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INVESTIGATION OF MINCED MEAT FLOW IN PIPELINES

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The rapid growth of the food industry in the USSR requires the construction of production lines. Such an organisation of the technological processes for treating viscous-plastic raw stuff and semi-products in large quantities requires the design and application of interoperational transportation means. The latter has a number of advantages: the sanitary conditions of foodstuff production are improved as touching of the product by the workers is eliminated; painstaking manual operations are mechanized; labour productivity is raised, and the production costs are reduced with a simultaneous improvement of the processed product quality.

Pipelines transport equipped with pumping installations actuating the flow inside, is a simple and reliable type of inter-operational transport providing its rapid dismantling for washing. Such units can be used for inter-operational transportation of minced meat.

Theoretical Premises

Scientific grounds of the physico-mechanical properties of the transported products, rate of flow and character of resistance during their movement through the pipelines, are required for correct calculation and reliable operation of the inter-operational transport pipeline devices.

These problems have not been investigated sufficiently for minced meat. This paper aims, by using the results of experimental investigation, to provide the basis for hydrodynamical calculation of the flow of minced meat in the pipelines, the minced meat being intended for the production of pork Frankfurters.

It is known that the hypothesis formulated by Newton on the value of the force of viscous resistance, approved for a large number of homogenous liquids, is expressed by the formula (1):-

$$\Theta = \pm \eta \frac{du}{dr}$$

where Θ - is the stress of viscous resistance, kg/sq.m.:

η - the constant characteristic for this liquid, the so-called viscosity dynamic coefficient, kg/sec/Sq.m.;

$\frac{du}{dr}$ - velocity gradient, 1/sec.

However, this hypothesis is inapplicable for heterogenous systems, for example, minced meat, which have the ability of forming a structure (space frame obtained due to the cohesion of separate sections of macromolecules) and as if occupy due to their physico-mechanical properties an intermediate position between the viscous and plastic systems approaching one or the other depending on the strength and degree of development of the structural lattice. The structural lattice provides them with some mechanical properties which are determined by the molecular forces of cohesion between the elements of the structure; interaction of the structure elements with the dispersion medium, and the degree of development of the structure in the entire volume. Considering the above, minced meat and especially fine Frankfurter meat can be referred to viscous-plastic systems which at slight deformation are similar to solid or plastic bodies, and in case of strong deformations causing destruction of the structural lattice, flow in the same manner as viscous liquids. Hence, one of the physico-mechanical properties characterizing minced meat will be the maximum shear stress (Θ_o), i.e. the stress at which the shear starts (relative deformation), the other property being the plastic viscosity (η). These two values are in the so-called equation of Shvedov-Bingham (2), which characterises the stationary viscous-plastic flow:

$$\Theta = \Theta_o + \eta \frac{du}{dr}$$

It is most expedient to determine these two characteristics of minced meat under conditions of lengthy movement in a stable stationary flow which corresponds most to their flow in the pipe-lines. The method of determining should be chosen so that the measuring time should be much less than the time of structural changes.

Methodical Premises and Experimental Investigation of Maximum Shear Stress and Viscosity

On analysing data available in literature on the investigation of the physico-mechanical properties of dispersion systems as well as the viscometers used for this purpose, we consider the rotational viscometer designed by Prof. M. P. Volarovich and repeatedly used for most various dispersion systems, to be the best intrument (3).

The following instruments were used for determining the maximum shear stress: the conical layermeter of Volarovich system by the method of Academician P. A. Rebinder (4), shear meter of Simonyan (5) and the RV-8 rotational viscometer of Volarovich system mentioned earlier. The latter is provided with two corrugated rotors having a diameter of 32 and 15 mm while the internal diameter of the cylinder into which the tested minced meat is charged, is 38 mm.

All the research was carried out either at the Moscow Mikoyan Meat-Packing Plant and at the Ostankina Meat Dressing Plant, or at the laboratories of the Moscow Technological Institute of the Meat and Dairy Industry on minced meat provided by the Moscow Mikoyan Meat-Packing Plant. The content of fat, moisture and salt were determined during each investigation.

