Parametric study of the effect of hydrodynamic cavitation on cellulose in an electromechanical converter with a discrete secondary part

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Abstract. Hydrodynamic cavitation is a very effective destructive effect on cellulose fiber. This paper presents a study of the effective parameters of the hydrodynamic cavitation process implemented by an Electromechanical Converter with a discrete secondary part for effective pretreatment of cellulose fiber.

1. Introduction
The availability of an unlimited and renewable natural resource makes pulp and its derivatives one of the most important products for use in various fields and fields of industry. The high importance of the product determines the high relevance of research projects aimed at improving the properties and quality of cellulosic materials, as well as reducing production costs.

To date, the scientific literature has presented many studies on the effects of ultrasonic cavitation on cellulose fiber [1, 2]. However, if hydrodynamic cavitation is used in the process of breaking the cellulose fiber, there is only fragmentary information about the effectiveness of this energy effect. At the same time, in recent years, a direction has been actively developing to study the capabilities of nano-sized cellulose particles, the use of which will allow creating new materials with unique properties. In the development of new processes for the production of nano-sized cellulose particles, technologies are of particular value that allow controlling the processing process with the possibility of changing the properties and parameters obtained by part of the pulp.

The existing processes of grinding cellulosic fibers to nanosized particles are in most cases associated with significant energy costs. Among the methods already developed, cellulosic fibers are ground by mechanical influences such as crushing, cutting, impact, etc.

To carry out grinding processes, a large number of structural versions of machines already exist. At the same time, the search for new unique and innovative technologies for grinding cellulose fiber does not stop. One of these promising technological directions is the effect of hydrodynamic cavitation on cellulose fiber. The destruction of the material in this case occurs under the influence of shock waves and microjets of liquid. These processes are used in industry, however, these phenomena are not sufficiently studied. Little equipment has been developed for efficient grinding processes.
Currently, studies on the effects of hydrodynamic cavitation on cellulosic fiber are very limited. This research aims to enhance knowledge in this field.

2. Main part
In this study, an electromechanical converter with a discrete secondary part (ECDSP) [3-5] was used to generate hydrodynamic cavitation in the pre-treatment of cellulose fiber. Unlike diaphragms, ECDSP is able to create a cavitation cloud under certain conditions throughout the entire volume of the working chamber, significantly accelerating the processing process, while increasing the energy efficiency of the process.

![Typical design of electromechanical converter with secondary movable part.](image)

Figure 1. Typical design of electromechanical converter with secondary movable part. 1 - inductor; 2 - 3-phase distributed winding; 3 shows a pipe of non-magnetic material; 4 shows a set of ferromagnetic elements; 5 - treated raw material flow

In addition to hydrodynamic cavitation, the treatment in ECDSP is accompanied by a radome of additional energy effects, including the impact of elements, magnetostriction and friction.

In early experimental studies, the effectiveness of the process of breaking cellulose fibers by hydrodynamic cavitation in ECDSP was confirmed. Examination of the fractional composition of the mass treated in the plant showed that the grinding was carried out by fibrillation and splitting of fibers in length with their slight shortening, which is essential for the quality of the resulting mass. Hydrodynamic cavitation treatment of the mass in ECDSP increases the rate of dewatering and reduces its moisture retention. By using ECDSP, the amount of fibers precipitated several times decreases. In this scientific study, the slope is used to study the most optimal parameters of the process of grinding cellulosic fiber of hydrodynamic cavitation in ECDSP. According to the present invention, the efficiency of the plant depends simultaneously on several factors:

- maximum speed of ferromagnetic element movement;
- temperature of the treated mass;
- residence time of the treated mass.

2.1. Evaluation of cellulosic fiber treatment duration by hydrodynamic cavitation
Evaluation of quality of pulp fiber grinding process in ECDSP repeats similar studies performed in [6]. This experimental study is necessary to confirm the previously obtained results.

Results of tests of pulp fiber grinding process in electromechanical transformer with discrete secondary part are given in table 1.
Table 1. Treatment duration dependence on pulp quality

| Processing time, min | Average fiber length, mm |
|---------------------|--------------------------|
| 10                  | 2.8                      |
| 20                  | 2.4                      |
| 30                  | 1.91                     |
| 40                  | 1.81                     |
| 60                  | 1.75                     |
| 80                  | 1.7                      |

2.2. Evaluation of the speed of the ferromagnetic element

Despite the number of research works, there is currently no unified concept of mathematical modeling, there is no way to describe and evaluate the process of movement of the discrete secondary part. The nature of the process of movement of ferromagnetic elements in the device depends on many factors that affect the course of processes and the final result. So, as part of the study, it is necessary to determine at what effective speed the ferromagnetic elements must move in order to ensure the performance of the process.

\[ \chi = 2 \frac{p - p_{ss}}{\rho u^2}, \]

where \( p \) – is the hydrostatic pressure of the incoming flow, \( p_{ss} \) – the pressure of saturated steam, \( \rho \) – the density of the treated liquid medium, \( u \) – the velocity of the element relative to the treated liquid medium.

