

## Annotation sheet

**Name:** Alikhan

**Surname:** Uteyev

**Title Czech:** Laboratorní zařízení pro hydrotermickou předúpravu bioodpadů

**Title English:** Universal laboratory equipment for hydrothermal pretreatment of wastes

**Scope of work:** number of pages: 61

number of figures: 24

number of tables: 14

number of appendices: 3

**Academic year:** 2015/2016

**Language:** English

**Department:** Process Engineering

**Specialization:** Power Engineering and Process Technology

**Supervisor:** Ing. Lukáš Krátký, Ph.D.

**Reviewer:**

**Tutor:**

**Submitter:** Czech Technical University in Prague, Faculty of Mechanical Engineering,  
Department of Process Engineering

### Annotation - English:

The main goal of this thesis is to design of “Universal laboratory equipment for hydrothermal pretreatment of wastes”. This work divided into two main parts. In the first part, the theory will be covered. There will be a brief description: what is the problem of wastes and biomass. Farther the process of pretreatment of biomass will be described. I will focus on one process and describe it in more detail, because that thesis based in one concretely pretreatment. The second part is calculating and design of equipment. The main aim of that part is choose the right characteristics and with them calculate main dimension of our vessel. Finally, I will create assembly drawing according to the calculated values.

**Keywords:** Biomass, lignocellulose, pretreatment, hydrothermal, liquid hot water, steam explosion

**Utilization:** For Department of Process Engineering, Czech Technical University in Prague

**Declaration**

I confirm that the bachelor's thesis was disposed by myself and independently, under leading of my thesis supervisor. I stated all sources of the documents and literature.

In Prague.....

.....

Name and Surname

## **Acknowledgements**

I would like to express my sincere thanks to my thesis supervisor Ing. Lukáš Krátký, Ph.D., for his professional guidance, support and valuable advice during the writing this thesis.

Also, I would like to thank all the staff of the Department of Process Engineering for given me immense knowledge.

Finally, from the bottom of my heart I would like to thank my family: my parents and my sister supporting me materially and spiritually throughout my life.

## Content

<b>Annotation sheet</b> .....	<b>1</b>
<b>Declaration</b> .....	<b>3</b>
<b>Acknowledgements</b> .....	<b>5</b>
<b>1 Theoretical part</b> .....	<b>7</b>
<b>1.1 Introduction</b> .....	<b>7</b>
1.1.1 Waste classification .....	7
1.1.2 Motivation.....	9
<b>1.2 Pretreatment</b> .....	<b>9</b>
1.2.1 Physical pretreatments .....	10
1.2.2 Biological pretreatment.....	10
1.2.3 Chemical pretreatment .....	11
1.2.4 Physico-chemical pretreatments .....	12
<b>2 Hydrothermal pretreatment of wastes</b> .....	<b>16</b>
<b>2.1 Liquid hot water</b> .....	<b>16</b>
2.1.1 Principle .....	16
2.1.2 Reactors .....	20
<b>2.2 Steam explosion</b> .....	<b>26</b>
2.2.1 Principle .....	26
2.2.2 Batch reactors .....	28
<b>3 The aim of thesis</b> .....	<b>33</b>
<b>4 Design of vessel</b> .....	<b>34</b>
<b>4.1 Initial parameters</b> .....	<b>34</b>
4.1.1 Main dimensions .....	35
4.1.2 Design of mixing system .....	37
<b>5 Construction of reactor</b> .....	<b>40</b>
<b>5.1 Strength calculation</b> .....	<b>40</b>
5.1.1 The thickness of the vessel .....	40
5.1.2 Strength Dimensioning of Stirrer Shaft .....	47
<b>Conclusion</b> .....	<b>51</b>
<b>References</b> .....	<b>52</b>
<b>List of symbols</b> .....	<b>54</b>
<b>List of figures and tables</b> .....	<b>56</b>
<b>Appendix A</b> .....	<b>58</b>

# **1 Theoretical part**

## **1.1 Introduction**

Every year the problem of waste in all countries is becoming more serious. Waste risk is determined by their physical and chemical properties, as well as the conditions of their storage or placement in the environment. Uncontrolled attitude of waste could lead to environmental effects, therefore all major countries have adopted special laws that regulate the complex waste management (collection, transportation, sorting, disposal, recycling, liquidation, burial, storage requirements, rules of marking and storage), which constitute a danger to human health and the environment on which life depends. Those or other wastes contain hazardous substances, pathogens, toxins or explosives. Waste introduce to the danger to humans and the environment.

The legislation of a number of countries where the main goal of the state is recognized as environmental protection, and the implementation of laws related to the collection of rules, recycling and waste reduction as the main sources of environmental pollution is controlled very strictly. [1]

### **1.1.1 Waste classification**

Waste is classified according to several criteria such as appearance, physical state, and the bearing of risk. According to the criteria of appearance, there is production waste (industrial waste) and household waste (municipal). Waste production is waste that occurs after the production process, they are not deliberately; each has its own production of industrial waste. Consumer waste is not applicable to domestic goods and products, as well as unnecessary human products or residues generated in the municipal services system. In aggregate state can be divided into solid, liquid and gaseous wastes. In danger can be divided into the garbage which is dangerous for the people and one that is dangerous for the environment.

#### **Biomass**

Biomass is a collection of plant and animal organisms. Therefore, a large amount of garbage can be classified as biomass because it contains a part of the animal or plant organisms. This type of waste as a municipal solid waste, biological waste, paper, medical, and forestry wastes compelling cost of the biomass.

The one of the well-known type of a biomass is lignocelluloses biomass, so I want to focus on it, which is contained in all the above-mentioned wastes. Lignocelluloses substrates are generally composed of cellulose, hemicelluloses, lignin and a wide variety of organic and inorganic compounds. Because all biotechnological technologies (anaerobic fermentation, alcoholic fermentation, biogas plants) are based on the treatment of lignocelluloses biomass. [2]

Annual stock of lignocellulose for 2007 is 200 billion metric tons, which is one of the major renewable resources. It includes residues, herbaceous, hardwood, softwood, pulp and waste industrial byproducts. [3] In the table 1 below is shown many kinds of raw materials.

Raw material	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Agricultural residues			
Corn cobs	38.8-44.0	33.0-36.4	13.1-18.0
Corn stover	34.32-36.5	20.11-31.3	11.9-13.55
Wheat straw	33-40	20.0-33.8	15.0-26.8
Rice straw	35.0-36.6	16.1-22.0	12.0-14.9
Sugar cane bagasse	34.1-49.0	15.79-29.6	19.4-27.2
Barley straw	37.5	25.1-37.1	15.8-16.9
Rise husk	33.43	20.99	18.25
Rye straw	41.1-42.1	23.8-24.4	19.5-22.9
Rapeseed straw	36.59-37.0	19.6-24.22	15.55-18
Sunflowers stalks	33.8	20.2-24.27	14.6-19.9
Sweet sorghum bagasse	41.33-45.3	22.01-26.3	15.2-16.47
Herbaceous			
Switchgrass	41.2-32.97	25.95-31.1	17.34-19.1
Alfalfa stems	24.7	14.7	14.9
Coastal Bermuda grass	25.59	19.29	19.33
Hardwood			
Aspen	43.8	18	20.8
Hybrid Poplar	48.95	21.73	23.25
Eucalyptus	44.6	21.4	30.1
Eucalyptus globulus	44.4	21.8	27.7
Softwood			
Pinus radiata	45.3	22.5	26.8
Spruce	43.8	20.8	28.83
Cellulose wastes			
Newspapers	60.3	16.4	12.4
Recycled paper sludge	60.8	14.2	8.4
Industry co-products			
Distiller's grains	12.63	16.9	-
Brewer's spent grain	18.8-20.97	15.18-32.8	21.7-25.62

*Table 1. Composition of selected lignocellulosic materials (%wt. dry matter). [3]*

### **1.1.2 Motivation**

Any interference with the natural environment entails consequences. Therefore, thanks to cycling in nature ensures systematic utilization of organic waste and the involvement of the decay products in the new processes of life.

However, nature does not always have time to cope with the effects of human activity. This also applies to biomass, which is not only dangerous for the environment, but also represent a risk of spreading infections, which are dangerous to humans. Situated on the road to environmental management this issue is resolved strictly in the world that implies not only reduce waste, but also to use them as raw material.

Very large amounts of products of our activities are associated with oil production, which is every day becomes less. Looking at the amount of biomass you can immediately tell that this resource will be cheaper and of the same quality, and most importantly a positive impact on the environment. Approximately 17% of the volume of products derived from petroleum in the US is classified as chemicals. [4] If these chemicals are obtained from renewable resources (e.g., biomass in a biorefinery), it would reduce petroleum dependence. The term “biorefinery” borrows its origin from the classical petroleum refinery concept and refers to biomass conversion into fuels and chemicals with high added-value through the integration of clean processes. [3]

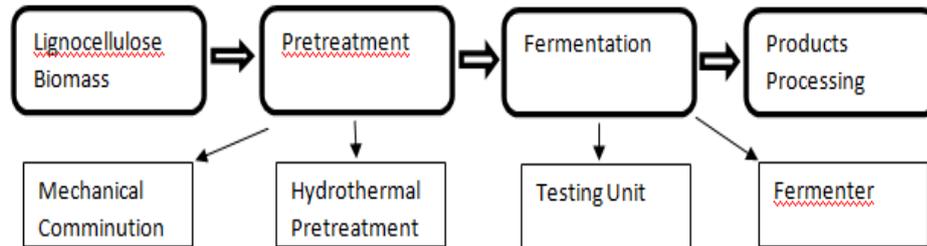
The increasing problem of the CO<sub>2</sub> emissions besides some energy security concerns has strengthened the interest in alternative, nonpetroleum-based sources of energy. Biomass is the only suitable and renewable primary energy resource than can provide alternative transportation fuels such as bioethanol or biodiesel in the short-term. [5]

## **1.2 Pretreatment**

Nowadays, production of bioethanol based on sugar and ethanol from starch, but there are a large number of disputes about sustainability. In this work, I will focus on the utilization of lignocelluloses biomass, as this is a good alternative.

Ethanol production from lignocellulosic biomass comprises the following main steps: hydrolysis of cellulose and hemicellulose, sugar fermentation, separation of lignin residue and, finally, recovery and purifying the ethanol to meet fuel specifications. The task of hydrolysing lignocellulose to fermentable monosaccharides is still technically problematic because the digestibility of cellulose is hindered by many physico-chemical, structural and

compositional factors. Owing to these structural characteristics, pretreatment is an essential step for obtaining potentially fermentable sugars in the hydrolysis step. The aim of the pretreatment is to break down the lignin structure and disrupt the crystalline structure of cellulose for enhancing enzymes accessibility to the cellulose during hydrolysis step. [5]



*Figure 1. Lab-technology for biogas yield evaluation [2]*

At this time, a large number of pretreatments used in a wide variety of raw materials. Researches preceding basic treatments focus on the evaluation and development, support for the subsequent enzymatic hydrolysis processing biomass with lower enzyme dosage and shorter bioconversion time.

In accordance with the physical and chemical properties of the individual raw materials, the corresponding pretreatment should be chosen. Certain pretreatment has an effect in further processes of transformation in terms of digestibility of cellulose, and the appearance of toxic compounds. Most pretreatments were administered for in the last decades. They are divided into physical, biological, chemical, physico-chemical, in accordance with different force or energy consumed during pretreatment.

## **1.2.1 Physical pretreatments**

### **1.2.1.1 Mechanical comminution**

The aim is to reduce the particle size and degree of crystallinity of lignocellulose. In order to decrease the degree of polymerization and to increase the specific surface by combining of milling, grinding or chipping depending on the final particle size of the material (10–30 mm after chipping and 0.2–2 mm after milling or grinding). [5]

### **1.2.2 Biological pretreatment**

Fungal pretreatment has been investigated to improve the supply of lignocellulosic for feed and paper applications. This method is environmentally friendly and has been received attention as a pretreatment to improve the enzymatic scarification of lignocellulosic biomass to ethanol production process. Biological pretreatment is using microorganisms

such as brown, white and soft-rot fungi. One of the commonly used microorganism is white-rot fungi, as it is the most effective which occurs through the action of lignin-degrading enzymes such as peroxidases and laccases. [5]

### **1.2.3 Chemical pretreatment**

#### **1.2.3.1 Alkali pretreatments**

Alkaline pretreatment efficiency depends on the amount of lignin in the biomass. Alkaline pretreatment increases the digestibility of cellulose and improves the efficiency of lignin solubilization. Treatment may take from a few seconds to several days at room temperature. It cause less sugar degradation than acid pretreatment and it was shown to be more effective on agricultural residues than on wood materials

The alkaline pretreatment is performed with using sodium, potassium, calcium and ammonium hydroxides. NaOH causes swelling, increasing the internal surface of cellulose and decreasing the degree of polymerization and crystallinity, which provokes lignin structure disruption. NaOH has been reported to increase hardwood digestibility from 14% to 55% by reducing lignin content from 24–55% to 20%. [5]

There is also often used Ca (OH)<sub>2</sub>, i.e. lime. Lime reduces crystal index by removing amorphous substances such as lignin. Also removes the acetyl groups from hemicellulose. This pretreatment lower cost but inferior in safety compared with NaOH or KOH. [5]

#### **1.2.3.2 Acid pretreatment**

The main purpose of using acid solubilization is pretreated biomass hemicellulose fraction and makes it more suitable for fermentation. This type of pretreatment may take place with dilute and concentrated acid.

Dilute acid pretreatment are more beneficial to the industry for a wide range of lignocellulosic biomass. Reactors used: percolation, plug flow, shrinking-bed, batch and countercurrent. Suitable temperature variation requires less time at high temperature, and vice versa (e.g. 120 °C-180 °C). It presents the advantage of solubilizing hemicellulose, mainly xylan, but also converting solubilized hemicellulose to fermentable sugars. Pretreatment is the cause of degradation products in contrast to concentrated acid. Used acids: H<sub>2</sub>SO<sub>4</sub> (often used), hydrochloric acid, phosphoric acid, nitric acid. [5]

### **1.2.3.3 Ozonolysis**

Ozone is a strong oxidant. It shows good results in delignification. The parameter of this method is room temperature to normal pressure. In this case, there is no risk of inhibitory compounds, though method is not economically profitable. [5]

### **1.2.3.4 Organosolv**

Mixtures use a large amount of water or organic solvents, including methanol, ethanol, ethylene glycol, acetone, tetrahydrofurfuryl alcohol. The solvent is removed by extraction and separation, for example, evaporation and condensation, and they must be recycled to reduce maintenance costs. Necessity of removing the solvent is that it can be inhibitory to enzymatic hydrolysis and fermentation of microorganisms. [5]

### **1.2.3.5 Ionic liquids (ILs) pretreatment**

ILs is salts composed of cations and small inorganic anions, most often being liquid at room temperature. Adjusting anions and cations constituting the alkyl can change their properties as a solvent. The IL anionic activity can be dissolved carbohydrates and lignin as a hydrogen bond formed between IL unhydrated chloride ions in IL hydroxyl protons and sugar in a ratio of 1: 1 stoichiometry.

Due to the complex relationship non-covalent interactions, polymers include cellulose biomass hemicellulose and lignin properly destroyed while minimizing the formation of degradation products. However, the majority of data shows the effectiveness of IL that has been designed using pure crystalline cellulose, and its applicability to more complicated combinations of components in the lignocellulosic biomass needs further investigation. [5]

## **1.2.4 Physico-chemical pretreatments**

### **1.2.4.1 Steam explosion: SO<sub>2</sub>-steam explosion**

Steam explosion pretreatment commonly used method. The biomass is treated with steam under pressure for a few minutes or seconds and then suddenly is depressurized, and it is called hydrothermal pretreatment. This processing is the mechanical bond strength and the chemical effects due to hydrolysis of the acetyl groups in the hemicellulose. Autohydrolysis is the cause of the acetic acid from the acetyl group under a high temperature; the water may enter also to an acid at a high temperature. The mechanical effect is a consequence of the sharp pressure drop and separation of fiber under explosive

decompression. Lignin is removed partially and redistributed through a combination of partial hydrolysis of hemicellulose and solubilization. Cellulose surface exposed by removing hemicellulose, it gives access to cellulose fermentation.

