Paweł Tomtas

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Formation and elimination of foam in the technological process of potato starch production

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Foam is defined as a dispersed gaseous phase in a small quantity of liquids. Foam formation in liquids is facilitated by the presence of surfactants which reduce surface tension and increase viscosity. The precondition for foaming is that the ratio of gas volume to a solution of surfactants is appropriate for each system [9]. Clean liquids do not form foam under normal conditions. Due to the surface tension of the system, the liquid-gaseous phase aims for the lowest energy state, which is reached with the minimum surface area of the phase boundary. In practice, however, in process fluids there are impurities stabilizing the foam through adsorption at the boundary surface [10].

Foam is determined by the following properties: foam-forming capacity of the solution (amount of foam produced from a unit of liquid volume in specific conditions), durability of the foam (its half-life, i.e. the amount remaining after a given time), and liquid content in the foam and the resulting shape of the bubbles. Consequently, one distinguishes spherical foam containing a large amount of liquid, in which the bubbles are similar in shape to a sphere, and cellular foam with a small amount of liquid, in which the bubbles are shaped as polyhedrons, separated by thin layers of liquid. Another determining factor is the degree of gas dispersion [6].

In technological processes, foam is formed during intensive mechanical operations such as pumping, mixing, saturation; it is the result of chemical processes, of which one of the effects is the release of gas bubbles or thermal processes, where gas is also released.

The problem of foaming occurs in many branches of food industry and concerns, among others, potato starch production, sugar beet processing in sugar factories, beverage production or technological operations in the dairy industry. This article discusses the influence of foaming on the integrity of the potato starch production process. Additionally, methods of foam elimination or reduction of foam formation intensity have been discussed.

It should be noted that during starch production, the formation of foam and its impact on the technological process is disadvantageous. This concerns in particular the adverse effect on such process parameters as mass or volume output of the dosed liquid. For this reason, foam should be eliminated or its formation should be limited by the maximum possible extent.

KEY WORDS:
foam, starch, defoamer pump,

SŁOWA KLUCZOWE:
piana, skrobia, pompa odpieniająca

SUMMARY:
The article presents the problem of foaming in liquids in the potato starch production process. The influence of foaming formed in process lines on the maintenance of proper production parameters, as well as on the operation of equipment used in the process is discussed. Foam formed in liquids has a negative impact on the process and requires elimination. The paper discusses methods of foam elimination or ways of limiting the intensity of foam formation. Additionally, benefits of limiting foam formation influencing the stabilization of liquid flow in industrial installations, their influence on the elimination of errors and inaccuracy of liquid flow parameters measurements are presented. Also, the paper analyzes the ways of reducing liquid flow disturbances in systems requiring uniform inflow to devices and apparatuses in the process lines. Simplifying hydraulic systems by eliminating additional elements, such as stabilizing tanks, as well as discarding or limiting the use of chemical anti-foaming agents are also discussed.

STRESZCZENIE:
W artykule omówiono problem tworzenia piany w cieczach w procesie produkcji skrobi ziemniaczanej. Przedstawiono wpływ tworzącej się piany w węzłach technologicznych na utrzymanie właściwych parametrów produkcji, jak również na pracę urządzeń wykorzystywanych w procesie. Tworząca się w cieczach piana ma negatywny wpływ na prowadzony proces i wymaga likwidacji. Omówiono metody likwidacji piany oraz sposoby ograniczenia intensywności jej powstawania. Dodatkowo przedstawiono korzyści wynikające z ograniczenia tworzenia piany wpływające na stabilizację przepływu cieczy w instalacjach przemysłowych, ich wpływ na eliminację błędów i niedokładności pomiarów parametrów przepływu cieczy. Przeanalizowano ograniczenie zaburzeń przepływu cieczy w układach wymagających jednostajnego napływu do urządzeń i aparatów w ciągu procesowym. Przeanalizowano uproszczenie instalacji hydraulicznych związane z rezygnacją z dodatkowych elementów np. zbiorników stabilizujących, jak również rezygnację lub ograniczenie stosowania chemicznych środków antypieniących.

