FINAL PROJECT DEGREE

“DESIGN AND INTENSIFICATION OF A CELLULOSE DRYER”

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Background of the Project

The pulp and paper industry is heavily involved in developing new products from biomass and cellulosic material. In this context there is a constant search for appropriate production methods. One unit operation that comes into play is drying. The drying step in processing biomass and cellulosic material serves several purposes such as reducing transport and storage costs and extending shelf life. Also, in many cases the material needs to be dry in order to be processed further. In such cases the properties of the dry material is of significant importance. Thus it is important to use the drying process that will give the dry material the right properties. Intensification of the drying process is another key issue for nowadays research. The experience of using various presses and chemical additions for the intensification of drying process on preliminary steps is already existing practice. In order of this project, the flash drying process must be intensified using the press and unit for the addition of chemicals aiming on moisture reduction in the pulp feed.

Definition of goals and scheduling

Main parts of the project and description of the work goals are listed in Table 1.

Table 1: Scheduling and work goals description

Project stages	Description of the goals and solutions
Part I – "Project definition and acquirement of starting materials"	Initial scoping of the project The relevance and usefulness of the research must be showed; Data collected from company members during the first and second meeting must be analyzed and main objectives and goals of the project must be briefly overviewed. Researchers must describe possible solution for the technological task taking into account information from company and literature survey of related technologies. Initial process description and calculations of mass balance are the key issue for solving this problem. Market survey can be used for the rejection of obviously unsuitable technological solutions and selection of appropriate one. Performance of the equipment, main dimensions and costs are the main criteria for the selection.
Part II– "Process and lay out design"	Detailed scoping of the project Design of the main equipment must be done with the help of Aspen software. Performance and dimensions of the equipment are the key points in that part. Process description, block diagram and calculations must be done in a more specific way. Final selection of the chemical additions must be done. All technical information must be represented according to the SFS-EN ISO 10628 standard.
Part III – "Economical analysis"	Economical estimation Calculations of profitability, investments and operation costs must be done. Sensitivity analysis is required.
Part IV – "Summary and conclusions"	Final report compilation This final version must be done taking into account results of previous parts.

Market survey

The production of cellulose in Finland has improved significantly, now that the current annual growth of Finnish wood biomass is 104 million m^3. Due to this quantity of wood, it has been possible to achieve around 81 million m^3/year of sustainable volume of industrial round wood and energy wood removals [11]. In addition, one fifth of the annual growth is not in use nationally. This corresponds to approximately additional 6 million tons of cellulose (2014).

The global demand for high quality cellulosic products is continuously increasing and 15 million tons annual gap in cellulosic fibers has been estimated in 2030 [5]. For this very reason, new attractive high-value product visions have to be generated.

Regarding this project, the biggest objective is to create economically effective drying unit. There are several key points that must be considered in the future:

- Analysis of the main equipment market (where it is possible to buy the essential equipment);
- Comparison of prices and technological characteristics of different suppliers;
- The selection of the appropriate equipment which answer the demands of characteristics (capacity, price, dimensions and etc.).

Initial idea about the process description

The initial idea that has been developed about the process description is explained below. With the study of this design probably in the following parts described in Table 1, probably this initial idea will change.

Firstly wood pulp comes to the press which is aiming on preliminary dewatering of the raw material. After that stage the material goes to the mixer (fluffer) which is aiming on obtaining a large accessible fiber surface while keeping the other fiber characteristics unchanged. This operation has the purpose to intensify the heat transmission in the drying tube. The spray equipment for chemicals additions can be applied in the mixing stage. Chemical additions can become a good solution for the intensification of drying process and cut the cost for energy consumption. After the stage of mixing and chemicals adding wet particles are fed into the hot gas stream. For that purpose air heater is used. Then the stream flows into the drying tube where the flash drying process happens. Subsequently, dried material is collected in the special collector which is usually has dust separation arrangement. Finally, dried cellulose goes to the press equipment which has the aim to make it compact and ready for further sale or use. Recirculation system is an effective solution not to waste energy from heated air [1, 2].
It is possible to see main steps of flash drying process at Figure 1.

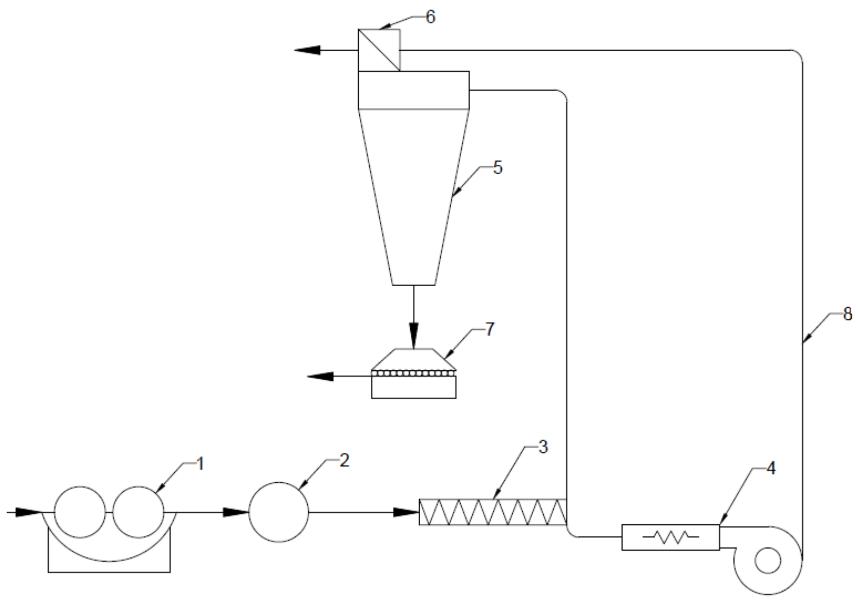


Figure 1: Simulated installation scheme.
1 – Press for preliminary dewatering; 2 – fluffer and spray system; 3 - feeder; 4 – flash dryer; 5 – collector of the dried pulp; 6 – air outlet; 7 – press for baling; 8 – air recirculation system.

In order to achieve efficient pneumatic drying process the velocity of the gas flow must be higher than the free fall velocity of particles otherwise the drying process will not occur. However, the most effective drying process happens when the velocity of the gas flow is as low as possible due to the fact that the time for the thermal contact between the gas stream and particles is increasing that way. It is possible to note, that the flash drying is a process for the surface moisture removal. [1].

Summary of initial process description is in Table 2.

Table 2: Basic Parameters with some additional information for the future calculations

Capacity (kg/day)	1000
Feed Moisture of material at Inlet (%)	40-45
Feed Moisture of material at Outlet (%)	10-20
Minimum Particle Size (mm)	0.7 (Softwood fibers)
Maximum Particle Size (mm)	2.5 (Softwood fibers)
Optimal Particle Size (mm)	0.7 (Softwood fibers)
Operating time per day (h/day)	8-10
Applications of the dried product (cellulose)	Non-woven tissue, fluffy materials, superadsorbents, etc.
Source of energy for drying process	electricity
Density of the bales with compressed dried material cellulose (kg/m^3)	300

Initial selection for the main equipment in the drying process

Twin Wire Press

Mechanical extraction of liquid from the pulp is carried out different types of presses. Advantage of this method is the separation of liquid without diluting. However, the one-step mode is not achieved the fullness of liquid department, as developed by the pressure in the press is not enough to remove liquor from the inner capillary cellulose fibers [2].

