A HEAT SHOCK PROCESS FOR THE PUFFING OF DRIED FOOD GELS

Original Copy.

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TABLE OF CONTENTS

Results

Page No.

SUMMARY

A number of traditional Asian foods which consist primarily of a dried starch gel containing various flavourings, puff when fried in hot fat. A study of this phenomenon has been undertaken and a theory put forward explaining the mechanism.

Factors affecting the puffing of starch gels such as moisture content, frying temperature, gel strength and method of heating were studied in detail. The puffing of a gelatine gel was also studied and it was shown that the puffing characteristics of each gel were basically similar.

Two major factors are considered to dictate the puffing characteristics of a gel. They are -

(a) Internal steam pressure, and

(b) Thermoplasticity of the gel.

These two factors are affected by such variables as moisture content, gel strength, frying temperature and rate of heating.

The postulate that "any polymolecular food gel will puff when fried under optimum conditions" is substantiated by experimental evidence, with the exception of non-reversible gels. These gels are formed by high energy primary chemical bonding and do not puff when fried. Sugar and fat were found to drastically modify puffing characteristics when added to a gel.

Three polysaccharide and three protein gels were satisfactorily puffed. All these gels were reversible and included wheat gluten, milk

protein, gelatine, starch, pectin and agar.

Some application of this process to the preparation of foods was made. It was applied to a number of raw materials and satisfactory puffing was obtained in such diverse materials as cheese, carrots and tapioca.

Both the market and product potential of products produced by this process are promising. It is suggested that the process may be suitable for the preparation of

(a) "Instant" foods,
(b) Snack foods,
(c) Powdered flavourings.

Although still relatively unknown, this process could become an established food processing operation with a much wider field of application than at the present time.

INTRODUCTION

There has been increasing interest in recent years in the use of dehydration as a technique for the preservation of foodstuffs. An extract of production figures compiled by Van Arsdel (1963) is given in Table (1). The production per year, in tons, of six dehydrated foods in the United States of America is shown and indicates this trend which is particularly marked in the production of dried potatoes (mainly instant mashed potatoes), and non-fat milk solids.

TABLE (1) Dehydrated Foods in 1000 tons Produced in the United States

Year	Egg Solids	Whole Milk	Non-fat Milk	Potatoes	Other Vegetables	Dried Fruits
1941	23	23	183	1	6	491
1945	53	109	321	38	27	539
1950	47	62	441	20	10	359
1955	12	55	702	10	17	409
1960	23	49	909	80	34	-

This trend in the dehydration of foods is mainly due to the following three factors:-

(a) An increased knowledge of mechanisms of storage deterioration and methods of preventing these reactions.

(b) Development of more refined processes which subject the raw material to less vigorous, and thus more gentle drying conditions.

(c) Development of the so-called convenience or "instant" dehydrated food products.

Modification of texture of dried foods has played an important part in this development. Such a process as Steam Gum Puffing (Food Engineering Staff Report, 1963) modified texture and was applied to partly dehydrated vegetables to facilitate further drying. Development of a method for pricking green peas has made it possible to dehydrate and rehydrate faster than was previously possible. The use of low drying temperatures, now possible, and rapid rehydration due to easy access of water to the cotyledons through the pricked testa ensures a high quality product. Accelerated Freeze Dried foods owe part of their high quality to a very porous structure. This porous structure allows very rapid ingress of water into internal parts during reconstitution, thus overcoming the long soaking times normally required for dried foods.

Some use has been made of frying as a dehydration process in recent years. Vere-Jones (1957) developed a process in which meat was dried in fat under vacuum at low temperatures. Sathireswasti and Salunkhe (1958) reported on the dehydration of peas by deep fat frying with a view to the development of an Asian market.

It was thus noted with interest that many Asian peoples fry a variety of traditional foods which when heated in this way expand to many times their original volume. The most well-known to Europeans of these prepared foods is "Kroepoek oedang", more commonly known as Shrimp Slices.

A number of such foods in their fried and unfried state are shown

Fig. (1) Twelve different traditional puffed foods.

in Fig. (1). Eleven are of Indian origin and one, Kroepoek oedang, (top row, third from left) is of Malaysian origin. Except in two cases both the puffed and unpuffed form is shown. All of these foods, with one exception, are prepared from a starch gel. The exception is the flower seed (bottom row, third from left) which is known as "Phul Maekhane" and is shown puffed. The other foods are preparations of starch (such as rice or lentils), spices, flavourings, and other ingredients such as shredded vegetables. The preparations are heated, sometimes by steaming, to gelatinize the starch and are then dried. Sun drying is traditionally used.

These starch gels may be stored for many months without difficulty and as such provide a ready means of preserving food gathered during harvest seasons for use in times of need.

The frying of these starch gels may be considered as either -

(a) a further dehydration step in which the last few percent of moisture is removed, or

(b) a texture modification process to convert a hard inedible starch gel into a friable and palatable one.

As traditionally used, this process is solely one of texture modification to convert the stored material into an edible form.

Without any known exception this puffing phenomenon as traditionally used depends completely on the formation of a starch gel. It was, however, believed that this phenomenon relied not on the presence of starch but on the formation of a gel and as such should be applicable to all food gels.

If this postulate was true it should be possible to develop a porous structure by frying dried foods which had been gelled before drying. Such a technique could be used for improving rehydration characteristics regarded as so important in modern dehydrated foods.

This Thesis reports on a study of the puffing of starch gels. The possible application of this process to non-starch gels, and to utilisation of the process for applications other than for the development of a friable and palatable texture was also examined.

The Thesis is divided up into three sections. The first section deals with Analytical Methods and Experimental Techniques.

In the second section Fundamental Studies are undertaken and the results discussed.

In the third section entitled Technological Studies, some application of the method was made to particular product development, and the possible scope of the process is discussed.

ANALYTICAL METHODS

and

EXPERIMENTAL TECHNIQUES

I. MOISTURE DETERMINATION.

Aluminium moisture dishes were heated to 221°F. (105°C.) and cooled in a silica gel desiccator before weighing. Approximately 2 gm. samples of gel were weighed into the dishes when cool. Samples were dried at 221°F. (105°C.) for 24 hours, cooled in a desiccator and weighed. The determination was made in duplicate and the moisture content expressed on a dry weight basis (d.w.b.).

This method of expression was chosen because moisture content in such an expression makes it possible to relate puffing and other measurements directly to grams of dry starch or other gelling agent. Moisture is then not a variable in the results.

II. FAT ESTIMATION.

Fat was determined in 2 gm. samples by solvent extraction using the Soxlet method. Standard procedure, as prescribed by the A.O.A.C., was followed. Fat content was expressed on a fat free, moisture free basis.

III. PREPARATION OF A STANDARD GEL.

(a) Starch Gel.

A bulk supply of maize corn starch was purchased to ensure consistent raw material. Moisture content of the starch was 15.35% (d.w.b.).

It was necessary to develop a method for preparing a dried gel that could be expected to provide consistent material for the study of other variables affecting puffing. Gels made with different starch to water ratios were prepared and a gel made in the proportion of 10 gm. of starch to 100 ml. water (designated 10% gel) was finally chosen as a standard. This paste was sufficiently thick after preparation to permit pouring onto a stainless steel table and smoothing into a sheet 3/16 in. thick and 5 in. wide, using a metal template. Less viscous pastes lost their form while thicker pastes tended to be so viscous as to entrap air stirred in during mixing. The 10% gel was sufficiently fluid to allow this air to escape.

The effect of increasing the gel strength on puffing was studied and for this experiment a 15% gel was prepared. To obtain a dried gel of the same thickness a different template was used to allow for the increased concentration of starch. A 3/16 in. template gives a particular thickness to 10% dried gel. The same thickness is obtained by using a 9/64 in. template for 15% gels. 9/64 in. x 5 in. sheets were prepared and dried producing a product identical in all respects to the standard gel except that the concentration of starch in the paste was higher.

It was recognised at this stage that gel strength, or the number of bonds in the gel network per unit volume, may play a part in modification of puffing characteristics of a gel. It was also recognised that the number of bonds, per unit volume of starch gel, present immediately after setting increased with time up to a maximum. To avoid variations in strength, gels were allowed to firm for one hour. After firming, the 5 in. strips were cut into 1 ft. lengths and using two metal slides lubricated with copious quantities of water, were transferred onto punched metal trays. Each sheet was then sliced into bricks 1 in. x 2 in. x 3/16 in. and each tray placed immediately in a thermostatically controlled, agitated air cabinet where the gels were dried at 110°F. for 20 hours.

Little was known of possible modifications to the structure of dried gels on storage for long periods. Modifications to the bonds or the number of them could take place; so dried gels were used immediately on preparation, or stored for short periods only in airtight glass jars.

The method of preparation and dehydration of the Standard Starch Gel was then laid down as follows:-

1. Bring 80 ml. water to the boil.
2. Remove from heat and add a slurry of 10 gm. starch and 20 ml. cold water.
3. Bring to the boil while stirring, to complete

gelatinization of the starch.

4. Pour onto a stainless steel table top and smooth into a ribbon 5 in x $^3/16$ in. using a metal template suitably cut.
5. Allow to cool and set for 1 hour.
6. Place on punched metal trays.
7. Slice gel into blocks 2 in. x 1 in. x $^3/16$ in.
8. Dry at 110°F. for 20 hours.

(b) Gelatine Gel.

When study of the variables of moisture content and temperature of frying on puffing of the Standard Starch Gel had been completed it was thought desirable to show that these factors affected other gels in the same way. It was known at this stage that dried gelatine puffed and it was chosen to find out how composition affected a gel's puffing behaviour.

The preparation of a gelatine gel of the same concentration and thickness as the Standard Starch Gel was made difficult by the fact that it becomes liquid in its wet state at 77 - 86°F. However, the following procedure was developed and found satisfactory:-

1. Wet 10 gm. of dry powdered gelatine with a few drops of 95% ethyl alcohol and mix with 100 ml. of cold water.
2. Warm until all the gelatine has dissolved.
3. Prepare a "dam" on a flat table with a ribbon of

plasticine 3/16 in. high.

