PAPER RECYCLING MACHINE

A Final Year Project Report

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NUST

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

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ABSTRACT

In the modern era, excessive deforestation has created the need for recycling of papers. Today, Paper is being recycled on a large industrial scale, but there is no set for recycling on small local or domestic scale for example in the universities, offices and homes. A simple Paper recycling machine consists of a shredding unit for shredding waste paper into relatively smaller sized strips, then a pulping unit to make use of a mixture of water and paper strips to pulp paper to fibers. The pulp water mixture is deinked by froth flotation process and transported to forming section. The Forming section dries up the deinked pulp water mixture as it is pressed while moving it on a conveyor belt and simultaneously, water is removed under the pressure of the weight of gas-powered iron. The iron attachment allows it move back and forth to allow for even heating of the pulp to achieve efficient evaporation of remaining water. The cost will be reduced for this case as a large amount of water is removed directly through the wire mesh. Pumps and motors will also be used to transport pulp mixture and water, respectively. This machine will save the environment, because, to produce paper, trees are used and in recycling there will be of already used paper.

ACKNOWLEDGMENTS

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<u>ORIGINALITY REPORT</u>

We hereby declare that no portion of the work of this project or report is a work of plagiarism and the workings and findings have been originally produced. The project has been done under the supervision and guidance of SUPERVISOR and has not been a support project of any similar work serving towards a similar degree's requirement from any institute. Any reference used in the project has been clearly cited and we take sheer responsibility if found otherwise.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

CAD	Computer Aided Design
COVID-19	Corona Virus Pandemic
FOS	Factor of Safety
HCP	High Consistency Pulper
HCS	High Carbon Steel
HSS	High Speed Steel
IESE	Institute of Environmental Studies and Engineering
kWh	Kilo Watt Hours
LCP	Low Consistency Pulper
LS	Lead Screw
NUST	National University of Sciences and Technology
PMO	Project Management Office
PVC	Poly Vinyl Chloride
RPM	Rounds Per Minute
Rs.	Rupees
SS	Stainless Steel
UTS	Ultimate Tensile Stress

NOMENCLATURE

Θ	Evaporation coefficient (kg/m 2h)
μ	Friction Coefficient
σ	Stress
Φ_{inner}	Inner Diameter
Φ_{outer}	Outer Diameter
A	Pulp surface area (m^2)
F	Weight of belts and pulp
g	Amount of evaporated water per second (kg/s)
I	Moment of Inertia
L	Liters
M2 Material	Tungsten-Molybdenum High Speed Steel Alloy
m_{mb}	Mass of mesh belt.
m_p	Mass of pulp
m_w	Mass of Water
P_x	Power of x section
Rpm	Revolutions per Minute
v	Velocity of air above the water surface (m/s)
W_{iron}	Weight of Iron
y	Vertical Distance

CHAPTER 1: INTRODUCTION

Background

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 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.

Increasing 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.

Motivation

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.

So we have a vision to produce a machine that can be kept inside not only in NUST but in all the universities and offices, even at homes where paper is used in abundance. And instead of disposing off all that paper or burning them or selling them, we can re-use them by recycling and save our time and money.

Need for Small Scale Machine

As per now, there is no paper recycling machine project in any university of Pakistan. There are certain websites and dealing centers which produce paper recycling machine internationally but they are way too expensive to have in offices or in universities and colleges. Moreover, a lot of problems will have to be dealt with if paper is recycled in off-site plants, for example the transportation charges and time taken.

Last year a group of seniors took this project as their final year project, they tried to make a machine which was explaining the basic process of paper recycling which includes shredding; shredding the process in which used paper is crushed in to small pieces, grinding; grinding is the process in which paper is grinded with specific amount of water so that pulp can be made, floating; floating is the process in which all impurities in the pulp are removed from it and a new recycled pulp is made to make recycled paper, drying; drying is the process in which paper pulp is dried after spreading it on a belt.

All these processes are furtherly explained in detail in the CHAPTER 2: LITERATURE REVIEW

Project Highlights

As the previous design was the first attempt to make paper recycling machine at office level, which was the most difficult step and our seniors succeeded in designing the basis of the machine for the first time on a small scale. As a result, we have the basic design and a direction for the concept but it had a lot of shortcomings related to the quality of results, procedure of paper recycling and in terms of design of the machine.

In this report, we have tried to identify these problems and evaluate the possible solutions to these problems. The design is revised supported by the analytical Calculations. Also, calculations have been performed for the cost analysis, the power required by the machine and the calculations for the sizing and designing of the machine structure. Complete solid model of new design has been made and shown with complete drawings in this report. In the later part, we have tried to summarize the manufacturing plan process using manufacturing process tables, specifications of parts used and Engineering Drawings.

There is always room of further improvement. We have summarized the possible improvements as well in the end of the report. The Scope of this project and the report is about cutting down the cost of operation and improving the quality of the paper which is achieved by changing the heating system.

CHAPTER 2: LITERATURE REVIEW

Paper Production and Recycling

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

Machine Concept

Although paper is being recycled at mills but there are certain imitations associated with it. 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.

General 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.

Paper Sorting

Wastepaper is not 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.

De-fabrication of Paper

The separated 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.

Pulping Process

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 pulper can be further divided into two parts:

- 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 systems.

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

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

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	Re-pulping 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. 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.

Use of Actuators

To move our iron mechanism horizontally, we were faced with a challenge to make it compact and lightweight. Which meant we had to use a very simple but efficient system that can effectively achieve that. And so, we have applied simple screw mechanism to move the whole iron attachment along the length of the machine.

A screw is a mechanism that converts rotational motion to linear motion, and a torque to a linear force. It is one of the six classical simple machines. The most common form consists of a cylindrical shaft with helical grooves or ridges called threads around the outside. The screw passes through a hole in another object or medium, with threads on the inside of the hole that mesh with the screw's threads. When the shaft of the screw is rotated relative to the stationary threads, the screw moves along its axis relative to the medium surrounding it; for example, rotating a wood screw forces it into wood.

The figure below gives a good representation of our implementation of simple screw mechanism. A motor with adequate power to rotate the screw is attached at one end of the system. When powered, it rotates the screw such that it moves forward in one direction along the length of the belt.

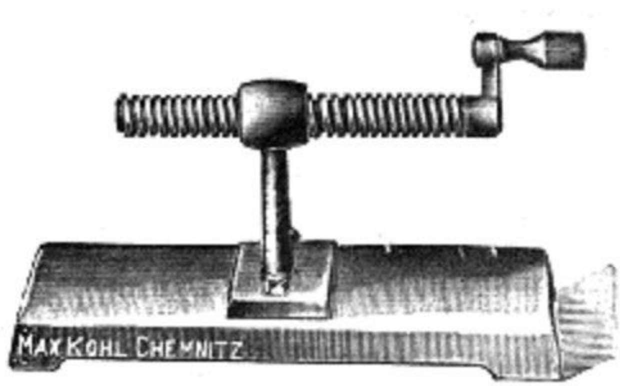

Figure 1: Simple Screw Machine[1]

[1] Picture from: wikiwand.com

The iron attachment is supported by two supporting rods that run along the length of the screw such that virtually no load is applied on the screw due weight of iron attachment. As it reaches the end of the screw, motor's polarity switches and it begins to move in the opposite direction of its initial motion.

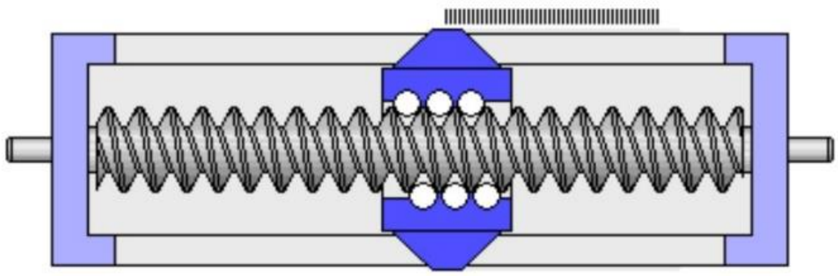

Figure 2: Mechanism of Screw Machine[2]

Using this, we can reduce weight of our overall product, make it simpler to use and maintain as the overall mechanism is among the simplest and most compact that we can use to move the machine. We an already developed actuator **Actuator_SimplicitySlide_2LRPS** for our mechanism which is shown in the figure 3.

Figure 3: Actuator Design[3]

[2] Picture from: wikiwand.com

[3] Picture from: wikiwand.com

Paper Forming

The paper forming section is the final unit of the machine. Here the de-inked paper pulp will be converted into recycled products. 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

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.

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.

- **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.

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.

The remaining water after the mesh belt drying section can be removed by 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 the recycled product. This figure shows a schematic of dry type paper recycling machine, curtesy of

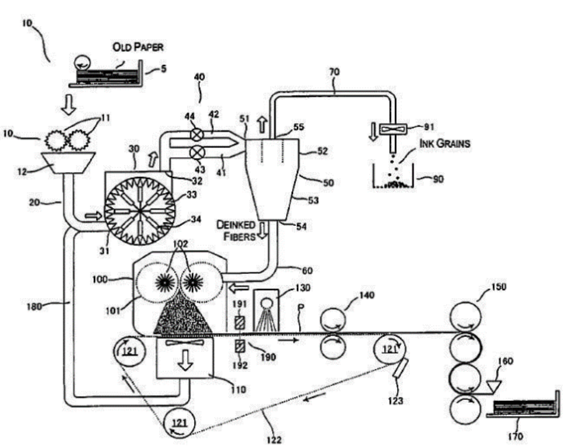

Figure 4: Schematic of Dry Type Paper Recycling Machine

Previous design

Group of four students from our senior batch worked on this problem and made a machine which was capable of producing recycled paper but it had a huge operating cost of machine, took a lot of time, was manually operated and the output of the was not high quality paper.

Problems in previous design

- High Operational Cost

  Operational cost of machine was high. In previous design, water was removed by evaporating water using induction heaters only, which is quite expensive way of removing water from pulp. Three heaters of 2000 watt were used for this purpose. For the production one batch, these three heaters were used for 30-35 minutes. Cost of electricity required for this purpose is Rs 54. Machine was producing 5 papers in one batch. If we calculate cost for recycling of 1 papers, it is almost Rs.11.

- Bad quality of paper

  Recycled paper was brittle and rough. The thickness was 1.4mm. While thickness of A4 paper is 0.05 mm.

- Manually Operated

  The existing design is manually operated, which means that after every step, the product was to be fed into the next part manually. After pulping, the valve was opened through which it traveled to the deinking chamber and similarly after deinking is completed it was the into the belt section by opening the valve. After the pulp was spread on the belt, heaters were to be turned on manually. So this process of manually operating the machine and waiting for the final product is a hectic work and it also increased the time taken.

- High Time of operation

  Machine was taking 35-40 minutes for the recycling of 5 papers. 90% of the time was consumed in evaporation of water.