The most important factors affecting the effectiveness of steam explosion are particle size, temperature, residence time and the combined effect of both temperature (T) and time (t). The time is described by the severity factor, which is shown in the equation (1.2.4-1)

$$R_o = t * e^{[T-100/14.75]} \quad (1.2.4-1)$$

and being the optimal conditions for maximum sugar yield a severity factor between 3.0 and 4.5. Higher temperatures result in an increased removal of hemicelluloses from the solid fraction and an enhanced cellulose digestibility, they also promote higher sugar degradation. [5, p. 6]

#### **1.2.4.2 Liquid hot water**

The hydrothermal treatment is also present processing liquid hot water. This treatment does not require any catalysts, chemicals, as well as rapid decompression. In order to support liquid water pressure is required, the temperature of 160 °C-240 °C leads to change the structure of lignocellulose. [5]

The basis of this hot water solubilization of hemicelluloses is to achieve the right cellulose and to avoid the appearance of inhibitors. After treatment should be filtered from suspension for the emergence of two fraction: solid cellulose-enriched fraction and a liquid fraction. To avoid the appearance of inhibitor required a pH of 4-7, because the hemicelluloses sugar stored in the oligomeric form and there is no threat of monomers. No degradation products. [5]

#### **1.2.4.3 Ammonia fiber explosion (AFEX)**

AFEX pretreatment uses liquid anhydrous ammonia under a high pressure at a temperature of 60 and 100 °C for variable time. After the pressure is rapidly reduced, in this regard, the ammonia gas is growing rapidly, due to which the fibers break down biomass, as well as the pulp passes partial decrystallization. [5]

AFEX cope with the destruction of the lignin-carbohydrate bonds and a decrease in the degree of crystallinity of cellulose. Under this treatment, a small amount of solid material is solubilized, leaving a small amount of hemicellulose and lignin. AFEX cope with the destruction of the lignin-carbohydrate bonds and a decrease in the degree of

crystallinity of cellulose. Deacetylation hemicellulose is present. AFEX is the cause of a good digestibility of biomass, which shows a good result after hydrolysis. [5]

#### **1.2.4.4 Wet oxidation**

Wet oxidation method uses oxygen as a catalyst. Processing occurs with low temperature and short time of the reactor. Working time is 10-15 minutes with the temperature of 170-200 °C and pressure of 1-1.2 MPa. Adding oxygen at a temperature above 170 ° C affect the overall demand for the energy required. The basic reaction in the wet oxidation is the cause of acid from hydrolytic processes and oxidation reactions. [5]

#### **1.2.4.5 Microwave pretreatment**

Process takes 5-20 minutes, by immersion the material in reagents and subjecting the slurry by microwave radiation. The reagent is a caustic sodium hydroxide. [5]

#### **1.2.4.6 Ultrasound pretreatment**

Ultrasound method is poorly understood for the extraction of hemicellulose. However, some tests have shown the effectiveness of this method.

Ultrasound field introduced into the solution for enzyme treatment to cause a cavitation effect, this increases the movement of the macromolecules to the substrate surface. Implosion of cavitation bubbles takes place through mechanical effects, which allows the opening surface of solid substrates for the enzyme, the best effect occurs at a temperature of 50 °C, which is the average temperature for many enzymes. [5]

#### **1.2.4.7 CO<sub>2</sub> explosion**

In this pretreatment method uses CO<sub>2</sub> as the supercritical fluid. This fluid is in a gaseous state, but is susceptible to pressure at a maximum temperature of the critical point in fluid, as density. This treatment is good destroys lignin improving digestibility of substrate. CO<sub>2</sub> molecules have a similar size as the body of water molecules and ammonia, thereby they can also penetrate into the pores of the lignocellulose. This procedure causes a high pressure, which causes an explosion that disrupts the structure of cellulose and hemicellulose, which enhances the ability of the enzyme to attack.

<b>Pretreatment method</b>	<b>Advantages</b>	<b>Disadvantages</b>
Biological	<ul style="list-style-type: none"> <li>– Degrades lignin and hemicellulose</li> <li>– Low energy consumption</li> </ul>	<ul style="list-style-type: none"> <li>– Low rate of hydrolysis</li> </ul>
Milling	<ul style="list-style-type: none"> <li>– Reduces cellulose crystallinity</li> </ul>	<ul style="list-style-type: none"> <li>– High power and energy consumption</li> </ul>
Steam explosion	<ul style="list-style-type: none"> <li>– Causes lignin transformation and hemicellulose solubilization</li> <li>– Cost-effective</li> <li>– Higher yield of glucose and hemicellulose in the two-step method</li> </ul>	<ul style="list-style-type: none"> <li>– Generation of toxic compounds</li> <li>– Partial hemicellulose degradation</li> </ul>
AFEX	<ul style="list-style-type: none"> <li>– Increases accessible surface area</li> <li>– Low formation of inhibitors</li> </ul>	<ul style="list-style-type: none"> <li>– Not efficient for raw materials with high lignin content</li> <li>– High cost of large amount of ammonia</li> </ul>
CO <sub>2</sub> explosion	<ul style="list-style-type: none"> <li>– Increases accessible surface area</li> <li>– Cost-effective</li> <li>– Do not imply generation of toxic compounds</li> </ul>	<ul style="list-style-type: none"> <li>– Does not affect lignin and hemicelluloses</li> <li>– Very high pressure requirements</li> </ul>
Wet oxidation	<ul style="list-style-type: none"> <li>– Efficient removal of lignin</li> <li>– Low formation of inhibitors</li> <li>– Minimizes the energy demand (exothermic)</li> </ul>	<ul style="list-style-type: none"> <li>– High cost of oxygen and alkaline catalyst</li> </ul>
Ozonolysis	<ul style="list-style-type: none"> <li>– Reduces lignin content</li> <li>– Does not imply generation of toxic compounds</li> </ul>	<ul style="list-style-type: none"> <li>– High cost of large amount of ozone needed</li> </ul>
Organosolv	<ul style="list-style-type: none"> <li>– Causes lignin and hemicellulose hydrolysis</li> </ul>	<ul style="list-style-type: none"> <li>– High cost</li> <li>– Solvents need to be drained and recycled</li> </ul>
Concentrated acid	<ul style="list-style-type: none"> <li>– High glucose yield</li> <li>– Ambient temperatures</li> </ul>	<ul style="list-style-type: none"> <li>– High cost of acid and need to be recovered</li> <li>– Reactor corrosion problems</li> </ul>
Diluted acid	<ul style="list-style-type: none"> <li>– Less corrosion problems than concentrated acid</li> <li>– Less formation of inhibitors</li> </ul>	<ul style="list-style-type: none"> <li>– Generation of degradation products</li> <li>– Low sugar concentration in exit stream</li> </ul>

*Table 2. Summary of the advantages and disadvantages with different methods for pretreating lignocellulosic biomass. [5]*

## **2 Hydrothermal pretreatment of wastes**

As mentioned above, one of the best for many reasons renewable resources is lignocellulosic biomass. Lignocellulose consists of three main components: lignin, hemicellulose and cellulose. The process of separation of the three components depends on many factors such as crystallinity, surface area, and moisture content. Pretreatment is required to properly convert lignocellulosic materials into monomeric sugars. Among the large variety of methods well manifests hydrothermal steam explosion, hot water and liquid CO<sub>2</sub> vapour explosion. Hydrothermal treatment is a good method for processing plants and agricultural waste. The big advantage is the low level of pollution and the effectiveness of this method. Standard terms and conditions of the processing temperature is 160 ° C and a time 30 minutes. [6]

### **2.1 Liquid hot water**

#### **2.1.1 Principle**

The material used is very extensive. LCMs (Lignocellulosic materials) fractionation into products are obtained from their structural components have a good possibility leads to Biorefinery concept. However, the problem is the characteristic of each material. Hydrothermal treatment is a method to achieve fractionation, and the first action is the solubilization of hemicellulose. Fig. 2 is a diagram of hydrothermal treatment Biorefinery.

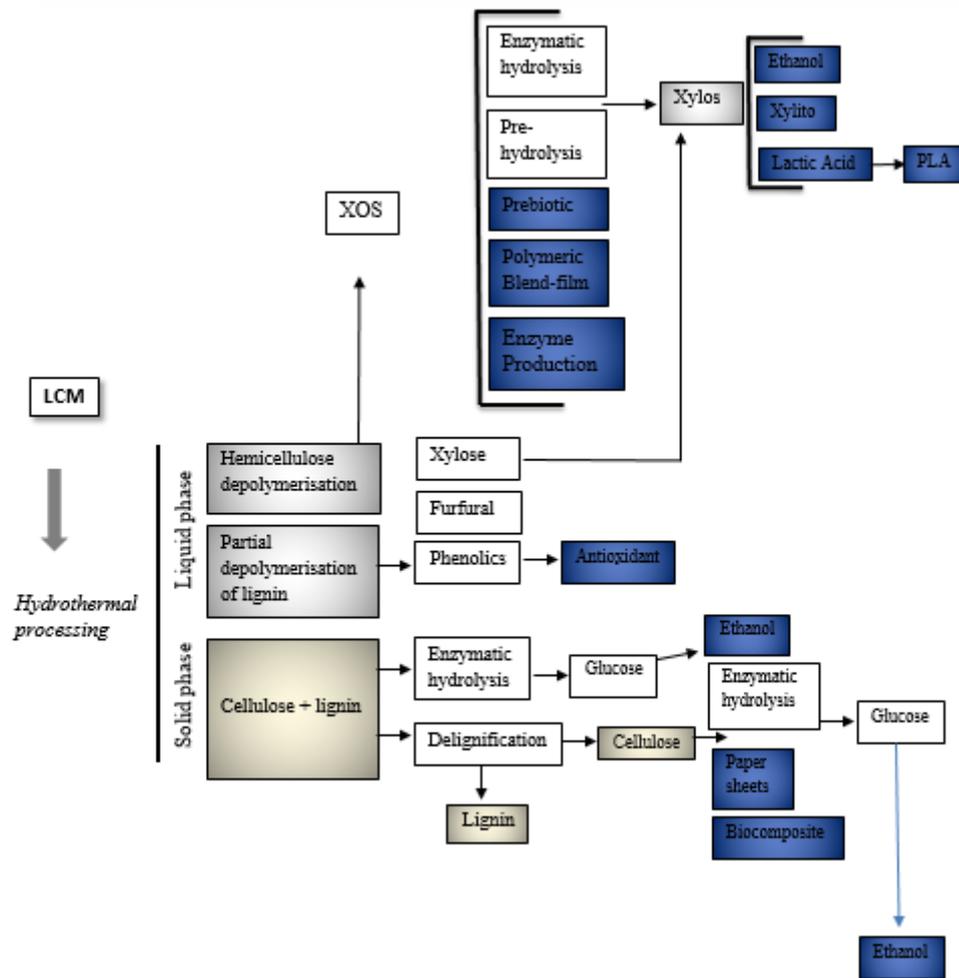
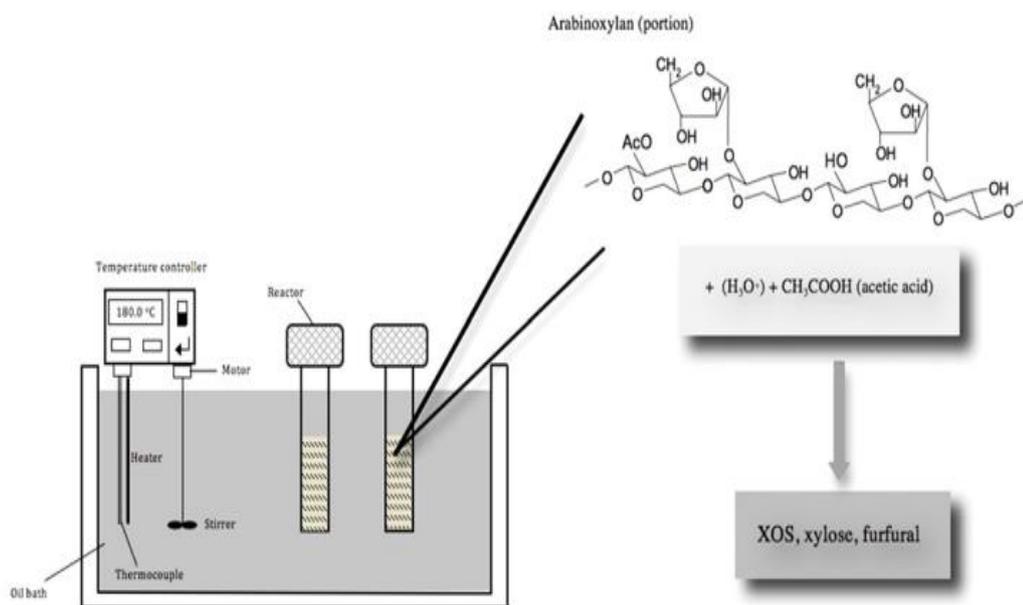


Figure 2. Scheme of a biorefinery using hydrothermal processing and LCMs as raw material. [3]

Returning hydrothermal liquid hot water has a number of attractive conditions such as price, simple implementation and low cellulose degradation under normal conditions. It is clearly seen that the LHW violates cellulose and lignin structure, also increases the surface area. LHW properties change with temperature, pressure and density. In the interval from 100 to 374 °C, become Subcritical Water conditions due to the overheating of water above the saturation pressure. At subcritical conditions, water changes its characteristics and become more acid and an effective solvent. The ionic product of subcritical water is up to three orders of magnitude higher than that at ambient conditions, which means that water is an acid/base catalyst precursor. In addition, the dielectric constant being much higher in the subcritical region of LHW favors ionic reactions. The hot and acid water breaks the links within the hemicellulose, releasing some of the acids that constitute the skeleton, resulting in a further diminution in the reaction pH value. The higher the temperature under which the process is conducted, the more efficient the breakdown of the hemicellulose is, but there is also damage to the cellulose fibers which in

turn decreases monomeric sugars yield. Temperature above 170–190 °C has found optimal for most feedstock. At these temperatures and above LHW may generate inhibitors for enzymatic hydrolysis and fermentation, include aldehydes (furan aldehydes), ketones, phenolics and organic acids such as vanilline, syringaldehyde, furfural and 5-hydroxy methyl furfural (HMF). 2-Furaldehyde (furfural) and HMF are furan aldehydes, which are degradation products of xylose and glucose, respectively. Toxic effects caused by inhibitors derived from mild acid hydrolysis of lignocellulosic materials on bacterial strains which have been reported. It is likely that fermentation rates and productivities have been decreased not only by individual compounds but also by their combined inhibitory effects of such compounds. [7]



*Figure 3. Batch reactor systems for hemicellulose depolymerization in hydrothermal processing. [3]*

### 2.1.1.1 Effect of hydrothermal processing on cellulose

One of the most common biopolymer of LCMs is cellulose. Enzymatic hydrolysis of cellulose content is well used after pretreatment to form a second generation biofuel (table 3). The access to the event structure of enzymes LCMs happening thanks to the localization of lignin on the surface of the LCMs and the potential increase of the cellulose saccharification. In addition, the improvement of the enzymatic saccharification is done by increasing the size of the pores and increase the available area for better penetration of the enzyme. From Table 4 you can see the effectiveness of enzymatic saccharification outputs with different conditions.