4. Line the bottom of dam with sheet aluminium foil.

5. Pour into this dam the warm gelatine solution until level with the top.

6. Allow to set firm.

7. Remove by lifting the foil and chill in a refrigerator. This firms up the gel and makes it easier to handle.

8. Remove and invert on a punched metal tray.

9. Peel off the foil.

10. Dry at 75 - 80°F. until quite firm then increase temperature to 110°F.

11. Cut into suitable pieces using a pair of scissors while still flexible.

12. Store in airtight jars until required.

Powdered gelatine (moisture content 21.2% d.w.b.) of good quality was used for preparing these gels.

IV. THE STANDARDISATION OF MOISTURE CONTENT OF A DRIED STARCH GEL.

Moisture content was thought to be a factor affecting puffing characteristics of gels. In order to study this factor it was necessary to devise means of obtaining samples varying in moisture content. Two methods of attaining moisture equilibrium were used.

(a) The Use of Relative Humidity Controlled Atmospheres.

It was known that most food substances exhibit an adsorption isotherm. The adsorption isotherm is the relationship between moisture content of a hygroscopic material and its vapour pressure, or relative humidity. Thus, by controlling relative humidity of the air surrounding dried gels, it was evident that moisture content could be controlled. An even distribution of moisture throughout the gel was ensured by maintaining the relative humidity constant until equilibrium had been reached. Relative humidity was controlled and maintained by using saturated salt solutions.

Glass jars were used for humidity chambers and supports were made to support gel samples above the saturated solutions. The lids were made water and air tight with rubber gaskets, and the whole container submerged in a water bath maintained at 30°C. with a "Tecam" agitating, thermostatically controlled, heating unit. Relative humidities of various saturated salts were obtained from the published measurements of Adams & Merz (1929), Carr & Harris (1949), Richardson & Mathus (1955), Spencer (1926) and Wink & Sears (1950).

An experiment was designed to determine the minimum time required to reach an equilibrium moisture content. Four humidities were used to represent the working range. They were -

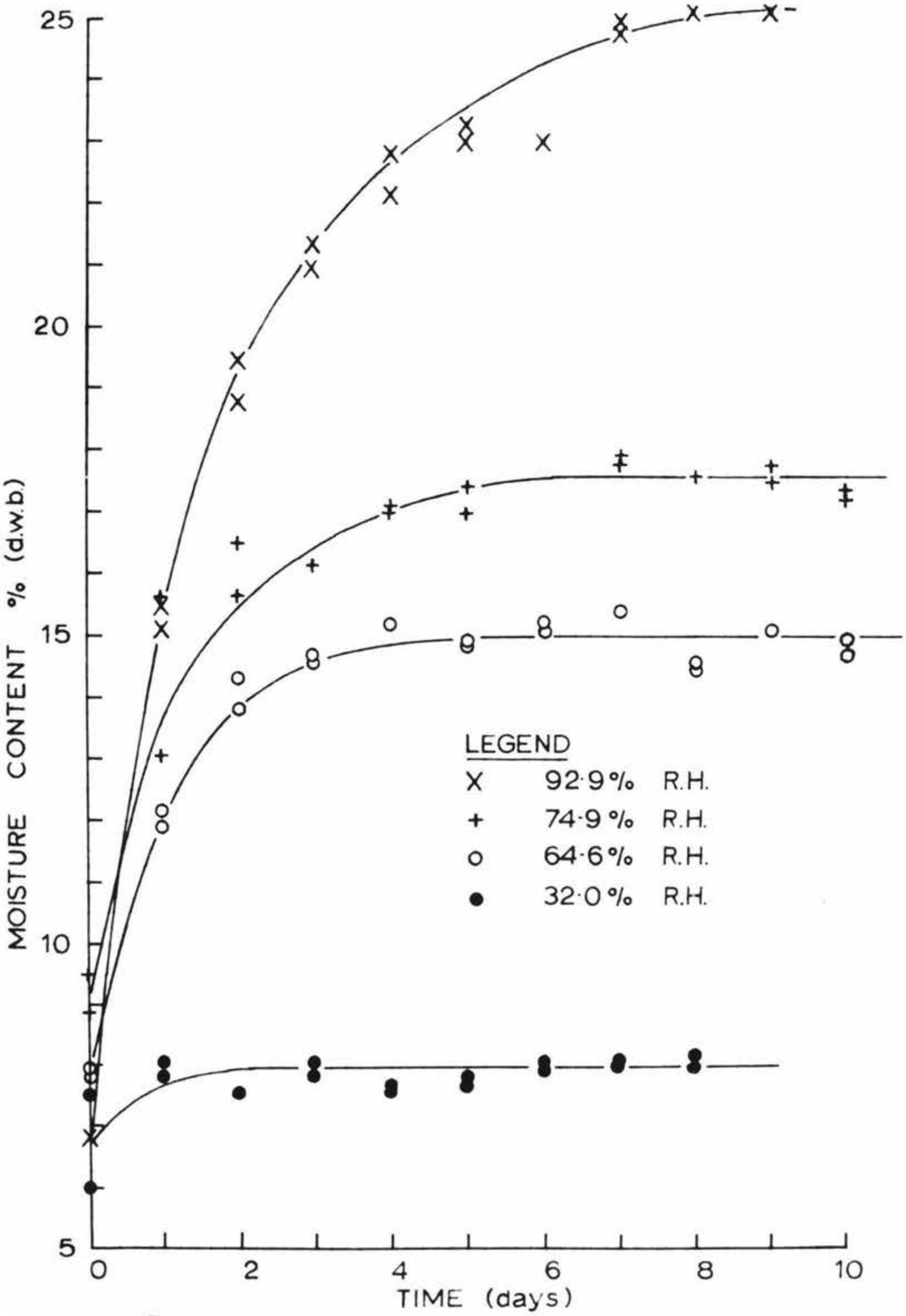


FIG. 2 Graph showing rate of uptake of moisture by 10% STARCH gel at four humidities.

Saturated Solution	Relative Humidity
$CaCl_2.2H_2O$	32.0%
Na_2CrO_4	64.6%
NaCl	74.9%
$NH_4H_2PO_4$	92.9%

A sample was removed every day for 11 days and the moisture content determined. The results of this preliminary experiment on the moisture adsorption of 10% starch gel showed that equilibrium over $CaCl_2.2H_2O$ was established in about 2 days. However, moisture content of the gel over $NH_4H_2PO_4$ (92.9% R.H.) reached equilibrium only after 9 days. Results, shown graphically in Fig. (2), are tabulated in Table (2).

As a result of this experiment all gels equilibrated by this method were held for 10 days in the desired Relative Humidity before puffing.

TABLE (2) Uptake of Moisture by 10% Standard Starch Gel at Four Different Relative Humidities

Saturated Salt Relative Humidity Moisture Content	$NH_4H_2PO_4$ 92.9% %(d.w.b.)	NaCl 74.9% %(d.w.b.)	Na_2CrO_4 64.6% %(d.w.b.)	$CaCl_2.2H_2O$ 32.0% %(d.w.b.)
Time (Days)				
0	6.8, 6.8	9.5, 8.9	7.8, 7.9	7.5, 6.0
1	15.5, 15.2	13.1, 15.7	12.2, 11.9	8.1, 7.8
2	19.5, 18.9	15.7, 16.5	13.8, 14.3	7.6, -
3	21.4, 21.0	16.2, -	14.7, 14.6	7.8, 8.1
4	22.2, 22.8	17.0, 17.1	15.2, 15.2	7.7, 7.6
5	23.0, 23.3	17.0, 17.4	14.8, 14.9	7.8, 7.7
6	23.0, -	-, -	15.1, 15.2	7.9, 8.1
7	25.0, 24.8	17.9, 17.8	15.4, 15.4	8.0, 8.1
8	25.2, 25.2	17.7, 17.6	14.6, 14.5	8.0, 8.2
9	25.1, 25.1	17.5, 17.75	15.1, 15.0	-, -
10	-, -	17.25, 17.35	14.9, 14.7	-, -

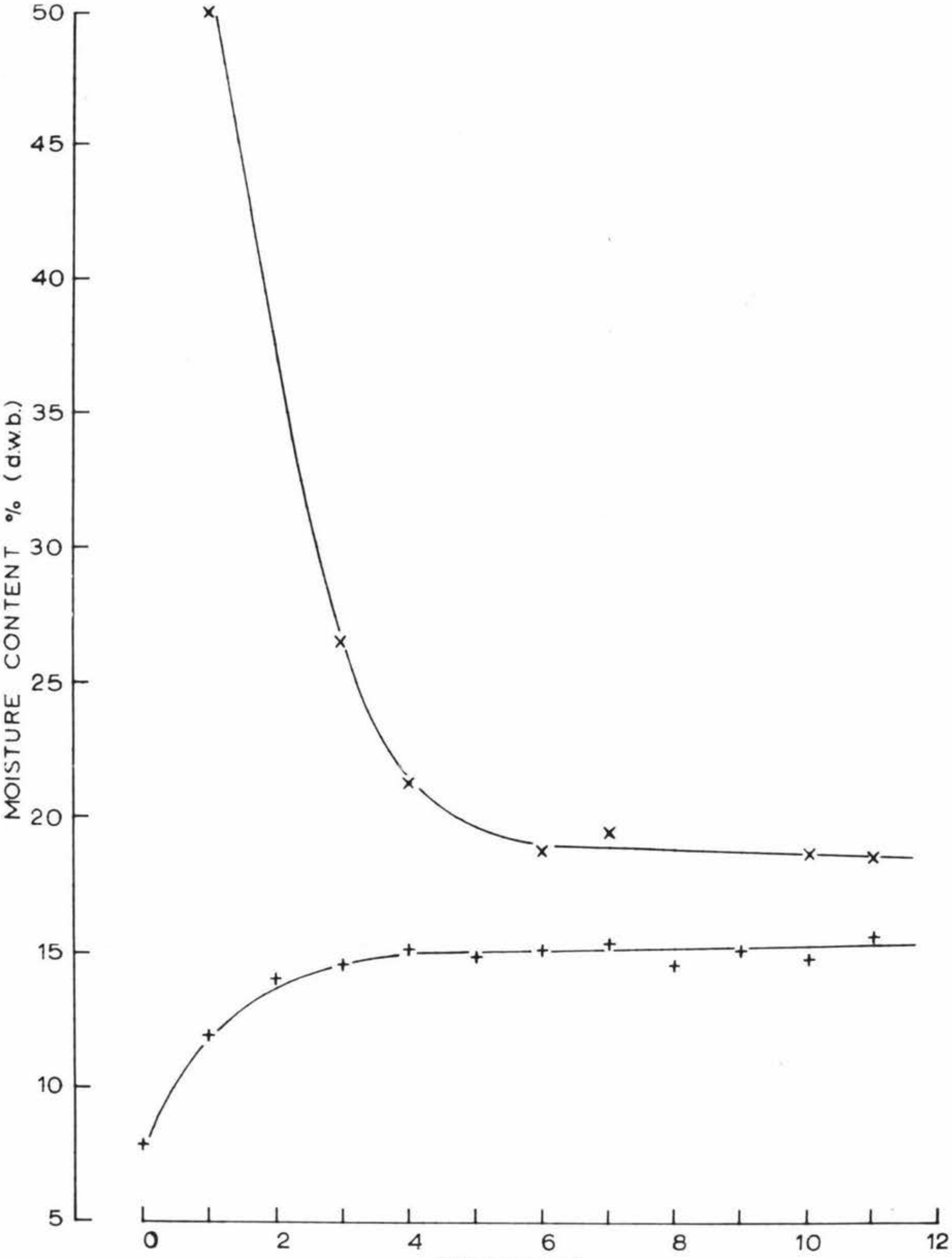


FIG 3 Graph of moisture sorption showing hysteresis in 10% STARCH gel.