The operation of the pulp dewatering on the first stage can be obtained by using Twin Wire Press. Main advantages of this technology are:

• reduced consumption of energy by flash dryer due to the fact that pre dried wood pulp demand less thermal energy for meeting requirements in moisture content;
• gentle dewatering leading to easier maintenance;
• compact design which is extremely important to make the whole unit transportable;
• high productivity, reliability and filtrate quality.

Fluffer

Fluffer is a high-consistency mixer for pulp particles which has the purpose to obtain a large accessible fiber surface while keeping the other fiber characteristics unchanged. Fluffer is used for the intensification of the heat transmission to the wood pulp particles in the flash drying stage.

Main advantages of this technology are:

• homogeneous particle size after mixing;

• reduce the energy consumption on the next stages;
• low investments costs;
• gentle treatment of fibers.

According to the number of phases, it is possible to find a few kinds of reactors, two of which would be useful for this process:

a)Tubular reactor:

While the reactants flow, they are becoming products. Fluid flows at high speed,so this is the reason that the products are unable to diffuse back and therefore there is not remixed. The conditions at any point only changes over time of the reaction are measured in terms of the position along the tube length.

The reaction rate is faster at the entrance of the pipe because the concentration of the reactants is at its highest level and the reaction rate is reduced as the reactants flow through the pipe due to the decrease in reactant concentration.

One example of tubular reactor in the market nowdays is below:

• Turbulizer Paddle mixer (used by Bepex company): is a continuous high mixer with adjustable paddle angles and tip-to-wall clearance provides flexibility for control of residence time and mix intensity [3].

Figure 2: turbulizer paddle mixer

b) Stirred tank reactor:

In a stirred tank reactor, one or more reagents are introduced into the reactor equipped with an impeller (agitator), whose main function is that the products are removed continuously. The impeller stirring the reactants to ensure a good mix so that there is a uniform composition throughout the system.

The composition of the output is the same reactor. These are exactly the opposite of those conditions in a tubular flow reactor.

The best known model of this reactor is Flex-O-Mix – Wet Mixing Machine (used by Bepex and Hosowaka companies); unlike conventional agglomeration machines, the Flex-O-Mix features a continuously deforming mixing chamber that keeps wetted particles from adhering to the chamber walls. In addition to preventing clogging, this action inhibits particulate over densification while getting a more uniform particle with more consistent density, cohesiveness and solubility [4].

Figure 3: Flex-O-Mix reactor

Chemicals addition spray system
It is possible to use spray system inside the fluffer for chemicals addition. Rough estimation of possible variants showed that intensification substances might be: ethanol, n-butane and other alcohols. Content of intensification chemicals must be approximately 1% of the wet pulp. However, it is of crucial importance to estimate the influence of aforementioned additions on the cellulose properties after drying, safety of the process and ecological impact.

Organic liquid substances are usually used as drying agents. There are several examples of types of hydrophobic organic compound, such as polysiloxanes, hydrocarbons, ethers, ketones, chlorohydrocarbons or nitro hydrocarbons. The membranes are dried from their aqueous state by direct evaporation of water. The resulting air dried membranes are suitable for the desalination of water by reverse osmosis.

There are some examples of organic substances:
- Octane;
- Heptane;
- Deane;
- Nitrobenzene etc.

Flash dryer
After wood pulp fluffed into small particles it is dropped into the flash dryer where it is pneumatically transported by hot air while being dried. It is possible to make several drying stages. Recirculation of the drying air can be a good solution to minimize energy consumption.

Slab press
Finally, slab press can be used to compact the pulp fluffs from the flash dryer into bales.

Initial selection of flash dryer

It is possible to choose the existing dryer according to the main dimensions of the container with maximal capacity. Choice must answer main technological demands, must be financially effective.

Main goals:
• To create a transportable dryer using existing models;
• Container must be used as a method for transportation;
• Mobile dryer must be convenient for the exploitation, service and using.

Table 3: The size of the container [5].

Length	13,556 m
Width	2,352 m
Height	2,812 m

After the size analysis, a previous selection of 3 types of dryers could be done at the beggining, without more information, in order to have an initial idea:

• SPX SFD 47 (Denmark);
• Bepex PCX-20 (USA);
• Hosokawa DMR-1 (Netherlands).

Table 4: Parameters and sizes of dryers.

Company Name	**Water Evaporation (Kg/h)**	**Batch / Continues**	**Price Unit (€)**	**Price Test/ Location (€/day)**	**Temp. Range (°C)**	**Unit Dimension**	**Cyclone/ Filter bag**
SPXFLOW	120	Continues	380,000	3,300 / Denmark	450-500	4.6×3.3×4	Cyclone
Bepex	376	Continues	335,000	5,500 / USA	93-427	27.5×23.6×23.5cm	Bughouse
Hosokawa	79-103	Continues	300,000 to 400,000	2000 / Holland	150-200	1.4×0.7×1.94	Filter

After table analysis the best suited for price and performance is BEPEX. There are three charts below which explain our decision. This is only an initial approximation in order to have a first idea about the flash dryer with the purpose of starting work.

Figure 4: Comparison of dryers

Process description

After the detailed study of this process, it has been decided that this is going to be developed in the following way:

Pulp with solid content 10-12 % enters the screw press where the primary dewatering happens. The screw press is powered by the electric motor (M1). Two streams can be observed after the screw press. First one is squeezed water from the pulp (m = 826.375 kg/h). This water is removed to the sewerage. The second stream is pulp with the solid content 45 % (m = 236.125 kg/h). Gravitation forces transport this pulp by the inclined pipe to the hopper.

The hopper has agitators powered by the electric motor 2 (M2). The mixing with water solution of glyoxal happens in the hopper. The content of glyoxal in water solution is 36 %. Water solution of glyoxal is distributed to the mixing hopper by the spray system from the tank for chemicals (V = 100 l.). The hopper and the screw feeder are the parts of the same feeding unit. The well-mixed pulp with 45 % solid content and 1.5 % of glyoxal can be distributed to the drying chamber by screw feeder. The screw feeder is powered by the electric motor 3 (M3). The screw feeder acts not only as the feeding element but also as the mixing one.

The operation of the pneumatic drying happens in the drying chamber. For that purpose the ambient air is blown and heated by the air blower and air heater, correspondingly, to the drying chamber. The air flow rate is 50 m^3/min. The inlet temperature of air flow in the bottom of the drying chamber is 223 °C and inlet pressure is 1.6 bar. The specific direction for the air flow is provided by the air agitator powered by the electric motor 5 (M5) which is located in the bottom of the drying chamber. At the same time this agitator impacts as a grinding element which disperses the pulp to the micro particles. The directed air flow serves for the drying process intensification and efficient distribution of the grinded cellulose flakes to the top section of the drying chamber where the classification system is located. The classification system is powered by the electric motor 4 (M4) and has the main purpose to separate the fine particles and at the same time to reject badly dried coarse particles for the recurring grinding and drying. The size of the particles can be controlled by the rotation speed of the classifying unit which can be controlled by the motor 4 (M4).

Air stream carrying the cellulose particles with solid content 85 % flows out of the drying chamber and has the outlet temperature 100 °C. It distributes the cellulose to the bottom section of the cyclone with the fixed bed dust separation arrangement approximately in the middle of it. The dried product is collected in the bottom section of the cyclone and transported by the rotary feeder powered by the motor 6 (M6) to the shaping machine while the air flow with temperature 80 °C goes through the bag filter and comes to the exhaust fan. The shaping machine creates the bales of cellulose packed in the polyethylene bags. The block diagram, process flow diagram and PI diagrams of the process are represented on the Figures 5, 6 and 7.