Raw material	Temp. (°C)	Time (min)	Particle size	Ethanol Yield (%)
Wheat straw	195	6-12	-	89
Rice Straw	180	30	250-420 µm	100
Switchgrass	210	15	-	72
Eucalyptus globulus	230	-	8 mm	86.4
Wheat straw	214	2.7	0.5-2 mm	90.6
Corn stover	195	10	-	61.2
Sugar cane bagasse	220	2	-	85
Wheat straw	200	40	0.5-2 mm	96
Poplar nigra	240	60	2-5 mm	60
Sweet sorghum bagasse	190	-	-	74
T85 bermudagrass	230	2	500 µm	70
Ulex europaes	230	-	8 mm	82

*Table 3. Production of bioethanol using hydrothermal processing as pretreatment under different operational conditions and raw materials. [3]*

Raw material	Temp. (°C)	Time (min)	Saccharification yield (%)
Prairie cord grass	210	10	94.53
Oil palm fronds	178	11.1	92.78
Coastal Bermuda grass	150	60	67.4
Corn stover	190	15	69.6
Wheat straw	195	3	72
Switchgrass	200	10	74.4
Tamarix ramosissima	200	180	88
Eucalyptus grandis	200	20	96.6
Barley husks	212	-	100
Eucalyptus globulus	230	-	97.9
Wheat straw	180	30	90.88
Prairiecordgrass	190	1	81.28
Sugarcane bagasse	190	10	69.2

*Table 4. Enzymatic Saccharification of pretreated solids with hydrothermal processing as pretreatment. [3]*

As described in various scientific papers cellulose degrade under various conditions. There is information about the reduction of 5.29% and 19.55% cellulose, temperature at 250 °C, as there is a mention that cellulose started to degrade in hexoses and oligosaccharides above 230 C and almost all cellulose decomposed at 295 °C, and so on. As the experience is dependent upon the particular raw material. [3]

#### **2.1.1.2 Effect of hydrothermal processing on hemicellulose**

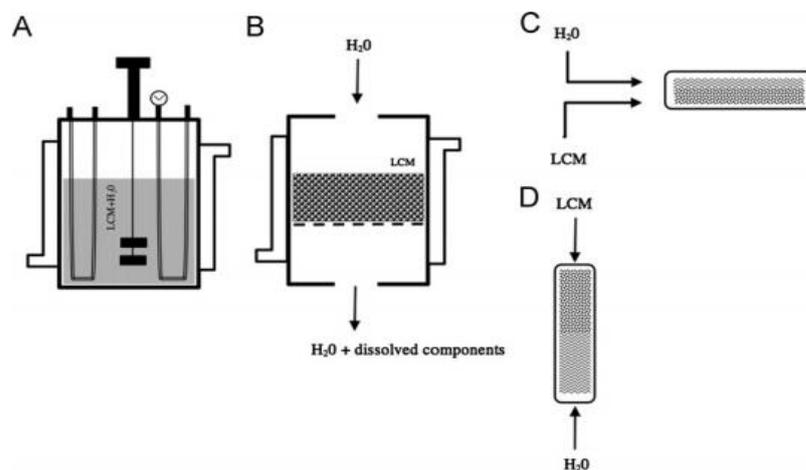
The second most frequently occurring in nature polysaccharide is hemicellulose. It consists of amorphous heteropolysaccharides, composes 14-50% of the dry weight LCMs (lignocellulose materials). The hemicellulose structure contains various units such as the five-carbon and six-carbon sugars. The most common unit of hemicellulose in waste is xylan. Almost all of the hemicellulose can be removed by the hydrothermal treatment, it decomposes in oligosaccharides, monosaccharides decomposition products without sugar (e.g., furfural or hydroxymethylfurfural) and acetic acid (from hydrolysis of the acetyl group). Moreover, the origin of high molar mass xylo-oligosaccharides (XOS) and xylose from xylan at moderate temperatures in the hydrothermal treatment, it is one of the main products of the hemicellulose present in the liquor phase. Xylose can be dehydrated to furfural under severe operating conditions, and furfural can be converted to degradation products. Xylooligosaccharides are bioactive molecules with high-added value and have great prebiotic potential making them useful as ingredients for functional foods. Various scientific studies have shown the effectiveness of this method, such as spoken about 69.2% of the XOS from baseline xylan with the 208 °C, the raw material was the rye straw or has information about the 58.3% crude XOS at 179 °C and a time of 23 minutes using ultrafiltration XOS for cleaning, etc. [3]

#### **2.1.1.3 Effect of hydrothermal processing on lignin**

Lignin is one of the most common heterogeneous aromatic polymers. Lignin is often found in conjunction with hemicellulose and not only as physical impurities but also as covalent bond. During the hydrothermal treatment, lignin and lignin-hemicellulose bonds may be subject to degradation, partial depolymerization and recovery of deep localization. So much of lignin in the dissolution depends on the particular process and materials.

### **2.1.2 Reactors**

Hydrothermal treatment uses different types of reactors, such as Batch reactor, Semi-continuous reactor, the Continuous reactor.



*Figure 4. Representation of different reactor configurations for hydrothermal processing. (A) batch; (B) semi-continuous (flow-through reactor); (C) continuous (co-current); (D) continuous (counter-current) [3]*

### 2.1.2.1 Batch reactor

Nowadays there are not a small number of reactors; one of the commonly used is a batch reactor. Batch Reactor is a generic term for industrial vessels. It is used in the laboratory study researches with great variation of materials to test and study the temperature, chemical processes, particle size, etc. These types of reactors are used for pretreatment as: sealed glass reactor, metallic tube reactor, mixed reactor, Zipperclave reactor, microwave reactor, steam reactor, high-throughput reactor. A very large number of treatments suitable for batch reactor, such as: hydrothermal pretreatment, acid pretreatment, steam pretreatment, AFEX.

Different types of plants are used for various pretreatments. Each type of reactor has its minimum and maximum settings receiving, from 1.5 mg biomass in glass reactors to 2000 g biomass in steam explosion. In addition, steam explosion reactor can easily be suitable for such materials with high solids content, while the other reactors of this will depend on the process, such as for Parr reactor. Parr reactor may be loaded with solid material in AFEX condition during mixing with a material, which pre-soaked in water with an acid. If we select right material, which will match the process, reactor exhibits consistent performance at increased temperatures and pressures. Finally, the Parr reactor was well used in various materials and various methods. [8]

Type	Size (g dry biomass loaded)	Solids loading (%)	Biomass particle size (mm)	Pretreatment technology
Sealed glass reactor	0.11 0.05	10 % (w/v) -	0.42-1 0.17-0.85	1 M Maleic acid Hot water/dilute H <sub>2</sub> SO <sub>4</sub>
Tubular reactor	1-2	5-30 % (w/w)	0.17-0.85	Dilute acid, water-only
Zipperclave reactor	50-300	Low to high Solids (1-50 % w/w)	6	Dilute acid-steam pretreatment
Parr reactor	50-100	5-10 % (w/w) High solids (>20% w/)	0.17-0.85 0.1-2	Dilute acid, water-only AFEX
Steam explosion reactor	400-2000	High solids (>20% w/w)	4 x 4 x 1 cm Woodchips, 2-10 mm corn stover, wheat straw, etc.	Auto-hydrolysis, SO <sub>2</sub> and H <sub>2</sub> SO <sub>4</sub> steam explosion

*Table 5. Typical features of batch reactors. [8]*

#### 2.1.2.1.1 Batch reactor for LHW

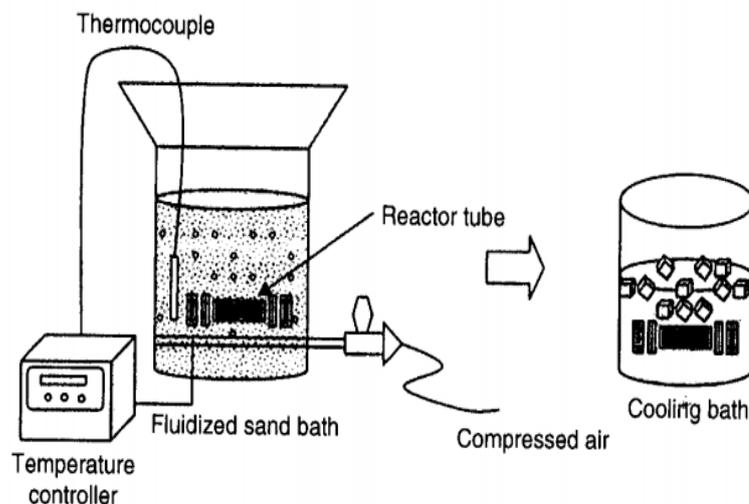
##### **Tubular reactor**

The tubular reactor is a strong reactor that is capable of withstanding high pressure. Depending on the temperature and the one used acid is necessary to correctly choose the material for tubes. One of the most common material is stainless steel or Hastelloy pipe or Swagelok fitting allows. The correct material allows working with hot sand baths or oil baths. Hastelloy tube protects rare elements during the pretreatment, so they are cheap to use in the form of caps on the ends of pipes. In the production of a large reactor often use 25.4 mm Swagelok unions with caps. Unions and caps are available in Hastelloy, but the cover the inside of the unions of gold can be cheaper. For hot water treatment and dilute acid using zirconium. [8]

To study the conditions and pretreatment properties often uses the small tube reactor, so it is easier to control and it is cheaper. These studies make it possible to improve the hydrolysis of hemicellulose. Tubular reactor allows working with large amounts of feed material 30%, and has the ability to rapidly heat and drop the temperature. Typically, tubular reactor made from stainless steel for hot water treatment or alkali, from Hastelloy C-276 for dilute acid and glass for processing with H<sub>2</sub>SO<sub>4</sub> at 0.44-1.9% and temperatures 120-250 °C. It is also important to choose the right size of the reactor for proper heat distribution during the process. For example, often use the diameter of tubes at least 12.7

mm OD x 0.899 mm wall thickness x 150 mm length, and 14.3 mL total volume, 25.4 mm OD x 1.65 mm wall thickness x 114 mm length, giving 45 mL total volume for LHW and dilute acid pretreatment. However, the working volume should be less than the total volume to provide sufficient space for the liquid expansion. [8]

In Figure 5 you can see the schematic drawing of tubular reactor. Typically, tubular reactor consists of several regulators such as temperature fluidized sand bath and the ice bath, which is immersed in the reactor to stop the reaction. To align with the reactor sand bath use a tube length of 150 mm. By the end of each tubular reactor is mounted a pair of removable tubes fittings Swagelok. Before milled the biomass is impregnated with dilute acid overnight. Then remove the remaining water to achieve the desired level of solids loading and the biomass charged into the reactor. To monitor the process of temperature in each reactor is lowered special thermocouple probe. Naturally, thermocouple probe is near the reactor in a sand bath for a good monitoring point. Also, need to follow that the reactor was not close to the surface of the sand bath at risk of instability in the temperature. [8]



*Figure 5. Apparatus for pretreatment using a tubular reactor in a fluidize sand bath. [8]*

Pretreatment can take place with several reactors at the same time connected to the screened wall. Nevertheless, it is necessary to keep a large number of reactors without preventing the heat conduction. One example is the Multi-Cell reactor is the sum of the 10 reactors connected in a ring with 30 mL of Hastelloy C-276. All of them are placed in special sand bath having a large size and it reaches 10 °C, and then transferred to smaller bath to continue the process. The temperature was monitored by thermocouples in the centre of each reactor, and then with help of a special mechanism, they are placed in an ice

bath. The tubular reactor enables the processing of hot water with a lot of material and allows for a good analysis of the kinetics of the process. [8]

### Mixed reactor

Mixing reactor was designed to work with large amounts of biomass. Dimensions may change from 25 ml to 5 gallon. Mixing reactor such as a Parr reactor equipped with a magnetically driven internal mixing and mixing pressure reaches 34.5 MPa. Stirring is necessary in order to maintain homogeneity and the right temperature, but it is necessary to maintain a low viscosity of the material to 10%. Exceeding the limit of solids concentration ( $> 10\%$ ), will entail the wrong temperature condition. The reactor made from different materials, which are selected according to the processes conditions. Available materials: stainless steel 316, C1018 low carbon steel, alloy 20, titanium grades (2, 4, 7), zirconium 702 and 705, nickel 200. Usually 600 ml Parr reactor and under rated for 20.68 MPa, and 1 L is designed up to 13.78 MPa. The temperature can be constantly change from 225° C to 500 °C depending on the design of the mixing device, the material and processing conditions. The mixer reactor is more expensive than tubular reactor or a glass reactor, but it is well used as it shows good results in analyses and fermentation. In addition, it can work with a large number of raw materials, until the raw material is ground. [8]

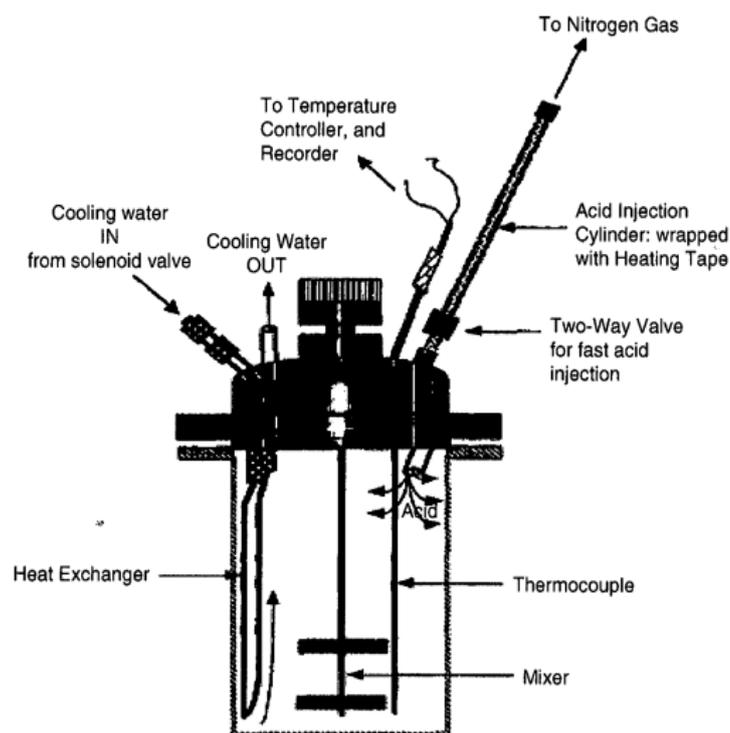


Figure 6. Stainless-steel reactor with acid-injection system, mixer and cooling coil. [8]

### 2.1.2.2 Continuous and Semi-continuous reactor

In the modern world Continuous reactor and Semi-continuous reactor are often used in academic studies, but its price is difficult to affordable.

Flowthrough pretreatment system uses a liquid stream, which is faced with a thick layer of biomass, thus washing away the soluble and products with low weight of molecules from the reactor. This system allows you to monitor the regularity of release of lignin, hemicellulose and cellulose, and give results of the kinetics of the reaction; it is one of the advantages that distinguish this type of reactors. Flowthrough reactors and all related reactors, such as continuous plug-flow reactors, countercurrent/co-current reactors, tubular percolating reactors and co-current shrinking bed reactors use water-only dilute acid ammonia recycle percolation (ARP) system, two-stage (water-only followed by ammonia) system etc. Studies have shown that when using water in pretreatment by a Flowthrough reactor is the high yield of sugar and the subsequent enzymatic hydrolysis of the cellulose residue. Most of xylan solubilized with hot water flowthrough pretreatment was in oligomeric form. This system shows its benefit in the study of the pretreatment, but the need for a large volume of liquid is a problem. [8]

Flowthrough system was tested with different methods of pretreatment. Using 50.8 mm diameter reactor made from titanium with sintered titanium frits. The process uses dilute acid water (0.08 wt.%  $H_2SO_4$ ), at a temperature of 170-220 °C. Acid used for the heating coil of 6.35 mm Hastelloy tube dipped in a sand bath at the reaction temperature. The Flowthrough reactor has a spring-loaded piston, which are located behind 'shrinkage bed' as solubilized biomass components. The pistons prevented freshly solubilized biomass components from being diluted by the solution that normally would have occupied the void volume created by pretreatment, and are rapidly removed from the reaction zone. This entire system has > 92% solubilization of lignin and cellulose. [8]

One example is the circulation of concentrated ammonia through a bed of coarse corn in the reactor. The reactor has a thick wall in 25.4 mm from 316 stainless steel and tubes length 25.4 cm. To protect the boiling ammonia during processing is applied nitrogen (2.5 MPa). The ammonia is pumped through a layer of material into the receiver; the receiver is made from stainless steel A 1 L. To redeem the following reaction the reactor is cooled. [8]

For the dilute acid pretreatment was a used small reactor of 3.6 mL and 14.3 total volume from Hastelloy C-276 and for hot water was used stainless steel, when using

biomass as the corn stover. A high-pressure pump has been used to deliver fluid through the material. Water without or with catalyst before it supplied to the reactor passes through preheating coil (316 stainless steel tube 6.35 mm OD x 8.89 mm wall thickness x 1.27 m long). The liquid in out was cooling by the outlet tubing from 316 stainless steel (6.35 mm OD x 8.89 mm wall thickness x 1.27 m long). For the adjusting of pressure was used back-pressure regulator and for monitoring was used a pressure gage (pressure range 0-10.3 MPa). At the output is set of thermocouples (6.35 mm stainless steel) for temperature monitoring. Crushed biomass solids fed to the reactor. At the both ends reactor is covered by two gasket filters, which are connected with outlet and inlet tubes. Air in the reactor and in the substrate was purged by pumping ambient fluid temperature in the reactor for a few minutes until the reactor pressure reaches a predetermined pressure of 159-181 kg per square meter. Stream is subsequently paused to allow the soaking of biomass substrate. To achieve the desired flow rate the inlet tube and reactor transferred to the second sand bath after the first sand bath, which reached 100 °C. After reactor and inlet tubes were moved in an ice-water bath to stop the reaction at the required end time. The outlet liquid or effluent was stored for further research. From the reactor take out pretreated solids, washed and carried out compositional analysis and subsequent enzymatic hydrolysis testing. [8]

## **2.2 Steam explosion**

### **2.2.1 Principle**

Steam explosion as simple as LHW, as well as based on the hot water. Steam explosion use the high pressure and then rapid decompression to divide the material into separate bundles of fibers. From acetylated material components are released at a high temperature, which catalyzes hydrolytic reactions in the materials polymers. Hemicellulose is dissolved in hot water to these reactions and auto-hydrolysis procedures extends further to extract biofuel. This method is well used because hemicellulose responds well to steam explosion. Moreover, this method may also increase the availability exploded enzymatic materials.