It is well recognised that starch exhibits the phenomenon of hysteresis. The author confirmed that hysteresis also occurred in dried starch gels. Gels were separately dehydrated and rehydrated over saturated Na_2CrO_4 (64.6% R.H.).

A plot of the results (see Fig. (3) and Table (3)) showed that the rehydration curve approached equilibrium faster than the dehydration curve. Both curves became essentially parallel to the "days" axis after 8 days. At 11 days the curves were still separated by 3% moisture (d.w.b.).

TABLE (3) Dehydration and Rehydration of Starch

Time Days	Dehydration % Moisture	Rehydration % Moisture
0	59.0	7.9
1	50.0	12.0
2	-	14.1
3	26.6	14.6
4	21.3	15.2
5	-	14.9
6	18.9	15.1
7	19.5	15.4
8	-	14.6
9	-	15.1
10	18.8	14.8
11	18.6	15.6

The sample dehydrated above Na_2CrO_4 was puffed, and its volume compared with the volume of a sample rehydrated to a similar moisture content and puffed under the same conditions.

The results were as follows:-

	Moisture Content % (d.w.b.)	Puffing c.c./gm.(d.w.b.)
Dehydrated sample	18.65	7.25
Rehydrated sample	18.4	7.27

The results above showed no significant difference between samples puffed after rehydration and after dehydration. It would appear that hysteresis was not a significant factor. However, it was considered prudent to avoid hysteresis effects by approaching equilibrium from a lower level. Rehydration of a gel had also been shown to reach equilibrium faster than dehydration.

This rule was adhered to in all cases except in circumstances where it was necessary to prepare gels containing very low moisture, e.g. below 6% (d.w.b.) for a starch gel.

(b) The "Tumbling" Method of Moisture Equilibration.

The saturated salt method of moisture equilibration had two major disadvantages -

1. The equilibrium moisture content of a sample was fixed for any particular salt. This meant that the range of moisture contents obtainable depended upon the range of salt solutions available.
2. Equilibrium conditions were reached only after 10 days, limiting the number of experiments possible in any given period. Thus a more rapid and versatile method was required.

Apparatus consisting of a rotating jar was set up and an experiment, designed to test its efficiency, was conducted.

Approximately 40 gm. of dried starch was placed inside the jar and rotated at the rate of 25 r.p.m. Inside the metal cap of the jar was soldered a cup in which water could be placed. By directing a fan heater onto this metal cap the water was vaporized in 2 - 3 hours, and was rapidly absorbed by the starch gel.

The whole apparatus was then placed in a cabinet thermostatically controlled at 86°F.

It was necessary to keep the apparatus at constant temperature as the micro-climate within the jar contained a fixed quantity of water, and variations in temperature would cause a change in Relative Humidity.

Four samples were treated in this way and after a given period of time the moisture content was determined and the remaining gel weighed and puffed. Puffing volumes were then compared with results obtained by method (a) for moisture equilibration. Obviously if equilibrium had not been reached throughout the gel the centre would not puff to such a large volume as surface areas. This would result in a decrease in overall puffing volume.

The results, which may be found in Table (4), indicated that 2 days were necessary to reach equilibrium conditions.

TABLE (4) A Comparison of Obtained Puffing versus Expected Puffing of Starch When Equilibrated by "Tumbling" Method for Various Times.

Time Rolled Hours	Puffing Obtained c.c./gm.(d.w.b.)	Puffing Expected c.c./gm.(d.w.b.)
12	5.56	7.5
24	6.95	7.5
48	6.2	6.1

A modification to this method was made. Moisture was added by wetting a wick of felt. This felt wick was enclosed in a punched metal sheath to prevent starch touching any wet surface. 24 hours were allowed for moisture to transfer from the wick to the starch gel after which period the wick was removed and at least a further 48 hours allowed for the material to reach equilibrium. A variation in moisture content of the starch was obtained by altering the length of wet wick added to the jar. Varying the amount of starch for any particular wick also provides an opportunity for controlling moisture content.

Fig. (4) shows a view of the apparatus and the wicks used. Fig. (5) shows the apparatus working inside its thermostatically controlled cabinet while bringing starch gel samples to an equilibrium moisture content.

. . . .

Summary

Two methods were used to establish an equilibrium moisture content.

(a) A range of moisture contents in starch gels was obtained by holding samples over saturated salt solutions for 10 days at 86°F. (30°C.). Equilibrium moisture content was approached from a lower level except in exceptional circumstances.

(b) An extensive range of moisture contents in starch gels was obtained by rotating them in a jar with a wet wick for 24 hours. After this period the wick was removed and rotation continued at constant temperature (86°F.) for 48 hours. After this treatment the samples were considered to be in equilibrium with the atmosphere within the jar and to have a constant, evenly distributed, percentage moisture content.

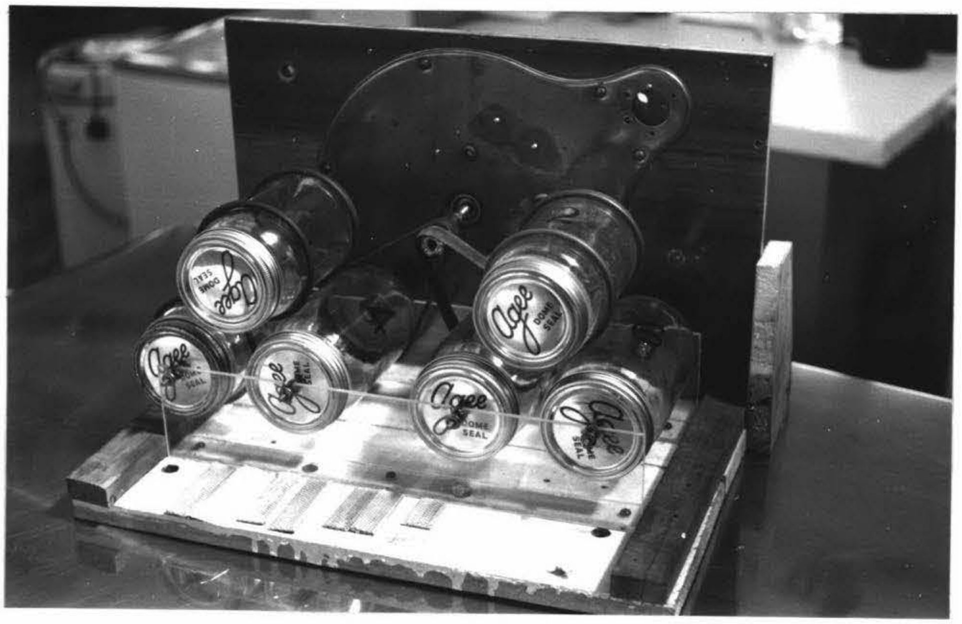


Fig. (4) Glass jar "Tumbler" used for equilibrating moisture content in gels to different levels. Wicks are lying in front.

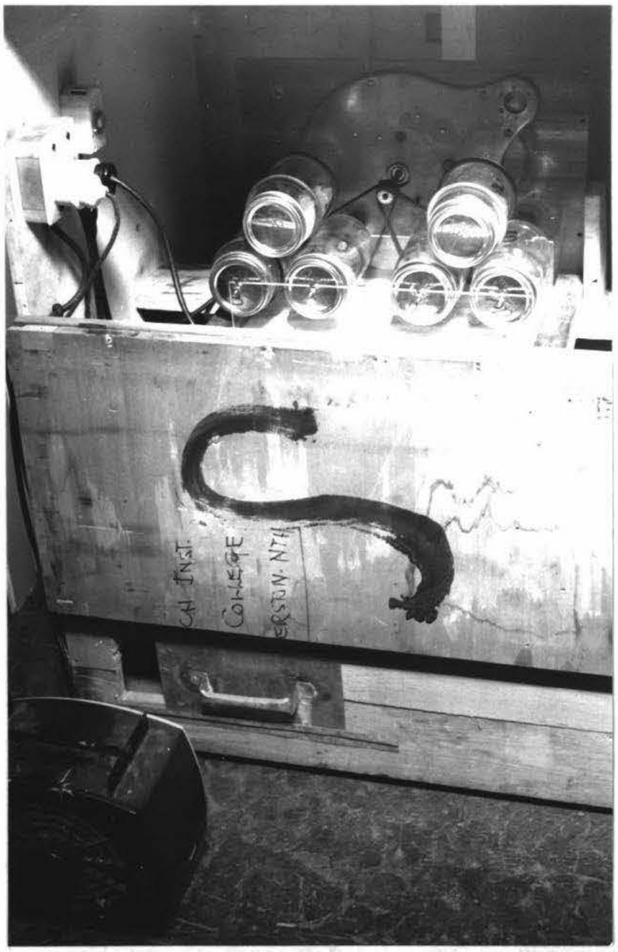


Fig. (5)

"Tumbler" shown operating in temperature controlled cabinet with the door open. Heater in bottom left hand corner is controlled by thermostat next to switches in top left hand corner.