TITLE:
Powstawanie i likwidacja piany w procesie technologicznym produkcji skrobi ziemniaczanej

CAUSES AND LOCATION of foaming in starch production

The technological process of potato starch production can be divided into two main phases: the first phase, the so-called wet phase, comprises the stage

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- **stacja wymycia** – montaż nowoczesnych wymywaczy, hydrocyklony do piasku, automatyka, montaż wirówek miazgowych,
- **stacja rafinacji** – montaż hydrocyklonów, wirówek,
- **stacja odwadniania** – montaż efektywnych filtrów, automatyka, regulacja gęstości mleczka,
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from potato delivery to obtaining dehydrated starch (with a moisture content of about 40%) and the second, the so-called dry phase, which includes the process of drying wet starch and its packaging. The problem of liquid foaming concerns only the wet phase of the process. The starch production process from the stage of potato receipt to the production of starch milk (further dehydrated and dried) is mechanical and involves many discrete operations such as: transporting (pumping) liquids between successive technological units, centrifuging liquids, centrifuging potato pulp, flushing out starch from potato pulp, potato grating, discharge of liquids into tanks, etc. These operations are usually turbulent, which results in foam-forming, which has a negative impact on the quality of the process.

The potato is an agricultural crop with a high volumetric water content of ca. 75%, the remaining components are dry matter, of which starch (the main product) accounts for the largest share, followed by alcoholic fermentable sugars, hemicellulose, nitrogenous substances, cellulose, fats and minerals. Some of them, namely, cellulose, some nitrogenous substances and fats are water-insoluble and as a consequence of the production process they are transformed into a basic waste product, i.e. potato pulp. The remaining components of dry matter are water-soluble. These are nitrogenous substances, minerals and sugar cane, which in their entirety are transformed into the second product of the waste starch factory, i.e. cellular juice [8]. The third by-product of the potato starch production process is the technological wastewater generated at the stage of refining raw starch milk, i.e. juice water. The fourth by-product of starch production is dirty water produced during washing and transport of potatoes containing small amounts of organic substances [7]. The above mentioned liquids, i.e. cellular juice, juice water, dirty water and additionally raw starch milk (with unremoved juice water), can be classified as a group of liquids containing components reducing surface tension in various concentrations and thus contributing to foam formation.

In the technological process of starch production and specifically in the considered locations where foaming liquids appear, it is possible (successively from the beginning of the process) to distinguish the following main stages:

- hydrotransport and washing of potatoes,
- centrifugation of potato pulp,
- production of potato protein (preheating cellular juice, centrifuging protein coagulum),
- extraction of starch,
- raw milk refining.

HYDROTRANSPORT AND POTATO WASHING

After receipt, potatoes are transported from the container to the scrubber by means of hydrotransport. For this purpose the so-called return water is used which is in constant circulation, or, additionally, potato washing water is permitted. **Figure 1** shows an example of the transport and washing water circuit in one of the starch-producing plants.

Such water contains various types of organic impurities as well as offcuts, i.e. potato fragments, left over after transport. The presence of these components in water leads to foaming, which is why it is necessary to prevent its formation by adding a chemical defoaming agent before returning the water for hydrotransport. In addition, offcuts and other solid organic contaminants that contain chemical substances causing foaming are removed by means of a rotary sieve.

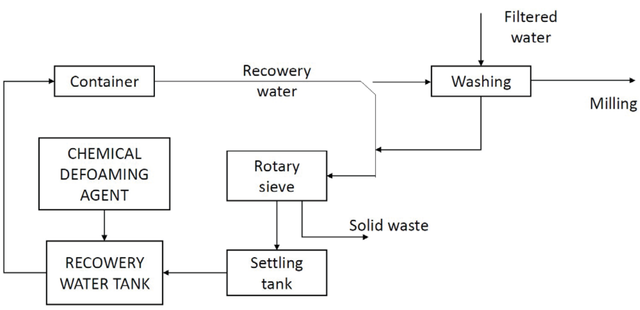

Fig. 1. Diagram of hydrotransport and washing water circuit

Rys. 1. Schemat obiegu wód hydrotransportu i mycia

POTATO PULP CENTRIFUGATION

After the potatoes are grated, potato pulp with cellular juice content is obtained. The saponin (solanine and solaneine) and protein substances which are present in the juice lower the surface tension and form extensive foam. In addition, the substances found in the cellular juice are gradually adsorbed by starch grains, causing their contamination. Particularly bothersome is one of the amino acids, the so-called tyrosine, which after oxidation changes into melanin causing the starch to turn gray [8]. Therefore, prior to extraction, potato pulp is centrifuged on sedimentary centrifuges (decanters), whose principle of operation is based on the use of large centrifugal forces generated by a fast rotating drum which act on solid particles (starch grains contained in the supplied potato pulp) leading to their very rapid sedimentation (**figure 2**).

