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Title: Energy Auditing of the Ethiopian Pulp and Paper Factory.

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Abstract

The objective of this thesis is to understand the energy utilization and look for ways of conservation for the Ethiopian pulp and paper S.co. To understand the process, a thorough assessment of the production process was carried out, as it is a vital step to identify energy conservation opportunities. Job implementation reports of the factory were investigated and it was found that, recently it is using around 15GJ/ton. World and European best practices were also investigated, and it was found out that in around 2000 G.C., 7.1GJ/ton to 7.64GJ/ton was a good practice. A benchmark that was useful before 13 years is good enough for a developing country like Ethiopia. To close the gap, energy conservation opportunities were also identified and listed out. One of the opportunities was selected on the basis of importance and a detailed audit was carried out. Specifically, the primary drier section was quantitatively modeled. It was found out that 1.41Mw of waste heat was being ejected through the hood. It was also pointed out that recovering of some of this waste heat would have a positive contribution towards closing the gap. Economic analysis of the recovery system suggested that it was economically feasible. Energy loses due to: - rework, steam leakage, and condensate leakage, were also quantitatively estimated. And it was found out that, potentially, about 1.924 GJ/ton or 1,572,500 birr per year can be saved by using modern heat recovery system; 1.55GJ/ton or 809028 birr per year can be saved by avoiding rework; 0.204 GJ/ton or 106508 birr per year can be saved due to avoiding steam leakage and 0.245 GJ/ton or 132795 birr per year can be saved by avoiding condensate leakage.

Key words

Pulp, Deflaking, Refining, Hydration, Fibrillation, lignin, cellulose, hemicelluloses, Bank paper, white bond, Kraft liner, Fluting medium, newsprint papers, consistency, resistance, opacity

Table of contents **page**

CHAPTER ONE

INTRODUCTION

1.1 Background

Ethiopia is a country having an Agriculture led Economy. It is expected that Agriculture and forest based industries are going to emerge soon in the country. Agriculture based industries such as food complexes, sugar, breweries, and textile industries are emerging in the country. The same is true for the forest based industries like furniture and particle board making industries. Similarly, the pulp and paper industry is one of the most probable industries to emerge soon, as it is highly related to forestry.

Ethiopia is currently producing 2022.2MW of power, of which 91% from hydropower [1]. As part of the government's growth and transformation plan, EEPCo has launched hydropower, and other renewable energy, projects to meet the 10,000MW target in the coming five years [1]. This shows that it is planning to supply the necessary capacity to do work (Energy) for the industries to come. In the absence of power, development is unthinkable. Energy these days is an employment opportunity, a means of income and a way for a better standard of living. In this regard EEPCo is doing the right thing. In this regard the government is doing the right thing, no doubt about this.

However, along with energy production, energy conservation is very necessary. EEPCo supplies the necessary power for the industries and its task seams to meet their demand. However, more effort is needed to conserve energy in industries. These days energy is an international commodity because its production affects the environment. It must be consumed appropriately everywhere in the world as its production is highly related to the global environmental issues which has a devastating effect on the world.

At the national level energy is the basis for industrial development. It must be sold responsibly. It should not be wasted because it is a job opportunity that is wasted. It is the development opportunity that is to be wasted. Hence, we as a nation must focus on energy conservation as good as on energy production.

Daily livelihood of human beings demands energy supply. More energy is required as population grows and as people become more modern [12]. As people become more civilized they will start to consume more and more power. They start to use more electricity; they want refrigerators, washing machines, cars, instant coolers and so on. All of these things consume energy. Energy conservation can be taken as a good means to finding a huge amount of energy that could be utilized to meet the growing development demand of the country.

One of the main means of reducing the threat of increased global warming, caused by human use of fossil fuels, is to reduce the industrial use of energy [4]. And this in turn can only be done after energy auditing.

Many of the factories in our country were established many years back and it is unlikely that they update themselves. For instance, the Ethiopian pulp and papers Share Company was established and got legal recognition in August 29, 1955 E.C [14], which is almost 50 years ago. However, scientific and technological development efforts are going forward in the world. Various energy efficient devices are being developed and utilized year after year. Hence it would be necessary to evaluate the performance of our old industries continually and at least understand their position in terms of energy conservation.

The research questions and sub questions that are to be addressed in this research are:

- How appropriately is this factory utilizing energy?
- How is the total energy distributed in the factory?
- How is the factory performing?
- Where is it compared to the world best practices?
- What feasible energy management opportunities are available in the factory?

1.2 Significance of the study

As it is stated earlier energy conservation is the appropriate utilization of the limited energy which is developed at the expense of the environment one way or another. The knowledge that is developed through researches like this will depict our position in terms of energy conservation and direct feasible ways for the appropriate utilization of power.
An energy auditing research like this is vital for depicting the picture of our industries with reference to international benchmarks and find feasible alternative ways to close the gap.

Moreover, the pulp and paper industry is definitely a forest based industry as it consumes a huge amount of wood. Hence it is the most likely industry to emerge soon in the country since the demand for paper is very clear. There is no demand problem as long as the supply is possible. The country is very suitable for forestry development as long as it is commercialized for the population's 80% farmers of Ethiopia. Hence there is a very high probability that pulp and paper industries are going to boom in this country. Therefore outputs of researches like this could be very important for the future similar industries.

Also one way of mitigating the challenges of energy consumption at the global level is energy conservation. In order to conserve the energy there has to be the necessary knowledge as to how it is being wasted. This can only be obtained through an audit report. The proper utilization of power is going to be achieved through continual assessment of the energy utility in an industry. This in turn will reduce the unnecessary pollution of the environment. For this, researches like this will play a very important role.

1.3 Objective

1.3.1 General objective

The general objective of this research is to asses the energy use of the Ethiopian pulp and paper factory; and to recommend possible ways of energy saving so that the overall efficiency of the factory may be improved.

1.3.2 Specific objectives

- Describe the process and the energy consuming equipments used in the factory.
- Collect data through interviews and measurements.
- Analyze the collected data.
- Identify energy management opportunities.
- Evaluate the technical and economic feasibility of the alternatives.

CHAPTER TWO

LITERATURE REVIEW

2.1 Historical Notes on the Development of Paper Technology

Paper is a very useful item – no doubt about it. It is used not only for writing purposes but also for packaging, toilet, making money and many other purposes. It was Egyptians who, around 3000 B.C., first made paper out of a marsh grass called Cyprus papyrus. They cut thin strips from the plant's stem and softened them in muddy waters of the Nile. They were able to produce a paper like material called papyrus. It is from this word that the word paper came from [6].

In 105 AD papers in its form we know today was first made in China by T'sai Lun. He disintegrated the individual fibers of plants and mixed them with water in a vat. Then a screen was sub merged in the vat and lifted up through the water, catching the fibers on its surface. Then dried, this thin layer of intertwined fiber became what today we call paper [6].

In the third century the secret art of paper making began to creep out of China, first to Vietnam and to Tibet. Introduced in Korea in the 4th century and spread to Japan in the 6th century. It then slowly spread through Asia to Nepal and later to India. Then it made its journey to the west in 751AD. Gradually the technology moved through the Muslim world – to Baghdad, Damascus, and Cairo. Then like this it continued spreading. It can be said that paper making was spread in Europe in the 12th century [6].

In Europe the use of parchment – made from animal skin was the preferred medium for artists and literati of the time. However, parchment was very expensive. It was in the 15th century that paper became an everyday item. Especially, when Johan Gutenberg perfected movable type and printed his famous bible in 1456. Birth of the modern paper and printing industry is commonly marked from this date [6].

Printing technology rapidly developed and created an ever increasing demand for paper. Early European papers ware made from recycled cotton and linen. But soon this becomes insufficient and various alternative sources of row materials were searched as an input to the paper industry. Today, the long soft fibers of soft woods such as spruce have become the most suitable sources of pulp for mass production.

In 1799,Luois- Nicolas Robert, patented the first machine to produce continuous paper. But he couldn't control the patent right and it was further developed in England. The invention was the core of the Fourdrinier machine, and the basis for modern paper making. This new machine made papers soon replaced traditional single sheet papers made by hand.

Hennery Fourdrinier, the son of a paper maker and a stationer, with his brother, invented and improved the fourdrinier machine. A paper making machine that could make continuous paper (rolls). The patent was granted on July 24, 1806 [16].

After this the mass production of paper become a thrilling industry supplying huge volumes of paper for the production of newspapers, books, magazines, paper bags, toilet paper, money and a huge variety of other purposes.

Paper drying cylinders were first patented in England in 1820. Prior to this time paper drying was essentially hanging hand sheets out to dry. The first dryer was fired by charcoal. In 1839 the improved 'Ranson'' dryers was patented and steam gradually become the common method of heating [16].

Early dryers were very slow but with very large diameter. Often there was only one dryer in a factory. Early speed of the drum was about 100m per minute. Cylinder pressure expectations were less than 200kilopaskals.

The 1900 and the 1904 dryers were about 3m in diameter and were very huge. Their name was Yankees. Due to the huge surface area and due to huge temperature gradient created between the external surface and the inside of the cylinders they are obsolete now. These days there were only one dryer to be used in a factory. One huge, slow paper dryer was used [7].

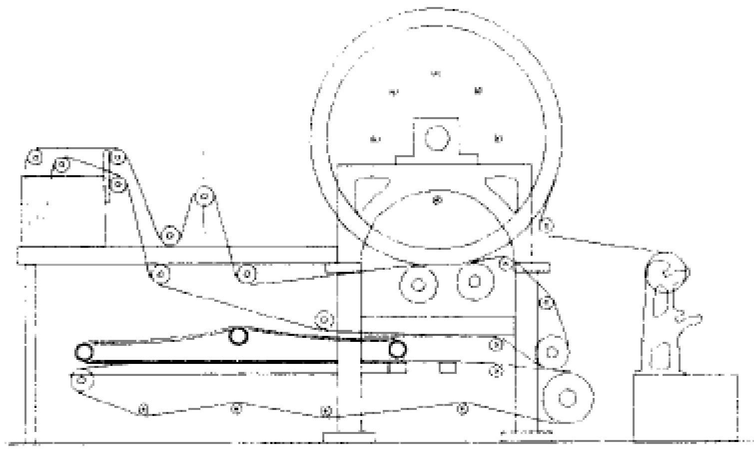


Fig.1 The 1900 Yankee Dryer [7]

As time goes on the design of the Yankees were improved along with the advancement in the means of production. The diameter was increased to about 3.5 meters and various improvements were made in the safety of the drying drums.

In the 1960's the Yankees design was revolutionized. The diameter was extended to 5 meters and the ribbed shell was developed as a means of increasing heat transfer while maintaining high radial stability. Ribs protrude through the condensate layer reducing the insulating effect. Heat transfer improvements with an optimized ribbed shell can be 35% better than a plain shell. By the end of the seventeenth century, designers were able to produce Yankees with a speed of 1600 meters per minute [7].

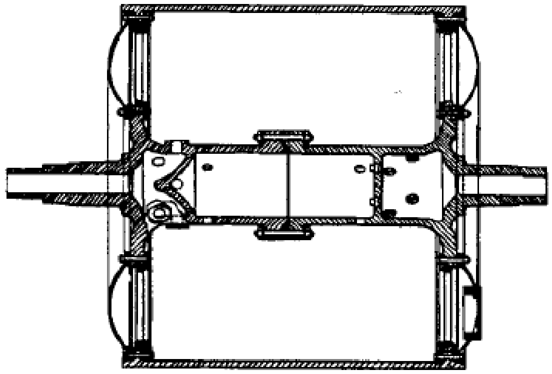


Fig.2 the 1940 Yankee Dryer [7]

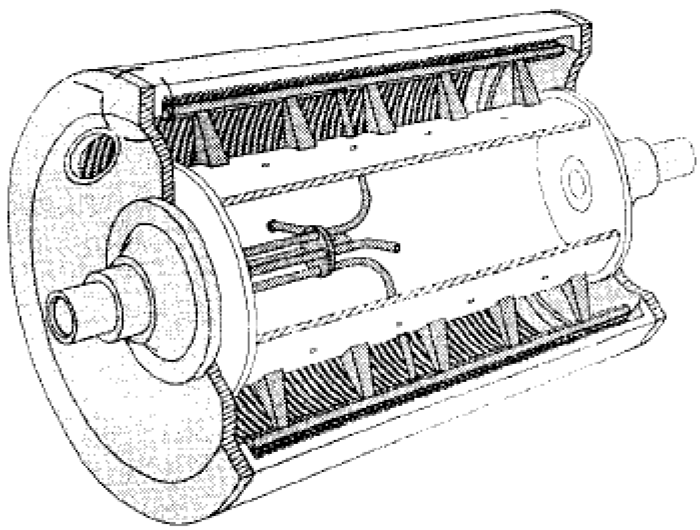


Fig.3 The 1960's Ribbed shell Yankee Dryer [7]

In the 1970's, the finite element method was introduced in the stress analysis of the Yankees. More accurate, fast and reliable design of the Yankees was made possible. Paper dryers for over 1800 meters per minute operation and a diameter of about 5.5 meters were made possible. The 1980's saw 18 feet ribbed dryers going to 7.75 meters wide [7].

Hence it can be said that the design and efficiency of the Yankee dryers have developed through years as design methods and technologies developed. In years, dryers were improved both in size and speed. Both the speed of the dryers and the diameters were improved through years. In the 1960's the heat transfer rate of the dryers were improved by 35%, which is around 1953 in Ethiopian calendar.

2.2 Emerging technologies

2.2.1 The condebelt process

Is a new means of drying paper and board. The paper web coming from the press section is dried between two steel belts instead of the traditional steam cylinders. The web travels between a steam heated upper steel belt, and a water cooled lower steel belt. The hot upper belt evaporates the moisture in the web and which again will condensate on the cooled lower belt [5].

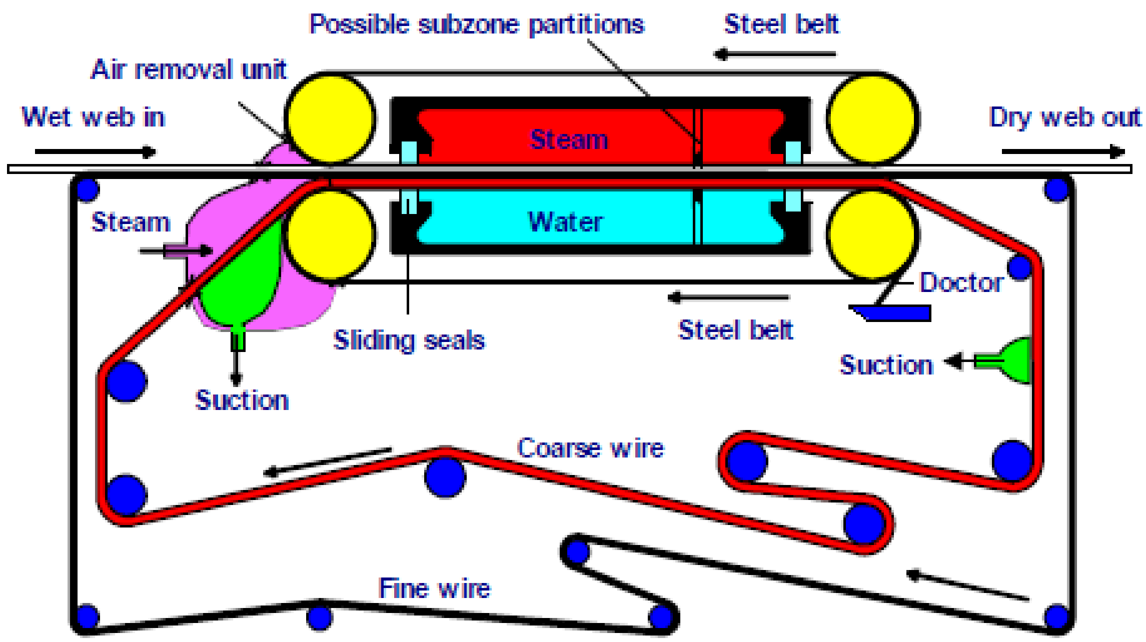


Fig.4 Schematics of the condebelt drying process [5]

At the moment there are two Condebelt drying processes in commercial operation. The first one has been running since May 1996 at Stora Enso´s Pankakowski mill, Finland, producing core board, linerboard and special boards. The second one started-up in January 1999 at Dong Il Paper Mfg. Co.Ltd.´s Ansan mill in South Korea producing linerboard and fluting [5].

2.2.2 Internal heat pumps

Normally heat pumps are used to heat a room by their condensers. They collect heat from a cold reservoir and eject it to a room that needs to be heated. But the intension here is to recover the heat that is rejected through the hood. There is a huge amount of energy that is being ejected to the atmosphere. The set up shown below can be used to recover the heat. Heat can be sucked from the hot air which is relatively cooler than the condensate then it is rejected to the condensate which is at a relatively higher temperature. There will be a working fluid such as ammonia in between.

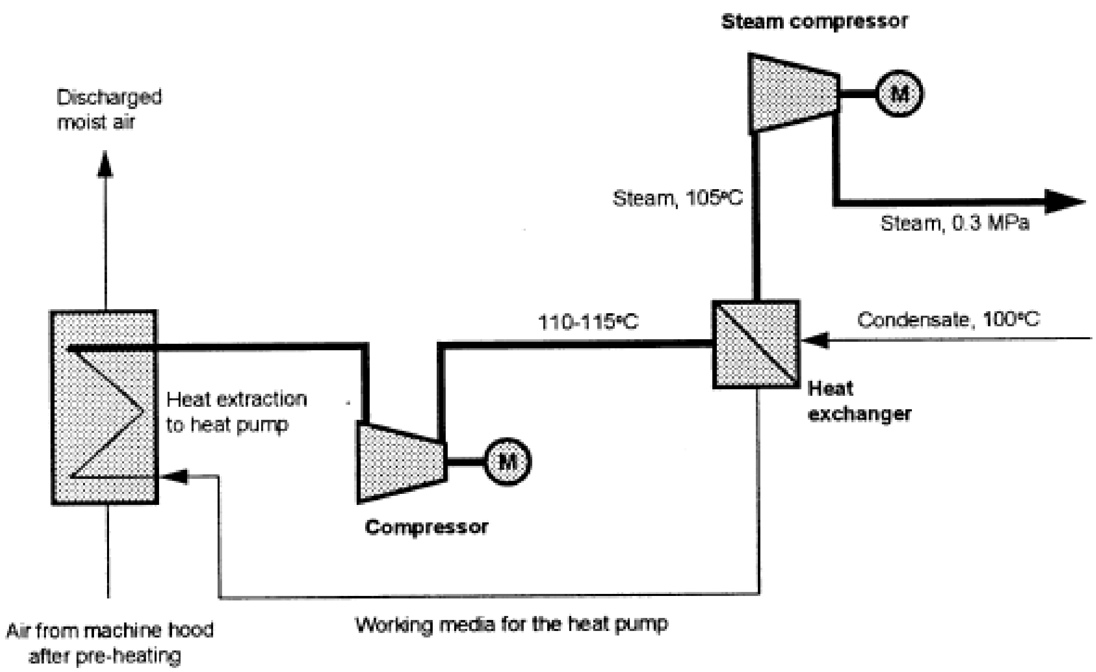


Fig.5 Internal heat pump [5]

There are many applications in the pulp and paper industry for heat pumps, but the investment costs are quite high which has hampered the use of this kind of equipment. Furthermore, the environmental problems that are associated with the conventional working media have made the use of heat pumps even more difficult even if the thermodynamics of the heat pump is very advantageous [5].

2.2.3 Total site integration tools

Energy consumption is affected also by the production speed of the machine and by unit operation development of the paper machine. The technological choices will have effects on the energy balance of mill site. It can be concluded that intelligent process solution in the future will try to combine the whole energy - water - fiber - chemicals - system to create a good integration of the mill for improved energy performance of the factory.

Several computer-based tools capable of analyzing the complex system including cross media effects are under development and first analytical studies have been made with integrated paper mills [5].

CHAPTER THREE

PAPER MAKING PROCESS

3.1 Description of the paper making process in the Ethiopian pulp and paper factory.

The raw material for paper making, pulp, is imported from abroad. Wood is processed to produce pulp in a separate plant. The size of the wood is reduced by chopping it in to fine pieces. Then it is thermally and chemically treated to alter its composition. Normally, wood is predominantly composed of 30% lignin, 45% cellulose, and 20% hemicelluloses; whereas, pulp is composed of, 85% cellulose, about 10% lignin and 5% hemicelluloses [2]. Hence pulp is a refined and chemically treated form of wood that is prepared in a separate plant.

Factories that prepare their own pulp are known as integrated paper mills. Whereas those that receive the pulp by purchasing from other mills are known as non integrated mills [3]. In this regard the Ethiopian pulp and paper factory is a non integrated mill. It produces paper from pulp and it doesn't produce on its own.

The standard paper manufacturing process is divided into a number of steps [3].

