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**Theory of Emulsions:
Physical and Chemical
Makeup of
Sausage Ingredients**

IN COMMINUTED sausage, such as frankfurters and bologna, there is approximately 30 per cent fat; yet, without magnification, inspection of well-made products reveals little evidence that fat is a major component. This is because present-day processing reduces all components to an extremely small particle size. Fat distributed and bound properly affects juiciness, tenderness and flavor desirably. Fat unbound or only partly bound coalesces during processing, forming pockets, or "caps," which are fat collected between the casings and the product.

Present methods of manufacturing comminuted sausage, such as frankfurters and bologna, although largely empirical, generally perform satisfactorily, if not optimally. Good judgment regarding the factors that affect fat binding, such as the total and type of fat in the formula, the type and quality of meat, and the effects of variations in processing procedures, is the principal asset successful sausage makers possess. A challenge to utilize the binding of raw materials to the fullest extent possible arises from the competi-

verts ice, lean and fat meat, and curing and flavoring agents into batter, or meat emulsion. A recent investigation of meat emulsions by Hansen¹ indicates that part of the fat in them exists in the form of dispersed globules enclosed in matrices formed by protein membranes. These protein membranes are formed by the mechanism first described in 1840 by Ascherson, who observed that a coagulation in the form of a membrane occurs inevitably and instantaneously when albumin comes in contact with a liquid fat.²

In the ensuing period, considerable work has been done in studies of protein-stabilized emulsions, and extensive information on emulsions in mayonnaise, salad dressing and homogenized milk has provided a background for our studies of meat emulsions.³ These include work on methods to measure the emulsifying capacity of meat, the characteristics of meat-stabilized emulsions, the efficiency of meat proteins as stabilizers and factors that affect meat proteins as emulsion-stabilizers.^{4,5}

Our preliminary experiments indicated that full em-

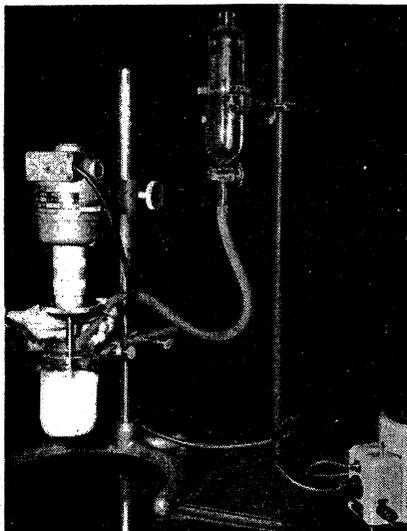


FIGURE 1. Arrangement of apparatus for emulsification.

Theory of Emulsions: Physical and Chemical Makeup of Sausage Ingredients

By **CLIFTON E. SWIFT** and **WILLIAM L. SULZBACHER**
Meat Laboratory
Eastern Utilization Research and Development Division
Agricultural Research Service
U.S. Department of Agriculture
Beltsville, Md.

tive nature of the industry. However, optimal efficiency is seldom obtained, and the strongest efforts to obtain the most from materials are most prone to produce unsatisfactory, poorly-bound products. Obviously, the development of methods for evaluating the fat emulsifying capacity of sausage ingredients and knowledge of the factors involved in the process of fat binding can provide an improved basis for utilizing materials and processing them effectively and efficiently. Efforts in this connection have been underway in our laboratory for several years.

The experimental work presented relates to meat emulsions prepared by a process known as emulsion curing. Emulsion curing, as generally conducted, involved 8 or 10 minutes of comminution which con-

ployment of the capacity of meat to emulsify fat requires thorough disintegration and dispersion of tissue in a relatively dilute system and that collapse of an emulsion can serve as an endpoint in determining the capacity of meat to stabilize an emulsion, provided that sufficiently viscous emulsions are formed.

HOW STUDY WAS CONDUCTED: Then, using the equipment shown in Figure 1, we studied the effects of comminution of meat, dilution of meat slurry, emulsification at different rates of mixing, addition of fat at different rates, effects of temperature, and the stability and rigidity of emulsions. This study was conducted by systematically varying the following basic method: 50 grams of ground meat were placed in a pint jar with 200 ml. of cold 1 M. NaCl solution. (M., or molar, indicates the concentration of the sodium chloride, or common salt, solution.) The mixture was comminuted for two minutes in a Servall Omni-mixer. During the operation, the jar and contents were cooled by immersion in an ice bath. Twelve and five-tenths grams of the resulting slurry were placed in another jar; 37.5 ml. of cold 1 M. NaCl were added, and the mixture was mixed for a few

seconds. Then melted lard or vegetable oil was added from a graduated cylinder and high-speed cutting and mixing were begun. The fat was added at a rate of 0.8 ml. per second from a graduated separatory funnel through Tygon tubing into the stirred mixture.