V. MEASUREMENT OF VOLUME OF PUFFED GELS.

An organic liquid was necessary in volumetric measurement by displacement since water would be rapidly absorbed, collapsing the puffed gel. A potato starch gel was reported by Fish (1958) to absorb less than 0.5% Benzene (d.w.b.) and it was thought that the absorption of petrol ether of similar boiling point (available commercially as Shell X2) would be comparable with that of benzene. Absorption of this order would not be a significant error in volumetric measurement.

During preliminary experiments, volumetric measurements were made in a graduated 500 ml. cylinder by displacement. This method proved adequate for initial experiments but for greater accuracy a more refined technique was necessary.

A cap, incorporating a foot to submerge floating gels, and a centrally placed needle point was made to fit over a 1 litre and a 2 litre conical flask. Each flask was calibrated to find the volume of petrol ether required to fill to the needle tip. Volumetric flasks and a burette were used. Apparatus is shown in Fig. (6).

The results, in Table (5), indicated that errors in filling to a needle point were small. Placing of the needle in the neck of the conical flask ensured a large total volumetric capacity and a large height : volume ratio at the end point. This ensured maximum accuracy.

TABLE (5) Calibration Volumes of 1 litre and 2 litre Conical Flasks.

	1 litre Flask	2 litre Flask
	1112.6 ml.	2056.95 ml.
	1112.25 ml.	2057.4 ml.
	1112.4 ml.	2057.25 ml.
		2057.6 ml.
		2057.05 ml.
Mean Volume:	1112.4 ±0.2 ml.	2057.25 ±0.4 ml.

A weighed sample of from 5 - 40 gm. of gel was fried and allowed to cool to room temperature. As soon as ambient temperature had been reached puffed material was placed in the flask and a known quantity of petrol ether added to bring the level up to the needle point.

Volume of puffed gel was obtained by subtracting the added quantity of petrol ether from the mean calibrated volume.

Volumes were expressed c.c./gm. of dry starch or dry gel. Moisture content was not then a variable in the results and a direct comparison could be made between gels puffed at two different moisture contents.

Care was exercised to ensure that no air remained trapped between pieces of puffed gel. Air was allowed to escape by rotating the flask before completely filling.

Errors due to fat pick-up during frying were ignored. Fat pick-up for a 10% Starch gel fried at 380°F. was 22.1% (fat free basis). Volume of the gel, including fat, was approximately 4 c.c./gm. of dry starch. The error due to fat pick-up, assuming a specific gravity of 1.0, may be as high as 0.221 c.c./gm. of dry, fat free starch. However, the true error is difficult to determine for during cooling, some of the fat is drawn in through holes in the surface bubbles to occupy space within the puffed gel that would otherwise be occupied with air. An attempt to find out what proportion of the fat pick-up that remained on the outside surface was not made because of the problems involved.

Volume of fat pick-up could be expected to range from $^{1}/20$th to $^{1}/10$th of the volume of puffed starch. (See Fig. (15) showing the relationship of puffing to moisture content at constant frying temperature, and Fig. (25) showing how fat pick-up is affected by the moisture content of a gel when fried at constant temperature.) This ratio should be constant for like gels of similar moistures, fried at the same temperature, and should not affect reproducability of the results. It was considered that the variable was not large enough to make interpretation of results difficult; so no correction was made.

Difficulty was experienced in obtaining reproducable results until it was found that fat dissolved by repeated use of the solvent was affecting displacement volume of starch gels; possibly due to a modification of surface tension effects. Fat free petrol ether was thereafter used for each measurement.

Summary.

Weighed samples of gels of from 5 - 40 gm. were fried under known conditions of temperature and moisture, and placed in a calibrated conical flask when cool. A known quantity of fat free petrol ether was added to bring the level up to the needle point. Volume of sample was obtained by subtracting added volume from calibrated mean volume and expressed as c.c./gm. of dry gel. Fat pick-up was ignored.

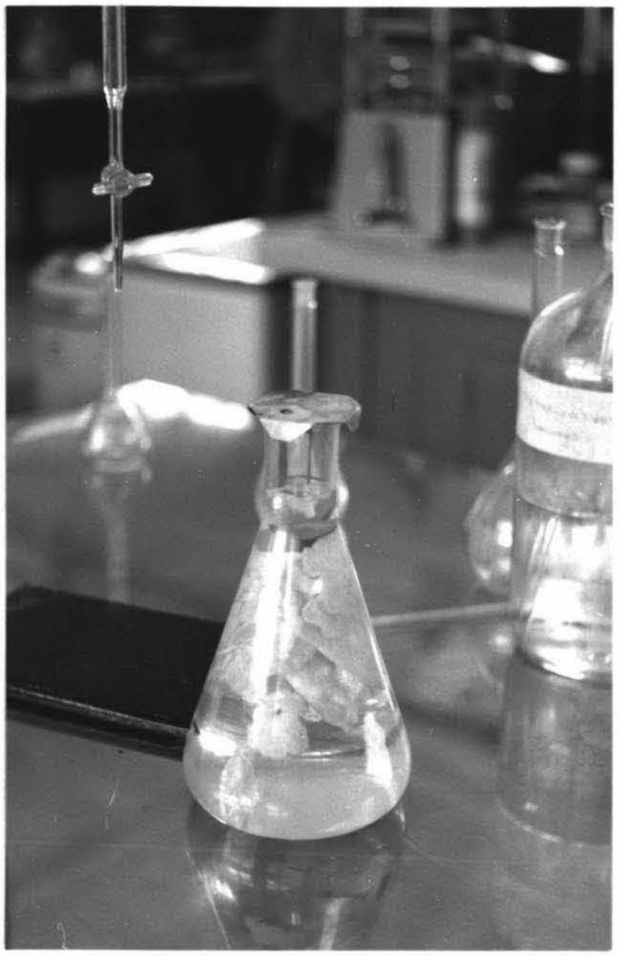


Fig. (6) Apparatus for measuring volume of puffed gels. The cap with its foot and needle can be seen. The sample being tested is puffed cheese.

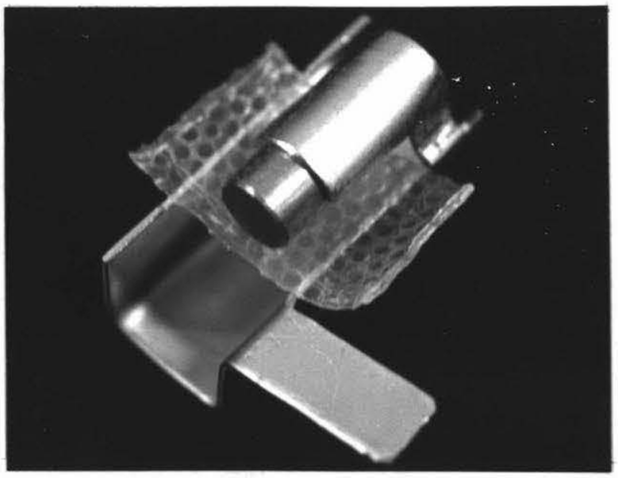


Fig. (7)
Thermoplastometer
with gel in place.

VI. MEASUREMENT OF THERMOPLASTICITY OF A GEL.

As experimental work progressed, it was noticed that heating of a dried gel softened it considerably. It was also noticed that gels with a higher moisture content were softer at ambient temperature. Experimental results showed that moister gels puffed at lower temperatures. The above facts seemed to indicate that plasticity played a considerable part in, and may even dictate, the behaviour of a gel during puffing.

An empirical test was developed for the purpose. An instrument was made, and is shown in Fig. (7), which consisted of a bridge made of sheet stainless steel bent in the form of a "U". The bridge was $\frac{3}{4}$ in. wide, $\frac{3}{4}$ in. deep and 2 in. long. A weight weighing 13.695 gm. was made from 7/16 in. bright steel rod. It was $\frac{3}{4}$ in. long. The weight and size of material was altered until a satisfactory result was obtained for both starch and gelatine gels, and the one finally chosen is described above.

The method of conducting the test was as follows:-

A piece of dried gel $\frac{3}{4}$ in. to 1 in wide, and of known moisture content was placed across the bridge and the weight placed on the top with its long axis parallel to the instrument's sides. A holder kept it over the centre. The entire instrument was rapidly submerged in hydrogenated oleo oil held at a known temperature.

The temperature, hereafter referred to as the "Critical Softening Point", at which the gel collapsed just within 5 seconds of submerging, was determined. At a lower temperature than the

"C.S.P." the weight would be supported for more than 5 seconds.

After each test a new piece from the same sample was chosen and the test repeated at a different temperature until the "C.S.P." was found.

No experiment was designed to test the method. However, it was noted that small variations in gel width did not affect reproducability and the "C.S.P." could be easily determined to within 5°F.

The instrument is referred to elsewhere in the text as a Thermoplastometer and a typical result of an experiment to determine the "C.S.P." of a 10% starch gel using this instrument was as follows:-

	Fat Temperature	Result
Test No. 1	300°F.	Did not collapse
No. 2	340°F.	" " "
No. 3	360°F.	" " "
No. 4	374°F.	Collapsed in 2 seconds
No. 5	370°F.	" " 2 seconds
No. 6	365°F.	" " 4 seconds

Thus the Critical Softening Point (C.S.P.) was 365°F. for this sample.

VII. METHODS OF APPLYING HEAT TO PUFF GELS.

Traditionally gels of various types such as shrimp flakes have been puffed by frying or deep fat frying. There was no reason to believe, however, that puffing could not be obtained using other methods of heat application, and two other methods were shown to produce satisfactory results. The bulk of the experiments, except those designed to study other methods of heat application, were conducted using a deep fat fryer for puffing.

(a) Deep Fat Frying.

A small, commercial, electrically heated deep fat fryer was used. The fat used for frying was hydrogenated oleo oil available commercially under the trade name "Chefade".

