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Design of Scrubber for Sedimentation and Dissolution of Milk Dust

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Abstact. In the work, the necessity of creating a device for settling the dispersed phase of milk dust - dry milk product, at the section of the coolant outlet to the environment is investigated. The quality of dry product deposition in the used devices: cyclones and filters has been evaluated. Technological factors occurring in scrubbers during sedimentation and dissolution of milk product are considered. The design of scrubber, providing the use of patented technology of return of precipitated dispersed phase of milk dust into a full commercial product, is offered.

Keywords: spray drying, cyclones, bag filters, finished product losses, heat energy recovery, scrubber design requirements.

Introduction

Spray dryers are the only alternative for drying dairy products. They have been widely used in the world since 1930, when a workable spraying disk device was developed and a specialized European company "Niro – Atomizer" was established. Subsequently, the designs of drying plants were improved, their productivity increased, the quality and range of the produced product improved, but inevitably remains the main disadvantage of the technology - high energy consumption and significant losses of the finished product into the environment [1]. Drying in general is the most energy-consuming process among dehydration technologies. For one kilogram of evaporated moisture from evaporated dairy product during drying, an average of three kilograms of saturated water vapor is consumed. Even higher costs are incurred during contact heating of air - heat carrier in heat generators directly burning combustible materials (gas, oil products). When dust with product quantity 275÷800 mg/m^3 [1,2] of heat carrier is discharged into the environment, there is no possibility of reuse of heat energy introduced into the air - heat carrier during primary heating, before letting it into the drying tower, as the dispersed phase of dust in contact with heat-exchange structures will quickly contaminate them [3]. It should be borne in mind that the humidity of the coolant at direct air intake from the environment, with its average humidity (for the Republic of Belarus) more than 80 %, significantly exceeds the moisture content of the exhausted, absorbing secondary moisture from the dried product [1,4].

Thus, with the high cost of thermal energy resources, the challenge is acute: to ensure good product deposition performance from milk dust.

1. Methodology

Modern drying plants of average productivity are chosen as objects of research. In the Republic of Belarus, it is the equipment of the Slovak company "Vzduchutorg" of VRA-4, VRC, VRD types, with heat carrier capacity of 46 ÷50 thousand m^3/hour and installations of the concern "GEO", having capacity up to 130 thousand m^3/hour. At medium-sized plants the aspiration system is initially limited to one or two cyclones. In addition, dairies can purchase bag filters from the named company with the number of 340 pcs. of bags, each 6 m long, 0, 18 m in diameter. The cost of the filter is more than 300 thousand dollars. The bags are replaced every 9 months. The firm directs potential buyers of new drying equipment to the use of filters, supplying, for example, in the VRD plant one cyclone of larger size. It should be borne in mind that the size of the cyclone has a decisive influence on the quality of sedimentation. These indicators are in an inverse relationship, i.e. with a large dust flow entering a large cyclone the quality indicators deteriorate. At the principled attitude of environmental protection structures to the established norms of product losses (10 mg/m^3) the owners of such installations have no choice but to use the proposed filters. It is fair to assess the quality of filtration as satisfactory. During a day filters installed after cyclones capture 250÷300 kg of finished product. Their disadvantage is impossibility of drying WMS (whole milk substitutes) for livestock farming using fat additives. Besides, the lint from bag filters is intensively lost and gets into the product, which reduces its grade. Even in a more difficult situation are the owners of drying plants with high capacity, although the company "Niro – Atomizer" also produces filters "Sanicryptm". Summarizing, it should be concluded that a significant improvement in the quality of product capture at the output to the environment, does not provide for the use of filters environmental requirements and the more so does not approach the possibility of heat recovery by repeated cyclic return of the coolant to the heating heat exchangers.

The only apparatus, fundamentally capable of solving these problems, should be recognized special scrubbers, devices for wet dust cleaning [3].

In the dairy industry, there have been attempts to use Y9-OMP volumetric scrubbers and Venturi scrubbers [1]. In the former, raw milk was used as the precipitating liquid. Large volumes of milk with captured dry product, the subsequent cycle of processing of such raw material along the entire technological line, starting from storage tanks, made the technology unacceptable, although the quality of coolant purification was much better than when using cyclones.