The above instruments were used for determining the maximum shear stress, and the calculations were carried out in accordance with the formulae (2,4,5).

The experiments and the following calculations made it possible to determine the following: 1) The maximum shear stress of pork stuffing for Frankfurters ranged from 34 to 62 kg/sq.m at a temperature from 14 to 18°C depending on the fat and moisture content of the minced meat. Minced meat is encountered in practice having these extreme and any other mean values of the maximum shear stress, consequently either the mean or the greater values should be considered for calculations. 2) The conical layermeter, the shear-meter of Simonyan and the rotational viscometer having a 15 mm diameter rotor provide well coinciding results. The rotational viscometer furnished with a 32 mm diameter rotor provides data approximately 1.46 times less than the same instrument with a 15 mm diameter rotor. However, we consider the data provided by the viscometer, furnished with a 32 mm diameter rotor, to be more exact for pipeline transportation in small diameter pipes (up to 35 to 40 mm) while the readings of the viscometer with a 15 mm diameter rotor meet better the requirements of large diameter pipes. This case presents an analogy: the 32 mm diameter rotor causes great destruction of the structural lattice, i.e. in the same manner as in case of a small diameter pipe. 3) The maximum shear stress drops with a raise of the temperature and degree of structure destruction. 4) A change in the moisture and fat content influences the physico-mechanical properties and mostly the value of the maximum shear stress; 5) Storage strengthens the structure thereby increasing the maximum shear stress illustrated by the graphs on Figures 1 and 2 where the load P, causing the rotor to revolve, is proportional to the maximum shear stress.

The viscosity was determined on the rotational viscometer with the same rotors of two various diameters; calculation of the values of effective viscosity in experiments with the 32 mm diameter rotor was carried out according to the formula (6):

$$\eta = K \frac{P - P_f}{N}$$

where K - instrument constant
N - rotor speed, r.p.s.
P - load causing rotor operation, in g
P_f - load required for overcoming friction in bearings, in g

Calculations of the values of plastic viscosity was carried out in accordance with formulae (2) with preliminary plotting of integral rheological relations for the 32 mm diameter rotor (Fig.1) and for the 15 mm diameter rotor (Fig.2.).

Experiments and calculations based on these relations made it possible to determine:

1. The plastic viscosity of fresh Frankfurter stuffing is 1.0 kg/sec/sq.m., and after 24 hours ageing in a large amount, it is approximately from 1.15 to 1.20 kg/sec/sq.m. at a temperature from 14 to 18°C which is observed from the graphs on Fig.1 and 2.

2. Slight changes in the fat and moisture content per unit of plastic viscosity have no essential influence.

3. The plastic viscosity is a more stable characteristic than the maximum shear stress.

4. The effective viscosity is the function of the velocity gradient (number of viscometer rotor revolutions per second) which strives to the value of the plastic viscosity when increasing.

5. The values of effective viscosity change when using rotors of various diameters. This is explained by the fact that the shear does not concern the entire width of the ring when applying a 15 mm diameter rotor in case of velocity gradient values obtained practically during experiments. The plastic viscosity values do not depend upon the rotor diameter.

<u>Determination of movement Rate and Pressure Drop</u>

The movement rate of minced meat and the pressure drop due to the friction resistance while moving along the pipeline were studied on an industrial installation designed for interoperational transportation at the Ostankino Meat Dressing Plant and at a specially designed stand at the Moscow Technological Institute of the Meat and Dairy Industry. The stand and the industrial installation are of analogous design and consist of a hopper on the bottom of which is a worm conveyor for developing pressure of the minced meat before the eccentric-vane (slide valve) pump, a pump, the drive to the latter, and an electric motor. Stainless steel pipes having a diameter of 0.0495 m are mounted in the industrial installation. Seamless aluminium pipes having a diameter of 0.0315 m or tinned copper pipes having a diameter of 0.0495 m of various lengths were tested on the stand. Pressure gauges were arranged on the pipelines by means of special devices for determing the pressure drop.

A 1.5 m long experimental opening pipe was used for investigating the movement rate of the minced meat along the pipeline. This pipe was inserted into an exactly ground steel pipe to prevent pressing out of the minced meat between the joints of the two halves.

