.\,V \quad 20$$

Where: Q = Flow rate through screen (e.g., pulp flow)
V = Velocity through holes (depends on pressure difference, pulp consistency, etc.)

$$A_0 = \frac{Q}{V} \quad 21$$

Velocity Through Screen

For slotted or perforated screens in pulpers, the empirical velocity is often in the range of V = 1.5 to 3.5 m/s. Higher velocities increase throughput but risk more fiber loss or plugging. Screen hole Size Selection (Fiber Retention) The hole or slot size depends on Fiber type, Contaminant size to be rejected and required pulp quality.

Typical sizes are: Perforated: 6-12 mm and slotted: 1.5-3 mm (width), with lengths 20-80 mm

Design of trash trap

Trash Trap (Grit Chamber / Junk Trap) In a waste paper pulper system, the trash trap (also known as a grit chamber) is a sedimentation or centrifugal chamber used to remove heavy impurities (sand, metal, glass, grit). Protect the pulper rotor and downstream equipment and maintain pulp quality. The trash trap is located beneath the pulper, where heavy materials settle by gravity or are ejected by centrifugal force.

2.16 Design Parameters

Symbol	Parameter	Unit
Q	Flow rate of pulp slurry	m^3/s
V_s	Settling (or sedimentation) velocity of grit	m/s
V_t	Horizontal (flow) velocity in chamber	m/s
t	Retention time	s
h	Effective depth of chamber	m
L	Length of chamber	m
B	Width of chamber	m
A	Cross-sectional area (A - B xh)	m^2
P_s	Density of grit	kg/m^3
P_u	Density of slurry (water + fiber)	kg/m^3
μ	Dynamic viscosity of slurry	$N{\cdot}s/m^2$
d_p	Diameter of grit particle	m
g	Acceleration due to gravity (9.81 m/s2)	m/s^2

2.17 Settling Velocity (Stokes' Law for fine grit)

For small particles (laminar regime, $Re_p < 1$):

$$V_\delta = \frac{(P_s - P_\omega) g d_p^2}{18\mu} \tag{22}$$

If flow is turbulent (Re_p > 1), use an empirical drag relation:

$$V_\delta = \sqrt{\frac{4 - p\omega) d_p^2}{18}} \tag{23}$$

Where C_d = 0.4-0.7 (drag coefficient).

$$\frac{h}{V_s} = \frac{L}{V_f} \tag{24}$$

Therefore,

$$L = \frac{V_f}{V_s} h$$

And since Q= V_f A =V_f B h:

$$V_f = \frac{Q}{Bh}$$

Substitute into the first equation:

$$L = \frac{Q}{BV_s}$$

Retention time

$$t = \frac{L}{V_f} = \frac{B}{Q} = \frac{BhL}{Q} \quad 25$$

Typical design retention time is15-60 seconds depending on consistency and grit load.

2.18 Dilution water inlet design

In a waste paper pulper dilution water is added to adjust the pulp consistency (percentage of fiber in the slurry).It helps Maintain optimal rotor turbulence, aid in fiber disintegration, reduce power consumption and Improve junk removal efficiency.

Symbol	Parameter	Unit
Q_p	Flow raté of pulp suspension entering pulper	m³/s
C_i	Initial consistency of pulp (fraction, e.g., 0.04 for 4%)	-
C_f	Final (target) consistency after dilution	-
$Q\omega$	Flow rate of dilution water	m³/s
Q_t	Total mixed flow rate after dilution (Q, - Q, + Q.)	m³/s
W_f	Mass flow rate of dry fiber	kg/s
P	Density of slurry or water (~ V J0 kg/m³)	kg/m³
*	Mass Balance for Fiber and Water	