Problem Statement

Detailed design, analysis and manufacturing plan to upgrade existing paper recycling machine with enhanced paper quality and reduced operating costs

Objectives

The objectives of these projects are

- Improving the design to make it look aesthetically pleasing
- Calculations to support the design improvements
- Reducing the operating costs
- Improving the quality of paper through design improvements

CHAPTER 3: METHODOLOGY

Goal

The focus point of our model is to improve the existing model to make it efficient for domestic and office use. For better understanding of drawbacks and improvement areas, we conducted several surveys at the Bulleh Shah Paper Mill, and the markets in Lahore and Rawalpindi. A number of manufacturers were also contacted regarding our design concerns and we got to know certain aspects of improvement. Our paper recycling machine is smaller in size and its design consists of the following basic processes.

- Pulping unit
- De-inking unit
- Forming unit

Design Improvements

The processes are already discussed in general in the previous chapter. However, following are the highlights of design improvement incorporated in our machine.

1. **Sorting is excluded** from the machine because for the small scale design it is not necessarily needed, it would only generate additional irrelevant costs. For example, at home or at office, it can be easily done at this level by hand at the time of feeding paper.
2. It will be a **batch type,** low consistency paper recycling machine with a capacity of 20 A4 size papers per batch. It is not feasible to make continuous process as it would require very high energy to continuously remove water content from pulp in a small, confined volume.
3. **Sizing Slit** is used to control the thickness of pulp being spread on the belt which eventually defines the thickness of paper
4. **Gas Heaters**, gas cylinder filled with propane gas, are used for the heating purpose instead of electric heaters. They have very low operating costs as compared to the electric heaters. More than 50% operating costs are reduced by this improvement.

5. **Forced Convection Fans** are set up along with the gas heaters for efficient heating of the pulp. It increases the rate of heating and water removal as it increases the convection rate.
6. **Press Heating mechanism** is used. This mechanism is done with the help of an iron heater which reciprocates in 2 directions. i.e. the vertical motion using one linear actuator and the horizontal motion using another linear actuator.

   When the belt carries the pulp to this point after initial heating, the first step is to make the belt stationary at this stage. There is a uniform metallic surface at the bottom of the belt at this point in order to support the belt against the downward pressing force.

   In the second step, the vertical actuator motor comes into working and lowers the iron press assembly onto the surface of the belt. It is lowered to the point where it just touches the belt. However, it needs to be noted that the iron heater does not come directly in contact with the belt. We use a thin cotton cloth as a medium for uniform distribution of heat.

   Then in the third step, the horizontal actuator comes into working. The heater is moved slowly along the length of the belt several times, uniformly pressing as well as heating the pulp. This process removes water content by two ways. i.e. via conduction and via pressing. It is more efficient process and results in smooth surface of paper. It also *reduces water content removal time* for the batch and is *more efficient* in terms of operating cost and delivering quality of paper.

7. **Servo motors** are used for the actuation movement of press rollers. There are two servo motors used one for the horizontal and one for the vertical actuation. This automation process reduces human effort and increases accuracy and precision of the process.

Model and Design Calculations

This section explains complete design of our machine, including the model and the calculations.

Pulping Unit

This is the first part of the machine. This unit will defiber the paper into pulp, which will be sent to ink removal process. It consists of a container, rotor blades and motor.

The consistency of pulp is improved for better defibering of the fiber. Number of rotor blades are also increased which also helped in defibering of pulp.

We know that the machine is a batch process with the capacity of 20 A4 papers. And using the weight of papers and water, the consistency is calculated as,

Number of A4 paper	= 20	
Weight of 1 A4 paper	= 5g	
Weight of 20 A4 papers	= 0.1kg	
Weight of water used for 20 A4 papers	= 4kg (4 liters of water weigh 4kg)	
Consistency	= 4000/100	= 2.5 %
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	
Volume of 1 paper	= 3.1185 cm^3	
Volume of 20 papers	= 62.37 cm^3	= 0.06237 dm^3
Total Volume required becomes	= 0.06237 + 4 = 4.156 L	
Volume of container after clearance	= 4.5 L	

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

Radius at bottom = 13cm

Radius at top = 15cm

Mean radius = 14cm

Keeping a clearance of 1 cm between rotor blades and the container wall, following conclusions were made, assuming cylinder,

Blade radius = 6cm

Height from mean radius = 27cm

Volume = $pi*r^2*h$ = 4.77 dm^3

Material of container was chosen as Stainless steel to avoid corrosion

Density of SS = 7.7g/cm^3

The thickness of container was chosen on the basis of thickness of stainless steel sheets available in market

Thickness of container = 0.15cm

Outer mean radius = 14.15cm

Volume of SS used = $pi*(r_o^2 – r_i^2) *h$ = 3.58165cm^3

Weight of SS used = 3.58165*7.7 = 27.57g

Shear Strength of A4 paper = 1MPa

Shearing force = 1MPa * paper thickness * paper length * number of papers = 250N

Assuming constant angular velocity throughout one blade profile and the material used for rotor is High speed steel M2 Material

Density of HSS M2	= 8.138 cm^3
Thickness of rotor	= 0.15 cm
Width of rotor blades	= 2.5 cm
Radius of blades	= 6 cm
Mass of entire rotor	= 18.3105*6 = 109.863
Number of blades	= 6
Shearing force becomes	= 625N

Shearing force + weight of water/6 + weight of papers/6 = centrifugal force by one blade

$250 + 9.8 + 0.98 = mw^2r$

r = 6 cm

Angular velocity for one blade = 4870.211rpm

Angular velocity for one blade = Angular velocity for entire rotor

Motor required for 5000 rpm at 4kg load. Base weight set equal to container to balance off vibrations. The base also consists of the motor.

Two holes are drilled in the pulping container. The higher one is to pump in water from an external source and the lower one is to pump the water and pulp mixture from the container to the de-inking unit. The design of the pulping unit is shown in the figures 3 and 4.

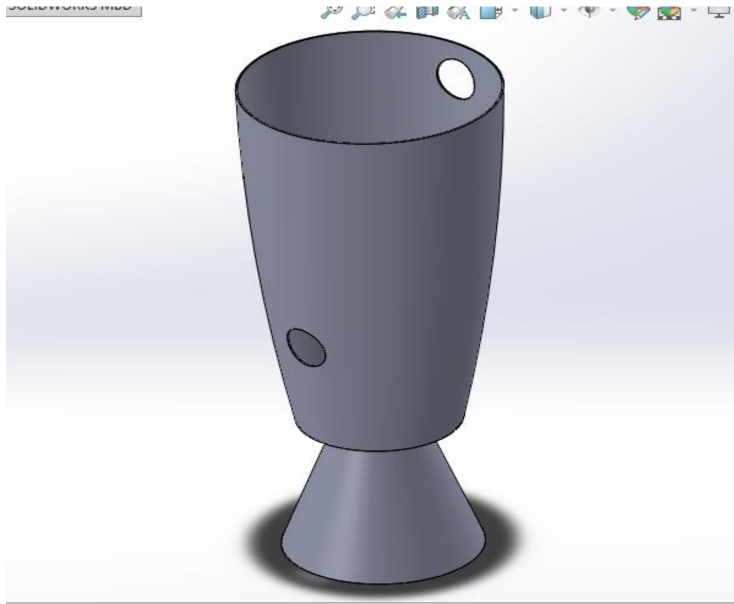

Figure 5: Design of pulping container

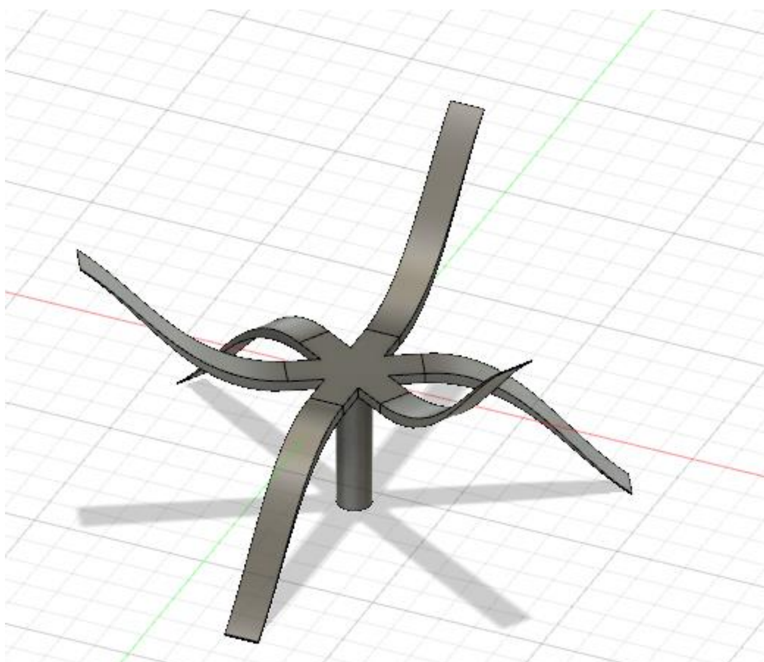

Figure 6: Design of rotor blade.

Flotation Unit

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. 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.

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
- Gas Heaters
- Press Heating Mechanism
- Forced Convection Fans

Working

The pulp from the de-inker will fall over the mesh belt that will pass through a sizing slit to evenly distribute the pulp over the mesh. From here, the pulp moves slowly over the mesh belt through a calendar roller, which presses the pulp to remove water from it and also, shrinking the thickness of the pulp. Two gas heaters are also operational here to heat and remove water through convection.

Press Heating Mechanism:

After this section comes the press heating pert About 60% of water is removed in this section. The pulp is made to stop for some time using timing belt. At this instance, a metallic support comes into working from the bottom which supports the belt for vertical load. After the belt stops, the press heater iron slowly comes in contact with the surface of belt and moves over the surface. It is controlled by two linear actuators i.e. the horizontal actuator for movement on the belt surface and the vertical actuator for connection with the surface of the belt. Firstly, the vertical actuator lowers the iron onto the surface of the pulp until it just touches the belt. Then the horizontal actuator actuates it along the conveyor belt. In this process, water is removed gradually, just like in the process of ironing of clothes. It also uniforms the paper surface. The conveyor of this section is made up of timing belt and rollers. In between the belt and iron press, a Light Weight cotton belt is also used as a medium between which helps to avoid formation of pores and helps in uniformly distributed heating.

Use of Balancing Rods:

During this Press Heating process, the weight of iron and the whole assembly is supported by the balancing rods which are positioned in the roof of the actuator assembly, as shown in the figure 7. And the whole weight of actuators and the iron press assembly is supported by the walls of the machine.

Therefore, due to weight there are 2 major modes of failure that can occur. One is the buckling in the walls of machine and the second one, which is more important and crucial, is the bending in the balancing rods. Hence the size of balancing rods is calculated in the coming section. Similarly, a motor is used to move the platform horizontally on the surface of the belt. That motor has to overcome the frictional force due to weight of the press assembly. This frictional force and the power of motor are also calculated as follows. Total time spent in this section is 20 minutes.