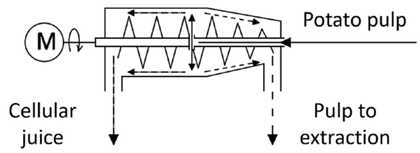

Fig. 2. Scheme of cellular juice removal

Rys. 2. Schemat usuwania soku komórkowego

After centrifugation, the pulp, into which the anti-foam chemical is continuously dosed, is fed for extraction, while the cellular juice is either directed to the settling tanks or is used for the production of potato protein. In both cases, in order to avoid adverse effects of the foamed liquid on the process, as well as the need to meet the requirement for an undisturbed flow of liquid into the machines downstream, the foam must be eliminated. This is achieved by using centrifugal anti-foaming pumps.

Similarly, the foam is eliminated during the technological process of potato protein recovery at the coagulation stage, which is also carried out on a decanter. The coagulate, thickened to 35-42% DM, is subjected to drying, while the foaming leachate is fed to plate heat exchangers, where the heating circulating water is warmed. Such a circuit is shown in **figure 3**. This is a fragment of the potato protein recovery installation designed by Mysak and commissioned in the fourth quarter of 2018 [13]. As can be seen, in both cases the use of skimming devices is of vital importance for the quality of the process. On the one hand, it is important for correct operation of the centrifugal pump feeding fresh cellular juice to the cold side of the exchanger, and on the other hand, it is vital for even feeding of warm leachate, which in turn translates into stable operation of heat exchangers. The consequence of not using the anti-foaming devices is in this case the difficulty of maintaining constant parameters, i.e. flow and temperature. When the juice transfer to the exchanger is too low (blockage of flow through the pump), the temperature may rise, causing protein coagula-

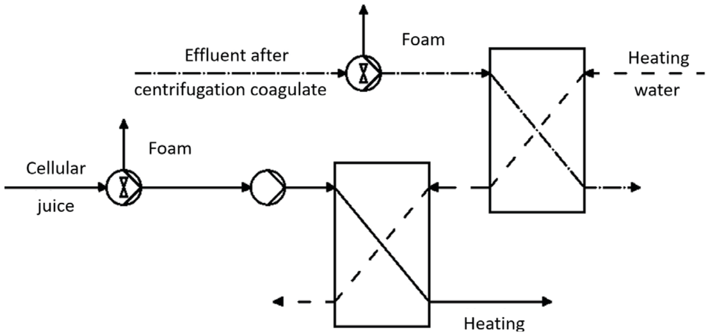

***Fig. 3.** Scheme for heating cellular juice*

***Rys. 3.** Schemat podgrzewania soku komórkowego*

tıon, which leads to clogging the heat exchanger and, consequently, to production downtime while cleaning the system is performed. In the case of an insufficient leachate supply after centrifugation of the coagulate resulting in low heat transfer to the heating water, the juice will be underheated, necessitating an additional amount of heat at a later stage, which in turn has a negative impact on the heat balance of the system.

STARCH EXTRACTION

Extraction is usually performed over a four-stage process of washing out the starch grains from the potato pulp and is carried out on rotary sieves (***figure 4***). The potato pulp is transferred to a smaller base of a cone lined with perforated sheet (item 1), which rotates at a speed of approx. 1000 rpm. Rotation of the cone ensures even distribution and slippage of the pulp towards the cone's larger base, while at the same time the entire surface of the sieve is sprayed with a rinsing liquid from the sprayer (item 2), which is a mixture of raw starch milk washed out at previous washings and the recycled water obtained from other stages of the process. Extraction is performed by applying counter-flow, i.e. the pulp is fed from I° stage to IV° and further on as waste pulp, while the rinsing liquid is applied from III° stage to I° stage, with the exception of IV° stage, where only recycled (process) water is fed on the sprayers.