The pipes assembled in this manner are installed on the stand. Experimental investigation of the movement rate is carried out as follows: the minced meat is pumped through the pipe; when the pump is disengaged, the installation is removed from the stand and carbon powder is poured into the pipe from the face end in an ever layer; when the installation is mounted in its place, the pump is engaged for time sufficient for the product to move to a definite distance; these operations are repeated once or twice after which the pipe arrangement is removed, cooled, disassembled, the upper half of the opening pipe is removed, and the upper part of the revealed minced meat is cut off. Fig. 3. illustrates three photographs of cuts taken during three various experiments.

The experimental results make it possible to determine the following: 1. The velocity of the minced meat flow in the cross section of the pipe varies, being the highest along the pipeline axis, somewhat lower in other points of the flow core, and the lowest in the boundary layers. However, it is possible that the deformation of the velocity epure in the centre occurred only due to the first impulse while in general the flow core moves as a solid body. 2. There is a boundary layer from 2 to 8 mm thick. 3. Insignificant sliding of the product is observed along the walls. 4. The above makes it possible to present the epure of the velocity distribution in the cross section of pipeline as illustrated on Fig. 4.

To determine the pressure losses, the readings of the pressure gauges are recorded in various sections of the pipeline, graphs are plotted (pressure - distance from pipe end according to data recorded by two - three pressure gauges), the weight rate is measured, the general and efficient output of the electric motor is measured simultaneously by means of a set of electric measuring instruments.

Experimental data and some theoretical values are given in Table 1, where the actual rate of the product is compared with the theoretical rate calculated according to the Buckingham equation with or without the third term:-

$$Q = \frac{\pi p R^4}{8 \eta l}\left(1 - \frac{8}{3}\,\frac{1}{R}\,\frac{\Theta_o}{p} + \frac{16}{3}\,\frac{l^4}{R^4}\,\frac{\Theta_o}{p^4}\right)\ \frac{м^3}{сек}$$

or $$Q = \frac{\pi p R^4}{8 \eta l}\left(1 - \frac{8}{3}\,\frac{1}{R}\,\frac{\Theta_o}{p}\right)\ \frac{м^3}{сек}$$

where p - pressure at pipe inlet, kg/sq.m.
η - plastic viscosity, kg sec/sq.m.
Θ_o - maximum shear stress, kg/sq.m.
l - pipe length, m
R - pipe radius, m.

We consider that corrections (7) should not be applied due to the insignificant sliding of the product along the walls of the pipe. The Table provides also the pressure at the pipe inlet, i.e. the drop of pressure at overcoming the resistances calculated by the Buckingham equation without the third term:

$$p = 16 \frac{1}{d} \left(\frac{8Q\eta}{\pi d^3} + \frac{\Theta_o}{3} \right) = \lambda \frac{1}{d} \gamma \frac{W^2}{2g} + \frac{16}{3} \frac{1}{d} \Theta_o$$

where W - mean velocity of product flow, m/sec.
γ - specific weight, kg/cu.m.
d - internal diameter of pipe, m.
λ - hydraulic resistance coefficient: $\lambda = \frac{64}{Re}$

Re - Reynolds criterion: $Re = \frac{Wd\gamma}{\eta g}$

The experiments and the calculations made it possible to determine the following:

1. The pressure changes along the pipe according to the straight-line equation and at the outlet equals zero, consequently, the entire pressure is used to overcome the flow resistance, i.e. the pressure at the pipe inlet equals the pressure drop on this section.
2. The pipelines for minced meat can be calculated according to the Buckingham equation.
3. A considerable amount of the motor power is consumed for creating a pressure of the minced meat by the screw conveyor and for the losses in the pump.
4. Pipes of small diameter (one or two inches) should not be used so as to reduce the pressure drop.
5. Transportation of the minced meat to a distance over 8 - 10 metres is inexpedient, especially in case of small diameter pipes.

Conclusions

The following has been determined by experimental investigations:

1. The physico-mechanical properties of minced meat for fresh pork Frankfurters: the maximum shear stress and the plastic viscosity.

2. The presence of the structure condition in the minced meat flow through the pipes for practically met with mean velocities of movement (up to 0.4 m/sec).