Paper Remover:

After the press heating process, we enter into the last section having with two calendar rollers along with a paper remover. The rollers further press and finalize the paper and in the last step, the paper is removed from the belt using a specially designed metal sheet. It connects with the walls of the machine and placed at the end of the belt. Paper usually sticks on the belt surface due to the pressing and the paper remover is designed with a minimum clearance from the belt. As paper reaches this point, it detaches from the belt and moves over its surface onto the final rollers and out of the machine.

Power Required to Drive the Belt

In order to find the power required, we need to find out the maximum tension. We find this out by firstly assuming that the whole system is vertical and assuming masses suspended by a pulley. So the maximum tension that we can obtain by resolution of forces is shown below:

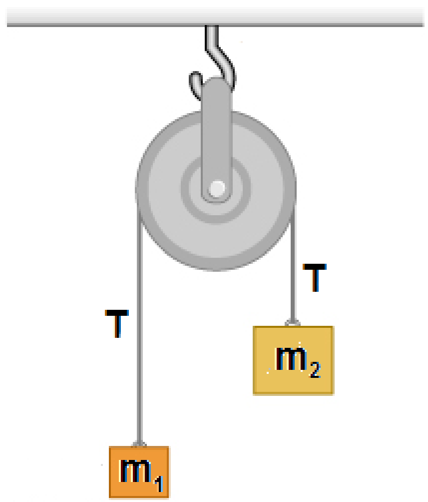

Figure 7: Free Body Diagram of Simple Pulley Mechanism

$$T1 = \frac{2m1m2g}{m1 + m2}$$

$$m1 = mass\ of\ belt = 0.2kg$$

$$m2 = mass\ of\ pulp + belt = 3.6kg$$

$$T1 = 4.032kg$$

We see that our above calculation does not take into account the friction between the surface of belt and roller where they wrap, which means that there will be loss of energy due to friction and we need to apply more force to compensate for the lost work. In a frictionless scenario, if we were to increase the tension on one side of the rope it would begin to slide across the cylinder. If friction exists between the rope and the surface though, the friction force will oppose with sliding motion, and prevent it up to a point.

When analyzing systems with belts, we are usually interested in the range of values for the tension forces where the belt will not slip relative to the surface. Starting with the smaller tension force on one side (T1) we, can increase the second tension force (T2) to some maximum value before slipping. For a flat belt, the maximum value for T2 will depend on the value of T1, the static coefficient of friction between the belt and the surface, and the contact angle between the belt and the surface (Beta) given in radians, as described in the equation below.

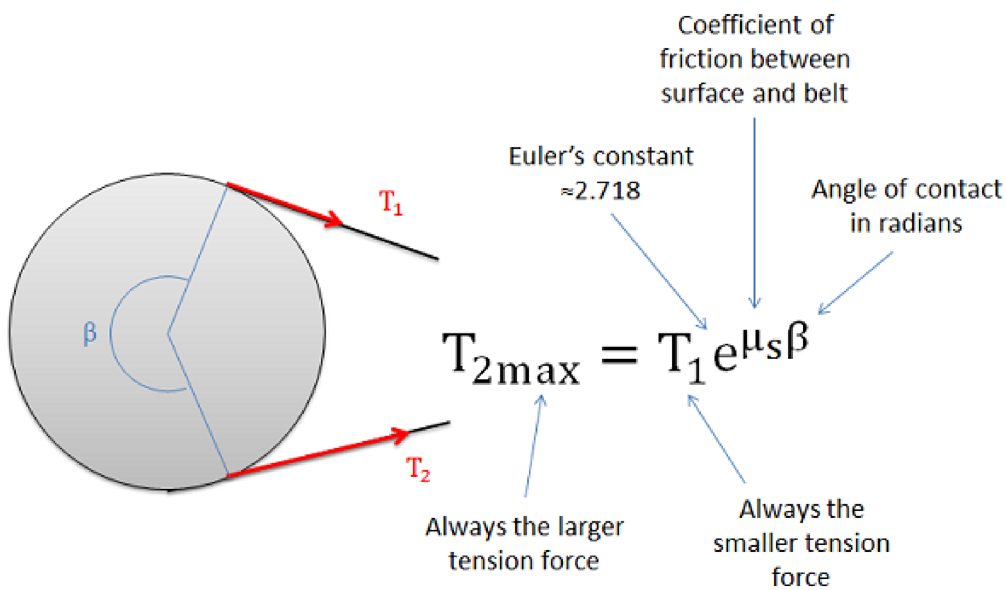

Figure 8: Body Diagram of Belt at Roller.

$$T2 = T1 * e^{\mu\beta}$$

$$\beta = \frac{\pi}{2}$$

$$\mu = 0.4\ (Plastic\ acrylic)$$

$$T2 = 4032 * e^{0.4*\frac{\pi}{2}} = 7.557\ \text{N}$$

$$Power = \left(7.557 + (3.8 * 9.8)\right) * 0.1 = 4.4797\ W$$

Power Required to Drive the Press Heater Mechanism

W(iron) is the weight of the complete assembly of upper down actuator given in figure A1, that we need to balance with the help of 2 balancing rods attached along the axis of belt motion. Balancing rods are shown in figure given below in blue color.

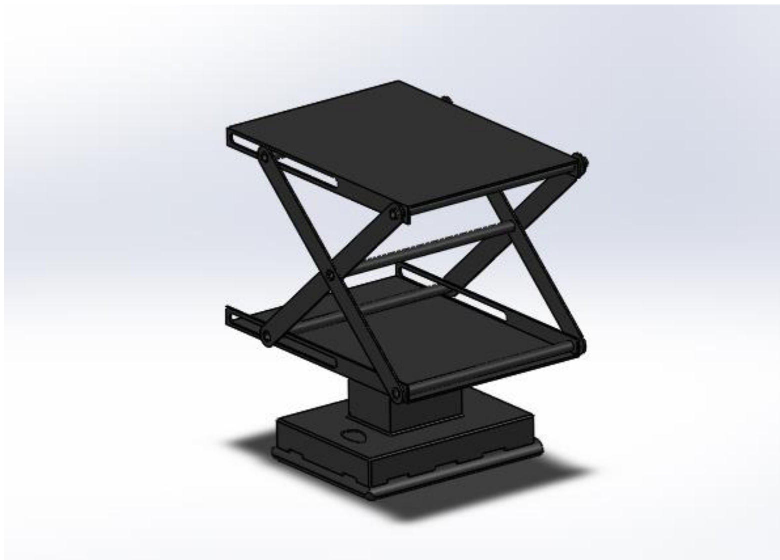

Figure 9: Up/Down Actuator

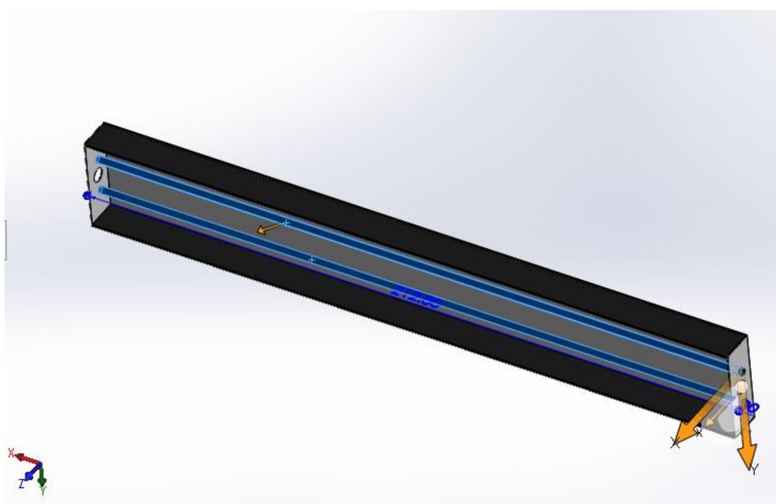

Figure 10: Balancing Rods (Highlighted in blue)

$$Wiron = 8.708 * 9.8 = 85N$$

Friction coefficient of contact between balancing rod and up down actuator assembly is 0.15.

$$\mu(friction) = 0.15$$

$$frictional\ Force = 85 * 0.15 = 12.75N$$

There are 4 contact point for load bearing and 8 surfaces

$$Frictional\ force\ of\ single\ surface = \frac{12.75}{8} = 1.59375N$$

$$Frictional\ force\ of\ single\ contact = \frac{12.75}{4} = 3.1875N$$

Power needed to move the screw can be found as:

$$Power = (Weight + Frictional\ force) * Speed\ of\ motor$$

Speed of the motion of up down actuator assembly is assumed to be 0.03m/s.

$$Power = (85 + 12.75) * 0.03 = 2.9325W$$

Assuming negligible friction in screw to drive the whole heater assembly, power required to drive the motor to drive the whole assembly is 2.9325 Watt.

Design of Balancing rods

Formula for the bending stress is following:

$$\sigma = \frac{Moment * vertical\ distance}{2nd\ moment\ of\ area}$$

There are two balancing rods to balance the up down actuator assembly and we are calculating stress for one rod so that we divide the weight by 2.

$$Moment = M = \frac{Weight}{2} * horizontal\ distance$$

$$M = \frac{85}{2} * 1.05 = 44.625 N.m$$

Vertical distance in formula is the distance of outside of rod the neutral central axis which is half of the outer diameter of rod.

$$vertical\ distance = y = 0.01m$$

$$2nd\ moment\ of\ area = I = \frac{\pi}{2}(r2^4 - r1^4)$$

Where; $r1 = inner\ radius$ & $r2 = outer\ radius$

$$I = \frac{\pi}{4}(0.01^4 - 0.007^4)$$

$$I = 5.96 * 10^{-9}\ m^4$$

$$\sigma = \frac{44.625 * 0.01}{5.96 * 10^{-10}} = 74.874\ MPa$$

$$UTS = Ultimate\ Tensile\ Strength\ for\ Stainless\ Steel = 247\ MPa$$

$$\sigma < UTS$$

Hence, rods will not fail from weight of up down actuator assembly.

