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THE INVESTIGATION OF THE INFLUENCE OF BASIC PARAMETERS ON ENERGY CONSUMPTION OF HOMOGENIZATION PROCESS

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Key words: energy consumption, homogenization process, homogenization pressure, microstructure, protein of dairy products.

As a result of many years studies it has been proved that apart from temperature, pressure, homogenized medium type, etc. the construction of the homogenizing valve is one of the principal parameters influencing the energy consumption of the homogenization process. Moreover, there have been presented the results of the study on the influence of homogenization pressure on the properties and the microstructure of the protein phase of dairy products. The conclusion that can be drawn is that homogenization at high pressure is not advisable for two reasons: high energy consumption of the process and lowered properties of the products.

INTRODUCTION

The homogenization process consists in a breaking up of the dispersed phase particles e.g. homogenization of the emulsion. Homogenization was used in the food industry for the first time in Canada in 1930. Two years later it was introduced in the USA. European countries employed homogenization on an industrial scale after World War II.

Nowadays homogenization is widely used in many industry branches, e.g. in the chemical industry in the production of lubricants, oils, PCV emulsion, caoutchouc, insecticidal substances etc., in the pharmaceutical and cosmetic industry in the production of vitaminized confection, creams, Cologne waters, shampoos, medicines, etc., in the food industry in the production of drinks, fruit, jams, mayonnaise, baby food, and patricularly at technological lines for the mechanical treatment of such products as milk, cream, ice-cream mixtures, homogenized cheese, cottage cheese, buttermilk and other dairy products.

On the basis of the 1974 international agreement concluded by the CMEA countries Poland specializes in improvements of milk homogenizer construction and the adaptation of such homogenizers for other liquids and mixtures.

HOMOGENIZATION MECHANISM

Depending on the generalized driving force that is used, homogenizers may be divided into:

— ultrasonic homogenizers where ultrasonic energy is the generalized driving force,

— electric homogenizers — the energy of electric pulses constitutes the generalized driving force,

— colloidal mills — the generalized driving force originates from phenomena induced in the liquid by the quickly rotating mixer,

— pressure homogenizers — the generalized driving force comes from phenomena that may be observed in the liquid stream which is flowing through narrow gaps.

In practice, pressure homogenizers are most widely used and that is why they will be the object of further analyses presented in this work.

There are generally two fundamental attempts of explaining the homogenization phenomenon in pressure homogenizers [3].

In one of them it has been assumed that the homogenization process occurs at the place where the medium enters a narrow gap in the homogenizing valve (Fig. 1) and the generalized driving force originates from a sudden speed and pressure change in the section between the valve-seat opening and the valve head,

$v_0 \ll v_1, \qquad p_0 \gg p_1$

This results in the fact that the front layers of the dispersed phase particle separate from the rest and the homogenization process occurs. In accordance with the presented interpretation of phenomena, the length of the gap, the breaking ring, etc. have no essential impact on the process of breaking up since they are situated behind the characteristic section AA (Fig.1) where breaking up occured and they cannot act backwards.

In the other attempt to explain the homogenization mechanism it has been

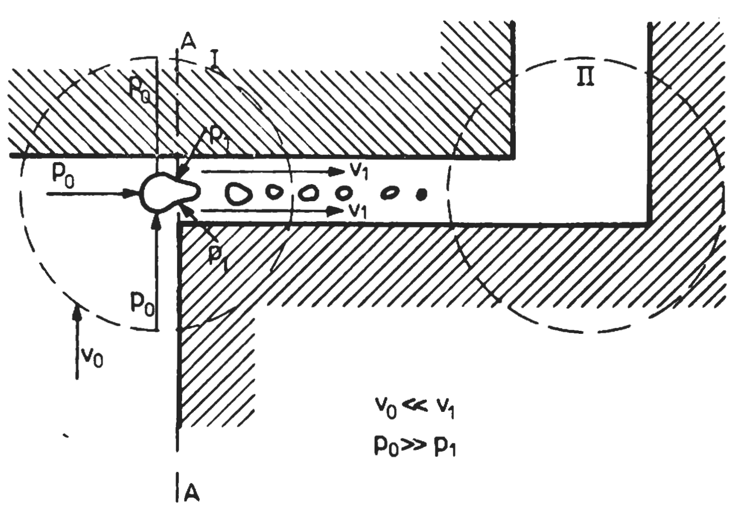

Fig. 1. Homogenizing valve diagram; 1 — valve head, 2 — valve seat, v_0 — speed of the medium in the opening of the homogenizing valve-seat, p_0 — pressure in the opening of valve-seat, v_1 — speed at the entrance of the medium into the gap

assumed that the process mainly takes place during the medium flow through the gap and during its exit, hence the crucial factors influencing the process are: grinding of the dispersed phase particles against the gap walls, implosion of the particles at the time of exit and striking against the breaking up ring.

