Firewood kiln dryer

LAB University of Applied Sciences
Bachelor of Engineering, Mechanical Engineering and Production Technology
2021
Vasilii Emelianov

Abstract

Vasilii Emelianov	Publication type Thesis, UAS	Completion year 2021
	Number of pages 45	
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Abstract

Birch firewood drying is a very complicated and comprehensive problem that requires the right principle and equipment that must be chosen according to scientific standards and rules. This study aims to find the most efficient, easy to operate and affordable solution for firewood drying and helps to implement this idea as a business start-up for young entrepreneurs. This thesis is based on knowledge from the scientific literature related to the theory of wood drying and experience from the working life in field of wood processing and timber production. The result of the project is a fully calculated firewood dryer that is a profitable and effective complex of special devices that makes drying of birch firewood in very short time possible. This project shows that firewood drying is a simple process that requires basic knowledge in the theory of wood drying and engineering and could be used as a business idea.

Keywords

Kiln dryer, firewood, effectiveness

1. Introduction

Humanity has been searching for energy sources since ancient times, initially fire perceived as something mystical, as a substance from Gods that presents people heat and gives the possibility to cook food and to process metal. Nowadays, the situation has changed, we know a lot about combustion processes, we know how to heat energy and heat from the fire, we have mastered the art of fire.

The first-ever used energy source is firewood, which is the most accessible and widespread type of energy source on our planet. Humans started to use wood biomass to produce heat energy about 400 thousand years ago, moreover some scientists say that there are proofs that ancient people used fire 1,5 million years ago. The mastery of fire-making led ancient people to rapid evolution, the evolution that differs humans from animals.

From this moment wood remains one of the most used power and energy sources, with growing popularity all over the world during the last years. But in this thesis, I would primarily talk about firewood cut into small pieces, used in households.

(Price David, Energy and Human Evolution)

Ancient people explained the burning process as a mystical process controlled by gods and spirits, but in real, modern life burning of every material is a very complicated and comprehensive physico-chemical process, that requires knowledge and experience in many scientific spheres. To start burning of any material, including woos, three main components are needed: oxygen, heat, and fuel. From the scientific side of view this process called combustion. When wood is heated to a specific temperature (many factors define this temperature, such as moisture contents, species, environmental conditions) pyrolysis starts, pyrolysis is characterized by breaking of bonds in the wood structure, this releases atoms and energy.

(A.S.Androsov, Theory of burning and explosions, 4.)

Figure 1. Firewood (Image: Marcociannarel)

Many years ago, firewood that is shown on the figure 2, was one of the most used heat and energy sources for almost every private house and in manufacturing purposes, but in the 21st century the situation has changed, and nowadays people have other types of energy sources, such as gas, electricity, etc. But concerning all the advantages of using modern types of energy sources, people still use wood in households and in businesses and the volume of firewood consumption growth annually.

Figure 2. Birch firewood pieces (Drova96.ru)

The change of firewood consumption would be correlated with change in fuelwood, firewood and fuelwood have mostly the same purpose, but they are used by different customers and in different areas. For firewood the most used segment is households, for fuelwood this segment is factories and other businesses that are concerned about using renewable energy sources.

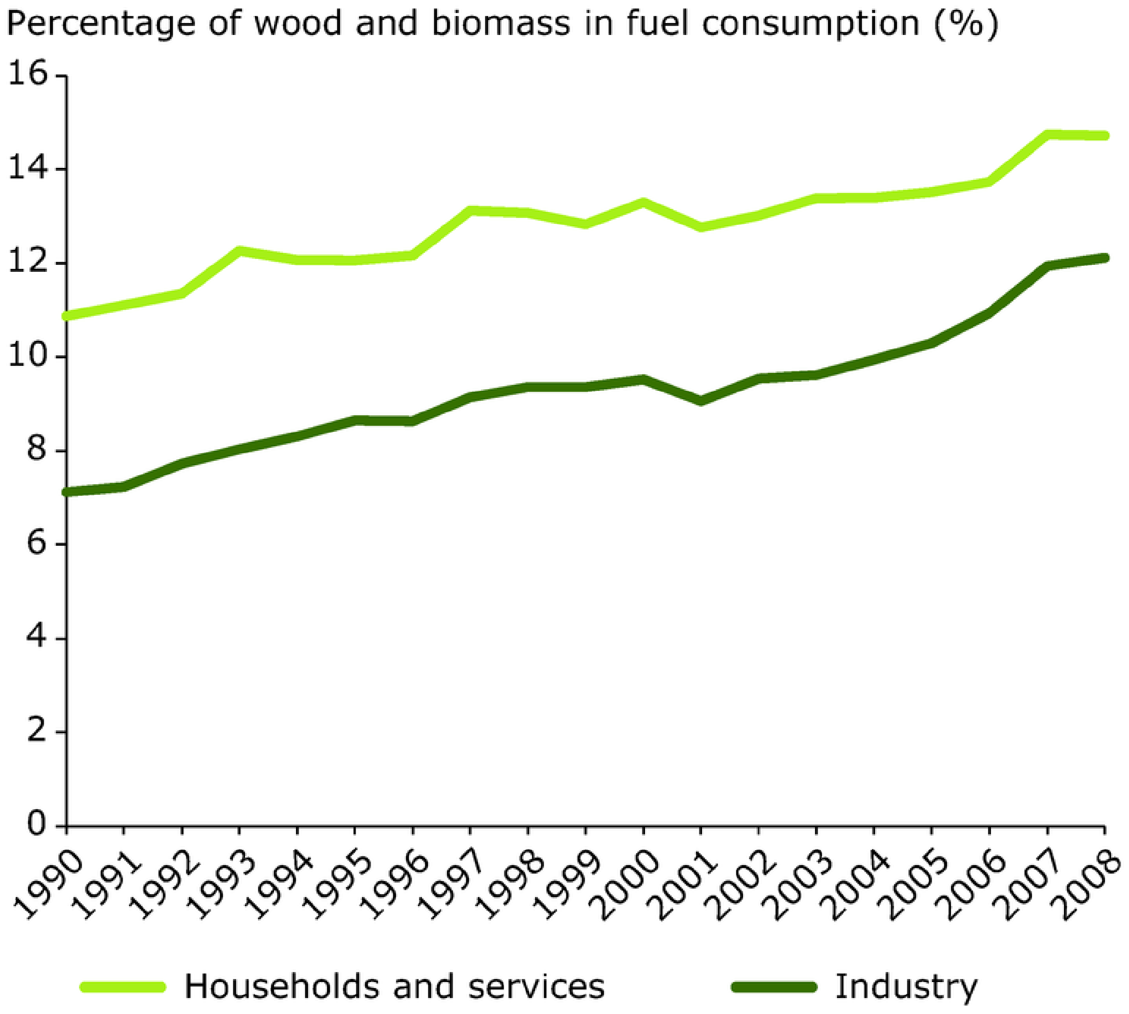

Figure 3. Percentage of wood and biomass in fuel consumption (European environment agency)

On the figure 2 the annual growth of wood fuel is shown. This success of such and old fashioned and a complicated to use in manufacturing processes fuel is the result of decision of the Europe and many other developed regions to start using more renewable energy sources instead oil, gas, and other hydrocarbons. Also, this growth could be a result of developing forestry industry that is concerned about using every piece of harvested wood.

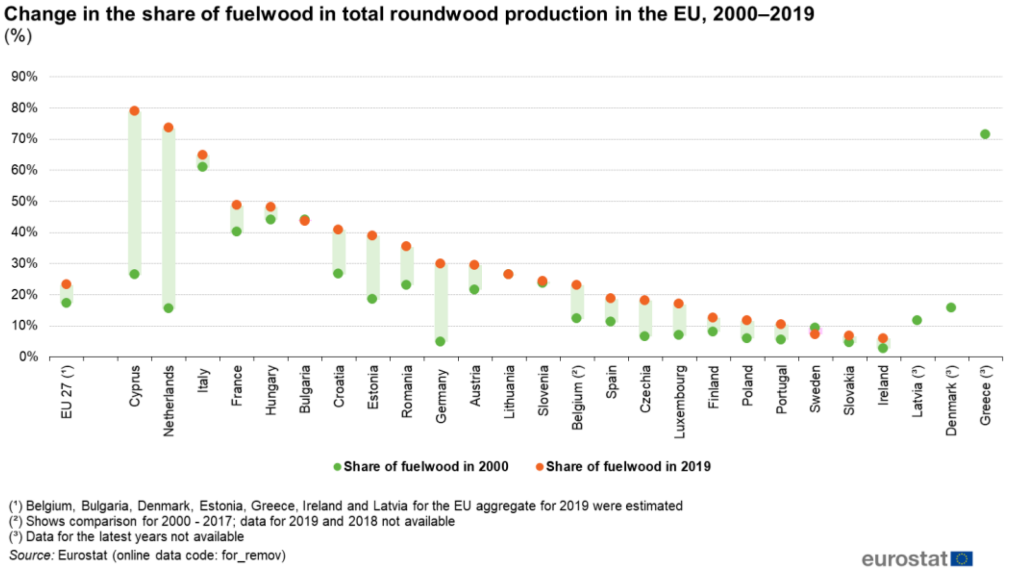

Figure 4. Fuelwood harvesting share (Eurostat)

Considering the collected data, presented on both figures 3 and 4, shows that during the last years popularity of wood as an energy source grows annually and would grow due to the restrictions, recommendations, laws and willingness of people to change the ratio among usage of renewable energy sources and non-renewable fossil fuels.