1. Preparation of the pulp
    - Disintegration
    - . Deflaking.
    - Refining.
    - Mixture of additives.
    - Cleaning.
2. Formation of the sheet
    Wet pressing
    Drying
    Coating

3. Paper finish

- Calendaring.
- Winding process.
- Cutting

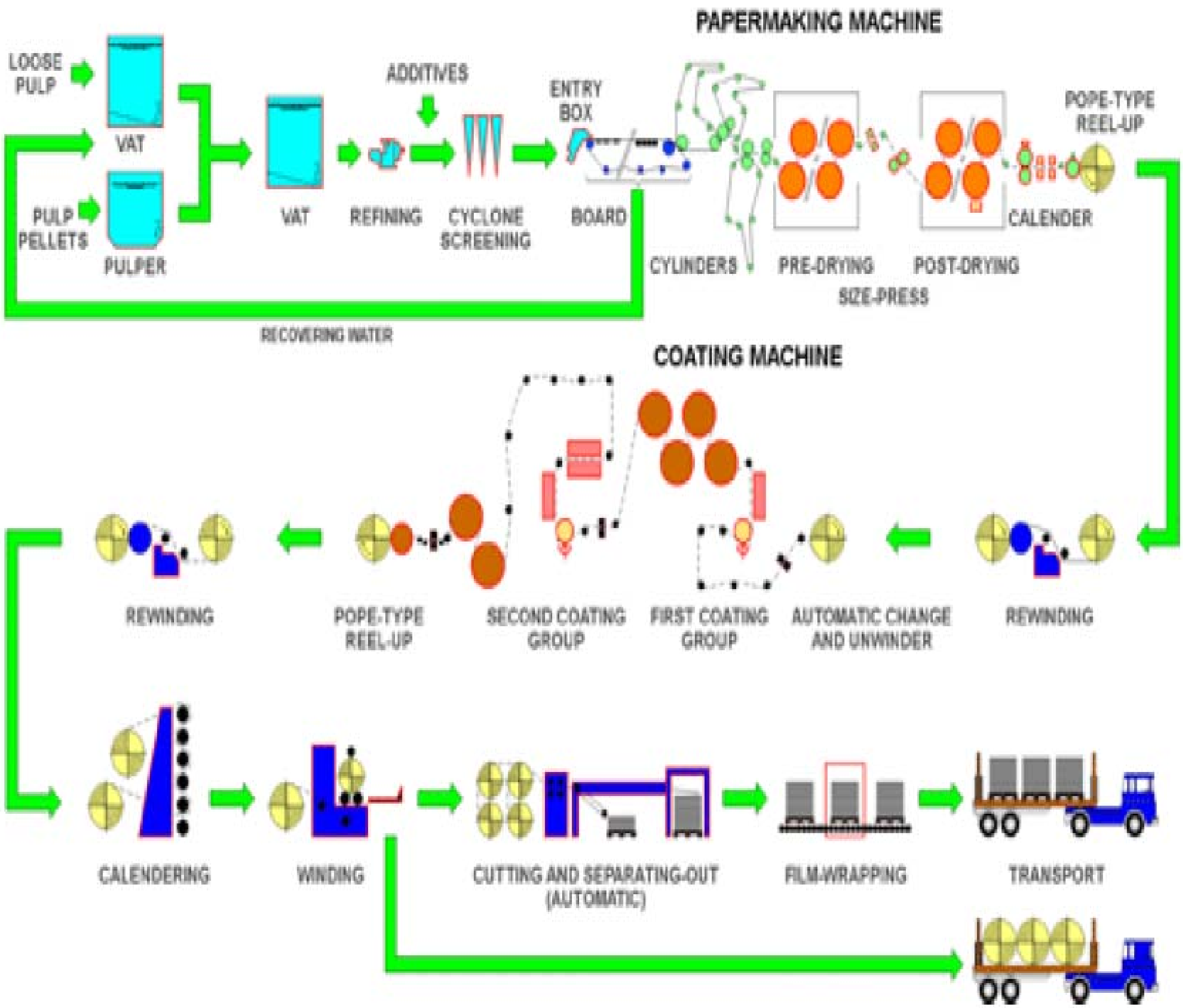


Fig.6 Flow chart of the standard paper manufacturing process [3]

In the Ethiopian pulp and paper factory many of the above steps of paper making processes are undertaken except for the Coating process. The coating process is completely omitted. Even though much of the standard manufacturing steps exist in the factory the extent to which the steps are implemented may vary.

According to the 2012/2013 budget year implementation report of the factory, the variety of paper types produced in the factory are, Bank paper (45 gram/sqm), white bond (60 gram/sqm) , Kraft liner (175 gram/sqm), Fluting medium(140 gram/sqm). White bond paper is the most typical one.

Bank paper is a thin strong writing paper of less than $50 g/m^2$ commonly used for type writing and correspondence. Bond paper is a high quality durable writing paper similar to bank paper but having a weight greater than $50\ g/m^2$. The Kraft linerboard is mainly used for manufacturing high-grade color printed corrugated box for household appliances, food and a large number of other industries [16].

The quality of the paper produced in the factory is greatly affected by omitting the coating process. Also since it is recycling used papers and has no means to de-ink the recycled paper the quality is greatly compromised.

The types of products are similar to newsprint papers which are usually used for news papers and Kraft liner papers that are used for carton making.

3.2 Pulp processing

3.2.1 Disintegration

The first step in the production process is to deliver the pulp and the recycled paper to the hydropulper using a conveyor. The pulp is received in the form of pressed sheets which have to be broken down in water so that it will be suitable for use. The hydropulper is the device in which the disintegration process is carried out. It is made of a cylinder shaped recipient, which has a propeller in the bottom part, which shakes up the sheets of pulp and paper that are placed in it.

The first step in the preparation of paper is disintegration of the pulp and the recycled paper or cartoon. There are two types of raw materials used by the factory. One is the pulp and the other is recycled paper. As the factory produces two types of papers one for cartoon making and the other for white paper making, so are the types of pulps. One is the unbleached pulp for the cartoon and the other, the bleached pulp for the normal paper making. For both products, recycled papers and cartons are used respectively along with the pulps. The papers and the cartoons that come to be recycled can have different colors and impurities. However the factory doesn't have any means to purify the inks and the impurities associated with the recycled paper. It uses human labor to categorize the papers by colors and to remove some impurities such as staplers and so on.

The hydropulper uses electrical power to move its motor that drives the propeller. The conveyor is also driven electrically. Due to the long ness of service life of the motors there could be an efficiency decline on the motors. Or due to the some under load of the motors there could be certain loss of efficiency which must be investigated. This process is normally called stock preparation. According to [5], 60kwh/t is a good practice for stock preparation.

Fig.7 Pulp and paper being disintegrated in the hydropulper

By means of continuous rubbing of the pulp against the propeller, the fibers that form the pulp and papers will be separated, leaving a suspension in the water. The amount of suspension is measured by consistency or percentage of dry material. The pulper disintegrates the mixture to a consistency of 6 to 12%.

The water that is used here is recycled from the paper mill. The temperature of this mixture is the ambient temperature. As the cellulose is disintegrated and is mixed up with water it goes on becoming a better and better suspension. This suspension is then pumped to a huge tanker called a Chester to be stored for a while. In the meantime it stays being steered by stirrers coupled to electric motors.

The hydropulper continues to disintegrate the pulp and the paper until a certain level of consistency is reached. The point of time at which the hydropulper should stop disintegrating the mixture is decided by an experienced person. It is simply a subjective decision of an individual that determines the end of the disintegration process. Wrong judgment can lead to energy wastage.

From the energy management point of view subjective control is unacceptable. If a mistake is made in this stage, every other step is going to be a mistake and reworking is going to come. A huge amount of energy is going to be lost if an exact point of time to end the operation is not objectively determined. As it is stated earlier, using energy well in excess of the 60kwh/ton comes due to this. A huge amount of energy could be unnecessarily consumed due to such a subjective control system.

3.2.2 Deflaking

This process is an energy intensive process. It uses electricity as its energy source. Along with the refining process it consumes well above 100 kwh/ton, depending on the quality of paper required [5].

Total disintegration is not usually possible by using the pulper machine only. We will have to use the deflaker machine for further disintegration of the fibers. A deflaker is a machine composed of three disks (they can be grooved or perforated). Two of them are static and one is rotating at high speed in between the two stationary discs. When the fibers get in between the disks, they will be subjected to violent collisions and will be forced to be individualized [3].

Fig.8 The deflaking machines

By the time when the picture was taken there were three such machines and only the two of them were engaged. Right beneath the machines, on the ground flour, are chesters where the mixture is stored and sucked to the deflakers. The mixture is sucked from one tanker deflaked and stored on the next tanker.

The point of time at which the deflakers should stop disintegrating the mixture is decided by an experienced person. It is simply a subjective decision of an individual that determines the end of the disintegration process. From the energy management point of view subjective control is unacceptable. If a mistake is made in this stage, every other step is going to be a mistake and reworking is going to come. A huge amount of energy is going to be lost if an exact point of time to end the operation is not objectively determined.

3.2.3 Refining

Refining is the operation in which the size of the fibers is reduced by subjecting the mixture to pass between static and rotary blades of some clearance. When the fiber gets in between blades it will be forced to be broken and stripped. As the cellulose gets finer and finer then the suspension becomes more and more uniformly distributed. This process continues until specific standard is fulfilled. At this stage the suspension is uniformly distributed. Refining and further separation is performed while it is accumulated in the Chester. The steering process never stops even for a moment.

The effects of the refining process can be generalized as:
Hydration: The water penetrates between the fibrils producing a hydration effect in the fiber. This means that water and cellulose react chemically.
Fibrillation: the release and separation of the fibrils
Trimming: breakage of the fibers.
Therefore generally refining has a positive effect on paper quality.

Fig.9 Refining machines

By the time when this picture was taken there were two refiners with a trade mark "Jourdan". Only one of them was engaged and the other was disassembled. Right beneath the machines, on the ground flour, are chesters where the mixture is stored and sucked back to the refiners.

Table 1

Typical power usage in refining, by product type [5]

Type of paper	**Net energy [1] for refining [kWh/t]**	**Gross energy [2] [kWh/t]**
Tissue	no data	up to 100
Printing and writings	60 - 100	90 - 300
Carbonless papers	150 - 200	250 - 500
Glassine/Greaseproof papers	450 - 600	600 - 1000
Tracing papers	800 - 1200	1600 - 3000

Notes:
1) Net energy is derived from the gross power minus the no load [3] or free running power
2) Gross energy is the total electrical energy consumed including the losses
3) The no load of a motor is the power that is taken up by mechanical drag and turbulent forces and this therefore not available to treat the fibres.

For refining the electrical energy is primarily used to drive the rotor in the refiner. The energy usage varies by product. Refining is among the most energy intensive and vital stages of the paper making process. It consumes well above 100kwh/ton by the best available practice [5]. Here also the point of time at which the refining process is going to end is decided subjectively by experienced personnel. From the point of view of energy conservation, this is not acceptable. The exact time to end the refining process must be objectively determined.

3.2.4 Mixture of Additives

Depending on the type of papers produced that is whether it is a writing paper or a toilet paper or paper for magazine, different types of additives are added to give certain qualities to the final product. Qualities such as resistance and opacity for instance can not be obtained from the fiber alone. Some chemicals such as china clay and aluminum sulfate are added to the mixture of cellulose and water. The china clay helps the paper to be non porous. It helps it to fill the possible pores in the paper. The aluminum sulfate prevents over absorption of ink in the paper. Since the additives are inorganic and the cellulose fibers organic some blendes are required to bind the two ingredients [2].

The additives are separately prepared as a solution in a plant. The china clay and the aluminum sulfate are mixed with water on a mixer plant. Electric motors are used to derive the mixers. When the mixture becomes ready for use it will be allowed to be mixed with the paper mixture and then it is also steered very well until required parameters are fulfilled. The steering and the agitation process are powered by electric motors.

3.2.5 Cleaning

Cyclonic separation method is used for the purpose of cleaning the paper mixture. Fluid is pumped into the cyclones on one side letting it swirl by the sides of the cylindrical wall. Then the mixture is let to exit by the top of the cyclone. Heavier and denser contaminant will not have enough power to pass through the exit at the top; hence will be forced to settle at the bottom of the cyclone where they can be rejected. Huge pressure difference is exhibited between the two ends of the cyclone set showing that great power is consumed to make the system work. Electric motors are used to drive the pumps.

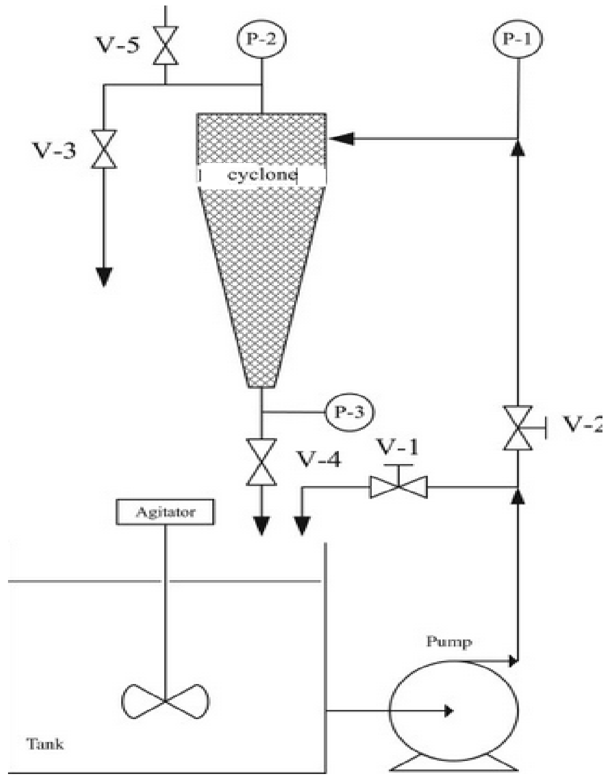


Fig.10 Cyclonic separator

The mixture is then further purified to check for any unwanted ingredients. Common impurities are sand, wire, string, metals, splinters, ash, resin, and so on [2]. Good quality paper making depends on this process. In this factory, multi-stage dynamic or cyclonic cleaners are used for cleaning. Heavier impurities are expelled out by centrifugal screening. The number of stages helps to save as much cellulose as possible.

Fig.11 Cyclonic separator in the factory

3.2.6 Sheet formation

Once the pulp and paper has been provided with the necessary balance of properties, the mixture is then fed to a rectangular tanker called the Head box, where it is going to be poured though a very small slot of opening to a bronze sieve called the Forming table where paper making begins. At this stage the mixture is about 98% water and 2% cellulose. The head box is responsible for the output of pulp into the forming table, in the form of a thin, wide and uniform sheet.

Inside the head box there are two porous cylinders arranged horizontally and rotating continuously. They help the mixture to be uniform. They are driven by electric motors. At the top of the head box, water is continuously sprayed from 14 spots arranged in line. This helps to dilute the mixture so that it can keep its 2% consistency. Obviously the water is pumped by a pump that is driven by an electric motor. Therefore the head box is fully operated by electrical energy.

The amount of water sprayed on the top of the head box to dilute the pulp mixture coming from the cyclonic cleaner is determined from an experience and some kind of a trial and error. It would be preferable if some kind of instrumentation is installed to make an objective control.

Fig.12 External & internal view of the head box

The highly diluted pulp mixture (98% water), is let through a thin line of slot to a belt of bronze sieve called the forming table which is continuously moving. It is driven by rollers which in turn are driven electrically. The forming table looks like a sheet of cloth waived from a bronze wire. As the mixture is taken by the table some of the water starts to be removed through the bronze sieve due to gravity.

At the other end of the forming table, there are vacuums arranged so that they can force the water removal process more actively because the water can't be removed by passive means only. Then water is sucked out from the mixture by a series of vacuum placed at the other end of the forming table. There are 8 vacuum suckers but not all of them are engaged at once because if they do the friction on the sieve belt will be higher and the whole process can be full of resistance. Therefore only five or four of the vacuums are engaged at once. The vacuum is created by turbo machines which are driven by electric motors.

Fig.13 A spray of water to clean the forming table

The bronze sieve of the forming table must be cleaned every time it circulates. Spray of clean water is arranged at 5 different spots. Therefore the bronze sieve will be cleaned at five different spots on its way back to completing its cycle.

Fig.14 Water jet paper trimmer

The width of the forming table must be wider than the size of the paper required to be produced because usually the quality of the paper is not good around the edge of the paper. The desired width of the paper is obtained using a cutter called the water jet trimmer. It is found near the end of the forming table just before it gets in to the wet pressing section. What the water jet trimmer does is that it injects a jet if water on the paper. Since it is wet it will easily be trimmed by the water jet. The one that is trimmed of the main paper is dropped and collected on the ground until it is taken back for rework. Sometimes the paper that is trimmed off the main sheet is remarkable. When the paper that is trimmed off is unnecessarily big then it is wastage. More rework means wastage of energy as well as resource. Hence the amount of paper that is trimmed off must be as small as possible.

3.2.7 Wet pressing

Wet pressing is a process of passing the sheet of paper between rollers. The paper is supported by a fabric called a felt. The felt is used both to support the sheet and to absorb the moisture in it. Immediately after the forming table, wet pressing continues to dewater the sheet of paper. Here it is taken by two mechanical press machines to further remove some of the moisture from the paper. On leaving the forming table and getting into the wet pressing process, the sheet of paper has approximately 20% consistency. But at the end of the wet pressing it will be left with approximately 60% water, i.e. 40% consistency. The wet pressing process is powered by electricity.

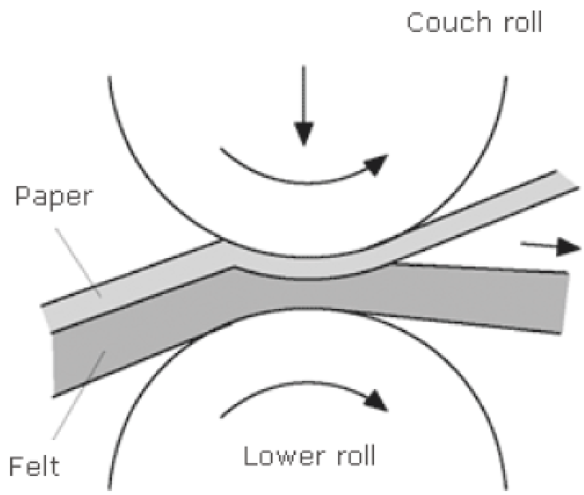


Fig.15 Wet pressing

The felt is a fabric that turns around the rolls. The rolls apply pressure on the sheet of paper both to compact the fibers and to remove the moisture which is to be absorbed by the felt.

3.2.8 Drying

After wet pressing is carried out, the remaining moisture which is 60% is going to be removed by heat. The stream of paper getting out of the wet pressing section is let to pass around a series of rolling hot barrels. The group of hot cylindrical drums is heated by steam coming from boilers. Each drum is connected to pipe for steam and a pipe for condensate return. Steam is injected to it continuously as condensate is returned.

A felt is used to sandwich the paper between the drum and itself, letting one side in contact with the drum at a time. On the first drum a low pressure steam is injected since the temperature of the paper stream should be raised smoothly. For uniform distribution of temperature, the paper stream switches contact with the drum, i.e. one side in contact with one drum and the other side in contact with the next drum. The felt helps to apply pressure on the paper so that the moisture in the paper will be heated to an elevated temperature and pressure.

As the paper continues to pass over a number of drums, steam starts to come out of it. Vapor comes out as a flash of steam during the time of switch from one drum to the next. Hence in the process of drying, the order is first heat transfer then evaporation (mass transfer). On the later drums stronger steam is injected elevating the temperature and pressure of the paper that is sandwiched between the felt and the drum. Just at the moment of switch to the next drum the pressure will suddenly drop letting the moisture from compressed liquid state it to a saturated vapor state. This time a flash of steam comes out of the paper stream.

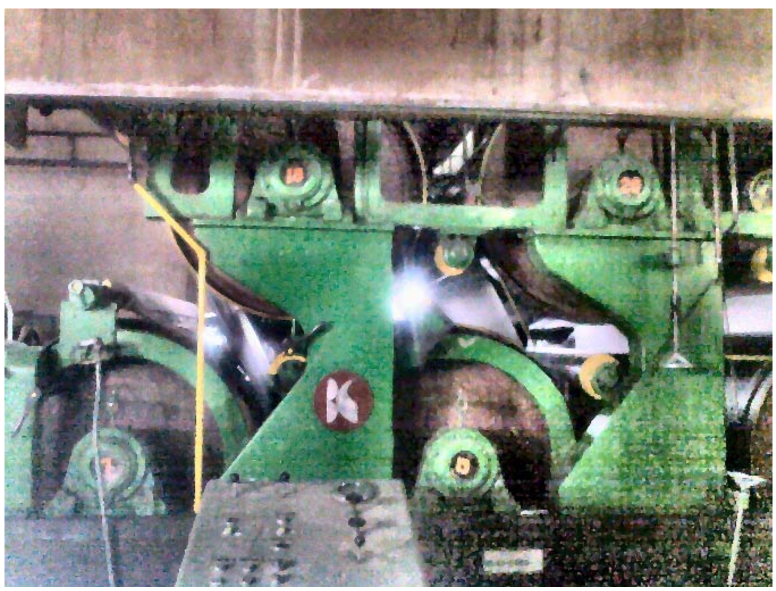


Fig.16 The dryer section

Both energy and mass are transferred during the drying process one after the other. Heat is transferred from the drums to the moisture in the sheet of paper first and then water is evaporated from the sheet of paper in the time of switch.

The first drum is used more or less to increase the temperature of the moisture in the paper to a certain extent. A smooth elevation of temperature is made here since huge temperature gradient would damage the quality of the paper. Then the temperature continues to escalate as the sheet of paper passes by more drums. There are 16 heating drums as the first group of dryers. Eight of them heat on one side and the other eight drums heat on the other side of the paper. At the end of the process the paper almost dries.

Then after this a starch solution is poured on the paper to level some of the uneven cellulose fibers. Then the paper is made to pass through a second group of drying drums. There are six drums here to dry the sheet for the second round. After which it will be left with 5% moisture which is necessary in its final composition to maintain elasticity.

Fig. 17 Starch pouring

For a better evaporation rate the quality of the air existing in the neighborhood is very important since unsaturated air facilitates evaporation. Also higher air temperature absorbs more vapor, hence is also required. Ventilation of the air in the neighborhood is also another positive thing for a better rate of evaporation from the sheet of paper.

The drums are connected to one another using a gear system and are driven by a pinion that is mounted on a shaft. The shaft is also coupled with a gearbox. The input to the gearbox is a pulley that is driven by a belt connected to a line shaft. The line shaft is a central driver that is used to drive all the moving parts starting from the forming table to the drying drums and the calendar. The line shaft is a long shaft supported at many points. This shaft is driven by a huge electric motor that has its own separate ventilation system.

3.2.9 Calendaring

A calendar is normally a roller that passes the paper by and straightens the fiber so that it will be suitable for the purpose of printing. It has a series of rolls positioned one on top of the other which rotate making the sheet of paper pass between them. There are seven rollers used for calendaring in this paper factory. By the time of the visit, only two of the rollers were being used.

Fig.18 The calendaring machine

3.2.10 Rolling and packing

Then rolling and packaging of the paper proceeds. As it is said earlier, there are two types of products. One is a role of white or colored paper that can be used for the purpose of printing. These papers are made of a mixture of bleached pulp and recycled paper. The other product is a role of paper that is used for the purpose of carton making. This is made of a mixture of unbleached pulp and recycled cartoon. A huge steel shaft of diameter about 200mm, rotating on two bearings, is used to receive the incoming sheet of paper and roll around it.