So far there has been no experimentally proved interpretation of homogenization mechanism and the fundamental theoretical assumption are still at the stage of hypotheses. Therefore there is a great need for experimental studies on the influence of fundamental parametres on the course and energy consumption of the homogenization process.

TWO-STAGE HOMOGENIZATION

The two-stage homogenization consists in running the medium through narrow gaps of homogenization valves two times in succession, which results in the fact that the medium is broken up twice. During the first stage, dispersed phase particles are submitted to breaking up and they make up stable agglomerations called clusters which are still able to appear, e.g. creaming. In the second stage of homogenization process minute particles of the dispersed phase acquire new envelopes from sufrace-active substances, the clusters are subject to division and consequently the distribution of the dispersed phase particles is more regular in the whole emulsion volume. For example, in order to homogenize milk at the second stage the pressure of 3-5MPa is enough, whereas at the first stage the pressure value is expressed in the form of a function of the required breaking up degree of the dispersed phase particles in homogenization process.

The homogenizers now being generally produced are equipped with two separate homogenizing heads, but their exploitation is relatively strenuous and their construction complicated.

THE STUDY OF THE INFLUENCE OF FUNDAMENTAL PARAMETRES ON THE ENERGY CONSUMPTION OF THE HOMOGENIZATION PROCESS

Because of the necessity to use high pressure of 10-15 or even 20 MPa, the homogenization process is very energy-consuming. Besides the capacity of the homogenizers is also very high ranging from 1 to 10, or even, in the close perspective, to 25 m^3/h which is conditioned by usage considerations. The power drawn by the homogenizers ranges within the limits from about 4,5kW at the homogenizer's capacity of 1 m^3/h to about 150-160kW at the homogenizer's capacity of 20 m^3/h.

For the purpose of versatile studies the Department of Food Machines of the Technical University of Lublin has been constructed a research stand (Fig.2) which later has been installed in the Regional Dairy Co-operative in Lublin [1, 2]. The objects of the study were as follows:

— the prototype of a homogenizator CHO—20 of a capacity equal to 2 m^3/h

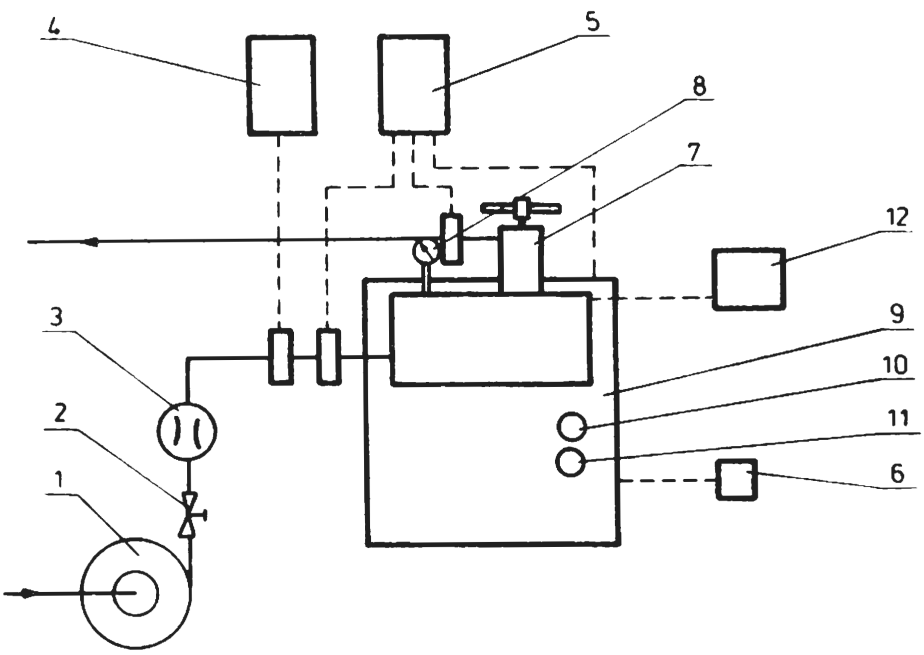

Fig. 2. Diagram of the research stand; 1 — feed pump, 2 — throttle valve, 3 — flow-meter, 4 — pressure recorder at the feeding, 5 — medium temperature recorder at the feeding and outlet plus oil temperature recorder in the pump block, 6 — working time meter, 7 — homogenizing head, 8 — manometer, 9 — the studied homogenizer, 10 — oil pressure manometer in the lubrication system, 11 — ammeter, 12 — homogenization pressure recorder

and a serial homogenizer CHO—10 of a capacity of 1 m^3/h, both produced by the Factory of Food Industry Machines and Apparata "Spomasz" in Bełżyce, and for the sake of comparison, a two-stage homogenizer produced by Gaulin,USA,

— cream containing 13-18% fat,

and market milk containing 2% fat,

Analyses that have been carried out showed that one of the essential parameters influencing the energy consumption of the homogenization process may be the design of the homogenizing valve, therefore the studies comprised four design variants of homogenizing valves: flat valve (Fig.3a), conical valve (Fig.3b), shape A valve (Fig.3c), and shape B valve (Fig.3d). The originality of the construction design of shape A valve consists in the connection of all two-sage homogenization parameters in one valve [4], the medium under high pressure is transmitted to an opening in the seat of the homogenizing valve, then it flows through a narrow gap of first stage homogenization, the gap being formed between the valve-seat and the valve-head, where it is homogenized. Then from a chamber between the first and second stage it flows through a gap meeting the demands of the second stage of homogenization, where it is homogenized through the breaking up of clusters. In the studied valve, the height of the gap at the second stage has been chosen with respect to the condition of pressure reduction $\Delta P_{II} = 3$ MPa during the flow of the medium through the gap. Use has been also made of the phenomenom of the stream striking against the breaking up ring after going out of the first-stage homogenization gap.

Shape 8 valve also meets all the demands of two-stage homogenization. It is worth underlining that the height of the first stage homogenization gap is being reduced when moving away from the valve axis, which allows to obtain

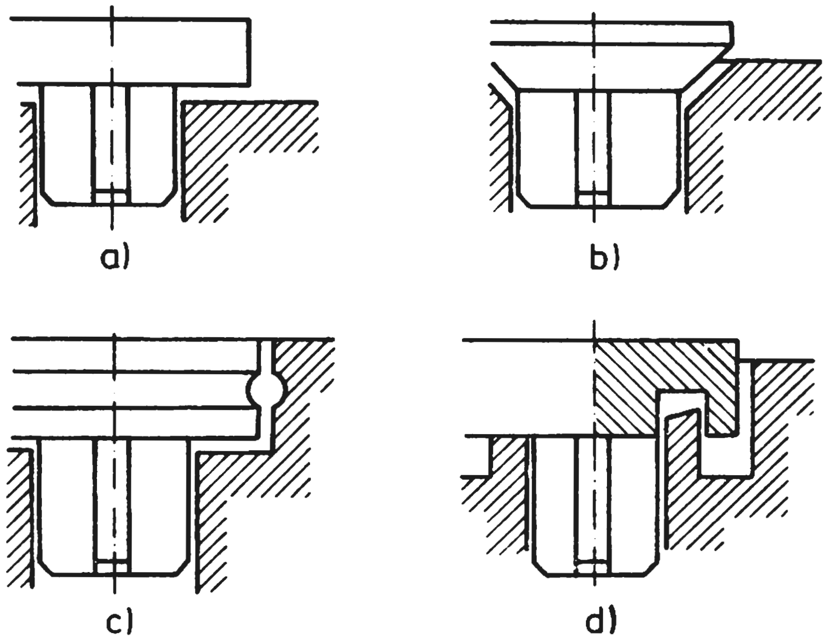

Fig. 3. Diagrams of the studied homogenizing valves; a — flat valve, b — conical valve, c — shape valve A, d — shape valve B

maximum speed values of the medium after leaving the gap and at the same time to take better advantage of the phenomenon of striking of the homogenized medium stream against the breaking up ring. Besides, the phenomenon of emulsion whirling in the chamber between the first and the second homogenization stage has been used [4].