Emulsion formed, persisted and finally collapsed, the transition being marked by a gradual increase, followed by a sudden decrease, in viscosity. Addition of fat was immediately terminated on observation of the abrupt transition. Occasionally in routine work, it is necessary to change conditions to increase the viscosity so that an endpoint is more pronounced; in other cases, it is necessary to supplement manually the mixing of very rigid emulsions with a piece of tubing so that the mixtures flow into the blade of the Omni-mixer. The volume of fat added is reported as emulsifying capacity, that is, ml. fat emulsified, per 2½ g. of meat.

Table 1 shows the effect of varying the comminution of 50 g. of meat in 200 ml. of 1 M. NaCl. Varying comminution influenced the emulsifying capacity of the sample, a maximum being attained with two minutes of comminution.

Minutes at 13,000 rpm.	Emulsifying capacity/2.5 g. tissue ml.
1	137
2	148
3	133
4	131

150 g. tissue in 200 ml. 1 M. NaCl

Table 2 indicates the effect of diluting the emulsions. The volumes, 22.5, 47.5 and 100.0 ml. 1 M.

Volume 1 M. NaCl	Emulsifying capacity ml.	Emulsion
22.5	82	semi-solid
47.5	127	viscous, mixable
100.0	179	moderately viscous

NaCl in the left-hand column represent different dilutions of 2.5-gram samples of homogenized tissue in which fat was emulsified. Dilution increased emulsifying capacity from 82 to 127 and 179 ml. With the lowest dilution, a semi-solid emulsion was obtained;

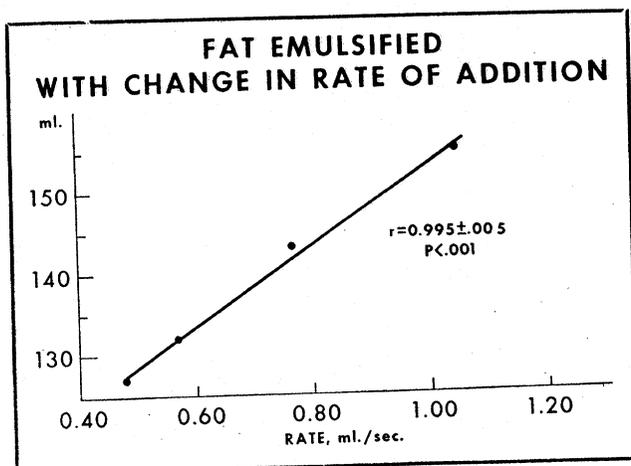


FIGURE 2. Influence of the rate of addition on the amount of fat emulsified.

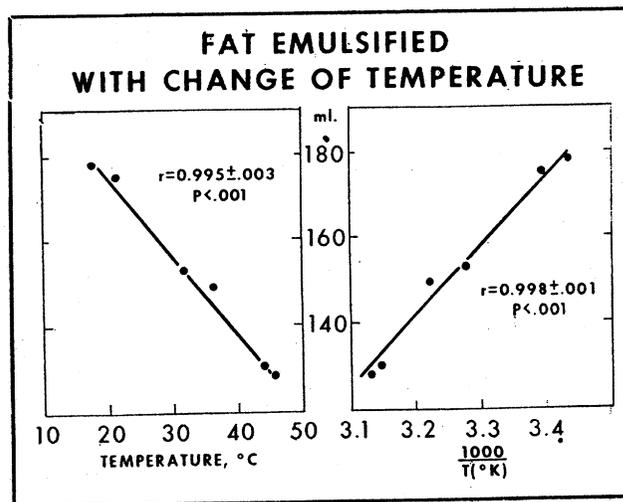


FIGURE 3. Influence of maximum temperature attained on the amount of fat emulsified.

in 47.5 ml. of solvent, the emulsion was viscous but mixable; use of 100 ml. NaCl yielded a moderately viscous emulsion. Thus, increasing the dilution decreased viscosity and increased emulsifying capacity. Mixing and detection of endpoint was most readily accomplished on diluting with 47.5 ml. (check the figures in Table 2).