Calculation for minimum use of material in balancing rods

For the calculation of minimum use of the material in balancing rods we will be using factor of safety. The factor of safety used for computing the allowable moment for cold-formed stainless-steel flexural members is 1.85.

$$Factor\ of\ Safety = FOS = \frac{UTS}{\sigma(allowable)} = 1.85$$

$$\sigma(allowable) = \frac{UTS}{FOS} = \frac{247\ MPa}{1.85} = 1.33\ MPa$$

To calculate the inner diameter of the balancing rod at UTS, we just have to put UTS value of stainless steel (material of balancing rod) in place of stress in the formula and find r1.

$$I = \frac{M * y}{UTS} = \frac{44.625 * 0.01}{247\ MPa} = 1.8066 * 10^{-9} m^{(4)}$$

$$\frac{\pi}{4}(r2^4 - r1^4) = 1.8066 * 10^{-9}$$

$$r1 = 0.0093675m$$

$$d1 = 0.009367 * 2 = 0.018734m$$

Hence, the inner diameter of balancing rod at allowable bending stress can be calculated as; $I = \frac{M*y}{\sigma(allowable)} = \frac{44.625*0.005}{133.5\ MPa} = 3.3425 * 10^{-9} m^{(4)}$

$$\frac{\pi}{4}(r2^4 - r1^4) = 3.3425 * 10^{-9}$$

$$r1 = 0.00870567m$$

$$d1 = 0.00870567 * 2 = 0.0174113m$$

We can use inner diameter of 1.74113 cm

RPM Calculation of motor

Taking the speed of screw driven by the motor equal to 0.03m/s.

$$speed = 0.03\frac{m}{s}$$

Formula for calculating RPM of a motor is given as:

$$RPM = \frac{speed * 60}{\pi * d}$$

Where d is the outer diameter of balancing rod.

$$RPM = \frac{(0.03 * 60)}{3.14 * 0.02} = 28.64\ RPM$$

3D Model and Animation Video

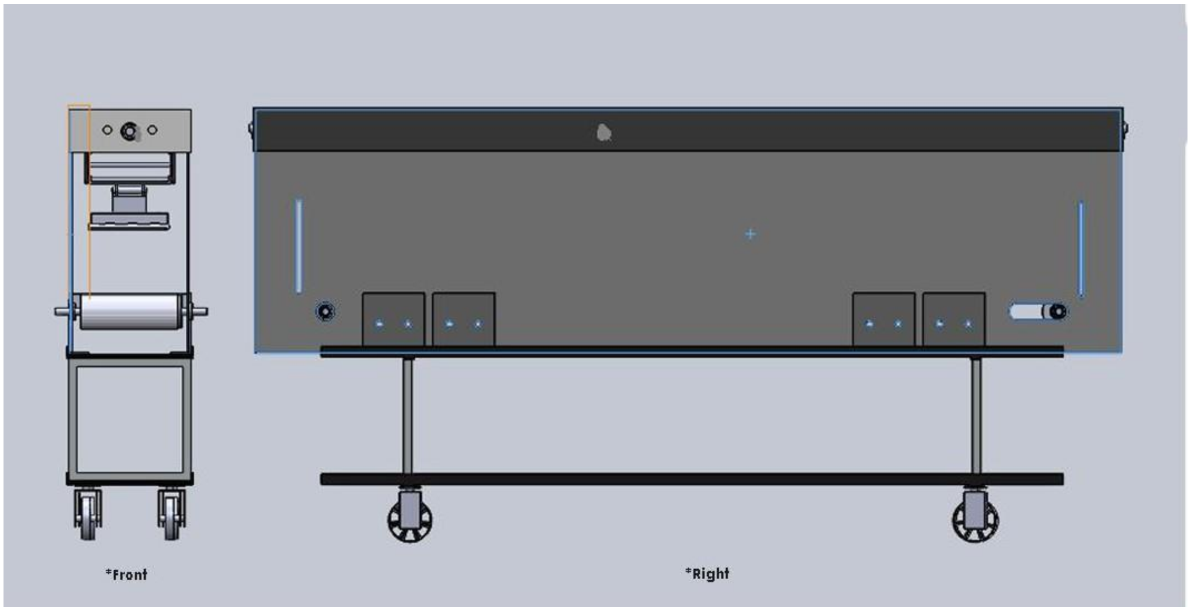

Figure 11: Paper Recycling Machine - Front View and Right View

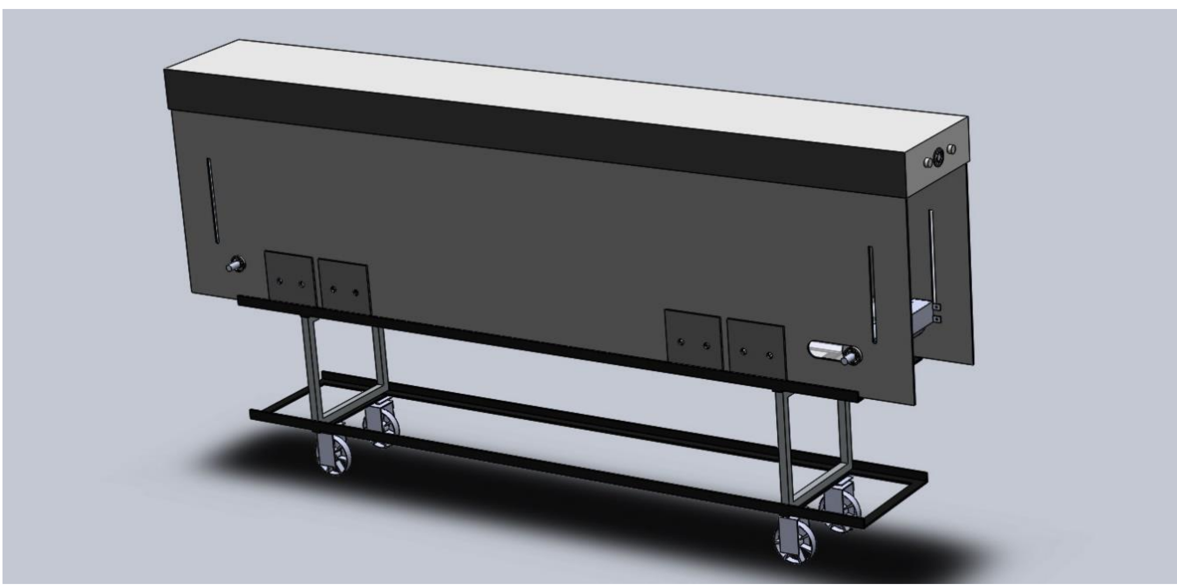

Figure 12: Paper Recycling Machine - Isometric View

CHAPTER 4: RESULTS AND DISCUSSION

Heat energy Calculations

This section shows the calculations for the heat energy required to evaporate the water content. We have performed experiments before designing our new model of paper recycling machine. In our results of those experiments we found that thickness of recycled paper was 0.2mm. By using this information, we can find the total number of papers which we can recycled in one batch with defined dimensions of the machine.

$$Experimental\ thinkness\ of\ paper = 0.2\ mm$$

$$Length\ of\ machine\ for\ recycling\ paper = 180\ cm$$

$$Width\ of\ output\ paper = 20\ cm$$

$$Volune\ of\ paper = (0.2 * 10^{-3}) * (20 * 10^{-2}) = 7.2 * 10^{-5}\ m^3$$

$$Density\ of\ Paper = 1201\,\frac{kg}{m^3}$$

Now, by using the volume and the density of paper we can find the present mass of the paper present on the drying belt.

$$Mass\ of\ single\ batch\ of\ paper = 86.472\ g$$

$$Mass\ of\ an\ A4\ sized\ paper = 5\ g$$

$$How\ many\ paper\ can\ we\ recycle\ in\ one\ batch = \frac{86.472}{5} = 17.2944$$

$$approximate\ No.of\ papers = 17\ per\ batch$$

To produce better pulp and for improved deinking we will keep consistency of paper pulp at 2.5. 2.5 consistency means that if there are 100 parts of paper pulp by mass then there will be 97.5 part of water and 2.5 part of paper in the mixture.

Amount of water that we need to make pulp with paper's consistency of 2.5 is calculated as:

$$Paper : Water$$

$$2.5\ g : 97.5\ g$$

$$5 : 195\ g$$

$$85\ g : 3315\ g$$

$$Total\ mass\ of\ pulp = 85 + 3315 = 3400\ g$$

Also, from the experiments, we found that 20% of water content can easily be removed only by the motion of iron on the surface of pulp without heating.

$$Remaining\ water\ content = 3315 *\ 80\% = 2650g$$

This water content is at room temperature and it must be evaporated.

Amount of heat energy required to evaporate present water content can be broken down in to two.

- Heat required to raise it temperature from room temperature to boiling point (100 Degrees Centigrade) Q_1
- Latent Heat of Vaporization Q_2

$$Total\ Heat\ required = Q1 + Q2$$

Heat required to raise temperature from room temperature (25^0C) to 100^0C is calculated by energy balance given as:

$$\dot{W}_{elec} + \dot{Q} + \dot{m}_{in} (h_{in} + \frac{Vin}{2} + gz_{in}) - m_{out} + (h_{out} + \frac{Vout^2}{2} + gz_{out}) = 0$$

There is no work done out case, so that, $W_{elec} = 0$

Mass of before and after will be same because there is no evaporation and only change in temperature is $\dot{M}_{in} = \dot{m}_{out}$ ṁ

Formula for enthalpy is following;

$$H_{in} = C_pT_{in}$$

$$H_{out} = C_pT_{out}$$

There is no displace against gravitational pull so that:

$$Z_{in} = Z_{out}$$

Water content is not in motion so that velocity before and after will remain same and equal to zero.

$$V_{in} = V_{out}$$

By incorporating about equations our main equation becomes:

$$Q_{in} = mC_p(T_{out} – T_{in})$$

$$m = 2600g = 2.6kg$$

$$Cp = 4.2\frac{KJ}{kg}$$

$$T_{out} = 100^0C$$

$$T_{in} = 25^0C$$

$$Q1 = 2.65 * 4.2 * 75 = 834.75\ kJ$$

$$Latent\ heat\ of\ vaporization = Q2' = 2260\ kJ/kg$$

$$Latent\ heat\ of\ vaporization\ for\ 2.65\ kg\ of\ water = 2260 * 2.65 = 5989\ kJ = 6MJ$$

$$Total\ heat\ required\ to\ evaporate = 5989 + 834.75 = 6.824\ MJ$$

Total amount of heat energy required to evaporate that present water content in one batch is found to be = ***6.82MJ***

Cost of fuel to produce required heat energy

We know the amount of heat energy required to evaporate water content and we also know the heat value of LPG and natural gas, by using simple rules of Math we can find the cost of consuming fuel in one batch.

- By using LPG as Fuel

$$Price\ of\ LPG\ in\ Pakistan = Rs\frac{92}{kg}$$

$$Heat\ value\ of\ LPG = 46.1\frac{MJ}{kg}$$

$$Amount\ of\ LPG\ required\ fot\ 6.834\ MJ\ heat = \frac{6.82}{46.1} = 0.148\ kg = 150\ g$$

$$Price\ of\ 150g\ of\ LPG = \frac{150}{1000} * 92 = Rs\ 13.8$$

$$Price\ of\ electricity\ per\ paper = \frac{13.8}{6} = 2.3$$

By including the working and operating costs of motors and the electricity used to drive belts, it will become Rs. 2.5/paper.

So that cost of consuming fuel per paper is found to be **Rs. 2.5/paper.**

- By using commercially available Natural Gas

Sale price of natural gas is available in following table, which is also available on govt. websites.

Slabs	Rs./MMBTU
Upto 0.5 HM3 per Month	110
Upto 1 HM3 per Month	110
Upto 2 HM3 per Month	220
Upto 3 HM3 per Month	220
Upto 3 HM3 per Month	700

If there is use maximum use of natural gas and count goes above 3 HM3 than sale price will be Rs. 700 / MM BTU. Which is the highest possible price.