The difference between households and businesses is the type of fuelwood, households mostly use firewood from the figure four, while manufacturers use chips and pellets to heat their machines and other systems. Also, for households not only heat given by wood matters, beauty of clean flame and fragrant smoke means a lot for many firewood users.

Humanity search for the best and the most efficient way of using every fuel type, for firewood this way is dried firewood. Drying changes wood to a fuel, an efficient fuel, that could be delivered worldwide.

People in different regions use different wood species to heat their houses, but for our northern countries, including Finland, Sweden, Russia, Norway, etc, the most used species are hardwood, including birch and alder. High thermal effectiveness, quality and outfit gives all the opportunities to become bestsellers in the field of eco energy sources.

About 8 months ago I decided to start a business, and my idea was to design a chip and effective dryer for firewood, that every person with basic knowledge in engineering would be able to assemble and use. In this thesis I would step by step show the process of designing this machine, I would show how easy it is to operate and why dried firewood popularity grows year by year. Also, some solutions on how to improve the system and to make it automated would be mentioned in this thesis, but my basic idea is to design something very simple, that almost everyone is capable of operating.

I was searching the net to find the best solution to implement my idea, but most of them are too complicated and more suitable for high quality timber products, than for firewood, my solution is supposed to be as cheap as possible to give this type of fuel to compete with other modern heating systems, with manual operation principle and easy installation process. My goal was to evaluate what is the fastest way to dry wood, not concerning quality, in terms of exterior, and my decision was to stop on the air-heated system without active safety and special controlling units.

2. Theory of drying

Forest industry, which involves all the spheres such as loggers, pulp and paper producers, sawmills, and plywood factories, faces the task of increasing the quality of the products without significantly expanding the harvesting areas. All the resources should be used rationally, with maximum outcome. One of the solutions for this problem is obligatory drying of all the timber products. During the last decade drying capacities have increased due to the construction of new types of dryers, automatization in all the aspects of this comprehensive process, also new drying modes were calculated to establish the most rational and profitable drying cycle. However, this problem has not been fully resolved, drying of the wood remains one of the most important tasks for the forest industry.

Figure 5. Kiln drier for wood (Nevastankomash group)

From the theory side of view, drying is the process of removing water from the material by vaporizing. In ancient times the only one way to dry wood was drying in atmospheric conditions, nothing except fresh air, sun, and wind. In the modern world it could be done using many special methods but all of them are based on gaseous or liquid atmosphere inside the drying chamber. Gas or liquid that dries wood, is called a drying agent. Hot drying agent directed to wet wood, giving its heat, and then cooling, water is vaporized by direct heat contact. Other methods that are based on mechanical extruding of water from the wood are used in the pulp and paper industry, but this is a much different method that would not be described in this thesis. Most of the producers who make high quality dry wood for construction purposes, as well as for furniture, use steam as a gas. Hot steam is transferred from a boiler to the chamber and wood is dried gently, with changing cycles. But there is a problem that in normal atmosphere pressure water could not be heated over 100C, that leads to a problem of very slow drying. Air, as a drying agent, could be heated to a very high temperature. But controlling and moisturizing is much more difficult in this case. Nowadays, gas dryers are the most used in the world, other methods used only for special purposes. Any of the methods utilize a significant amount of energy to produce heat, various types of fuel are possible to use. It could be natural gas, wood wastes, as well as chips, sawdust, bark. Some of the dryers use electric energy. The only thing that matters is how fast and how well the drying is done.

Drying wood is a very important step in the process of preparing wood the be delivered to the final customer, because when this is done, wood from a raw natural material becomes industrial material that meets various requirements for industrial and domestic usage. For constructional elements the most critical requirement is shape and size, for furniture exterior, for firewood is heat of combustion. Also, dry wood is fungi resistant, it makes wood durable, even in the unprotected atmosphere, moreover fungi could be a reason for many diseases, that is unacceptable in modern world.

Figure 6. Fungi damaged firewood

From this moment I would primarily talk about firewood drying. This process is similar to the process of drying timber products, but this process is much more severe, with less control and without moisturizing to eliminate wood cracks. For firewood there are only two requirements, the first is heat of combustion that is correlated with moisture percentage, and the second is fungi resistance. Appearance, cracks stay on the background. Also, to reduce the logistic costs it is very important to reduce the weight of the final product by removing the water from the wood.

1. Heat of combustion
2. Resistance to the atmosphere or fungi resistance
3. Weight

(P.V.Boldyrev, Wood drying, practical guide 2002, 5-12.)

Standard moisture requirement for firewood is 15% of moisture or less, for constructional timber products it could be even 8% to make planing and gluing possible. Moisture inside the wood sample in percent is calculated using the following formula:

$$W = (m_w/m_d)100\% = ((m-m_d)/m_d)100\% \quad (1)$$

m_w=mass of the moisture (water) in the sample

m_d=mass of the dry sample (0% of water inside)

m=total sample weight

(A.I.Rasev wood drying 1990, 21.)

Formula of the moisture contents (1) allows to evaluate moisture contents of the sample even without special devices, only weighing scales and the mass of dry wood is needed.

As it was mentioned before, in this thesis I would primarily focus on firewood, and the best suitable species for firewood in the northern region is birch. Birch has one of the biggest heat of combustion among all the deciduous trees and this species is very common for this specific region. Not only high heat combustion makes this species a perfect fuel for households, but also birch has no resin, as conifers do, birch's flame is clean, hot, long lasting, and fragrant, giving stable and efficient flame for households. To make this type of firewood more efficient, stable, and clean, drying process is required. After drying it is not needed to vaporize huge amounts of water from inside during the combustion process, moisture contents drop from 70-90% (standard moisture contents for fresh harvested birch) to 10-18%. One more advantage of dry firewood is that this firewood makes calculating and forecasting of the needs for boiler, fireplace, grill possible. Dry firewood has defined value of heat that it gives during the combustion process (Heat of combustion), drying makes firewood excellent fuel for households.

Heat of combustion is calculated using following formula:

$$q = \frac{Q}{m} \tag{2}$$

(Noifert. Constructional design edition 38, .467)

where Q is the amount of heat that was released in the process of full burning in Jules, and m is the mass in kilograms. For dry birch this number is 15 MJ/kg, that could be calculated by special test in calorimeter using formula (2) or taken from the books.

(Noifert. Constructional design edition 38, .467)

Moisture is controlled using a tool called moisture meter, a very efficient and fast tool for controlling moisture content after drying. Also, in advanced drying systems it is possible to install this device into the chamber to control moisture during the cycle.

Figure 7. Difference in moisture contents of the tested sample

On the left picture the final result of intensive drying is shown, the right picture shows the same sample after the first 24 hours of drying. The moisture contents before the drying was 60%. 4,5% moisture contents make birch almost absolutely dry (0% of water), now it becomes high-efficient fuel, protected from fungi damage and ready to be delivered to the final customer all around the world.

3. Principle of operation

The working principle of this machine is based on hot air supplied into the drying chamber, air is heated around the heat generator inside the special separate section and then immediately transferred with the help of fans to the main section with wood. Heat is given to the firewood pieces, air is cooled, due to transfer of heat, and then returned back to the heat generator. Very simple cycle that makes drying possible. Body of the kiln dryer, which looks like a ship container, divided into two sections. One of the sections is the place where the heat generator stays, the second is made for cages full of firewood. Firewood pieces in the cages are piled to provide free passage of the air through the cages, without obstacles and to be sure that even the centre of the cage is dried to the needed moisture percentage.