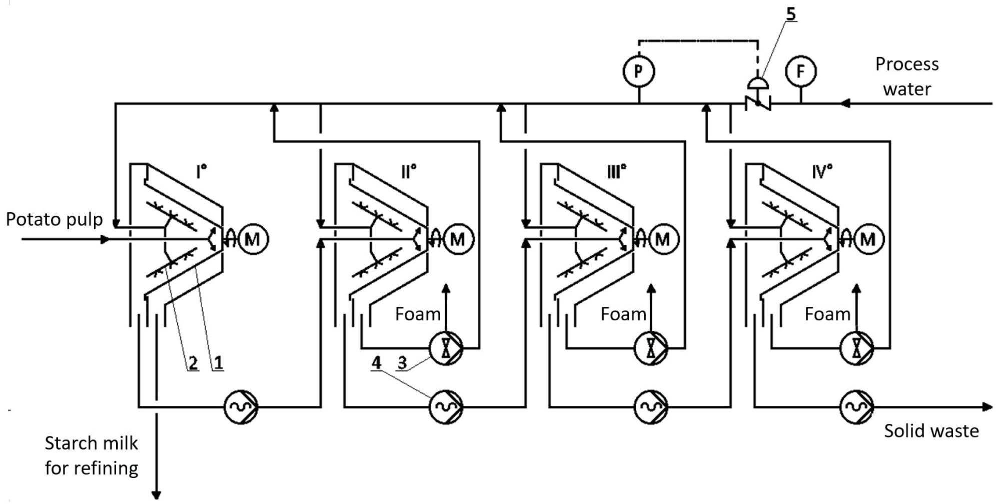

***Fig. 4.** Diagram of 4-stage starch extraction system: 1 – rotating screen of the washer, 2 – sprayer, 3 – milk pump (rinsing liquid), 4 – potato pulp pump, 5 – automatic control valve*

***Rys. 4.** Schemat 4-stopniowego układu ekstrakcji skrobi: 1 – obrotowe sito wymywacza, 2 – natryśnica, 3 – pompa mleczka (cieczy płuczącej), 4 – pompa miazgi ziemniaczanej, 5 – automatyczny zawór regulacyjny*

The leaching process is turbulent, water and washed starch suspension containing foaming substances passing through the holes in the sieves strikes and splashes on the walls of the device housing, which results in foaming. For the proper operation of the washers, and in order to achieve the lowest possible loss of starch (which then passes to the pulp), it is necessary to maintain constant parameters of pulp feed and rinsing liquid supply to the sprayers. The foamed liquid interferes with the proper operation of the returning liquid pumps, its feeding may be uneven, and as a result there will be pressure drops in the system in the milk separating collector, or interruptions in the pumping of the rinsing liquid. The system of automatic regulation of recycled water supply, which is designed to adjust the amount of water supplied, due to the inertia of the system is then not able to respond to high pressure changes in the collector, resulting from the lack of consistency in the operation of the milk return pumps. In consequence, potato pulp may not be sufficiently rinsed, and as a result, leachable starch will be transferred to the potato pulp, causing production losses. Therefore, before applying milk for spraying at the previous stage, it is necessary to eliminate any occurring foam, and this is achieved by using foam pumps.

RAW MILK REFINING

Refining raw milk is the next stage of the process prone to the problem of foaming. The first stage of refining is the concentration of milk to a content of approximately 25% of DM with concurrent separation of juice water in the case of using 2-phase centrifuges. When the 3-phase centrifuges are used, an additional separation of the fine fibre fraction is performed. Juice water contains the same ingredients as cellular juice, but while they are in a lower concentration, they still tend to form foam. Juice water is treated as waste water and is directed to settling tanks. Some of the juice water is used to supplement the recycled water and is added to the recycled water tank (clarified water from clarifiers). A chemical anti-foam agent may be added to this tank at the same time, limiting the formation of foam before water is fed back into the process - to the collector of the extraction station and to the collector of fine fibre sieves. In the case of fine fibre screens, also the feed, which is an overflow from the mhc station, occasionally requires the removal of foam, and this is done by means of skimming pumps. Another step in the removal of foam from the liquid is the addition of pre-compacted milk (by centrifuges) to the first stage of the cleaning station. In order to maintain the balance in the process (hydro cyclone separation of phases), the milk must be fed uniformly with a fixed flow rate, and to this end defoaming pumps or chemical anti-foaming agents are used. Lack of uniformity of milk supply to the mhc station disturbs its work, which is manifested by losses of starch for overflow (in the case of excessive liquid stream, too high density, excessive load on the pumps working in series) or insufficient cleaning of milk at the exit of the last stage of the mhc station (too much water in the system). Here, as in the case of washing-up stations, the automatic control systems (milk density, amount of rinsing water) are used to correct the parameters, while the low inertia of the system does not allow the process to be carried out effectively in the case of large and fast changes in working parameters.