MM BTU is the unit of energy, it's relation with Joule is following

$$Energy\ in\ 1\ MM\ BTU\ =\ 1055\ M\ Joules$$

$$Price\ for\ 6.83MJ\ =\ \frac{700}{1055}*\ 6.834\ =\ Rs\ 4.53838\ =\ Rs.4.5$$

It will be increased to Rs. 4.9 after incorporating rest of electricity used to drive all motors.

$$Price\ per\ paper\ =\frac{4.7}{6}\ =\ 0.783\ =\ Rs\ 0.8\ per\ paper$$

Hence price of recycling per paper is found to be **Rs. 0.8 per paper**.

Paper Thickness and Quality

As stated earlier, the precious model used only heating to remove the water content from the pulp. There was no pressing involved and neither was any thickness control measure used in the machine. Hence, the paper which was being produced by the earlier model was of thickness 6mm. Note that the actual thickness of the A4 paper is 0.13 mm approximately.

Also, it had pores on the surface which were formed due to the bubbles of water escaping the surface without the surface being pressed or rolled. It was a hard paper with rough and uneven surface. In this new design, though the improvements we have achieved 0.2 mm thickness of paper.

NOTE:

We have the sample results of paper and the reference of the previous samples along with all the equipment at NUST but unfortunately due to the COVID-19 situation, we cannot access them.

Manufacturing Plan

In this section we'll discuss the complete process plan to manufacture the machine. There are Engineering Drawings, Dimensions, Materials and Operations elaborated for every part in this section. Since the pulper and the Deinking Unit has already been manufactured so it is not included. The plan includes the paper forming unit with all the features explained.

Process Design Parts

This area will elaborate the materials, specifications and description of parts that will make up the machine assembly. There are process tables supported by CAD models to elaborate the design.

The Engineering Design of main parts are also attached in the APPENDIX I: Engineering drawings

Table 3: Process Design Parts Specifications - Machine Base

Sr. #	Sub-Assembly	Part Name	Details	Quantity	Dimensions/ Specifications	Material
I	Supporting Base	L Beam	To support weight of machine "1"	4	Length: 1.8 m	Cast Iron
		Square Rod	To support weight of machine "2"	1	Length: 2.4m Area: 0.02x0.2 m^3	Cast Iron
		Metal Plate	For support on the walls "3"	2 Each	Area: 0.15x0.15 m^2, 2.1x0.6 m^2 Thickness: 0.005 m^3	Cast Iron
II	Wheels	Wheel Assembly	"4"	4	Φ=100mm	N/A

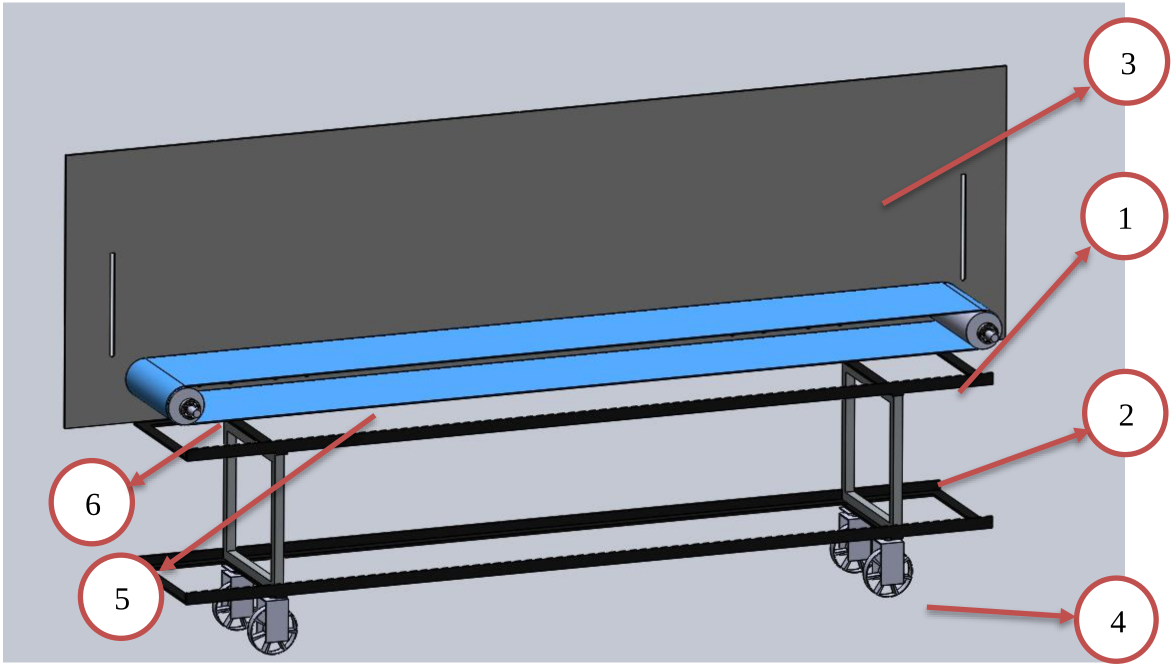

Figure 13: Machine Base

Table 4: Process Design Parts Specifications – Shaft and Bearing Assembly

	Sub-Assembly	Part Name	Details	Quantity	Dimensions/ Specifications	Material
I	Shaft and Bearing Assembly	Acrylic Belt	The Belt on which pulp moves "5"	1	Length: 4.3m Width: 0.25m	Acrylic
		Rollers	Both Ends of Belt "6"	2	Φ_{outer} = 80mm Φ_{inner} = 20mm	SS
		Shafts	Within Rollers Assembly	2	Length: 20mm $\Phi = 20mm$	SS
		Ball Bearings	Within Rollers assembly	2	Φ_{outer} = 40mm Φ_{inner} = 20mm	High CS

Table 5: Process Design Parts Specifications - Actuators

Sr. #	Sub-Assembly	Part Name	Details	Quantity	Dimensions/ Specifications	Material
I	Horizontal Actuator	Balancing rods	To support the weight of press heater "7"	2	Φ = 20mm Length: 2.2m	SS
		Ball Bearing	For both ends of screw	2	Φ_{outer} = 40mm Φ_{inner} = 20mm	High CS
		Metal Sheet	Outer covering "8"	1	Area: 0.5x2.3 m^2 Thickness: 0.005 m	Cast Iron
		Iron Rod	To make screw "9"	1	Φ = 20mm Length: 2.2 m Pitch = 5mm	SS
		Metal Plates	For Moving Platform and supports "10"	1 Each	Area: 0.2x0.27 m^2, 0.36x0.36 m^2 Thickness: 0.05	Cast Iron
II	Vertical Actuator	Metal Plate	Supporting surface welded with platform and iron "11"	2	Area: 0.25x0.31 m^2 Thickness: 0.005 m	
		Trusses	For Mechanism of Actuator "12"	4	0.280m 0.005m	Cast Iron
		Balancing Rods	Will work as the pin joints in the mechanism "13"	6	0.105m x 0.005m	SS
		Gas Iron	Gas iron welded with metal surface "14"	1	N/A	N/A

