PAPER RECYCLING MACHINE

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

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ABSTRACT

Paper recycling machine consists of a shredding unit for shredding waste paper into relatively smaller sized strips. A pulping unit will make use of a mixture of water and paper strips to pulp paper to fibers. The pulp water mixture will be de-inked via froth flotation process and will be transported to forming section. Forming section dries up the de-inked pulp water mixture via heaters while moving it on a conveyer belt. The dried pulp is passes through calendar rollers for strengthening fiber bonds and provide recycled sheet of equal thickness. Pumps and motors will be used to transport pulp mixture and water respectively.

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ABBREVIATIONS

NUST	National University of Sciences and Technology
PMO	Project Management Office
IESE	Institute of Environmental Studies and Engineering
SS	Stainless Steel
HSS	High Speed Steel
RPM	Rounds Per Minute
Rs.	Rupees
PVC	Polymerization of Vinyl Chloride

NOMENCLATURE

M2 Material	Tungsten-Molybdenum High Speed Steel Alloy
g	amount of evaporated water per second (kg/s
Θ	evaporation coefficient (kg/m^2h)
v	velocity of air above the water surface (m/s)
A	water surface area (m^2)
x	humidity ratio of air (kg H^2O in kg Dry Air)
x_s	maximum humidity ratio of saturated air at the same temperature as the water surface (kg H^2O in kg Dry Air)

CHAPTER 1: INTRODUCTION

Motivation

Global warming is the biggest threat to our planet. There is logical agreement that the Earth's climate is changing because of Global Warming/Climate change caused fundamentally by the Human utilization of oil, coal, and natural gas. Global warming is quickening as planetary temperatures achieve record highs. The melting of Polar ice caps and mountain glaciers may cause sea levels to ascend by something like three feet, most likely substantially more, and by eighty feet in coming hundreds of years. Half of the world's plant and creature species are in danger of termination by 2100 (The Guardian, 2017) as environments are devastated and biological communities unwind. The tremendous Siberian permafrost peat bogs are obviously beginning to melt, discharging methane and quickening global warming. Antarctic glaciers are sliding into the ocean quicker than recently expected, which may result in worldwide seaside flooding. Quickly liquefying polar ice caps and glaciers give visual proof of global warming.

Expanding temperatures can decimate humans and wildlife natural surroundings.

Planting trees and saving the existing ones can help us battle this war against Global warming. Whereas, it can be seen that thousands of trees are cut down every year. The total tree cover loss in Pakistan is 10,022.4 hectare (ha) while the gain is only 847.3 (ha)., leaving a huge gap of over 9,000 (ha), a gap which would most likely increase exponentially given the rise in everyday demand. (Khan, 2014)

Paper Usage at NUST:

NUST uses 15 tons of paper every year which include exam papers, assignment papers and a large amount of A4 type office papers. According to the data collected from PMO and research conducted by IESE, 5 tons of paper is wasted every year at NUST.

It takes 24 trees to make 1 ton of paper. So 5 tons of wasted paper means 100 trees gone to waste every year only to fulfill the paper demand at NUST

A big chunk of this wasted paper is burnt, some is mixed with inorganic waste and the rest is sold to waste paper processing sites individually by workers.

Existing Projects:-

There is no paper recycling project in any university of Pakistan. Moreover, if steps are taken to recycle paper in off-site plants, a lot of problems will have to be dealt with for example,

- Important papers will have to be shredded
- Transport will have to be provided for off-site plants
- NUST will be missing out the opportunity of benefitting from recycling paper

Also, buying a paper recycling machine is not the best option since the office sized compact machines are very expensive.

Problem Statement

Keeping in mind the factors of global warming, expensive machines and problem of sending paper to be recycled to off-site plants, we have come up with the following problem statement.

"To develop an economical and compact paper recycling machine for NUST."

Objectives

The objectives of these projects are

- Design of paper recycling machine.
- Manufacturing of paper recycling machine
- Converting waste paper to pulp
- De-inking of waste paper
- Forming of paper
- Semi-automatic machine
- Recycled paper in usable form
- Compact in size

- Cost effective manufacturing and use

CHAPTER 2: LITERATURE REVIEW

Existing Paper Recycling Machines/Mills

Paper is being recycled throughout the world for around two decades. Presently it is either recycled on large mills or office sized machines.

Paper Recycling Mills:-

Huge paper recycling mills have been performing the task of recycling paper in bulk. They perform the following four tasks:-

- Sorting
- Pulping
- De-inking (can be skipped depending on the final product required)
- Paper forming

The recycled paper, obtained after following the above mentioned 4 processes, since is not of the same strength or color as it is in its original form, is used in making packing cartons, insides of tissue paper boxes and books or magazines, and sent to press for making newspapers. Moreover, using 1.2 tons of waste paper, only 1 ton can be recycled while the rest is separated in deinking methods.

These paper recycling mills are of the area of 100 acres to 300 acres such as the Bulle Shah Paper Mill situated in Kasur, Pakistan which is spread over an area of 240 acres and has a capacity of producing 240,000 tons of paper and 210 million corrugated boxes annually.

Office Sized Machine:-

Paper recycling mills cover a lot of area and consume hours to recycle paper since they have to produce in bulk. To counter this difficulty, an office sized paper recycling machine has been built by Epson, the Paper Lab A-800.

The Paper Lab is a dry type paper recycling machine which can recycle 720 sheets of A4 sized paper in one hour or 1 sheet within 5 seconds.

Another advantage of this compact paper recycling machine is that it can produce A4 sized paper of any required color after feeding a white used A4 paper.

The paper lab makes use of the following technique for recycling paper:-

- Dry type de-fabrication
- Separation of inked particles
- Re-fabrication

However, the Paper Lab is a very expensive machine and costs $60,000.

Paper Recycling Processes

All the paper recycling processes mentioned above will be explained separately for both Paper recycling mills and the Paper Lab A-800.

A Paper Mill has the following processes.

Sorting:-

Waste paper isn't just pure paper when it reaches paper recycling sites. It is mixed with plastics, glass, metals and stones. These have to be separated before sent for further processing.

The most basic method consists of a rolling drum with paddles and cams. The waste mixture passes over the rolling drum, since the paper is lighter than the contaminants, and is very thin and flat, it gets pushed forward whereas the heavier and thick particles get separated and stay behind the drum.