3. The pressure drop in the minced meat flow through the pipes. Investigation has shown the possibility of applying the Buckingham equation for calculating minced meat pipelines.

4. Investigations and practical experience on operating the industrial installation have proved the expediency of using pipelines for interoperational transportation.

5. The conical layermeter can be applied with success due to its simple design for objective qualitative evaluation of the physico-mechanical properties of minced meat under working conditions.

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Table 1.

Nos. Characteristics		Symbol and unit	Experiment No. 1	7	15	19	30	41	46	50
1. Characteristics of pipe	length	l m	2,165	1,61	2,88	1,61	4,145	2,83	2,93	2
	diameter	d mm	31,5	49,5	49,5	49,5	31,5	49,5	49,5	50
2. Characteristics of minced meat	Max. shear stress	kg/sq.m	35	47	59	59	37	42	29	56
	Viscosity	kg sec/sq.m	1,0	1,1	1,15	1,15	1,14	1,0	1,0	1,0
3. Volumous rate	Experimental	Q cu.m/sec.	1,21 $.10^{-4}$	1,59 $.10^{-4}$	1,1 $.10^{-4}$	2,26 $.10^{-4}$	0,182 $.10^{-4}$	6.95 $.10^{-4}$	7,61 $.10^{-4}$	5,15 $.10^{-4}$
	Theoretical by Buckingham equation with three terms	Qp' cu.m/sec.	1,22 $.10^{-4}$	1,69 $.10^{-4}$	1.57 $.10^{-4}$	2,28 $.10^{-4}$	0,231 $.10^{-4}$	6,53 $.10^{-4}$	7,76 $.10^{-4}$	5,4 $.10^{-4}$
	with two terms	Qp" cu.m/sec.	1,195 $.10^{-4}$	1,24 $.10^{-4}$	1,01 $.10^{-4}$	1,87 $.10^{-4}$	0,125 $.10^{-4}$	6,45 $.10^{-4}$	7,73 $.10^{-4}$	5,1 $.10^{-4}$
4. Pressure drop	Experimental	p kg/sq.m.	23500	9800	21140	13000	28400	26500	23100	18000
	Theoretical	p' kg/sq.m.	24100	10090	20800	13100	29600	26200	23500	18700

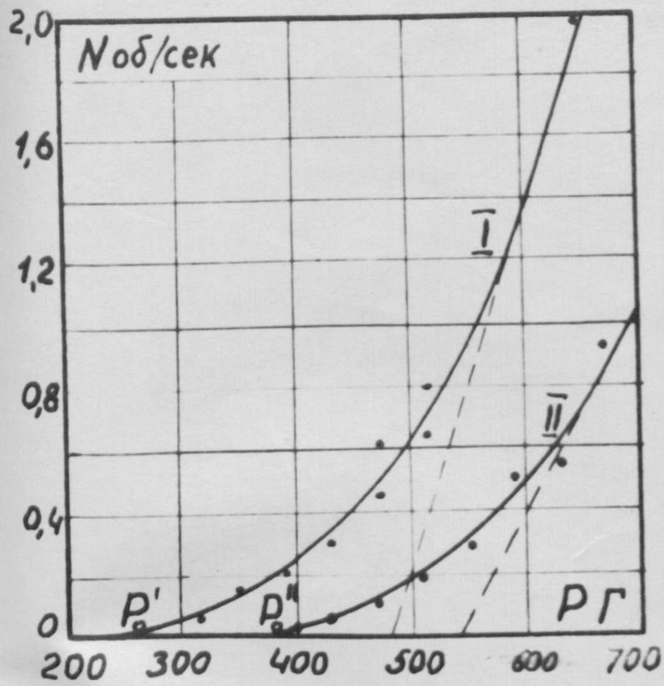


Fig.1. Graph of Frankfurter stuffing flow in rotational viscometer furnished with a 32 mm diameter rotor.

1 - Fresh minced meat.

2 - Minced meat aged for 24 hours.