RATE OF MIXING: The data shown in Table 3 indicate the effect of varying rate of mixing on emulsifying capacity. Decreasing the rate of mixing from 13,000 to 9,200 rpm., and then to 6,500 rpm., increased emulsifying capacity from 142 to 168 and to 185. Each of these three speeds produced visibly different emulsions; a viscous one at high speed, a slightly viscous one at medium speed, and a grainy one at low speed. Use was made of 13,000 rpm. in most of our work since the breaking point of the emulsions produced was most readily detectable.

Rate of mixing rpm.	Emulsifying capacity ml.	Description of emulsion
13,000	142	viscous, mixable
9,200	168	slightly viscous
6,500	185	grainy, suspension

Figure 2 shows the effects of varying the rate of addition of the fat to the emulsifying mixture. Emulsifying capacity was linearly related to the rate of addition.

Figure 3 shows the effect of varying temperature on emulsifying capacity. The amount of fat emulsified was inversely and linearly related to the maximum temperature obtained during emulsification. In view of evidence which will be shown later that the emulsions are stable at 75° C., heating in the range shown should not have caused the emulsions to break; rather, assuming a cause associated directly with the process of emulsification appears warranted. This might be through an increased surface area resulting from an increased dispersion of fat produced at higher temperatures, possibly some denaturation of protein which would then be unable to form protective membranes, or possibly, too, production of an altered, unstable form of membrane.

RIGID MEMBRANES: Figure 4 (page 14) is a photo of the membranes surrounding fat globules in a diluted

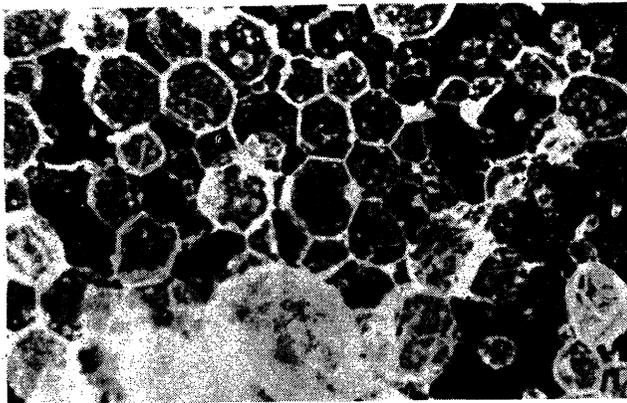


FIGURE 4. Fat globule membranes formed in emulsion that has been prepared from meat.

emulsion. The membranes formed around each fat globule have a non-uniform, polyhedral form. Rigid membranes, such as these, are known to be more or less brittle and have a limited mechanical strength. On the other hand, they can be heated without breakdown. A heated emulsion is shown in Figure 5. This emulsion had been heated 30 minutes at 75° C. without separation of fat.

In other work, studies were made of efficiency of proteins in stabilizing fat emulsions. This involved the preparation of extracts of water-soluble and salt-soluble proteins and then determination of the amounts of fat that dilutions of these proteins would convert into stable emulsions.

Table 4 shows data obtained in a study of the water-soluble proteins and sodium chloride-soluble proteins which indicate the amounts of proteins removed from different concentrations of protein solutions to form insoluble membranes. These experiments involved measuring the protein content of the solution before and after emulsification to determine how much protein had been removed, and measuring the fat emulsifying capacity. From these data, indices of efficiency were calculated, in terms of ml. fat emulsified per mg. of protein.

TABLE 4: PROTEIN EFFICIENCY AS EMULSION STABILIZER				
Extract	Protein		Fat emulsified	
	Present mg.	Used %	Total ml.	ml./mg. Protein
Water	646	69	175	.45
	263	75	95	.48
1 M. NaCl	512	80	250	.61
	102	81	145	1.75

The efficiency observed by the experimenters with water-soluble protein was 0.45, 0.42 or 0.48 ml. fat/mg. protein, while that of the salt-soluble proteins was 0.61 and 1.75 in corresponding units. Concentration of proteins in the water-soluble extract did not affect emulsifying capacity appreciably. Variation of the protein concentration of solutions of salt-soluble proteins produced an appreciable change; when the proteins were diluted, efficiency increased. The removal of proteins from solution in the process of emulsification is depicted in the results of ultracentrifugal studies.