Star shaped screens are installed on the conveyer belt. Glass, which is heavier than plastic, metals and paper, falls through the star screens and is collected in bins placed below.

An eddy field is created by inducing magnetism in the metals present by an already present alternating magnetic field in the mill. The eddy field propels the metals off the belt.

The only contaminant remaining would be plastic. To remove plastic, the remaining lot is passed through a hot alkaline water solution. Paper is turned to loose fiber due to maceration and the plastic is removed by passing it over a fiber sized mesh screen. Paper is collected in a separate container.

Pulping:-

Pulping is the process of converting paper into small fibers with the help of water and high power rotors.

Paper is mixed with large amount of water, around 100 times by weight of the paper is water in the pulping chamber. With the help of maceration and blades of the rotor, the paper is converted to pulp.

The pulpers can be further divided into two parts: (McKinney, 1997)

- **Low consistency pulper:** A circular rotor is used in a low consistency pulper. The rotors move at a very high speed of 16 – 20 ms^{-1}. The paper is cut by the shear forces of the moving rotor. The mechanical de-fabricating forces are high but a large amount of power is consumed in moving the water. Vortices are generated in the mixture and baffles are used for better mixing.
- **High consistency pulper**: These use a helical rotor for pulping action. A circular pattern from top to bottom is generated instead of vortices. The rotor has a relatively low speed but shearing forces are high when the paper is crumbled and pulled towards the rotor. The rotor is very large and consumes a lot of area of the pulper tub and is very difficult to design.

Table 1: Comparison of Pulper types

	Low Consistency Pulper	High Consistency Pulper
Percent Consistency	3 – 6	12 – 15
Percent Rotor/Tank Volume	0.1	8
Specific Power in kW	6	22
Percent No Load Power	70 – 80	50 – 60
Speed of Rotor in ms^{-1}	16 – 21	8 - 15

Deinking:

Deinking is a key process in a sustainable technique for papermaking. The main task is to separate ink film from fibers. This task is based on physical properties of particles and their differences in them. As a result multiple steps are required for the deinking of printed paper. This includes screening, cleaning, washing or flotation. Large particles ranging from 100 to 300μm are removed mostly by cleaning and screening while particles smaller than this are removed using mostly washing method or flotation process.

A worry about reusing paper pulp is that the fibers quality is degraded with each cycle and subsequent recycling the fibers turn out to be excessively short and frail to be helpful in making paper. Traditional deinking disposes of large particles from these ink system.

Washing:

Wash deinking comprises of a washing stage where dispersants are added to wash out the printing inks. Particles size ranging medium to fine are washed out when the pulp slurry

is de-watered. This procedure is most valuable for removing particles having size less than 30 μm. This procedure is progressively regular when making deinked pulp for tissue. This stage is considerably more effective than typical washing/dewatering stages. (Wikipedia)

Flotation Deinking

The flotation process is developed based on mineral flotation. The table given below shows the difference between the two processes. This process is carried using air bubbles in slurry. Flotation is done to remove hydrophobic elements and is carried out in a flotation cell. The slurry is diluted to about 1-3% consistency.

Table 2- A comparison between flotation deinking and mineral flotation (Husovska, 2013)

Parameter	Flotation Deinking	Mineral Flotation
Particle surface energy	Ranges from low to medium to high, usually very complex	Energy is fairly uniform
Size of Particle	Broad Distribution	Broad Distribution
Density of Particle	Very Low	Higher than water
Properties of Pulp	Heterogeneous	Homogeneous
Characterization of Final Product	Brightness of Paper Sheet	Done using chemical analysis
Particle separation from Stock	Repulping in the presence of chemicals	No chemicals are required

Air bubbles are introduced into the fiber slurry. The relative motion of the slurry as compared to air bubbles forces the ink to float as foam to the top which can then be removed from the tank and collected.

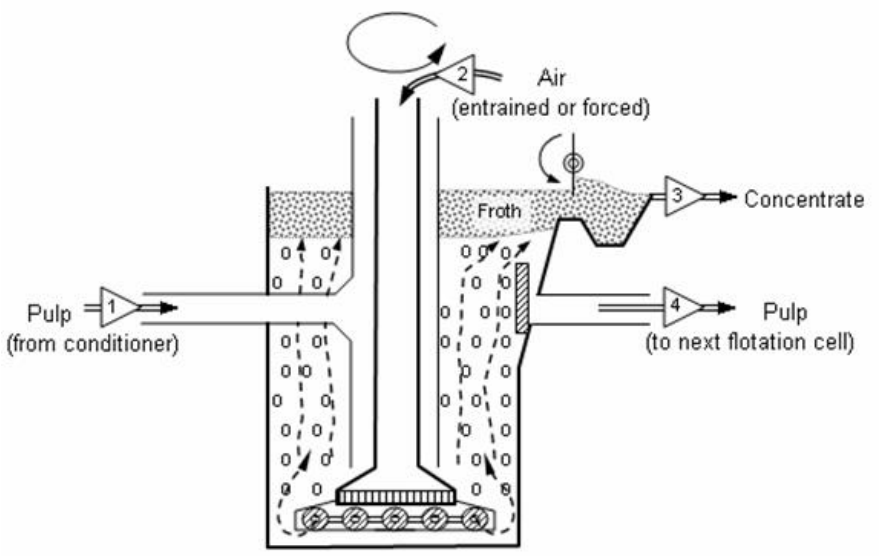

Figure 1-Froth Flotation Cell (Wikipedia)

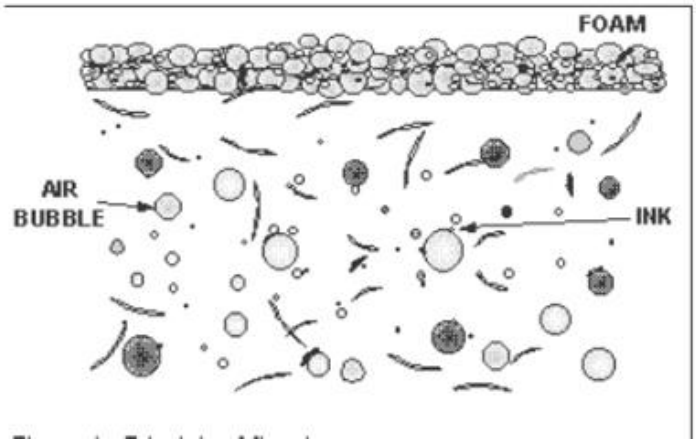

Figure 2- Working of Froth Flotation (Heindel, 1997)

The pulper cuts the paper to smaller fibers, water and chemicals are added. The pH is normally adjusted to ensure efficient deinking. Chemicals used for deinking are:

- Sodium hydroxide for pH control
- Hydrogen peroxide for bleaching
- The brightness of pulp being deinked is increased by hydrogen peroxide and sodium dithionite.