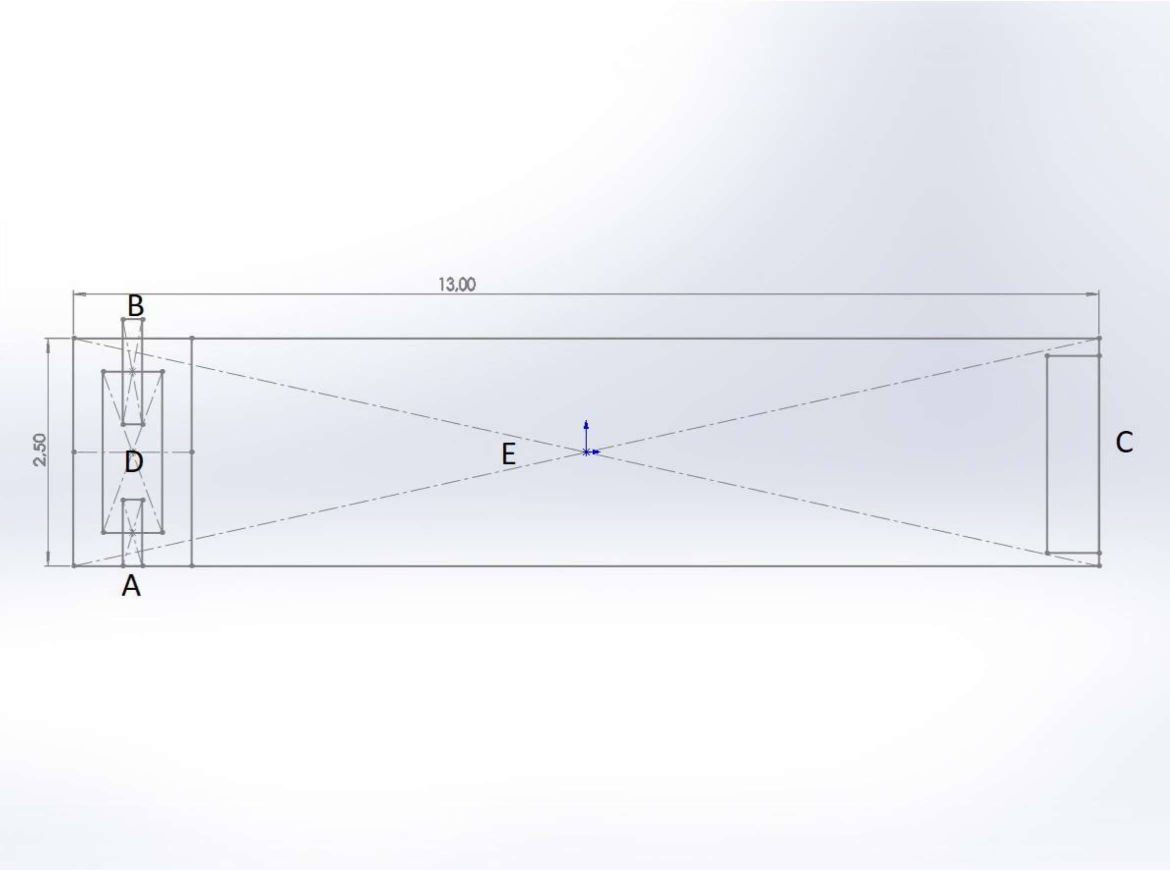

Figure 8. Sketch of firewood dryer

On the figure 8 the most important components of the drier are marked. Letter A shows the inlet for fuel, letter B – exhaust pipe, C is the gate for cages, D is the heat generator and E is the heated chamber. Dimensions for the drier are 13 m length, 2,7 m wide and 2,5 m height.

Heat generator for this drier works on the wood biomass, that in my opinion the most reasonable fuel for the system. During the process of producing firewood, many wastes are left, such as wood chips, sawdust, short pieces of firewood that could not be sold to the final customer. Wood powered heat generator is the clue to effective utilization of all the wastes with maximum effort and it allows maximum profits from the process of drying.

The problem with wastes as a fuel for the heat generator is that feeding system could not be automatized due to material heterogeneity, and this leads to one more huge problem related to human factor, it can cause many mistakes in drying process and that the process could not be perfectly balanced in the different stages.

Figure 9. Different types of fuel

Those types of fuel are fed into the combustion chamber till the needed temperature is reached, many ways of heating cycles are possible, but I would go back to this problem in the next chapters, where the process of drying is described.

The heated air is the working body in this system, that makes the drying process fast and easy to operate. Also, it minimizes the price of the project, no need in water supply, no pumps and other instruments that are used to control water flow. There are many other possibilities for the wood drying process, but air is the most efficient for firewood, because temperatures inside the chamber can raise up to 180C, compared to steam, for example. Also, the heat generator requires no comprehensive pipe system, which increases the price of the final product significantly.

For an effective and safe drying cycle two more holes on the left and right walls are needed. One hole is the place where the side fan is located, and the second hole is made to connect a pipe that takes moisture-laden air (steam) out. Also, this hole could be used to lower the inside temperature in case the maximum limit is reached.

Below on the figure 10 the basic sketch of the dryer is presented, fuel in the heat generator (1) is burned and energy is released. Air around the heat generator is heated and then transferred to the drying chamber (2), red arrows show hot air, blue show air with lower temperature after the full circle is done (firewood takes some heat, also some heat is lost, system is not perfect) , and then it goes again and again. Green arrows show an inlet for fresh air and outlet for hot moisturized air.

This idea, that is presented above, fully satisfies the requirements for successful drying, especially when quality stands in the background. We have high temperatures, steam could be taken out and air recirculated through the material inside. These three components are supposed to dry firewood from 80% to 20% moisture content in about 50 hours.

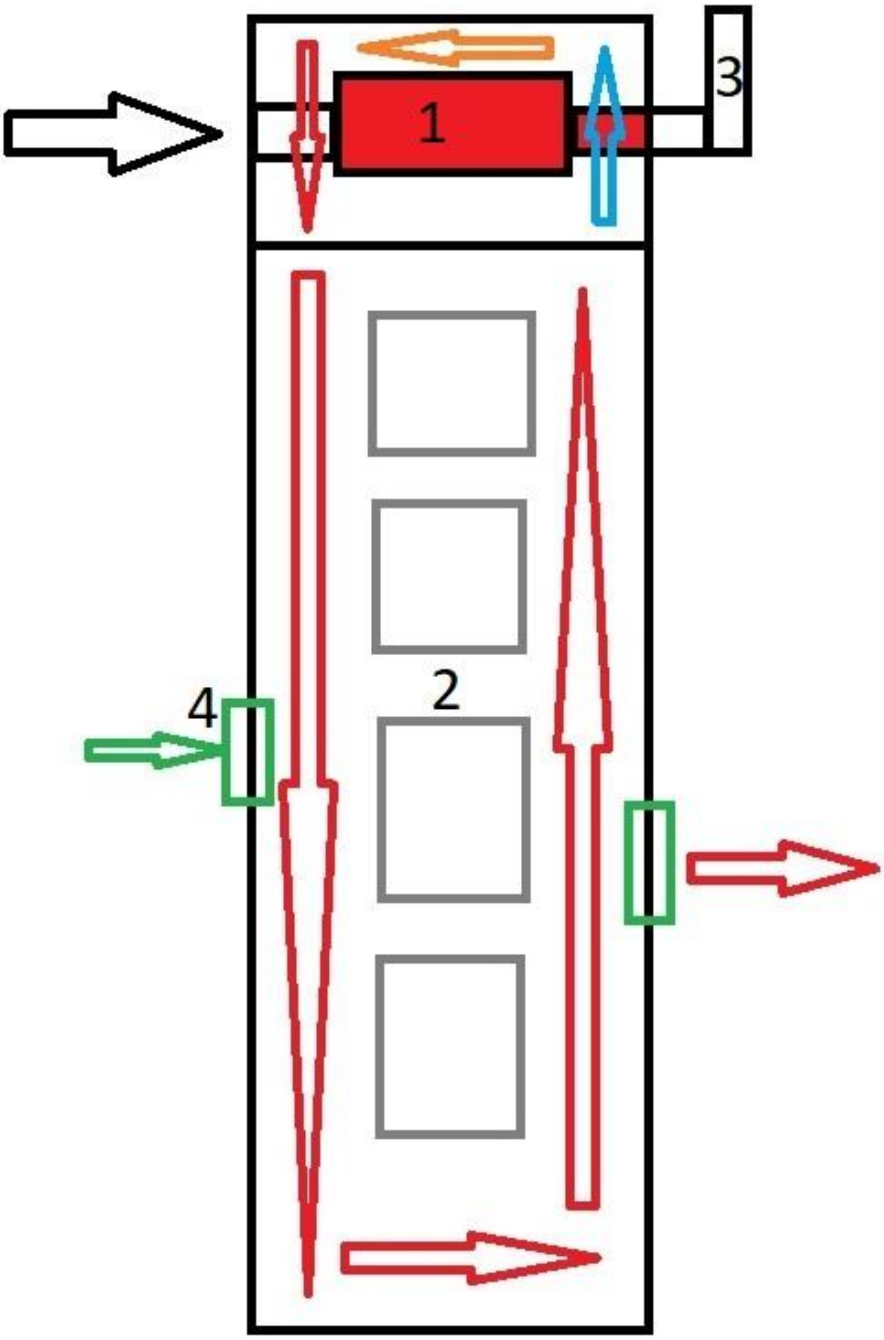

Figure 10. Working process

4. Design

Design was made with help of SolidWorks software. The design work is made to show real dimensioning of the dryer, show the connections and the basic structure. Design work shows primarily self-made constructions, not the standard parts bought from suppliers. The main points concerning materials used, types of connections and other detailed information would be mentioned in chapter number 3.