METHODS of foam elimination

Foam undergoes spontaneous degradation as a result of coalescence, i.e. joining of bubbles, which is supported by dewatering caused by gravitational outflow of excess liquid from the space between bubbles [10]. However, it is a slow process and unacceptable under the conditions of technological processes in an industry. It is, therefore, necessary to take measures preventing the formation of foam and eliminating the foam produced.

There are three methods of foam elimination [6]:

- chemical (by introducing an anti-foam substance into the system),
- thermal (by heating the system, which reduces surface friction, causes partial evaporation of the solvent and an increase of pressure inside the bubbles), and
- mechanical (using pressure changes, shearing, compression or impact).

As indicated above, in the potato starch production process, foaming and foam elimination treatments are executed by means of both chemical and mechanical measures. Typical areas of application of particular agents are described above, but it should be noted that this is a general specification, technology suppliers themselves determine where and which foam removal measure to apply as it is closely related to the specification of the machines available (frequently purchased from third-party suppliers) and depends on the operational parameters.

Chemical foaming agents are intended to operate in a specific environment and may cover different ranges of temperature, pH, pressure or inertia of a chemical component. Chemical foaming agents act by adsorptive rugging of foam stabilizer molecules (impurities that form and stabilize the foam). Such agents can act in two ways: displacing the foam stabilizer from the bubbles' walls or tearing the membranes locally. The skimming agent must penetrate the membrane and replace the foam stabilizer on the boundary surface or form a mixed membrane with it. In this manner, the foam stabilization mechanism is blocked and the foam disappears [10].

Foam undergoes spontaneous degradation, but it is a slow process and unacceptable under the conditions of technological processes in an industry. It is, therefore, necessary to take measures preventing the formation of foam and eliminating the foam produced.

Chemical foaming agents can be used as foam inhibitors (antifoams) or as defoamers.

The main chemical components of the foaming agents are [2]:

1. The liquid carrier – oil (vegetable or mineral), water, polyol (alcohol-based) or ester (chemical-based) – must be inert to the medium in which it operates, and must be capable of spreading quickly,
2. Distributing agent (usually esters, oils or wetting agents) – Is designed to distribute the agent and allow it to enter into a specific system of foam bubbles that it encounters,
3. Hydrophobic particles (silica or waxes) – fill gaps and prevent foaming.

The basic properties that an anti-foam preparation should [4]:

- ensure high performance at low doses,
- ensure that there is no negative impact on the subsequent stages of the technological process,
- be degradable and should not transfer to the product, semi-products and waste,
- not adversely affect the course of technological processes in the case there is presence of traces of these preparations
- not adversely affect the processes of biological decomposition of pollutants in water and sewage in the case of the transfer of certain amounts of these compounds to sewage,
- be non-toxic to the biocenosis of surface waters,
- have a positive environmental assessment,
- be approved for use in the food industry.

An equally important factor connected with the use of chemical anti-foaming agents is the control and dosage method. Mechanisms for stabilizing and controlling foam are very subtle, they occur in colloidal systems on the phase boundary in very thin foam membranes. The use of agents must be very accurate and skillful, since lack of precision may have negative effects, such as accumulation of sticky deposits [10]. For example, administration of too much anti-foaming agent to the potato pulp before extraction causes its sticking and thus worsens the conditions of washing out starch grains from the pulp, which is associated with production losses. The anti-foaming agent should be dosed automatically in quantities corresponding to the current flow rate of the foaming liquid, taking also into account changes in flow rates.