Venturi scrubbers, widely used in various industries, with excellent quality indicators, did not continue to be used in the dairy industry due to the incompatibility of the device with the drying tower due to high hydraulic resistance - 35 kPA at permissible - 3 kPa.

Thus, a scrubber should be designed to overcome the effects of hydraulic resistance, with an irrigation density at the level of the Venturi scrubber.

2. Results and discussion

2.1 Hydraulic resistance of scrubber design depends on two main indicators: local and hydraulic resistances. In order to reduce the indicators of local resistances it is necessary to refrain from sharp changes in the area of dust flow along the trajectory of its movement from the discharge centrifugal fan to the solution outlet to the intermediate tanks, where the flow velocity is sharply reduced. The main requirement is the absence of shut-off and control valves on the pressure line of the flow.

Hydraulic resistance is due to the dimensions of the scrubber vessel, the viscosity of the liquid, which will increase as the concentration of solids in the reconstituted milk product increases. This means that it is necessary to avoid deposits on the internal surfaces of the scrubber, formed on dead-end sections, changes in the flow regime. Provision should be made for scouring of deposits in such areas not only during cleaning and washing, but also during scrubber operation. Thus, the inlet and outlet pipelines and the main scrubber vessel should have smooth outlines of internal surfaces, without sharp constrictions, preferably cylindrical in shape. The volume of the scrubber vessel should not impede the free passage of the flow, without local areas of increasing velocity head.

2.2 Flow velocity

When cycloning dry dust there is a requirement to limit the flow velocity to 20 m/s, because of the resulting effect of blowing off the settled product and involving it in the movement to the outlet pipe, i.e. to the exit to the environment. Wetting of the product particles by the precipitating liquid eliminates this effect. The adhesion of the wet dust-liquid mixture is more likely to be so high that there is a need to ensure that there is no deposit. Thus, an increase in velocity to the level of flow turbulization will be useful until a critical velocity head occurs, an undesirable increase in hydraulic head. When calculating the cross-sectional area of the inlet nozzle based on the design velocity value:

$$\vartheta_v = \frac{Q}{S}\ (m/s) \tag{1}$$

where $\boldsymbol{\vartheta}_v$ – flow velocity in the inlet pipe, m/s;

Q – fan supply, m^3/s;

S – cross-sectional area of the inlet branch, m^2.

It should be kept in mind that when cycloning wetted dust, there is a Coriolis acceleration as it approaches the deposition surface, which should be accounted for in the overall flow velocity balance.

Thus, we propose the main device of the scrubber - dust wetting zone, a device in the form of a wet cyclone, with the size ratio recommended by NIIOGAZ.

The recommended value of D, not more than 1.2 m and the flow thickness at the cyclone inlet 0.2 D can be increased based only on the limitation of hydraulic resistance, but taking into account more effective settling due to wetting of dust by a special slotted nozzle installed at the point of adjoining the inlet pipe to the cylindrical body of the scrubber (Figure 1).

The slot nozzle is introduced into the cyclone from above. The slit has a width sufficient for outputting a continuous flow of wetting liquid on the dust surface and a length equal to the length of the inner part of the outlet pipe (Figure1). Liquid velocity at the outlet of the slot is equal to the velocity of dust at the cyclone inlet. A solid film of liquid covers the surface of the dust flow and due to relatively high density, under the action of centrifugal force presses the dust to the deposition surface, simultaneously wetting it in the film-drop mode. In addition to the centrifugal action, the wetted dust in its downward movement strikes the liquid surface at the bottom of the cyclone.

This provides a centrifugal-impact mechanism for contacting the dust with the wetting liquid.

2.3 Foam in the scrubber.

The protein in the milk product will form foam when in contact with the liquid and the agitating motion of rotation. Foam in itself is a useful phase to ensure wetting, but at significant volume is a detrimental factor, increasing hydraulic resistance and preventing the separation of air from the liquid as it moves to the outlet. At the same time, the impact of the flow as it moves from above to the liquid surface on the bottom is one of the technical methods of foam destruction. In addition, it is necessary to arrange foam overflow from the scrubber through a special vertical pocket connected with the drainage system by a special overflow channel.