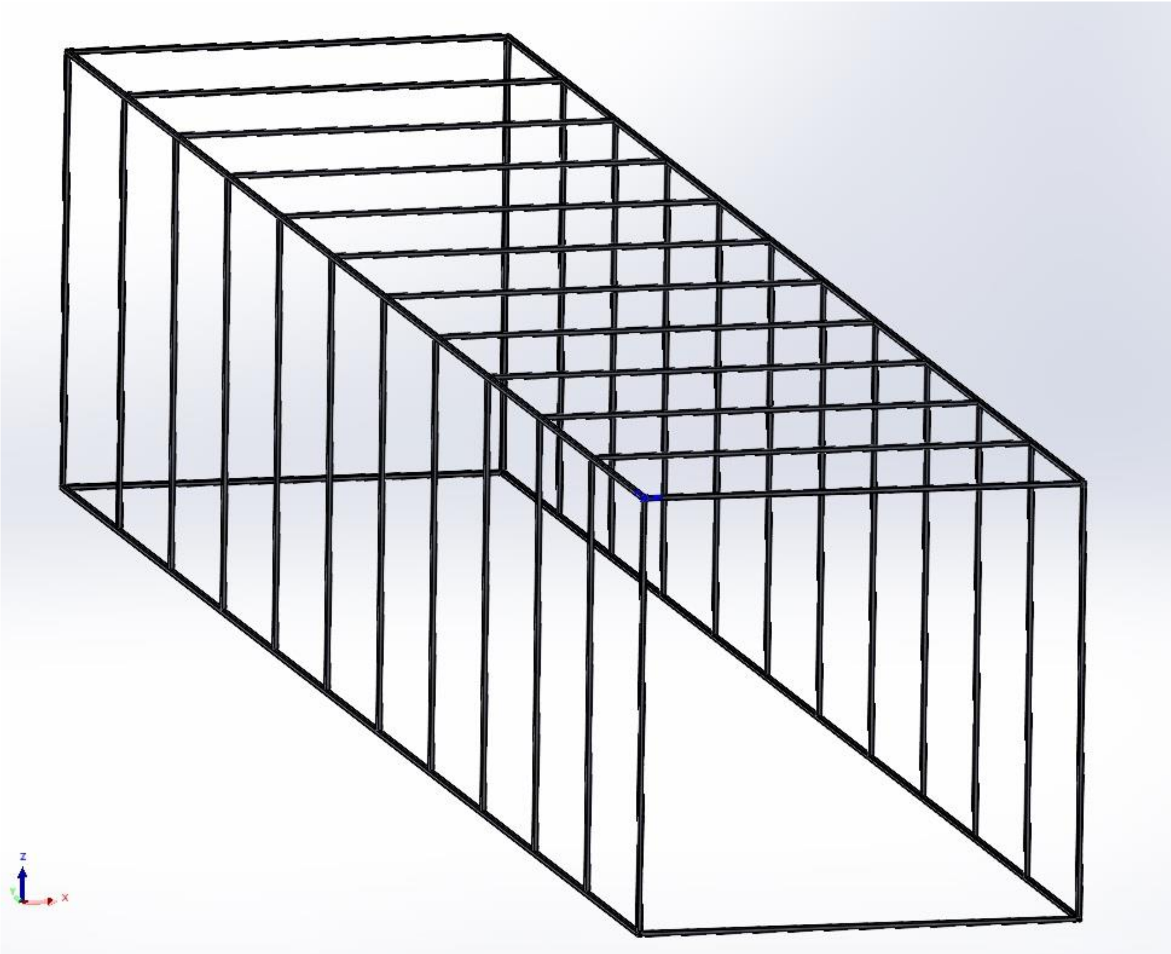

Figure 11. Main frame

On the figure 11 the main frame is shown, the welded structure made from 30x30x2,6 mm rectangular steel tube. It is a very common tube that can be bought in almost every country in a hardware store.

After the assembly of the main frame metal sheets are attached to the body of the dryer. Also, other elements are installed, such as electric cabinet, fans, pipes, etc. But before the frame is covered with metal sheets, heat generator is installed inside.

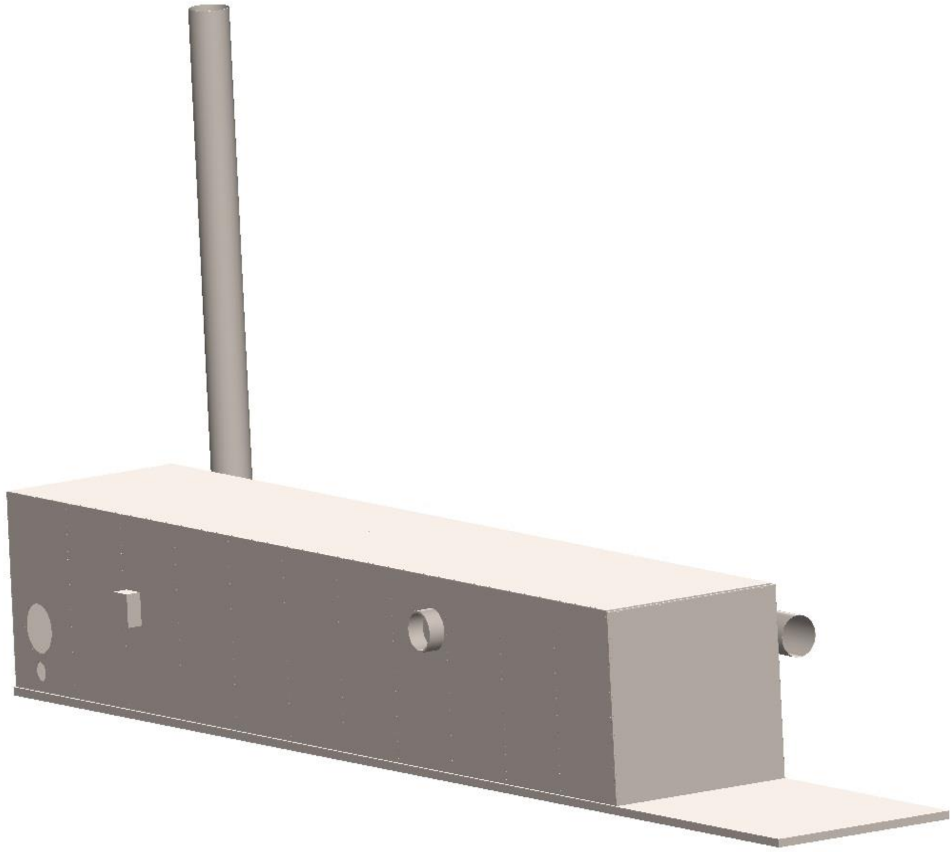

Figure 12. Dryer 3D model

On the figure 12 a 3D model of the dryer is presented. The most important components are shown on this model, outlet pipe for steam on the right side, side fan, holes for heat generator installation, exhaust pipe and a box for electric controllers.

On the figure 13 heat generator is presented, this generator has a pair of economizers, that are made as a connected pipeline, an inlet for fuel, grate firings and a hole for cleaning. The exhaust pipe is connected to the economizer.

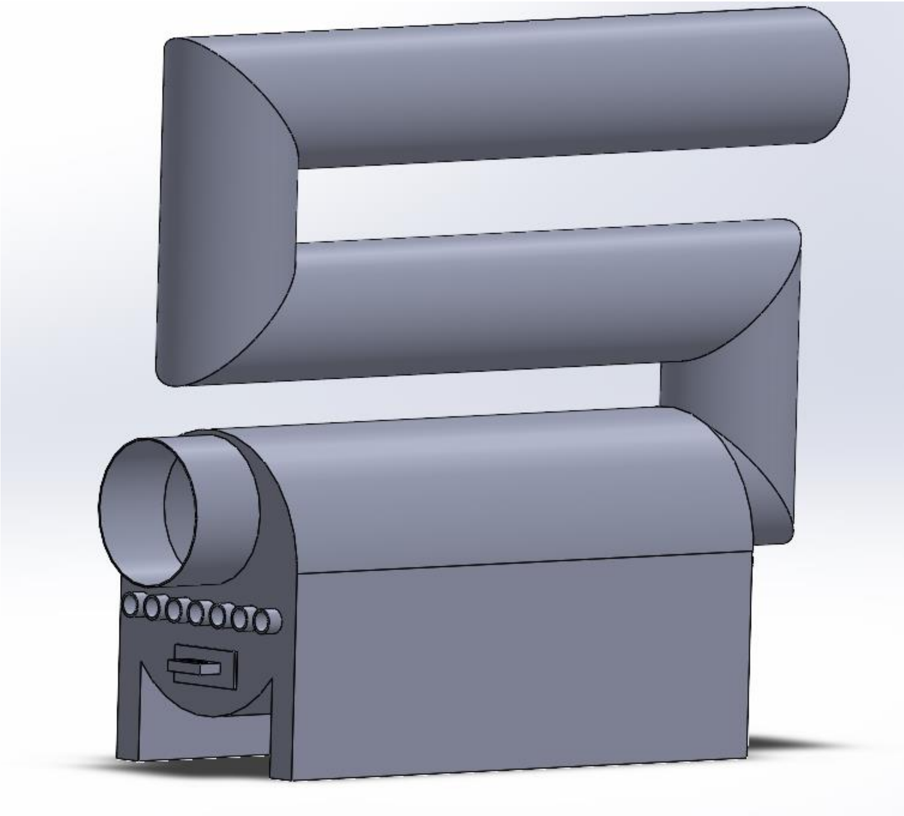

Figure 13. Heat generator

5. Calculations

Before choosing the correct components, calculations are needed.

1. Heat generator

Heat generator is the most important working device of the drier, correct and accurate calculations lead to long-lasting and efficient work, providing high-quality drying with the lowest operational costs.