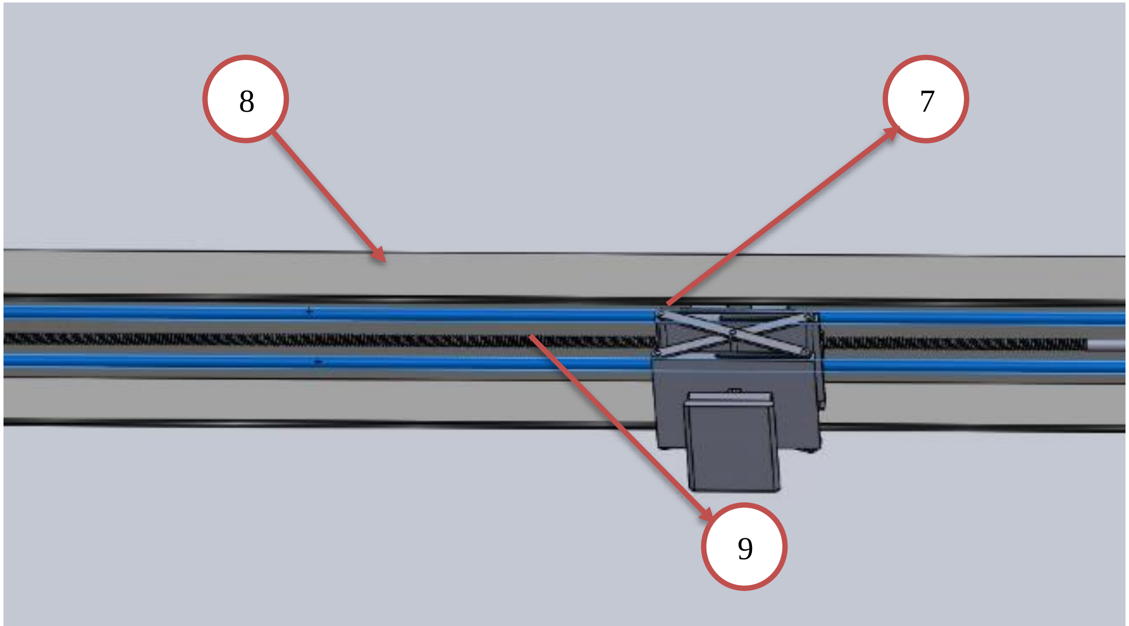

Figure 14: Horizontal Actuator Components

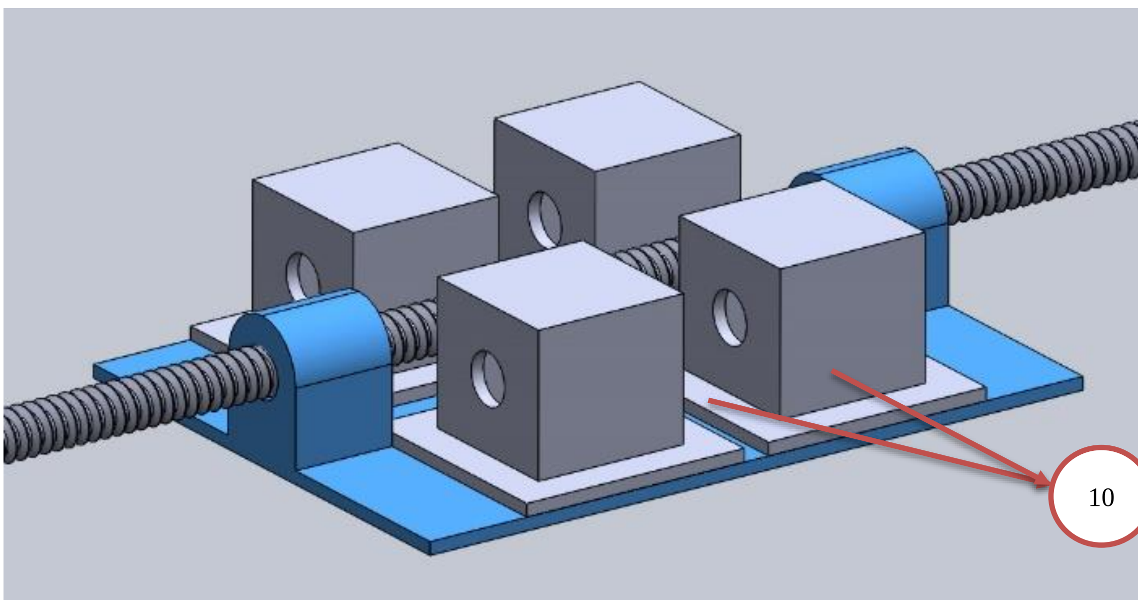

Figure 15: Horizontal Actuator Components

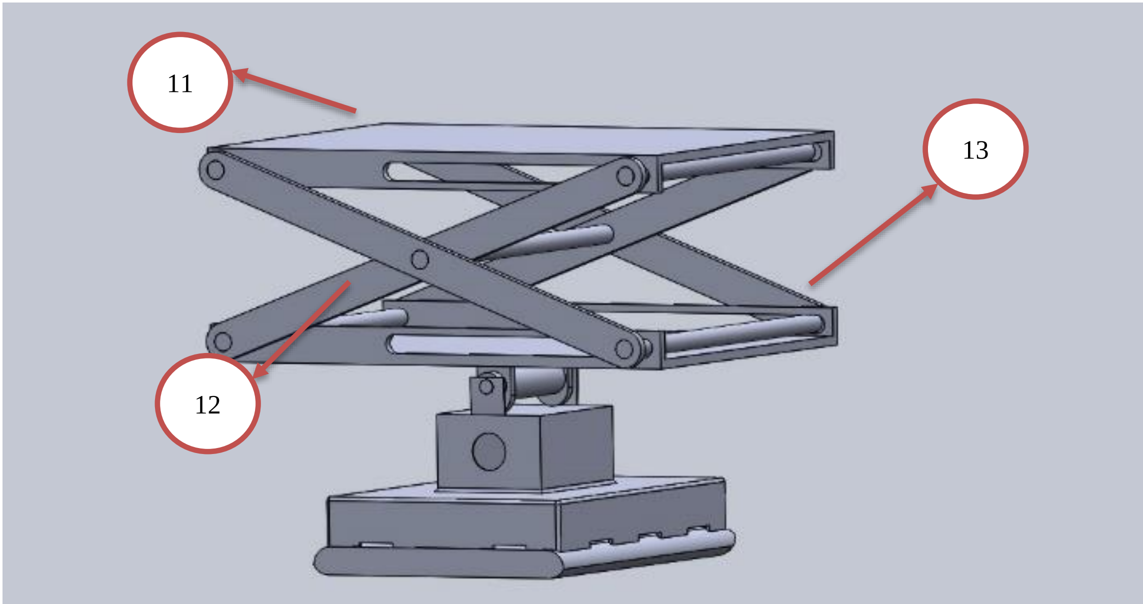

Figure 16: Vertical Actuator Parts

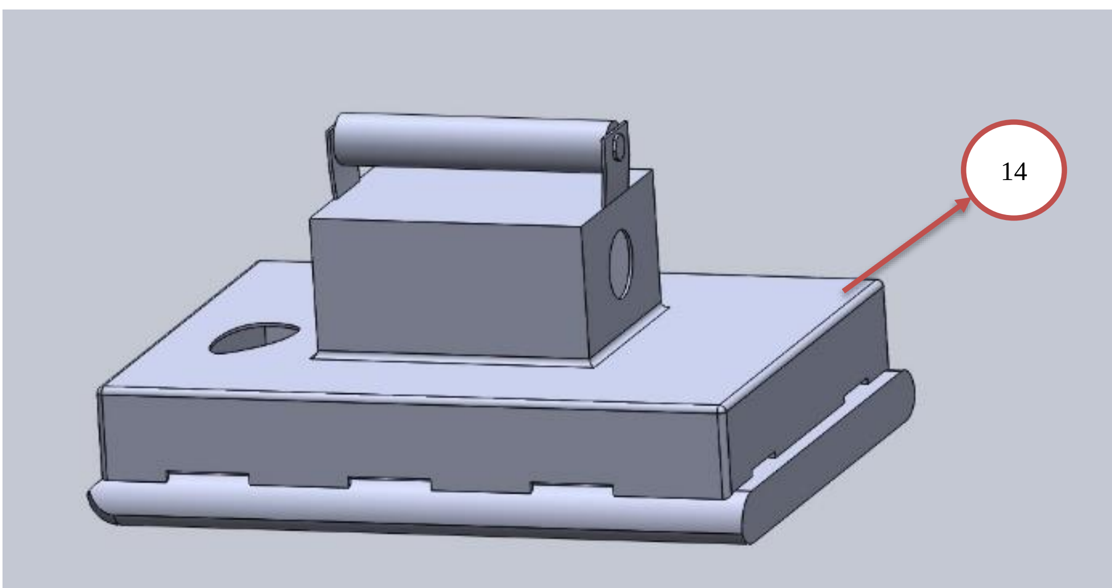

Figure 17: Iron Press Heater

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

Conclusion

This paper demonstrates the working of a paper recycling machine that can produce good quality office use recycled paper at a competitive cost to what is being produced in the market. This paper includes improvement to the prototype machine made in 2019 by a group of final year students of BS Mechanical that demonstrated that it is possible to make a simple machine at economical rates that can recycle waste paper from offices to reduce the need for new paper, so that there can less usage of trees to make new paper.

But that project had many shortcomings. First, the quality of paper was below standard as to what is acceptable even for basic writing. Secondly, the operational cost of the overall machine was very high, which meant an overall higher price of recycled product compared to the market. And so, to remedy their mistakes and to give a overall better product to the market, this research paper shows the working of a simple, economical, easy to manufacture and maintain machine that gives better recycled paper that is above standard as to what was being produced previously.

Two major solution to the previous machine is the use of a different belt material and use of gas-powered iron. Firstly, the use of **write belt material here** as belt allows for easy removal of water and allows for easy separation of pressed and dried paper from the belt surface without the use of excessive force. Secondly, the use of gas-powered iron allows for proper pressing of paper pulp, allowing removal of excessive water and strong paper the iron moves over the pulp drying it from extra heat. This gives us clean and flat paper that can be used in offices at rates much cheaper compared to the precious prototype.

One step Forward

It is evidently possible to recycle paper at domestic and office level at affordable costs. The quality of paper is also adequately fine and can be used for daily uses. Through newly implemented techniques in this machine we have achieved much lower operating costs and better quality. This can prove to be a revolution and reduce paper wastage to a large content.

At homes, at schools, in offices and in every room where paper is used frequently, the paper can be recycled easily saving time and costs.

However, our machine is very basic model that uses gas heaters and iron pressing techniques. And it can be improved in several aspects to improve its efficiency, quality of paper and total time for a batch production.

Recommendations

There is always place for improvement in every field and project and as the world is changing towards green environment and automation, we can still incorporate major improvements in this machine. Some of the recommendations are listed as follows

- Integrated Solar Hybrid heating system

Integrated Solar Hybrid heating system can be used instead of gas heating. The gas heater is undoubtedly cheaper in terms of operating costs but they are harmful for the environment. The burning of gas produces carbon dioxide which is a drawback. Therefore, we can use the solar energy to produce heat required for the system. They are renewable and environment friendly energy source and produce much lower costs as well.

As calculated in the results section, the heat required for one batch of the papers is 6.83 MJ. This amount of energy can be easily extracted from the solar heat pumps and that can be used instead of gas heaters. It will require higher initial installation cost but operating costs are reasonable and can be incorporated

- Felt roller mechanism

This process is very costly to incorporate on the projects at university level. In this process multi-layer model is made where pulp moves between special belt called “felt”. The felt is made up of absorbing material along with many steam heating rollers to press the pulp throughout its way. It presses as well as stretches the paper for enhanced results. It has a high initial cost as well as operation and maintenance costs but once it is implemented, it provides the most efficient results.

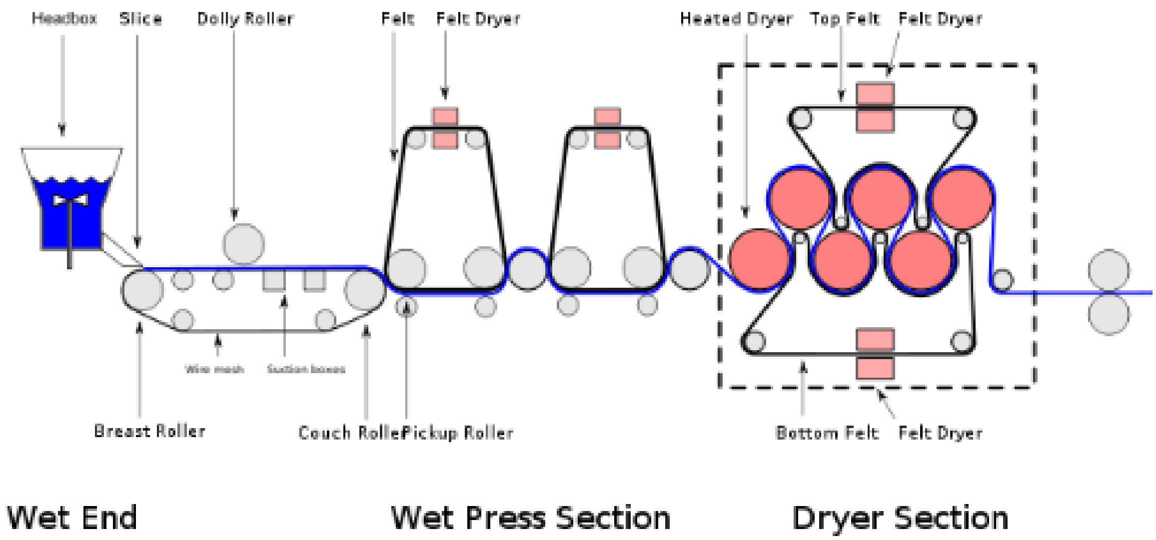

Figure 18: Felt Roller System

- Brightness Control

The brightness and contrast of paper is not being controlled yet in this model. Bleach can be used for better and controlled quality of paper. It can be used as a spray actuated and controlled by sensors. This mechanism can be incorporated in the last section of machine.

- Multi-layer Compact Design

The design of machine can be made more compact and aesthetically pleasing. It can be covered in Compact design for example a shorter length of machine with multiple stories of pressing heating and calendaring instead of lengthy model. It will be more compatible with the office space.