The following chemicals are added together with air bubbles to improve deinking:

- Sodium hydroxide is added to swell the fiber and detach ink
- Sodium silicate is added to assist dispersion of ink
- Alum assists in frothing of ink particles
- Increased in temperature improves the deinking process.

High speed impeller blades are used to produce high shear and ensure high air generation. High air stock and shear increases the probability of ink particle to collide with air. This prevents the ink particles from being trapped in the fiber. High shear mixing keeps the fiber suspended. (Husovska, 2013)

Paper Forming

The paper forming section is the final unit of the machine. Here the de-inked paper pulp will be converted into recycled product. The section consists of the following basic parts:

- Sizing Slit
- Mesh Belt
- Forced Convection Fans
- Rollers

The basic functioning part of the Paper Forming Section is the Conveyor Mesh Belt. Its function is to carry the pulp from the deinked section to the product side while allowing the pulp to dry easily. Some of the most widely used conveyor belt types are as follows:

1. Slider Bed
2. Metal or “Piano Hinge” Conveyor

3. Roller Bed
4. Incline & Decline Conveyor
5. Horizontal Belt Conveyor
6. Brake and Meter Belt Conveyor
7. Wire Mesh Belt Conveyor (Brakefield)

Wire Mesh Belt has holes or mesh that facilitate air ventilation. This type of belt conveyor is therefore ideal for transporting wet substances that need to be dried. Components that otherwise are impossible to be handled using standard duck or PVC belts are transported using this type of conveyors. The wire mesh is placed on roller or longitudinal runners. In addition, toothed pulleys are used to clasp onto the wire mesh belt.

The Belt Conveyors are made of different Materials. A few Belts highlight materials including Rubber or a Fabric, for example, Nylon, Polyester, Neoprene, or Nitrile. Belt properties decide the transport line's essential applications. For instance, Mining and Milling Industries generally utilize rubber to deal with mass materials including Raw Ore and Aggregates. Markets generally use PVC transport lines, and air terminals may utilize neoprene, polyester, or elastic for gear taking care of.

These materials may include distinctive coatings, thicknesses, and formations to convey a scope of dealing with properties. Some offer nourishment well-being evaluations while others perform well in high temperatures. Other normal properties of general-use belts may incorporate high or low friction dimensions and explicit mass taking care of organizing. A few belts enable particulates to go through instead of ride along the transport framework. (Compact Management Company)

Industries may utilize Filter Belts to empty overabundance fluid out of parts or to sift through poisons. Water treatment organizations regularly utilize these kinds of transport frameworks amid Water Treatment Processes. Makers may utilize Metal or Synthetic Fibers to make Filter-Capable Belts.

- **Woven Metal Belts:** Woven Belts include interlinking chains of metal or wiring intended to permit wind current as a thing moves along. Organizations normally utilize Woven Belts to encourage drying, cooling, and warming procedures in the nourishment, gadgets, and glass-working enterprises, among others. Producers may offer Pre-Fabricated woven belt plans or may specially craft a Woven Belt to meet a client's particular application needs. (The Engineering Toolbox)
- **Hinged Belts:** Hinged Belts frequently include metal development. The Hinged Quality of the belt gives it a level, strong surface fit for turning around the pulley framework through interlocking pivots. Organizations use Hinged Belts for little item, scrap, and reusing applications. Metal-Hinged Belts are solid and can confront thorough use.
- **Plastic Interlocking Belts:** Plastic Belts furnish makers and material handlers with a secluded choice to metal and fabric based belts. Organizations may utilize Plastic Belts in sustenance taking care of and bundling forms or in the car business. Secluded plastic belts function admirably in applications that require visit cleaning and belt substitution. (Brakefield)

The use of the belt dependably directs the material's, properties, and style of the belt utilized. For example, for this situation a permeable, corrosion and heat resistant belt is required that permits to deplete the water while enabling the pulp to interlock on the belt. The SS 300 Series highlight Austenitic steel material. These are non-attractive tempered steels that contain elevated amounts of Chromium and Nickel and low dimensions of Carbon. They are known for their imposingness and Resistance to Corrosion.

These evaluations of impeccable have Chromium (18-30%) and Nickel (6-20%) as their major alloying additives. Type 304 is the most generally utilized alloy of every single hardened steel. At the point when Nickel is added to stainless steel in rate referenced the crystalline structure changes to "Austenite." This improves their corrosion resistance property and adjusts the structure from Ferritic to Austenitic. Austenitic evaluations are

the most normally utilized Stainless Steels, representing over 70% of generation and are thus effectively accessible. Amalgam 304/304L pursued by Alloy 316L are the most regularly determined evaluations.

Rollers

The remaining water after the mesh belt drying section will be removed on the steam-heated rollers. There are simple cylinders through which steam at high temperature is passed. The passing steam heats the surface of the rollers. Through the gap between the outer surfaces of two steam rollers rotating in the opposite direction, the dried pulp passes. The heated surface of the rollers evaporates the remaining of the water content of in the recycled product.

Calendar rollers work in conjunction with the steam rollers. They are usually covered with rubber or felt material. The rubber laden rollers are used when there is no soaking required. Felt on the other hand has the property to absorb water just like a sponge.