Before the calculations the most critical points about drying would be mentioned:

1. Material should be heated
2. Water is vaporized
3. Air is the working agent

To calculate the minimum power of the heat generator that allows the vaporization of water from the firewood, many factors should be taken into account.

$$Qall = Qvap + Q\theta + Ql \qquad (3)$$

(B.A.Sokolov Boilers and their operation, .54)

Qall, that is calculated using formula (3), is the total amount of heat needed to vaporize all the water inside, to make firewood moisture content 18%, Qvap and Qθ are the amount of heat to vaporize the water and heat the material inside from outside temperature to the operational standard, Ql is thermal losses to the atmosphere.

The contents of the drier is approximately 22 cubic meters of firewood, moisture contents in the beginning of the drying cycle is 50-70%, 60% moisture contents would be taken in calculations, and the moisture contents is 18%, 60%-18%=42%. 42% of water was vaporized.

$W=(m_w/m_{dry})*100$ (1)

(A.I.Rasev wood drying, 21.)

m_w is the mass of water, m_{dry} is the mass of absolutely dry material, and W is the moisture. m_{dry} for birch is 500 kg/m^3.

(Aviation material Weights handbook, edition Mechanical engineering, Moscow, 1975 y. 173.)

m_w=(W*m_{dry})/100

m_w=(60*500)/100=300kg

Mass of water in 60% birch is 300kg, mass of water in 18% birch is 90, that was calculated using the same formula:

m_w=(18*500)/100=90kg

210 kg of water is vaporized during 2 days cycle from each solid cubic meter of birch.

Total weight of vaporized water is 4620kg.

$Qvap = Hvap * m = 2256 * 4620 = 10422\ MJ$=217125 kJ/h (4)

(B.A.Sokolov Boilers and their operation, .15)

Hvap for water, that is used in formula (4), is 2256 kJ/kg.

The next step is calculating total amount of heat for heating the water inside the wood from outside temperature to 100 ^{O}C to start vaporizing process. Outside temperature is assumed to be 10 ^{O}C. Also, in this step the total heat wasted on wood would be calculated.

$Qwater = c * m * \triangle t$ =4,2kJ*300*22*90=2500 MJ=52100 kJ/h (5)

$Qwood = c * m * \triangle t$=1,8kJ*500*22*140=2772 MJ=57750 kJ/h (6)

(B.A.Sokolov Boilers and their operation, .15)

The results of the calculations made with help of formulas (5) and (6) that are given in the MJ and should be converted to kJ/h to make the conversion to kW possible. As it was said before, the drying cycle is supposed to be 48 hours, all this energy has to be transferred to the material in these 48 hours.

The final component of the sum of heat is total losses of the system. Total losses are calculated only for the walls of the dryer. Losses through the exhaust pipe are neglected, due to a pair of heat utilization chambers (economizers). Also, energy conversion efficiency coefficient shows the energy losses, those losses are primarily flows through the exhaust pipe.

To calculate the heat losses for the system, the total area of the walls should be calculated.

S_t=13*2,7+13*2,7+13*2,5+2,5*2,7+2,5*2,5=115 m^2 (6)

$Ql = S * K * \triangle t$ (7)

(B.A.Sokolov Boilers and their operation, .27)

K is the heat transfer coefficient, this coefficient is calculated using following formula:

$$K = \frac{1}{\frac{1}{\alpha}+\frac{\delta}{\lambda 1}+\frac{\delta}{\lambda 2}+\frac{1}{\beta}+\frac{\delta}{\lambda 3}} \quad W/m^2 * K \tag{8}$$

(Boiler thermo calculations, ed. 3, .49)

Where:

α is a coefficient of heat transfer among inside walls and is equal to 25 W/m^2 x ^oC

β is a coefficient of heat transfer for outside surface 23 W/m^2 x ^oC

δ is the thickness of a wall layer, 0.001m for one sheet metal and 0,005m for PPE layer.

λ is a coefficient of thermal conductivity of a wall layer, for steel this coefficient is 58, for PPE this coefficient is 0,04, for air 0,034

Using this formula (8) coefficient K=1,1

(Boiler thermo calculations, ed. 3, .49)

$Ql = S * K * \triangle t = 115 * 1{,}1 * 140$ =17710 kJ/h=4,9kW

Considering big area of the walls and high temperature change, the result calculated with help of formula (7) is quite satisfying and reasonable.

The sum of heat need for the system is:

$$Qall = 217125 + 52083 + 57750 + 17710 = 345000\ kJ/h = 96\ kW \quad (3)$$

(B.A.Sokolov Boiler plants and their operation, .27)

Minimum requirement for the heat generator calculated using formula (3) is 96 kW, but this value does not take into account energy conversion efficiency. Many aspects should be considered while calculating the energy needs for the system:

1.5-12% of energy is gone through the exhaust pipe. In my project this value was taken as 5% due to the pair of economizers.

2. Energy losses due to incomplete fuel combustion, these losses could be up to 12%

3. Manufacturers of boilers and heat generators assume that all the fuel has 12% moisture content to give more satisfying results, in real life fuel is up to 60%. The difference between 18% and 50% firewood is about 2 times. Dry firewood gives 2 times more heat than wet wood of the same volume.

Summing up previous aspects of energy losses, 83% is the maximum reachable energy conversion efficiency. Also, to reach the minimum requirement for energy needs while using wet fuel, power of the heat generator should be doubled.

Power=96*1,17*2=224kW

Concerning that not all the fuel would be wet 200 kW is enough to heat and run the system.

(B.A.Sokolov Boiler plants and their operation .56)

The main parameter for the heat generator that provides power value is volume of the combustion chamber. To calculate and order the needed heat generator, maximum power should be divided by calorific value in m^3 for wet birch. Wet birch remains the most used power source for this project. For 50% birch this value is 1023 kW/h/m3, to convert solid cubic meters to bulk meters coefficient of 0,6 is used.

$$V = \frac{P}{q} = \frac{200}{1023} = 0{,}2 \quad (9)$$

$$Vreal = \frac{0{,}2}{0{,}6} = 0{,}36\ m^3$$

The minimum requirement for working volume of the combustion chamber is calculated without special formulas and knowledge with help of formula (9) and for the chosen heat generator equals to 0,36 m^3. This requirement is for fully filled heat generator considering the fact that working volume would locate above grate firing.
(GOST 3243-88)

2. Fans

Fans are chosen to provide fast and dense air flow through the cages. The following calculations are done to evaluate needed volume of air in m^3/h.

To calculate minimum requirements for volume to make vaporization of water from wood possible the following formula is used:

$$L = \frac{1000D}{d2 - d1}\ kg/h \quad (10)$$

(U.R.Osipov Design and calculating equipment for heat treatment of wood, .119-123)

D is the mass of vaporized water per hour of drying, about 100 kg.

$$d2 - d1 = (t1 - t2)(0{,}4 + 0{,}00037d1) = 28\ g/kg\ air \quad (11)$$

(U.R.Osipov Design and calculating equipment for heat treatment of wood, .119-123)

t1 and t2 are the temperatures in the beginning and the end of cycle. 150 and 80 ^{0}C respectively.

d2-d1=28

$L = 3500\ kg/h$

V = 3000 m^3/h

(U.R.Osipov Design and calculating equipment for heat treatment of wood, .119-123)

This requirement is calculated for standard board dryer using formula (10), the main difference in the principle of those two dryers is the passage of air inside. When boards are dried, free passage without obstacles is provided, that is provided by special stacking system, layers of boards between rows of dried planks. When firewood is dried, bulk fill of cages makes free passage impossible. Value of 3000 m^3/h should be increased many times to make sure that air reaches every single piece of firewood.

It is supposed that firewood dries many times faster than timber products for construction purposes, the normal cycle for 20% spruce is 6-7 days, for firewood this time does not exceed 2 days. Due to the lack of information concerning firewood drying, the calculated requirement for air volume going through the fans should be increased three times due to the time of drying and at least 1.5 times due to the difficult passage through the drying chamber.

The chosen fans should have a capacity of 5000 m^3/h each, also this huge amount of air makes the transfer of heat from the heat generator possible without overheating and thermal losses to the atmosphere. The chosen fans are presented in the next chapter.

6. Components

Firewood kiln dryer that I am designing is a very simple and easy to operate system that does not involve many complicated components, that is why everyone with basic knowledge of the process could use it.

1. Heat generator

Heat generator is the component that uses burning energy of the fuel to produce heat that does some work. This should be a durable and an efficient machine, that is built and constructed for long-lasting and profitable work. The most suitable material for this generator is sheet stainless steel, which provides all the characteristics mentioned above, as well as high thermal conductivity.

Heat generator has three main components, one of them is the combustion chamber, the second one is the exhaust system equipped with a pair of economizers, and a small turbine that pumps air inside the combustion chamber to rump up the drier. Economizers are used to increase energy conversion efficiency; this element has a very primitive structure and looks like two connected pipes above the main chamber and used to utilize the heat of the exhaust gases. Gases go not directly to the atmosphere but do some work on the path to the exhaust pipe. This idea was borrowed from a classic boiler, that uses heat of the exhaust gases to preheat the water that goes inside. To increase the area of the heating elements, metal plates were added to the body of the heat generator.

As a part of the solid fuel system grate firing is used to make burning of solid wood wastes burning possible. This component is presented by 6 hollow pipes that go through the whole combustion chamber, and they also transfer the heat from inside to the drying chamber.