The mean value of the fat globules diameter has been determined by the microscopic method in accordance with PN-75-A-86059.

The results of the study of pressure influence on the homogenization effect with respect to milk and cream have been shown in Fig.5 and Fig.6 respectively. The analysis of the study results shown that the required 85% of homogenization effect with various homogenizing valves may be obtained at the following pressure valves: milk: flat valve — 14,8 MPa, shape A valve — 10 MPa, shape B valve — 9 MPa both after 24 and 600 working hours; cream: flat valve — 10,8 MPa, shape A valve — 10,7 MPa, Gaulin homogenizer — 9,7 MPa, shape B valve — 9 MPa after 24 working hours, and about 10,5 MPa after 600 working

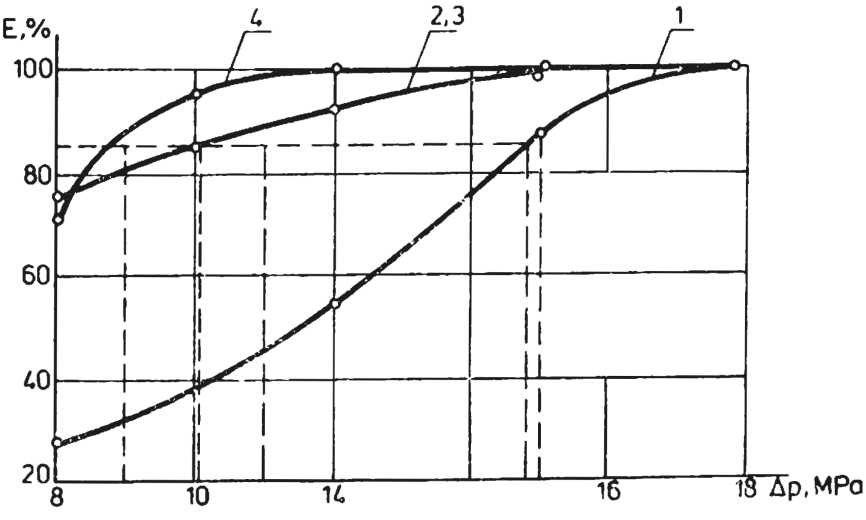

Fig. 4. The dependence of milk homogenization effect on pressure for different homogenizing valves