Temperature of frying proved to be critical and it was found necessary to calibrate the thermometers used for measuring fat temperature against an accurate set. The 3 in. immersion 0 - 600°F. mercury-in-glass thermometers, graduated in two degrees intervals, were checked against a set of normal 80 m.m. immersion mercury-in-glass thermometers, each covering a range of 50°C. in 0.2°C. divisions. These Laboratory Standard Thermometers were made by G.H. Zeal, England, to B.S. 1365 specifications.

Modification to working thermometer readings was made accordingly.

It was also found necessary to stir the fat well to prevent heat gradients being established within it. The thermostat was not relied on to control fat temperature. Instead, the temperature was brought up to that required for a particular experiment using the thermostat only as an on/off switch. When the correct temperature was obtained the fryer was stiched off and the gel fried immediately. Frying time was short (approximately 10 - 15 seconds) and the ratio of sample size to fat volume was very small; so the fat temperature drop during puffing was not significant.

Gels were fried in a basket immersed in fat. When puffing was completed the basket was removed and the sample shaken to remove excess fat, and then tipped onto a tray to cool. A volumetric measurement was made as soon as the sample had reached room temperature and before it took up significant amounts of atmospheric moisture.

(b) Fluidized Bed Heating.

A fluidized bed of hot salt was suggested as a possible method of fatless frying of potato chips by Sachsel (1963). In some products, such as those for which rapid rehydration is an important factor, a coating of fat picked up during frying would be a disadvantage. It was decided to study a non-fat puffing method and the principle of using a fluidized bed of hot salt appeared to show promise.

A diagram of the apparatus constructed for the purpose is shown in Fig. (8). Compressed air was passed through a reducing valve, which gave control of velocity through the salt bed, and into a metal coil heated by a "Fisher" burner. The heated air was then passed through a $\frac{1}{2}$ in. thick bed of brass turnings situated at the bottom of a 3 in. diameter pipe. This bed of turnings, held in place by 40 mesh gauze, distributed the air evenly resulting in satisfactory fluidization of a 1 in. salt bed. "Black Horse" vacuum crystallized Sodium Chloride was used. Samples to be

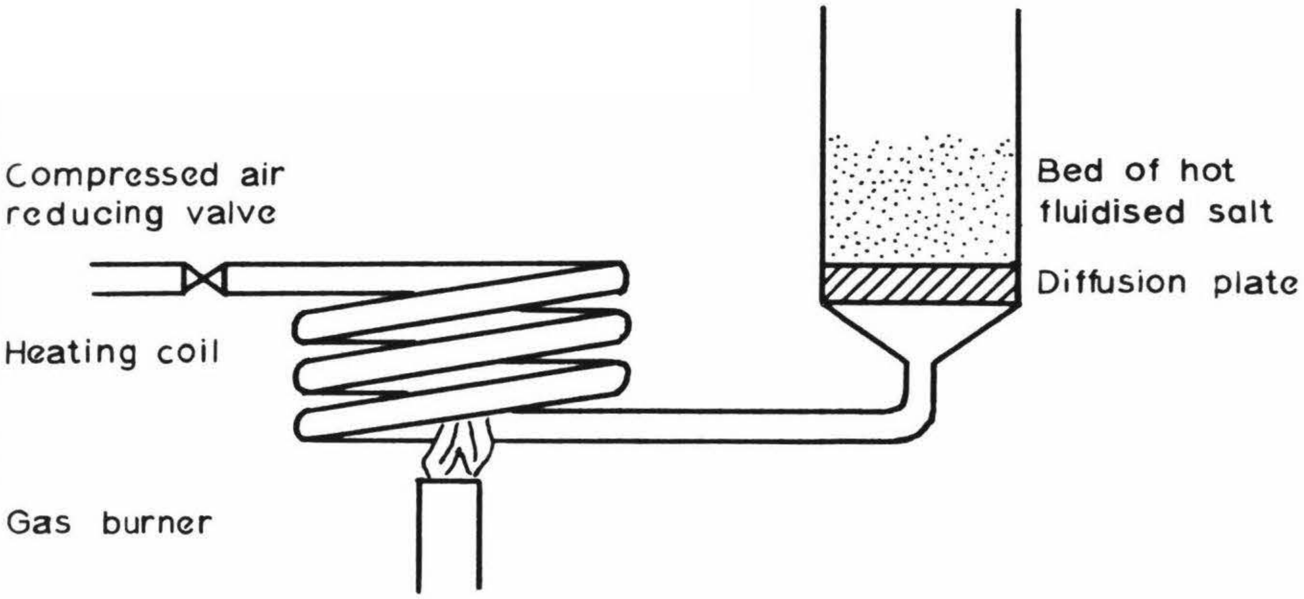


FIG 8 Schematic diagram of experimental fluidised salt bed heater used for fatless puffing of dehydrated gels.

Fig. (9)

Experimental apparatus for fluidized bed heating of dried gels. Apparatus shown schematically above in Fig. (8).

puffed were placed in a small punched metal basket and put into the bed of hot fluidized salt until puffing had been completed. A mercury-in-glass thermometer was used to measure bed temperature. Fig. (9) shows the actual experimental apparatus that has been described here.

(c) A muffle furnace was also used to puff gels.

FUNDAMENTAL STUDIES

RESULTS

INTRODUCTION

As far as was practicable an historical development of the Thesis has been attempted in the presentation of results. Each section of the results follows the preceding in a logical fashion. As more was known about the puffing mechanism, attention was directed towards particular aspects of this phenonomen, and experiments were so designed to study these aspects and provide a greater understanding of the process.

I. EFFECT OF VARIABLES ON PUFFING OF STANDARD STARCH GELS.

It was known from previous experience that moisture content of shrimp flakes affected their puffing characteristics. It was also noted that puffing did not take place until the fat was hot enough. With this information as guide, a study was made on how moisture content and frying temperature affected volume increase of a starch gel during puffing. The gels used in these experiments were Standard Starch Gels, the preparation of which is laid down in "Analytical Methods and Experimental Techniques".

(a) The Effect of Varying Moisture Content of a Gel on Puffing at Constant Temperature.

The moisture content of thirteen Standard Starch Gel samples was allowed to come to equilibrium over thirteen saturated salt solutions for 10 days. Samples were then weighed, puffed in fat, and their volumes measured as previously described. The

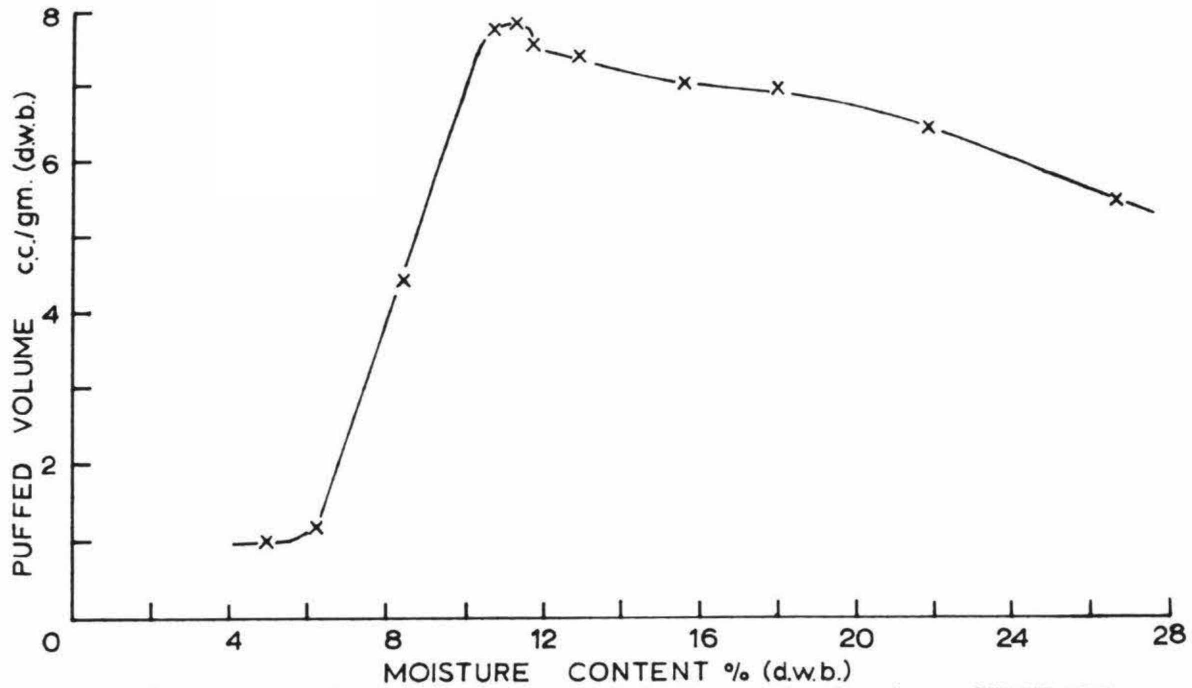


FIG 10 Graph of puffing vs. moisture content for STANDARD STARCH GEL (10 %) at constant frying temperature (= 400°F).