The heat generator has 3 holes, exhaust, inlet for fuel and also, the hole to take the garbage and ash out. Inlet and ash holes are equipped with the doors that also could be used as an air supply booster when the dryer is ramped up or the temperature inside should be increased. Also, one more hole is used to connect the turbine that pumps up the fresh air inside when it is needed to increase the temperature. All the holes are equipped with dumpers to control air inlet and outlet.

2. Frame, Walls and Foundation

Walls are the main isolation component for the system. Thermo isolation increases the efficiency of the system, as well as ensures quality of the drying. Walls are made from sheet zinc coated steel with 1 mm thickness and a profile used to make the frame is a rectangular tube 30x30 and 2,6mm wall thickness, that was considered the most economically reasonable for this structure. Also, this tube is very light, 1-meter weighs about 2 kilograms, that makes assembly possible without special machines. All frame elements are painted to avoid corrosion and destruction of the frame. Vertical tubes are added to strengthen the structure and to make connection of the metal sheets possible. They are located 1,2 meters away from each other, so 1,25 meters metal sheets are perfectly screwed to the frame to avoid air leakages. Also, on the top the same type of connection is used.

To increase load resistance of the structure it was decided to add strengthening elements to the main frame after the final assembly. Those elements are presented by 10 angles bolted to the ceiling and wall of the dryer. They are made from the same rectangular tube and support the frame in vertical and horizontal direction.

Inside the frame and zinc coated sheets a thermo isolation pie is created, this pie used to minimize thermal losses of the system and this pie is presented by two layers of expanded polypropylene covered with foil from one side, and also two layers of the foil from both sides of the polypropylene glued to the walls.

Figure 14. Foiled EPP (Image: Ukar)

Expanded polypropylene (EPP) is a very efficient material, it is light, water and high-temperature resistant. Foil from one side reflects the hot air back to the dryer wall. Thickness of the EPP layer is 5mm, it sells in different rolls and could be easily installed on site. All these steps create a perfect air thermal isolated atmosphere inside the walls, hot streams bounce back from the foil, and EPP keeps it inside to minimize the losses.

Foundation is a very important part of the dryer. Without a good foundation it is impossible to establish reliable and long-lasting work of the machine in such severe conditions. The total load on the foundation is about 20 tons, quite a high load, also one more requirement for the foundation is water and temperature resistance. Moreover, to be sure that the frame would stay in the same place many and many years, after the frame is assembled, to avoid damage from possible collapses while the chamber is loaded and unloaded, walls should be fixed. Considering all the requirements, as a foundation the layer of concrete was chosen. The height of the concrete layer is 10 centimetres, and it is reinforced with the help of reinforcement mesh that could be bought in every shop. Reinforcement increases the strength of the concrete, making it possible to withstand severe vertical loads for a long time without cracks. Another option for foundation is dry screed, this type of foundation is very cheap, however it establishes high load resistance. Also, compared to the concrete foundation, it is smoother and does not require polishing to make loading with help of a pallet jack possible. But it is less durable, and cracks can occur when load drops, or when metal cages stay directly on the floor without any lining.

To ease the usage during the process of loading and unloading some guide should be added to the floor. The initial idea was to attach bearing-based wheels to the cages, to roll the cages U-beam could be anchored to the floor. This idea is very easy to implement, also it satisfies the requirements for lifetime of the system and makes transporting of the cages with pallet-jack possible, but this idea was abandoned after price calculation. It increases the price of the cage by about 400-euro, 4000 euro for one load. Also, this type of loading decreases the usable space of the dryer.

The final idea on how to guide the cages during loading was the most simple and chip one, two wood boards are attached to the floor with marks painted above to provide equal spacing between cages. It saves the space inside, increases the lifetime of the concrete, and could be easily replaced.

3. Electronic devices

Electronic devices in the system are presented by a group of fans, a turbine and by system of electronic controllers and units. To avoid a rise in the final price of the product, a decision to choose only local suppliers was made. It would lead to decrease in the costs of the possible repairs and deliveries and would make communication between customer and supplier faster and easier.

Fans are used to transfer the air through the main drying chamber and to return it back to the heating area where the heat generator is located. Also, fans are used to expel the moisturised steam from the inside out. Fans, used in the system, are the same, electric power needed for each fan is 0,75 kW, and it would be good to mention that they are three-phase current. Fans operated from the main electric cabinet and could be started separately. Fans are a very important part of the system, that allows to control moisture percentage inside the chamber and, they control the heating cycle.

Fans should be reliable and efficient to ensure long and profitable work without repairs and interrupted cycles. Interrupted cycle means that during the drying cycle something was broken and drying is not possible unless the problem is fixed, this leads to a huge financial loss, because firewood drying cannot be interrupted due to the further problems with quality and moisture contents. To avoid possible problems in working cycle, the decision to contact supplier and change the motors to water and heat resistant, instead of standard atmospheric motors.

The chosen fans are made by a Russian factory called “Teplomash”, this company specializes in industrial heating and ventilation equipment. The model of fans is VO-4, with AIR 71A2 electric motor. Technical characteristics of this model:

RPM	Power	Amperage	m^3/h	Mass	Blades	D1	D4	L
3000	0,75kW	1,75A	5500	18	5	396	450	350

Table 1. Fan technical parameters (Teplomash)

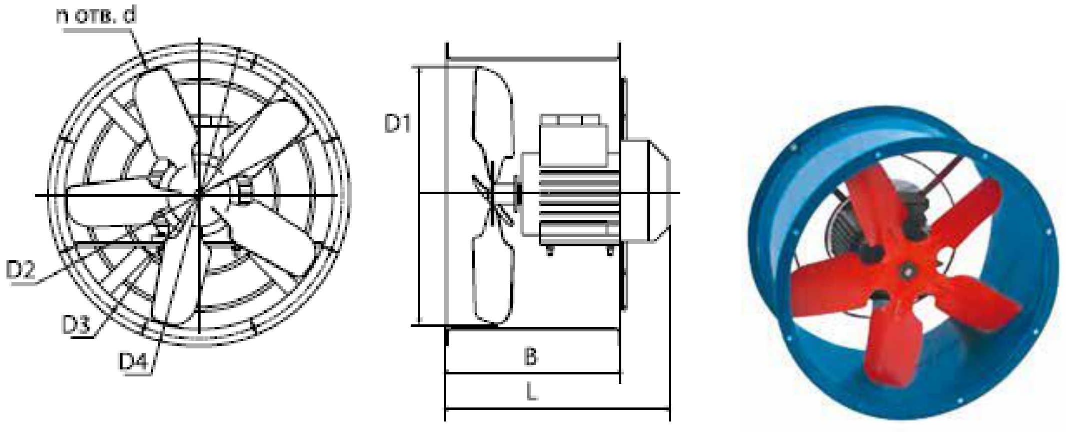

Figure 15. Fans (Image: Teplomash)

The turbine, that is used to increase air intake for heat generator, was chosen according to the power of the heat generator, that is equal to about 200 kW. The chosen turbine could is turned on only when heat generator rumps up and when temperature should be increased. This turbine has capacity of 760 m^3 of air per hour, with 0,4 kW power needed.

Figure 16. Turbine (Kotel-es)

4. Sensors

This system has 3 temperature sensors, that makes controlling and operating possible. Also, the dryer could be equipped with a moisture sensor that shows when the side fan should be turned on. One sensor is located on the side wall near the inlet for fuel, another is located on the opposite side and the third one is on the front door. All of them show different temperatures and help to control the drying cycle.

The most important one is located near the inlet for fuel, this sensor is connected to the temperature relay that controls turbine turning on/off. This sensor shows the temperature of the air when it goes out of the section with the heat generator. Relay used in a pair with this sensor and predefined operating temperature could be entered on the special digital screen, that controls turning turbine on and off. When the turbine is off, the amount of air that goes inside the combustion chamber is decreased, so temperature does not grow up. Then, when the temperature drops, the turbine is turned on again.

One more sensor is located on the front door, this sensor helps to understand the temperature of the air flow in the middle of a circle. This sensor gives extensive information about air passage and possible obstacles. The temperature here should be an average temperature of two previous sensors if everything works correctly. This sensor is standard temperature gauge, temperature range from 0-200 degrees Celsius.