The ultracentrifuge patterns shown in Figure 6 indicate the amounts of water-soluble proteins and salt-soluble proteins present before and after the solutions

had been used in emulsification. Appreciable water-soluble protein and most of the salt-soluble proteins were removed during the emulsification process.

FURTHER INVESTIGATIONS: In work that followed, we further investigated the factors that affect the emulsifying efficiency of these proteins, particularly the effect of varying pH and sodium chloride on both water-soluble and salt-soluble proteins, the effects of different salts on the emulsifying capacity of

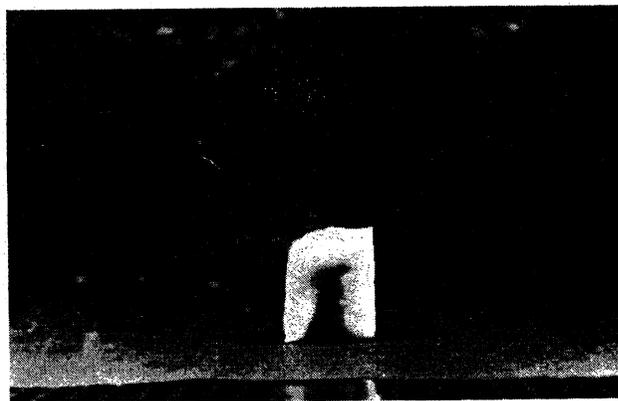


FIGURE 5. Emulsion at 30° C. after heating at 75° C. (167° F.).

water-soluble proteins, the effects of pH and NaCl on the emulsifying capacity of meat proper, and the effect of varying the water content of salted meat on emulsifying capacity.

The effects on the emulsifying capacity of water-soluble proteins of varying NaCl at 0.5, 1.0 and 2.0 M. concentrations at pH values ranging from 4.0 to 7.85 are shown in Figure 7 (page 16). Results indicate that at all pH values the emulsifying capacity of proteins increased in increasing concentrations of NaCl. Vari-

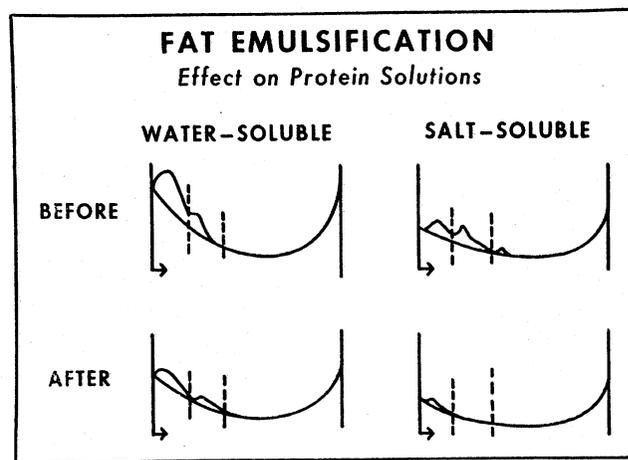


FIGURE 6. Sedimentation of salt-soluble and water-soluble proteins.

ation of pH had a marked effect with a maximum at approximately pH 5.2 and sharply reduced activity in either more basic or acidic solutions. It is notable that water-soluble proteins exert their maximum activity at a lower pH than is normally obtained in meat and respond favorably to higher concentrations of NaCl than those desired for flavoring purposes.

Also, in connection with the effect of NaCl in ac-

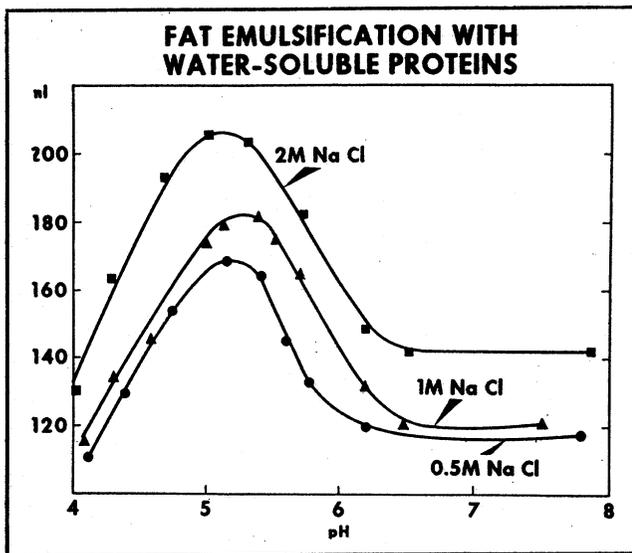


FIGURE 7. Influence of pH and concentration of NaCl on the amount of fat which is emulsified by water-soluble proteins.