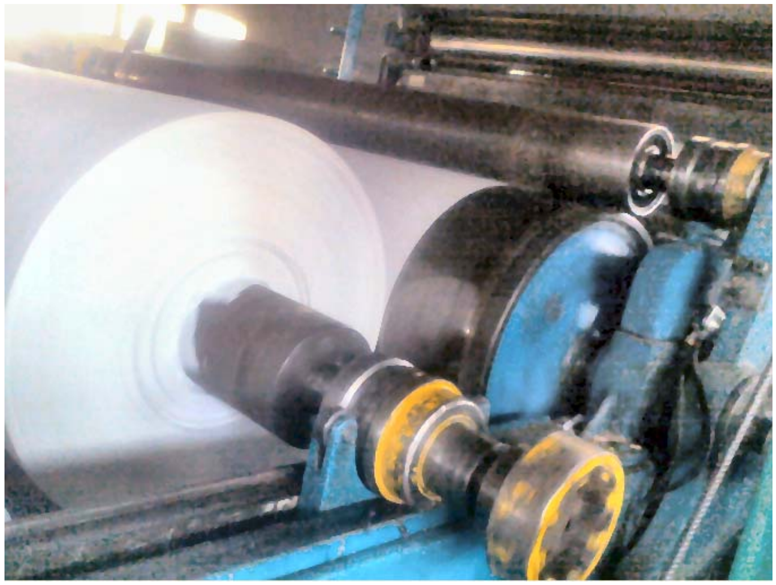


Fig.19 paper rolling

Next, this roll is taken to a pneumatically operated machine for a final sizing, rolling, and packaging of the paper according to the request of the customers.

3.3 The carton box making process

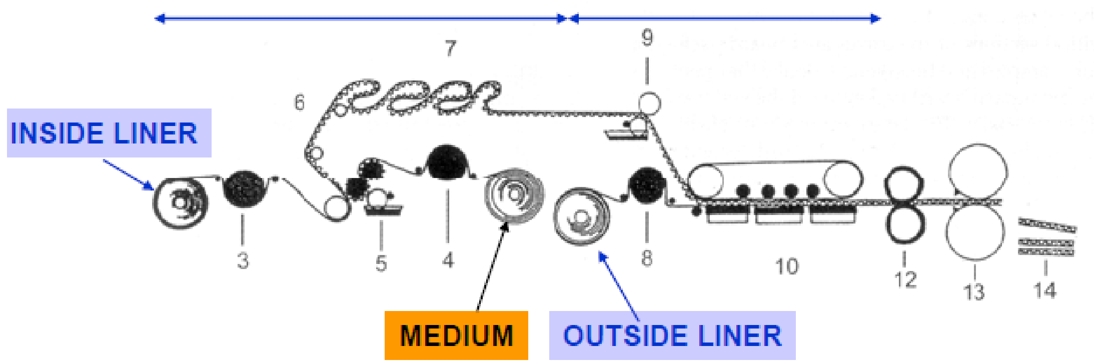
The manufacture of corrugated packaging can be roughly classified into two processes: the containerboard combining process, which glues one or more sheets of fluted corrugating medium to one or more flat facings of linerboard; and the box manufacturing process, which is used to assemble the corrugated sheets into boxes.

3.3.1 Carton sheet making

As it is said earlier the factory produces unbleached paper to be used for the production of carton box. There is a separate plant to make the carton sheet and box. First a role of paper is brought and inserted to a machine on one side. This role is accepted by the machine and heated by a steam heated drum to remove any of the moisture trapped during storage of the paper. This role of paper is called Linerboard. On the other side of the machine, a different role is inserted to be corrugated by a couple of grooved rollers. This roll of paper is called the corrugating medium. Unusually this paper is made of recycled carton. A starch solution is poured on the paper during corrugation to facilitate the process and to help adhesion during layer formation. Then the two roles, the corrugating medium and the linerboard, will be allowed to stick together and then heated by steam heated rolls to remove some of the moisture.

Fig. 20 paper being inserted to the corrugator machine.

Later, in the process a roll of linerboard is allowed to stick to the bottom surface. Then the carton is dried, scored, cut and loaded.



3. Inside liner conditioning roll (preheating)
4. Medium conditioning roll (heat & steam)
5. Glue
7. Bridge
8. Outside liner conditioning roll (preheating)
9. Glue
10. Heating and cooling section
12. Slitting and scoring
13. Cut off
14. Piled delivery

Fig. 21 Corrugated board manufacturing process [13]

Immediately after the bottom linerboard is glued, it is let to pass by a large steam heated iron plate cover by a heat resistant belt. This helps both to remove the moisture and straighten the carton plate.

3.3.2 Carton box making process

The steps are :

Printing ---- Punching ---- Forming ---- Bundling ---- Palletizing

Printing is performed on corrugated box blanks that have been formed, scored and cut by a corrugator. The box blanks are subsequently cut or die-cut into specific shapes for further forming into finished boxes. Before the bundling process, a combination of several box manufacturing machines is utilized to process box blanks into different types of corrugated boxes. The actual box is made by the customer during packaging.

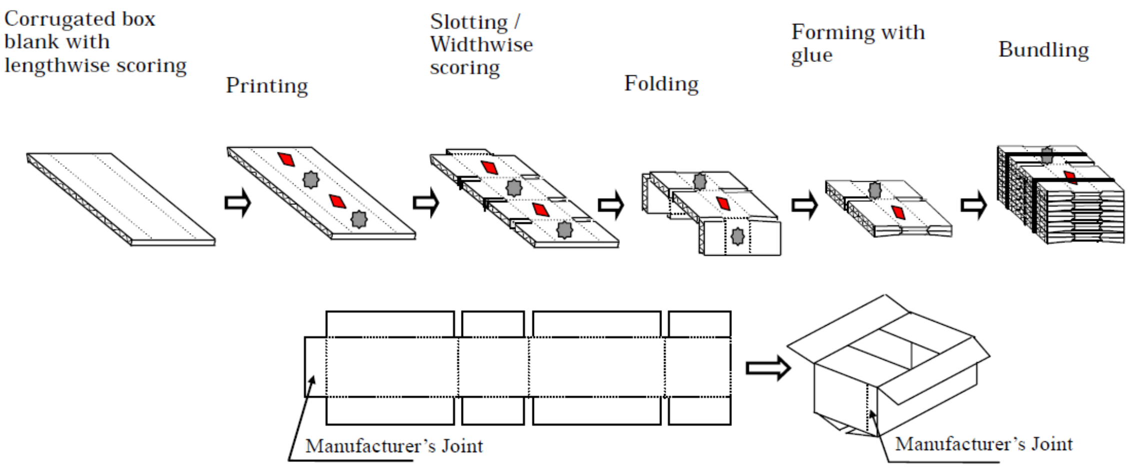


Fig.22 Carton box making process[13].

3.4 Feed water treatment

The source of the water that goes to the boiler is the Awash River water. The water passes through a water treatment process before it gets to the boiler or to the paper mill. The river water is pumped to a huge tanker where water treatment begins. First it passes through the flocculation process where aluminum sulfate is added to the river water to sediment the suspended dirt from the water. The aluminum sulfate groups the dirt particles to gain more weight and settle to the bottom of the water. The mud accumulated at the bottom of the tanker is continually removed using a certain cleaning mechanism.

Then water coming from the tanker is sent to a sand filter to be filtered by the sand. Here remaining suspensions are trapped by the sand. Through time the sand will be covered by the accumulation of the dirt. This time it will be taken off and is washed well to be reused again. The water coming out of this sand filter can be sent directly to the paper mill where it is used to dilute the mixture in the head box; and to wash the sieve of the forming table. Or else, it is further purified to be a makeup water for the boiler.

In the further purification process the water passes through a sand filtration once again and then softening process proceeds to avoid the calcium and the magnesium carbonates from the water. zeolite is the chemical that is used for softening. Sodium is the active chemical that replaces the calcium and the magnesium in the water. When the sodium is vanished it is regenerated by letting it react with a normal salt ($NaCl$).

Then the softened water is further de ionized by a reverse osmosis process. This process is used to filter the ions and some organic molecules from the water. A vary high pressure is normally required to pass the water through the membrane. This will help the water to be less conductive and easy to boil in the electric boiler. Then this water is stored in a tanker to be used as a makeup water to the boiler.

This make up water which is at an ambient temperature is de aerated by the use of steam before it is sent to the boiler along with the condensate return.

The hydropulper uses recycled water that comes from the dewatering process at the forming table, and at the wet press. 100% of the water used at the hydropulper is recycled water. The recycled water is stored in the chesters and then is pumped to the hydropulper by means of pumps when needed.

Normally, sand filtered water is distributed to basically three directions in the factory. It is further purified and is supplied to the electric boiler; it is also used to dilute the paper mixture at the head box; and it is used to clean the forming table. All of the water is supposed to be recycled. Of course 55% of the water in the paper mixture is removed by evaporation through a hood in the ventilation. But this water is compensated by the water which is used to clean the forming table. Therefore enough water is recycled to be used in the hydropulper. Even some of the water will be excess. Excess recycled water is sometimes avoided by supplying it to the neighboring farm of vegetables which is owned by the factory.

The part of the Sand filtered water that is supplied to the boiler is pumped in to the second sand filtering tank. After that it is pumped in to the zeolite resin tank where it is softened. Then it is sent to the RO membrane. At last, it will be collected in the condensate return tank. From the condensate return tank it is be pumped to the de aerator unit just before it is sent to the boiler.

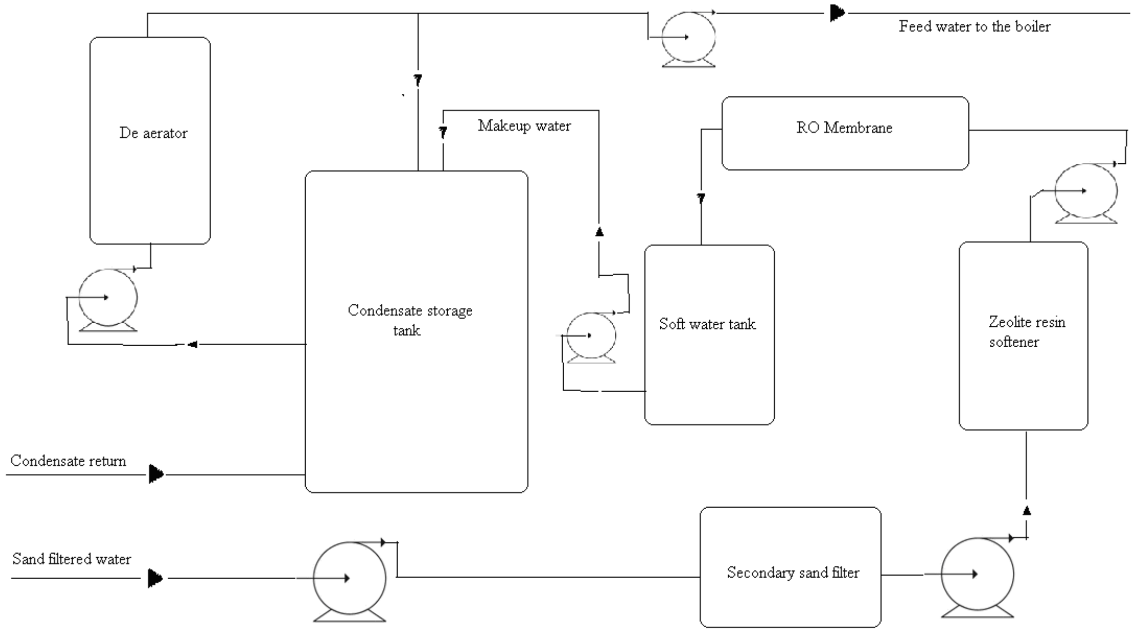


Fig. 23 The water treatment plant and the condensate storage tank

3.5 The major drive system of the factory

The major drive system of the factory is a mechanical line shaft system. It is used to derive the forming table, the wet pressing rollers, the drying drums, the calendaring machines, and the rollers in a synchronized manner. Mechanical line-shaft drive systems have been applied as systems of shafts with pulleys and belts driving the machines of the industrial revolution [16]. A large line shaft supported at many points is driven by one big electric motor. The motor is so big that it is ventilated by a separate ventilation system with ducts.

Fig.24 Electric motor driving the line shaft.

Fig.25 External view of the fan for cooling the electric motor.

The large pulley attached to the shaft is coupled to pulleys above the line shaft by flat belts. The belts drive pulleys that could drive shafts attached to spur gears driving the drying drums, the forming table, the calendar, and the rollers and so on. A clutch system is used to engage and disengage the pulleys with the shafts. The pulleys are tapered so that tightening of the belts plus speed regulation through varying the speed ratios is possible.

Fig.26 speed adjustment by changing the position of the belt

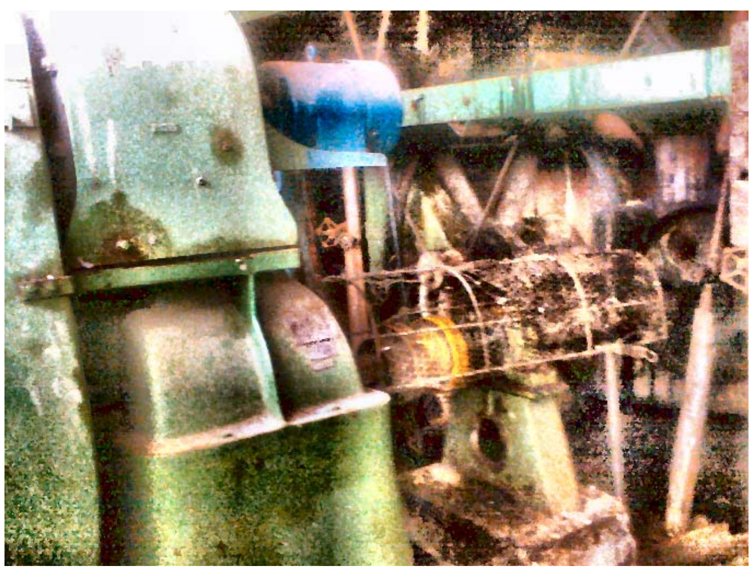


Fig.27 Shaft driving the drying drums.

Therefore, the whole motion from the forming table to the drying drums and the rolling process is driven by the line shaft drive system as shown in the above pictures.

3.6 Further description of the factory

Informal and formal interview and discussion was undertaken during visiting the factory. According to the discussions with one of the long serving personnel, due to the age of the factory many of the instrumentations have stopped functioning. For instance the consistency of the paper mixture is observed by eye. Experienced individuals with skill are utilized to decide whether the stirring and mixing process is enough or not. Everything is subjectively monitored by eye; which means that the disintegration process is not being monitored objectively by means of instruments. The exact time at which the steering and refining process should end is not known for sure. There will be two possibilities here, either the process is elongated unnecessarily or the mixture could be sent without getting the proper consistency. In both ways, energy will be lost. If the process is prematurely ended, then the mistake will be very costly since reworking is going to come. Also if the process is unnecessarily elongated, the intensity of the energy use will be elevated.

Normally, a paper of 60 grams/square meter is produced in the factory. This means that 54 – 61 grams/square meter is the actual weight of the paper. Paper quality is controlled manually in the factory. A piece of paper is torn off the flowing paper and is measured taking certain time on the balance. Then mass per square meter of the paper is measured and if it is not correct then corrective measure is taken manually. In the mean time a huge amount of paper could be rejected due to the manual quality control system. Which means that all the energy embedded with the paper is also wasted.

The factory has already planned to purchase on spot quality controlling device, to check and correct the parameters in almost no time. It also has an already finished study plan to replace the manual quality control by an automatic quality control system.

According to the discussion made with long serving personnel in the factory, the production capacity of the factory was previously 34 ton/day of white bond paper or 45-50 ton/day of Kraft liner or heavier paper. This was when many of the automatic quality control systems were working properly. However, currently, it has declined to 20 ton/day and 27-35 ton/day of the respective papers. The main reason for this was, according to the interviewee; too much rework due to lack of automatic control devices, and due to the down time encountered in relation to failures occurring on the old machines.

According to the interview, it may not be so much reliable, the production cost is 25000 birr/ton for the white bond paper and 17000 birr/ton for the Kraft liner paper. And the selling price is 31000 birr/ton and 25000 birr/ton respectively. As productivity increases, profitability is going to increase.

The reason behind the decline in productivity is mainly due to the rise in the amount of reworking due to manual quality control system. Also the downtime in the factory is very high. Steam regulation systems, for example are manual. In a manual steam control system, people observe and regulate the steam supply to the drying drums from experience.

Live steam is supplied to the drying drums that are found at the end of the drying process. The steam recovered is supplied to the drums at the beginning of the drying section. The main reason is that too much heat is not required at the beginning of the drying process. The paper has to be heated step by step due to quality reasons.

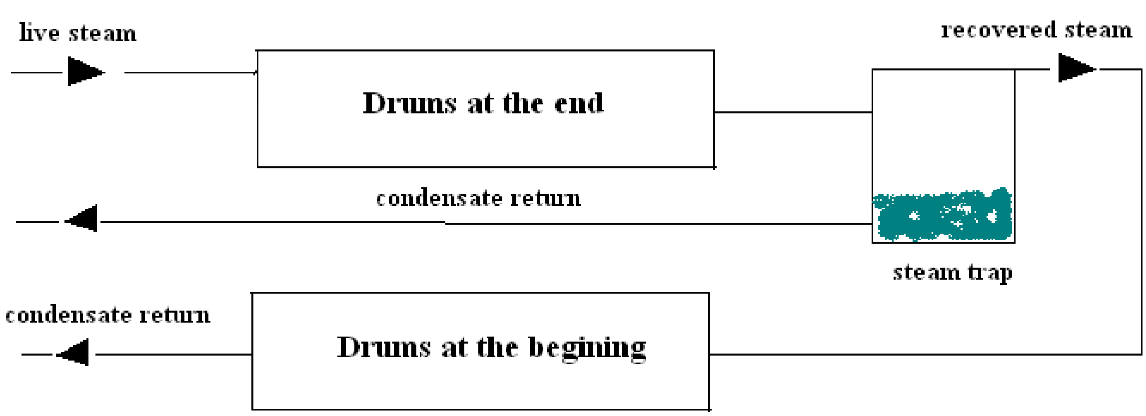


Fig. 28 Steam recovery

Even though the factory has never made any formal energy audit in its entire age, it is undeniable that it has made a great endeavor to conserve energy in an uncoordinated manner. It understands what it is losing due to lack of instrumentation. Recently it has established a committee to study the factory and come up with an improvement proposal that is good enough to convince the government for loan.

The factory has planned to purchase and install instruments from a company called Measure - X. It will measure all the necessary parameters right on the spot and take corrective measures. It spontaneously checks the quality of the paper and set out the mixture right away. The factory has already decided to replace the manual and subjective quality control by an automatic and objective quality control system. Besides it has also decided to replace the refiners, by a more efficient and reliable once, so that the production process could be free of down time. Refining is the bottle neck of the process.

It has also decided to replace the bronze sieve that it is using by a synthetic one. The manufacturer of the current sieve is only one in the world and is found in USA. The technology has already been replaced by synthetic sieve. Hence it will not be reliable to depend on a spare part which is not widely available in the world market. Moreover, it fails every four months and has to be replaced at a cost of 180,000ETB. The synthetic sieve is somehow cheaper.

The new boiler which was installed August 2012 heats the water indirectly; which means that, the resister is covered by a copper. It can’t have a direct contact with the water. The resistance is coated. Therefore, there is no electrical interaction between the water and the resistor. This means that it doesn’t matter whether the water has conductivity or not. It doesn’t have any electrical contact with the water to be boiled. Unlike this, the old boilers do have a direct electrical contact with the water to be boiled. This means that the conductivity of the water means a lot to the process. Current would flow through the water to be boiled.

A number of accidents have occurred up on the workers in the boiler room. I heard that one man was brutally hurt and the other was seriously injured due to high electric shock of very high voltage.

Fig.29 Heating element of the old boiler

The fact that the conductivity of water should be minimized necessitated the reverse osmosis process. It is a process of passing water through membrane to filter the ions in the water so that conductivity of the water may be reduced. This process requires a lot of power to be consumed. The reason is that it requires a huge amount of pressure difference. Moreover, there is a leakage at some point past the RO pipes, and due to this the pump is continuously working. During previous days the pump was operating for a maximum of 3hrs and stops for at least 4hrs. The reason was that no leakage was in the pipe line so that the condensate return tank would be filled. The make up water tank also fills in three hours of operating time and then the pump would be stopped. But currently the pump is working for 24hrs due to the presence of leakage

The third quarter's report of this year's power consumption and implementation reveals that the energy cost of the factory currently is 1793birr/ton of paper. Or it is

4285KWh/ton of paper. Therefore, energy per ton of the factory would be 15.426 GJ/ton. International bench mark suggests that 4 – 5.5 GJ/ton is required for paper drying and 235KWh/ton for stoke preparation and 350kwh/ton for running the drying section would be required. Hence the bench mark is about 7.5GJ/ton internationally.

Previously it was also said that the cost of production of 1 ton of paper is 2500bir. Hence it is quite easy to see that the energy cost is above half of the unit production cost of the paper.

Some say, in the paper industry, profit is obtained by selling water. This is to mean that care has to be given not to reduce too much of the moisture content. About 7% moisture contained in the final product of the paper would make the factory profitable. The ability to maintain this quality is lacked by the factory. The reason is that there is no automatic control system. There is no on the spot quality detector and feedback control system. Sometimes the moisture content can be reduced as much as 3% at the end of the process. Customers do not need this as water content is good for the flexibility of the paper. It is very good for it to be stronger as well. On the other hand energy is needed to reduce the percentage of water vapor from the paper. There are two loses here. One is the lack of money value that would have been obtained due to the presence of a few percentage of water vapor in the paper; and the other is the energy cost that is incurred for removing water vapor from the paper.