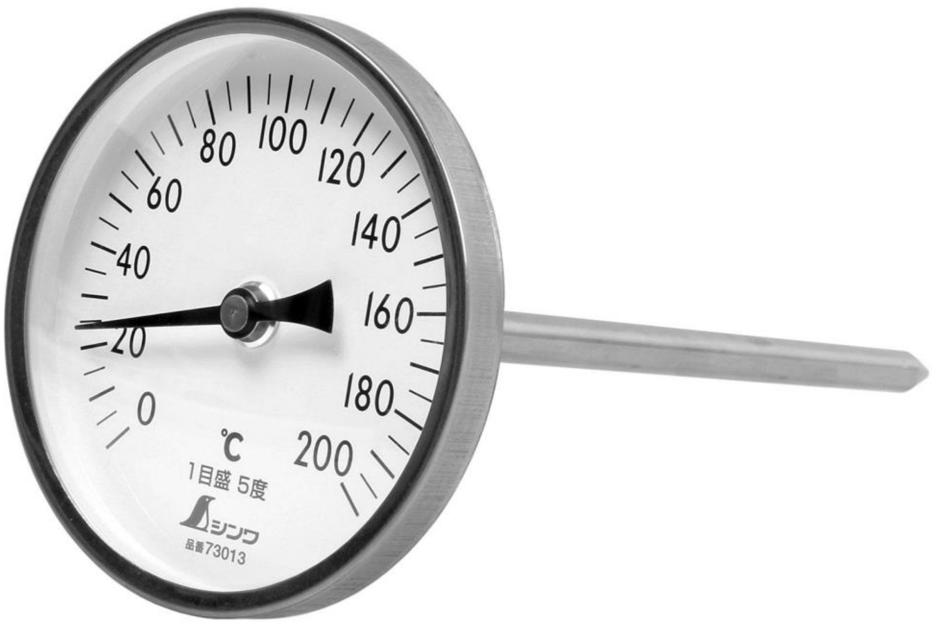

Figure 17. Temperature gauge (Image:VI.RU)

The last sensor is placed on the opposite side directly in the same place as the first inlet sensor is located. This sensor shows the temperature at the end of the cycle. It is the same thermo gauge as in the previous one. The detailed information on how to operate this gauge would be shown and described later in chapter 2.4.

5. Assembly components

As it was mentioned above, the main frame is assembled using welding. But the walls are connected to the main frame and each other using special bolts with rubber washers. The size of those bolts is 4,8x28mm, 28 mm is the length of the bolt and 4,8 and the diameter.

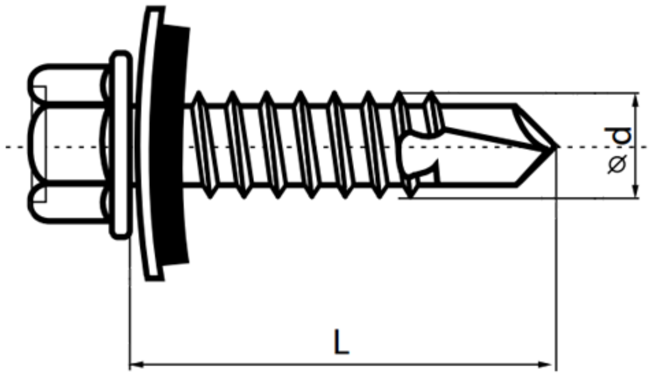

Figure 18. Bolts (Image:VI.RU)

6. Cages for firewood

Cage for firewood is the component that holds firewood during the drying cycle. They are bulk filled to make air passage through possible. There are two possibilities of material, one is metal, and another is wood, but metal seems more suitable because it is more reliable and long-lasting especially in high temperature atmosphere. Also considering the mass that one cage is supposed to hold (about 1,5 tons), wood could not be used as the main material. The main frame is made from equal steel angle, the size of this angle is

40x40x3mm, and a rectangular 20x40x2 tube creates a frame for the walls. Walls made from reinforcing mesh; the same mesh used in the foundation.

Figure 19. Firewood cage

To ensure easy access to the material inside after drying, the door is attached to one side of the cage. Also, this type of unloading makes packing of the ready dry product easier and faster, with space saving.

7. Operating rules and safety instructions

The first step of the drying process is loading the cages inside. It could be made with the help of a pallet-jack or a wheel loader. To ensure the correct positioning of the cages guides could be added to the floor. It could be done using metal, wood, or paint. In case if cages stay incorrectly during the drying process, air passage could face obstacles, it may cause problems with moisture contents of the final product.

After an operator has checked the positioning, the door could be closed and fuel inside the heat generator is ignited. After fuel starts to burn, the lower actuator turns into on position, thermometer starts working, also fans could be activated after this is done.

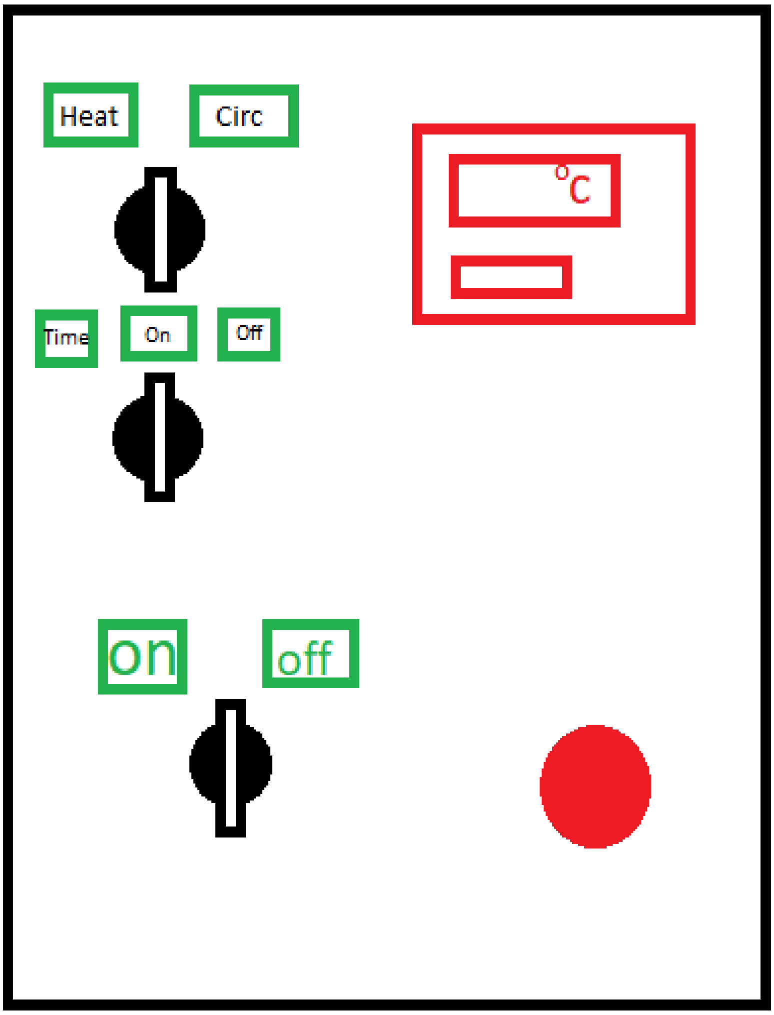

Figure 20. Controlling units

On the figure 20 the main operating units are presented. The controlling units are made in a very simple way to make sure, that every person who are making this work is able to run the system smoothly and according to instructions given by responsible personnel. The units are three actuators and a digital screen that shows predefined temperature when turbine is turned off.

The first phase is called heating. heat generator must be heated up to the operational temperature of 100-120 ^oC, this temperature means that walls are hot enough to start the drying process. In this phase the upper actuator should stay in the left heating position. This position means that only 1 out of 3 fans is working, and the t heat generator gives less heat to the drying chamber.

After the defined temperature is reached, the upper actuator should be changed to the circulation position. In this position 2 more fans are activated, this means that more heat transfers from the heat generator to the drying chamber, also air starts to go through the cages. This is the main phase of the drying process. If temperature drops down due to the emergency or planned stops in the heat generator working cycle, the heat phase should be activated again, until working temperature is reached.

One more actuator, the third one, controls the fourth fan that is responsible for taking the steam out of the dryer. It has three positions: on, off and time. Operator uses this fan in case moisture content in air is too high and steam should be expelled. Time position actuates a time relay that controls the schedule of turning on and off, on a time relay there is a controlling unit for time of working, and time of delay after working cycle is done. Controlling the steam inside is done using visual inspection of outlet pipe for steam or using special sensor, that measures moisture contents in the air inside, of outlet pipe for steam. Steam release is done only after 10-12 hours of drying cycle, when firewood is hot enough to start vaporization. Considering, that this system is not perfectly controlled, taking steam out is responsibility of an operator, and time relay cannot fully deal with this problem.

During the drying process, especially on the second day of drying, when wood and air is dry enough to make pyrolysis gases burning, it is very important to control rises in temperature change. Temperature should not exceed 180^oC, this temperature is critical for the start of pyrolysis. The digital display in the right up corner should give this information accurately because it is connected via wire with a sensor that is located right after the heat generator section outlet.

After the second day, when material inside the cages should be dry, control measurement on the test sample from one of the cages could be done to ensure that firewood is dry enough to finish the cycle. If tested piece satisfies the requirements for moisture contents, actuator that controls the fourth fan, could be turned on for 8-12 hours to cool down the material.

The basic principle described in this chapter is chosen by an operator and depends on many factors. Those factors could be quality of the fuel, outside temperature, characteristics of the firewood inside. Operator is a person that is fully responsible for the process of drying, and considering human factor, operator should work according to many given instructions by a responsible person who calculates the drying cycles for the best quality of the final product and for effectiveness of the system,

8. Costs and economical reasons

To calculate the final cost of the project, many suppliers of different materials and devices were contacted to get commercial offers.

Calculations are started with the costs of constructional elements. Metal price is calculated using commercial offers from the local suppliers and does not include delivery costs.