Fiber Mass Conservation

Fiber mass remains constant before and after dilution:

$$W_f = Q_p\, pC_i = Q_t\, pC_f \quad 26$$

Simplify:

$$Q_pC_i = (Q_p + Q\omega)\, C_f$$

Solving for the Dilution Water Flow Rate $Q\omega$

$$Q_p\, C_i = Q_p\, C_f + Q\omega\, C_f$$

$$Q\omega = Q_p\, \frac{C_i - C_i}{C_f} \quad 27$$

Dilution Water Flow Rate:

$$Q\omega - Q_p\, \left(\frac{C_i}{C_f} - 1\right)$$

Alternative Formula for Total Flow Rate

$$Q_t = Q_p + Q\omega = Q_p\, \frac{C_i}{C_f} \quad 28$$

Parameter	Typical Range
Pulp consistency before dilution	3-5%
Pulp consistency after dilution	2-3%
Retention/mixing time	5-10 min
Water pressure at inlet	1-3 bar
Inlet location	Tangential or radial near rotor zone

2.19 Design of discharge outlet

The accept line or discharge outlet carries the acceptable pulp slurry from the pulper (after pulping and junk separation). The Parameters are defined as:

Symbol	Description	Unit
Q_d	Volumetric discharge flow rate (accept flow)	m^3/s
C_f	Consistency of accepted pulp (fiber mass fraction)	-
P	Density of slurry (= 1000 kg/m3)	kg/m^3
W_f	Dry fiber mass flow rate	kg/s
A_d	Cross-sectional area of outlet pipe	m^2
D_d	Diameter of discharge pipe	m
V_d	Flow velocity in outlet pipe	m/s
∩	Discharge efficiency (ratio of accept to total pulp volume)	-
Q_t	Total flow rate in pulper (pulp + water)	m^3/s

2.20 Mass and Volume Flow Relations

Fiber Mass Flow Rate

$$W_f = Q_d \, p \, C_f \qquad 29$$

For steady-state operation, the accepted pulp carries all usable fibers:

$$W_f = Q_t p C_t n \qquad 30$$

Equating 2.29 and 2.30:

$$Q_d C_f = Q_t \, C_t n \qquad 31$$

Hence:

$$Q_d = Q_t \frac{C_t n}{C_f} \qquad 32$$

Main formula for Discharge (Accept) Flow:

$$Q_d = Q_t \left(\frac{C_t n}{C_f}\right)$$

Pipe Flow Relation

Flow rate and velocity are related by:

$$Q_d = A_d \, V_d = \frac{\pi D_d^2}{4} \qquad 33$$

$$D_d = \sqrt{\frac{4Q_d}{\pi V_d}}$$

Hence the diameter of the discharge line:

2.21 Reagent for production of Pulp

Hydrogen Peroxide (H_2O_2) Bleaching, is used in paper recycling for its ability to break down residual lignin and remove ink particles.

General Reaction is

H_2O_2 + Lignin → Water-Soluble Products}
Oxidation of Chromophoric Groups

H_2O_2 → 2OH·

Reaction with Lignin
Lignin – OH + OH· → Lignin - O. + H_2O
Sodium Hydroxide (NaOH) Treatment is used in paper recycling to help dissolve lignin and improve brightness.

Alkaline Reaction:
NaOH + Lignin} → Water - Soluble Products
Hydrolysis of Lignin:
Lignin + NaOH → Soluble Lignin Derivatives
These chemical treatments are crucial in the paper recycling process to improve the quality of recycled fibers by removing impurities such as ink and residual lignin.

3. RESULTS AND DISCUSSION

3.1 Digester
Table 3.1 depict the geometric dimension of the digester fabricated.

Table 3.1: Summary of Design parameter for the digester

Purpose	Formular	Dimension
Vessel	$V = \frac{Q_{dry}}{pC_s}, t$	0.283m³
Cylinder Geometry	$V = \pi.\left(\frac{D}{2}\right)^2 .H$	Solve for H = 1.0 m or D = 0.6 m
Agitator Power	$P = K.V$	0.42Kw/m³
Shell thickness (if pressured)	$t = \frac{P.D}{2.\sigma.E}$	3mm

Plate 3.1a and 3.1b is the picture of the fabricated digester, while 3.1c is the pulp produced.

(a) (b) (c)

Plate 3.1 (a) and (b) Plate of the digester (c) Slurry from digester

3.2 Slurry Volume produce from digester

Volume of slurry gotten from the digester when mixed is shown in table 3.2 and 3.3.