CHAPTER FOUR

ENERGY CONSUMPTION AND BENCH MARKING

4.1 Energy consumption of the factory

According to the 2012/13 first six month job implementation report of the factory, the factory utilized 4131 KWh/ton of energy for the production of paper, which is 14.871 GJ/ton of energy. Also according to the 2012/13 third quarter job implementation report of the factory, it utilized 4285.25 KWh/ton of energy for the production of paper, which is 15.4269 GJ/ton of energy.

When the previous reports of the factory were investigated, the factory was using fuel oil along with electricity so that it is not so easy to find clear information about how much energy has been transferred in to the steam. In order to estimate the energy consumption rate, an efficiency of 75 % was taken for the furnace since typical boiler efficiency is 75-85% [17]. The amount of oil consumed is given in the reports; and assuming a heating value of 38 MJ/liter of the fuel oil [8], we can estimate the energy consumption of the factory in the previous years.

Table 2

Summary of energy consumption in 2010/11(source: job implementation report of the factory)

Energy of fuel [GJ/ton]	Electric energy used[Mwh/ton]	Electric energy used[GJ/ton]	Specific energy[GJ/ton]
5.9	0.9	3.24	9.14

Table 3

Summary of energy consumption in 2011/12(source: job implementation report of the factory)

Energy of fuel[GJ]	Electric energy[GJ]	Total production[ton]	Specific energy[GJ/ton]
1946.01	41045	4599	9.35

Table 4

Summary of energy consumption in the first six month 2012/13(source: Job implementation report of the factory)

Electric energy used[Kwh/ton]	Electric energy used[GJ/ton]	Specific energy[GJ/ton]
4131	14.871	14.871

Table 5

Summary of energy consumption in the 2012/2013 3rd quarter (source: job implementation report of the factory)

Electric energy used[Kwh/ton]	Electric energy used[GJ/ton]	Specific energy[GJ/ton]
4285.25	15.43	15.43

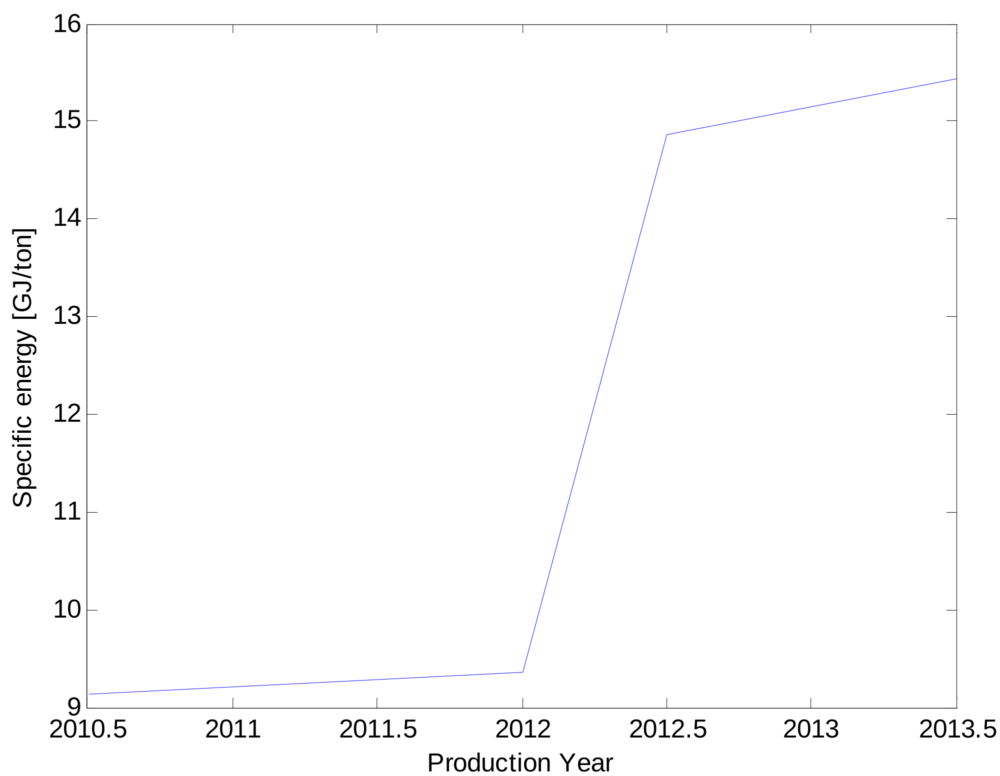


Fig. 30 Specific energy consumption of the factory

4.2 Bench marking

The best available practice worldwide indicates that a standalone paper mill utilizes not more that 8 GJ/ton. Actually the amount of energy utilized depends on the type of paper produced.

Table 6

Typical electrical energy consumption at modern paper mills [5]

Paper grade	Power consumption [kWh/t]
Newsprint	500 - 650
LWC paper	550 - 800
SC paper	550 - 700
Fine paper (uncoated)	500 - 650
Fine paper (coated)	650 - 900
Multiply board	≈ 680
Sack paper	≈ 850
Linerboard	≈ 550
Tissue	500 - 3000 *

The above table shows the electric power consumption against the type of paper products. The products of the Ethiopian pulp and paper factory resemble the newsprint and the liner board type of paper. Therefore, its specific energy consumption should be in the range of 500kwh/t (1.8GJ/t) to 650kwh/t (2.34GJ/t). This is the electrical power excluding that which is utilized for steam generation. Normally steam is not generated using electric boilers in paper mills in developed countries therefore the above figure does not include energy for steam generation.

Table 7

Energy consumption in an integrated mill that produces Newsprint paper [5]

Department	Process heat [MJ/t]	Electric power [kWh/t]
Wood handling	150	50
Refining	0	2110 [1)]
Washing and screening	0	50
Bleaching	0	75
Bleach chemical preparation	0	5
Bleached stock screening	0	35
Power boiler	0	25
Total pulp mill	**150**	**2350**
Stock preparation	0	235
Paper machine	5300 [1) 2)]	350
Total paper mill	**5300**	**585**
Effluent treatment	**0**	**39**
Total per tonne of paper	**5450**	**2974**

Notes:
1) From a Finnish integrated TMP mill higher electricity consumption in the range of 2400 kWh/t was reported for the refining stage (including reject refining) and a lower value of 4800 MJ/t process heat consumption for the paper machine respectively [Finnish comments].
2) A Swedish newsprint mill reports a heat demand of about 4 GJ/t for drying paper, a need that will be reduced by about 10% with a future shoe-press installation.

As shown in the above table, the heat energy consumption in the paper machine is about 5300MJ/ton or 5.3 GJ/t. Therefore the total energy consumption per ton of paper is in the range of 5.3+1.8 = 7.1GJ/t to 5.3+2.34 = 7.64 GJ/t .Hence, we can take that for the year 2001 the best practice indicates that for good quality paper manufacturing energy use of 7.1 to 7.64 GJ/t is acceptable.

The Institute for Industrial Productivity has prepared a table for world best energy use bench marks for pulp and paper production. In that table energy consumption rate of a number of product types is presented. The products of the Ethiopian pulp and paper factory resemble newsprint and Kraft liner.

Table 8

World best practice final and primary energy intensity values for stand – alone paper mills [9]

Raw Material	Product	Process	Fuel Use for Steam (GJ/ADt)	Electricity Use (kWh/ADt)		Total (GJ/ADt)	
				Final	Primary*	Final	Primary*
Pulp	Uncoated fine (wood free)	Paper machine	6.7	640	1939	9.0	13.7
	Coated fine (wood free)	Paper machine	7.5	810	2455	10.4	16.3
	Newsprint	Paper machine	5.1	570	1727	7.2	11.3
	Board	Paper machine	6.7	800	2424	9.6	15.4
	Kraftliner	Paper machine	5.9	535	1621	7.8	11.7
	Tissue	Paper machine	6.9	1000	3030	10.5	17.8

ADt = Air dried metric ton.
**: Primary energy assumes electricity generation, transmission and distribution losses of 67%.*

According to the above table, for newsprint 5.1 GJ/ADt for steam generation and 570 kwh/ADt or 2.052 GJ/ADt for drive systems and a total of 7.2 GJ/ADt is used. Also for Kraft liner 5.9 GJ/ADt for steam generation and 535 kwh/ADt or 1.926 GJ/ADt for drive systems and a total of 7.8 GJ/ADt is used.

ADt is to mean Air Dried Metric ton. Air-dried metric ton (2204.6 lbs.), is a weight measurement for selling wood pulp [10]. This is equivalent to 0.99999 metric tons. Metric ton is the same as a ton. Therefore ADt can be taken as a ton with a negligible error.

Hence for the Ethiopian pulp and paper factory, energy consumption in the range of 7.1 to 7.8 GJ per ton of paper is quite acceptable. Hence this can be taken as a bench mark.

CHAPTER FIVE

ENERGY CONSERVATION OPPORTUNITIES

5.1 Energy Conservation Opportunities Identified by inspection

Recently, the Ethiopian pulp and paper factory is using 15.4269 GJ/ton of energy. Whereas, it is supposed to use about 7.5 GJ/ton of energy. Especially in recent years its energy consumption rate has increased drastically. Well, there has to be a reason for this. What are the key reasons for such an exaggerated deviation from an international practice? We need to look at ways of minimizing the energy consumption rate of factory.
The maximum amount of power that the factory can consume is 18 Mega Watts. This is a potential power presented by EEPco. Up to 15 Mega Watts for steam generation and up to 3 Mega watts for the drive systems could be used by the factory. Hence the power consumed for steam production is 83.33% of the total. Therefore, it is clear that the major part of the problem must be from the steam generation and utilization side.

Therefore a special focus must be given to the paper drying section of the paper mill because it is the part of the factory that consumes more than 80% of the energy.

A. Minimizing *Rework*

Rework is one of the boldly visible problems in the factory. If there is a possibility of avoiding or minimizing rework, then a huge amount of energy can be saved. To minimize rework, the causes must be identified. One of the main causes of rework is the lack of instrumentation and process control. Rework can be made when the paper does not fulfill the required parameters, i.e. when the gram of the paper is not within the appropriate range due insufficient stock preparation; or when the paper does not fulfill proper opacity or any other parameters.
Rework often occurs when the surface temperature of the drying drum escalates and the paper web sticks on it and is forced to be torn. Then a huge amount of paper will be taken

back to the process line. Hence, instrumentation and process control can bring about a huge amount of energy to be saved.

B. *Avoiding Condensate leakage*

The other problem that the factory has is condensate leakage. There was a continuous leakage of condensate from the condensate storage tank, and the distribution pumps. Condensate is a key asset for energy conservation. If possible there must be almost no leakage of condensate. It is within the capacity of the factory to do this. The main cause of condensate leakage was corrosion of the condensate storage tanker. Due to aging of the tanker, it is corroded and hence condensate can be leaking through it easily. A very good condensate tanker has to be used so that the energy possessed by the condensate may be utilized. The other reason that leakage occurs is due to sealing problem in the pumps. The pumps are not well sealed. Some of the pumps are pumping condensate to the ground. Leakage should be avoided completely by using proper sealing. This is also within the capacity of the factory.

C. *Avoiding steam leakage*

Steam leakage is also there in the factory at many points. This must also be minimized since a huge amount of energy is being wasted with the steam. The factory can work seriously to highly minimize steam leakage. Since the factory is in a very critical condition it needs to minimize steam leakage, so that the energy consumption rate may be reduced.

D. *Proper insulation*

Lack of proper insulation and lack of insulation is also one of the causes of energy wastage in the factory. There are a number of spots in the steam and condensate pipe lines where there is no insulation at all. Also there are many pipes that are insulated but are yet very hot externally, which means that the insulation is not proper. If it were properly insulated the outer surface would not have been so hot to burn a hand.

E. *Avoiding Usage of Obsolete Technology*

When we look at the drying drums in the factory their diameter is 1.5m and the speed is about 0.785m/s. and when we look at the history of drying drums, they have advanced both in size and speed. They were improved to have a better heat transfer rate for every injection of steam that was followed by a bigger surface area of drum which means bigger diameter of drums. Side by side, the improvement in the speed is also there which means improvement in the production rate. These days a typical drying drum has a diameter of 5.5m and a drying speed of about 30m/s. This is because the modern driers have ribs that can increase the heat transfer rate by more than 35% than the old once. According to history, our drying drums are at least two times obsolete in terms of technology. There must be no need for justification to show that the use of a more than two times obsolete drying drum must be ended.

In terms of energy, a better heat transfer means absorption of more heat in a single thermodynamic cycle, which means a better cycle efficiency. Of course, the amount of investment could be very high but there must be a way out.

When we also look at the drive system which is used to drive the drying drums along with the forming table, we find it to be the line shaft. In such a system of drive, one big motor is used to drive one big shaft. The shaft is connected to another shaft by belts. And then the second shaft is connected to a gear box. Then the gear boxes are connected to drying drums or other parts. Here, one can observe a number of stages of energy conversion: Electrical energy into mechanical energy, mechanical energy into another mechanical energy, mechanical energy into another mechanical energy, at last mechanical energy into another mechanical energy. As it is known, energy conversion is associated with efficiency, and efficiency would drastically reduce as the stages of energy conversion increases. By the way line shaft technology is obsolete since 1970's.There must be no need for justification to show that the use of an obsolete drive system must be ended.

F. *Boiler replacement*

Replacement of the old boilers by new ones gives a good deal of energy management opportunity. Due to its newness it has good control devices. And the heater of modern boilers do not have direct electrical contact with the water hence the water does not need any special treatment. Whereas the heater of the old boilers do have direct contact with the water, and due to that special treatment to reduce the conductivity of the water is required. In other words the reverse osmosis plant is required, which consumes a lot of power.

G. Carrying *out detailed motor audit*

Some amount of energy conservation opportunity can be obtained by investigating drive systems like electric motors, pumps and propellers. The factory has to investigate each and every electric motor and has to check if it is loaded correctly. It also needs to use modern high efficiency motors.

H. *Use of a heat recovery system*

The use of a heat recovery system is among the greatest energy conservation opportunities. The dryer sections have hoods to suck out the hot air and the moisture to the outside air. This is done to give proper ventilation so that the drying process is facilitated. It also helps to reduce the temperature near the drying section so that people can work in the section. However it is pooling a huge amount of energy from the dryer section and simply ejecting it to the air. Recovering some of this heat would bring a remarkable energy conservation opportunity.

5.2 Detailed Energy Audit of the Factory

As it is indicated above, there are a number of opportunities for conservation of energy in the factory. If detailed energy audit is made for each and every conservation opportunities, indicated above, the presentation will be too vast. Hence, selection has to be made depending on the importance of the opportunity. Decision has to be made as to which section needs to be seen in detail first. Priority should be given for that section of the factory which is thought to be remarkable in terms of energy conservation. Accordingly the primary drying section is selected for detailed energy audit. The detailed analysis made for the primary drier section contains the analysis of 16 drums the felt and the paper web which makes it to be vary vast. The secondary dryer section is similar in form with that of the primary section but contains 6 drums only. Its analysis is also similar to that of the primary drier section. However since starch is poured on the paper web as it gets to the secondary drying section, the moisture content will be altered. Due to the similarity and vastness of the work the analysis of the secondary drying section is left out. However its effect will be approximately included in the conclusion.

5.2.1 Detailed Energy Audit of the Primary Drying Section

The primary drying section is composed of 16 drying drums whereas the secondary drying section is composed of 6 drying drums that take steam and give the condensate back. The paper gets sandwiched between a heat resistant felt and the drum itself. Therefore the primary drying section is composed of 16 drums, felts, the drying paper and a hood that is used to suck the hot air along with the moisture using a fan place at the other end.

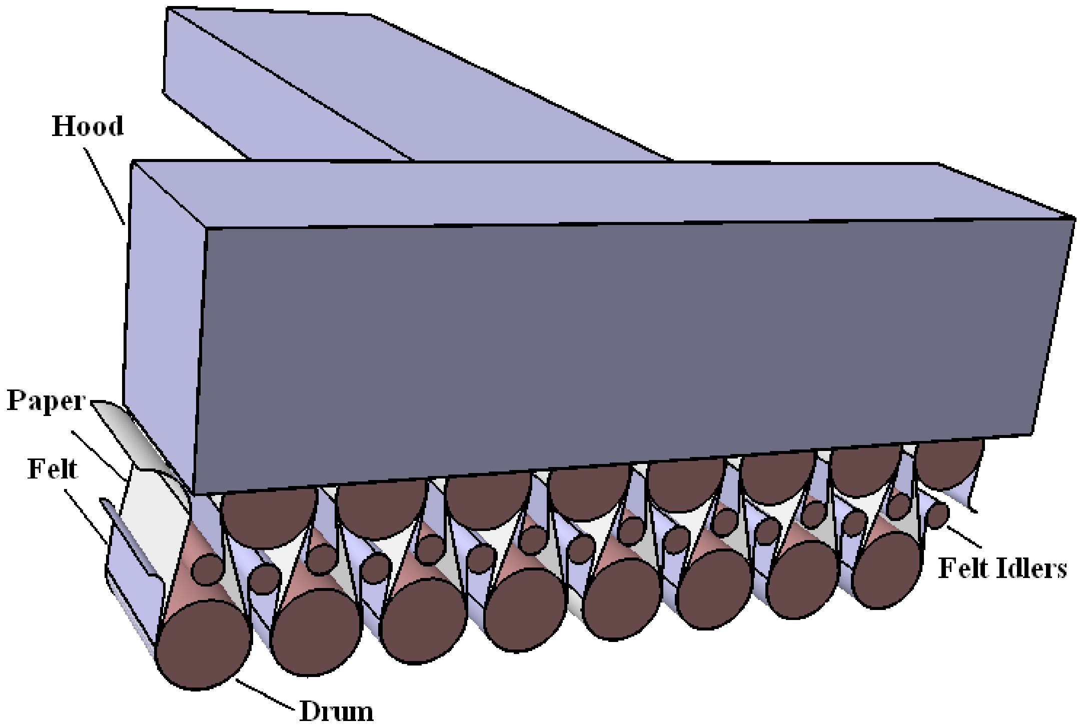


Fig. 31 The primary dryer section

Steam is injected into the drying drum and condensate is ejected out. In the process, the drying drum gets heated. The heat that is supplied by the steam to the drying drum is consumed partly by the paper web, partly by the felt itself, and the other part is spent by convection through surfaces that are exposed to the air. There is also loss due to radiation but it is neglected in this analysis because its value is in the range of a few hundreds of watts which is very small compared to that of heat due to conduction that it is in the range of hundreds of kilo watts.

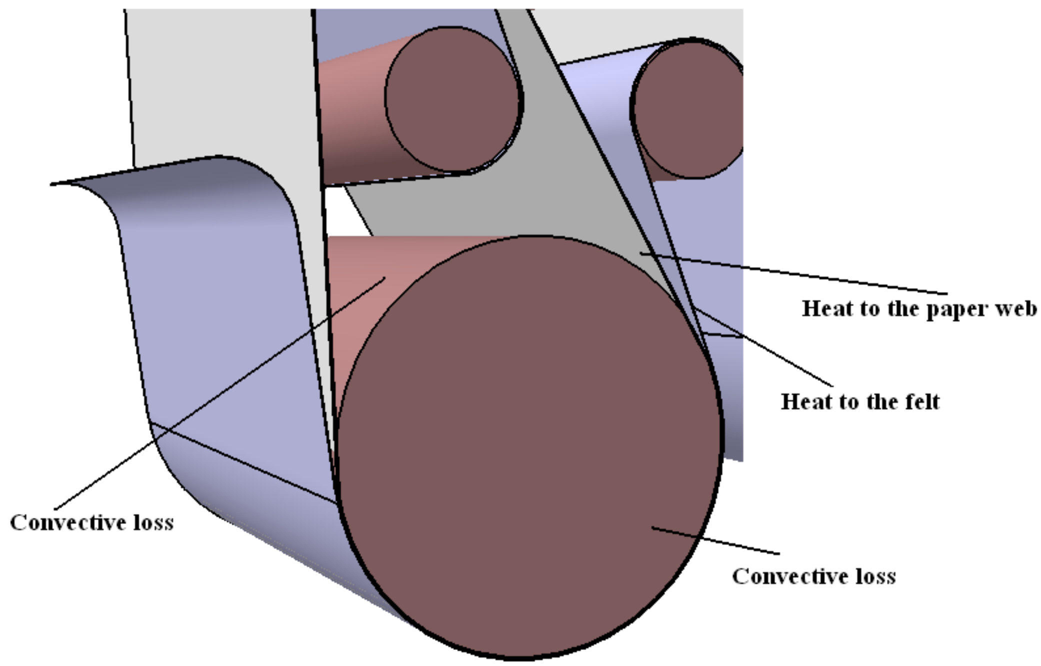


Fig.32 Heat losses from drum and felt

5.2.1.1 Assumptions taken in this analysis

1, While the paper is between the drum and the felt evaporation does not take place.

2, Steady state is assumed in the control volume between inlet and exit of the paper web. That is all properties of the paper web in the control volume are functions of position only.

3, The drying drum is rotating, therefore the case of heat transfer is a forced convection. The relevant Nusselt number correlation seems to be that which is used for the flow over a static horizontal cylinder.

$$R_e = \frac{\rho VD}{\mu}$$

Density of air at the factory where the temperature is 28°C, an altitude of about 1700m above sea level and an assumed relative humidity of 30% is calculated using an online air density calculator to be 0.947 kg/m³.

Table 9

Data collected

Pysical quantity	Symbol (if any)	Value	Unit
Density	ρ	0.947	Kg/m³
Drum diameter	D	1.5	m
Relative velocity of air	V	0.785	m/s
Angular speed		0.16667	rps
Gap between drums		0.8	m
Mass per unit area of felt		1.08	kg/m²
Thickness of the felt		0.0025	m
Span of the paper web		2.6	m

Where, R_e is the Renhold's number

ρ is density of air at the film temperature

V is the velocity of air

D is the diameter of the drum

And μ is the viscosity of air.

$$R_e = \frac{0.947 * 0.785 * 1.5}{1.87 * 10^{-5}}$$

Hence,

$$R_e = 59631$$

Also, $$P_r = \frac{\mu * C_p}{k}$$

Where, P_r is Prandtl's number.

μ is the viscosity of air.

C_p is specific heat capacity of air.