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APPENDIX I: ENGINEERING DRAWINGS

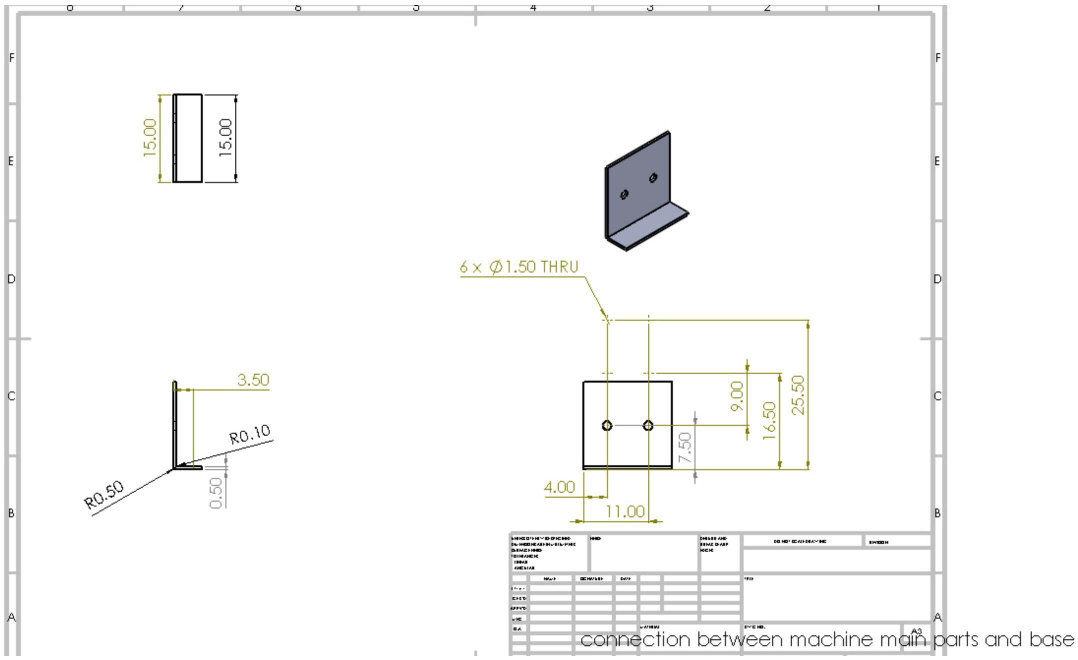

Figure 20: Engineering Drawing – Walls Support

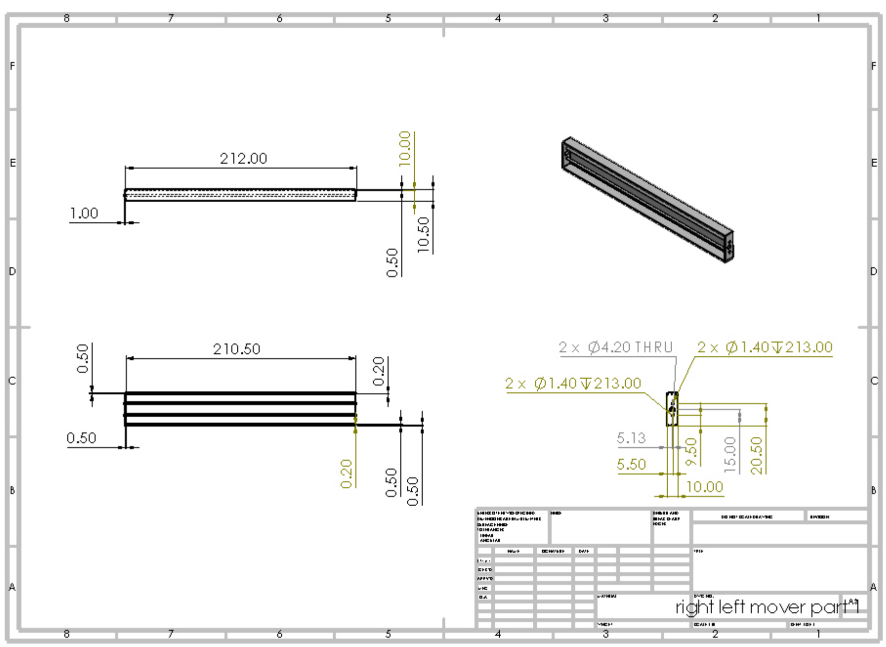

Figure 21: Engineering Drawing – Horizontal Actuator Roof

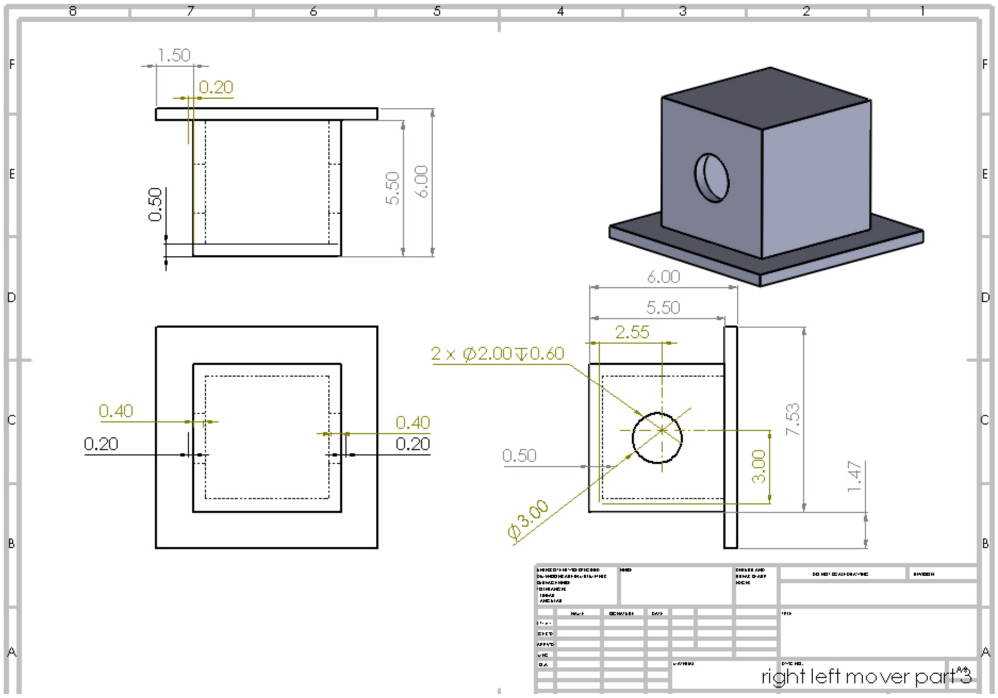

Figure 22: Engineering Drawing – Platform Support with Balancing Rods

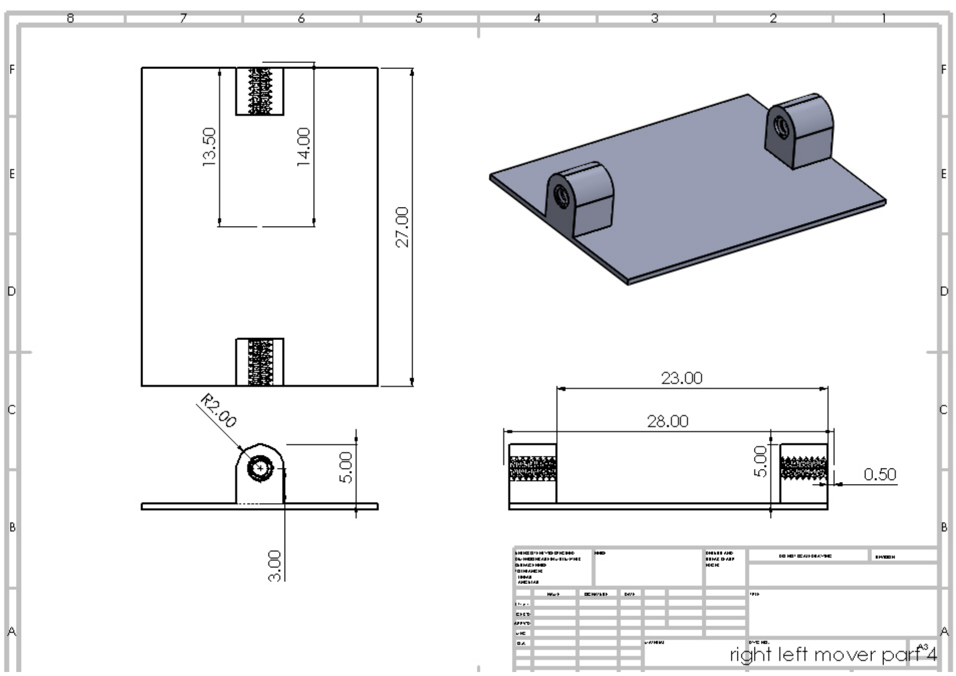

Figure 23: Engineering Drawing – Platform Support with Screw