As an example of the lignocellulosic material, I will take the oil palm empty fruit bunches (OPEFB). The amounts of OPEFB produced in Indonesia, Malaysia and Thailand, when converted to ethanol, could make up almost 2% of the gasoline consumption in these countries. [9]

With temperature 160-200 °C and a pressure of 0.6-1 MPa formed saturated and superheated steam (SS,SHS), and whereby 100 g sample of dry OPEFB explode, explosion

reaction takes 5 minutes. Suddenly opening the valve to storage tank collection occur the explosion. The severity factor of each treatment was defined by

$$S_o = \log\left(e^{\left(\frac{T-100}{14.75}\right) * t}\right) \quad (2.2-1)$$

where T is the temperature (°C) and t the duration of the treatment (min). [9]

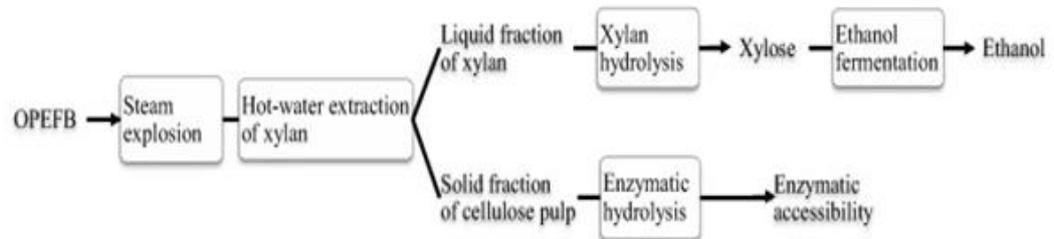


Figure 7. Flow chart of xylose production from OPEFB in the pilot-scale steam explosion, and of its use in ethanol production. [9]

Xylan recover after steam explosion. Xylan dissolved in water followed by hydrolysis passes into xylose. For example, we were taken three different pressure and temperature of saturated steam explosion 160 °C / 0.6 MPa, 170 °C / 0.8 MPa and 180 °C / 1.0 MPa. With increasing temperature, the severity rate increases. However, with increasing pressure and temperature decreasing the xylose recovery in the liquid fraction from 19.71 ± 0.33 to 14.15 ± 0.10 g/kg dried OPEFB. Also contains information that at low severity factors hemicellulose can be recovered from the explosion SS. While increasing the severity factor the whole mass hemicellulose-derived material can be reduced and the soluble materials go into furfural or pseudo lignin through condensation. [9]

Material code	Severity factor	Xylose (g/kg)	Glucose (g/kg)	Acetic acid (g/L)	Furfural (g/L)
Saturated steam (SS)					
160 °C/0.6 MPa	2.47	19.71±0.33 <sup>b</sup>	1.37±0.10 <sup>fg</sup>	0.07±0.01 <sup>e</sup>	0.02±0.01 <sup>de</sup>
170 °C/0.8 MPa	2.76	18.64±0.22 <sup>c</sup>	1.38±0.01 <sup>fg</sup>	0.09±0.01 <sup>d</sup>	0.02±0.00 <sup>de</sup>
180 °C/1.0 MPa	3.05	14.15±0.10 <sup>d</sup>	4.17±0.05 <sup>c</sup>	0.13±0.02 <sup>c</sup>	0.03±0.00 <sup>cd</sup>
Superheated steam					

180 °C/0.6 MPa	3.05	20.79±0.11 <sup>b</sup>	5.01±0.11 <sup>b</sup>	0.15±0.01 <sup>b</sup>	0.05±0.00 <sup>cd</sup>
200 °C/0.6 MPa	3.64	1.61±0.11 <sup>h</sup>	0.62±0.06 <sup>h</sup>	0.27±0.00 <sup>a</sup>	0.14±0.02 <sup>a</sup>
200 °C/1.0 MPa	3.64	3.50±0.07 <sup>g</sup>	1.58±0.05 <sup>f</sup>	0.26±0.01 <sup>a</sup>	0.12±0.02 <sup>a</sup>
Acid pretreatment prior to steam explosion					
160 °C/0.6 MPa (SS)	2.47	18.43±0.15 <sup>e</sup>	2.03±0.02 <sup>d</sup>	0.08±0.00 <sup>de</sup>	0.02±0.00 <sup>ab</sup>
180 °C/0.6 MPa (SHS)	3.05	87.58±0.21 <sup>a</sup>	10.97±0.18 <sup>a</sup>	0.16±0.00 <sup>b</sup>	0.07±0.01 <sup>b</sup>
Alkali pretreatment prior to steam explosion					
160 °C/0.6 MPa (SS)	2.47	12.33±0.12 <sup>e</sup>	1.63±0.15 <sup>f</sup>	0.04±0.01 <sup>f</sup>	0.00±0.00 <sup>f</sup>
180 °C/0.6 MPa (SHS)	3.05	13.34±0.12 <sup>f</sup>	1.79±0.08 <sup>e</sup>	0.06±0.01 <sup>f</sup>	0.01±0.02 <sup>e</sup>

*Table 6. Sugar recovery in liquid fraction and byproduct concentration after steam explosion. [9]*

## 2.2.2 Batch reactors

### 2.2.2.1 Steam reactor

Naturally, for steam explosion pretreatment required steam reactor. Steam reactor is needed to cope with the heavy load of solid material. This reactor is necessary to have a rapid heating and cooling system throughout the reactor. It is also necessary to have good control over the pressure to quickly injecting steam into the biomass. Reactor is based on patent of Masonite to improve solubilisation of hemicelluloses from the biomass.

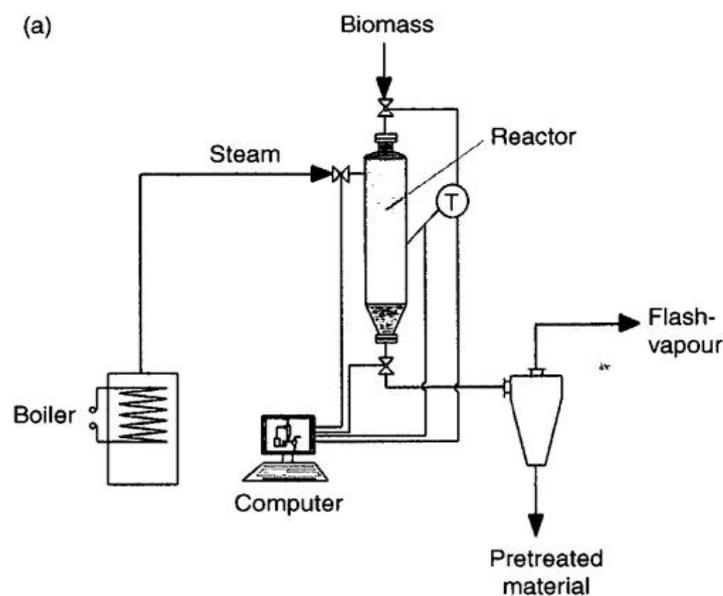
A 25 L reactor is a reactor type that works without chemicals or catalysts. Biomass located in a pipe or chamber in which steam flows. This chamber has two valves, the top for loading of biomass, and the second outlet for the treated material. Explosion depends on the coming steam pressure and thence the name of the method and the reactor. Quickly relieved pressure is the cause of trapped condensate and steam within the biomass particles that causes an explosion and release of biomass fibres. [8]

Heating of the reactor depends on many factors, such as a pipeline, control valve depends on the thickness and quality of the walls of the reactor tubes and dependent on the mass of the reactor and the biomass and the biomass of moisture. In NREL 4 L steam

reactor, the steam enters the top and bottom of the reactor, in order to evenly cover the entire biomass from all sides. A large number of digester machines used and the upper and lower injection. [8]

Rapid cooling occurs during a sudden opening of the bottom valve, thus, there is a discharge treated material and sending it in a flash tank vessel, the temperature falls to 100 °C. Batch reactor makes it possible to rapidly heat and cool the reactor with the correct time control. It is this type of reactor gives full control of the temperature. [8]

One of the biggest advantages of this type of reactor is that we can use larger particulate material. This is a plus for the economic part of the process, since there is savings in milling and defibration during a steam explosion process. While using the catalyst, or water, the biomass must soak for a certain time. For example for NREL reactor operates with a dilute acid, which is absorbed into the biomass at a temperature of 40-60 °C and the time 2-4 hours. [8]



*Figure 8. Steam reactor [8]*

Example of the reactor circuits and equipment is shown in Figure 8, 9. The vessel has a volume of 118 litres, the internal diameter 450 mm, height 600 mm and wall thickness 8 mm. It is made from 316 stainless steel that can withstand up to 5 kg of material. It has such devices as temperature indicator, exhaust valve, pressure gauge, safety valve, thermocouple panel insertion. Boiler work is done by a cluster pipe that can heat up to 250 °C at a pressure of 1 MPa. To maintain the temperature and pressure better to set another gas heater on the pipe section in the heating boiler pipe. Safety valves are in pipeline section, they release safety 1MPa. All the necessary systems are wrapped wool. The

explosion produced by a sharp decline in steam, which is collected in the tank at the end of each treatment. [9]

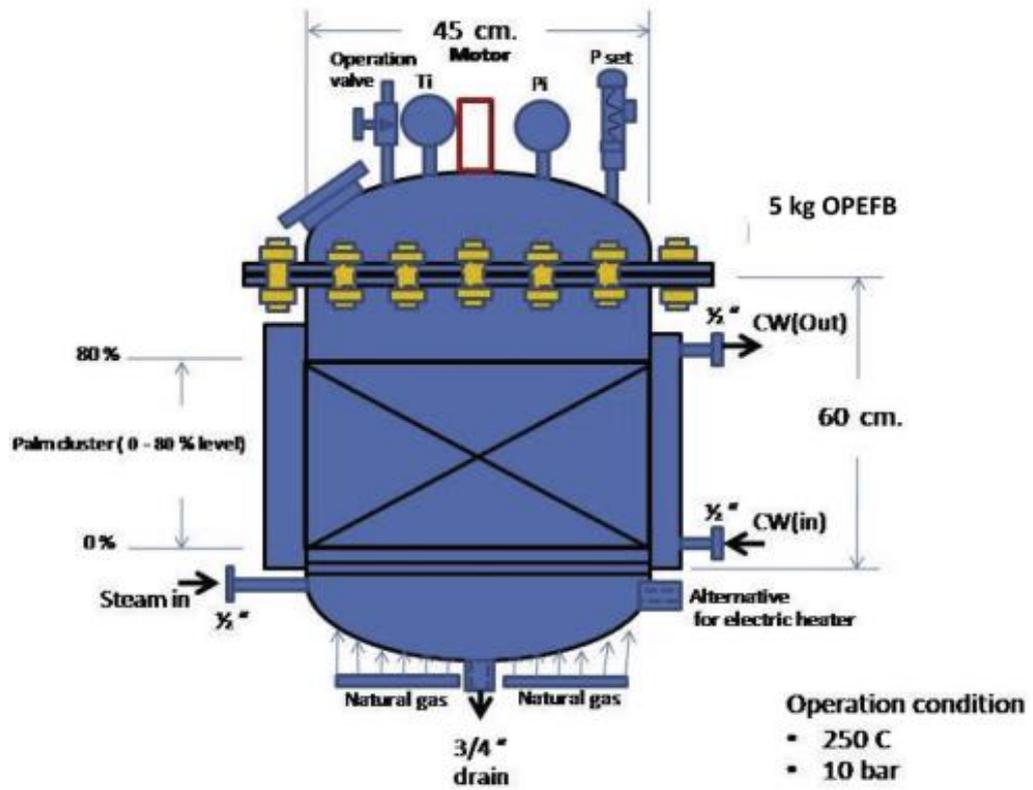
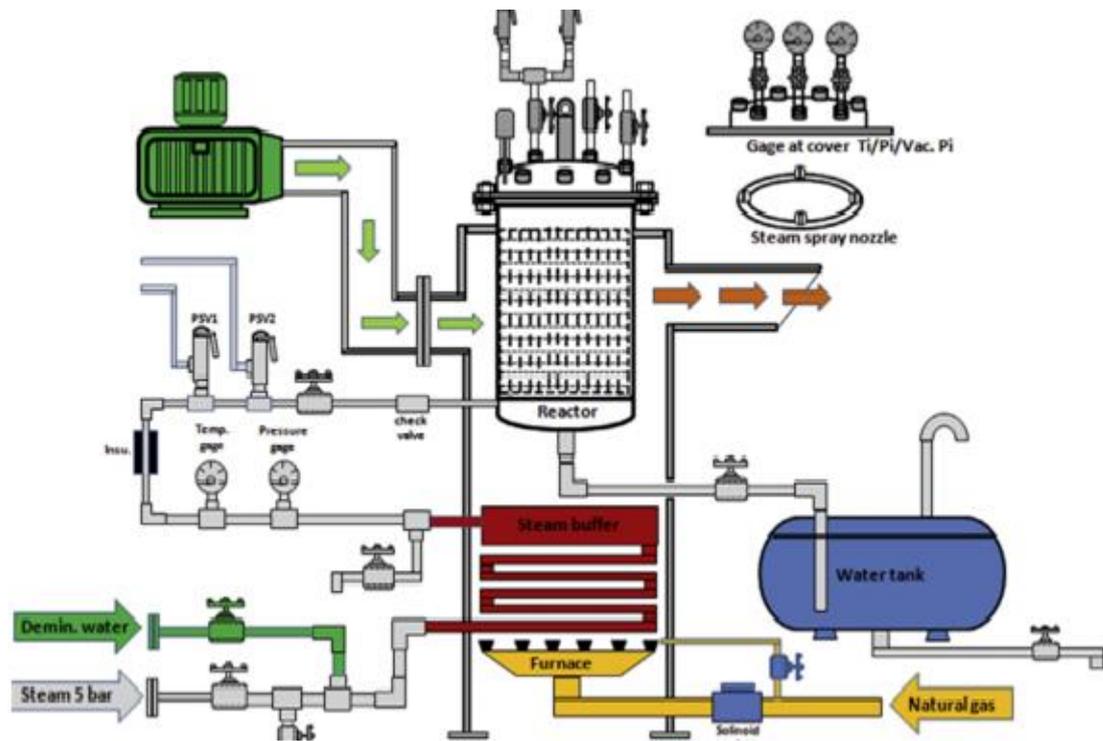


Figure 9. Steam explosion vessel. [9]



*Figure 10. Schematic flow diagram of the steam explosion process (feed unit is not included). [9]*

#### 2.2.2.2 Zipperclave

This type of reactor is mentioned in various literary sources. As an example of using this type of reactor used for the steam pretreatment of soaked in dilute acid corn leaves. If the reactor is equipped with Kalrez O-rings, it can operate at a temperature of 230 °C and a pressure of 13.78 MPa. Zipperclave reactor tested together with 4 L steam explosion reactor under the same conditions and with the same raw material. The reactor had a special electric heater protective layer for temperature control. In addition, the reactor had a steam injection. The result is that the reactor within 5-10 seconds, increasing the temperature during the pre-heating and steam injection. At the end of the process, steam produced in 10-15 seconds and send it to the heat exchanger for condensation and subsequent analysis close to the material balance. [8]