Felt is a textile material produced by processing fibers. It can be made of natural fibers such as wool or animal fur. Or from synthetic fibers such as petroleum-based acrylic acrylonitrile or wood-pulp based rayon. Blended fiber made by blending different type of fibers are also common

The processes in the Epson Paper Lab A-800 are explained below: (Toshiaki YAMAGAMI, 2014)

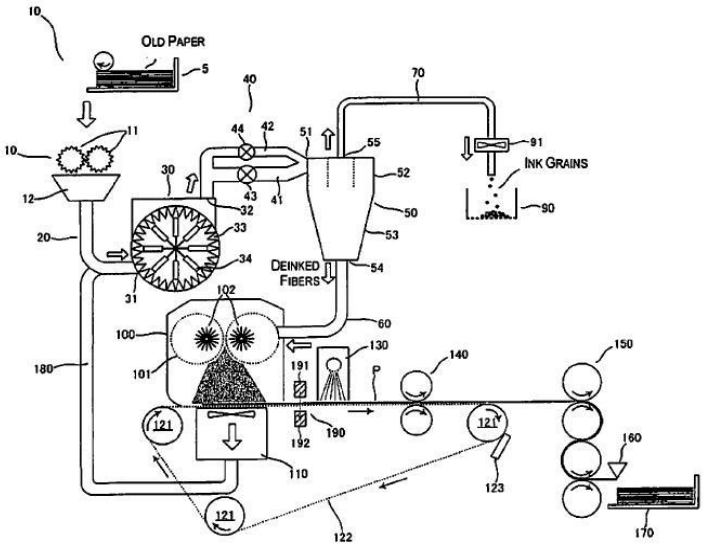

Figure 3- Schematic of Dry Type Paper Recycling Machine

De-fabricator:-

Used paper is fed to a coarse crusher which cuts the paper into size of few centimeters. This paper is then fed via hopper to a dry type de-fabricator. The paper is then defibrated between a moving rotor and a static stator to a size in microns. By this time, along with the paper, the ink granules are also finely crushed and can be easily separated from paper. The de-fabricator also generates an air flow, the tiny paper fibers, ride this air and move on to the ink separator.

For the dry type de-fabricator, for example, it is possible to use a dry type used paper defibrating unit equipped with a disc refiner, a turbo mill (made by Turbo Kogyo Co., Ltd.), a ceren miller (made by Masuko Sangyo Co., Ltd.), or a wind generating mech`anism.

Cyclone:

The crushed paper fibers move into the ink separating unit. The paper fibers are crushed so fine that the ink particles are distinct from the non-inked white part of the paper.

Here the cyclone comes into play. The inked parts of the paper fibers are heavier than the non-inked parts. The cyclone uses air to separate the ink particles from the non-ink particles.

The velocity of the air is to a minimum where the lighter non-ink particles are carried to the other end of the cyclone and the ink particles, being heavier, fall down and are rejected.

Although this method wastes a lot of paper with ink particles but the non-ink particles are pure white paper, and it helps in keeping the quality of the paper high.

Paper Forming:

The de-inked paper particles move to the paper forming unit. Here the particles are sprayed with hot steam and a binding material. The newly created paper paste then moves onto a conveyer belt.

The first unit on the conveyer belt is the sizing unit where the thickness of the paper paste is adjusted to the desired amount.

Steam rollers are installed on the later stage of the belt. The paper paste is compressed between hot steam rollers and the belt, evaporating the absorbed water.

A moisture detector is attached which detects the quantity of moisture in the paper. Once the moisture content is decreased to 4% by weight of the paper, it is moved to the calendaring unit where the paper surface is smoothened and the paper is finally cut to required size.

CHAPTER 3: METHODOLOGY

Initial Survey

A wet type paper recycling machine with a compact size was chosen since the dry type process is being currently used in the Epson Paper Lab A-800 only and doesn't have a lot of information revealed to the general public.

An information survey was conducted at the Bulle Shah Paper Mill and the design used for the paper recycling inspired the design for our paper recycling machine.

A number of market surveys in Brandreth Road, Lahore and Gawalmandi, Rawalpindi were conducted. During this survey, a number of manufacturers were contacted regarding our design concerns. Also, a number of foreign manufacturing companies were contacted to get a gist of the available designs in usage.

Our paper recycling machine consists of the following processes and the design approach for each part is explained separately.

- Shredding unit
- Pulping unit
- De-inking unit
- Forming unit

Moreover, it will be a batch type low consistency paper recycling machine with a capacity of 25 A4 sized papers per batch since the rotors for low consistency paper recycling machines are easy to design and the size of pulper tub required is also small for them as explained in literature review.

Shredding unit

The shredding unit consists of a simple shredder which will be used to shred full A4 sized sheets to a size of 6cm by 2cm strips for easy pulping.

Pulping Unit:

The calculations for the design of pulping unit are performed below

Number of A4 paper = 5

Weight of 1 A4 paper = 6g (Full Print)

Weight of 50 A4 papers = 30g = 0.03kg

The amount of water was chosen for the clearance value which will be explained in the de-inking unit design.

Water used =2L = 2kg

Total volume of container required = Volume of water + volume occupied by papers

A4 paper width = 21cm

A4 paper height = 29.7 cm

A4 paper thickness = 0.005 cm (Prepressure.com)

Volume of 1 paper = 3.1185 cm^3

Volume of 5 papers = 15.5925 cm^3 = 0.0156 dm^3

Total Volume required = 0.156 + 2 = 2.0156 L

Volume of container after clearance = 2.25 L

The bottom and top radius were chosen very close to each other to provide a more cylindrical design

Mean radius = 6.25cm

Assuming cylinder,

Volume = pi*r^2*h

Height from mean radius = 25cm

Material of container was chosen as Stainless steel to avoid corrosion

The top of the pulper is open and is covered with a lid. Water and paper are filled in the pulper from the top. The lid is closed when the blade is switched on.

After pulping the valve at the bottom is opened and the pulp is transferred to the de-inking chamber.

The design of the pulping unit is shown below.