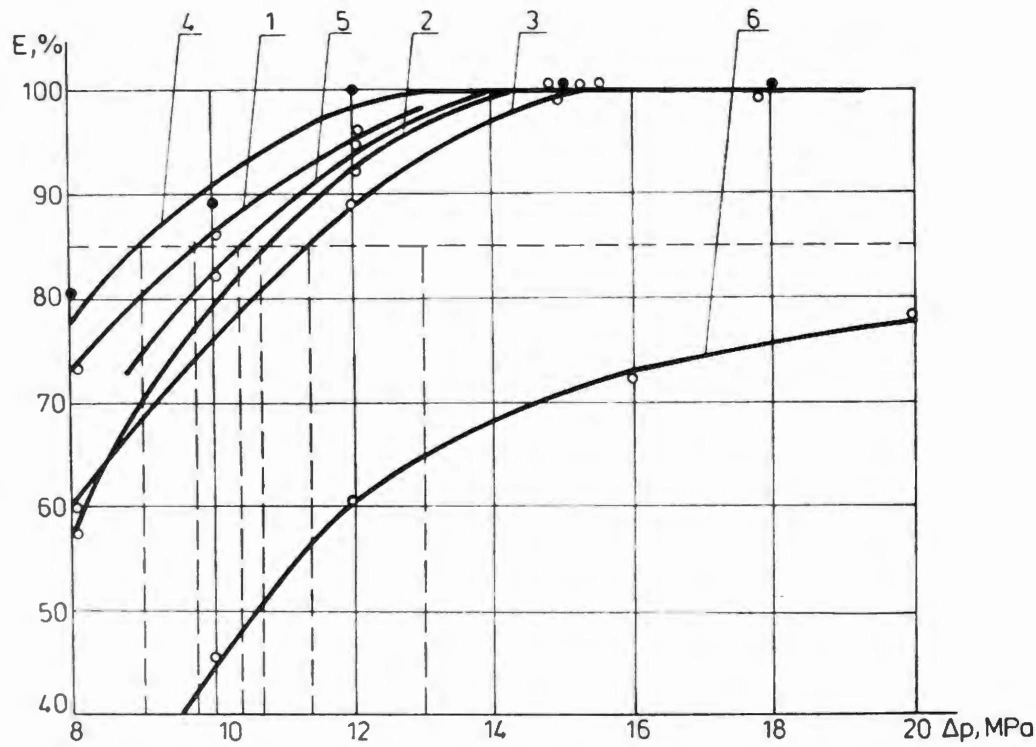

Fig. 5. The dependence of cream homogenization effect on pressure for different homogenizing valves

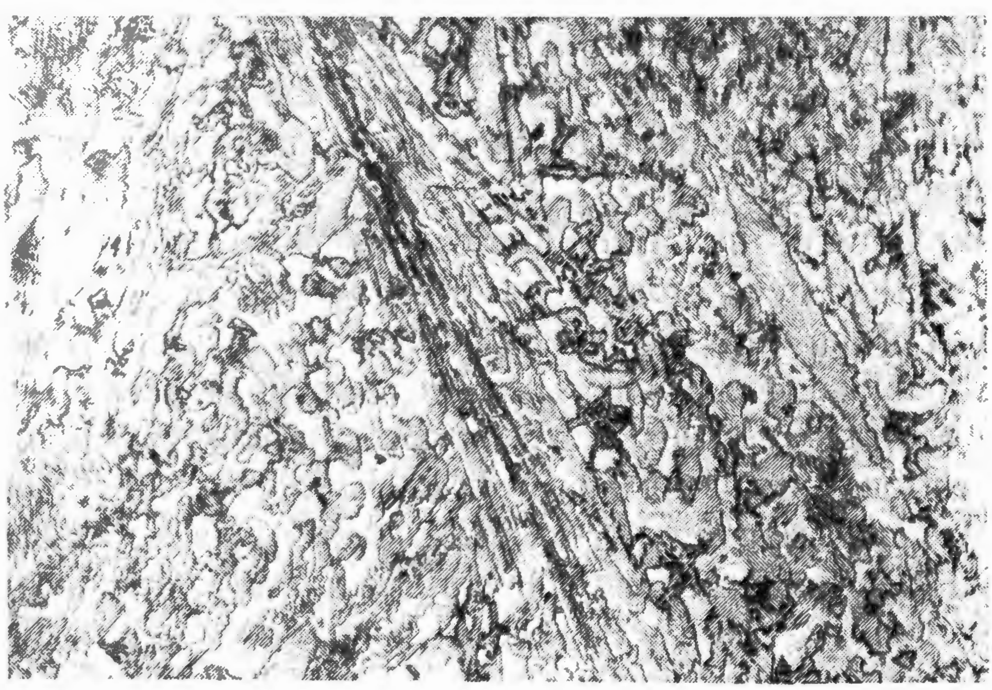

Fig. 6. Microstructure of the material in the near surface zone of the stellite homogenizing valve (300x enlargement). The shape of carbides and other metallic phases is lengthened and directed from the surface to the centre

hours. During the study of CHO-10 homogenizer equipped with a conical homogenizing valve, at pressure 20 MPa only 78% of homogenization effect of cream has been obtained. The technological instructions connected with milk and homogenized cream production obligatory in Poland recommend the following homogenization parameters: for milk: temperature — 45-65°C, homogenization pressure 10-15 MPa and for cream: temperature 45-60°C, pressure 13-16 MPa.

The study results presented here show that with an optimum design solution of the homogenization valve (valve B) it is possible to obtain the required 85% homogenization effect at much lower pressure values in comparison with those recommended by the technological instructions, for milk the pressure difference is from 6 to 2 MPa, for cream from 2,5 to 5,5 MPa. The studies have also proved that within the considered pressure values the homogenizer's efficiency coefficient reaches the value of 75%. Consequently at the reduction of homogenization pressure by 1 MPa the homogenizer of 1 m^3/h capacity draws less energy by about 0,37 kWh. When using in the technological line of 10 m^3/h capacity, homogenizers equipped with type B valves it is possible to reduce, in comparison with parameters stated in the technological instructions, the energy consumption of the line per hour by the following values: in the milk homogenization process by 7,5-22 kWh, and in the cream homogenization process by 9-20 kWh.