And k is thermal conductivity of air.

$$P_r = \frac{1.87 * 10^{-5} * 1000}{0.027}$$

$$P_r = 0.7$$

The relevant Nusselt number correlation is;

$$N_u = 0.027 R_e^{0.805} P_r^{1/3}$$

Hence,

$$N_u = 167.5$$

But,

$$N_u = \frac{hD}{k}$$

Where, h is convective heat transfer coefficient.

Hence, $$h = \frac{kN_u}{D}$$

$$h = 0.027 * 167.5 / 1.5$$

$$h = 3.015 \text{ W/m}^2\text{K}$$

And if we treat the case, like a natural convective heat transfer in a horizontal cylinder, for comparison;

Table 10

Inputs

Fluid Temp, T_∞ =	27	°C
Surface Temp, T_w =	94	°C
Film Temp., T_f = [$T_f = (T_\infty + T_w)/2$]	61	°C
Cylinder Diam., D =	1.5	m
Fluid Density, ρ* =	0.947	kg/m³
Fluid viscosity, μ =	1.87E-05	N-s/m²
Fluid Sp. Heat, C_p =	1	J/g-°K
Fluid Sp. Heat, C_p =	1000	J/kg-°K
Fluid Thermal Conductivity, k =	0.027	J/s-m-K
Fluid Thermal Expans. Coeff, β =	0.002997	°K⁻¹

For Natural Convection Heat Transfer from an Isothermal Horizontal Cylinder ;

$$Nu = \left\{ 0.60 + \frac{0.387\ Ra^{1/6}}{[\,1 + (0.559/Pr)^{9/16}\,]^{8/27}} \right\}^2$$

$$Gr = \frac{D^3 \rho^2 g\ \Delta T\ \beta}{\mu^2} \qquad Nu = \frac{h\,D}{k} \qquad Pr = \frac{\mu\, C_p}{k}$$

$$\text{for } Ra \le 10^{12} \qquad (\,Ra = Gr\,Pr\,)$$

Table 11

Outputs

Temp Diff, ΔT =	67	^oC
Abs. Film Temp, T_f =	334	^oK
Prandtl Number, Pr =	0.7	
Grashof Number, Gr =	1.71.E+10	
Rayleigh No., Ra =	1.18E+10	
Nu =	253	
h =	4.55	W/m^2-K

Therefore the use of h greater than 5 would be reasonable. Since heat loss due to convection is in the range of a few hundreds of watts, use of h=6 W/m^2K would not cause too much error in the overall calculation.

4, To estimate the convective heat transfer coefficient for the side loss in the drying drum, it is considered as if it were a rotating disk. And for a rotating disk in the turbulent flow regime, the Nusselt number correlation becomes [15];

$$N_u = 0.0193 R_e^{0.8} \quad \text{for } P_r = 0.7$$

Using the above equation,

$$N_u = 0.0193 * (59631)^{0.8}$$

$$N_u = 127.6$$

Hence,

$$h = \frac{kN_u}{D}$$

$$h = 2.3 \text{ W/m}^2\text{K}$$

5, Evaporation takes place in the gap between two consecutive drums, the gap is taken to be 0.8 meters.

6, The mass per unit area of the felt is 1.08 Kg/m^2. This was determined by taking a sample of the felt. The specific heat capacity of the felt, which is labeled on its specification, is 1.67kJ/kgK.
And the thickness of the felt is 2.5 mm or 0.0025m

7, The temperature of the paper web as it gets out of the drum equals to the surface temperature of the drum.

8, The convective heat transfer coefficient of the paper web as it passes from one drum to another is found from the following Nusselt number correlation.

$$R_e = \frac{\rho VL}{\mu}$$

$$R_e = \frac{0.947 * 0.785 * 0.8}{1.87 * 10^{-5}}$$

$$R_e = 31803$$

Hence the flow is in the turbulent regime.

$$N_u = (0.037 R_e^{4/5} - A) P_r^{1/3}$$

Where, $A = 0.037 * Re_{x,c}^{4/5} - 0.664 * Re_{x,c}^{1/2}$

But, $Re_{x,c} = 4000$, the critical R_e

$$A = -13.82$$

This means,

$$N_u = 143.65$$

Hence,

$$h = \frac{kN_u}{L}$$

$$h = 0.027 * 143.65 / 0.8$$

$$h = 4.85 \text{ W/m}^2\text{K}$$

Along with the above idealizations and assumptions, measurements were taken in a single process time. All of the measurements were taken for a certain unique process. In other words, the inlet and outlet temperatures of drum number one is process dependent, that means the value used in this analysis is used for this process only. The reason is that the workers use different steam valve arrangements until a steady production of paper is achieved at different times. Therefore this data is unique for this process. The speed of the drums also depends on the intensity of steam supply and on the mass per square meter of paper being produced. As it decreases the speed increases. And as the steam supply increases, the speed of the drum also increases. By the time this data was taken, the old boilers were being serviced due to sudden failure. Hence only one boiler was functioning.

5.2.1.2 Modeling of the Drying Drums

Modeling of Drum #1

Table 12

Data collected for drum #1

Parameter	vaue	unit
Density of air	0.947	kg/m^3
Diameter of the drum	1.5	m
relative velocity of air	0.785	m/s
angular speed of drum	0.17	rps
gap between two drying drums	0.8	m
span of the felt	3	m
mass per unit area of the felt	1.08	kg/m^2
thickness of the felt	0.0025	m
span of the paper web	2.6	m
mass flow rate of cellulose	0.327	kg/s
Paper web inlet temperature	27	°C
Paper web outlet temperature	50	°C
Drum surface temperature	50	°C
Felt inlet temperature	52	°C
Felt outlet temperature	44	°C
Sides surface temperature of drum	48	°C
Temperature of the paper web as it gets into the next drum	43	°C

Conceptual approach

Heat is supplied to the drum by the injected steam, which will be equal to the total heat lost from the drum. Heat is lost from the drum by convection from the surfaces that are exposed to the air, which are the horizontal and the side surfaces of the drum. Heat is also lost from the drum by conduction to the paper web. The sum of all this losses equals to the heat supplied to the drum.

On the interface between the drum and the paper, heat is transferred from the drum to the paper web by conduction. Also on the interface between the paper web and the felt, heat is transferred from the paper to the felt by conduction. Imagining a control volume attached to the paper web, a mass and energy balance equations can be established.

Similarly, the felt also receives heat from the paper web by conduction. It also losses heat to the ambient air by convection. Hence, by imagining a control volume attached to the felt, an energy balance equation can be established. Then solving all of the equations simultaneously would give the quantities of heat being conducted in the interfaces.

As the paper web travels from on drum to the next, heat and mass are transferred from it. By imagining a control volume attached to it, and establishing mass and energy balance equations will be possible. Solving the equations would give the evaporation rate and the change in the moisture contents.

The energy equation for a fixed control volume is given by:

$$\dot{Q} - \dot{W}s - \dot{W}ss = \frac{\partial}{\partial t}\left[\int_{cv}\left(u + \frac{1}{2}V^2 + gz\right)\rho d\Upsilon\right] + \int_{cs}\left(h + \frac{1}{2}V^2 + gz\right)\rho(V.\boldsymbol{n})dA$$

Where, $\dot{Q}$ is heat added to the system.

$\dot{W}s$ is shaft work

$\dot{W}ss$ is shear work [20].

For our case the system doesn't do any work, steady state is assumed, and kinetic and potential energy terms are neglected.

Then the above equation condenses to;

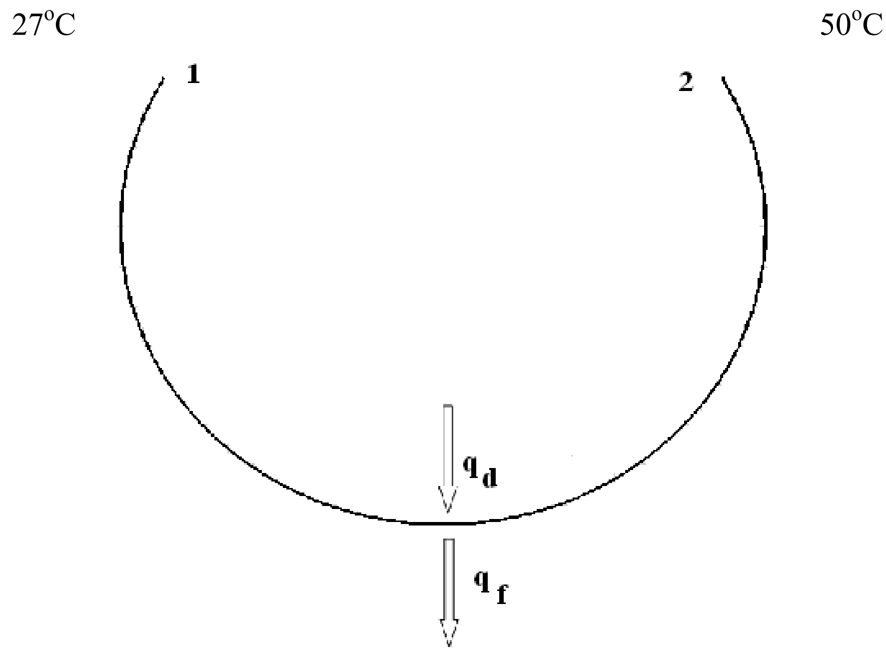
$$\dot{Q} = \int_{cs}(h)\rho(V.\boldsymbol{n})dA$$

Which means that the heat added to the system equals the (energy flux)$_{(out)}$ - (energy flux)$_{(in)}$.

Hence for our case,

$$\dot{Q} = (\text{energy flux})(\text{out}) - (\text{energy flux})(\text{in})$$

Consider a control volume on the paper web from inlet to outlet of the drum.



q_d is heat transferred from the drum to the paper control volume. And q_f is heat transferred out of the paper control volume.

Mass balance of the control volume becomes:

$$\left.\frac{dm}{dt}\right|_{out} - \left.\frac{dm}{dt}\right|_{in} = 0 \qquad \text{…………….} \ (1)$$

Since,

Speed of the paper web = 0.785 m/s.

Span of the paper web = 2.6 m.

Then, area flow rate of the paper web is = 0.785*2.6 = 2.04 m^2/s.

mass per square meter of paper = 0.16 kg/m^2.

Hence, mass flow rate of the cellulose part of the paper web = 2.04*0.16 = 0.327 kg/s.

Let $\left.\frac{dm}{dt}\right|_{c}$ be the mass flow rate of cellulose.

And $\left.\frac{dm}{dt}\right|_{w}$ be the mass flow rate of moisture on the paper.

Moisture content of the paper at this stage is 60 %.

Which means that, the mass flow rate of the moisture part only can be calculated and found to be = 0.49 kg/s.

Mass balance of cellulose and moisture becomes;

$$\frac{dm}{dt}_{c2} + \frac{dm}{dt}_{w2} - \frac{dm}{dt}_{c1} - \frac{dm}{dt}_{w1} = 0 \quad \text{………………… (2)}$$

Because there is no evaporation when the paper is in contact with the drum

Energy balance of the paper web control volume

At steady state,

$$q_f - q_d + C_{pw}\Delta T \frac{dm}{dt}_w + C_{pc}\Delta T \frac{dm}{dt}_c = 0$$

⇨

$$q_d - q_f = \left(C_{pw} \frac{dm}{dt}_w + C_{pc} \frac{dm}{dt}_c \right) \Delta T \quad \text{…………… (3)}$$

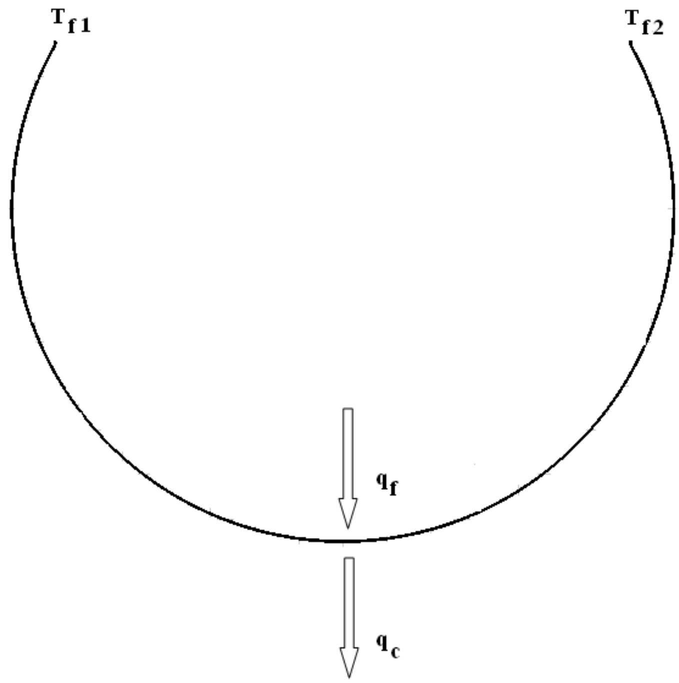
But C_{pw} = 4.187 kJ/kgk , and C_{pc} = 1.55 kJ/kgk

Hence,

$$q_d - q_f = 58813.95W \quad \text{…………………………..(4)}$$

Energy balance of the felt

52^oC 44^oC



$$q_c - q_f + C_{pf} \frac{dm}{dt}_f (T_{f2} - T_{f1}) = 0 \quad \ldots\ldots\ldots (5)$$

Where q_c is the convective heat transferred from the bottom felt surface. q_c can be calculated based on the mean temperature T_f.

$$T_f = (T_{f1} + T_{f2})/2$$

And,

$$q_c = h * A * (T_f - T_\infty) \quad \ldots\ldots\ldots\ldots\ldots (6)$$

Where,

h is the convective heat transfer coefficient.

A is the area of the felt in the control volume.

T_∞ is the ambient temperature.

But, $h = 6$ W/m^{2}K

r = 0.75m - radius of the drum.

t =0.0025m – thickness of the felt.

θ = 4.19rads – contact angle.

$L = 3m$ – span of the felt.

$A = 9.45m^2$ – Heat transfer area.

$T_f = 48^oC$

$T_\infty = 27^oC$

Hence using equation 6,

$$q_c = 1190.876W$$

Let C_{pf} (specific heat of felt) = 1.67 kJ/kgK

The mass per square meter of the felt = 1.08 kg/m^2

And span of the felt is = 3m

Hence, mass flow rate of the felt = 2.54 kg/s

Plugging values into equation 5,

$$1190.876 - q_f - 33980 = 0$$

$$q_f = -32788.9W$$

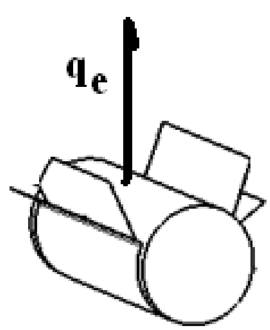
Plugging values into equation 4,

$$q_d + 32788.9 = 58813.95W$$

$$q_d = 26025W$$

Convective heat losses through surfaces that are exposed to air
Convective heat loss through the cylindrical surface

Surface temperature T = 50^oC



Angle θ of exposed surface = 2.093 rads.

Radius of drum r = 0.75m.

Span of drum = 3.3m.

Hence, heat transfer area = 5.181m^2.

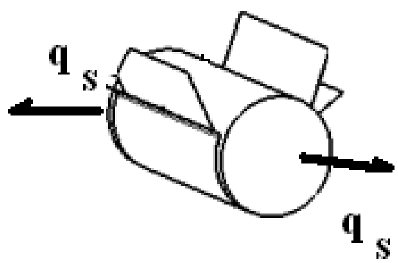
Convective heat transfer coefficient h = 6 W/m^{2}K.

$$q_e = h * A * (T - T_\infty)$$

$$q_e = 714.978\text{W}$$

Convective heat loss through the sides of cylinder

Sides surface temperature T = 48^{o}C.



Heat transfer area = 2x (π*0.75^2) = 3.53 m^2

The convective heat transfer coefficient *h =2.6w/m^2*.

Thus,

$$q_s = h * A * (T - T_\infty)$$

$$q_s = 170.62\text{W}$$

Total Heat Transfer Rate from the Drum

$$q_T = q_d + q_e + q_s$$

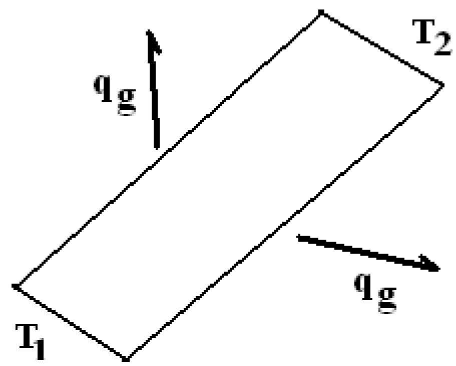
$$q_T = 26910.60\text{W}$$

Estimation of the Evaporation rate

Evaporation takes place after the paper comes out of the drum. It takes place in the gap between two drums. This gap is 0.8 m. And the span of the paper is 2.6m.

Mass balance of the paper control volume

$$\frac{dm}{dt}_{w2} + \frac{dM}{dt} - \frac{dm}{dt}_{w1} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$



Where, $\frac{dM}{dt}$, is evaporation rate.

$\frac{dm}{dt}_{w1}$ Moisture mass flow rate at 1

$\frac{dm}{dt}_{w2}$ Moisture mass flow rate at 2

Energy balance of the control volume

$T_1 = 50^oC$ and $T_2 = 43^oC$

Latent heat of vaporization of water = 2260 kJ/kg.

$$q_g + \frac{dM}{dt} * (g) + \frac{dm}{dt}_{w2} * h_2 - \frac{dm}{dt}_{w1} * h_1 + C_{pc} * \frac{dm}{dt}_{c} * \Delta T = 0 \quad \ldots\ldots \text{(8)}$$

Where, g is the latent heat of vaporization.

h_1 is enthalpy of water(moisture) at 1.

h_2 is enthalpy of water(moisture) at 2.

q_g is heat transfer due to convection.

But,

$$q_g = h * 2 * A * (T - T\infty)$$

Where,

h = 4.85 W/m^{2}k.

T = 46.5^{o}C

Hence,

q_g = 393.432W

h1 = 209.35 kJ/kg

h2 = 180.076 kJ/kg

Then equation 8 becomes,

$$393.432 + 2260000 * \frac{dM}{dt} + 180076 * \frac{dm}{dt}_{w2} - 102548 - 3543 = 0$$

$$2260000 * \frac{dM}{dt} + 180076 * \frac{dm}{dt}_{w2} - 105700 = 0$$

Dividing both sides by 10^6,

$$2.26 \frac{dM}{dt} + 0.18 \frac{dm}{dt}_{w2} = 0.1057$$

From equation 7,

$$\frac{dM}{dt} + \frac{dm}{dt}_{w2} = 0.49$$

Solving the above two equations simultaneously gives,

$\frac{dM}{dt} = 0.008409$kg/s , which is the evaporation rate.

And $\frac{dm}{dt}_{w2} = 0.481$kg/s , which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes;

59.58373%

Summary

Total heat supplied by the drum which is obtained from the steam = **26910.60W**

Heat absorbed by the paper web = **58813.95W**

In this drum the heat absorbed by the paper is greater than that which is supplied by the drum. This is because the paper is partially heated by the felt.

The analysis done for drum #1 will be repeated for the other 15 drums. Getting through all of the above steps for every drum will be unnecessary. Hence only the important outputs and inputs have been presented as follows.

Modeling of Drum #2

Table 13

Collected data for drum #2

Parameter	vaue	unit
Paper web inlet temperature	43	°C
Paper web outlet temperature	79.7	°C
Drum surface temperature	79.7	°C
Felt inlet temperature	80	°C
Felt outlet temperature	84	°C
Sides surface temperature of drum	75.4	°C
Temperature of the paper web as it gets into the next drum	64.6	°C

T_{in}=43°C and T_{out} = 79.7°C

Moisture content of the paper at this stage is 59.5837%.

T_{f1} = 80 °C and T_{f2} = 84 °C

$$q_c = 3118.962W$$

$$q_d = 112663.4W$$

$$q_f = 20108.87\text{W}$$

Drum Surface temperature T = 79.7°C

$$q_e = 1638.232\text{W}$$

Sides surface temperature T = 75.4°C.

$$q_s = 393.24\text{W}$$

$q_T = 114694.85\text{W}$

Evaporation rate

$T_1 = 79.7^{o}C$ and $T_2 = 64.6^{o}C$

T (Average temperature) = 72.15^{o}C

$q_g = 910.9464\text{W}$

h1 = 333.7624 kJ/kg

h2 = 270.463 kJ/kg

$\frac{dM}{dt} = 0.018701\text{kg/s}$, which is the evaporation rate.

$\frac{dm}{dt}_{w2} = 0.463\text{kg/s}$, which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **58.62612**%

Summary

Total heat supplied by the drum which is obtained from the steam = **114694.85W**

Heat absorbed by the paper web = **92554.51W**

Modeling of Drum #3

Table 14

Collected data for drum # 3

Parameter	vaue	unit
Paper web inlet temperature	66	^{o}C
Paper web outlet temperature	74	^{o}C
Drum surface temperature	74	^{o}C
Felt inlet temperature	52	^{o}C
Felt outlet temperature	67	^{o}C
Sides surface temperature of drum	75.4	^{o}C
Temperature of the paper web as it gets into the next drum	62.7	^{o}C

T_{in}=66^{o}C   and T_{out} = 74^{o}C

Moisture content of the paper at this stage is 58.6261%

T_{f1} = 52 ^{o}C and T_{f2} = 67 ^{o}C

$$q_c = 1843.023W$$

$$q_f = 65555.19\text{W}$$

$$q_d = 85104.15W$$

Surface temperature T   = 74^{o}C

$$q_e = 1461.042\text{W}$$

Sides surface temperature T   = 75.4^{o}C.

$$q_s = 393.24\text{W}$$

$$q_T = 86958.43\text{W}$$

Evaporation rate

T_1 = 74^{o}C   and T_2 = 62.7^{o}C

T (Average temperature) = 68.35^{o}C

$$q_g = 834.28\text{W}$$

h1 = 309.868 kJ/kg

h2 = 262.4984 kJ/kg

$\frac{dM}{dt}$ = 0.013419kg/s , which is the evaporation rate.