Block diagram

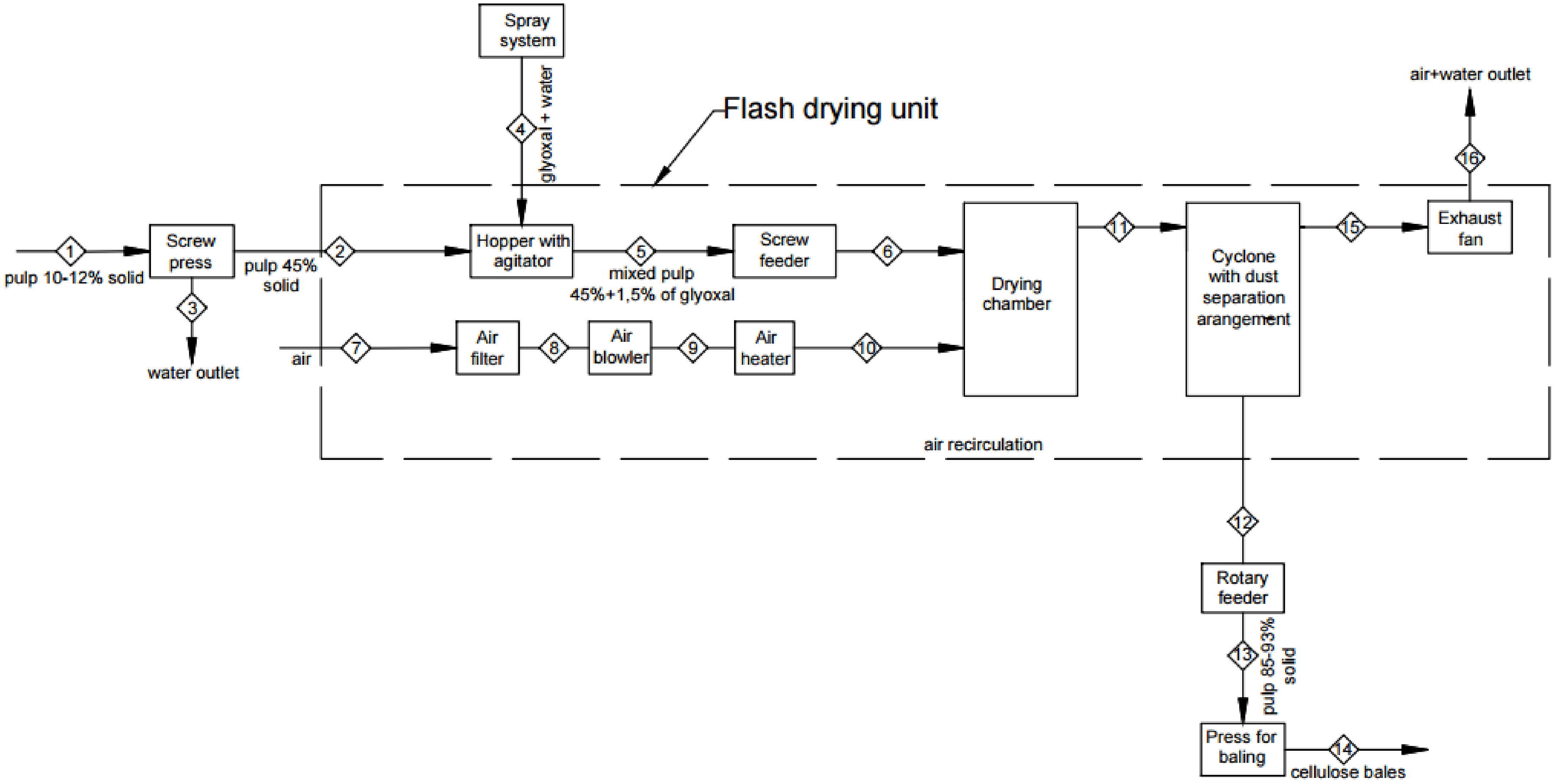


Figure 5: Block diagram

Process flow diagram

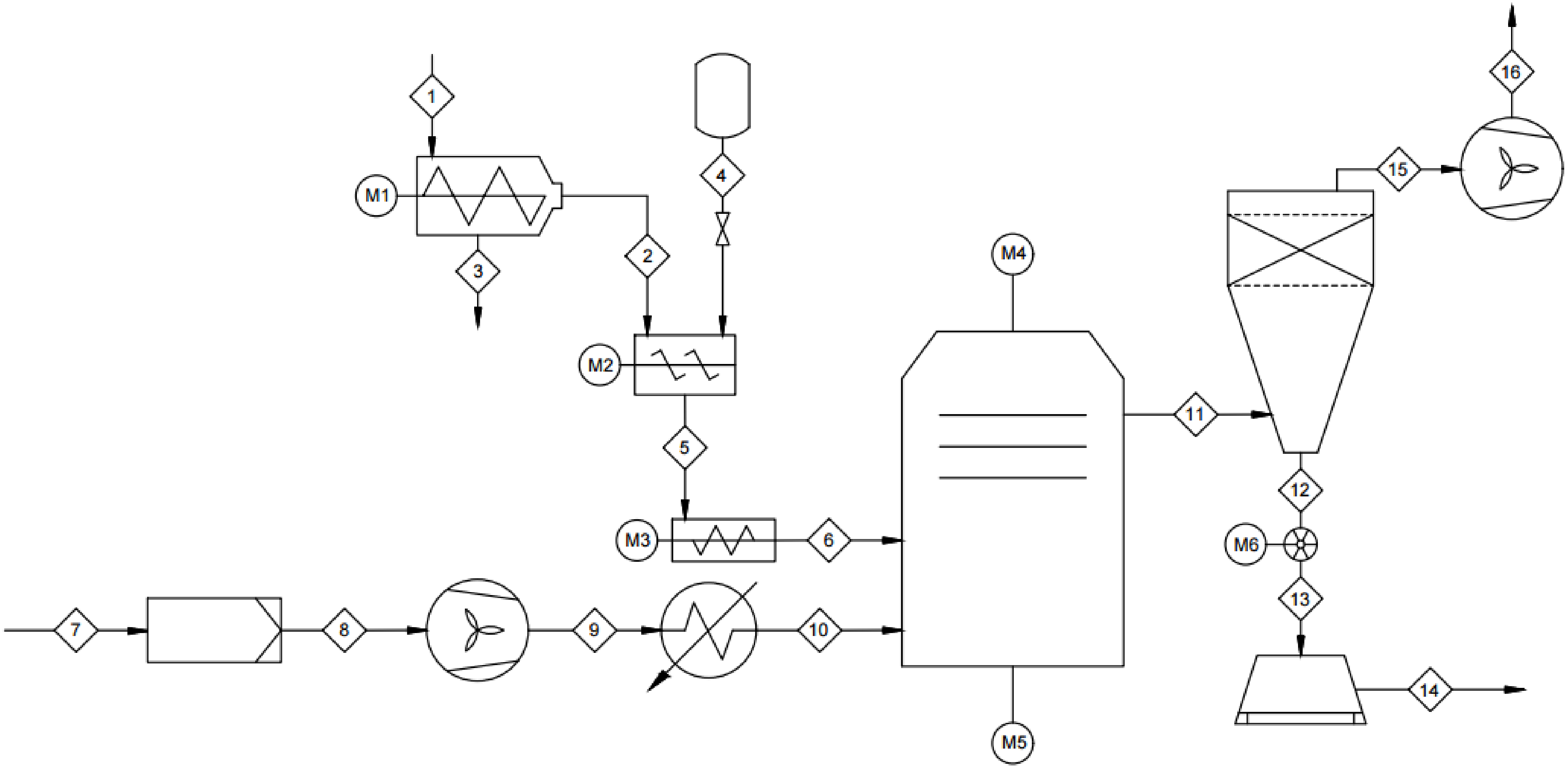
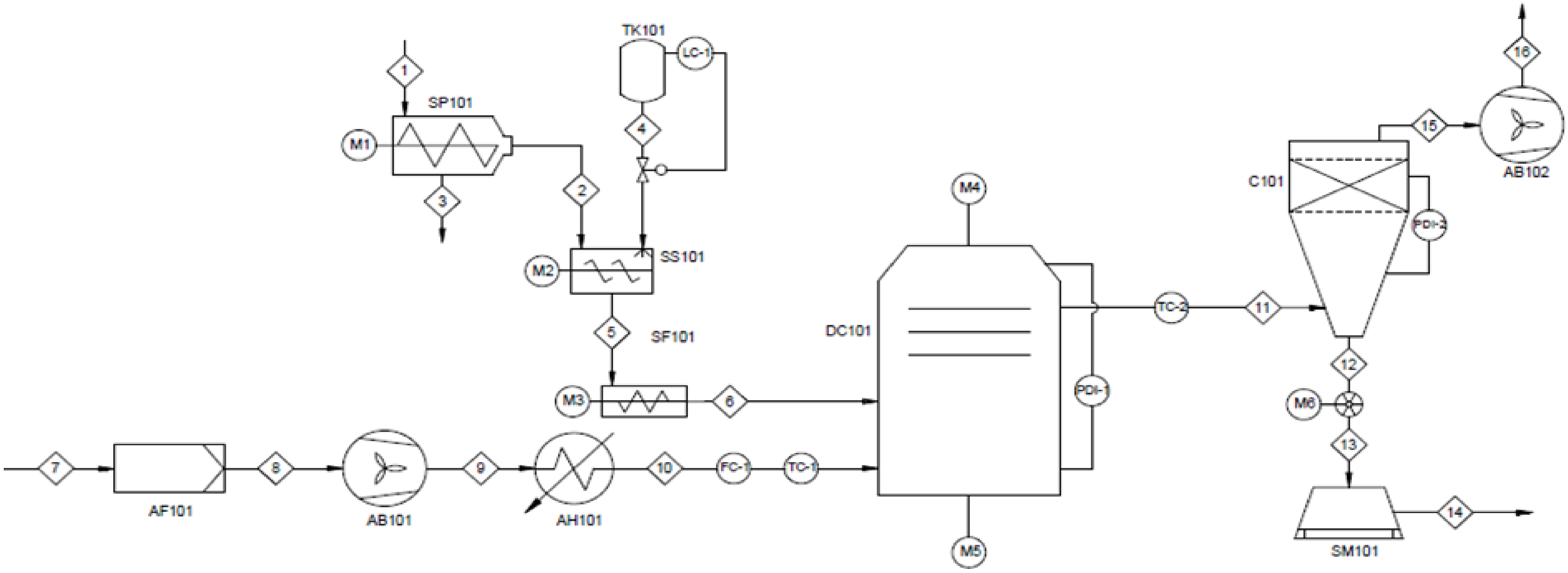