Design:-

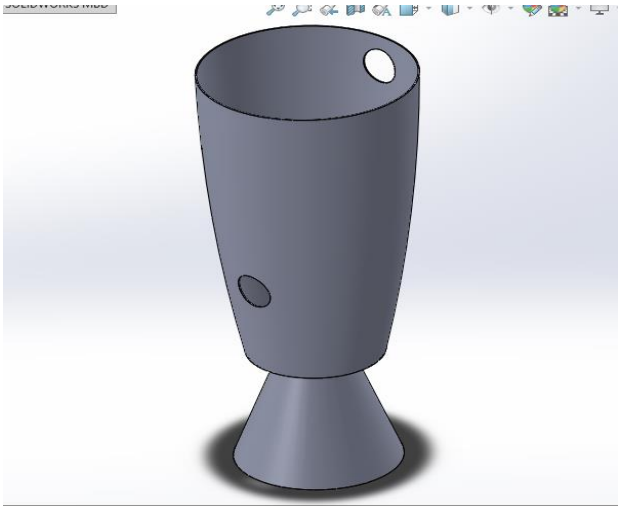

Figure 4-Design of pulping container on SolidWorks

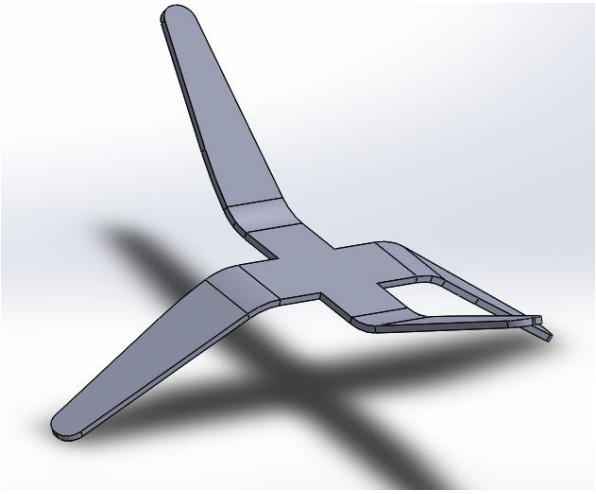

Figure 5- Design of rotor blade on SolidWorks.

Flotation Unit:

The de-inking begins after 5 batches of pulper are transferred.

The flotation process will be used to deink the paper pulp. Paper after being shredded and being converted into pulp will be sent to the flotation cell. A separator will be used.

The pH value of the water is risen to 9 by adding an adequate amount of NaOH in the water pulp mixture.

To calculate the amount of 1M NaOH solution required take a look at the following equation: (Heindel, 1997)

$$C = \frac{n + (M)x}{V + x * 1L}$$

Making use of

$$NaOH + H_2O \longrightarrow Na^+ + OH^- + H_2O$$

$pH_1 = 7$ then $pOH_1 = 7$

$pH_2 = 9$ then $pOH_2 = 5$

$C = 10^{-5}$

The volume of water used = 10L

To create 1M solution take out 40g or 1mole of NaOH crystals and dissolve in 1L of water, since the molar mass of NaOH is 40g/mol.

The volume of NaOH required comes out to be 100mL for 10L of water. (Kumar S. , 2012)

Once the air is fed into the cell, the ink particles will start to rise and form foam on the top. This form will then be removed and water will be added to make up for the lost water.

There are three valves in the de-inking unit. Two at the front and one at the back. The valve at the back is used to remove the ink mixed with water present in the separator.

The two valves at the front are placed one above the other. The upper valve has steel gauze on the inside of the de-inking container. After the de-inking process, the upper valve is opened and excess water is flown out to the recycling reservoir. The pulp isn't allowed to escape because of the gauze and the pulp becomes concentrated.

Starch is added into this concentrated pulp by 2% of the weight of paper. Starch helps bond the paper fibers together.

After mixing starch with water, the lower valve will open and the concentrated pulp will flow down a tray attached to the de-inker into a container.

Different views of the de-inker are given below:

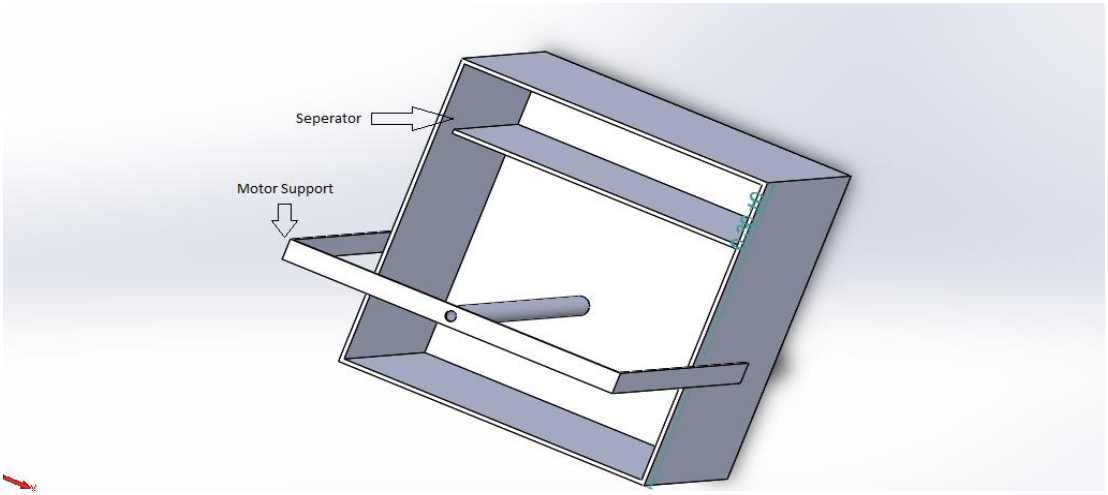

Figure 6-- Flotation Deinking Cell

Paper Forming Unit:

As mentioned in the Literature Review, the paper forming section is the final unit of the machine. Here the de-inked paper pulp will be converted into recycled product. The section consists of the following basic parts:

- Sizing Slit
- Mesh Belt
- Forced Convection Fans
- Rollers

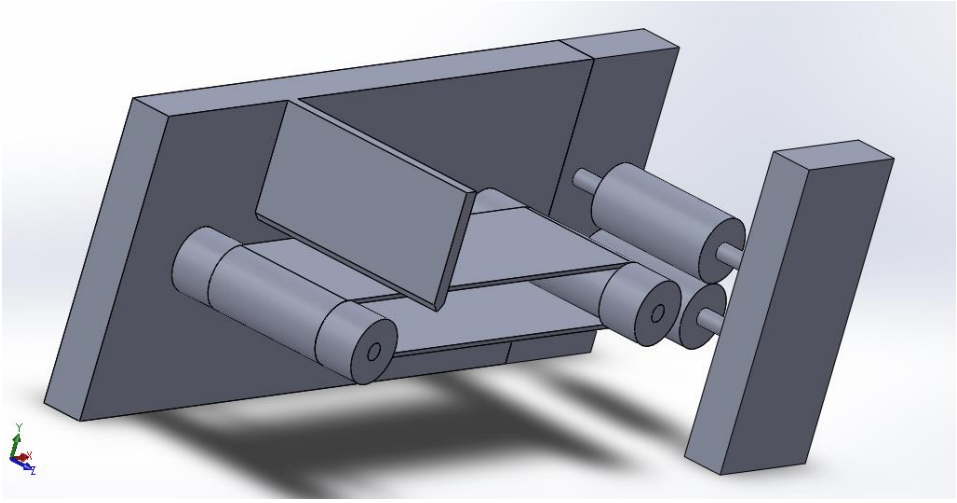

Figure 7--Paper Forming Section Design

The pulp from the de-inker will fall into the container and will pass through a sizing slit and then from under a roller to evenly distribute the pulp over the mesh. Heating fans facing the belt will remove the water content from the pulp via forced convection evaporation. The motor connected to the rollers of belt is stopped and the belt remains at a halt till the paper is dried to desired amount. A scraper is attached at the end of the belt which scrapes off the paper from the belt. The reduced moisture paper will draw out through calendar rollers. Calendar rollers placed slightly lower than the base of the belt allowing the paper to draw smoothly into the clearance of the rollers. A slide sheet can also be used for smoother drawing. Combined with natural evaporation the water content is reduced to 5-6%. (Wikipedia) Calendar rollers smoothen recycled product achieve the required thickness and finish.

The belt runs on a single 15W motor at 1.43cm/s velocity and sits on two rollers of 2.5” diameter each.

The calendar rollers run on a separate motor with the same angular velocity and are connected to each other via gears.

The belt is covered with a sheet of stainless steel at top. On the inside of this sheet are three fan heaters of 1000W each. These raise the temperature of the surroundings to 80'C for 40 minutes.

Drying Time Analysis (Wikipedia)

Moisture Removal After Each Process

- Capacity = 50 A4 sheets in one operation
- 50 A4 Sheets = 300 g
- Weight of Water = 10 kg
- Water content in Pulp = **97 %**
- Water content after Drying Unit = **5-6%**

Calculating Evaporation Rates

Local Conditions (Islamabad): (Compact Management Company)

- Minimum Conditions: 3 °C, 55% Relative Humidity (R.H)
- Maximum Conditions: 38 °C, 66% R.H

$$\mathbf{g_s = \Theta A (x_s - x) / 3600}$$

Where,

- *$\Theta = (25 + 19 v)$*
- *v = 0.3 m/s for natural indoor convection, 16.5 m/s calculated for the fans used for forced convection*
- *$A = 1.8\ m^2$*
- *x_s @38 °C = 0.037125*
- *x_s @ 3 °C = 0.0064605*
- *x @38 °C = 0.0298*
- *x @3 °C = 0.0027*
- *R.H @38 °C = 66%*

- *R.H @ 3°C = 55%*
- *Dew Point @ 38°C = 30.4 °C*
- *Dew Point @ 3°C = -5 °C*
- *Wet Bulb @ 38°C = 31.86 °C*
- *Wet Bulb @ 3°C = 0 °C*

Natural Evaporation Rate:

- At Minimum Conditions: $4.4 * 10^{-5}$ kg/s
- At Maximum Conditions: $7.7 * 10^{-5}$ kg/s

Forced Evaporation Rate:

- At Minimum Conditions: **9.5 * 10^-4 kg/s**
- At Maximum Conditions: 4.9*10^-4 kg/s
- By using the above forced and natural evaporation rates, the drying time for the pulp comes out to be as follows:
- Drying Time:
- Time (Minimum Conditions) = 11mins
- Time (Maximum Conditions) = 6mins

CHAPTER 4: RESULTS AND DISCUSSIONS:

There are four parts of the process:

- Shredder
- Pulping Unit
- De-inking Unit
- Drying Unit

Machine Dimensions:

Owing to the individual dimensions of each of the units of the machine, the total machine dimensions can be easily calculated. The area required by the final prototype of machine is logically approximated to higher values setting positive tolerances.

The different dimensions of the final prototype are hence:

Pulping Unit

- Blade size (end to end)**:** 2.5”
- Valve dia**:** 1”
- Pulper Capacity**:** 2.25 L

De-inking Unit

- De-inker dimensions: 7.5” x 10.5” x 12”
- De-inker Capacity: 15 L
- Separator dimensions: 3” x 10” x 10.5”
- Tray dimensions: 7” x 19”
- Container dimensions: 3.5” x 7” x 7”
- Slit dimensions: 1” x 2.5”

Drying and Calendaring Unit

- Belt Stand dimensions: 8.5” x 69” x 23”
- Belt dimensions: 7” x 65”
- Belt roller diameter: 2.5”
- Entrance roller diameter: 1.25”
- Calendar rollers diameter: 2”

Machine Specifications:

The machine prototype as discussed will use 50 shredded A4 size sheets of paper and will convert it into recycled paper in different cycles.

The power requirements of the different sections of the machine are summarized below. The process times calculated are also mentioned herewith the machine requirements.

Pulping Unit

- Motor Power: 150 W
- Process Time: 1min
- Container Material: Stainless Steel
- Blade Material: High Speed Steel

De-inking Unit

- Air Pump: 18 W
- Motor Spec: 24V
- Process Time: 5-10 minutes
- Container Material: Stainless Steel
- Blade Material: Stainless Steel

Drying and Calendaring Unit

- Belt Motor: 15W

- Belt Velocity: 1.43cm/s
- Process Time 40-50 minutes
- Belt Material: German Canvas
- Heater power: 1000W
- Temperature Provided: 80’C

Paper Recycling Cost:

Power Consumption with Heaters = 3000W

Electricity Consumption 100g (2ft) Paper = 3kWh

Electricity cost for 2ft Paper = 51 Rs.