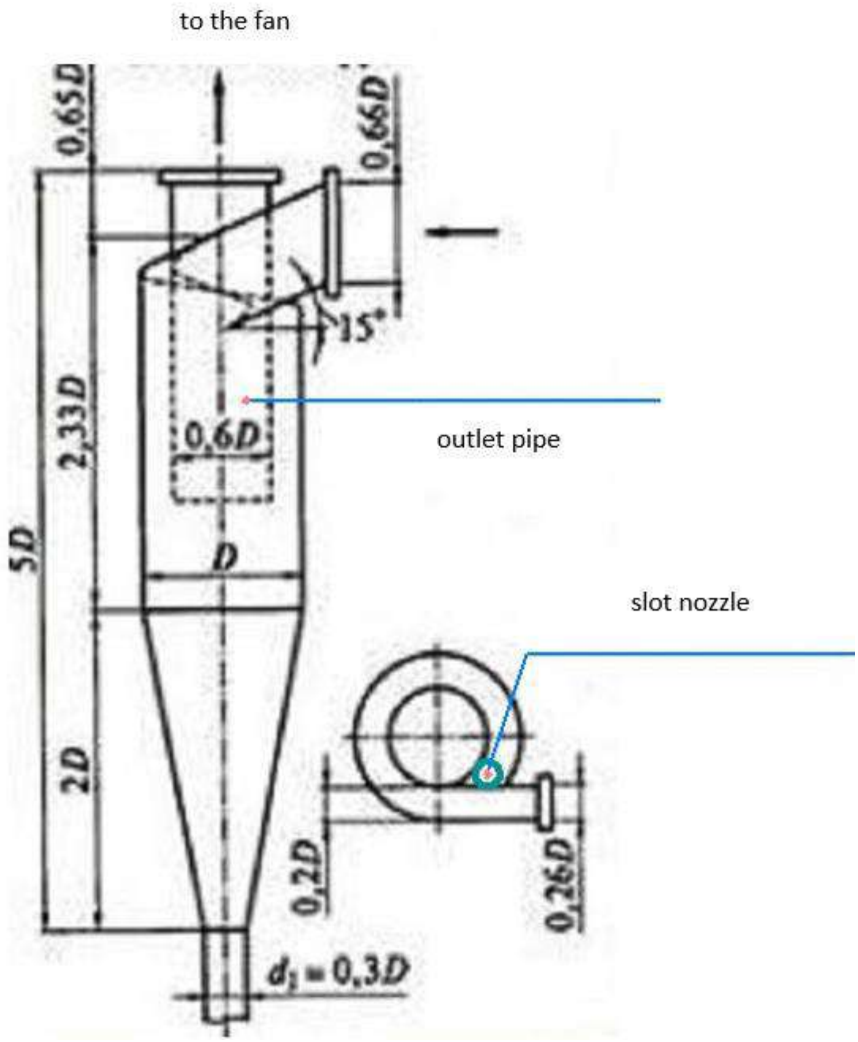
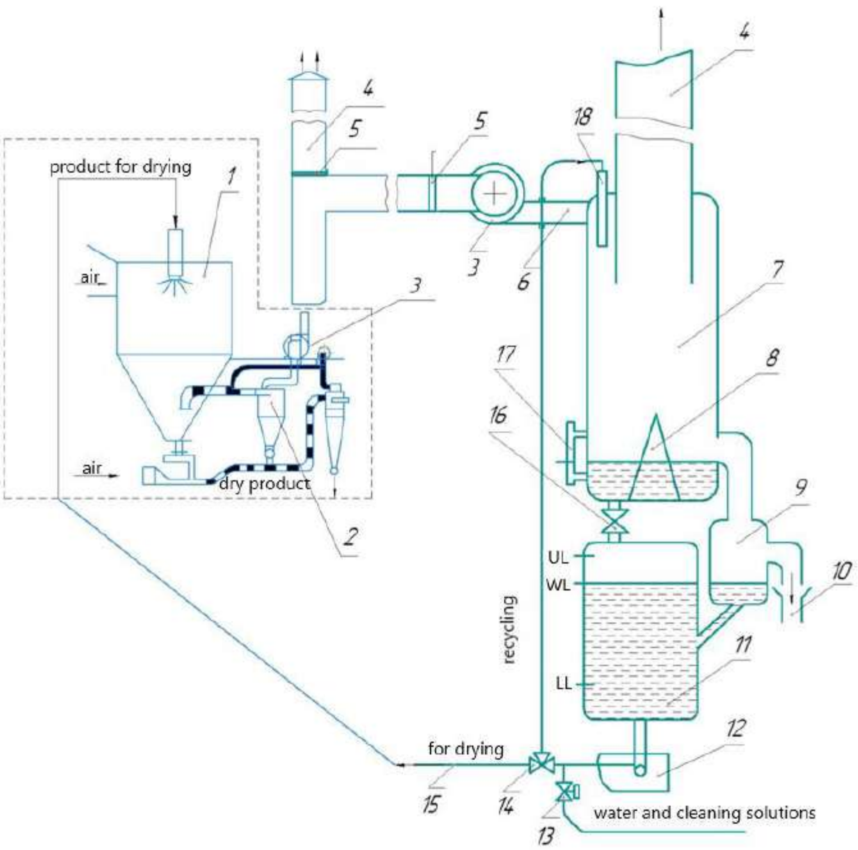