Metal needed:

1) 30x30x2,6 mm tube 300kg
2) Zinc coated metal sheets: 250 m^2 what is equal to 80 sheet metal pieces (2,5*1,25), weight of 1 sheet is 25,3 kg.
3) Material for cages: 130 kg of metal for each cage

1 ton of metal of small-sized profile that is used for this project worth about 1000 euro, depending on the size, but this difference could be neglected.

Total weight of the metal: 300+1300=1,6 tons, what is equal to 1600 euro in costs.

Price for zinc coated metal sheets is 1250 euro per ton of material.

Total weight of metal sheets is 80*25,3=2024 kg, about 2 tons, what is equal to 2500 euro.

PPE isolator: 250 m^2 = 25 rolls (1x10m)

1 roll of PPE worth 15 euro, 25x15=375 euro

Heat generator:

Price for the heat generator was taken from one of the biggest producers of firewood dryers and air heat generators. Standard price for this 200 kW heat generator is 3600 euro. Price for heat generator was calculated using a little bit different type of heat generator because the designed heat generator is ordered on demand from welder.

Figure 21. GRV Heat generator (GRV)

Fans and turbine:

Price of 1 fan is 120 euro, for a turbine 105 euro according to the catalogues of the producers.

Electric cabinet:

Price for the fully assembled cabinet is calculated by electrician and worth about 350 euro. This price includes 4 big 12A actuators (one for each fan) and one small 5A actuator for turbine, 4 circuit brakers, a time relay and one temperature relay. This price also includes price of assembly, wires, and installation.

Other components:

small components such as gauges, bolts, aluminium tapes and thermal sealant for seams and other assembly components worth about 150 euro all.

The total price of the dryer without foundation and installation costs is:

1600+2500+375+3600+350+150=8575 euro.

To calculate economical aspects of drying many factors should be considered, but two the most critical and important are:

1. Price of the material before drying
2. Price of the material after drying
3. Price of the drying

Wet firewood is sold only locally, without possibility to be exported. Price of wet firewood stays on the level of 40 euro per solid m^3. This price differs a lot from the place of distributing. Primarily, wet firewood is sold in bulk m^3, without special quality requirements, after drying firewood is sold in special packages, depending on the demand of a customer. Standard price for 18% moisture content (without package and transportation costs) is 70 euro.

Total profit by selling firewood is calculated using following equation:

Price of the dry firewood – price of the wet firewood – price of the drying = profit

The only missing component is price of the drying (PD):

PD=Salary + fuel + electricity / 22 (12)

The price, calculated using formula (12), is divided by 22 because the given result should be in m^3.

Salary of the operator depends on the country, for the specific region where the project is supposed to be done is 120 euro for cycle. Price of the fuel is equal to 0, if there are not enough wastes for the whole cycle, they could be bought locally for 10 euro for m^3. The last component is electricity, price for 1 kW/h is 0,13 euro. The total energy consumption if the whole cycle lasts 48 hours:

Electricity = (0,75*3*48+0,75*4)*0,13=14,43 euro (13)

The fourth side fan supposed to work no longer that 4 hours, that is why 0,75 is multiplied by 4, the turbine effect on the calculation is neglected due to short working time and low energy consumption. The final price for electricity, that is a sum of all the electronic devices presented in the formula (13), is about 15 euros, that is very efficient and profitable electric system.

To calculate price for the fuel, 0,2 m^3/hour should be multiplied by 10-euro, 2 euro/h is the maximum price of fuel for the system, if there is no wastes after the material preparation. In this case fuel costs about 100 euro.

PD=(15+100+120) / 22=10,6 euro

Profit = 70-40-10,6=19,4 euro/m^3

One drying cycle gives 19,4*22=427 euro profit, what is equal to 6400 euro per month if 15 cycles are completed.

9. Solutions for system improvements

This system could be improved in many ways: safety, material, automation and control, effectiveness, but in this section the most useful and critical would be discussed.

1. Automated feeding system

Automated feeding system is the system that adds fuel independently and controlled by a group of digital sensors.

This system allows to control system temperature accurately and effectively by adding small amounts of fuel reacting on temperature drops and raises. Automated feeding creates an opportunity to implement controlled drying cycles, that are fully predefined and calculated.

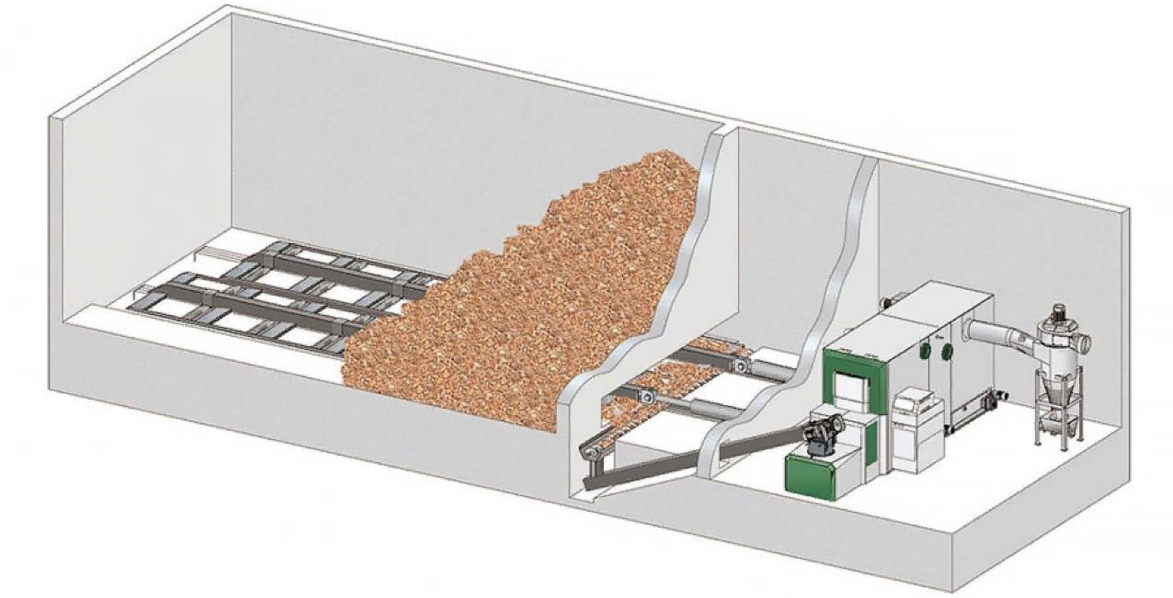

Figure 22. Automated feeding system (Kotlykirov.ru)

Considering all the facts that are mentioned above this system also has some disadvantages that could be significant for small entrepreneurs and people who are just starting business in firewood industry:

1. Price

2. Need for fuel of the same shape and size

3. Complexity of installation process

4. Need for complex of additional equipment such as chipper

5. Difficult to set up

The system of automated feeding is a perfect solution for developing firewood producers who are interested in increased capacities of the drying complex and who wants to improve the quality of the final product by fully controlled cycle. This system solves many problems related to human factor and could be the next step after manual feeding.

2. Safety system

The improved safety system could be a complex solution that includes many aspects such as thermal and phase control relay and spark-guards. But the most useful and important solution that solves the problem of overheating of the heat generator in case of power outage is autonomous power supply system.

Overheating remains the most critical problem of heat generators that are wood powered. When problems with electricity appears and fans stop working while combustion chamber is full, overheating would lead to a huge problem up to complete destruction of heat generator walls. As it was said in the previous chapters, fans are not only a tool that transfers air through the main section, but also the tool that cools down the heat generator and taking heat from it. To establish safe working of the system, uninterrupted power supply must be provided.

Autonomous power supply system is presented by a diesel generator that is connected to the power supply system of the dryer.

Figure 23. Husqvarna diesel generator (Husqvarna.ru)

The chosen generator that fits system requirements is Husqvarna G3200P. This generator is connected to the main electric cabinet with help of special relay, that controls power supply. When power supply from the main source is not active, diesel generator starts working.

10. Conclusion

In this thesis, a very simple kiln dryer is presented. The goal was to create something profitable and economically reasonable, easy to operate, and possible to calculate and design without special knowledge, only knowledge of a mechanical engineer.

The system is not a perfect solution and could be described as my vision of a suitable solution for small entrepreneurs who has problems with qualified personnel and has no extra money for advanced systems.

As it was said before, the designed system is a very simple solution, and in the process of writing this thesis, many ways how to improve the system came to my mind. Those solutions could improve not only productivity and effectiveness of the system but also such important aspects as control and safety. The chosen type of kiln dryer remains a very useful complex of different devices even without special improvements and does work that is needed for the customer.

During the process of writing the thesis some minor problems were faced, and would like to mention the most essential:

1) Lack of information in field of firewood drying

2) Lack of information in field of material selection for thermo isolators

3) Many problems with suppliers

Now I would like to say some words about the first problem. Most of the theory was taken from the books that are created for timber products kiln dryers, the principle basically the same, but there are many differences, that were neglected or figured out by me concerning many aspects of firewood drying.

Other aspects of the thesis went smoothly and without big troubles, also some problems were discussed with specialists in field of wood drying, firewood producing and material selection.

At the end of the project the goal was reached, firewood kiln dryer was designed and calculated, and the next step is assembly of the real model and start drying firewood.

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