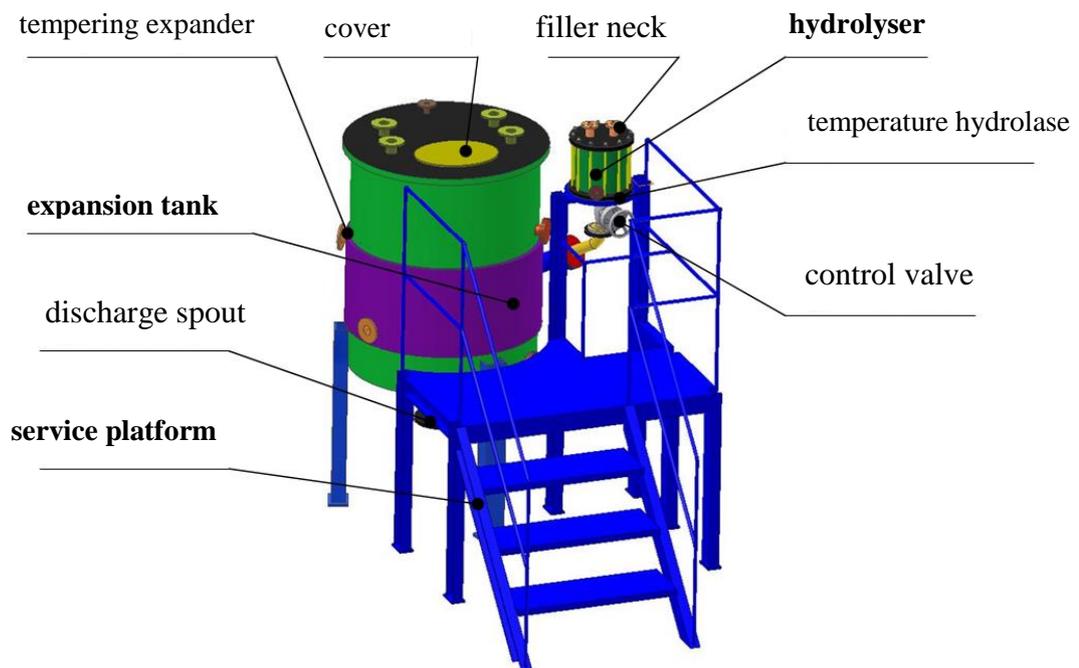
The main impellers were modified for special, which due to its form as a farmer plow biomass deflected directly to the centre of the reactor, it is necessary to download large solids (> 30% w/w). To clean the agitator from adhering biomass used stationary blade. The steam is injected at an angle from below; it improves the mixing and uniformly heats the biomass. Hastelloy bucket with a volume of 2.5 l filled with biomass charge was placed in a reactor vessel, for heating the reactor using biomass charge insulation against condensation, thereby reducing condensation. [8]



*Figure 11. Zipperclave laboratory reactor. [10]*

### 3 The aim of thesis

The aim of the thesis is to design of reactor for steam explosion and LHW pretreatment (hydrolyser of 2<sup>nd</sup> generation). The requirements is to combine those two types of pretreatment in one reactor, which will be small for economic benefits. In addition to install mixing system for improvement of digestibility of raw material. The cause of this topic is the desire to improve the existing laboratory reactor of my supervisor and his colleagues. As that laboratory reactor was designed by teachers without any mixed system, for one type of pretreatment and oversized. Reactor of my supervisor is shown in figure 12.



*Figure 12. Laboratory equipment for the pressure hydrolysis. [11]*

## 4 Design of vessel

### 4.1 Initial parameters

The first step is to create the basic conditions for the pretreatment, such as pressure and temperature, as well as the mass of material. Knowing these conditions, we can determine the approximate size of the vessel. The initial conditions I received from supervisor, as well as the approximate dimensions of the storage vessel. Based on the size of the storage vessel I can orient with weight, since the amount depends entirely on my choice. The operating temperature of 20 °C to 200 °C and temperature in double jacket 250 °C, pressure in vessel 1.5 MPa, pressure in double jacket 0.6 MPa. I will start with the mass of batch 5 kg, and then by calculation will check whether it is suitable mass of batch for storage vessel. I got a recommendation by the volume of the storage vessel from the supervisor, so preferred volume is 1.03 m<sup>3</sup>. Using the usual heat transfer equation we can describe the process of heat transfer in the system.

$$Q = m * c_p * (T_1 - T_0) = m_v * r_{LG} + m_L * c_p * (T_2 - T_0) \quad (4.1-1)$$

Where  $c_p$  is specific heat capacity,  $m$  is mass of batch,  $T_1$  is working temperature,  $T_2$  temperature after pretreatment,  $T_0$  final temperature,  $m_v$  mass of vapour state,  $m_L$  mass of liquid and solid state and  $r_{LG}$  is latent heat of evaporation. Mass of batch consists of a mass of liquid and gaseous form. Knowing this, we can express one of the masses, and substitute in the equation. Having mass of gaseous form, we can find the volume, which should not exceed the volume of the storage vessel.

$$m = m_v + m_L \quad (4.1-2)$$

$$m_v = m - m_L \quad (4.1-3)$$

$$m * c_p * (T_1 - T_0) = (m - m_L) * r_{LG} + m_L * c_p * (T_2 - T_0) \quad (4.1-4)$$

Express the mass of the liquid state and substitute values:

$$m_L = \frac{m * c_p * T_1 - m * c_p * T_0 - m * r_{LG}}{T_2 * c_p - r_{LG} - c_p * T_0} \quad (4.1-5)$$

Substitute values:

$$m_L = \frac{5 \cdot (4180 \cdot 200 - 4180 \cdot 20 - 2180000)}{100 \cdot 4180 - 2180000 - 4180 \cdot 20} = 3.87 \text{ kg} \quad (4.1-6)$$

With the help of the density and the mass, we can find the volume of a gaseous form. Vapor Density at 100 °C is 0.6 kg / m<sup>3</sup>:

$$V = \frac{m_v}{\rho_{vapor}} = \frac{1.13}{0.6} = 1.88 \text{ m}^3 \quad (4.1-7)$$

As mentioned above, this volume should not exceed the volume of the storage vessel 1.03 m<sup>3</sup>, which means that we do not have selected the correct batch mass. Next, we need to reduce the mass and to check whether the volume is suitable to the recommended storage vessel. Reduce the mass of 3 kg and a check as well. Substituting to the given equation 4.1-3 the volume of gas was calculated.

$$m = 3 \text{ kg}$$

$$m_L = 2.319 \text{ kg}$$

$$m_v = 3 - 2.319 = 0.681 \text{ kg}$$

$$V = 1.135 \text{ m}^3$$

$$V > V_{(S.V.)}$$

Volume of gaseous form again exceeds the volume of the storage vessel. Again, reduce the mass of batch and using the equation 4.1-3

$$m = 2.5 \text{ kg}$$

$$m_L = 1.932 \text{ kg}$$

$$m_v = 0.56 \text{ kg}$$

$$V = 0.94 \text{ m}^3$$

$$V < V_{(S.V.)}$$

As we can see 2.5 kg suitable for our volume, we take this as the basis mass.

#### 4.1.1 Main dimensions

Knowing the amount of material, I can determine the main dimensions of the vessel. Such as diameter of vessel, diameter of double Jacket, the height of the vessel, etc. Most of the major dimensions are determined by the diameter of the core. I will take the volume of vessel approximately 4 liters. Further, with the help of a simple formula I can calculate the diameter.

$$V = \pi * r^2 * H \quad (4.1.1-1)$$

$$H = 1.5 * D = 3 * r \quad (4.1.1-2)$$

$$r = \sqrt[3]{\frac{0.004}{\pi * 3}} = 0.075 \text{ m} = 75 \text{ mm} \quad (4.1.1-3)$$

$$D = 150 \text{ mm}$$

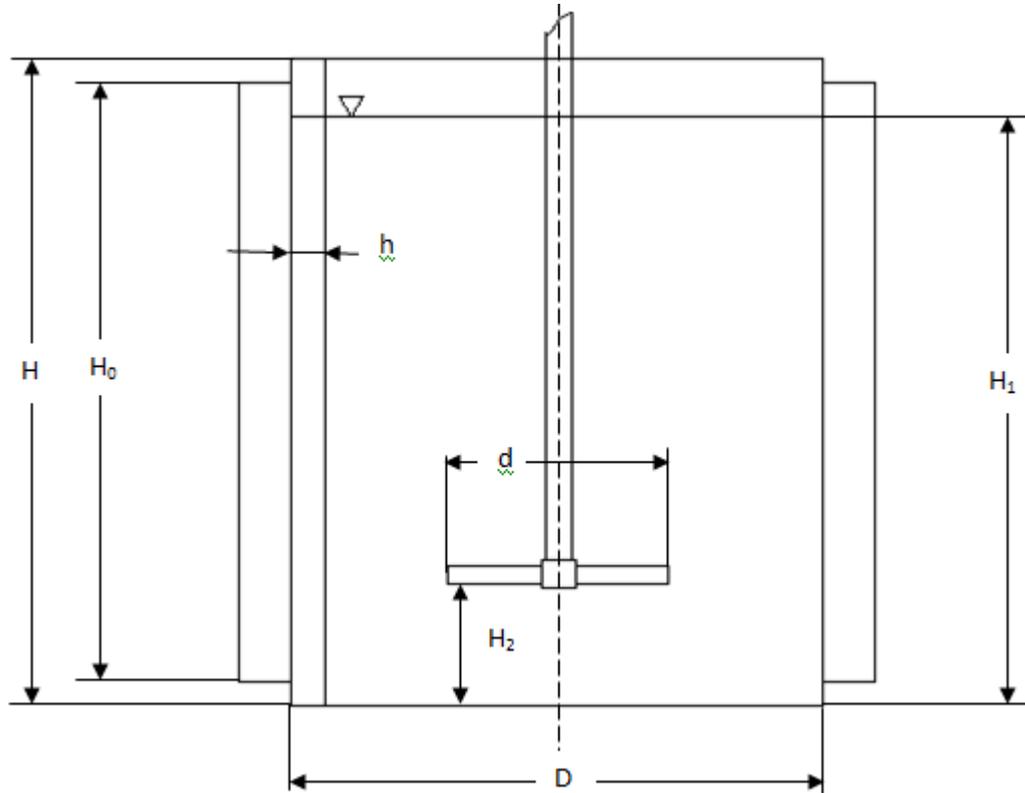


Figure 13. Sketch of vessel with basic dimension.

I choose the appropriate diameter from the standard catalogs. Because my diameter of the tube is not much, I decided to install my double jacket directly to the flange. These catalogs present the diameter and thickness of the wall, but the minimum wall thickness we checked in the next step.

Inside diameter of vessel D mm	Thickness of the wall S mm	Norm
168.3	3	DIN2463
Inside diameter of the double jacket D mm	Thickness of the wall S mm	Norm
204	2	DIN2463

Table 7. Standard dimension of tube. [12]

$$H = 1.5 * D = 1.5 * 168.3 = 252.45 \approx 252 \text{ mm} \quad (4.1.1-4)$$

Because I use standard flanges, their height is 30 mm. This means that it is necessary to take into account the height of the double jackets, which will be welded on flanges. Since the entire height of the inner tube is 252 mm, and it will be installed to inside diameter of the flange, the height of the double jacket is smaller than the inner. The height of double jacket is height of inner tubes minus two times thickness of flanges.

$$H_0 = 192 \text{ mm}$$

$$H_1 = D = 168.3 \text{ mm}$$

$$d = \frac{1}{3} * D = 56.1 \text{ mm} \quad (4.1.1-5)$$

$$H_2 = (0.5 \div 1) * d = 0.7 * 56 = 39.2 \approx 39 \text{ mm} \quad (4.1.1-6)$$

$$h = 0.1 * D = 16.83 \text{ mm} \quad (4.1.1-7)$$

Further design sizes that depend on me may change if they do not have consequences in the stress analysis and is acceptable to the raw material supply (for example, the height of the vessel, double jacket and thickness of flanges).

#### **4.1.2 Design of mixing system**

Power consumption of mixing equipment.

According the figure 14, I can choose specific power, but firstly I need to know what type of straw will be. After consulting with my supervisor, we conclude that it would be untreated, hydrate straw.

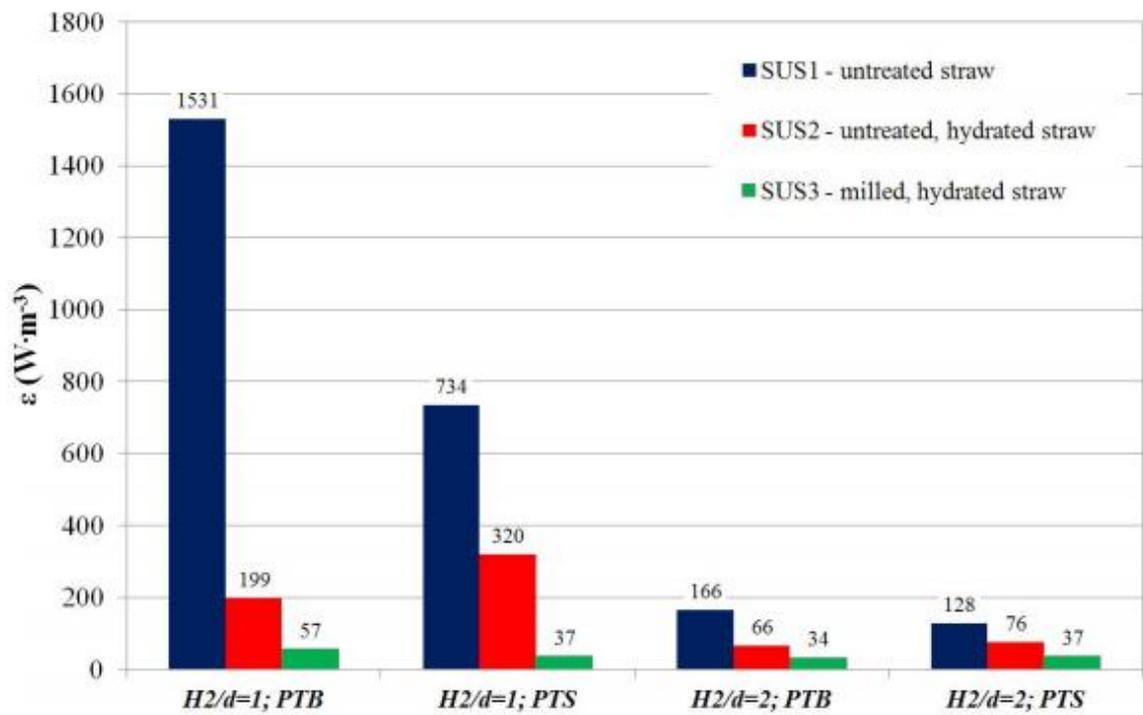


Figure 14. A comparison of the specific power consumption levels for the tested configurations and suspensions. PTB – the impeller pumps towards the bottom of the vessel; PTS – the impeller pumps towards the surface of the batch. [13]

My specific power equal 320 W/m<sup>3</sup> but for real, I need to take 400 W/m<sup>3</sup>. Then from standard formula of specific power I can find power consumption, whole this formulas were taken from lecture of “Hydromechanical Equipment”.

$$\varepsilon = \frac{P}{V} \quad (4.1.2-1)$$

$$P = V * \varepsilon = 0.0025 * 400 = 1 \text{ W}$$

If I know power consumption, I can express number of revolution.

$$P = P_0 * \rho * n^3 * d^5 \quad (4.1.2-2)$$

$$n = \sqrt[3]{\frac{P}{P_0 * \rho * d^5}}$$

P<sub>0</sub> is power number from Fig. 15.

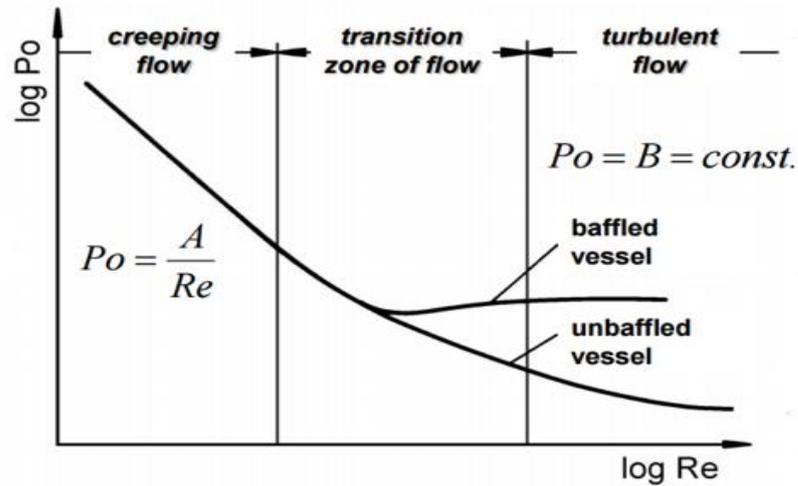


Figure 15. Power consumption of agitator. [14]

$$P_0 = 1.27$$

$$n = \sqrt[3]{\frac{1}{1.27 * 1000 * 0.056^5}} = 11.26 \text{ s}^{-1}$$

I have to check the Reynolds number. It is necessary for correct power number. My Reynolds number must be bigger than 100.