$\frac{dm}{dt}_{w2}$ = 0.449kg/s , which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **57.91054** %

Summary

Total heat supplied by the drum which is obtained from the steam = **86958.43W**

Heat absorbed by the paper web = **19548.96W**

Modeling of Drum #4

Table 15

Collected data for drum # 4

Parameter	vaue	unit
Paper web inlet temperature	62.7	°C
Paper web outlet temperature	108.4	°C
Drum surface temperature	108.4	°C
Felt inlet temperature	80	°C
Felt outlet temperature	90	°C
Sides surface temperature of drum	106	°C
Temperature of the paper web as it gets into the next drum	69	°C

T_{in}=62.7°C and T_{out} = 108.4°C

Moisture content of the paper at this stage is 57.9105%.

T_{f1} = 80 °C and T_{f2} = 90 °C

$q_c = 3289.087W$

$q_f = 45763.87W$

$q_d = 154869.6W$

Surface temperature T = 108.4°C

$q_e = 2530.4W$

Sides surface temperature T = 106°C.

$q_s = 641.86W$

$q_T = 158041.84W$

Evaluation rate

T_1 = 108.4°C and T_2 = 69°C

T (Average temperature) = 88.7°C

$q_g = 1244.859W$

h1 = 454.0728 kJ/kg

h2 = 288.908 kJ/kg

$\frac{dM}{dt} = 0.047136$kg/s , which is the evaporation rate.

$\frac{dm}{dt}_{w2} = 0.402$kg/s , which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **55.18813**%

Summary

Total heat supplied by the drum which is obtained from the steam = **158041.84W**

Heat absorbed by the paper web = **109105.7W**

Modeling of Drum #5

Table 16

Collected data for drum # 5

Parameter	vaue	unit
Paper web inlet temperature	69	^oC
Paper web outlet temperature	75.3	^oC
Drum surface temperature	75.3	^oC
Felt inlet temperature	58	^oC
Felt outlet temperature	61	^oC
Sides surface temperature of drum	73.4	^oC
Temperature of the paper web as it gets into the next drum	65	^oC

$T_{in}=69^oC$ and $T_{out} = 75.3^oC$

Moisture content of the paper at this stage is 55.18813%.

$T_{f1} = 58\,^oC$ and $T_{f2} = 61\,^oC$

$q_c = 1843.023W$

$q_f = 14585.46$W

$q_d = 28382.94W$

Surface temperature T = 75.3^{o}C

$q_e = 1501.454$W

Sides surface temperature T = 73.4^{o}C.

$q_s = 376.99$W

$q_T = 30261.38\text{W}$

Evaporation rate

$T_1 = 75.3^oC$ and $T_2 = 65^oC$

T (Average temperature) = 70.15^oC

$q_g = 870.5944\text{W}$

h1 = 315.3176 kJ/kg

h2 = 272.14 kJ/kg

$\frac{dM}{dt} = 0.01092\text{kg/s}$, which is the evaporation rate.

$\frac{dm}{dt}_{w2} = 0.391\text{kg/s}$, which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **54.5064%**

Summary

Total heat supplied by the drum which is obtained from the steam = **30261.38W**

Heat absorbed by the paper web = **13797.49W**

Modeling of Drum #6

Table 17

Collected data for drum # 6

Parameter	vaue	unit
Paper web inlet temperature	65	^oC
Paper web outlet temperature	108.8	^oC
Drum surface temperature	108.8	^oC
Felt inlet temperature	85	^oC
Felt outlet temperature	95	^oC
Sides surface temperature of drum	105	^oC
Temperature of the paper web as it gets into the next drum	77	^oC

$T_{in}=65^oC$ and $T_{out} = 108.8^oC$

Moisture content of the paper at this stage is 54.5064%.

T_{f1} = 85 ^{o}C and T_{f2} = 95 ^{o}C

$q_c = 3572.629W$

q_f = 46047.41W

$q_d = 139970.1W$

Surface temperature T = 108.8^{o}C

q_e = 2542.835W

Sides surface temperature T = 105^{o}C.

q_s = 633.73W

q_T = 143146.68W

Evaporation rate

T_1 = 108.8^{o}C and T_2 = 77^{o}C

T (Average temperature) = 92.9^{o}C

q_g = 1329.598W

h1 = 455.7496 kJ/kg

h2 = 322.444 kJ/kg

$\frac{dM}{dt}$ = 0.03454kg/s , which is the evaporation rate.

$\frac{dm}{dt}_{w2}$ = 0.357kg/s , which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **52.20668**%

Summary

Total heat supplied by the drum which is obtained from the steam = **143146.68W**

Heat absorbed by the paper web = **93922.71W**

Modeling of Drum #7

Table 18

Collected data for drum # 7

Parameter	vaue	unit
Paper web inlet temperature	77	°C
Paper web outlet temperature	65.5	°C
Drum surface temperature	65.5	°C
Felt inlet temperature	57.8	°C
Felt outlet temperature	60.5	°C
Sides surface temperature of drum	105	°C
Temperature of the paper web as it gets into the next drum	63	°C

T_{in}=77°C   and T_{out} = 65.5°C

Moisture content of the paper at this stage is 52.2067%.

T_{f1} = 57.8°C and T_{f2} = 60.5 °C

$q_c = 1823.175W$

$q_f = 13291.37\text{W}$

q_d = -9705.59W

Surface temperature T   = 65.5°C

$q_e = 1196.811\text{W}$

Sides surface temperature T   = 63°C.

$q_s = 292.49\text{W}$

q_T = -8216.29W

Evaporation rate

T_1 = 65.5°C   and T_2 = 63°C

T (Average temperature) = 64.25°C

$q_g = 751.556\text{W}$

h1 = 274.236 kJ/kg

h2 = 263.756 kJ/kg

$\frac{dM}{dt}$ = 0.00213kg/s , which is the evaporation rate.

$\frac{dm}{dt}_{w2}$ = 0.355kg/s , which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **52.05722**%

Summary

Total heat supplied by the drum which is obtained from the steam = **-8216.29W**

Heat absorbed by the paper web = **-22997W**

This means that no heat is supplied by this drum; rather it has a cooling effect. The paper web is also cooled by this drum.

Modeling of Drum #8

Table 19

Collected data for drum # 8

Parameter	vaue	unit
Paper web inlet temperature	63	°C
Paper web outlet temperature	100	°C
Drum surface temperature	100	°C
Felt inlet temperature	70	°C
Felt outlet temperature	90	°C
Sides surface temperature of drum	112	°C
Temperature of the paper web as it gets into the next drum	60	°C

T_{in}=63°C and T_{out} = 100°C

Moisture content of the paper at this stage is 52.0572%.

T_{f1} = 70 °C and T_{f2} = 90 °C

$q_c = 3005.545W$

$q_f = 87955.11\text{W}$

$q_d = 161615.3W$

Surface temperature T = 100°C

$q_e = 2269.278\text{W}$

Sides surface temperature T = 112°C.

$q_s = 690.60\text{W}$

$q_T = 164575.20\text{W}$

Evaporation rate

$T_1 = 100^oC$ and $T_2 = 60^oC$

T (Average temperature) = 80^oC

$q_g = 1069.328\text{W}$

h1 = 419.17 kJ/kg

h2 = 251.18 kJ/kg

$\frac{dM}{dt} = 0.039199\text{kg/s}$, which is the evaporation rate.

$\frac{dm}{dt}_{w2} = 0.315\text{kg/s}$, which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **49.12968**%

Summary

Total heat supplied by the drum which is obtained from the steam = **164575.20W**

Heat absorbed by the paper web = **73660.21W**

Modeling of Drum #9

Table 20

Collected data for drum # 9

Parameter	**vaue**	**unit**
Paper web inlet temperature	60	^oC
Paper web outlet temperature	108	^oC
Drum surface temperature	108	^oC
Felt inlet temperature	66.7	^oC
Felt outlet temperature	71	^oC
Sides surface temperature of drum	111	^oC
Temperature of the paper web as it gets into the next drum	62	^oC

$T_{in}=60^oC$ and $T_{out} = 108^oC$

Moisture content of the paper at this stage is 49.12968%.

T_{f1} = 66.7 ^{o}C and T_{f2} = 71 ^{o}C

$q_c = 2373.247W$

$q_f = 20637.4\text{W}$

$q_d = 108318.5W$

Surface temperature T = 108^{o}C

$q_e = 2517.966\text{W}$

Sides surface temperature T = 111^{o}C.

$q_s = 682.48\text{W}$

$q_T = 111518.94\text{W}$

Evaporation rate

T_1 = 108^{o}C and T_2 = 62^{o}C

T (Average temperature) = 85^{o}C

$q_g = 1170.208\text{W}$

h1 = 457.192 kJ/kg

h2 = 259.564 kJ/kg

$\frac{dM}{dt}$ = 0.042212kg/s , which is the evaporation rate.

$\frac{dm}{dt}_{w2}$ = 0.273kg/s , which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **45.54919**%

Summary

Total heat supplied by the drum which is obtained from the steam = **111518.94W**

Heat absorbed by the paper web = **87681.09W**

Modeling of Drum #10

Table 21

Collected data for drum # 10

Parameter	vaue	unit
Paper web inlet temperature	62	°C
Paper web outlet temperature	112	°C
Drum surface temperature	112	°C
Felt inlet temperature	81.2	°C
Felt outlet temperature	87.4	°C
Sides surface temperature of drum	112	°C
Temperature of the paper web as it gets into the next drum	63	°C

T_{in}=62°C and T_{out} = 112°C

Moisture content of the paper at this stage is 45.54919%.

T_{f1} = 81.2 °C and T_{f2} = 87.4 °C

$q_c = 3249.391W$

$q_f = 29583.75W$

$q_d = 112081.1W$

Surface temperature T = 112°C

$q_e = 2642.31W$

Sides surface temperature T = 112°C.

$q_s = 690.60W$

$q_T = 115414.03W$

Evaporation rate

T_1 = 112°C and T_2 = 63°C

T (Average temperature) = 87.5°C

$q_g = 1220.648W$

h1 = 465.648 kJ/kg

h2 = 263.756 kJ/kg

$\frac{dM}{dt}$ = 0.039441kg/s , which is the evaporation rate.

$\frac{dm}{dt}_{w2}$ = 0.234kg/s , which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **41.71624**%

Summary

Total heat supplied by the drum which is obtained from the steam = **115414.03W**

Heat absorbed by the paper web = **82497.36W**

Modeling of Drum #11

Table 22

Collected data for drum # 11

Parameter	**vaue**	**unit**
Paper web inlet temperature	63	^{o}C
Paper web outlet temperature	112	^{o}C
Drum surface temperature	112	^{o}C
Felt inlet temperature	66	^{o}C
Felt outlet temperature	76	^{o}C
Sides surface temperature of drum	112	^{o}C
Temperature of the paper web as it gets into the next drum	64	^{o}C

T_{in}=63°C and T_{out} = 112°C

Moisture content of the paper at this stage is 41.71624%.

T_{f1} = 66 °C and T_{f2} = 76 °C

$q_c = 2495.171W$

q_f = 44969.95W

$q_d = 117725.6W$

Surface temperature T = 112°C

q_e = 2642.31W

Sides surface temperature T = 112°C.

q_s = 690.60W

$q_T = 121058.51\text{W}$

Evaporation rate

$T_1 = 112^oC$ and $T_2 = 64^oC$

T (Average temperature) = 88^oC

$q_g = 1230.736\text{W}$

h1 = 465.648 kJ/kg

h2 = 267.948 kJ/kg

$\frac{dM}{dt} = 0.034775\text{kg/s}$, which is the evaporation rate.

$\frac{dm}{dt}_{w2} = 0.199\text{kg/s}$, which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **37.85939**%

Summary

Total heat supplied by the drum which is obtained from the steam = **121058.51W**

Heat absorbed by the paper web = **72755.65W**

Modeling of Drum #12

Table 23

Collected data for drum # 12

Parameter	vaue	unit
Paper web inlet temperature	64	^oC
Paper web outlet temperature	114	^oC
Drum surface temperature	114	^oC
Felt inlet temperature	88	^oC
Felt outlet temperature	88	^oC
Sides surface temperature of drum	110	^oC
Temperature of the paper web as it gets into the next drum	62	^oC

Table 19 Collected data

$T_{in}=64^oC$ and $T_{out} = 114^oC$

Moisture content of the paper at this stage is 37.85939%.

T_{f1} =88 ^{o}C and T_{f2} = 88 ^{o}C

$q_c = 3459.212W$

$q_f = 3459.212\text{W}$

$q_d = 70419.44W$

Surface temperature T = 114^{o}C

$q_e = 2704.482\text{W}$

Sides surface temperature T = 110^{o}C.

$q_s = 674.35\text{W}$

$q_T = 73798.28\text{W}$

Evaporation rate

T_1 = 114^{o}C and T_2 = 62^{o}C

T (Average temperature) = 88^{o}C

$q_g = 1230.736\text{W}$

h1 = 469.876 kJ/kg

h2 = 259.564 kJ/kg

$\frac{dM}{dt}$ = 0.033459kg/s , which is the evaporation rate.

$\frac{dm}{dt}_{w2}$ = 0.165kg/s , which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **33.63391**%

Summary

Total heat supplied by the drum which is obtained from the steam = **73798.28W**

Heat absorbed by the paper web = **66960.23W**

Modeling of Drum #13

Table 24

Collected data for drum # 13

Parameter	vaue	unit
Paper web inlet temperature	62	°C
Paper web outlet temperature	112	°C
Drum surface temperature	112	°C
Felt inlet temperature	78	°C
Felt outlet temperature	80	°C
Sides surface temperature of drum	110	°C
Temperature of the paper web as it gets into the next drum	62	°C

T_{in}=62°C and T_{out} = 112°C

Moisture content of the paper at this stage is 33.63391%.

T_{f1} =78 °C and T_{f2} = 80 °C

$$q_c = 2948.837W$$

$$q_f = 11443.79\text{W}$$

$$q_d = 71399.31W$$

Surface temperature T = 112°C

$$q_e = 2642.31\text{W}$$

Sides surface temperature T = 110°C.

$$q_s = 674.35\text{W}$$

$$q_T = 74715.98\text{W}$$

Evaporation rate

T_1 = 112°C and T_2 = 62°C

T (Average temperature) = 87°C

$$q_g = 1347.84\text{W}$$

h1 = 465.648 kJ/kg

h2 = 259.564 kJ/kg

$\frac{dM}{dt}$ = 0.029096kg/s , which is the evaporation rate.

$\frac{dm}{dt}_{w2}$ = 0.136kg/s , which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **29.46299**%

Summary

Total heat supplied by the drum which is obtained from the steam = **74715.98W**

Heat absorbed by the paper web = **59955.52W**

Modeling of Drum #14

Table 25

Collected data for drum # 14

Parameter	vaue	unit
Paper web inlet temperature	62	°C
Paper web outlet temperature	112	°C
Drum surface temperature	112	°C
Felt inlet temperature	80	°C
Felt outlet temperature	84	°C
Sides surface temperature of drum	110	°C
Temperature of the paper web as it gets into the next drum	65	°C

T_{in}=62°C and T_{out} = 112°C

Moisture content of the paper at this stage is 29.46299 %.

T_{f1} =80 °C and T_{f2} = 84 °C

$q_c = 3118.962W$

q_f = 20108.87W

$q_d = 73973.17W$

Surface temperature T = 112°C

q_e = 2642.31W

Sides surface temperature T = 110°C.

q_s = 674.35W

$q_T = 77289.84\text{W}$

Evaporation rate

$T_1 = 112^oC$ and $T_2 = 65^oC$

T (Average temperature) = 88.5^oC

$q_g = 1240.824\text{W}$

h1 = 465.648 kJ/kg

h2 = 272.12 kJ/kg

$\frac{dM}{dt} = 0.024623\text{kg/s}$, which is the evaporation rate.

$\frac{dm}{dt}_{w2} = 0.112\text{kg/s}$, which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **25.50076**%

Summary

Total heat supplied by the drum which is obtained from the steam = **77289.84W**

Heat absorbed by the paper web = **53864.3W**

Modeling of Drum #15

Table 26

Collected data for drum # 15

Parameter	vaue	unit
Paper web inlet temperature	65	^oC
Paper web outlet temperature	112	^oC
Drum surface temperature	112	^oC
Felt inlet temperature	75	^oC
Felt outlet temperature	80	^oC
Sides surface temperature of drum	111	^oC
Temperature of the paper web as it gets into the next drum	66	^oC

$T_{in}=65^oC$ and $T_{out} = 112^oC$

Moisture content of the paper at this stage is 25.50076%.

$T_{f1} = 75\ ^oC$ and $T_{f2} = 80\ ^oC$

$q_c = 2863.774W$

$q_f = 24101.16W$

$q_d = 69888.14W$

Surface temperature T = 112°C

$q_e = 2642.31W$

Sides surface temperature T = 111°C.

$q_s = 682.48W$

$q_T = 73212.93W$

Evaporation rate

$T_1 = 112^oC$ and $T_2 = 66^oC$

T (Average temperature) = 89°C

$q_g = 1250.912W$

h1 = 469.164 kJ/kg

h2 = 276.332 kJ/kg

$\frac{dM}{dt}$ = 0.021973kg/s , which is the evaporation rate.

$\frac{dm}{dt}_{w2}$ = 0.090kg/s , which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **21.56916**%

Summary

Total heat supplied by the drum which is obtained from the steam = **73212.93W**

Heat absorbed by the paper web = **45786.98W**

Modeling of Drum #16

Table 27

Collected data for drum # 16

Parameter	vaue	unit
Paper web inlet temperature	66	°C
Paper web outlet temperature	112	°C
Drum surface temperature	112	°C
Felt inlet temperature	78	°C
Felt outlet temperature	85	°C
Sides surface temperature of drum	111	°C
Temperature of the paper web as it gets into the next drum	50	°C

T_{in}=66°C and T_{out} = 112°C

Moisture content of the paper at this stage is 21.56916%.

T_{f1} =78 °C and T_{f2} = 85 °C

$$q_c = 3090.608W$$

$$q_f = 32822.9538\text{W}$$

$$q_d = 73403.65W$$

Surface temperature T = 112°C

$$q_e = 2642.31\text{W}$$

Sides surface temperature T = 111°C.

$$q_s = 682.48\text{W}$$

$$q_T = 76728.44\text{W}$$

Evaporation rate

T_1 = 112°C and T_2 = 50°C

T (Average temperature) = 81°C

$$q_g = 1089.504\text{W}$$

h1 = 469.164 kJ/kg

h2 = 209.34 kJ/kg

$\frac{dM}{dt}$ = 0.026335kg/s , which is the evaporation rate.

$\frac{dm}{dt}_{w2}$ = 0.063kg/s , which is the moisture mass flow rate at 2.

Therefore, the moisture content at point 2 becomes, **16.27358**%

Summary

Total heat supplied by the drum which is obtained from the steam = **76728.44W**
Heat absorbed by the paper web = **40580.701W**

Total Heat supplied by the 16 drums = 1440109.63W
Power absorbed by the paper web = 948488.396W
The total evaporation rate in the hood = 0.4263678 kg/s

Estimation of steam flow rate in to the drying section

Steam temperature in = 120°C.

Enthalpy h_{in} = 2706 kJ/kg.

Condensate temperature out = 95°C.

Enthalpy h_{out} = 415 kJ/kg .

$$\frac{dm}{dt_{st}} * (h_{in} - h_{out}) = q_T \quad \text{………………………..…. (9)}$$

Where, $\frac{dm}{dt_{st}}$, is the steam mass flow rate into the section.

Hence,

$$\frac{dm}{dt_{st}} = \frac{q_T}{(h_{in} - h_{out})}$$

Thus,

$$\frac{dm}{dt_{st}} = \frac{1440109.63}{(2706 - 415) * 1000}$$

$$\frac{dm}{dt_{st}} = 0.6286 Kg / s$$

Or, $\dfrac{dm}{dt_{st}} = 2263Kg/hr$

This figure is acceptable because, by the time the data was taken, only the new boiler which has a maximum steam production capacity of 4302kg/hr, was working. Definitely it was not using its maximum capacity and; it was producing steam not only for this section but also for the secondary drier section, which continues after starch is poured onto the paper web, and for the carton drier section.

Net power taken by the paper web

Net power taken by the paper web is given by;

$$P_n = C_{pc}\frac{dm}{dt}_{c}(\Delta T) + \frac{dm}{dt}_{wout} h_{out} - \frac{dm}{dt}_{win} h_{in} \quad \ldots\ldots\ldots\ldots (10)$$

Where, P_n , is net power.

C_{pc}, is specific heat capacity of cellulose.

$\frac{dm}{dt}_{c}$, is mass flow rate of cellulose.

$\frac{dm}{dt}_{wout}$, is mass flow rate of moisture out.

$\frac{dm}{dt}_{win}$, is mass flow rate of moisture in.

ΔT , is temperature difference.

And *h,* is specific enthalpy.

Hence equation 10 becomes;

$$P_n = (1.55*1000*0.327*(112-27) + 0.09*469.164*1000 - 0.49*113.1925*1000)$$

As the paper comes out of the 16th drum, it will immediately get out of the hood hence evaporation takes place outside the hood. Hence, $\frac{dm}{dt}_{wout}$ is that which is found at the end of drum #15, which is 0.09kg/s.