tivating the emulsifying capacity of water-soluble proteins, we determined the emulsifying capacity of water-soluble proteins as affected by potassium thiocyanate, iodide, nitrate, bromide, chloride and sulfate. The data shown in Table 5 indicate the emulsifying capacity of water-soluble proteins decreased in the order of the salts named. This is the order of the Hofmeister series and appears to be the same effect that affects the spreading of proteins as shown in the previous studies of others.⁶ In interpreting this earlier work, the effect was attributed to the production of different degrees of unfolding of proteins. On the same basis, the results presented here suggest that NaCl increases the emulsifying capacity of water-soluble proteins by unfolding their structure, thus extending the ability of these proteins to enclose fat globules in membranes.

TABLE 5: THE EFFECTS OF DIFFERENT SALTS ON THE EMULSIFYING CAPACITY OF WATER-SOLUBLE PROTEINS^a

Salt series	KSCN	KI	KNO ₃	KBr	KCl	K ₂ SO ₄
Fat emulsified	165	146	134	130	119	117

^a4.80 mg. protein/50 ml., pH values before and after addition of salts were 5.32 and 5.12, respectively.

The results shown in Figure 8 were obtained on investigating the effects of varying pH and content of NaCl on the emulsifying capacity of salt-soluble proteins. The emulsifying capacity of salt-soluble proteins was not significantly different in 0.3, 0.6 and 1.2 M. solutions of NaCl, except where pH values approached pH 5.4, approximately the accepted isoelectric point of the salt-soluble proteins. In this pH range, increasing NaCl produced a significant increase in the emulsifying capacity, an effect that can simply be explained as the effect of salt in lowering the pH at which proteins attain minimum solubility.

In Figure 9, the results obtained with meat are shown on comminuting and dispersing samples in 0.3, 0.6 and 1.0 M. NaCl and then determining their emulsifying capacity at pH values adjusted in a range extending from 4.6 to 8.1. The results apparently reflect differences in the ability of the solutions both to extract proteins and to disperse and modify their

characteristics. Variation of both pH and content of NaCl strongly influenced emulsifying capacity. An increased concentration of NaCl increased the emulsifying capacity at pH values in the range 5.4 to 6.0, but had no significant effect otherwise. In general, emulsifying capacity increased markedly with increase in pH.

SIGNIFICANCE: The significance of these results can be understood by comparing these data with those previously shown that were obtained with water-soluble and salt-soluble proteins. The curves lack maxima at pH 5.2, at which pH the water-soluble proteins exhibited a maximum, but have a tendency to plateau at pH 5.0 where emulsifying capacity is approximately 100. These results indicate that the apparent contribution of water-soluble proteins throughout the entire range of pH values in all three concentrations was approximately 100. Also, a comparison of the curve shown here with Figure 8 indicates that the emulsifying capacity of meat and the salt-soluble proteins of meat are generally similar in the region pH 5-6 where increasing NaCl content apparently minimizes the effect of lowering pH and favorably affects emulsifying capacity. Further comparison of these results with those previously shown indicates that the

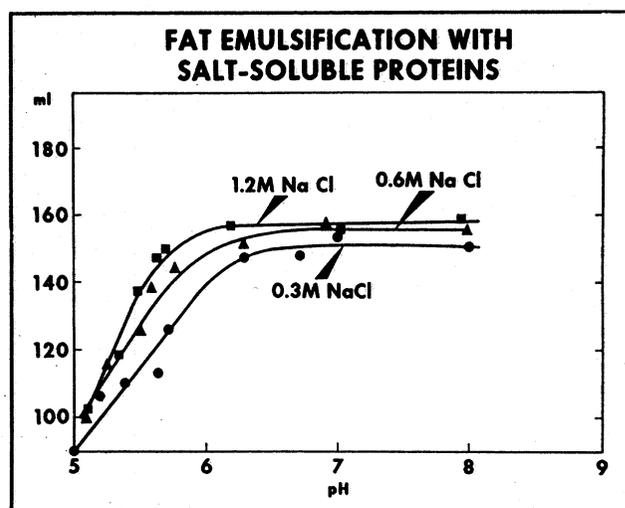


FIGURE 8. Influence of pH and concentration of NaCl on the amount of fat emulsified by salt-soluble proteins.