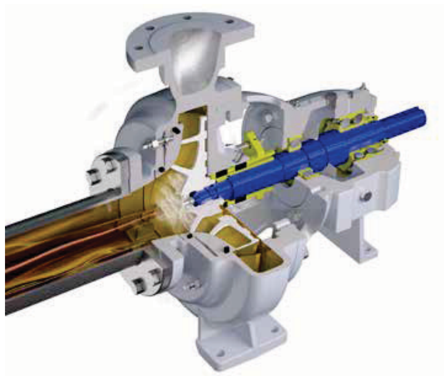

Fig. 5. Blocking the inflow of liquid to the rotor [11]
Rys 5. Blokowanie napływu cieczy do wirnika [11]

The mechanical means of starch production are used to remove the foam that has already been formed in the liquid, and for this purpose specialized centrifugal skimming pumps are mostly used, and their task is to break up the foam, release the gas and cause its discharge through a separate outlet. In a conventional centrifugal pump, the air contained in the foam is collected near the rotor axis, in consequence of the centrifugal effect working on the liquid and causing gas release. The centre of the rotor is a low pressure area, which leads to the accumulation of gas, as a result of which the flow of liquid into the rotor is blocked and thus the pump's operation is obstructed [1], as shown schematically in ***figure 5***.

According to one of the leading European pump manufacturers (Sulzer), conventional centrifugal rotor pumps, regardless of the type of impeller, are able to operate with a gas content of up to 4% [6], and when this value is exceeded, the effect described above occurs, which results in reduced pumping capacity, lowered efficiency and unstable pumping of liquids (***figure 6***).

In order to eliminate the above adverse effects of operation of conventional centrifugal pumps, special designs of pumps are used in the starch industry, the so-called defoaming pumps, where the foam introduced into the rotor after separation from the liquid is mechanically destroyed.

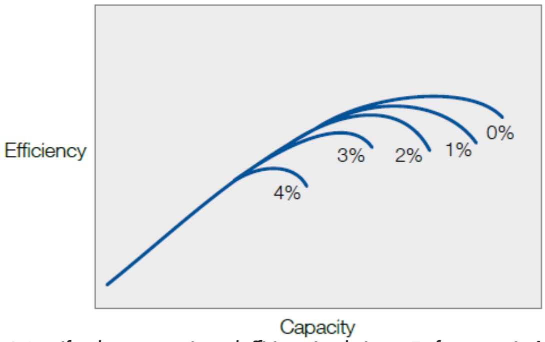

Fig. 6. *Centrifugal pump capacity and efficiency in relation to % of gas quantity [11]*

Rys. 6. *Wydajność i sprawność pompy wirowej w zależności od % ilości gazu [11]*

Figure 7 shows a diagram of the design of a pump often found in starch production installations. Such a pump consists of a housing (1) divided by a disc with a hole (2), two impellers on a joint shaft: an impeller (3) to separate the foam and pump the liquid and an impeller (4) to break up the foam and eject the separated gas, residual foam and droplets of liquid. The pump inlet has a large diameter to allow the free flow of the liquid/foam mixture.

The liquid/foam mixture introduced into the pump chamber (1) is rotated by the impeller (3). The back-pressure in the outlet pipe creates a water ring; foam bubbles accumulate near the axis of the impeller and are partially broken up by the rotating impeller. While the foam-free liquid escapes through an outlet port to the system, the mixture of the released gas and the remaining foam passes through the opening in the baffle (2) and enters the second chamber, where the second impeller (4) breaks up the remaining foam and the released gas is discharged through the second outlet of the pump. The remaining liquid from the broken foam is also removed through this outlet. The operation of the second pump rotor is broadly comparable to the principle of mechanical destruction of foam with its three stages of destruction [5]. In this case, it is the second stage, i.e. the foam bubbles are broken as a consequence of hitting the rotating blades and thrown towards the walls of the device housing, and the third stage, i.e. they collide with the housing wall or a film of the dripping foam.

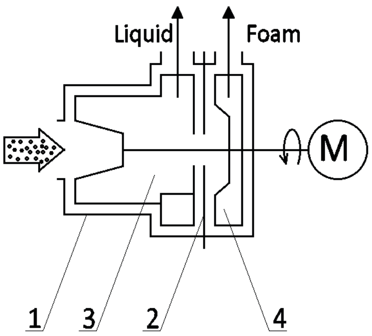

Fig. 7. *Skimming pump diagram: 1 - housing, 2 - baffle, 3 - liquid impeller, 4 - foam impeller*

Rys. 7. *Schemat pompy odpieniającej: 1 - obudowa, 2 - przegroda, 3 - wirnik cieczy, 4 - wirnik piany*

Another common design of the skimming pump used in the starch industry is a pump produced by the Swedish company Larsson (***figure 8***) [12], in which the air is removed from the liquid introduced into the chamber and the foam is destroyed. The foam-free liquid is transferred to the housing by means of special blades, where the respective impeller pumps it to the system, and the gas along with the remaining foam is discharged through a separate spigot.