Figure 6: Process flow diagram

Process and instrumental diagram



Controller	Purpose
LC-1	Chemical level control
FC-1	Air flow control
TC-1	Air inlet temperature control
TC-2	Pulp and air outlet temperature control
PDI-1	Drying chamber pressure difference indicator
PDI-2	Cyclone pressure difference indicator

Figure 7: Process and instrumental diagram

Process flow calculations

The streams were calculated for the summer and winter times with the average temperatures at 20 °C and -20 °C, correspondingly. The results of the calculations are represented in the Table 5 and 6.

Table 5: The streams for the temperature 20ºC.

Stream name	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	S-11	S-12	S-13	S-14	S-15	S-16
kg/h																
m_{Air}	0	0	0	0	0	0	2238	2238	2238	2238	2238	0	0	0	2238	2238
m_{Water}	956.2	129.8	826.3	6.4	136.2	136.2	0	0	0	0	136.2	18.2	18.2	18.2	118	118
$m_{Cellulose}$	106.2	106.2	0	0	106.2	106.2	0	0	0	0	106.2	106.2	106.2	106.2	0	0
$m_{Chemicals}$	0	0	0	3.6	3.6	3.6	0	0	0	0	3.6	0.5	0.5	0.5	3	3
m_{total}	956.2	129.8	826.3	10	139.8	139.8	2238	2238	2238	2238	2377.8	18.7	18.7	18.7	2359.1	2359.1
$m_{Overall}$	1062.5	236.1	826.3	10	246.1	246.1	2238	2238	2238	2238	2484.1	125	125	125	2359.1	2359.1
°C																
T	70	65	65	40	62	67	20	20	20	223	100	76	74.3	60	80	80
bar																
P							1	1	1.6	1.5	0.9				0.9	1.5
% (kg/kg)																
ω_{Air}	0	0	0	0	0	0	1	1	1	1	0.9	0	0	0	0.949	0.949
ω_{Water}	0.9	0.55	1	0.64	0.55	0.55	0	0	0	0	0.0548	0.146	0.146	0.146	0.05	0.05
$\omega_{Chemicals}$	0	0	0	0.36	0.015	0.015	0	0	0	0	0.0014	0.004	0.004	0.004	0.001	0.001
$\omega_{Cellulose}$	0.1	0.45	0	0	0.435	0.435	0	0	0	0	0.0438	0.85	0.85	0.85	0	0
kJ/h																
Q_{st}	137331	183799.9	1169491	8387.3	191145.4	193998.4	659012.7	659012.7	659012.7	1115598	1051775.5	26646.1	26516.3	25424.5	968428.5	968428.5
Q_{cell}	56487.8	55664.3	0	0	55170.3	55993.7	0	0	0	0	61428.4	57475.9	57195.9	54840.9	0	0
Q_{ev}	0	0	0	0	0	0	0	0	0	0	307981.5	0	0	0	266770.4	266770.4
$Q_{overall}$	1429798	239464.3	1169491	8387.3	246315.8	249992.1	659012.7	659012.7	659012.7	1115598	1421185.4	84122.	83712.3	80265.4	1235199	1235199