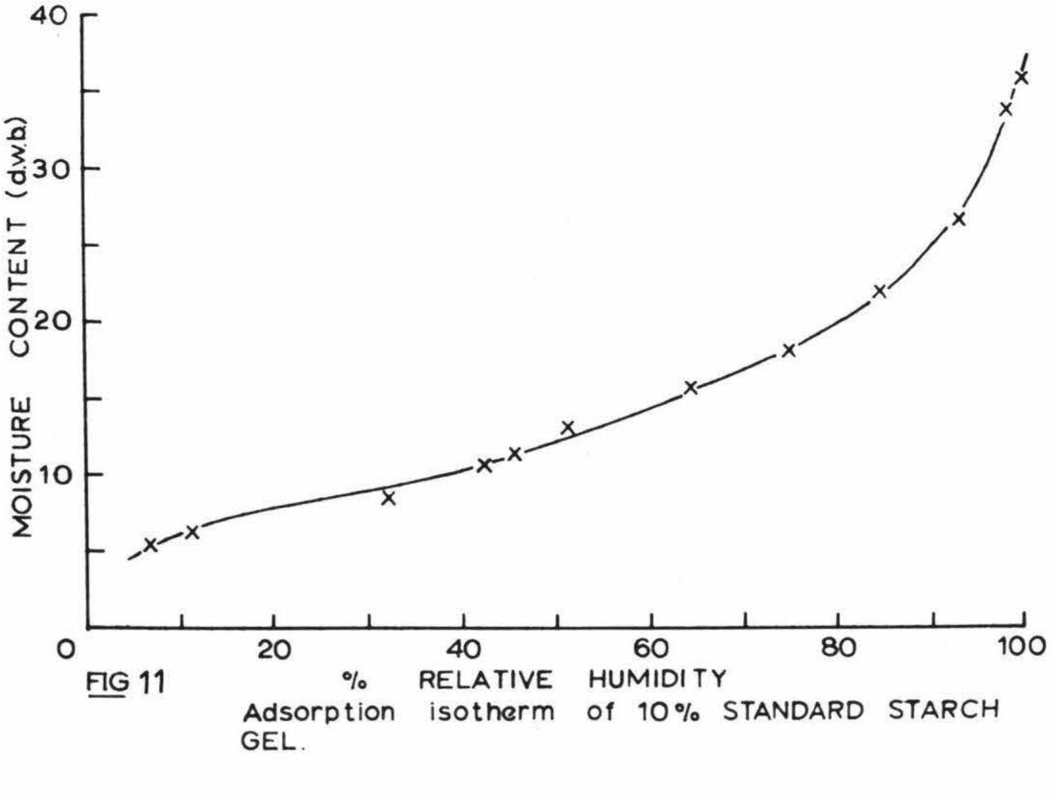


FIG 11 Adsorption isotherm of 10% STANDARD STARCH GEL.

results are tabulated in Table (6) and shown graphically in Fig. (10).

TABLE (6) Puffing of Standard Starch Gels Equilibrated Over Saturated Salt Solutions.

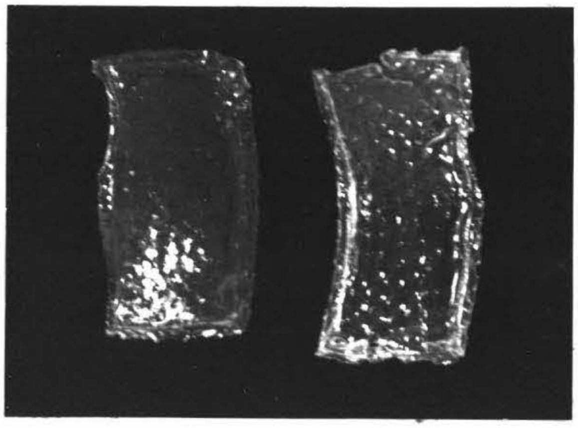
Saturated Salt	Relative Humidity %	Moisture Content % (d.w.b.)	Puffing c.c./gm. (d.w.b.)
NaOH	6.5 - 7.0	5.15	0.97
LiCl	11.1	6.3	1.2
$CaCl_2$	32.0	8.5	4.46
CrO_3	42.0	10.9	7.76
K_2CO_3	43.6	11.45	7.8
NaI	Unsat.	11.8	7.53
$Mg(NO_3)_2$	51.0	13.1	7.4
Na_2CrO_4	64.6	15.8	7.0
NaCl	74.9	18.2	6.98
KCl	84.5	22.0	6.44
$NH_4H_2PO_4$	92.9	26.8	5.45
$K_2Cr_2O_7$	98.0	33.8	4.77
H_2O (Dist.)	100.0	35.6	4.65

Temperature of frying was maintained constant at approximately 400°F.

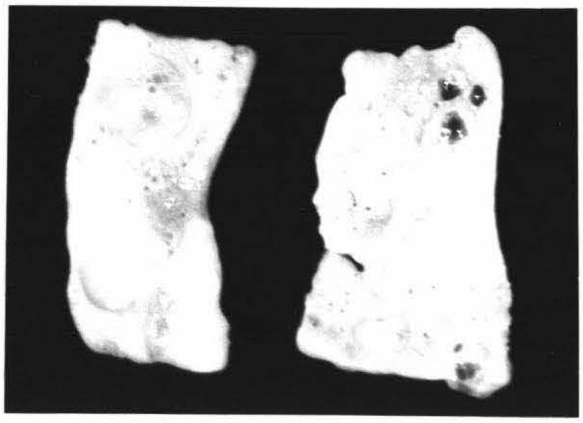
The graph shows that puffing did not start until at least 6% moisture was present. Puffing volumes increased rapidly above 6% to reach a peak at 11.5% moisture content. The maximum volume obtained was 7.8 c.c./gm. (d.w.b.) where the curve appeared to have a slight hump. The curve flattened out at higher moistures and finally fell as moisture contents exceeded 20%.

Fig. (11) shows the absorption isotherm for this starch which is drawn from humidities and moisture contents reported in

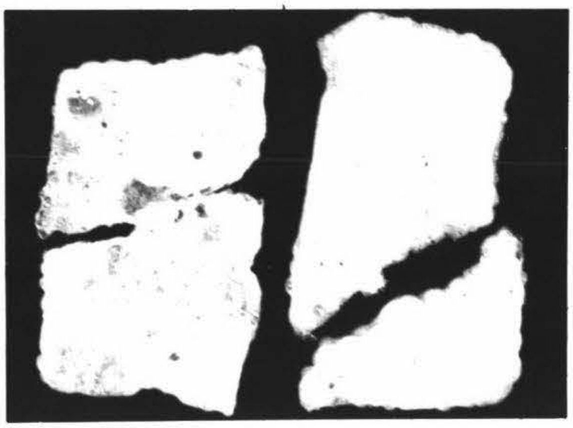
FIG 12



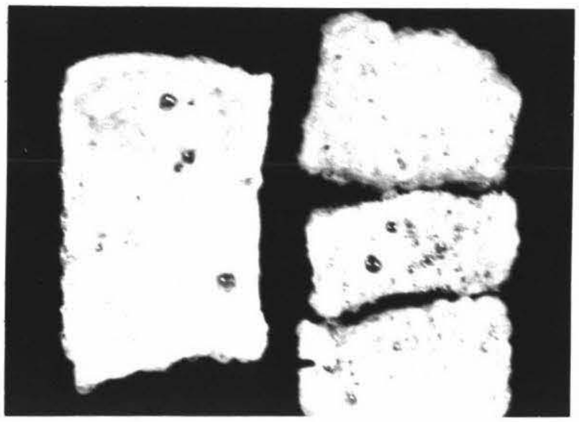
No1 4·55% Moisture



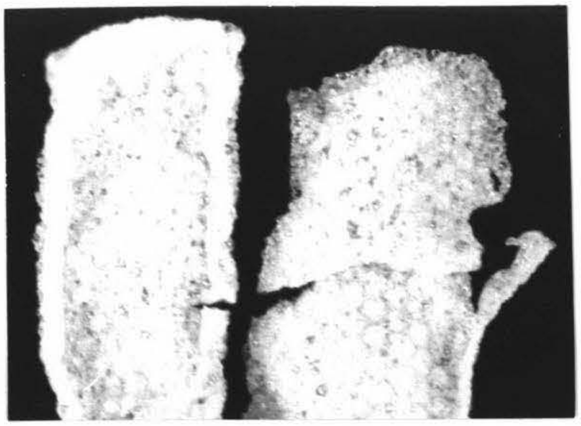
No2 9·5% Moisture



No3 10·9% Moisture



No4 12·4 % Moisture



No5 20·0% Moisture

Puffing vs. moisture content of STARCH GELS(10%) in fat at 400°F.

Scale

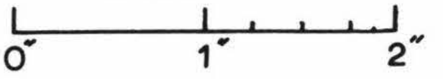


Table (6). This adsorption isotherm is considered in "Discussion of Results".

The texture, size of bubbles, and glossiness of surface of puffed starch gels show a marked change with moisture content.

To illustrate these changes two series of photographs of fried Standard Starch Gels are presented in Figs. (12) and (13), showing gels puffed at 400°F. and 360°F. respectively.

Fig. (12) - Frying Temperature 400°F.

No.1 Sample containing 4.55% moisture showed no signs of puffing whatever.

No.2 This sample at 9.5% moisture showed puffing. The size of bubbles in gels puffed under these conditions appeared to fall into two classes -

(1) Extremely large bubbles which may be either true bubbles or formed by the rupture of a large number of small bubbles.

(2) Extremely small bubbles.

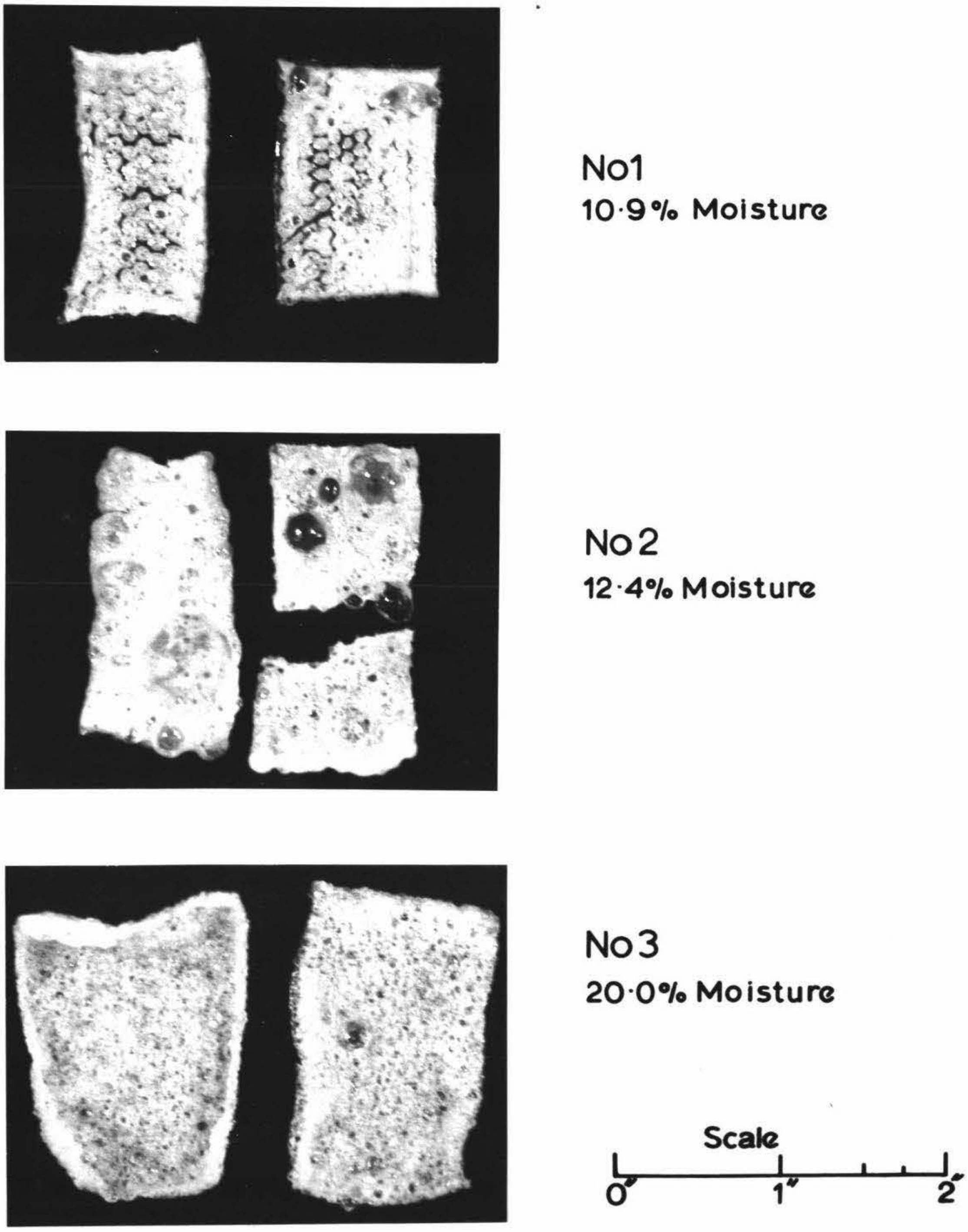
No. 2 shows both of these types of bubbles. The surface was extremely glossy and the texture hard and brittle.