Prototype Capacity:

Unit	**Time Per Unit (minutes)**
Pulping	**5**
De-inking	**15**
Forming	**40**
Total Capacity per cycle (g)	**Total Time (minutes)**
50 (2’ x 0.5’)	**60**
Total Waste (tonne)	**Total Recycling time 6h/day (days)**

5	168

NUST Paper Supply and Disposal:

Sources of Paper

The sources of paper being used at NUST are in different forms and types. Some of these are listed below:

- Regular letters
- Newspapers
- Research documents
- Exam Papers
- Office papers
- Used by faculty
- Used by administration
- Paper waste in cafes
- Concordia 1, 2, 3 and other NUST administered cafes
- Private cafes setup recently by students and private business caretakers

These sources of paper waste owe to major paper wastage in NUST.

According to the statistics of last three to four years, each year around 15 tons of paper is used at NUST and out of which around 5 tons is wasted. Most of this waste paper has to be shredded first because it is confidential paper. And then it is sent to disposal sites or private collectors of waste paper.

The disposal mechanisms and methods of this waste paper will be discussed in detail below.

Disposal

- Waste paper is burned

- Departments/ Schools independently deal with them on their own
- This means that the paper is either shredded first and then sold to the private paper collectors
- Or the paper is bundled and then burned or sold to private paper collectors
- Each school/ department follows its own mechanism as seen fit
- This means that there is no proper paper waste handling system applied to the schools' individual papers

Paper collected by NUST authorities is bundled and dumped in Project

Management Office (PMO) NUST

- Schools like SEECS and SMME shred their classified and confidential documents
- Same practice is followed in Main Office and other administration buildings

These practices are in conformance with the NUST policy. NUST Policy is discussed as below:

NUST Policy

- Schools should handle their own paper waste
- Garbage of the schools are collected by and dumped in PMO and then further waste segregation takes place

Total paper wastage

- Around 5 tons of paper wastage is collected yearly from all the schools

NUST's Innovation

Out of all these paper waste types, a system can be introduced to recycle most of the waste paper. It can be started by collecting one type of paper waste (for example examination paper), recycle them and reduce paper wastage. This will introduce a more environmental friendly solution to the problems.

Sources

The discussion above and quoted numbers have been gathered from two sources working at NUST

- PMO NUST.
- Dr. Anwar Baig (Professor of Environmental Sciences at Institute of Environmental Sciences and Engineering (IESE), NUST H12 with specialization in solid waste management.)

Benefits for NUST:

The Paper Recycling Machine project is basically aimed at implementation of Green and Environmental Friendly procedures at NUST. Setting up and example and fostering future implementation in other universities and organizations. The project promises a lot of potential and requires in depth and detailed work.

Following are the benefits as a result of this project that NUST could benefit from. And eventually the same practice can inspire other institutions and organizations.

- NUST can become first university to recycle paper on campus
- NUST can save 5 tons of waste paper annually
- Project provides NUST with potential to lead journey towards a safer future for generations to come
- The project is aimed to have a large socio-economic impact on the society
- As part of the project, effective waste management systems can be introduced at NUST
- Once the working prototype is complete and shows positive results, this will provide opportunity to market the machine and develop full scale working machine
- The machine can be sold to packaging and paper making industries
- The project addresses the United Nations Development Programme (UNDP)'s Sustainable Development Goals (SDGs)

- SDGs are a universal call to protect the planet
- These 17 Goals focus on areas such as climate change, innovation, sustainable consumption, among other priorities
- Associating NUST with UNDP's SDGs for future preservation promises a lot of potential to the university

The project promises to directly address and solve 4 of these SDGs namely:

- Sustainable cities and communities
- Responsible Consumption and Production
- Climate Action
- Life on land

Assumptions:

- 15 tons of paper at Rs.106/kg
- Annual Electricity units at Rs.17/kWh
- Machine: 4985 kWh
- Shredders: 1533 kWh
- 15 Departments at NUST
- Approx. 4 Shredders used per department
- Raw material is the waste paper
- 5 tons of paper (Rs.535,000) will be recycled

On the basis of the assumptions made above, the Cost Analysis is done. The analysis shows how much NUST could benefit from the development of the full-scale machine in the long run. This benefit in monetary terms is also very important along with the environmental and social impact. The sustainability of the project can be estimated from this analysis as done below:

The following chart discusses these results by comparing the market research done on the available machines in the market. The machines available are developed for very large

capacities of recycling and hence are very expensive to buy and implement on campus in a university.