Table 6: The streams for the temperature -20ºC

Stream name	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	S-11	S-12	S-13	S-14	S-15	S-16
kg/h																
$\mathbf{m_{Air}}$	0	0	0	0	0	0	2238	2238	2238	2238	2238	0	0	0	2238	2238
$\mathbf{m_{Water}}$	956.2	129.8	826.3	6.4	136.2	136.2	0	0	0	0	136.2	18.2	18.2	18.2	118	118
$\mathbf{m_{Cellulose}}$	106.2	106.2	0	0	106.2	106.2	0	0	0	0	106.2	106.2	106.2	106.2	0	0
$\mathbf{m_{Chemicals}}$	0	0	0	3.6	3.6	3.6	0	0	0	0	3.6	0.5	0.5	0.5	3	3
$\mathbf{m_{total}}$	956.2	129.8	826.3	10	139.8	139.8	2238	2238	2238	2238	2377.8	18.7	18.7	18.7	2359.1	2359.1
$\mathbf{m_{Overall}}$	1062.5	236.1	826.3	10	246.1	246.1	2238	2238	2238	2238	2484.1	125	125	125	2359.1	2359.1
°C																
T	70	65	65	40	62	67	-20	-20	-20	223	100	76	74.3	60	80	80
Bar																
P							1	1	1.6	1.5	0.9				0.9	1.5
% (kg/kg)																
$\boldsymbol{\omega_{Air}}$	0	0	0	0	0	0	1	1	1	1	0.9	0	0	0	0.949	0.949
$\boldsymbol{\omega_{Water}}$	0.9	0.55	1	0.64	0.55	0.55	0	0	0	0	0.0548	0.146	0.146	0.146	0.05	0.05
$\boldsymbol{\omega_{Chemicals}}$	0	0	0	0.36	0.015	0.015	0	0	0	0	0.0014	0.004	0.004	0.004	0.001	0.001
$\boldsymbol{\omega_{Cellulose}}$	0.1	0.45	0	0	0.435	0.435	0	0	0	0	0.0438	0.85	0.85	0.85	0	0
kJ/h																
$\mathbf{Q_{st}}$	1373310	183799.9	1169491	8387.398	191145.4	193998.4	569045.1	569045.1	569045.1	1115598	1051775.5	26646.13	26516.34	25424.53	968428.5	968428.5
$\mathbf{Q_{cell}}$	56487.8	55664.38	0	0	55170.3	55993.75	0	0	0	0	61428.438	57475.94	57195.97	54840.94	0	0
$\mathbf{Q_{ev}}$	0	0	0	0	0	0	0	0	0	0	307981.5	0	0	0	0	0
$\mathbf{Q_{overall}}$	1429798	239464.3	1169491	8387.4	246315.8	249992.1	569045.1	569045.1	569045.1	1115598	1421185.4	84122.07	83712.3	80265.47	968428.5	968428.5

Utilities

The power used in this process is shown in Table 7.

Table 7: Different valors for the utilities with the temperatures of 20ºC and -20ºC.

kW	
20 ºC	
Blower	52.6
Heater	126.8
Exhaust fan	52.6
-20 ºC	
Blower	52.6
Heater	151.8
Exhaust fan	52.6

Selection of the equipment

The stream table results, sequence of the process and the analysis of the related to the pneumatic drying technologies became the reference point for the equipment selection. Main information about selected equipment can be observed in the Table 8. The net load of the 45' high cube container is 25600 kg while the total weight of the selected equipment is approximately 6400 kg. Consequently, the reserve in the weight load is quite high. All equipment answers the demands in capacities and can be ergonomically located inside the container. All units were selected taking into account the applicability of them to the wood and paper mill industry (cellulose drying).

Table 8: Parameters of the selected equipment

Name	Model (Company)	Main dimensions [mm]			Capacity	Motor power [kw]		Weight [kg]
		L	H	W		1	2	
Screw press	CP-6 (Vincent)	2134	610	305	136-454 [kg/h]	3.73	-	454
Tank for chemicals	T-100 (Ekoprom)	565	515	565	100 [l]	-	-	20
Feeder	FT-40 N (Hosokawa)	1000	650	570	31-234 [l/h]	1.5	1,1	330
Drying chamber	MDF-2 (Hosokawa)	890	1900	890	310 [kg/h]	2.2	1,5	1150
Air heater	AH (Hosokawa)	1275	850	800	50-80 [m3/min]	175	-	635
Air blower	AB (Hosokawa)							
Exhaust fan	EF (Hosokawa)	500	500	300		55	-	96
Cyclone	CD-915 (Apzem)	500	1300	500	43-57 [m3/min]	-	-	126
Rotary valve feeder	S-AX 250 (TBMA)	590	200	200	200-300 [kg/h]	1.1	-	75
Baling machine	SHB1-WSB-1500 (Sinobaler)	4200	1000	950	500-900 [kg/h]	22	-	3500
45' high cube container	**Net load = 25600 [kg]**	**13556**	**2812**	**2352**	-	-	-	-

Screw press

Screw press of Vincent Company was selected for primary dewatering. The CP-6 model accepts variable feed rates and has low operating and maintenance costs. The main operation consists of a screw that rotates inside a screen, forcing liquid and pulp through this screen. The screens are usually built with stainless steel. The screw has a graduated pitch with interrupted flight in to maximize dewatering and prevent co-rotation when paired with resistor teeth.

Main parameters of CP-6 model are listed in Table 9.

Table 9: Screw press parameters [6]

Model	CP-6
Main dimensions [m]	
length	2.134
width	0.31
height	0.61
Utilities [kW]	
motor (max)	3.73
Capacity Dry Solid [kg/h]	
capacity	136-454
Weight [kg]	
Weight	454

Feeder

Feeding system FT-40N of Hosokawa was selected. The biggest advantage of this system is that consists of hopper with mixing agitators, which let to mix chemicals evenly with pulp, and screw feeder. Another big advantage is that these working elements are controlled by separate motors which let to control the residence time for chemicals accurately.

Main parameters of FT-40 N model are listed in Table 10.

Table 10: Screw feeder Finetron FT-40 N parameters [7]

Model	Finetron FT-40 N
Main parameters	
Screw diameter (m)	0.037
Screw pipe. Diameter (m)	0.0486
Capacity (L/h)	31-234
Hopper Capacity (L)	23
Utilities	
Screw rotation speed (rpm)	11-115
Agitator swing speed (rpm)	0.9-8.0
Screw agitator power (v,Hz)	200-220, 50/60
Screw rotation control	Frequency converter

Drying chamber

Drying chamber MDF-2 of Hosokawa was selected. The technology is extremely suitable for the technical task. This model allows making the drying process of cellulose in a very effective way due to the presence of auxiliary devices for grinding, air flow direction and particle classifying.

Main parameters of MDF-2 model are listed in Table 11.

Table 11: Drying chamber MDF-2 parameters [8]

Model	MDF-2
Main dimensions [m]	
length	0.890
width	0.890
height	1.900
Utilities [kW]	
Agitator motor (max)	2.2
Classifying motor (max)	1.5
Temperature [ºC] to meet 118 kg/h water evaporation	
Inlet air temperature	223
Outlet air temperature	80
Standard air flow rate [m3/min] (dryer outlet)	20-50
Weight [kg]	
Weight	1150

Cyclone with dust separation arrangement

Cyclone CD-915 of Apzem Company was selected. This is the compact model which has the fixed filter inside of it for dust collection. CD – 915 might become a good solution for collecting dried product and air cleaning.

Main parameters of CD-915 model are listed in Table 12.

Table 12: Cyclone CD-915 parameters [9]

Model	Cyclone + dust collector CD-915
Main dimension (m)	
Height	1.300
Width	0.500
Length	0.500
Utilities	
Power option	3 phase
Efficiency	Up to 99 %
Capacity (m3/min)	43-57
Air Temperature (ºC)	
Max Inlet	180
Max outlet	200

Rotary feeder

For the discharge of the dry cellulose to the shaping machine we need to use a rotary feeder, order to could get the required quantity. In this case Rotary feeder S-AX 250 belongs to TBMA Company was selected.

Main Parameters of S-AX 250 are listed in Table 13.

Table 13: Rotary feeder S-Ax 250 parameters [10].