Table 3.2a: Output from digester at consistency of 3% with 1 hour retention time

Dry feed mass (kg)	Retention time(hr)	Consistency %	Pulp Volume (kg)
20kg	1	3	0.62
40kg	1	3	1.30
60 kg	1	3	2.00
80 kg	1	3	2.62
100 kg	1	3	3.30

Table 3.2b: Output from digester at consistency of 4% with 1 hour retention time

Dry feed mass (kg)	Retention time(hr)	Consistency %	Pulp Volume (kg)
20kg	1	4	0.50
40kg	1	4	1.00
60 kg	1	4	1.50
80 kg	1	4	2.00
100 kg	1	4	2.50

Table 3.2c: Output from digester at consistency of 5% with 1 hour retention time

Dry feed mass (kg)	Retention time(hr)	Consistency %	Pulp Volume (kg)
20kg	1	5	0.40
40kg	1	5	0.80
60 kg	1	5	1.20
80 kg	1	5	1.60
100 kg	1	5	2.00

Table 3.3a : Output from digester at consistency of 3% with 2 hour retention time

Dry feed mass (kg)	Retention time(hr)	Consistency %	Pulp Volume (kg)
20kg	2	3	1.33
40kg	2	3	2.66
60 kg	2	3	4.00
80 kg	2	3	5.33
100 kg	2	3	6.66

Table 3.3b : Output from digester at consistency of 4% with 2 hour retention time

Dry feed mass (kg)	Retention time(hr)	Consistency %	Pulp Volume (kg)
20kg	2	4	1.00
40kg	2	4	2.00
60 kg	2	4	3.00
80 kg	2	4	4.00
100 kg	2	4	5.00

Table 3.3c : Output from digester at consistency of 5% with 2 hour retention time

Dry feed mass (kg)	Retention time(hr)	Consistency %	Pulp Volume (kg)
20kg	2	5	0.80
40kg	2	5	1.60
60 kg	2	5	2.40
80 kg	2	5	3.20
100 kg	2	5	4.00

Result Output from production of slurry in the digester

Table 3.2a to 3.2c shows that at a retention time of one hour and consistency of 3% the volume output increases as the mass of dry wastepaper increases. At 20 Kg the output was 0.62 and at 100 Kg of dry mass it increases to 2.50 Kg. The same trend was observed at consistency of 4% and 5% From Table 3.3a to 3.3c the output increases as the dry mass increases at consistency of 3% with 2-hours retention time. Same as with 1- hour retention, only that the 2-hours retention time gives more yield than the 1-hour yield. Generally, it expected that there will a point at which increase in dry mass of the waste will not cause an increase in the output, it is said to have reach the optimum point.

3.3 Pulper Result

Using a dry mass of 10 kg/h and a consistency varied from C = 0.03 to 0.05, and a slurry flow rate of Q_{stock} = 2.5 m^3/h. The pulp output gotten is shown in Table 3.4a to 3.6c Table 3.4a shows that in the Pulper machine the screened slurry from the pulper also increases as the mass input increases and likewise as the retention time and consistency increases. Table 3.4b shows that increase in consistency from 3% to 4% gives a yield less than that of the 3% consistency. Likewise, the same trend was observed in Table 3.4c. It can be deducted that there are minimum or optimum mass at which increase in will lead to increase output.

Table 3.4a: Output of Pulp from Pulper machine at 3% consistency and 1-hour retention time

Mass of Pulp (kg)	Retention time (h)	Consistency %	Output (kg)	
10	1	3	0.33	
20	1	3	0.66	
30	1	3	1.00	
40	1	3	1.33	
50	1	3	1.66	

Table 3.4b: Output of Pulp from Pulper machine at 4% consistency and 1-hour retention time

Mass of Pulp (kg)	Retention time (h)	Consistency %	Output (kg)	
10	1	4	0.25	
20	1	4	0.50	
30	1	4	0.75	
40	1	4	1.00	
50	1	4	1.25	

Table 3.4c: Output of Pulp from Pulper machine at 5% consistency and 1-hour retention time

Mass of Pulp (kg)	Retention time (h)	Consistency %	Output (kg)	
10	1	5	0.2	
20	1	5	0.4	
30	1	5	0.6	
40	1	5	0.8	
50	1	5	1.0	

It can be said from Table 3.5a – 3.5c, for the input mass used a consistency of 3% is better than that of 4% or 5%.