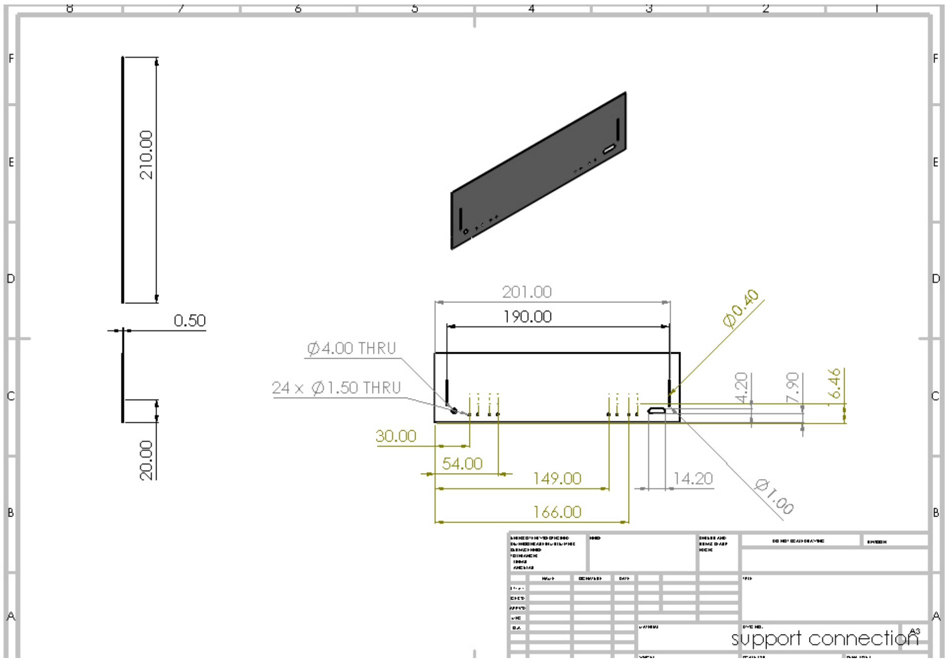

Figure 24: Engineering Drawing – Wall

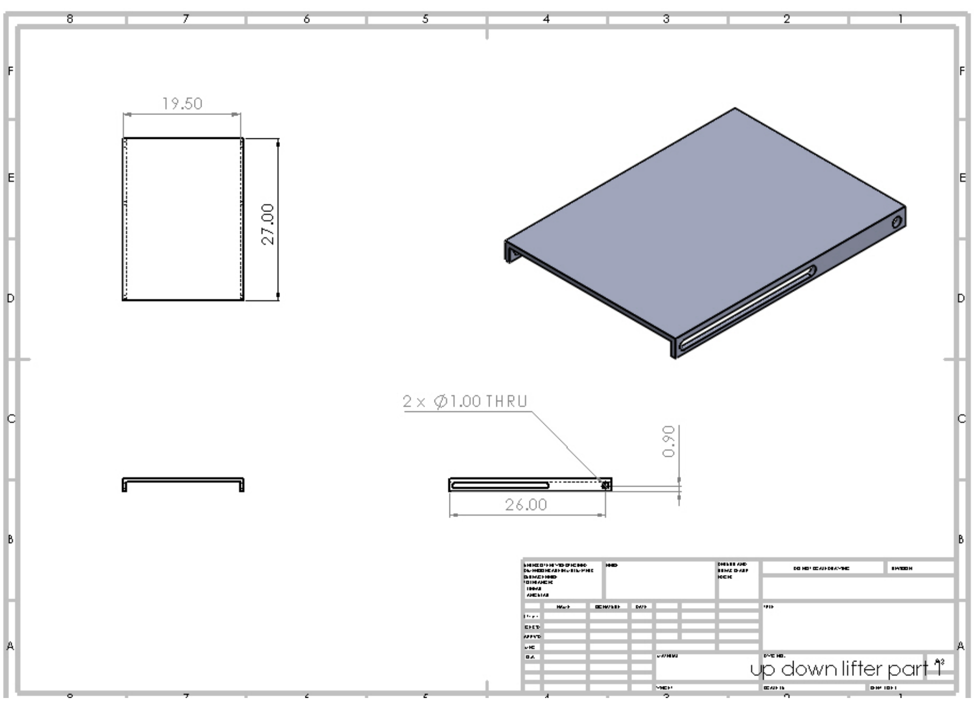

Figure 25: Engineering Drawing – Platform Roof

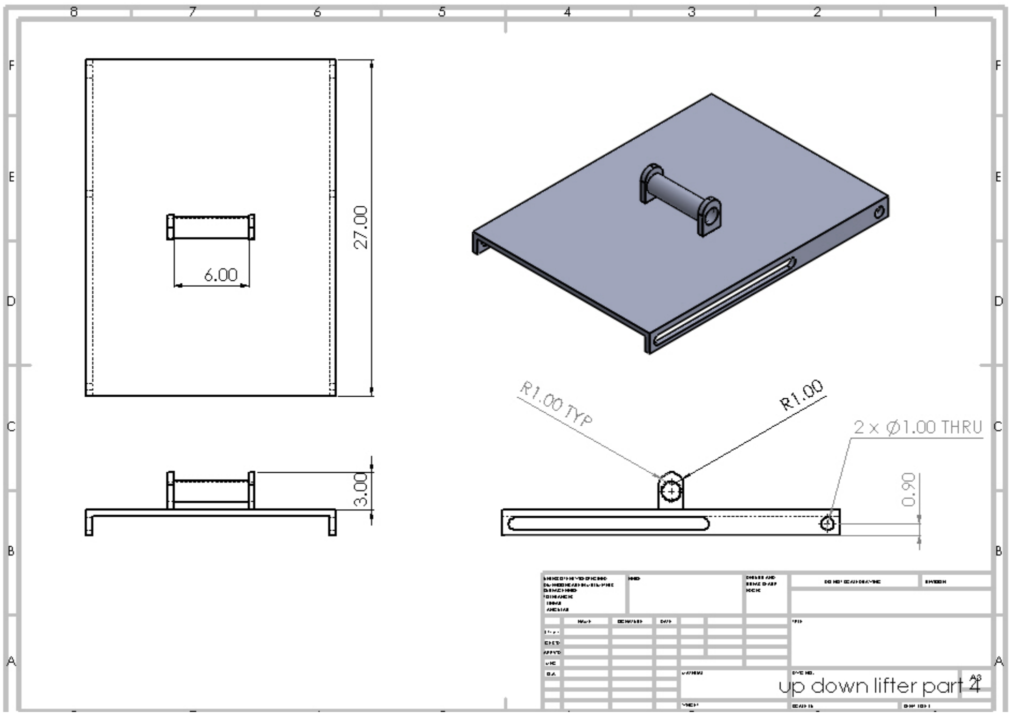

Figure 26: Engineering Drawing – Platform Base

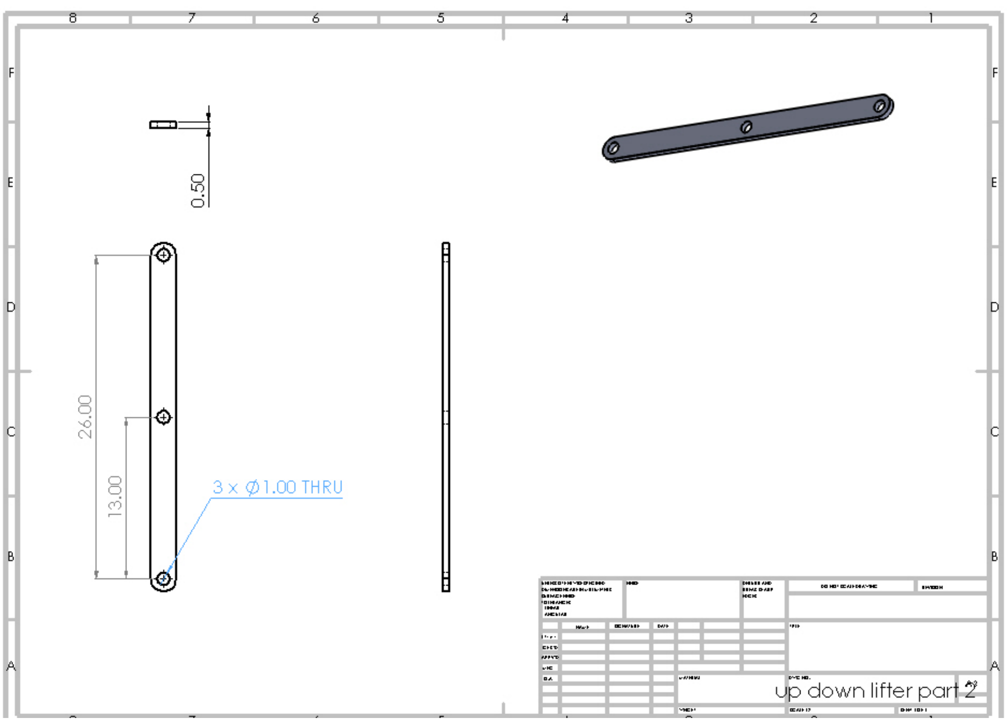

Figure 27: Engineering Drawing – Trusses

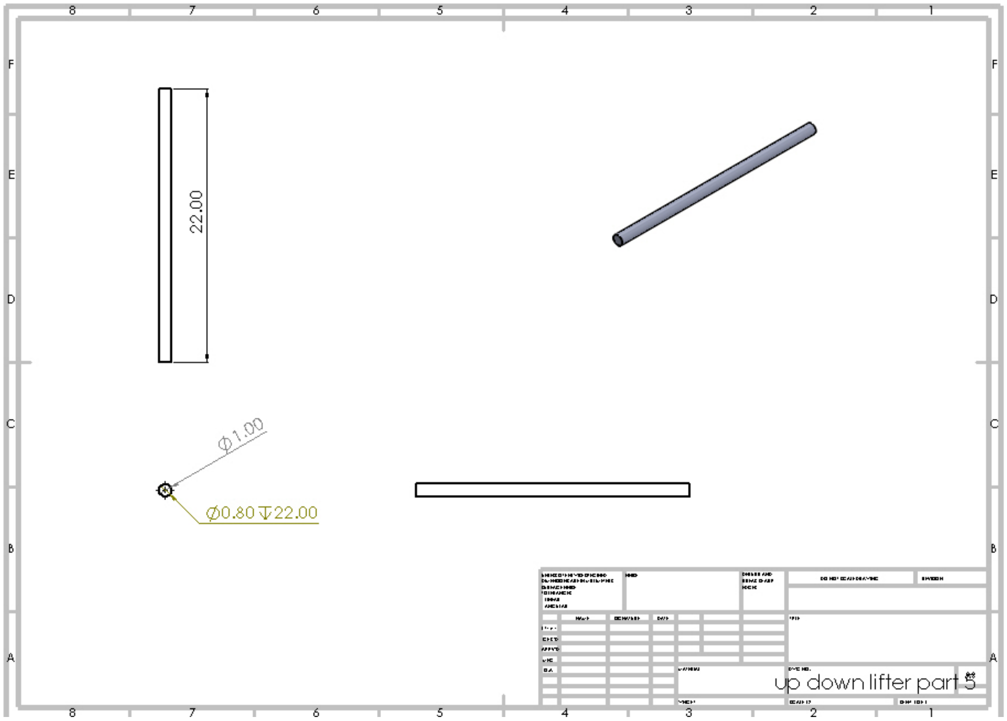

Figure 28: Engineering Drawing – Balancing Rods

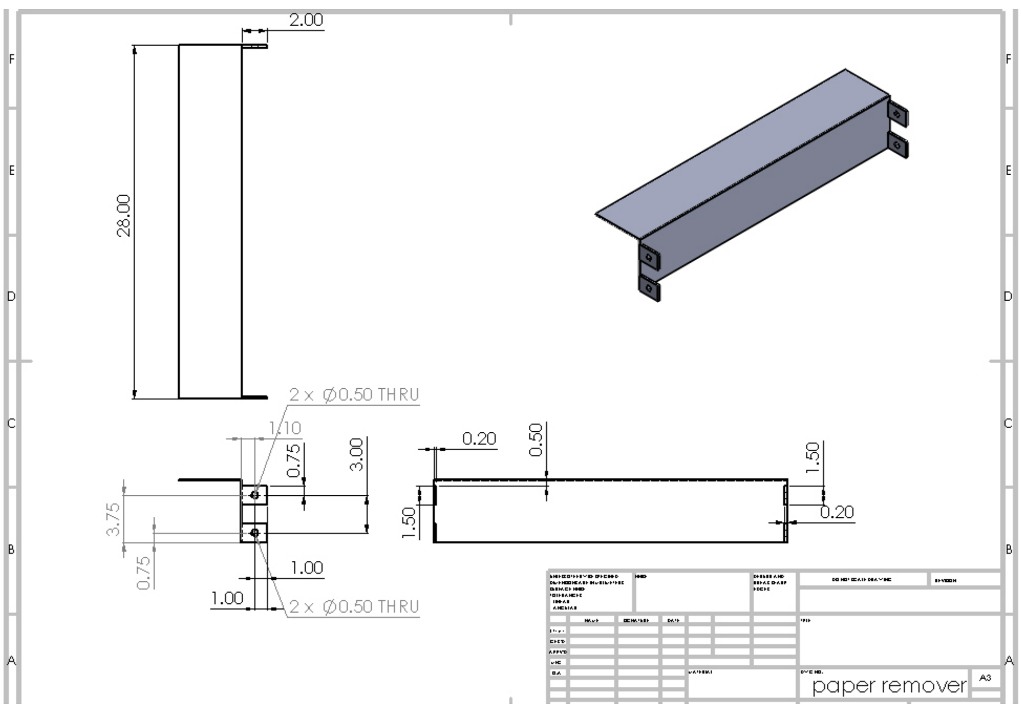

Figure 29: Engineering Drawing – Paper Remover