Therefore,

$$P_n = 29843\text{W}$$

Or, $$P_n = 29.843\text{kW}$$

5.2.1.3 Summary of the power usage in the dryer section

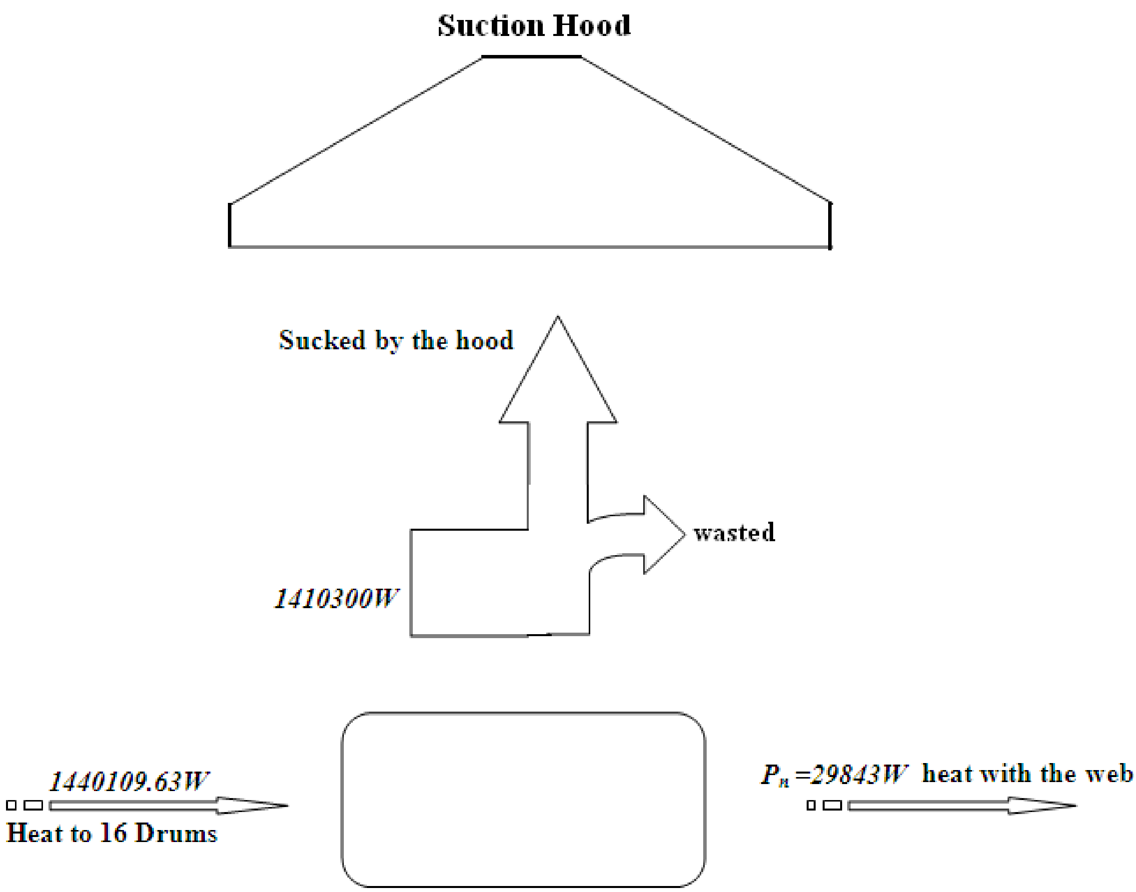


Fig.33 Summary of power usage in the dryer section

The heat that is sucked by the hood is predominantly ejected to the atmosphere outside the factory. When the researcher was taking the data, the mass per square meter of the paper that was being produced was 0.16 kg/m^2. The speed of production was 0.785m/s. The span of the paper was 2.6m. Hence assuming no rework, 0.33 kg/s was the production rate of the factory. The time required to produce 1000kg of paper was 50.5 minutes. Therefore, the first dryer section would consume $1.44 \times 10^6 \times 50.5 \times 60$ Joules of energy per ton of paper, which is around 4.363 GJ/ton.

Modern paper machines are equipped with heat recovery systems that are able to recover over 50% of the energy used by the paper machine [19].The use of a heat recovery system is technically feasible, because it is a matter of using heat exchangers. If water is allowed to be heated by the hot and moist air coming through the hood, using a heat exchanger, then there can be a possibility of recovering at least 50% of the heat. That means, there is a possibility of saving half of the power that was simply expelled to the external atmosphere.

5.2.1.4 Psychometric Analysis made on the hood

The average daily relative humidity for October around Adama town, which is the closest well known city near the factory, is 30%, according to www.myweather2.com. Therefore, the relative humidity of the air entering to the hood can be taken to be about 30%. And the dry bulb temperature is measured to be 27^{o}C and the local pressure 1bar. This means, using a psychometric chart, the absolute humidity of the air entering the hood becomes 0.0067kg/kg of dry air.

The relative humidity of the air should be as high as possible to reduce the amount of air injected into the hood. Lower relative humidity is caused due to higher flow rate of dry air. As the flow rate of dry air decreases the relative humidity inside the hood increases. Therefore the impact of the value of the relative humidity is on the value of dry air flow rate. In other words change in the value of the relative humidity would cause a change in the value of the sensible heat transferred in the heat exchanger from the dry part of the air, which is roughly 7.5% of the overall heat transfer. Therefore an error committed by taking some value of relative humidity in the dryer section would not be more than 3%. However, the moisture absorption rate of the air is best up to 80% relative humidity [18]. The typical temperature of the drying section is measured to be 75^{o}C and the local pressure is 1bar. Hence in such a situation, the moisture content must be obtained from the following mat lab formulation, which is prepared from the well known psychometric relationships.

$$\log_{10} p = A - \left(\frac{B}{T+C}\right) \quad \ldots\ldots\ldots\ldots\ldots (11)$$

Where,

p is the saturated vapor pressure in mmHg

T is the temperature in degree Celsius.

A = 8.07131, B = 1730.63, and C=233.426, for water

Specific humidity (sh) is given by;

$$sh = 0.00622 * RH * p/(p_l - 0.00378 * RH * p) \ \ldots\ldots (12)$$

Where, p is saturated vapor pressure in bars.

p_l is the local pressure in bars.

And, RH is the relative humidity.

$$sh = mass\ of\ vapor/(mass\ of\ vapor + mass\ of\ dry\ air)$$

However, the absolute humidity (Ah) is;

$$Ah = mass\ of\ vapor/(mass\ of\ dry\ air)$$

Therefore,

```
%{
 The Mat lab Formulation
 for Absolute Humidity
 in kg of vapor/kg of
 dry air
%}
A= 8.07131;
B = 1730.630;
C= 233.426;
T=input('Enter the dry bulb temperature of the air>');
D=A-(B/(T+C));
p=10^D;%saturated vapor pressure in mmHg
ph2=0.001333223684211*p %saturated vapor pressure in bar
pL=input('Enter the local air pressure in bar>');% local air pressure in bar
rh=input('Enter the relative humidity of the air>'); %relative humidity
sh=0.00622*rh*ph2/(pL-0.00378*rh*ph2);% specific humidity i.e mass of
%vapour per unit mass of air
Ah=sh/(1-sh)% absolute humidity i.e mass of vapor per unit mass of dry air
```

When this little code is run for a temperature of 75°C, for a local pressure of 1bar and for a relative humidity of 80% it gives us an absolute humidity of 0.2765 kg/kg of dry air. The total evaporation rate $(let\ it\ be\ \dot{m}_{ev})$ in the dryer section was calculated to be 0.426 kg/s.

Let $\dot{m}_d$ be the mass flow rate of the dry air entering the dryer section.

Hence,

$$0.0067 * \dot{m}_d = \dot{m}_{v1} \quad \dots\dots\dots\dots\dots\dots (14)$$

Where $\dot{m}_{v1}$ is the mass flow rate of vapor entering to the hood.

Let $\dot{m}_{v2}$ be the mass flow rate of vapor at the other end of the hood.

This means,

$$0.2765 * \dot{m}_d = \dot{m}_{v2} \quad \dots\dots\dots\dots\dots\dots (15)$$

But, making mass balance of the vapor contents at inlet and outlets of the hood:

$$\dot{m}_{v1} + \dot{m}_{ev} = \dot{m}_{v2} \quad \dots\dots\dots\dots\dots\dots\dots (16)$$

Plugging equations 14 and 15 into equation 16:

$$0.0067 * \dot{m}_d + 0.426 = 0.2765 * \dot{m}_d \quad \dots\dots\dots (17)$$

Solving equation 17 for $\dot{m}_d$:

$\dot{m}_d = 1.5789 kg/s$, which is the mass flow rate of dry air in the hood.

From equation 14,

$$\dot{m}_{v1} = 0.0106 kg/s$$

And from equation 15,

$$\dot{m}_{v2} = 0.4366 kg/s$$

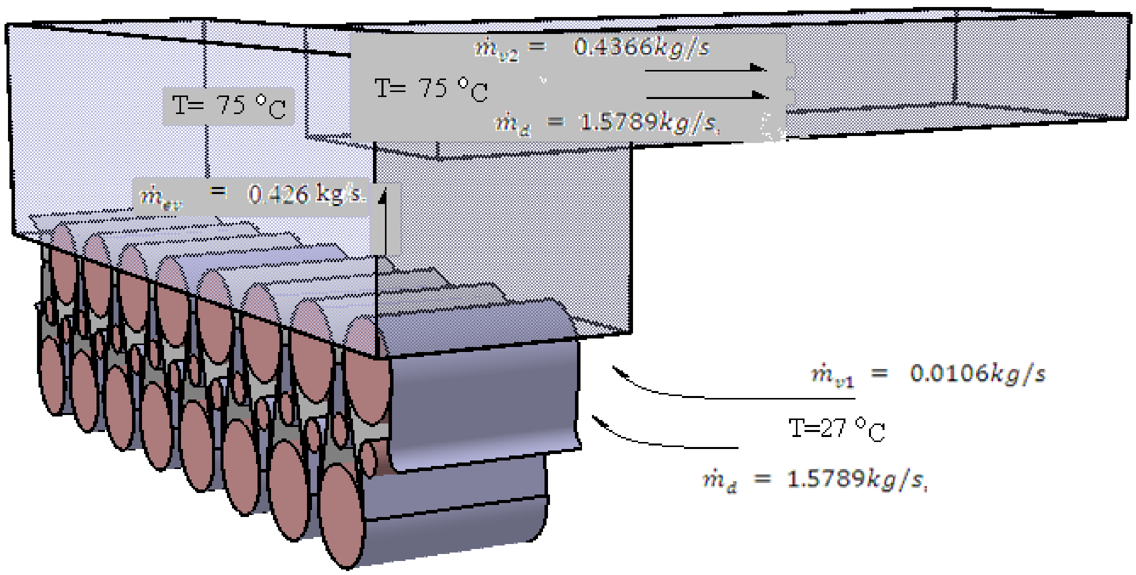


Fig. 34 Inlet and outlet air stream condition at the hood

At point 2 in the hood the temperature is75°C, the dry air mass flow rate is 1.5789 kg/s and the vapor mass flow rate is 0.4366 kg/s and the absolute humidity is 0.2765 kg/kg of dry air.

What can be done at most is to cool it to the temperature of 27°C. In so doing the maximum possible vapor that can be possessed by the mixture is found at the relative humidity of 100%. Using the mat lab code or a psychometric chart, for 27°C and 100% relative humidity, the absolute humidity becomes 0.0229 kg/kg of dry air. This implies that some of the vapor should be condensed during cooling. The rate at which vapor is condensed during cooling can be calculated.

Let $\dot{m}_c$ be the rate of condensation of vapor:

$$\dot{m}_c = \dot{m}_{v2} - 0.0229 * \dot{m}_d \quad \ldots\ldots\ldots\ldots\ldots\ldots (18)$$

$$\dot{m}_c = (0.4366 - 0.0229 * 1.5789) \text{kg/s}$$

$$\dot{m}_c = 0.4004 \text{ kg/s}$$

As the vapor comes off the mixture the latent heat of vaporization is given off through the heat exchanger. This heat (let it be Q_L) can be calculated as:

$$Q_L = \dot{m}_c * l \text{ .... } (19)$$

Where l *is the latent heat of vaporization.*

Hence, $Q_L = 0.4004 kg/s * 2260 \mathrm{kJ/kg}$

$$Q_L = 904.904 \, kJ/s$$

Which means, about 905 kilo watt of power is available from condensation only.

The sensible heat (let it be Q_s) can also be calculated as:

$$Q_s = C_{pw} * \dot{m}_{v2} * \Delta T + C_{pa} * \dot{m}_d * \Delta T \text{ .... } (20)$$

Where, C_{pw} is specific heat of water and C_{pa} is specific heat of air.

$C_{pw} = 4.18 \, kJ/kgK$ And $C_{pa} = 1.012 \, kJ/kgK$

Which means that equation 10 becomes:

$$Q_s = 4.18 \, kJ/kgK * 0.4366kg/s * (75 - 27) + 1.012 \, kJ/kgK * 1.5789kg/s * (75 - 27)$$

$$Q_s = 164.296kJ/s$$

Which means, about 164 kilo watt of sensible heat is available.

That means a total of about 1069 kilowatts of power is available for recovery. Using proper heat recovery system, more than 50% of this heat can be recovered [19]. Then it means 534.5 KW can be obtained.

Moreover, the condensation rate $\dot{m}_c = 0.4004$ kg/s. That means 24 kg/min of water can be recovered from the system. In one hour, 1440 kg of pure water can be recovered from the system. In other words, 1440 liters of pure water can be obtained from the system in one hour if it can be cooled to the ambient temperature.

The implication of this is that a remarkable amount of water can be obtained from the heat recovery system. The water to be obtained is clean and does not need too much purification therefore its usage is going to reduce energy usage associated with pumping and purification. The use of this water also saves some of the Awash River water from being used, which in turn would flow to the Koka dam to generate electricity.

5.2.1.5 Technically feasible heat recovery system

A technically feasible heat recovery system needs to be suggested. How is the heat recovered without affecting the ventilation required in the dryer section? Of course some sort of heat exchangers are required in the process, however it would be better to chose a proven system rather than an ideal one. Now days, modern paper mills use more or less similar heat recovery systems which are proven to function very well. Hence the choice of such a system would enable us to be more practical.

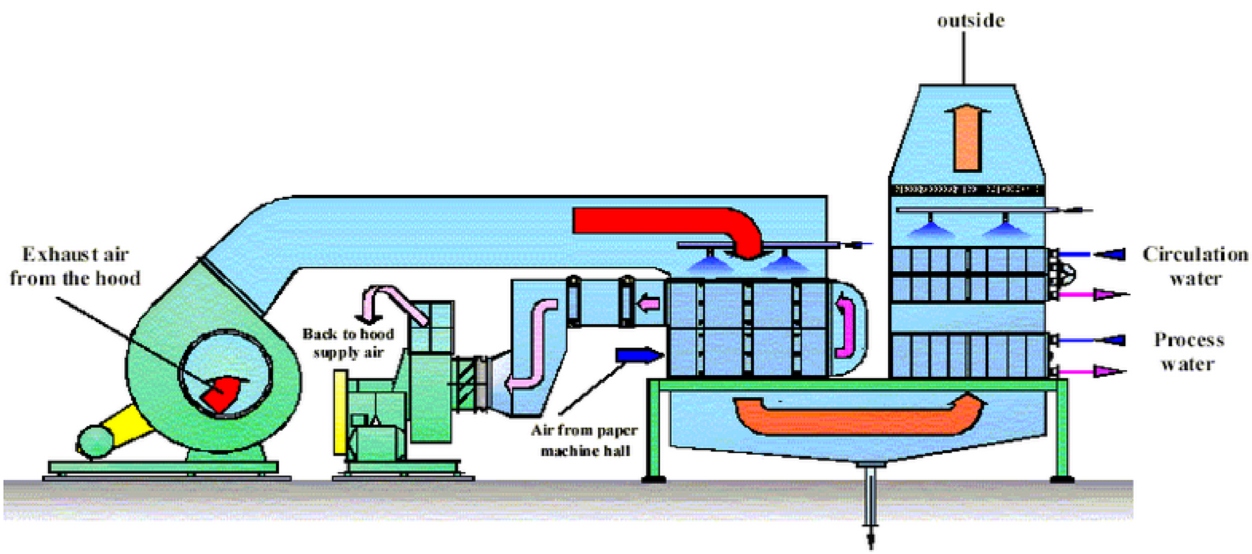


Fig 35 Modern heat recovery tower [19]

The system shown in the above figure is a typical heat recovery system that is being used these days. Especially in Europe and in some developed countries such a system is quite common. However it could be adopted for this particular factory. Exhaust hot and moist air from the hood is supplied though a duct. A shower of hot water is sprinkled to the incoming moist air enabling some of the moisture to condense down. In the meantime the hot shower and the condensate are allowed to exchange heat with air that is going to be used as hood air supply. Therefore, the hood air supply becomes hot air that improves the absorption rate in the hood while reducing the energy used for heating the ambient air. Also, the condensate is drained through the opening at the bottom recovering both energy and water.

There is also a second stage, in which a shower of water is sprinkled to the air stream where additional heat is exchanged with water that can be used back in the process. The shape of the duct makes the air stream to go down and then vertically up. This has the effect of separating the denser droplets of water from the dry air recovering the water.

Therefore this is the system that is recently being used in modern heat recovery systems worldwide. It is practically observed that it can save more than 50% of the energy coming from the dryer section [19].

5.2.1.6 Cost estimation of the heat recovery system

The websites www.matche.com and www.Alibaba.com were referred for estimating the costs of the heat exchanger, the water pump with motor, and the insulation materials cost.

Table 28

Cost estimation of the recovery system

Item No.	Name	Estinated price[Birr]
1	Two fans	100000
2	water pump with water	40000
3	The Duct work	1200000
4	Insulation material	40000
5	Heat exchangers	1000000
6	Mounting structures	300000
7	Labour and Miscellanous cost	500000
8	opportunity cost	500000
	Total cost	3680000

5.2.1.7 Cost benefit analysis of the system

The system saves more than 50% of the above power, which is 534.5KW. The energy tariff of the EEPco for the factory is 0.4086 birr/KWh. Therefore, the benefit of the system in an hour is 218.39 birr, which is 5241.5 birr in 24 hrs. In other words, the benefit is 157250 birr in one month. If we roughly think that factory works continuously for 10 months, the yearly benefit of the system will be 1,572,500 birr per year.

5.2.1.8 Cash flow

We can safely assume that the system works properly for more than 10 years.

Table 29

Cash flow

Benefit (birr)		1572500	1572500	1572500	1572500	1572500	1572500	1572500	1572500	1572500	1000000
	year	1	2	3	4	5	6	7	8	9	10
Cost (birr)		3680000	15000	15000	15000	15000	15000	15000	15000	15000	Salvage value

5.2.1.9 Present Value Analysis

Let's take a 10% interest rate which is an interest rate similar to that which is used by the commercial bank of Ethiopia when it lends money.

Equation used to calculate the present value of future money is:

$$N = \frac{M(n)}{(1+i)^n}$$

Where,

N is the present value of future money.

$M(n)$ is the value of a money after n years.

i is the interest rate.

n is the number of years.

Using the above equation, the present value of the benefit is 10385769 birr. And the present value of the cost is 3760024 birr.

Hence, benefit/cost = 2.76.

The ratio of the benefit to cost indicates that the use of a heat recovery system is financially feasible.

The total cost and the yearly maintenance and running costs are a bit exaggerated. Also, the service year can be more than ten years. Meaning that, the benefit to cost ratio is more than this figure.

By the time temperature data was taken, for the primary dryer section only one of the boilers, particularly the new boiler was functioning. The speed of the drying drum depends partially on the steam supply and partially on the type of paper being produced. When the steam supply is more, the production rate will be more. And when the gram of the paper is small, then the speed of the drum will be more. By the time the data was taken, only one of the boilers was working. Meaning, when both the boilers are working the power input to the primary drier section would increase. Implying that the benefit of the system, compared to the cost would also increase.

Referring to page 105 of this manuscript, a total of about 5349J of energy is used to purify one 1iter of water. However, assuming no rework, about an hour is required to produce one ton of paper. And previously it was found that; 1440 liter of pure water can be obtained from the heat recovery system in one hour. And since this water is more or less a pure one and no pump is required for its transport as it is already at an elevated position; its utilization would save 5349J/liter X 1440liter = 7702.56 kJ of energy can be saved in one hour. Or 7.702 MJ/ton of energy can be saved by recovering the water only.

Since 534.5 KW of heat can be recovered, it means that 1924200 kJ/hr can be recovered. It means that 1.924 GJ/ton can be saved by using this system.

5.2.2 Estimation of the rework rate

The following data is collected from the factory. The type of paper, the span, the weight, the average machine speed, the actual production time, and the amount of paper produced are all recorded in one shift. From these data, the amount of paper that should have been produced can be calculated. Hence the mass of the rework paper can be found.

Table 30

Data collected to estimate rework

Shift	Type of paper	Paper span[cm]	Date	gram/m^2	Average Machine speed[mpm]	Actual production time	Down time	paper produced in kg	Amount that should have been produced[kg]	Reworkable paper[kg]
1	Fluting medium	265	27/12/2013	140	41.5	7	1	6247	6466.53	219.53
2	Fluting Mediun	265	27/12/2013	140	42	6.75	1.25	6060	6310.71	250.71
3	Fluting Mediun	256	27/12/2013	140	40	2.75	5.25	1856	2365.44	509.44
1	Fluting Mediun	256	28/12/2013	140	55	7.25	0.75	6903	8574.72	1671.72
2	Fluting Mediun	260	28/12/2013	140	55	7.5	0.5	7414	9009	1595
3	Fluting Mediun	256	28/12/2013	140	53.5	7.5	0.5	8374	8628.48	254.48
2	Kraft liner	266	29/12/2013	175	43.5	7.5	0.5	8574	9112.16	538.162
3	Kraft liner	266	29/12/2013	175	40	7.25	0.75	8058	8099.7	41.7
3	Kraft liner	279	30/12/2013	175	37.5	7.5	0.5	6348	8239.22	1891.22
1	kraft liner	279	31/12/2013	175	42	7.25	0.75	8042	8920.33	878.327
2	kraft liner	279	31/12/2013	175	42	7.5	0.5	8337	9227.93	890.925
3	kraft liner	279	31/12/2013	175	42	2.75	5.25	2952	3383.57	431.573
2	kraft liner	242	1/1/2014	175	42	6.75	1.25	6307	7203.74	896.735
3	kraft liner	240	1/1/2014	175	42	7.5	0.5	7348	7938	590

Therefore within the above shifts considered, a total of 92820 kg or 92.82 ton of paper was produced. And 10660 kg or 10.66 ton of paper was sent back to the process line for rework. In other words, on average for every ton of paper produced, 0.115 ton of paper is reworked.

112 hours should be spent to produce 92.82 tons of paper. Which means, 1.2 hour should be spent to produce one ton of paper. The presence of a down time increases the average time required to produce one ton of paper. And when this time increases, the specific energy consumed will also increase.