Table 3.5a: Output of Pulp from Pulper machine at 3% consistency and 2-hour retention time

Mass of Pulp (kg)	Retention time (h)	Consistency %	Output (kg)	
10	2	3	0.66	
20	2	3	1.33	
30	2	3	2.0	
40	2	3	2.66	
50	2	3	3.33	

Table 3.5b: Output of Pulp from Pulper machine at 4% consistency and 2-hour retention time

Mass of Pulp (kg)	Retention time (h)	Consistency %	Output (kg)	
10	2	4	0.5	
20	2	4	1.0	
30	2	4	1.5	
40	2	4	2.0	
50	2	4	2.5	

Table 3.5c: Output of Pulp from Pulper machine at 5% consistency and 2-hour retention time

Mass of Pulp (kg)	Retention time (h)	Consistency %	Output (kg)	
10	2	5	0.4	
20	2	5	0.8	
30	2	5	1.2	
40	2	5	1.6	
50	2	5	2.0	

The decrease in output as the consistency increase is also seen in Table 3.6a – 3.6c, showing the mass fed is below minimum optimum value to cause an increase in slurry output from the pulper. Efficiency of the machine and better output in affected by the quantity of mass fed.

Table 3.6a: Output of Pulp from Pulper machine at 3% consistency and 3-hour retention time

Mass of Pulp (kg)	Retention time (h)	Consistency %	Output (kg)	
10	3	3	1.0	
20	3	3	2.0	
30	3	3	3.0	
40	3	3	4.0	
50	3	3	5.0	

Table 3.6b: Output of Pulp from Pulper machine at 4% consistency and 3-hour retention time

Mass of Pulp (kg)	Retention time (h)	Consistency %	Output (kg)	
10	3	4	0.75	
20	3	4	1.50	
30	3	4	2.25	
40	3	4	3.00	
50	3	4	3.75	

Table 3.6c: Output of Pulp from Pulper machine at 5% consistency and 3-hour retention time

Mass of Pulp (kg)	Retention time (h)	Consistency %	Output (kg)	
10	3	5	0.6	
20	3	5	1.2	
30	3	5	1.8	
40	3	5	2.4	
50	3	5	3.0	

Pulper Tank Dimensions (Assuming Cylindrical Shape)

$V = \pi \times \left(\frac{D}{2}\right)^2 \times H$

$V = 3.142 \times 0.6/2 \times 0.6/2 \times 1.2 = 0.339\ m^3$

3.4 Efficiency of the recycling machine

Efficiency of the waste paper recycling machine is measure as (at pulper machine output)

Material recovery rate (%) = $\frac{oven-dry\ weight\ of\ usable\ pulp\ produced}{oven-dry\ wei\quad of\ input\ waste\ paper} \times 100$

= 1.0/10 x 100 = 10%

Summary of design dimension for pulper

Description	Formula	Dimension
Open area ratio (perforated)	$\emptyset = \frac{\pi_D{}^2}{4P^2}$	2 mm
Open area ratio (slotted)	$\emptyset = \frac{D.L}{P_x.P_y}$	50 mm
Total open area	$A_0 = A_t.\emptyset$	150 mm
Flow rate through screen	$Q = A_0.\ V$	0.0508 m/s
Required open area for target flow	$A_0 = \frac{Q}{V}$	0.150 m^2.

(a) (b) (c)

Plate 2: (a) and (b) Plate of Pulper, (c) Slurry from Pulper

Plate 2a, b and c showed the fabricated pulper and the pulp output.

4. CONCLUSIONS

This study has developed a digester and pulper machines for wastepaper recycling systems within office and business environments, thereby contributing to environmental sustainability and resource conservation. The test run and performance evaluation of wastepaper recycling machine revealed that the consistency, mass fed and retention time affected the output. A consistency of 3% is better for good performance based on the mass used. The material recovery rate obtained is 10%.

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