No.3 At 10.9% moisture the gel showed slightly more even puffing. The surface was still very glossy.

No.4 12.4% moisture. Sample showed more even puffing than previous samples. Bubble size and uniformity of size had increased and was particularly noticeable in the right hand piece. The surface was slightly glossy.

No.5 20.0% moisture. Sample puffed very evenly and had a dull

FIG 13



No1
10·9% Moisture

No2
12·4% Moisture

No3
20·0% Moisture

Puffing vs. moisture content of 10% STARCH GELS in fat at 360°F.

surface. The texture, although crisp, was not hard.

The effect of frying at a lower temperature on puffing can be seen in Fig. (13).

Fig. (13) - Frying Temperature 360°F.

No.1 10.9% moisture. Areas of gel where no puffing had taken place are visible as black patches. White areas consist of very tiny bubbles with three large bubbles visible in top of the right hand piece.
Fig. (15) shows that gels fried at this temperature do not puff below 9.8% moisture. Thus only 1% moisture content is contributing to puffing.

No.2 12.4% moisture. Here can be seen very clearly large true bubbles and ruptured internal areas. Surface was very glossy.

No.3 20.0% moisture. Gel had a non-glossy surface. Puffing was even.

The structure of puffed starch gels is more clearly shown in the microphotograph below.

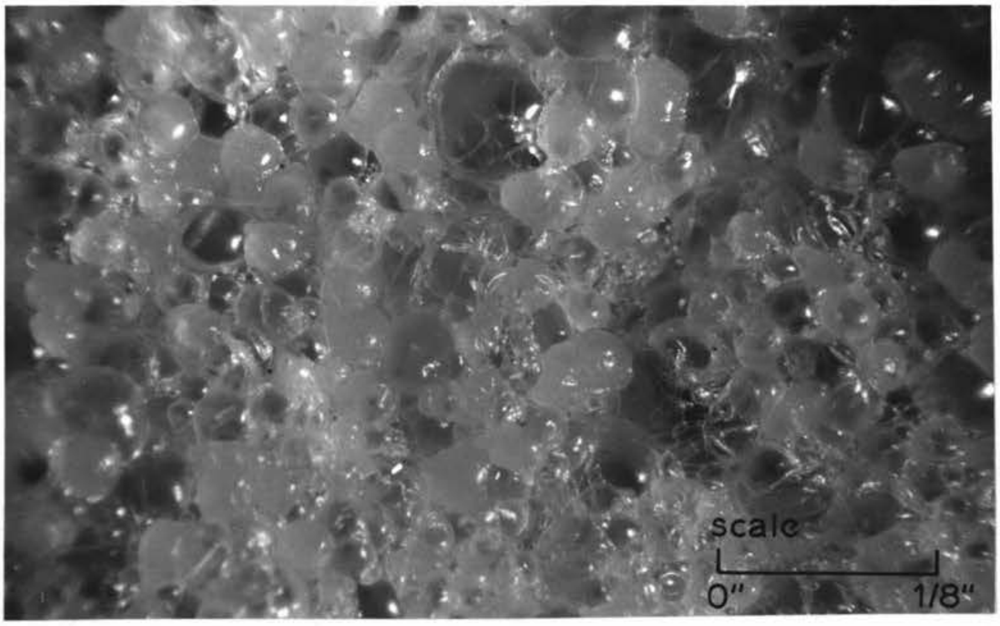


Fig. (14) Standard Starch Gel puffed in fat at 400°F. and 18.5% moisture.

It shows clearly the structure of a puffed starch gel. Size of bubbles, which appear very thin walled, vary markedly although not as markedly as in gels puffed at low moistures. No rupturing of buble surfaces is evident although this must occur. During and after puffing, moisture rapidly escapes as steam and is frequently seen to escape in spurts or jets suggesting that bubbles have been ruptured.

(b) The Effect of Varying Frying Temperatures on the Puffing of Standard Starch Gels.

Puffing did not take place for any particular gel until the frying temperature was high enough. When a sample did puff the process was very rapid, taking as little as 1 - 3 seconds from beginning of puffing to its completion. This "Critical Puffing Temperature" also appeared to vary for gels of different moisture content. It was decided on the above grounds to study the effect of varying puffing temperature at a wide range of moisture contents. From the results, a family of curves of puffing against moisture content, each curve representing a different constant temperature, was drawn.

A number of samples of Standard Starch Gel, the moisture content of which had been equilibrated at various levels using the "Tumbling Method" described previously, were puffed as follows. Each sample was divided into a number of lots and each lot weighed and puffed at a different temperature. Frying temperatures ranged from 320°F. to 440°F. in 20°F. increments. After puffing, the volume of weighed sample was measured.

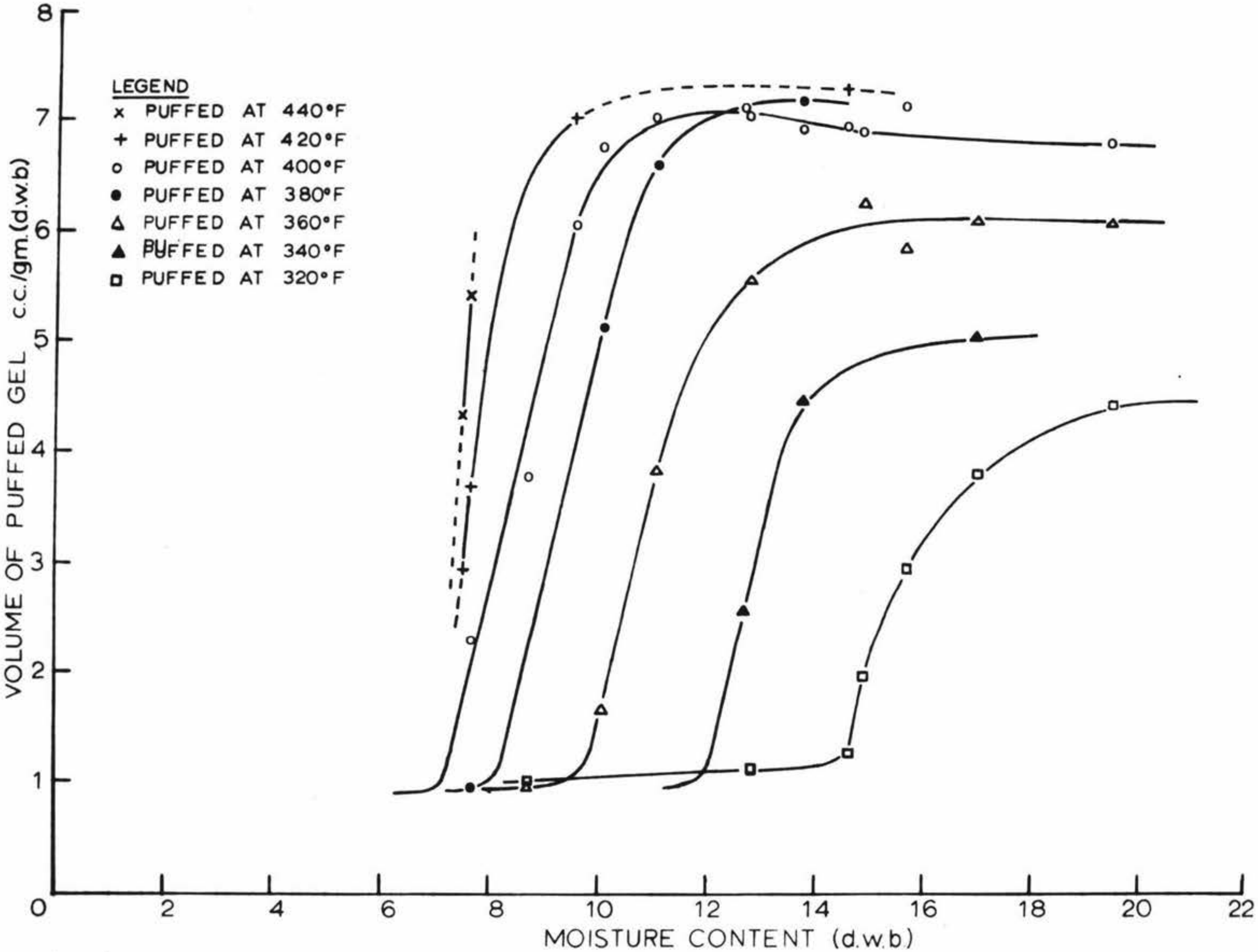


FIG 15 The puffing of 10% STARCH gels in fat vs. moisture content (before puffing). Each curve represents the relationship of moisture content vs. puffing at a particular constant temperature. Gels were puffed at 320, 340, 360, 380, 400, 420, and 440°F.