Model	S-AX 250
Main dimensions (m)	
Length	0.590
Width	0.200
Height	0.200
Utilities	
Watt (kW)	1.1
Electrical supply (V, Hz)	230/400,50
Air temperature (ºC; K)	
Max Allowable product Tª	120; 393
Weight (kg)	
Weight	75

Lay-out design of the plant (3D MODEL)

The 3D Model of the pilot flash drying unit was compiled in the AutoCAD software. The disposition of the main equipment was done following the ergonomics and convenience of its maintenance. The two-tire arrangement of the equipment inside the 45' container was used for the maximal use of the limited space and for the running of the process. The most heavyweight units were located on the container's floor while the special supporting stands were used for the other equipment. The most informative views of the pilot flash drying unit are represented on the Figures 8 - 13.

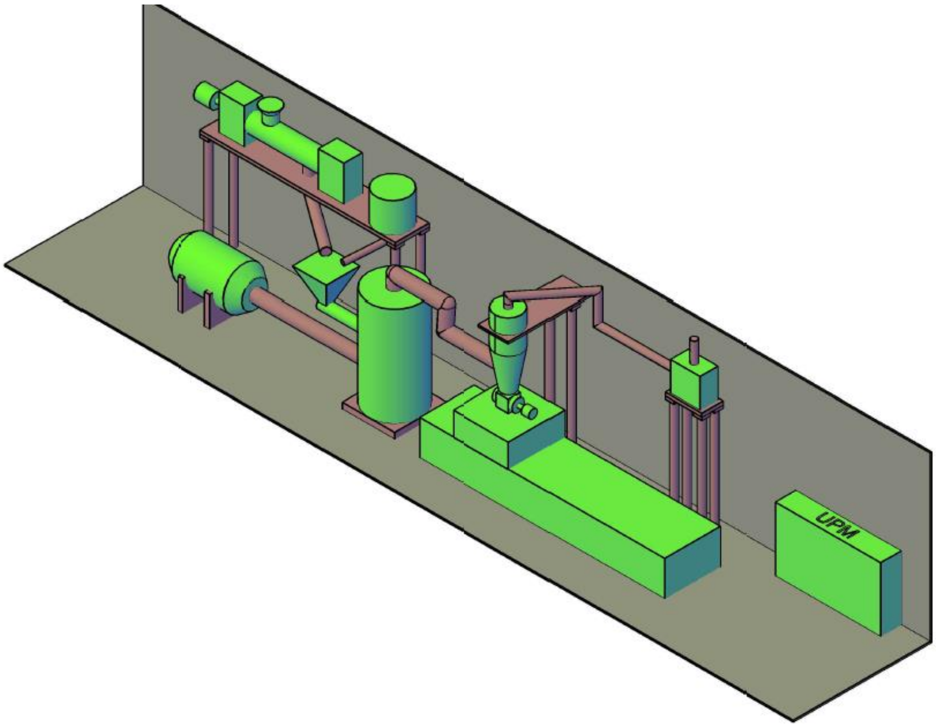


Figure 8: View A

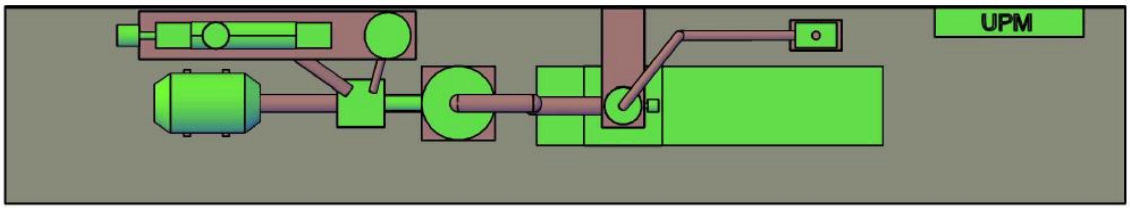


Figure 9: View from above

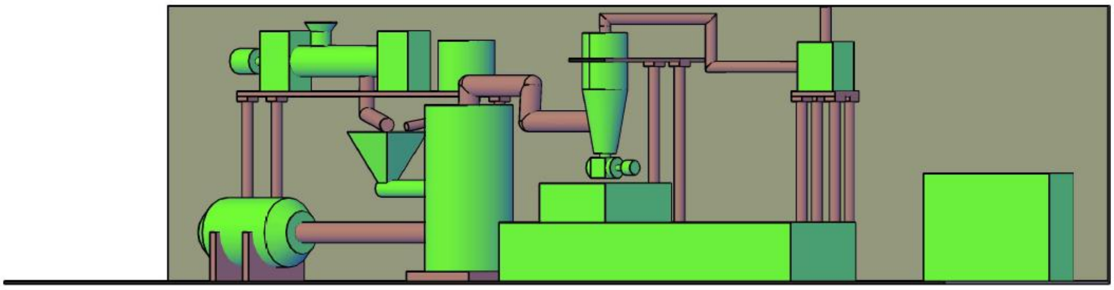


Figure 10: View B

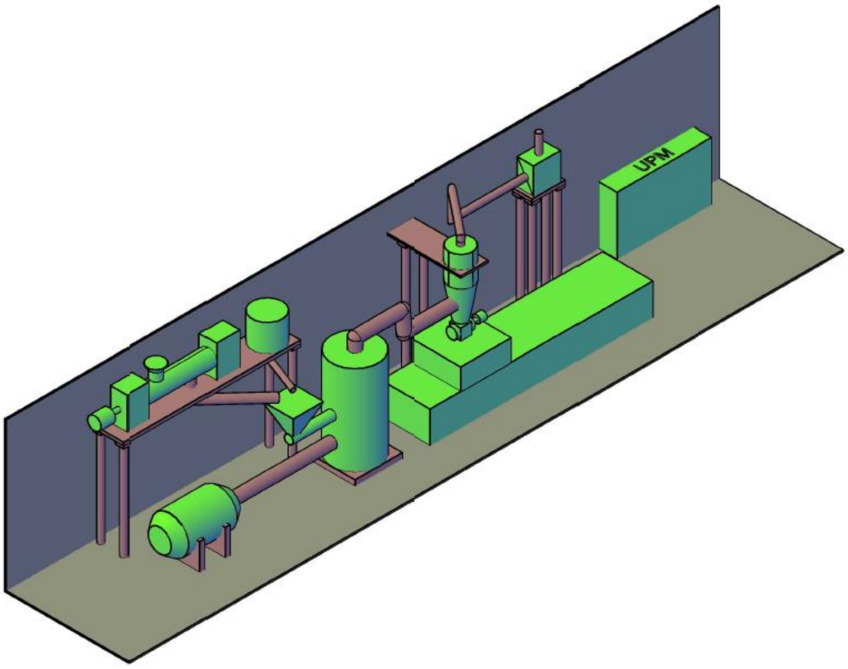


Figure 11: View C

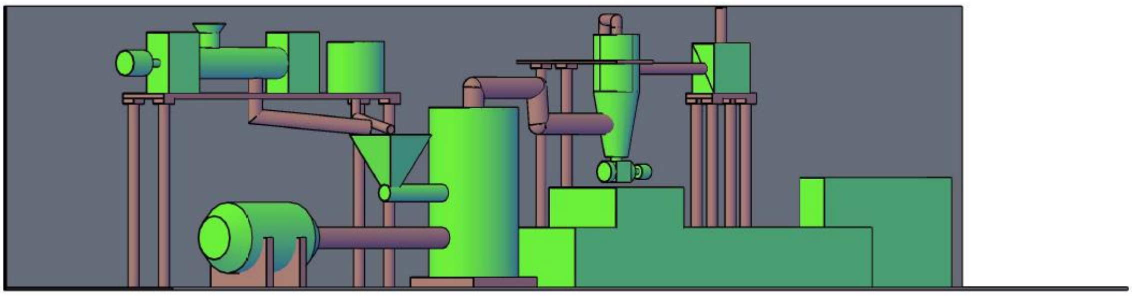


Figure 12: View D

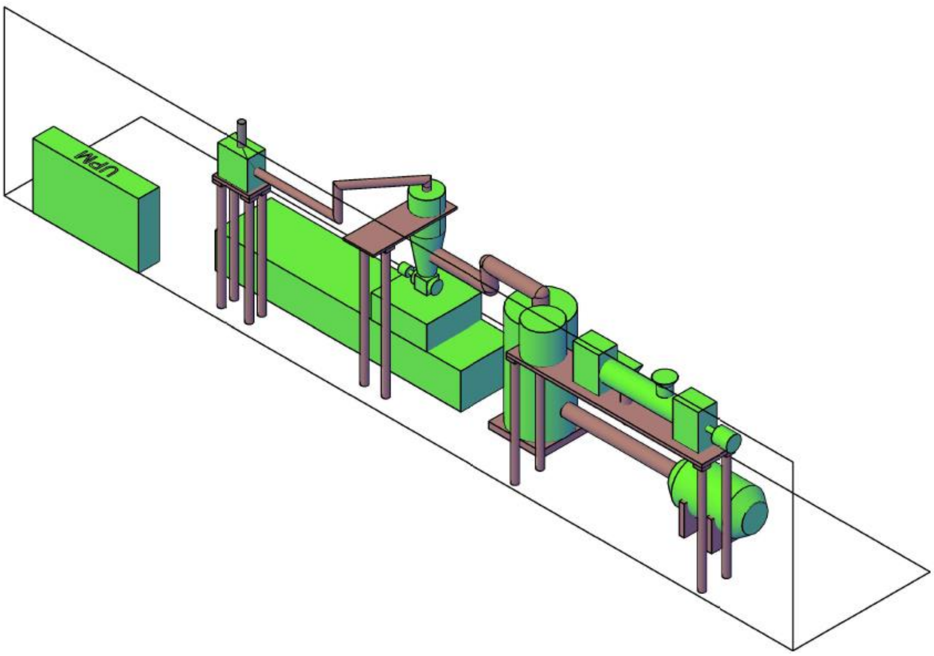


Figure 13: Real view for the transparent wall

Economic analysis of the project

Economic analysis is extremely important part because it can give the basis for the viability estimation of the project. Investment and operation cost estimate, profitability evaluation, sensitivity and SWOT analysis were the main parts of the economic analysis of the project.

The fixed capital investment cost and operation cost estimate were done using the total purchased equipment price and the initial information gained from the UPM Company members. Initial info and main results are listed in the Table 14.

Table 14: The fixed capital investment cost and operation cost estimate results.

Total purchased equipment price	774 000 EUR
Fixed capital investments	1 097 145 EUR
Annual operating cost after start-up	152 820 EUR
Number of working days	100 - 200
Test price of the unit	3096 – 4644 EUR/day
Annual net profit after start-up	Vary from the number of working days and the test price of the unit
The depreciation is based on the Modified Accelerated Cost Recovery System (MACRS) (Table method)	During 10 years after investments
Project life	10 years after start up
Taxation rate	t = 45 %
Investment period	In the second half of year 1
Start-up of the unit	In the end of year 1