Depending on the size of the dimensionless cavitation criterion, 4 types of flow can be distinguished:

\( \chi > 1 \) - lack of a cavitation;
\( \chi \approx 1 \) - cavitational;
\( \chi < 1 \) - developed cavitation;
\( \chi << 1 \) - supercavitational.

The presented four modes are characterized by different cavitation intensity: during the pre-cavitation mode, the continuity of the treated liquid medium is not disturbed, the k coefficient is greater than 1; cavitation mode shows cavitation origin, which is characterized by cavitation vapor-gas bubbles in liquid medium, which saturate liquid medium, coefficient \( \chi \) is taken equal to 1; operation in developed cavitation mode is connected with approach of cavitation (water-gas) medium resistance to air...
environment impedance, coefficient $\chi$ is less than 1; in the supercavitation mode, cavitation bubbles reach critical dimensions, resulting in subsequent collapse, the coefficient $\chi$ is much less than 1.

During operation, a large number of ferromagnetic elements are involved in the working chamber. With small pressure drops, a cavitation cloud will occur only after the first row of bodies. In this case, according to experimental data, the beginning of the formation of a cavitation cloud behind the first row of moving ferromagnetic elements occurs with a dimensionless coefficient of 1, while such a value is not enough to form a cavitation cloud behind the second and subsequent row of moving ferromagnetic elements. If the dimensionless coefficient is less than 1 in the processed raw material, a continuous cavitation cloud occurs throughout the entire volume of the working chamber.

The quality of the treated material was determined by sampling as part of the experimental studies carried out at ECDSP. Treatment was performed for each test sample for 30 minutes. The speed of the ferromagnetic elements was provided by the required current density in the inductor coils and kept constant throughout the experiment [10]. After the corresponding time, the treated material was replaced with a new one and the experiment was carried out again with a new speed of movement of the secondary discrete part. As a result, 5 velocities from 1 to 5 m/s were investigated.

| Table 2. Relationship of ferromagnetic element speed to pulp grinding efficiency |
|-----------------------------|------------------|
| Speed of ferromagnetic element movement, m/s | Average fiber length, mm |
| 1 | 5 |
| 2 | 4,7 |
| 3 | 3,5 |
| 4 | 1,6 |
| 5 | 1,4 |

Analysis of the obtained experimental data allows to conclude that with the speed of the ferromagnetic element less than 4 m/s, hydrodynamic cavitation does not occur in the treated medium. In this case, the breakdown of the cellulosic fiber occurs by mechanical action, including collisions of a large set of ferromagnetic elements and resulting friction.

2.3. Temperature estimation of treated raw materials

According to the present invention, the occurrence of cavitation depends on the speed of movement of the elements under the influence of an external electromagnetic field. However, in terms of the effect of dissolved gas and vapor pressure, the treatment temperature was examined for 30 °C, 50 °C and 70 °C. The duration of treatment for all temperatures was 30 minutes.

Treatment in each case was carried out for 30 minutes. After the corresponding time, the treated material was replaced with a new one and the experiment was carried out again with a new speed of movement of the secondary discrete part. As a result, a number of experimental studies were carried out. Averaged data was included in the final table.

| Table 3. Temperature dependence of treated raw materials on pulp grinding efficiency |
|-----------------------------|------------------|
| Temperature of the processed raw materials, °C | Average fiber length, mm |
| 30 | 2,46 |
| 50 | 1,52 |
| 70 | 1,61 |
Analysis of the obtained results made it possible to determine that the intensity of cavitation is affected by the amount of gas in the liquid. If the gas in the treated material is in excess, the individual cavitation cavities begin to collide and merge. A cushioning effect is created such that the impact when slammed is absorbed by other bubbles, and the impact is reduced. Thus, the optimum temperature for the pulp grinding process was about 50 °C.

3. Conclusion
A set of experimental studies confirmed the hypothesis about the effect of the speed of movement of the ferromagnetic element and the temperature of the processed raw materials on the efficiency of processing cellulose suspension with an intensive effect of hydrodynamic cavitation. According to the results presented in the study, it can be concluded that the use of optimal parameters of the temperature of the processed raw materials and the necessary speed of movement of ferromagnetic elements provides a better grinding of cellulose with a shorter treatment time. Optimum parameters of treatment are speed of movement of ferromagnetic element not less than 4 m/s and temperature of processed raw material 50 °C.

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