If there is a possibility of minimizing or avoiding rework, there will be a possibility of reducing the energy consumption rate of the factory. Currently it is consuming 15GJ/ton. If rework is avoided, it will have a capacity of consuming 15GJ/(1.115ton). In other word 13.45GJ/ton will be the energy consumption rate only by avoiding rework. Which means, about 10% energy saving can be achieved by minimizing rework only.

The main causes of rework are:

1, lack of proper pulp preparation.

2, lack of proper balance of admixtures.

3, lack of proper cleaning of the stock.

4, sticking of the paper web on to the drying drums due to overheating of the drum surface.

Energy conservation measures:

1, Use of instruments that can show the consistency of the mixture while it is being stirred up so that the point of time to end the process is determined

2, Use of on spot identifier of mixture balance

3, Use of additional stock cleaner attachments so that unwanted ingredients may be removed

4, Use of automatic pressure and temperature regulator device so that the surface temperature may be controlled

5, Use of on spot paper weight control system

6, Use of on spot moisture content controller.

Installation of the above instrumentation can reduce the rework remarkably.

Cost

Roughly, a cost of 4000000 birr is required to purchase and install those instruments.

Benefit

The factory produces 4600 tons of paper per year, hence with 1.55 GJ/ton saving opportunity, 4600 X 1.55 = 7130 GJ = 1980000 kwh of energy can be saved per year. With the energy tariff of 0.4086 birr/KWh, 809028 birr can be saved per year. The system can be assumed to work for 15 years.

Table 31
Cash flow

year	Cost [birr]	Benefit [birr]
1	4000000	809028
2	10000	809028
3	10000	809028
4	10000	809028
5	10000	809028
6	10000	809028
7	10000	809028
8	10000	809028
9	10000	809028
10	10000	809028
11	10000	809028
12	10000	809028
13	10000	809028
14	10000	809028
15		100000

Table 32
Present values

Present Value of cost	Present Value of benefit
4071033.562	6555842.062

Hence the benefit to cost ratio is 1.61, showing the financial feasibility of the solution.

5.2.3 Motor audit

The intension of this is to include some motors for audit. Since the motors were continuously working it was not possible to carry out a no load test. Three major motors on water supply line were selected because estimation of the energy consumed per liter of water was also required in the mean time.

A. *Motor drive at the Awash River*

It has been 40 years since it was installed. There are three submersible pumps at the Awash River. Only one of them was engaged and one was a stand by while the other was taken for maintenance. There was a lot of vibration and noise heard during operation of the pump indicating that the motor was not smoothly operating.

Table 33

Name plate information

Rated Voltage	Rated Current	Rated Speed	Rated Power	Rated Power	Phase	pf
380 V	73Amp	970 rpm	50HP	37285W	3	0.8

Table 34

On load measurement

Voltage	Current	Wire resistance
380 V	47Amp	1.84 ohm

Percentage loading

Let,

L_p be percent loading

V_r rated voltage

I_r rated current

V_m measured voltage

I_m measured voltage.

Then, $L_p = [(V_m * I_m)/(V_r * I_r)]*100$

Hence, $L_p = 64.4$ %

This means that the motor is not severely under loaded.

Power input to the pump

P = 3*380*47*0.8 -3*(47^2)*1.84

P = 30670 watts

Assuming a pump efficiency of 60%

Then; 0.6 x30670 = 18402 watts is on the fluid.

The pump is located 2m below the water reservoir and due to pipe length and elbows a head loss of 2m is present. Hence for an equivalent head of 4meters, a density of 1000 kg/m^3, and gravitational acceleration of 9.81m/s^2;

$\Delta P = 1000*9.81*4 = 39240$ Pa.

But, 18402 = 39240* Q

where Q is the volume flow rate.

Hence, Q = 0.469 m^3/s.

Which means that 0.469 m^3/s or 469liters/s of river water is sent to the factory.

Therefore, at this stage 30670watts/469 liters/s = 65 Joules/liter is consumed.

B. *Motor drive at the water bank pump*

This motor is used to distribute partially treated water from a reservoir to the factory, and to the Ro pump. It has been more than 40 years since it was installed. It was wound a number of times. There are two such motors; one is engaged while the other is a standby.

Table 35

Name plate information

Rated Voltage	Rated Cur	Rated Sp	Rated Power	Rated Power	Phase	pf
380 V	144Amp	1500 rpm	100HP	74570W	3	0.85

Table 36

On load measurement

Voltage	Current	Wire resistance
380 V	105Amp	1.04 ohm

$L_p = [(V_m * I_m)/(V_r * I_r)]*100$

$L_p = [(380*105)/(380* 144)]*100$

$L_p = 73\ \%$

This means that the motor is well loaded to a maximum efficiency point.

Power input to the pump

P = 3*380*105*0.85 -3*(105^2)*1.04

P = 67214.7 watts

No pressure gage and no flow rate gage is installed between the two ends of the pump, hence it very difficult to know the pressure and the flow rate of the water. Assuming that the flow rate is equal to that of the awash water flow rate, 469 liters/s, the energy consumed per liter will be, 67214.7Watts/469 liters/s = 143 Joules/liter.

C. Motor drive at the RO pump

This motor drives a pump that pushes water through a reverse osmosis plant. It has been more than 17 years since it was installed.

Table 37

Name plate information

Rated Voltage	Rated Cur	Rated Sp	Rated Power	Rated Power	Phase	pf
380 V	73Amp	1500 rpm	50HP	37285W	3	0.85

Table 38

On load measurement

Voltage	Current	Wire resistance
380 V	45Amp	2.1ohm

$L_p = [(V_m * I_m)/(V_r * I_r)]*100$

$L_p = [(380*45)/(380* 73)]*100$

$L_p = 61.64$ %

This means that the motor is not severely under loaded.

Power input to the pump

P = 3*380*45*0.85 -3*(45^2)*2.1

P = 30847.5 watts

Assuming a pump efficiency of 60%

Then; 0.6 x30847.5 watts = 18508.5 watts is on the fluid.

The pressure difference is read to be 31barr or 3100000 Pa.

But, 18508.5 = 3100000* Q, where Q is the volume flow rate.

Hence, Q = 0.0059 m^3/s.

Which means that about 6 liters/s of water passes through RO. Therefore, at this stage 30847.5/6 = 5141 Joules/liter is consumed.

Therefore, roughly, it can be said that [5141+ 143 + 65] J/liter = 5349 Joules/liter is consumed to treat and transport the river water.

These motors are all loaded at more than 60%. This indicates that they are loaded well. However, they are all very old motors, most of them 40 years of age. They also have been rewound a number of times. This means that at this time their efficiency could be a bit lower. Approximately, new motors 40 years ago had a maximum efficiency of 80%. And rewinding of motors is known to decrease their efficiency remarkably. Hence these motors can have an efficiency of up to 75%.

These days high efficiency motors do have efficiencies up to 95%. Replacement of these motors by modern high efficiency motors would definitely save a good deal of energy. According to the technical personnel in the factory, if replacement is an alternative, usually the motors would be bought from China. But these motors are made in America, and are well known for their performance. The factory is well satisfied by the reliability in the performance of the motors. Motors made in china are well known for their poor performance. Hence realistically, replacement of these motors is far from being an option.

5.2.4 Estimation of energy loss due to steam leakage

There are 35 steam leakage spots of 2 mm average diameter with average temperature of $105^{o}C$ and a pressure of 120.9 kPa, in the factory. This data was gathered by counting the spots and taking the temperature measurements using the infrared thermometer. However the spot diameter was rationally estimated. Using this data and an online energy calculator it is possible to estimate the energy lost in one hour.

Using www.rjstacy.com/calculator.html, which is an online steam leakage calculator, and feeding the above data after proper conversion of units and feeding one dollar for 1000 pound steam leakage, the amount of steam leakage in one day can be calculated. For example, in this case, 0.12 dollar was the cost in one day. This implies that 120 pounds of steam leaks in a day which is 54.4 kg.

Which means,

$$54.4\text{kg}/24\text{hr} = 2.27 \text{ kg/hr}$$

Hence, 2.27 kg of steam leaks in one hour from the factory at one spot.

From steam tables, the change in enthalpy required to generate steam is;

$$2683.4 \text{ kJ/kg} - 104.83 \text{ kJ/kg} = 2578.57\text{kJ/kg}$$

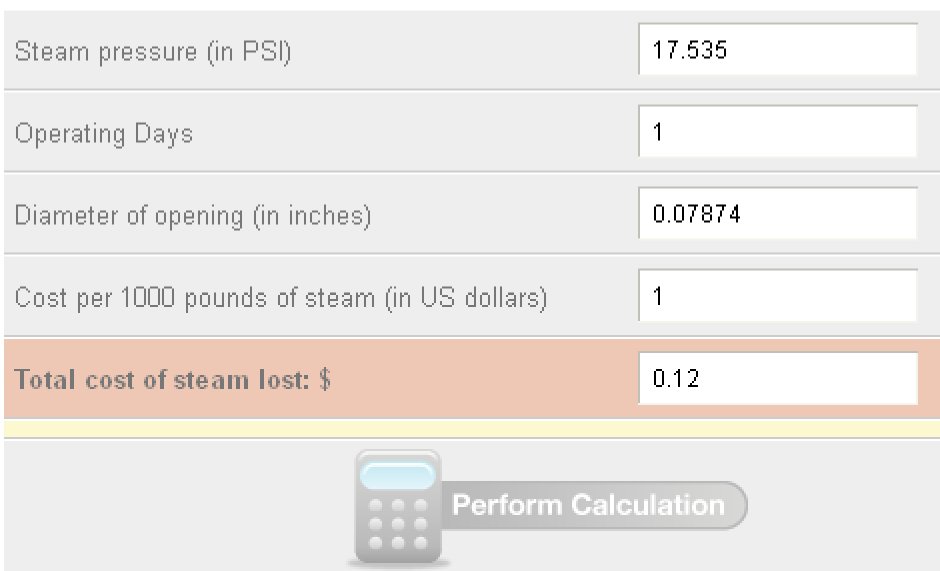
Which means;

$2578.57 \times 2.27 = 5.85$ MJ of energy is wasted in one hour due to steam leakage at one spot.

Therefore, at 35 spots it becomes,

$$35 \times 5.85 \text{ MJ} = 204.75 \text{ MJ}$$

204.75 MJ of energy is wasted in one hour.



Fig, 36 online steam leakage calculator

If elimination of steam leakage is possible then it means that 0.204 GJ of energy can be saved by the time one ton of paper is produced.

The Annual production of the factory is 4600 Tons.

Hence, in one year, 0.204 x 4600 = 938.4 GJ can be saved.

But 938.4 GJ = 260666.7 kwh

With a tariff of 0.4086 birr/kwh,

0.4086 x 260666.7 = 106508 birr can be saved per year

5.2.5 Estimation of energy loss due to condensate leakage

Roughly, on average a one liter container fills in 2 minutes at about 40spots in the factory. However this data was taken at different times since it was difficult to do it at once.

Hence, 40 x 1= 40 liters in 2 minutes =20 L/min = 0.33 liters/second.

Which means, approximately 0.3 liters of condensate leaks from the factories condensate return line in one second. And one hour is approximately the time required to produce one ton of paper.

Hence in one hour,

0.3 x 60 x 60 = 1080 Liters/hr

That means, 1080 liters of condensate with an average temperature of 80^oC leaks out from the line. The amount of energy used to compensate this begins from purification. Roughly, 5349 J/liter is the energy consumed for purification. That means, 5349 x 1080 = 5776920 Joules or 5.78 MJ of energy is used only for purification. And also heat should be added to bring the 80^oC temperature rise.

$$\Delta T = 80-27 = 53^oC$$

$$C_{pw} = 4.187 \text{ kJ/kgk.}$$

Which means that, $\Delta T \times C_{pw}$ = 221.9 kJ/kg, of energy must be added.

But one kg of water is equivalent to one liter, hence, 221.9 x 1080 = 239652 kJ or 239.65 MJ of energy must be added in the form of heat.

Therefore, a total of 245.43 MJ or 0.245 GJ of energy should be consumed to make up for the condensate leakage. In other words if condensate leakage can be eliminated, then 0.245 GJ/ton can be saved.

The Annual production of the factory is 4600 Tons.

Hence, in one year, 0.245 x 4600 = 1170 GJ can be saved.

But 1170 GJ = 325000 kwh

With a tariff of 0.4086 birr/kwh,

0.4086 x 325000 = 132795 birr can be saved per year.

5.2.6 Boiler replacement

In the beginning, the factory was using electrical energy for steam generation and for the drive systems. At that time the cost of electricity was good. However, the cost of fuel oil was much cheaper that the then cost of electricity. Once upon a time a research was made by some of the engineers in the factory to show that the use of furnace oil to boil the steam was financially advantageous for the factory. The idea was able to convince the then management and two boilers were purchased. The entire system was altered from electric boiler to fuel boiler system. In so doing, the electric boilers and their respective attachments were somehow side lined.

Through time the price of fuel oil escalated to the extent that the factory wouldn't survive by using it. The cost of electricity became very much better. Then the factory was forced to use electric boilers as an option once again. By the time the electric boilers were side lined they were thought to be no more important. The RO plant was not required by the time the factory was using fuel oil hence it was deteriorating as well.

As of 2012, the factory is using electrical energy completely. Taking into account the age of the factory, which by itself is the cause of down time, the system shift of the factory has aggravated the frequency of down times in the factory. Even though the cost of electricity was affordable by the factory the specific energy consumption has drastically increased by the time it turned back to the electric boiler system. It could have been even worse had they not bought one new electric boiler. The use of the old electric boilers necessitated the use of the reverse osmosis plant which once was sidelined.

Table 39

Energy consumption of the RO plant

Electric power used by RO [watts]	Flow rate [l/s]	Flow rate [l/hr]	Energy used [J/l]	Energy consumption of RO [J/hr]
43605	6	21600	7267.5	156978000

Note. Energy consumption of RO plant is about 0.16 GJ/hr

If new electric boiler is purchased then the RO plant is no more necessary. A new boiler costs 2500000 birr. And it saves 0.16GJ/ton. Average production of the factory is 4600 ton per year. That is, 736 GJ or 204444.4 kwh is saved. With the energy tariff of 0.4086 birr/KWh, 8353 birr can be saved per year. The system can be assumed to work for 20 years. When the present value analysis is made on this solution, it may seem to be financially not feasible. However it can be seen from its influence on the reduction of the factories down time.

Down time is caused by the presence of problem in the factory. Some problems make production to delay and some problems could force production to stop. Those problems which make production to delay are very important in terms of specific energy consumption. When the average time required to produce one ton of paper, is increased due to down time, then the specific energy will also increase. Figure 30 shows a drastic change in the specific energy near the time the factory decided to make a system shift from fuel to electric boilers.

On the other hand, the report of the factory shows that the number of reasons for down time has drastically increased near the time the factory decided to make the system shift.

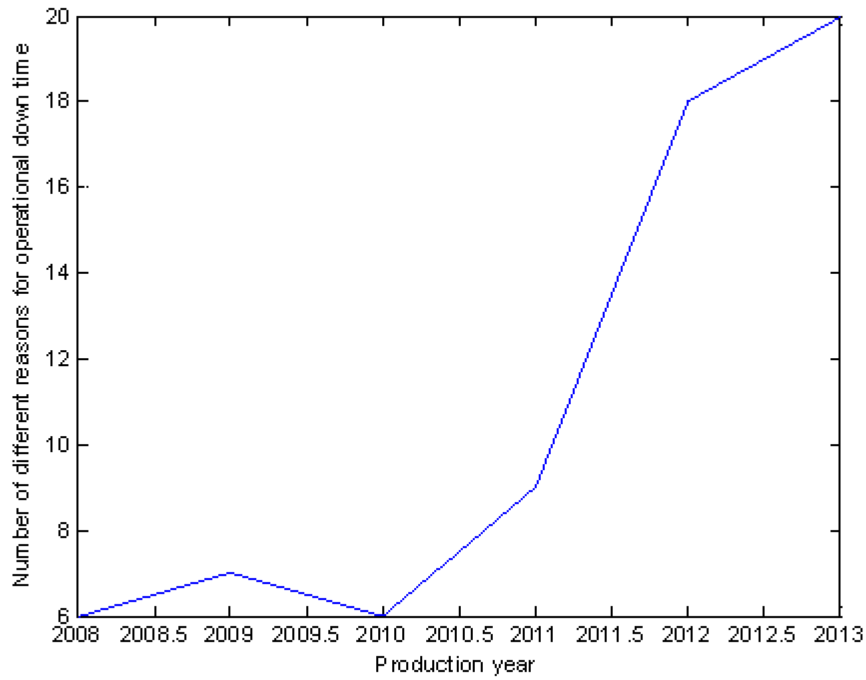


Fig. 37 Number of different operational reasons for down time *(source: job implementation report of the factory)*

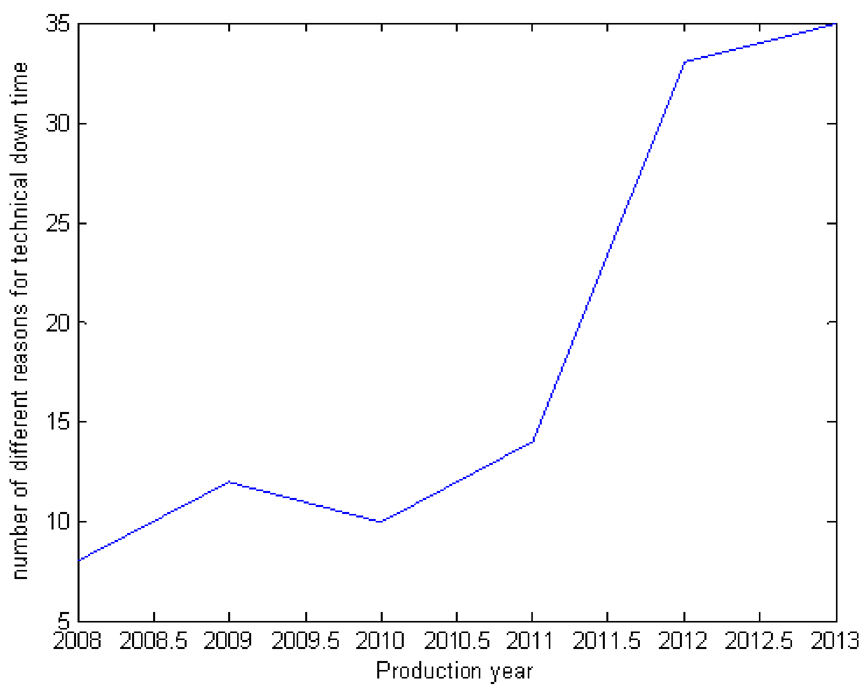


Fig. 38 Number of different technical reasons for down time *(source: job implementation report of the factory)*

CHAPTER SIX

Conclusion and recommendation

6.1 Conclusion

The Ethiopian pulp and paper factory is a government owned paper factory. It was established some 50 years back. Due to aging and a number of other reasons the factory is deteriorating in terms of energy use. Recently it is using twice the energy it is supposed to use. It is high time that it gives proper concern for the issue and work for a better performance. So far it was looking for a cheaper source of energy to save the cost; however, it should also search for ways of producing for lesser and lesser energy. It has to reduce the amount of energy used per ton of paper produced no matter what the source of the energy may be.

In the beginning the factory was using electrical energy for steam production. But some time in the past the engineers of the factory proposed to use fuel for steam production due to the then oil price which was remarkably cheaper than electricity. The proposal convinced the then management and steam production started after two boilers were purchased. The electrical system was sidelined. However, recently the use of a fuel oil was far beyond an option. The factory was force two use electrical energy especially in the last two years. Last year the factory was using electrical energy 100%. In addition to its age it was forced to use a once rejected and sidelined system for steam production.

When the energy consumption of the factory was investigated, it was using about 9.3 GJ/ton of paper but recently its consumption has jumped to 14 to 15.5 GJ/ton. What happened to the factory was a big question. When the number of different technical and operational reasons for down time was investigated, it was found that they showed a similar trend. They have drastically increased in number. Which means that, production delliance had occurred due to more versatile and unexpected reasons than before. This must have caused increase in the average time required to produce one tone of paper. This can drastically increase the specific energy consumption of the factory even though it may be affordable by the factory.

Due lack of quality in the stack preparation, that is due to lack of cleaning of unwanted ingredients in the stock; due to lack of perfect balance of mixture which is associated with lack of proper instrumentation and process control; due to lack of control of surface temperature of the drying drums; and a number of other reasons, continuous and smooth operation is almost impossible by the factory. Therefore rework is remarkably part of the production process. About 10% of the product is reworked, which has a direct impact on the specific energy consumption rate of the factory. Hence, 1.55GJ/ton or 809028 birr per year can be saved by avoiding rework.

The primary drying section which has 16 drying drums was analytically investigated. Since, the factory is not using a waste heat recovery system at the drying section, There, a huge amount of heat and water vapor is simply ejected to the atmosphere. Modern waste heat recovery systems have a capacity of saving more than 50% of the waste heat and also a remarkable amount of water can be condensed by using such a system. Up to 1.924 GJ/ton energy and 1440 liters per hour of pure water can be saved by using such a system.

Even though the secondary dryer section, which has 6 drying drums, was not deeply analyzed, it is clear that similar result would be found. If proportion is taken by drum number then about 0.6 GJ/ton would be the potential from the secondary dryer section.

A remarkable amount of steam and condensate leakage spots are also pointed out and roughly 0.5 GJ/ton of energy is wasted due to that.

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6.2 Recommendation

The main problem that increases the specific energy use is lack of continuous and smooth production, which in turn is due to aging and deterioration of some of the systems of the factory. In the absence of continuous, smooth and uninterrupted production rework will be there; down time will be there which will increase the specific energy use.

Hence to solve this problem, the factory should renew itself through;

1. Intensive and quality maintenance.
2. Modernization of the systems of the factory to enable itself competent in the world market.
3. Installation of modern process control systems so that down time and rework would be minimized.
4. Replacement of old systems by new ones.

Another main problem in this factory is the lack a heat recovery system. The dryer sections of the factory must be equipped with heat recovery systems so that a huge amount of energy as well as water can be recovered.

If the factory is able to solve these two main problems then:

1. It will improve its specific energy consumption and save a lot of money.
2. It will increase its production rate and profit more.

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