Another solution found in the starch industry is the Sulzer pump, a diagram of which is shown in Figure 9 [3]. The mixture of liquid and gas accumulates near the pump axis, from

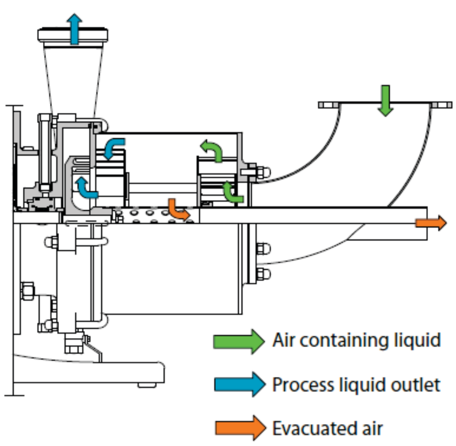

***Fig. 8.** Skimming pump by Larsson [12]*

***Rys. 8.** Pompa odpieniająca firmy Larsson [12]*

where it passes through special holes in the main impeller to the second chamber, where the auxiliary impeller separates the liquid and gas. The second chamber has two spigots, one to discharge the liquid and the other to release the gas.

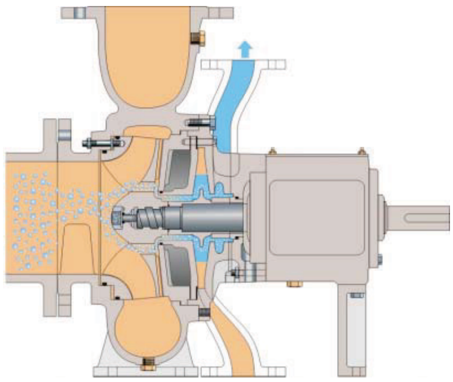

***Fig. 9.** Sulzer gas separation pump [3]*

***Rys. 9.** Pompa z separacją gazu firmy Sulzer [3]*

CONCLUSIONS:

Foam produced during the production of potato starch has a negative impact on the technological process and requires elimination as well as prevention. For this purpose, chemical and mechanical methods of elimination are applied. Chemicals are used as anti-foaming agents (antifoams), mechanical agents are mainly skimming pumps, and are used to eliminate already existing foams.

The problem of foaming occurs in many branches of food industry and concerns, among others, potato starch production, sugar beet processing in sugar factories, beverage production or technological operations in the dairy industry.

Proper selection of the method of elimination or limitation of foam formation and the place of application in the pipeline has a significant impact on the process and determines whether it progresses smoothly and uninterrupted, and whether liquids are supplied to devices placed downstream in a uniform manner guaranteeing the correct operation within their specified ranges. If also affects control and measurement equipment (electromagnetic flow meters, mass flow meters, pressure transmitters), where through the elimination of measurement errors, control automation effectively supports the process and is free of incorrect information.

Lack of effective foam reduction causes:

- improper operation of pumps - blocking the inflow of liquid to the impeller, disturbances in the pump's operation, lack of uniform inflow to devices downstream the process line,
- unbalanced flow in pipelines, which results in errors in the measurement of flow rate, density of liquids, pressure. In addition to their informative function, these parameters primarily constitute an element of automatic control systems and such errors could lead to incorrect settings and the resultant production losses,
- measurement errors of liquid quantities in process tanks,
- incorrect operation of technological equipment such as washers, hydrocyclones, plate heat exchangers, which leads to production losses
- spillage from tanks - difficulty in keeping order in the wet area.

When using chemical agents, it is imperative that the agent should be neutral in contact with the foamed liquid and that it is approved by the National Institute of Hygiene. It is also necessary to ensure effective control of the amount of the added detergent in correlation with the foaming liquid flow rate, and to maintain the required dosage accuracy. ■

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