The studies that have been carried out show that one of the fundamental parameteres determining the energy consumption of the homogenization process is the type and properties of the emulsion; to obtain the required 85% effect at similar homogenization parameters it was necessary to use in the milk working process a pressure of 9 MPa, and in the cream working process a pressure value of 10,5 MPa.

It may be concluded that there is a constant necessity to continue work on the improvement of homogenization valves design adapted to homogenization of certain products at minimum energy consumption. The other conclusion is that each homogenizer should be equipped with a set of the optimum homogenizing valves of various types at customer's request.

One of the crucial parameters influencing energy consumption of the process is the selection of the construction materials used for homogenizing valves. The valves have been made of alloy steels 3H13 and 4H13 in the annealed state, having a hardness ranging from 158-207 HB. They were working from several hours to a dozen or so, then they needed lapping since on the faying surface cold works and craters of gentle profile and regular shape appeared which proved that the wear of the faying surface was due to erosion and cavitation phenomena as well.

On the basis of the study results and overall analyses it has been established that the most proper material for homogenizing valves are stellites of a hardness ranging between 49-53 HRC. After hundreds of working hours stellite valves did not display any clear traces of wearing and the material structure both in the near-surface zone (Fig.6) and deep inside (Fig.7) was relatively uniform.

The influence of homogenization pressure on the quality of dairy products was also an object of the study. Both milk and cream were organoleptically evaluated after the homogenization process. In comparison to the raw state, cream was more homogeneous after homogenization, it seemed to be a richer and more tasty product. In milk containing 2% of fat, however, no positive changes were observed. At the same time in homogenized milk and cream there appeared a smell and taste of slightly burnt milk which is characteristic for powdered milk. It should be noted that this smell and taste was getting more intensive with the

Fig. 7. The microstructure of the material inside the valve head of the stellite homogenizing valve (300x enlargement). Carbides and other intercrystelline phases of spheroidal shape

increase of homogenization pressure, at pressure values between 8 and 12 MPa this unpleasant smell and taste was practically imperceptible, they appeared at pressure value of 15 MPa and at pressure between 18 and 20 MPa they reached a considerable intensity.

The analysis of observations made has shown that on the one hand the homogenization process prevents creaming which consists in an appearance of a fat layer on the surface, and this can be explained by the breaking up of fat globules. On the other hand, homogenization treatment, particularly when carried out at high pressure ranging from 15 to 18 MPa influence on the separation of whey during storing time which may be explained by changes caused by homogenization process, in the protein phase of both milk and cream.

Studies of homogenization pressure influence on the microstructure of cream protein phase have been carried out using an electron microscope. The results of the study are shown in Fig.8 and 9. The analysis of these results proves that the microstructure of cream protein phase depends considerably on homogenization pressure valves. In non-homogenized cream and in cream homogenized at a pressure value of 10 MPa, protein particles distributed regularly in the whole volume, whereas in cream homogenized at a pressure value of 15 and particularly 20 MPa an increase of protein particles dimensions and protein dispersion change may be observed.

CONCLUSION

Our studies have confirmed the rightness of the thesis that high pressure homogenization is not advisable for two reasons: high energy consumption of the process and less desirable properties of the products.