The economical evaluation of the project was done after the investment cost estimate and the operation cost estimate. The profitability criteria of time (PBP, DPBP), cash (CCR, PVR) and interest (ROROI, IRR) were taken into account for the non-discounted and discounted profitability evaluation (as the time value of money must be taken into account). The profitability estimation was done for 9 different cases (Table 15). Main differences between them were the number of working days of the plant and the test price of the drying unit. Different discount rates of 0 %, 5 %, 7 % and 10 % were taken into account.

Table 15 – Calculated cases.

№	Case 1		Case 2		Case 3	
	Number of working days	Test price/day [EUR]	Number of working days	Test price/day [EUR]	Number of working days	Test price/day [EUR]
1	100	3096	150	3096	200	3096
2	100	3870	150	3870	200	3870
3	100	4644	150	4644	200	4644

Main profitability criteria calculations for the aforementioned cases are represented in the Table 16. The cash flow diagrams of the first, middle and last one are listed on Figures 14 – 16. Case 1 № 1 (100 working days and 3096 EUR test price per day) was the least profitable one. Case 3 № 3 (200 working days and 4644 EUR test price per day) was the most profitable and reliable. As the upshot, it can be clearly seen in the Table 16 that with the increase of the working days and increase of the test price per day the project become more potentially profitable.

Table 16: The calculation of the profitability criteria for 9 different cases.

Criterion	Case 1 №1	Case 1 №2	Case 1 №3	Case 2 №1	Case 2 №2	Case 2 №3	Case 3 №1	Case 3 №2	Case 3 №3	Measure
CCP (r=0 %)	422869.569	848569.569	1274269.569	1110259.569	1748809.569	2387359.569	1797649.569	2649049.569	3500449.569	EUR
CCR (r=0 %)	1.385	1.773	2.16	2.012	2.6	3.176	2.638	3.414	4.19	-
PBP (r=0 %)	6.09	4.53	3.74	4.01	3.1	2.61	3.08	2.45	2.04	years
NPV (r=5 %)	119250.861	432312.058	745373.254	624759.754	1094351.548	1563943.342	1130268.647	1756391.039	2382513.431	EUR
PVR (r=5 %)	1.114	1.413	1.713	1.598	2.05	2.497	2.082	2.68	3.28	-
DPBP (r=5 %)	8.16	5.51	4.34	4.7	3.6	2.9	3.5	2.7	2.2	years
NPV (r=7 %)	29822.787	309256.307	588689.827	481032.106	900182.386	1319332.666	932241.426	1491108.465	2049975.505	EUR
PVR (r=7 %)	1.029	1.302	1.574	1.47	1.88	2.286	1.9	2.454	2.1	-
DPBP (r=7 %)	9.42	6.1	4.63	5.02	3.8	3.02	3.7	2.8	2.3	years
NPV (r=10 %)	-79475.622	158319.125	396113.872	304498.377	661190.497	1017882.618	688472.375	1164061.869	1639651.363	EUR
PVR (r=10 %)	0.92	1.16	1.397	1.305	1.66	2.02	1.690	2.167	2.644	-
DPBP (r=10 %)	10+	7.26	5.18	5.81	4.1	3.25	4.03	2.98	2.4	Years
ROROI (r=0 %)	3.85	7.734	11.61	10.12	15.94	21.76	16.385	24.145	31.905	%
IRR	7.8	14.2	19.8	17.71	25.6	32.84	26.2	35.67	44.55	%