Fig.1. - Schematic diagram of the NIIOGAZ cyclone

The operation of the scrubber as part of the spray dryer is as follows:

In the scrubber body *7*, foam tank *9*, and level tank *11* is poured hot water *($t=70^oC$)* drinking quality, pump *12* through three-way automatic valve *14* until reaching the level of the pocket for foam in the scrubber body and the working level of the WL in the level tank *11*. The centrifugal fan *3* is switched on together with the exhaust fan *3* of the drying unit. Diverter *5* closes the air outlet on the exhaust pipe of the drying plant to the environment. Dust after leaving the cyclones enters through two successively installed, in order to overcome the hydraulic resistance of the scrubber, fan *3* and the inlet pipe of the scrubber *6* and is cyclonized in the body *7* of the scrubber. At the same time, the pump *12* in the cycloning zone supplies hot water from the level tank *11* to the slotted nozzle *18*. The water from the slit nozzle *18* irrigates the dust stream from its inner side. Water and wetted product particles due to increased density intensively approach to the outer wall of the scrubber body, on the way wetting and involving in this movement the entire dust stream. This mixture in a vortex motion enters the lower part of the scrubber body, hits the liquid surface, the level of which corresponds to the lower edge of the overflow channel for foam and is set using the valve *16* and water glass *17*. The flow of the cleaned coolant is then separated. Partially it flows through the crossflow pocket together with the foam into the foam container *9*. The main flow in contact with the cone *8* forms an upward spiral flow to the outlet of the casing *7* and outlet pipe *4* and is discharged into the environment outside the room. Foam from the container *9* is discharged to the drain *10.*



1 - drying plant; 2 - cyclone; 3 - fans; 4,6 - air ducts, dust pipelines; 5 - shibers; 7 - case of scrubber; 8 - case for the formation of ascending helical flow; 9-capacity for foam; 10 - drainage; 11-capacity of levels; 12 - pump-dispersant; 13 - automatic valve for water, cleaning solutions; 14 - automatic valve; 15 – pipeline to drying unit; 16 - regulating valve; 17 - water meter glass; 18-slit nozzle; LL-lower level; WL-working level; UL-upper level

Fig.2. - Schematic diagram of centrifugal-impact scrubber as a part of spray drying plant for dairy products

After reaching the upper level of WL in the level vessel during circulation, the automatic valve 14 closes the access of the solution to the scrubber and opens the supply to drying. When the lower level of LU is reached, the solution supply to drying is stopped. The automatic valves 13 and 14 are opened and hot water is again supplied to the scrubber until the operating level of WL is reached. The recirculation process is resumed.

Washing and disinfection of equipment after stopping dust supply from cyclones, similar to the process of hot water supply and solution circulation, using slotted and ball nozzles (not shown in the diagram).