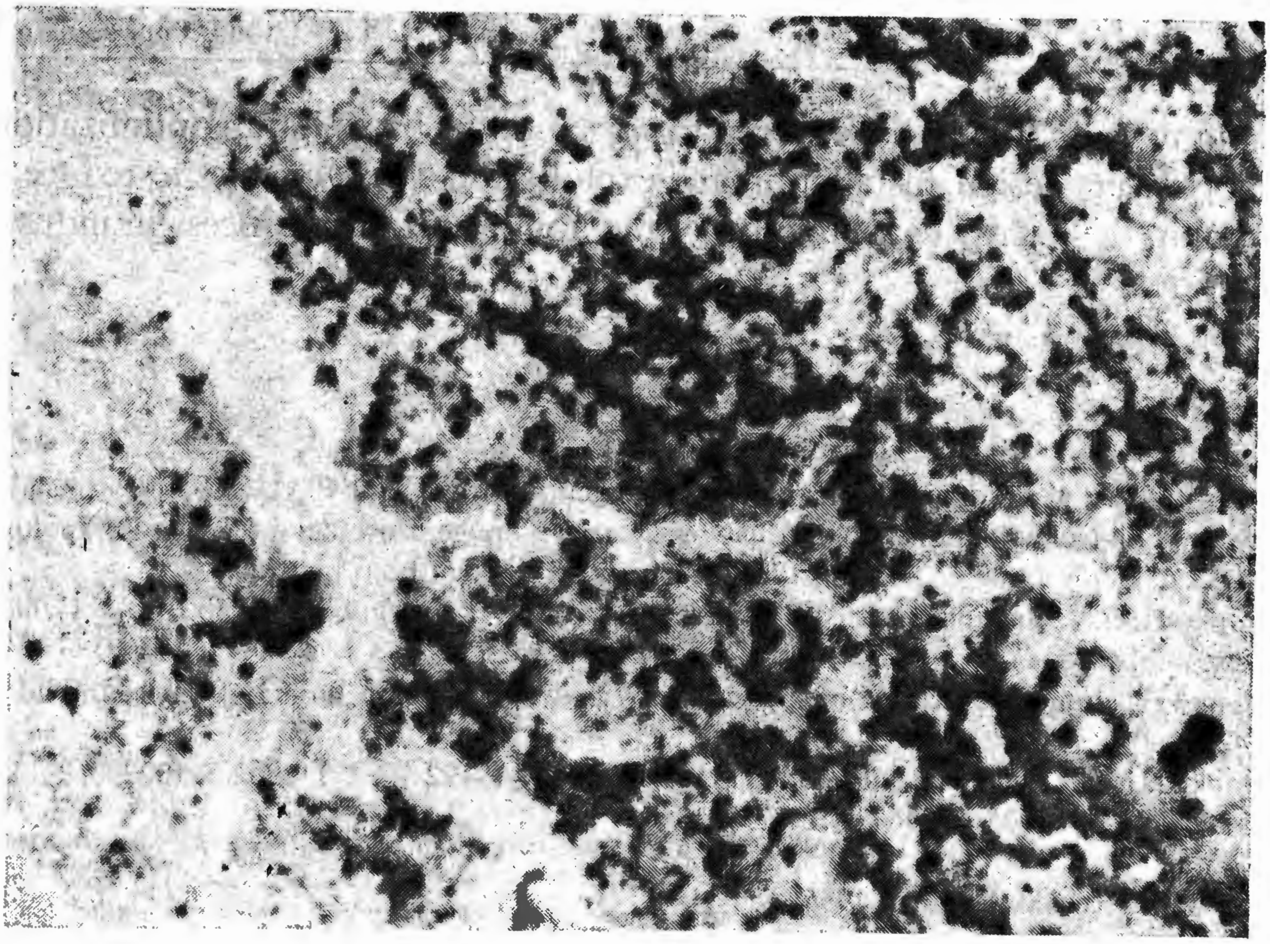

Fig. 8. The microstructure of the protein phase of nonhomogenized cream (9500x magnificatiion)