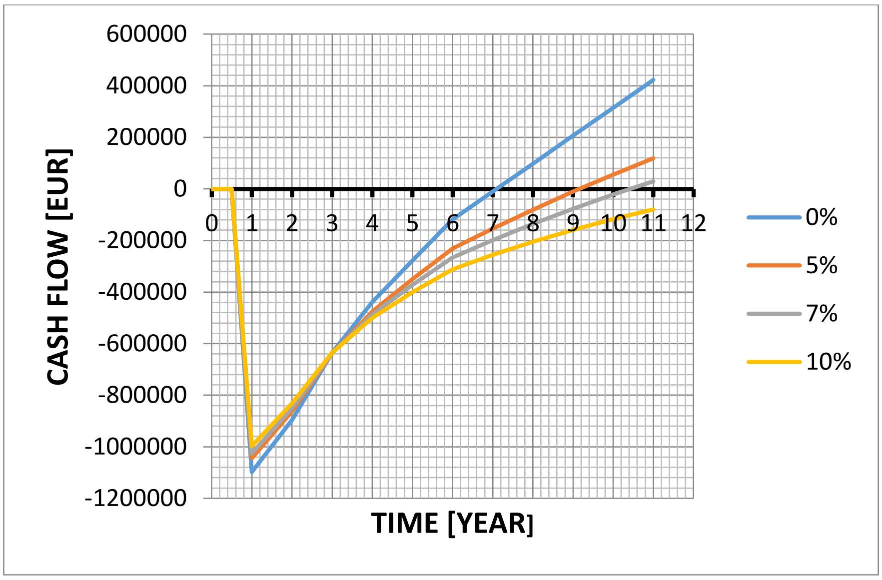


Figure 14: Cash flow diagram for Case 1 №1

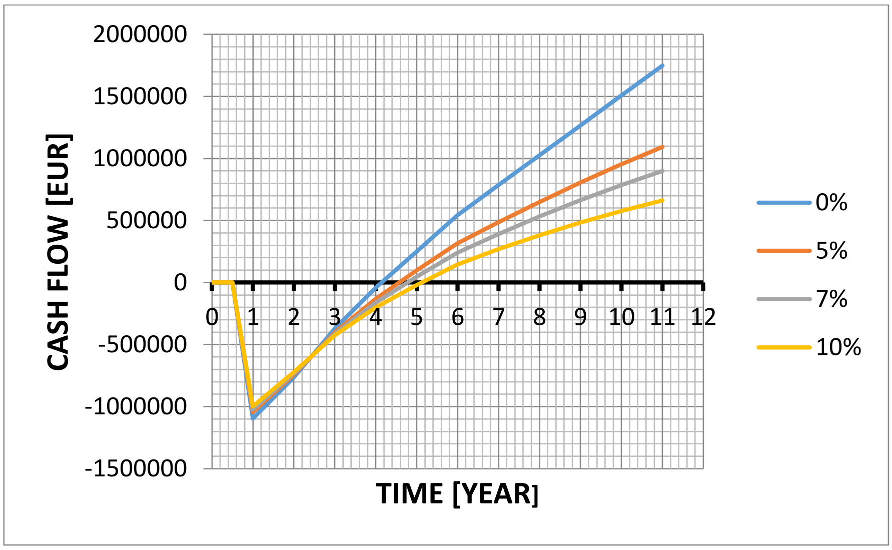


Figure 15: Cash flow diagram for Case 2 №2

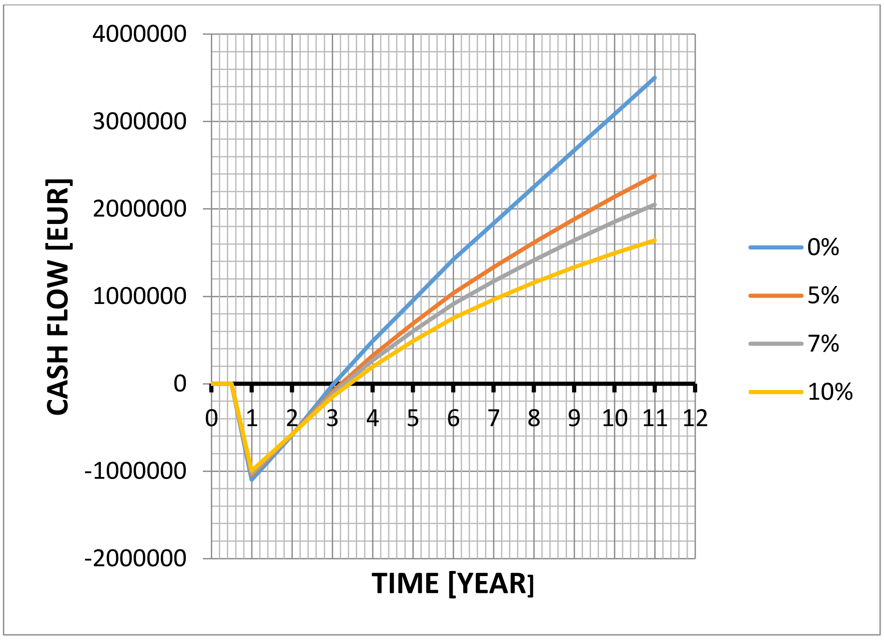


Figure 16: Cash flow diagram for Case 3 №3

The SWOT analysis is represented in the Table 17.

Table 17: SWOT analysis.

Strengths	Small size of the drying plant;
	Transportability of the drying unit by different modes of transport (marine, railway and road);
	Relatively high capacity of the drying unit due to the usage of the high-efficient technological equipment;
	Highly automated system let to make operation of the drying process with minimum human involvement;
	Technology which is suitable both for the hardwood and softwood species;
	Technology is acceptable for the drying with minor mechanical influence on the cellulose properties and fibers length;
	Possibility to use the chemical additions which accelerate the drying process of the cellulose before the flash dryer;
	The drying unit provides a low outlet moisture content which is close to 1-2 %;
	Particular particle size selection;
	Easy transport of dried cellulose in the polyethylene packages after the baling machine;
	Annual utility consumption on the relatively low level.
Weakness	Difficulties connected with the maintaining of the temperature of the process inside in the container (especially avoid overheating during summer time);
	Cellulose is a flammable material that requires additional preventive arrangement;
	All the equipment used in the process is from foreign suppliers what increases the costs;
	Relatively high fixed capital investments due to the high purchased equipment price.
Opportunities	Variable test price of the unit
	Pilot unit as the small scaled prototype of the original unit. Future business opportunities;
	Pilot flash dryer can be used as an advertisement;
	Partnership with equipment suppliers.
Threats	Market competition;
	Premature failure of the equipment;
	Sustainable market demand;
	Taxes (custom taxes).

Conclusions

The project was devoted to the pilot scale flash drying unit design. Main criteria for the design were the transportability of the unit inside the container and meeting of the demands in capacities at 1000 kg of dried cellulose per day. The preliminary dewatering, chemical addition system and baling of the dried product in the end of the flash drying process were the other important issues for the consideration.

At the end of this investigation, the dryer of Hosokawa Company was selected due to the smallest dimensions comparing with SPX and Bepex units and the achievement of the demands in capacity for dried cellulose at 1000 kg per day. The suitability of this technology to the initial process description is another great advantage of it as Hosokawa provides the equipment for mixing of the drying material with chemicals which can intensify the process of pneumatic drying. Another big advantage of this technology is the classifying unit located in the top section of the drying chamber because it can be useful for the particular particle size selection.

The equipment selection was of crucial importance to select the equipment answering the demands of capacities but in the same time which can be located in the container for future transportation. The disposition of the selected units represented on Figures 8 – 13 can be considered ergonomic and useful for the equipment maintenance. However, to make the process even more flexible it is possible to use the open-top container for the pilot flash drying unit transportation as the greatest challenge in lay-out design was connected with the limited height space. It can be also useful for the system cooling, especially in the summertime as the open-top container does not demand the additional ventilation systems.

The project can also be considered reliable and resistant to the external factors when analyzing the obtained results represented in the Table 16 and Figures 15 – 16. Even the highest test price at 4644 EUR per day seems to be reasonable as the pilot flash dryer has big number of advantages represented in the Table 17. Big threat can be connected mainly with the decrease of the number of working days which is closely connected with the market demand. The worst calculated situation is represented on the Figure 14, but the demand can be controlled by the variable test price as the decrease of it can have positive impact on the market demand.

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