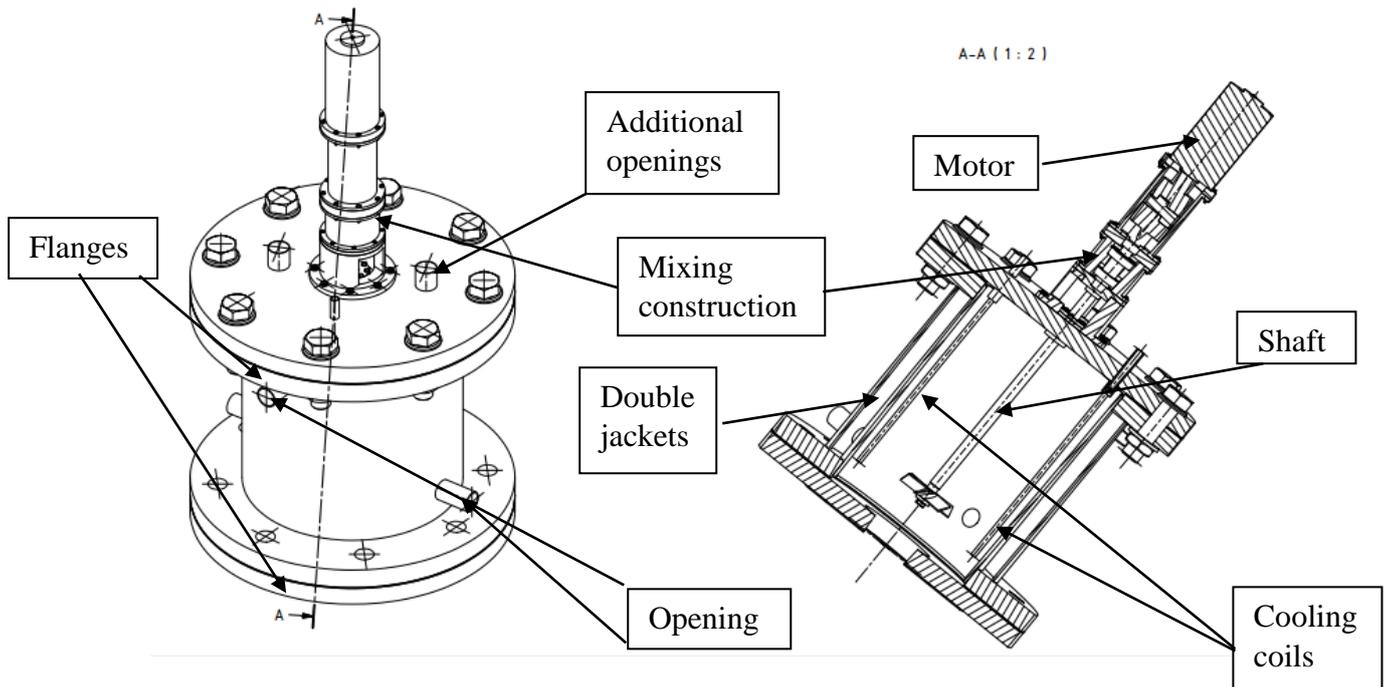
$$Re = \frac{\rho * n * d}{\mu} = \frac{1000 * 11.26 * 0.056}{282.5 * 10^{-6}} = 2.2 * 10^9 \quad (4.1.2-3)$$

According of my speed and power, I need found Servo Motor. From catalogue, I chose motor.

Motor type	Full load Power $P_n$ [kW]	$N_n$ Full-Load Speed [rpm]	Rated torque [Nm]	Full-Load Current [A]
NM50B4	0.06	1300	0.4	0.7

Table 8. Type of motor with basic characteristics. [15]

## 5 Construction of reactor



*Figure 16. 3D drawing of reactor with the main parts*

All the calculations were performed by EN13445 and ČSN 690010 standards. General presentation of construction plus loads will be create. Most of the major parts are made from stainless steel of group 15EO and number of material 1.4571, because that material has good resistance of corrosion, temperature and pressure. My design of reactor is shown in figure 16 with all main parts. Six openings: 2 goes into the vessel, 2 goes into the double jackets ( $90^\circ$  between each horizontal openings; each opening for double jacket located at different heights) and 2 additional openings for controlling the process and other needs. Two cooling coil are arranged parallel to each other, as well it will be substitute for baffles. Mixing construction will be consist of motor, bearings, bearing house, flexible coupling etc.

### 5.1 Strength calculation

#### 5.1.1 The thickness of the vessel

First step is to count the wall thickness of the vessel. To find the optimum thickness will be checked three cases. Terms of the first case: the internal pressure in the vessel 1.55 MPa, external pressure 0 MPa. Second case: the external pressure of 0.6 MPa, interior 0 MPa. The third case for the thickness of the walls in the double jacket: pressure inside the double

jacket 0.6 MPa external pressure is taken as 0 MPa. Since we have a wall thickness from the catalog, we need to check whether this thickness is suitable. Farther will be the calculation verifies deformation on the centre of the top flange and from this I can determine the minimum thickness for that flange, also will be calculation of the minimum thickness of the bottom flange.

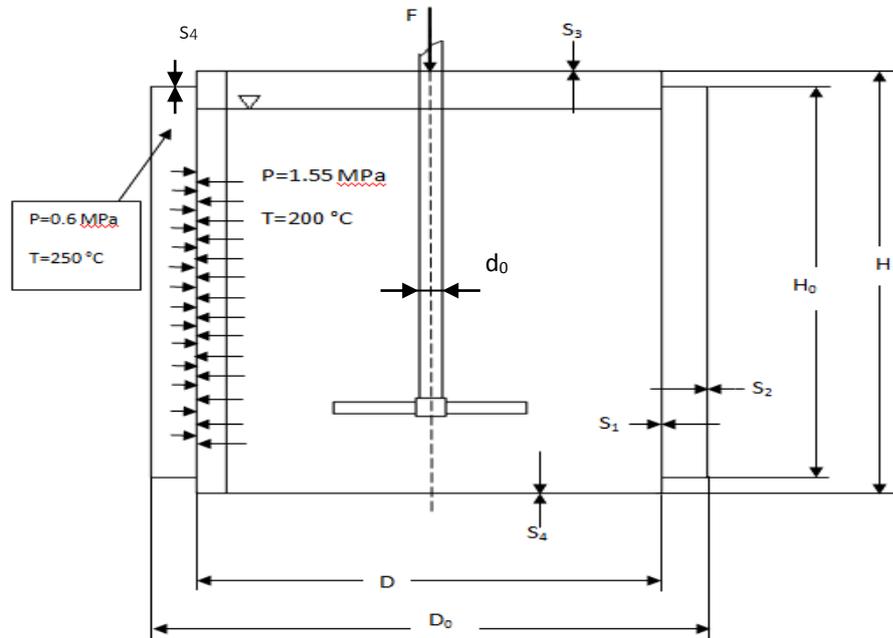


Figure 17. Sketch of vessel with the pressure on the wall

### 5.1.1.1 First case

Cylinder with internal overpressure 1.55 MPa. For the calculation, I use ČSN 690010 standard formulas for the thickness.

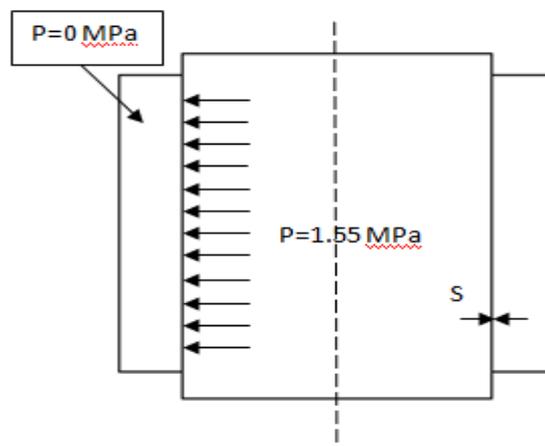


Figure 18. Sketch of vessel with internal overpressure

$$\sigma_D = \frac{P \cdot D}{2 \cdot S} + P \quad (5.1.1.1-1)$$

Express the thickness S:

$$S = \frac{P \cdot D}{2 \cdot (\sigma_D - P)} \quad (5.1.1.1-2)$$

For calculation I need to know allowable stress  $\sigma_D$ . That stress is ratio between Yield point and safety coefficient. Yield point depends on the work temperature. That table was taken from lecture of ‘‘Processing Equipment Design’’.

T (°C)	20	100	200	300
Re (MPa)	350	300	245	200

*Table 9. Temperature depend on the Yield point.*

$$\sigma_D = \frac{Re}{k} = \frac{245}{1.5} = 163.3 \approx 163 \text{ MPa} \quad (5.1.1.1-3)$$

$$S = \frac{P \cdot D}{2 \cdot (\sigma_D - P)} = \frac{1.55 \cdot 168.3}{2 \cdot (163 - 1.55)} = 0.8 \text{ mm} \quad (5.1.1.1-4)$$

The final thickness is defined, which depends on the ‘‘c’’, which is safety distance. It is selected according to the material, which is used. For stainless steel is 0.1 mm.

$$S_{Final} = S + c = 0.8 + 0.1 = 0.9 \text{ mm} \quad (5.1.1.1-5)$$

Alternatively, another formula to calculate S real by EN 13445 standard, equation number (7.4-1), but this formula include weld coefficient and usage of this formula depends on the type of chosen tube – seamless or welded. I can take tube without any weld, it means that weld coefficient equal 1.

$$S_{real} = \frac{P \cdot D}{2 \cdot \sigma_D \cdot \varphi - P} = \frac{1.55 \cdot 168.3}{2 \cdot 163 \cdot 1 - 1.55} = 0.8 \text{ mm} \quad (5.1.1.1-6)$$

I got that minimum thickness of vessel must be 0.9 mm. From the catalog, I can pick thickness 3 mm.

### 5.1.1.2 Second case

Cylinder with external overpressure 0.6 MPa. For the calculation, I use ČSN 690010 standard formulas for the thickness, but here external pressure, it means I used the scheme in the figure 20 for calculating the stability of cylindrical shells in a flexible region. Thickness depends on the strength and stability.

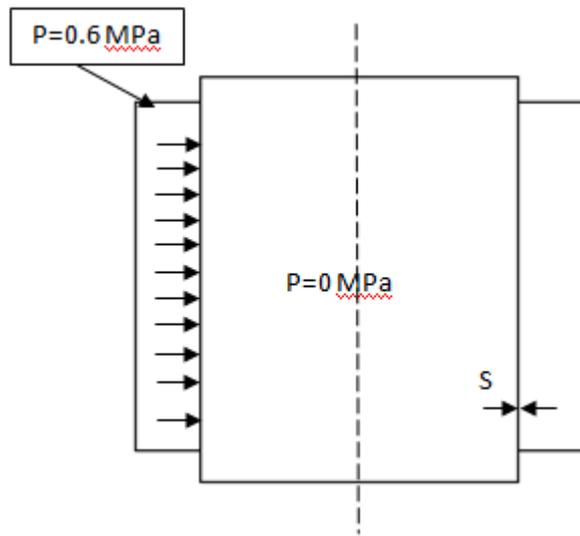


Figure 19. Sketch of vessel with external overpressure

$$S = S_R + c \quad (5.1.1.2-1)$$

$$S_R = \max\{S_{RP}; S_{RS}\} \quad (5.1.1.2-2)$$

$$S_{RP} = \frac{1.1 \cdot P \cdot D}{2 \cdot \sigma_D} = \frac{1.1 \cdot 0.6 \cdot 168.3}{2 \cdot 163} = 0.34 \text{ mm} \quad (5.1.1.2-3)$$

$$S_{RS} = K_2 \cdot 10^{-2} \cdot D \quad (5.1.1.2-4)$$

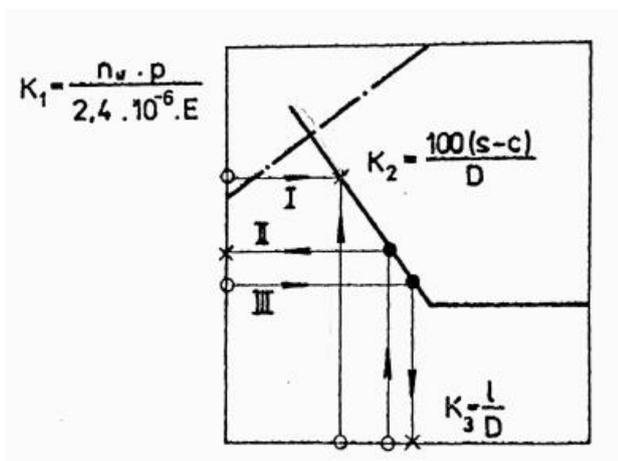


Figure 20. Scheme for calculating the stability of cylindrical shells in a flexible region

CSN 690010 part 3.

$$K_1 = \frac{n_u \cdot P}{2.4 \cdot 10^{-6} \cdot E} = \frac{2.4 \cdot 0.6}{2.4 \cdot 10^{-6} \cdot 2.1 \cdot 10^5} = 2.8 \quad (5.1.1.2-5)$$

$$K_3 = \frac{l}{D} = \frac{H}{D} = \frac{192}{168.3} = 1.1 \quad (5.1.1.2-6)$$

$$K_2 = 0.65$$

$$S_{RS} = 0.65 * 10^{-2} * 168.3 = 1.093 \text{ mm} \quad (5.1.1.2-7)$$

$$S_R = \max\{S_{RP}; S_{RS}\} = 1.093 \text{ mm} \quad (5.1.1.2-8)$$

$$S = 1.093 + 0.1 = 1.193 \text{ mm} \quad (5.1.1.2-9)$$

Minimum thickness of vessel must be 1.193 mm. I can pick thickness 3 mm.

### 5.1.1.3 Third case

Double jacket with internal overpressure 0.6 MPa. ČSN 690010 standard formulas for the thickness.

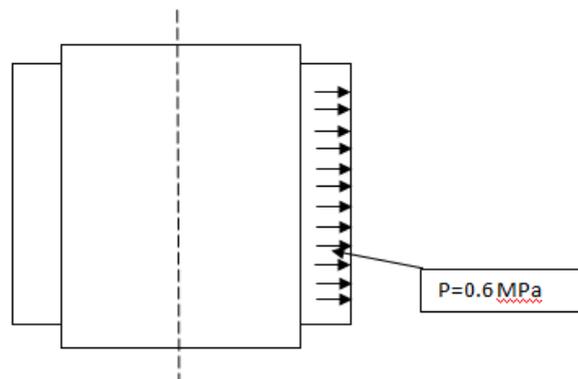


Figure 21 .Sketch of vessel with internal overpressure in double jacket.

T (°C)	20	100	200	250	300
Re (MPa)	350	300	245	220	200

Table 10. Temperature depend on the Yield point.

$$S_{D.j} = \frac{P * D_0}{2 * (\sigma_D - P)} = \frac{0.6 * 204}{2 * (146 - 0.6)} = 0.42 \text{ mm} \quad (5.1.1.3-1)$$

$$S_{D.j \text{ Final}} = S_{D.j} + c = 0.42 + 0.1 = 0.54 \text{ mm} \quad (5.1.1.3-2)$$

The real thickness formula comes from EN13445 standard, number of equation (7.4-1). Minimum thickness for double jacket must be 0.54 mm. From catalog, I selected 2 mm.

### 5.1.1.4 Deformation in center of top flange

Standardized flange DN150 PN16 was used, but due to the fact that this type of flange is not used at temperature of 250 °C, standard flange DN150 PN40 was recommended . Represent the weight of the motor as a single force ‘‘F’’ and top cover (flange D=300 mm) as beam. Those focuses of force give the stock thickness. Then from solving of simple problem, I can determine the minimum thickness (t).