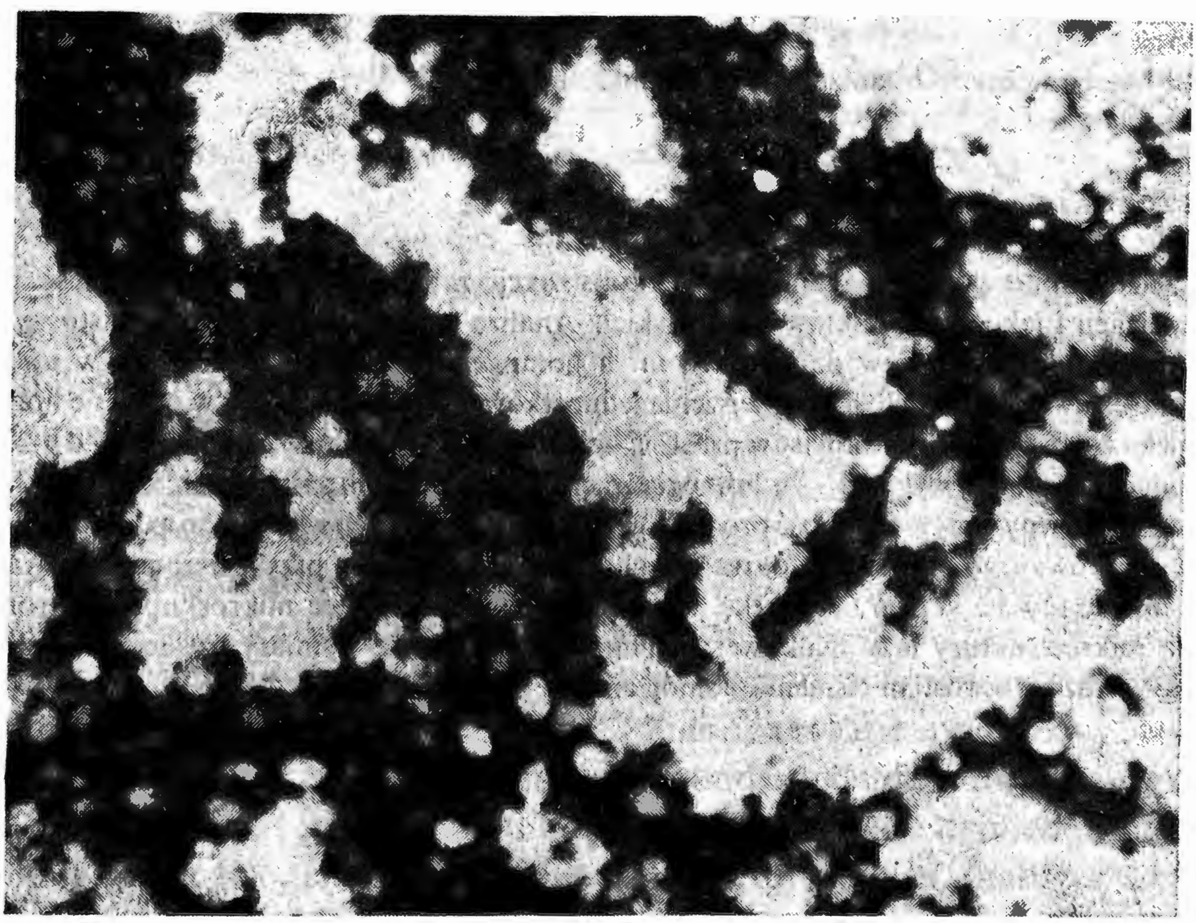

Fig. 9. The microstructure of the protein phase of homogenized cream at the pressure of 20 MPa (9500x magnification)

Many years studies have served to work out the bases for an optimization of homogenizers design, installation and exploitation which enables to reduce to a minimum the energy consumption of the homogenization process in industrial conditions.

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BADANIA WPŁYWU PODSTAWOWYCH PARAMETRÓW NA ENERGOCHŁONNOŚĆ PROCESU HOMOGENIZACJI

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Streszczenie

Przedstawiono wyniki badań wpływu konstrukcji zaworów na energochłonność procesu homogenizacji i jakości produktów mleczarskich. Analiza wyników wykazuje, że zastosowanie w liniach technologicznych o wydajności 10 m^3/h homogenizatorów wyposażonych w optymalne konstrukcje zaworów umożliwia zmniejszenie jednostkowego zużycia energii w procesie homogenizacji mleka o 7,5-22 kWh, natomiast w procesie homogenizacji śmietanki odpowiednio o 9-20 kWh.

Ponadto badania wykazały, że homogenizacja przy wysokich ciśnieniach rzędu 15-18 MPa wywiera negatywny wpływ na jakość produktów homogenizowanych wywołując m.in. zapach i smak mleka proszkowanego oraz skraca okres przechowywania w wyniku przyspieszonego rozwarstwiania się produktów na skrzep i serwatkę. Przeprowadzone za pomocą mikroskopu elektronowego badania mikrostruktury fazy białkowej śmietanki wykazały, że wymiary cząsteczek białkowych wzrastają wraz ze wzrostem ciśnienia homogenizacji.