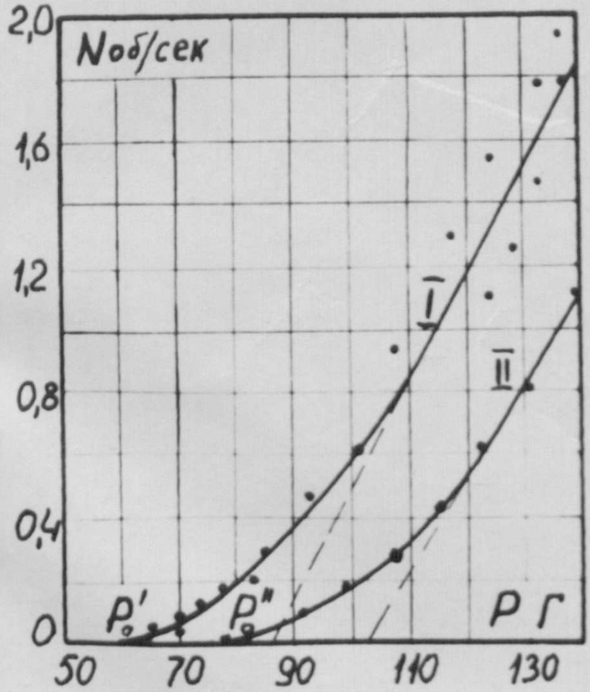


Fig.2. Graph of Frankfurter stuffing flow in rotational viscometer furnished with a 15 mm diameter rotor.

1 - Fresh minced meat,

2 - Minced meat aged for 24 hours.

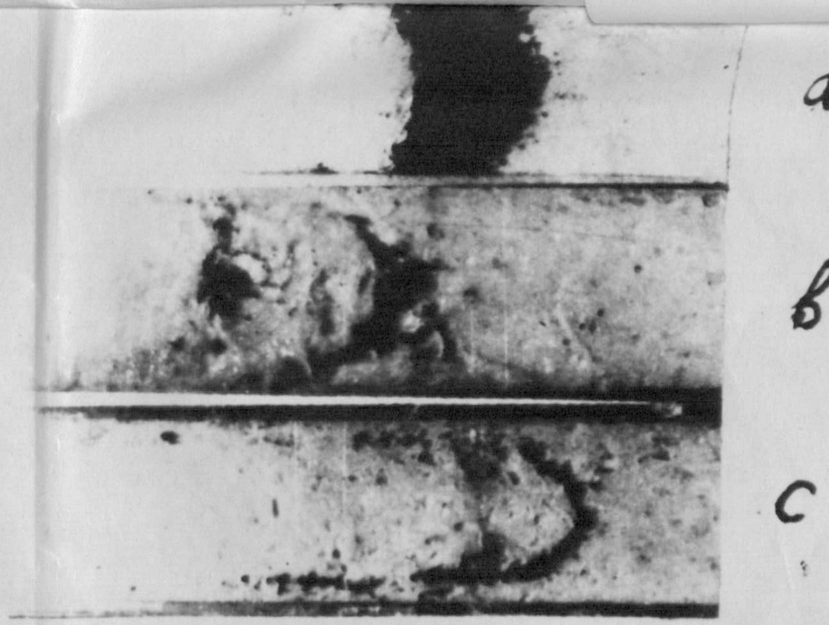
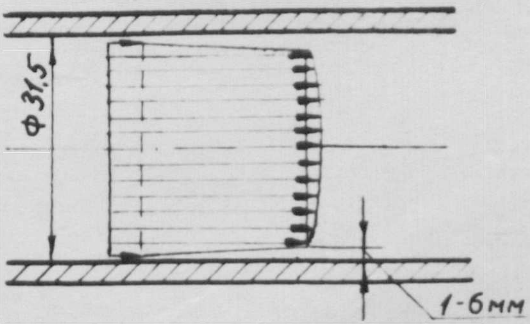


Fig.3. Experimental epures of velocity distribution in the cross section of the pipeline for Frankfurter stuffing. a - epure at 0.1 m from the pipe inlet; b - epure at 0.5 m from the pipe inlet; c - epure at 1.0 m from the pipe inlet.



4. Epure of velocity distribution during the flow of Frankfurter stuffing in the pipeline.