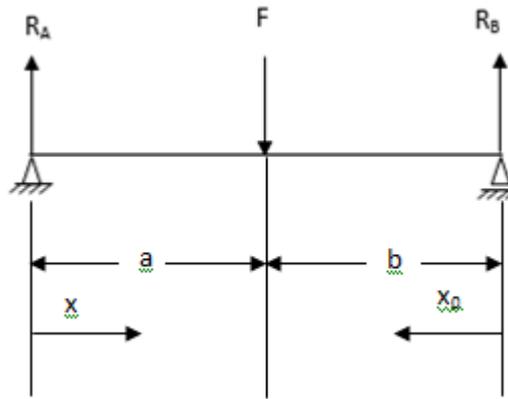


Figure 22. Sketch of beam (flange) with acting force and reactions.

$$a + b = D \quad (5.1.1.4-1)$$

$$F = G = m * g \quad (5.1.1.4-2)$$

The weight of motor is 1.5 kg, plus weight of all mixing construction (bearings, coupling, support etc.). It means the total weight is approximately 3 kg.

$$F=3*9.8=29.4 \text{ kgm/s}^2$$

The analysis of reaction  $R_A$  and  $R_B$ . Force is placed on the center, it means that distance "a" equal to distance "b" and  $R_A$  equal  $R_B$ .

$$G * a - R_B * D = 0 \quad (5.1.1.4-3)$$

$$G * a = R_B * D \quad (5.1.1.4-4)$$

$$R_B = G * \frac{a}{D} = R_A \quad (5.1.1.4-5)$$

The analysis of moments to the point A.

$$M_0(x) = R_A * x \quad (5.1.1.4-6)$$

If "x" equal 0:

$$x = 0$$

$$M_0(0) = R_A * 0 = 0 \quad (5.1.1.4-7)$$

If "x" equal distance "a":

$$x = a$$

$$M_0(a) = R_A * a = G * \frac{a}{D} * a \quad (5.1.1.4-8)$$

$M_0(a)$  is the maximal moment, because distance “a” equal distance “b” (moments the same;  $M_0(b)$  also the maximum moment). From standard equation of maximal stress, we can found the minimum thickness.

$$\sigma_{max} = \frac{M_{max}}{z} \leq \sigma_D \quad (5.1.1.4-9)$$

$$\sigma_D = \frac{Re}{k} = \frac{245}{1.5} = 163.3 \approx 163 \text{ MPa} \quad (5.1.1.4-10)$$

$$z = \frac{I}{r} = \frac{D*t^3}{12} * \frac{2}{t} = \frac{D*t^2}{6} \quad (5.1.1.4-11)$$

$$\frac{G*a^2}{D} * \frac{6}{D*t^2} = \frac{29.4*0.150^2}{0.3} * \frac{6}{0.3*t^2} = 163 * 10^6 \quad (5.1.1.4-12)$$

$$t = \sqrt{\frac{29.4*0.150^2*6}{0.3*0.3*163}} = 5.2 * 10^{-4} \text{ m} = 0.5 \text{ mm} \quad (5.1.1.4-13)$$

The minimum thickness of top flange must be 0.5 mm. Thickness of recommended flange is 30 mm but since there is a large margin of safety, the thickness can vary slightly changed.

### 5.1.1.5 Bottom flange

For calculating thickness of bottom, I used standard EN13445 and number of formula 10.4-12.

$$S_{PR} = K * D * \sqrt{\frac{P}{\sigma_D * \varphi}} = 0.4 * 168.3 * \sqrt{\frac{1.55}{163 * 0.7}} = 7.8 \text{ mm} \quad (5.1.1.5-1)$$

### 5.1.1.6 Control overpressure for pressure test

The special test which is named “Hydrostatic test” used for pressure vessel such as batch, plumbing, pipelines, gas cylinder, boilers. That test needed to insure that it is possible to work with the high pressure without damage of vessel and to indicate leaks. Hydrostatic test is carried out each 5 years.

The vessel usually is filled with a nearly incompressible liquid (typically water). For testing, pressure must be bigger than the operating pressure, for safety. Safety factor equal 166.6%, 143% or 150% of designed working pressure. In our case maximum working pressure is equal 1.55 MPa, it means that pressure for testing will be equal to 2.48 MPa.

### 5.1.2 Strength Dimensioning of Stirrer Shaft

To determine the stress on the Shaft, we must take into account all loads on it, as well as the material of the shaft. Material for shaft typically made from stainless-steel with special coatings (plastic, rubber, fiberglass, etc.), but material can be changing according the situation.

Calculation Procedure by VUCHZ. That method based on the driven power from electric motor. We can divide operation conditions into two categories: Light Operation and Heavy Operation.

I used Heavy Operation, because that operation condition depends on the solid phase, speed and distance between vessel and stirrers. I have loading of solid phase in my vessel, high-speed stirrer and small clearance between the stirrer and vessel in one side. Heavy Operation suggests the possibility stirrer becomes completely blocked. Therefore the maximum torque acting on shaft is

$$M_k = k_2 * M_{km} \quad (5.1.2-1)$$

$$k_2 = 2.8$$

The rated torque is ratio between label wattage of motor and the stirrer speed level.

$$M_{km} = \frac{P_m}{2 * \pi * n} = \frac{120}{2 * \pi * 11.26} = 1.69 \text{ N/m} \quad (5.1.2-2)$$

$$M_k = 1.69 * 2.8 = 4.732 \text{ N/m} \quad (5.1.2-3)$$

Force F is an additional bending force, which is determined form condition of overload or blocking the stirrer. That force acting on the working area in distance of  $\frac{3}{4}$  of the radius of stirrer.

$$F = \frac{2 * 4 * M_k}{3 * d} = \frac{2 * 4 * 4.732}{3 * 0.056} = 225.33 \text{ N} \quad (5.1.2-4)$$

$M_0$  is bending moment.

$$M_0 = F * l_1 \quad (5.1.2-5)$$

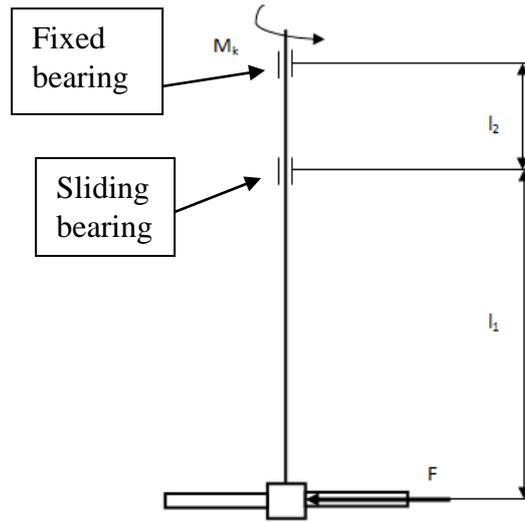


Figure 23. Sketch of shaft with impeller, force and moment.

$$l_1 = H - H_2 = 252 - 39 = 213 \text{ mm} \quad (5.1.2-6)$$

$$M_0 = 225.33 * 0.213 = 47.9 \text{ N/m} \quad (5.1.2-7)$$

This method uses reduce moment from formula to calculate the combined loads of overhung shafts

$$M_{red} = \sqrt{M_0^2 + \frac{3}{4} * M_k^2} = \sqrt{47.9^2 + \frac{3}{4} * 4.732^2} = 47.77 \text{ N/m} \quad (5.1.2-8)$$

Diameter of shaft is determined from formula

$$d_0 = \sqrt[3]{\frac{32}{\pi} * \frac{M_{red}}{\sigma_{kt}}} \quad (5.1.2-9)$$

$\sigma_{kt}$  is yield point of the shaft material.

$$\sigma_{kt} = \sigma_{all} * k_2 \quad (5.1.2-10)$$

For the stainless steel recommend permitted bending loads is 71.7 MPa.

$$\sigma_{kt} = 71.7 * 2.8 = 200.76 \approx 200.8 \text{ MPa} \quad (5.1.2-11)$$

$$d_0 = \sqrt[3]{\frac{32}{\pi} * \frac{47.77}{200800000}} = 0.01 \text{ m} = 10 \text{ mm} \quad (5.1.2-12)$$

Minimum diameter for shaft is 10 mm.

### 5.1.2.1 Bearing calculation

Bearings were calculated, because one bearing is fixed, actually all load (axial) acting on that bearing. Second bearing is sliding, that bearing is loaded by radial load, but that load is small and it means we can neglect it, but we can use second bearing like safety for axial load. Both bearings (fixed and sliding) were taken from "Inventor" catalogue and all calculation results were completed by "Inventor". My goal was just to set rpm and load acting on bearing.

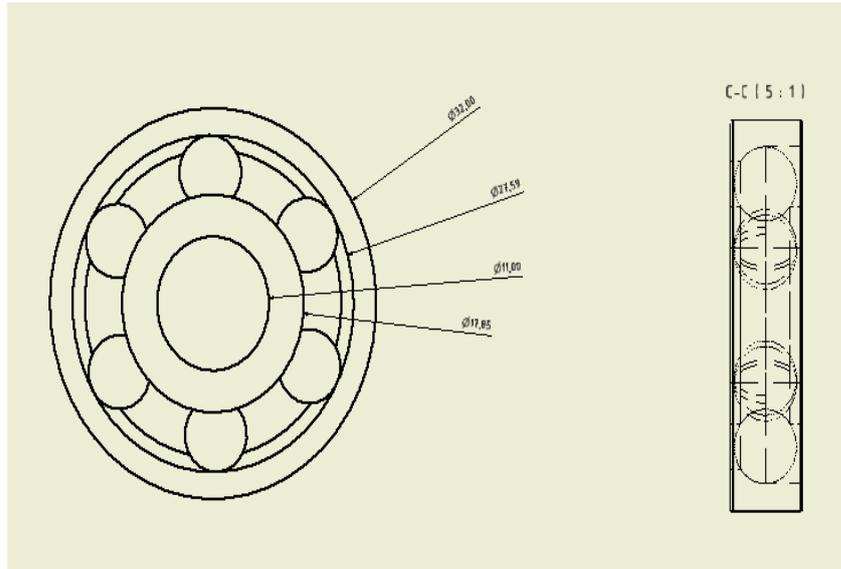


Figure 24. Bearing CSN 02 4632(E 11).

Bearing radial load	$F_r$	0 N
Bearing axial load	$F_a$	29 N
Speed	$n$	678 rpm
Required static safety factor	$s_0$	2.0 ul

Table 11. Loads on bearing

Designation		CSN 02 4632 (E 11)
Bearing inside diameter	$d$	11.000 mm
Bearing outside diameter	$D$	32.000 mm
Bearing width	$B$	7.000 mm
Nominal contact angle of the bearing	$\alpha$	0 deg.
Basic dynamic load rating	$C$	3820 N
Basic static load rating	$C_0$	590 N

Table 12. Bearing

Calculation method		ANSI/AFBMA 9-1990 (ISO 281-1990)
Required rating time	$L_{req}$	10000 hr
Required reliability	$R_{req}$	90 ul
Life adjustment factor for special bearing properties	$a_2$	1.00 ul
Life adjustment factor for operating conditions	$a_3$	1.00 ul
Working temperature	$T$	100 c
Factor of Additional Forces	$f_d$	1.00 ul

*Table 13. Bering life calculation*

Basic rating life	$L_{10}$	449474583 hr
Adjusted rating life	$L_{na}$	449474583 hr
Calculated static safety factor	$s_{0c}$	40.68966 ul
Power lost by friction	$P_Z$	0.00849 W
Necessary minimum load	$F_{min}$	6 N
Static equivalent load	$P_0$	15 N
Dynamic equivalent load	$P$	14 N
Over-revolving factor	$k_n$	0.000 ul
Life adjustment factor for reliability	$a_1$	1.00 ul
Temperature factor	$f_t$	1.00 ul
Equivalent speed	$n_e$	678 rpm
Minimum speed	$n_{min}$	678 rpm
Maximum speed	$n_{max}$	678 rpm
Strength Check		Positive

*Table 14. Results of bearing calculation*

We can see that whole properties satisfactory and there is stock.

## Conclusion

This thesis is showing how to design universal laboratory equipment for hydrothermal pretreatment of wastes. I briefly explained the process and the work of typically apparatus for that process.

The whole my thesis was divided into two main parts: theoretical part and design of equipment.

In theoretical part I explained how completely processes are going, what type of pretreatment has being used and what types of apparatus exist now. In the end of that part, I took pretreatment for which I need to design apparatus and explained this process more clearly.

The design part was started when I got main parameters, such as: temperature, pressures and mass of batch. According of those parameters, I calculated main dimension and began to draw. Necessary strength calculations were performed, but some detail do not have strength calculation because it was taken from standard catalogue.

In the end of the thesis, I got assembly drawing with all the additional details that were not included in the written part, such as the bearing house, sealing etc. All necessary details needed for the actual implementation of this apparatus in the laboratory.

Finally, I would like to say that I gained a lot of experience while I was working on the thesis. I am confident that knowledge required in the field of engineering and they will play a major role in the implementation of me as an engineer.

## References

- [1] Л. Я. Шубов, ТЕХНОЛОГИЯ ОТХОДОВ, 2011.
- [2] T. J. J. N. Lukáš Krátký, „Lab-scale Technology for Biogas Production from Lignocellulose Wastes,“ p. 54, 2012.
- [3] R. M. R.-J. B. D. F. A. ´. A. V. J. ´. A. T. He ´ctor A. Ruiz n, „Hydrothermal processing, as an alternative for upgrading agriculture,“ 2011-2012.
- [4] „<https://ru.wikipedia.org/wiki/%D0%9E%D1%82%D1%85%D0%BE%D0%B4%D1%8B>,“ [Online].
- [5] E. T.-P. M. B. M. N. P. Alvira, „Pretreatment technologies for an efficient bioethanol production process based,“ 2009.
- [6] K. W. J. Y. T. C. X. Y. Dongsheng Shen, „Effect of phosphoric acid as a catalyst on the hydrothermal pretreatment and acidogenic fermentation of food waste,“ 2016.
- [7] O. L.-S. H. A. C. G. D. Hiba Abu Tayeh, „Subcritical hydrothermal pretreatment of olive mill solid waste for biofuel production,“ 2015. [Online].
- [8] M. T. Bin Yang, Laboratory pretreatment system to understand biomass deconstruction.
- [9] T. R. C. R. Y. C. S. Duangwang, „Pilot-scale steam explosion for xylose production from oil palm empty fruit bunches and the use of xylose for ethanol production,“ [Online].
- [10] „[http://aseptec.com.my/product\\_info.php?products\\_id=238&osCsid=f9ae6727f4e1790bd29d4e2caf4e990e](http://aseptec.com.my/product_info.php?products_id=238&osCsid=f9ae6727f4e1790bd29d4e2caf4e990e),“ [Online].
- [11] L. K. Š. d. I. T. Jirout, Laboratorní zařízení pro termicko-expanzní hydrolýzu surovinIng.
- [12] „<http://www.inerez.cz/nerezove-trubky-a-jekly/nerezove-trubky-svarovane/?offset=0>,“ [Online].

- [13] T. J. Lukáš Krátký, „Improving specific power consumption for mechanical mixing of the feedstock in a biogas fermenter by mechanical disintegration of lignocellulose biomass“.
- [14] T. Jirout, „[http://users.fsid.cvut.cz/~jiroutom/huo\\_soubory/huo8a.pdf](http://users.fsid.cvut.cz/~jiroutom/huo_soubory/huo8a.pdf)“, [Online].
- [15] <http://www.motory-prevodovky.cz/elektromotory/asynchronni-motory/jednofazove-elektromotory/jednofazovy-elektromotor-0-06kw-detail>“, [Online].