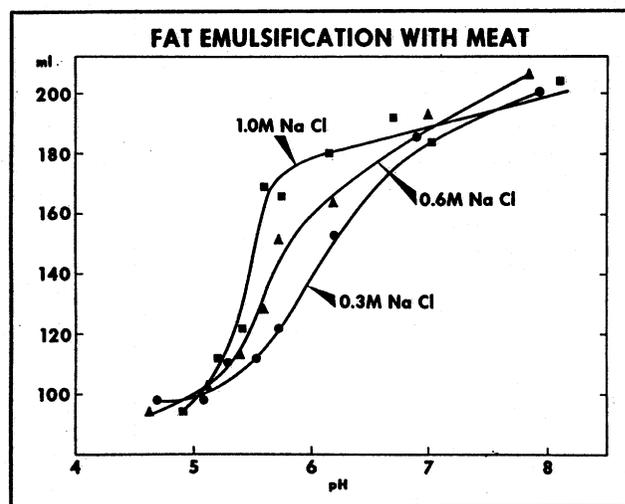


FIGURE 9. Influence of pH and concentration of NaCl on the amount of fat emulsified by meat.

emulsifying capacity of meat, but not of the salt-soluble proteins, increased at pH values ranging from 7 to 8. The evidence suggests that the effect of increasing pH was not exerted by modifying the action of dispersed proteins. Rather, a logical explanation is that increasing alkalinity increased extraction of the proteins.

To be fully effective, the proteins should be extracted and dispersed. In Table 6, data are given showing the results of a study of the effect on the emulsifying capacity of meat of varying ratios of water to meat added to cured meat before its use in emul-

TABLE 6: THE EFFECT ON THE EMULSIFYING CAPACITY OF MEAT OF VARYING CONTENT OF ADDED WATER

Ratio brine to meat ^a	Emulsifying capacity, ml. ^b			
	A	B	C	D
4.0	136	153	196	150
1.0	139	149	199	153
0.5	124	129	189	—
0.25	122	137	170	131
0.125	118	—	—	—
0.0	—	106	163	126

^aVolume of 0.6 M. NaCl indicated added to ground meat containing 5.85 per cent added NaCl.

^bFour samples, capacity determined on weights equivalent to 2.5 g. meat in meat-brine mixture adjusted to 0.28 M. NaCl and 50 ml. volume.

sification. In these experiments, after this "curing," the operation of emulsification was conducted at low salt concentrations so that proteins not dissolved, or fully hydrated, during the "curing" would not become dissolved; at the same time, conditions which would precipitate dissolved protein were avoided. This was obviously done in an effort to differentiate the effect of different levels of water in curing while eliminating extraction of proteins in the brine used in the emulsification process. The results show that emulsifying capacity was reduced 15 to 30 per cent by a drastic reduction of water content. The greater part of the meat proteins was conditioned by the treatment with NaCl so that they were dispersible in weak

brine and acting during the process of emulsification.

Obviously, the potential emulsifying capacity in meats is not obtainable when the water content of meat emulsions is restricted. On the other hand, reduction of added water apparently affects the interaction of NaCl with the proteins to only a moderate extent. The pH of ordinary meat is approximately 5.4 to 6.0, and the usual ionic strength of sausage emulsions is approximately 0.6, or approximately the equivalent of 0.6 M. NaCl. Under these conditions, the effectiveness of emulsification is most sensitive to change in pH and content of NaCl. The results indicate that increasing either or both pH and NaCl should improve the emulsification ordinarily obtained in preparing emulsion-based meat products.

Some may be interested in the recent work on this project. We found that one industrial firm using our method for determining emulsifying capacity has used this method in computing sausage formulations with the IBM computer. In general, success was obtained insofar as emulsifying pork fat was concerned, but emulsifying beef fat apparently constitutes a somewhat different problem. To handle this problem, we are now studying the emulsification of fats containing relatively large proportions of solids.

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