2.4 Calculation of level capacity

There are three automatic levels in the level tank, which switch the liquid supply for recirculation, until obtaining the designed solids concentration in the solution and for supplying it after laboratory analysis for drying. The operating level of the WL gives permission to recirculate hot water, and then the solution of milk product, until reaching the upper level of UL, at which point the tank should contain a solution with a concentration of solids suitable for drying. The upper level of UL gives the command to open the valve of solution supply for drying. When reaching the lower level of LU solution supply for drying is stopped and allowed by the pump in the scrubber body, the container for foam and the container of hot water levels until reaching the working level of WL in the container of levels and the level of the lower edge of the overflow pocket for foam in the scrubber body. In this case, the liquid level in the level tank is equal to the level in the foam tank. Recirculation of liquid along the route pump - scrubber body - level tank - pump is carried out until the time of level rise from the WL to the UL due to the dispersed phase of dairy product dust that entered the solution. Consequently, it should be known, at the established frequency of feeding the received solution for drying, the volume of the part of the tank of levels between the working level of the RU and the upper level of the VU. In the process of recirculation during 20 hours (the usual duration of the drying process), the solution will not be spoiled by microbial causes, because the temperature of the solution when feeding dust with a temperature of 70 and more ^{o}C, exceeds the temperature of the mode of long-term pasteurization.

From the point of view of production organization of preparation of the product for drying by evaporation at vacuum evaporator plants (VEP) and accordingly drying, the optimal is the arrival of the obtained solution for drying after the end of the VEP operation and transition to its washing. In other words, it is necessary to calculate the volume sufficient to contain the solution received in the scrubber for 20 hours.

3.1. The calculation is made according to the standardized indicators of the Ministry of Agriculture of the Republic of Belarus for some dry products.

Table 1. Indicators of dairy products during processing

Name of finished products	Mass of evaporated moisture during thickening kg/1000kg of raw material	Weight of condensed milk products kg/1000kg of raw materials	Mass of evaporated moisture during drying kg/1000kg of raw material	Weight of dry product kg/1000kg of raw material, moisture content 5%
Skimmed milk powder, SMP	807,3 thickening to solids concentration 45%, density 1190 kg/m^3	191,6	101,4	87,6
Whole milk powder 20%	738,76 Thickening to solids concentration 45%, density 1120 kg/m^3	260,8	133,3	119,2
Dried whey	880,4 Thickening to solids concentration of 50%, density 1209 kg/m^3	119,6	58,8	60,8

Since the purpose: technology of drying of the product obtained by dissolution in the scrubber, let's calculate the ratio of thickened products to dry ones:

- for SMP $191{,}6/87{,}6 = 2{,}180$;
- for whole milk powder $260{,}8/119{,}2 = 2{,}187$;
- for dried whey $191{,}6/60{,}8 = 1{,}967$.

The obtained figures for the ratio of dry products to condensed products allow us to determine the volume of product dissolved in the scrubber at its calculated concentration of 45% by dry matter, suitable for direct drying.

According to [1] Niro-Atomizer, Schwarte average losses of dry product with coolant at the outlet of the drying plant are 250 mg/m^3. Then the losses per hour of operation of the dryer will be for the drying plant VRA-4 with the volume of heat carrier 42000 m^3/hour

$$42000 \times 250 = 10500000 mg = 10{,}5 \ kg/hour\ of\ dry\ product.$$

respectively for 1 hour we get for SMP$_m$ = $10{,}5 \times 2{,}18 = 22{,}89\ \ solution/hour$.

Based on the density of the solution 1190 kg/m^2 find the volume of solution

$$V = \frac{m}{\rho} = \frac{22.89}{1190} = 0.019\ m^3/hour.$$

here m – is the mass of the solution, kg;

ρ – density of the solution, kg/m^3;

for 10 hours of work - 0,19 m^3;

for 20 hours of work - 0,38 m^3.

Similarly, for the solution of whole milk powder we obtain

for 1 hour of work – V = 0,02 m^3/hour;

for 10 hour of work – V = 0,2 m^2;

for 20 hour of work – V = 0,4 m^3/hour.

When calculating by serum, it should be taken into account that its losses in cyclones can be up to 800 mg/m^3, since all particles in its composition are very fine.

Conclusions

To reduce losses of dry dairy products during spray drying except traditional devices - cyclones and filters should be used scrubbers, which in combination with the previously developed technology of achieving the desired concentration of solids in the solution, provide drying of the resulting solution without other intermediate technological operations.

Active centrifugal-impact scrubber, taking into account the circulation mode of operation, can use not limited volume of irrigation liquid supplied to the milk dust by several slotted nozzles.

One should expect a high quality of the coolant cleaning, allowing its heat to be used repeatedly, after condensation of excessive moisture [4].

The considered features of operation of scrubbers for milk dust can be useful in the development of new designs.

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