Website:

- 1) <http://greenologia.ru/eko-problemy/gidrosfera>
- 2) <https://ru.wikipedia.org/wiki/%D0%9E%D1%82%D1%85%D0%BE%D0%B4%D1%8B>
- 3) <https://moodle.fs.cvut.cz/course/view.php?id=119>
- 4) [http://aseptec.com.my/product\\_info.php?products\\_id=238&osCsid=f9ae6727f4e1790bd29d4e2caf4e990e](http://aseptec.com.my/product_info.php?products_id=238&osCsid=f9ae6727f4e1790bd29d4e2caf4e990e)
- 5) <http://www.inerez.cz/nerezove-trubky-a-jekly/nerezove-trubky-svarovane/?offset=0>
- 6) [http://users.fsid.cvut.cz/~jiroutom/huo\\_soubory/huo8a.pdf](http://users.fsid.cvut.cz/~jiroutom/huo_soubory/huo8a.pdf)
- 7) <http://www.motory-prevodovky.cz/elektromotory/asynchronni-motory/jednofazove-elektromotory/jednofazovy-elektromotor-0-06kw-detail>

## List of symbols

c	safety coefficient	(mm)
$c_p$	specific heat capacity	(kJ/kgK)
D	diameter	(mm)
d	diameter of impeller	(mm)
F	force	(kgm/s <sup>2</sup> )
G	gravitational force	(kgm/s <sup>2</sup> )
H	height	(mm)
H	thickness of baffles	(mm)
I	second moments of area	(mm <sup>4</sup> )
$k_{1,2,3}$	coefficient of stability	(-)
k	safety coefficient	(-)
$l_1$	length of shaft	(mm)
m	mass	(kg)
M	moment	(Nm)
n	number of revolution	(rps)
P	power	(W)
Q	heat	(J)
$R_{A,B}$	reactions	(kgm/s <sup>2</sup> )
Re	Reynolds number	(-)
Re	Yield point	(MPa)
$r_{LG}$	latent heat of evaporation	(J/kgK)
S	thickness	(mm)
$T_{0,1,2}$	temperature	(°C)
t	thickness of flange	(mm)

V	volume	(m <sup>3</sup> )
Z	section module	(mm <sup>4</sup> )

**Greek symbols**

$\phi$	weld coefficient	(-)
$\epsilon$	specific power	(W/m <sup>3</sup> )
$\rho$	density	(kg/m <sup>3</sup> )
$\mu$	dynamic viscosity	(kg/ms)
$\sigma$	stress	(MPa)

# List of figures and tables

## List of figures:

Figure 1.Lab-technology for biogas yield evaluation [2] .....	10
Figure 2.Scheme of a biorefinery using hydrothermal processing and LCMs as raw material. [3].....	17
Figure 3.Batch reactor systems for hemicellulose depolymerization in hydrothermal processing. [3].....	18
Figure 4. Representation of different reactor configurations for hydrothermal processing. (A) batch; (B) semi-continuous (flow-through reactor); (C) continuous (co-current); (D) continuous (counter-current) [3] .....	21
Figure 5. Apparatus for pretreatment using a tubular reactor in a fluidize sand bath. [8]...	23
Figure 6.Stainless-steel reactor with acid-injection system, mixer and cooling coil. [8] ....	24
Figure 7. Flow chart of xylose production from OPEFB in the pilot-scale steam explosion, and of its use in ethanol production. [9] .....	27
Figure 8. Steam reactor [8] .....	29
Figure 9. Steam explosion vessel. [9] .....	30
Figure 10.Schematic flow diagram of the steam explosion process (feed unit is not included). [9].....	31
Figure 11. Zipperclave laboratory reactor. [10].....	32
Figure 12. Laboratory equipment for the pressure hydrolysis. [11] .....	33
Figure 13.Sketch of vessel with basic dimension. ....	36
Figure 14. A comparison of the specific power consumption levels for the tested configurations and suspensions. PTB – the impeller pumps towards the bottom of the vessel; PTS – the impeller pumps towards the surface of the batch. [13] .....	38
Figure 15. Power consumption of agitator. [14].....	39
Figure 16. 3D drawing of reactor with the main parts .....	40
Figure 17. Sketch of vessel with the pressure on the wall .....	41
Figure 18. Sketch of vessel with internal overpressure .....	41
Figure 19. Sketch of vessel with external overpressure.....	43
Figure 20. Scheme for calculating the stability of cylindrical shells in a flexible region CSN 690010 part 3. ....	43
Figure 21 .Sketch of vessel with internal overpressure in double jacket.....	44
Figure 22. Sketch of beam (flange) with acting force and reactions. ....	45

Figure 23. Sketch of shaft with impeller, force and moment. ....	48
Figure 24. Bearing CSN 02 4632(E 11). ....	49

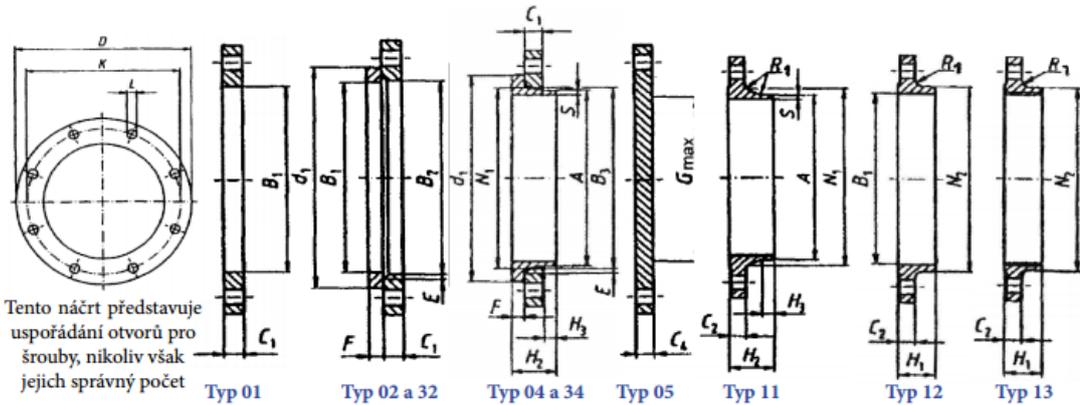
**List of tables:**

Table 1.Composition of selected lignocellulosic materials (%wt. dry matter). [3].....	8
Table 2.Summary of the advantages and disadvantages with different methods for pretreating lignocellulosic biomass. [5].....	15
Table 3. Production of bioethanol using hydrothermal processing as pretreatment under different operational conditions and raw materials. [3].....	19
Table 4. Enzymatic Saccharification of pretreated solids with hydrothermal processing as pretreatment. [3].....	19
Table 5. Typical features of batch reactors. [8] .....	22
Table 6. Sugar recovery in liquid fraction and byproduct concentration after stem explosion. [9] .....	28
Table 7. Standard dimension of tube. [12].....	36
Table 8. Type of motor with basic characteristics. [15] .....	39
Table 9.Temperature depend on the Yield point. ....	42
Table 10. Temperature depend on the Yield point. ....	44
Table 11. Loads on bearing.....	49
Table 12. Bearing.....	49
Table 13. Bering life calculation.....	50
Table 14. Results of bearing calculation.....	50

# Appendix A

## PŘÍRUBY EN 1092-1 / PN 40

str. H101



DN	Připojovací rozměry				Vnější průměr krku	Vnitřní průměr příruby				Tloušťka listu příruby			Vnější průměr kroužku	Tloušťka kroužku	Průměr nákrčku	Délka			Průměr krku		Tloušťka krku
	Vnější průměr	Průměr roztečné kružnice šroubů	Průměr otvoru pro šroub	Šrouby		A	B1	B2	B3	C1*	C2	C4				d1	F	G <sub>max</sub>	H1	H2	
	D	K	L	Počet	Rozměr	Typ příruby															
	01, 02, 04, 05, 11, 12, 13				11 34	01 12 32	02	04	01 02 04	11 12 13	05	32 34	32 34	05	12 13	11 34	11 34	11 34	11 34	12 13	11 34

10	90	60	14	4	M12	17,2	18,0	21	31	14	16	16	40	12	-	22	35	6	28	30	1,8
15	95	65	14	4	M12	21,3	22,0	25	35	14	16	16	45	12	-	22	38	6	32	35	2,0
20	105	75	14	4	M12	26,9	27,5	31	42	16	18	18	58	14	-	26	40	6	40	45	2,3
25	115	85	14	4	M12	33,7	34,5	38	49	16	18	18	68	14	-	28	40	6	46	52	2,6
32	140	100	18	4	M16	42,4	43,5	47	59	18	18	18	78	14	-	30	42	6	56	60	2,6
40	150	110	18	4	M16	48,3	49,5	53	67	18	18	18	88	14	-	32	45	7	64	70	2,6
50	165	125	18	4	M16	60,3	61,5	65	77	20	20	20	102	16	-	34	48	8	75	84	2,9
65	185	145	18	8	M16	76,1	77,5	81	96	22	22	22	122	16	55	38	52	10	90	104	2,9
80	200	160	18	8	M16	88,9	90,5	94	114	24	24	24	138	18	70	40	58	12	105	118	3,2
100	235	190	22	8	M20	114,3	116,0	120	138	26	24	24	162	20	90	44	65	12	134	145	3,6
125	270	220	26	8	M24	139,7	141,5	145	166	28	26	26	188	22	115	48	68	12	162	170	4,0
150	300	250	26	8	M24	168,3	170,5	174	194	30	28	28	218	24	140	52	75	12	192	200	4,5
200	375	320	30	12	M27	219,1	221,5	226	250	36	34	36	285	28	190	52	88	16	244	260	6,3
250	450	385	33	12	M30	273,0	276,5	281	312	42	38	38	345	30	235	60	105	18	306	312	7,1
300	515	450	33	16	M30	323,9	327,5	333	368	48	42	42	410	34	285	67	115	18	362	380	8,0
350	580	510	36	16	M33	355,6	359,5	365	418	54	46	46	465	36	330	72	125	20	408	424	8,8
400	660	585	39	16	M36	406,4	411,0	416	472	60	50	50	535	42	380	78	135	20	462	478	11,0
450	685	610	39	20	M36	457,0	462,0	467	510	66	57	57	560	46	425	84	135	20	500	522	12,5

DN 500 a vyšší na přání.

armat@armat.cz  
http://www.armat.cz  
Fax: +420 465 585 254



ARMAT spol. s r. o.  
Řetová 82, 561 41 Czech Republic  
Tel.: + 420 465 585 258 / 030 / 031

Flanges catalogue from (<http://www.armat.cz/pdf/nerezove-priruby-en-1092-1.pdf>)

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Tube	168.3X3 ; 204X2
2	2	Flange Type 1	DN150
3	1	Flange Type 5	DN150
4	2	Isolating Gasket	DN150
5	1	Sealing housing	
6	3	Packing	
7	1	Packing gland	
8	2	Cap	
9	2	Openings for coil	DN6
10	2	Coil for cooling	
11	2	Sealant	
12	1	coupling part 1	
13	1	coupling part 2	
14	1	coupling part 3	
15	2	CSN 02 4632 - E 11 ( not installed)	Single-row ball bearings, separable
16	1	Motor	NM50B4
17	1	Flange type 5	DN150
18	1	ASME B16.34 Globe Valve Flanged Ends - Class 125 3	Globe Valve
19	1	Sealing for valve	
20	1	Shaft	
21	1	Ring	
22	1	DIN 471 - 11x1	Tight feathers rounded off
23	1	CSN 02 2562 - 3x3x14	Tight feathers rounded off
24	1	CSN 02 2562 - 4x4x16	Hexagon head bolts; Product grades A and B
25	8	CSN 021733 - 2	Curved washer
26	8	CSN 02 1131 - M2 x 10	Slotted cheese head screws
27	8	CSN 02 1702 - 19	Washers for hexagon bolts and hexagon nuts
28	8	ISO 8676 - M18 x 1,5 x 65	Hexagon head screws. Product grades A and B
29	8	CSN 02 1702 - B 19	Washers for hexagon bolts and hexagon nuts
30	8	DIN 439 - M18 x 1,5	Hex Nut
31	1	Bearing house 1	
32	1	Cover 1	
33	1	Ring D 34 GOST 13941-B6	Retaining spring flat centric rings for bores and grooves for them
34	1	Impeller	D56
35	1	Impeller cover	
36	1	CSN 021733 - 5	Curved washer
37	1	ISO 4014 - M5 x 25	Hexagon head bolts;Product grades A

			and B
38	1	DIN 3760 - A - 16 x 28 x 7 NBR	Shaft Seal Ring
39	1	cover for bearing house with seal	
40	1	Mixing house part 1	
41	1	DIN 3760 - A - 11 x 26 x 7 NBR	Shaft Seal Ring
42	1	Seal cover 1	
43	1	Coupling Housing	
44	9	DIN 6796 - 3	Conical Spring Washer
45	9	ISO 4017 - M3 x 12	Hex-Head Bolt
46	8	DIN 433 - 1,5	Washer
47	8	DIN 84 - M1,4 x 10	Slotted Cheese Head Screw
48	32	CSN 02 1702 - B 1,7	Washers for hexagon bolts and hexagon nuts
49	8	CSN 02 1131 - M1,6 x 18	Slotted cheese head screws
50	16	CSN EN 24 036 - M1.6	Hexagon thin nuts. Product grade B (unchamfered)
51	8	CSN 02 1131 - M1,6 x 14	Slotted cheese head screws

Parts list from “Inventor 2017”

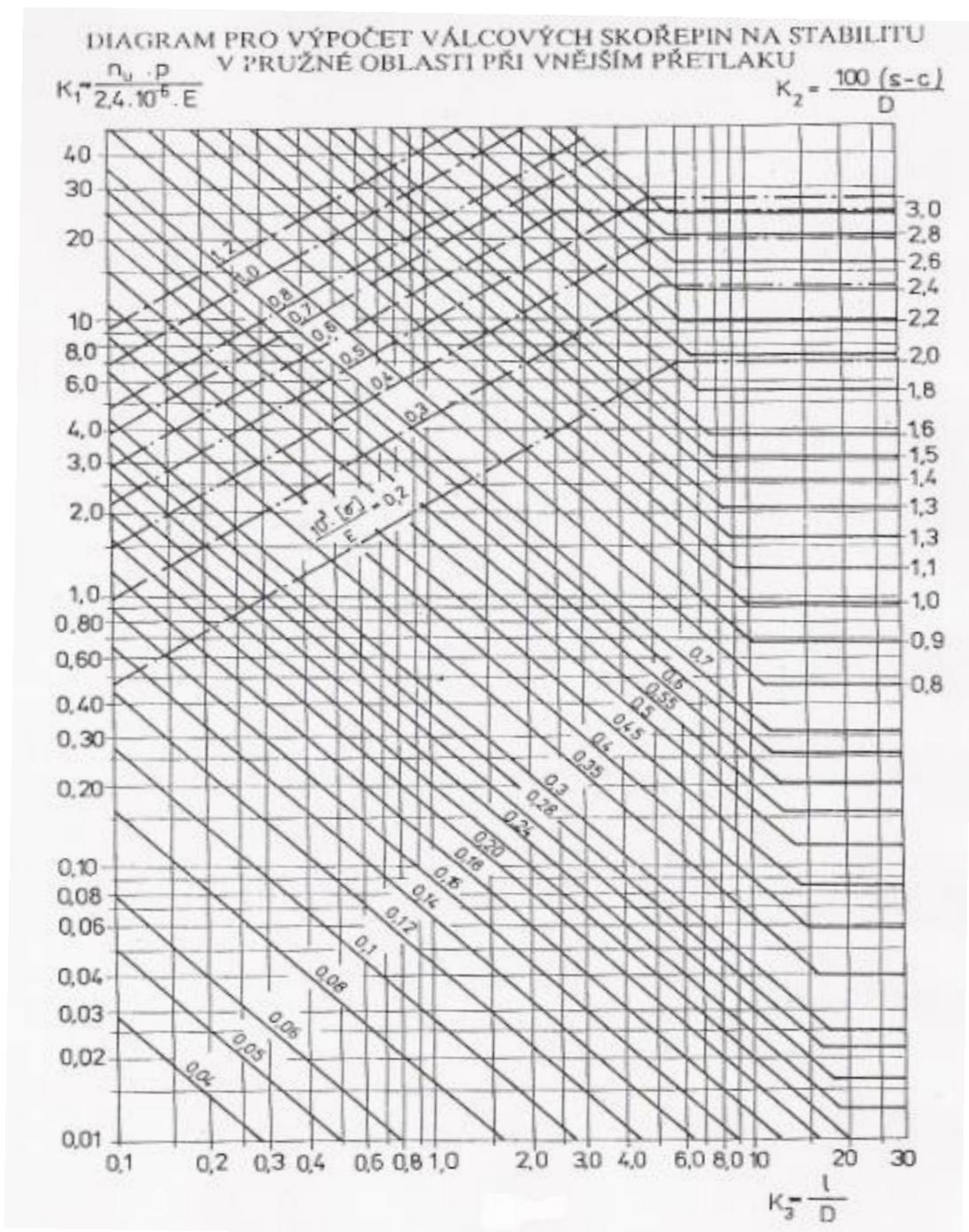


Diagram (full version of Fig.18) from lecture of “Processing Equipment Design”