The chart is as follows:-

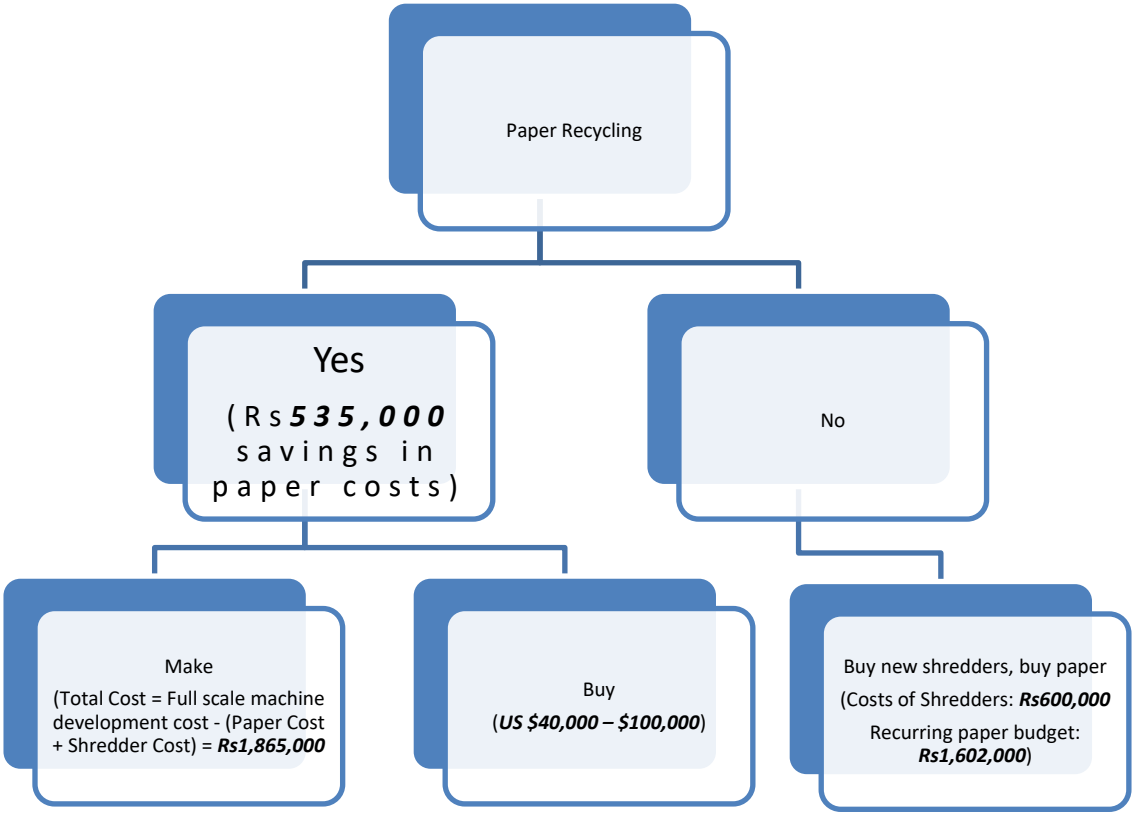

Figure 8-- Make or Buy Comparison

The machines that are available in the market cost between US $40,000 – $100,000. Some of the available machines are cited below:

1. https://bit.ly/2DDpTkh
2. https://bit.ly/2Mz01c8
3. https://bit.ly/2RkV8UK

CHAPTER 5: CONCLUSION AND RECOMMENDATION

The machine designed will be used to recycle paper. 50 used papers will be used at a time. The pulper will mix them with water and then shred them to form slurry.

This slurry will then be fed to flotation cell where ink will be removed using air and agitator. The slurry will be concentrated by removing water from the upper valve. From flotation cell the de inked slurry will move to paper forming section.

The lower valve will be opened and the concentrated slurry will move down the tray and into the container. When enough slurry will collected in the container, the lid of the container will open and it will pass through a slit. The slurry moves onto the belt with the help of an entrance roller. The slit and the roller determine the thickness of the paper.

The water will be evaporated up to a certain extent and the wet slurry will be converted into paper by heating it up using blower heaters. The machine being manufactured is a semi auto mated machine and is a batch process.

The greater the consistency more will be the efficiency of the deinking cell and longer it will take to dry them. The paper being produced will not be of a very good quality and the whole process will take a very long time to be completed.

The pulper will pulp the paper into fibers. Size of the fibers will vary from 10-300um. This will be in used in deinking section to remove ink particles from the fibers. If the size of fibers is to large then the ink particles will not be separated from the pulp and the papers will not de inked.

The efficiency of the de-inking unit will not be 100%. There will be some ink particles left in the recycled paper but they will be in a very low quantity. The more the consistency better will be our de-inking. The bubble size of air needs to be controlled for improving the probability of ink particle colliding with air bubble.

The forming unit will dry the paper but there will be moisture left which will determine the quality of machine. If the consistency is low, the drying process will be better but it will affect the deinking process. Hence there will be a compromise on the time and we will be operating on low consistency of paper pulp in water.

The machine produced will be a prototype. As for the machine itself the total cost analysis is given below:

Table 3- Cost analysis of Machine

	Total Cost (Rs)
Pulping unit	7,750
Shredding Unit	3,500
De inking unit	14480
Drying unit	64,200
Travelling Cost	5,000
Over All Total	**99,410**

Recommendations:

The quality of paper is still under study and still has room for improvement. Since the machine is semi-automated it can be fully automated. The paper will be fed into the machine and a recycled paper will be produced on the other side of machine. The process can be converted into a continuous process from batch process.

Baffle plates can be used in pulper for better mixing. Blade design can be improved for more shear stress and which will ensure uniform size of all the fibers. We are currently using circular rotor since we have a size constraint but the circular rotors consume a lot of

power. Helical rotor can be used for less power consumption if there is no constraint on the pulper size.

Another target for improvement will be flotation cell and the forming unit. Efficiency of flotation cell depends highly upon the amount of air and size of air bubbles and the fiber. The probability of air bubbles colliding with the ink particles and their strength to carry them to the top to make form determines the efficiency of the cell. Increased temperature increases the efficiency of deinking. Hence a heater can be used in the flotation cell or hot water can be used for this process. Moreover, instead of using simple starch compound, cationic starch can be used to provide better bonding properties.

The forming unit size and time depends upon how water is evaporated and to what extent. Thickness of the paper is also controlled in this section. Calendar rollers are being used to control thickness of the papers. Water can be evaporated in three different steps which will ensure that the moisture left is according to our requirements. Vacuum dryer will be used in the first stage to evaporate water. Then a hydraulic press in next stage and steam rollers in the final storage to dry paper more efficiently. The major difference between cardboard and paper is the moisture content and thickness. If these can be controlled we recycle used paper into new paper or cardboard. Thickness can be controlled using thickness sensors while moisture can be controlled using moisture sensors.

Cutter is not being used in the paper recycling machine. Hence the paper coming out will be of variable length. A cutter can used to cut the recycled paper. This will be done to cut the paper according to our needs and the required size

The time required to recycle paper can be reduced

Dry type recycling machine can be manufactured using the appropriate binder but this will increase the cost of the machine. This will be result in better de-inking and good quality paper. This depends upon the type of binder being used and how it is being used.

A moisture detector or humidity sensor can be used to detect the water percentage in the paper.

To reduce the electricity cost of the machine, the heaters being currently used can be replaced with solar air heaters. Three solar heaters consume upto 50W of power at maximum.

However, it will take more time to dry the paper and the overall recycling time will be increased. This can be countered by introducing a hydraulic or mechanical press to compress the slurry and force the maximum amount of water out of it before sending it to the belt.

A new cost analysis with solar air heaters is shown below:

Machine cost = 106,000 Rs.

Power Consumption with Air Heater = 50W

Electricity Consumption 100g (2ft) Paper = 0.05kWh

Electricity cost for 2ft Paper = 0.85 Rs.

Selling Price for 20ft tissue roll = 100 Rs.

Tissue rolls to sell for breakeven point = 1,087

Tissue rolls produced from 5 tonne waste = 5,000

Profit year 1 = 389,637 Rs.

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