Table (7) presents the experimental results in tabulated form. Fig. (15) presents them graphically.

TABLE (7) Puffing of Standard Starch Gels over a Range of Temperature and Moisture Contents.

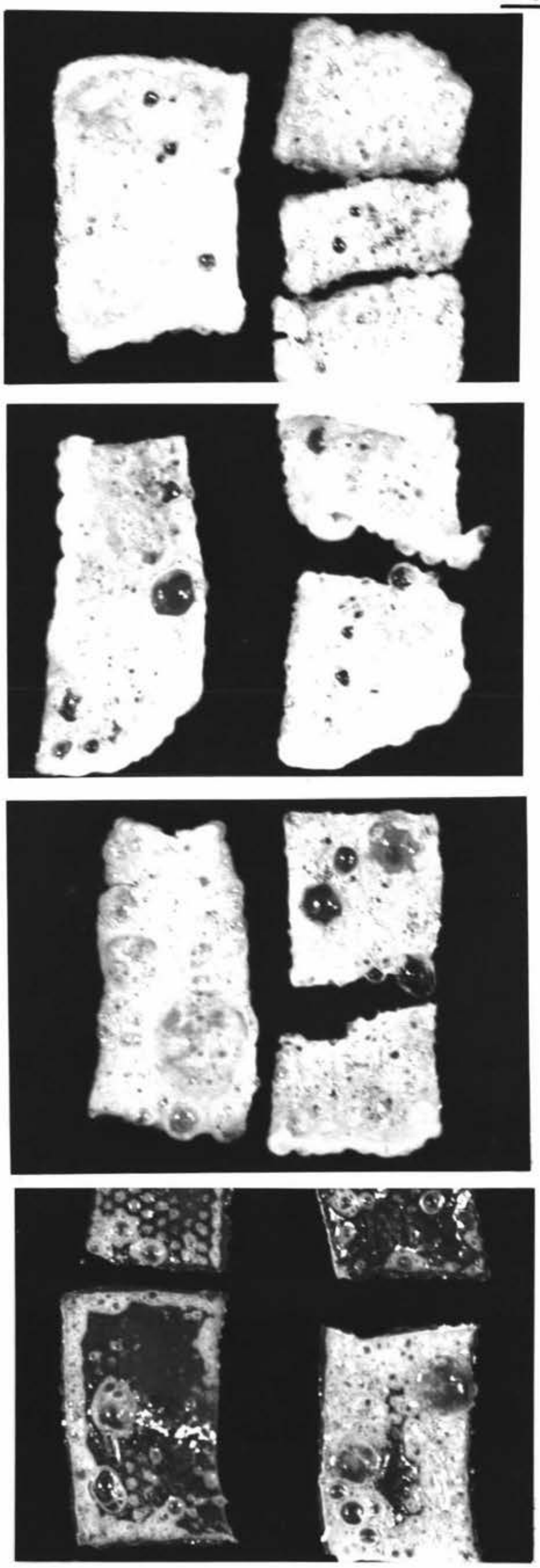
Moisture Content %(d.w.b.)	Puffing in c.c./gm. (d.w.b.) at Temperatures of -						
	320°F.	340°F.	360°F.	380°F.	400°F.	420°F.	440°F.
7.5	* -	-	-	-	-	2.96	4.3
7.63	-	-	-	0.96	2.25	3.66	5.4
8.7	1.01	-	0.96	-	3.74	-	-
9.6	-	-	-	-	6.03	7.0	-
10.1	-	-	1.66	5.1	6.75	-	-
11.05	-	-	3.3	6.58	7.0	-	-
12.7	-	2.54	-	-	7.1	-	-
12.8	1.14	-	5.53	-	7.03	-	-
13.8	-	4.43	-	7.17	6.92	-	-
14.6	1.28	-	-	-	6.95	7.3	-
14.9	1.99	-	6.26	-	6.9	-	-
15.7	2.98	-	5.87	-	7.14	-	-
17.0	3.81	5.05	6.1	-	-	-	-
19.5	4.43	-	6.1	-	6.82	-	-

* Spaces indicate that no record of puffing volume was made.

From a study of the family of curves in Fig. (15) the effect of varying temperature is readily seen. As frying temperature increases, so does the moisture content, at which puffing just begins, decrease. In other words, the "Critical Puffing Temperature" increases as moisture content decreases. Also, as frying temperature increases, so does the maximum volume obtainable, increase. A maximum is reached at 380°F. for Standard Starch Gel above which increase in puffing temperature

FIG 16

Puffing vs. temperature of frying of 10% STARCH GELS at 12·4% moisture (d.w.b).



No4 400°F

No3 380°F

No2 360°F

No1 340°F

does not give an increase in volume as measured after puffing.

It was also noted that the steep sections of each curve appeared to be almost parallel except in the case of the 440°F. and 420°F. curves.

In Figs. (16) and (17), gels of moisture contents 12.4% and 10.9% respectively, are shown which have been fried at different temperatures.

Fig. (16) - Moisture Content 12.4% (d.w.b.).

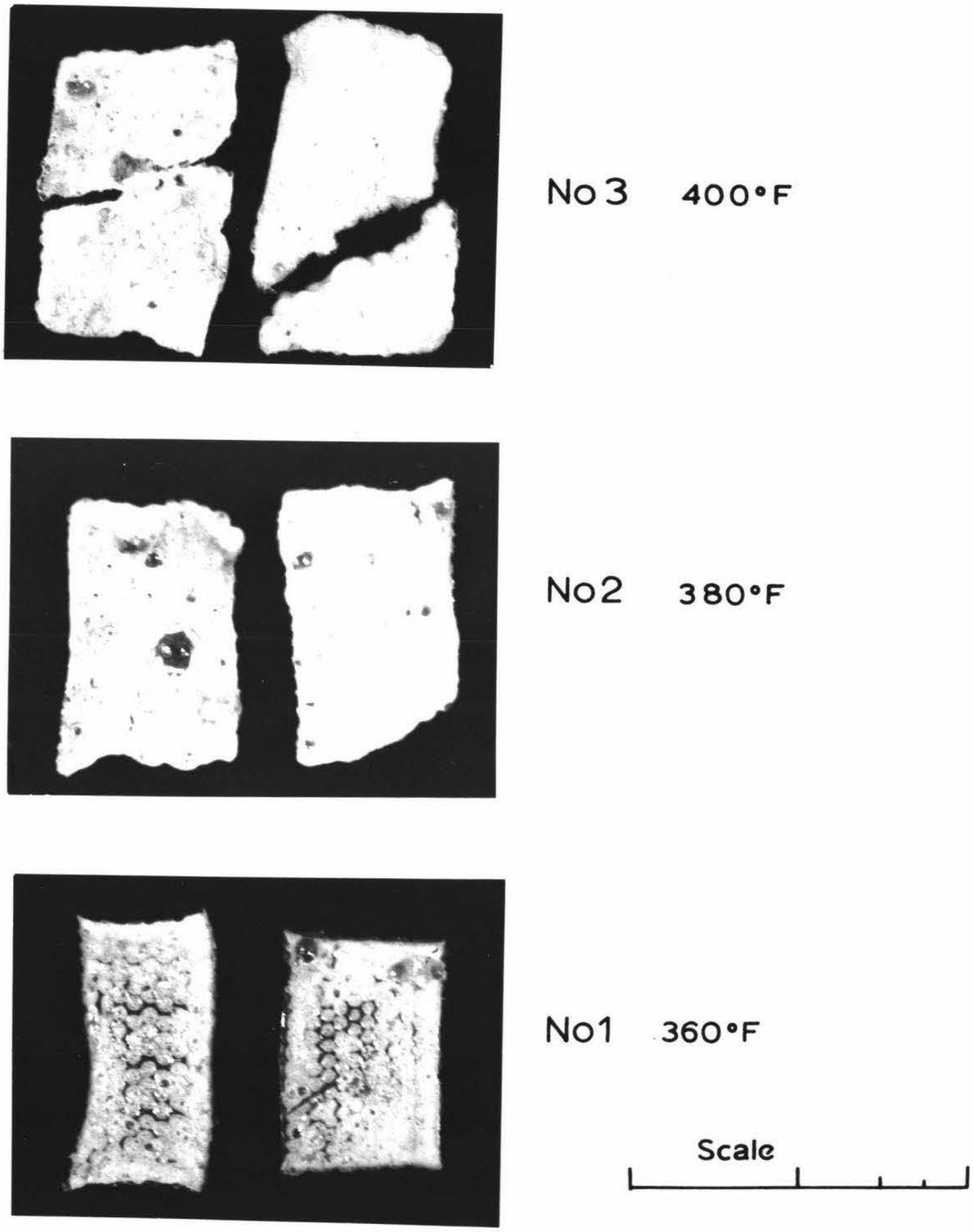
No.1 Fried at 340°F. This sample showed very limited areas of puffing and extensive dark areas where no puffing had taken place at all.

No.2 360°F. All areas of the gel were puffed although bubble size varied from very large to extremely small. The surface was very glossy.

No.3 380°F. A greater puffed volume and a more even bubble size was shown. Surface was still very glossy.

No.4 400°F. Bubble size was reasonably even, particularly in piece on the right. The volume was large and the surface only slightly glossy.

FIG 17



Puffing vs. temperature of frying of 10% STARCH GELS at 10·9% moisture (d.w.b).

Fig. (17) - Moisture Content 10.9% (d.w.b.)

A similar effect to the previous series was obtained except that puffing at the same temperature was not so extensive.

No.1 360°F. Gel showed dark areas where no puffing had taken place.

No.2 380°F. More even puffing occurred but gel still had large and small bubbles, and a very glossy surface.

No.3 400°F. Still more even puffing and a larger volume was obtained, but surface still glossy.

These photographs indicate very clearly the effect of increasing the temperature of frying, at a particular moisture, content on puffing. Increasing temperature of frying appears to have the same effect as increasing moisture content, i.e. resulting in more even puffing towards a non glossy surface.

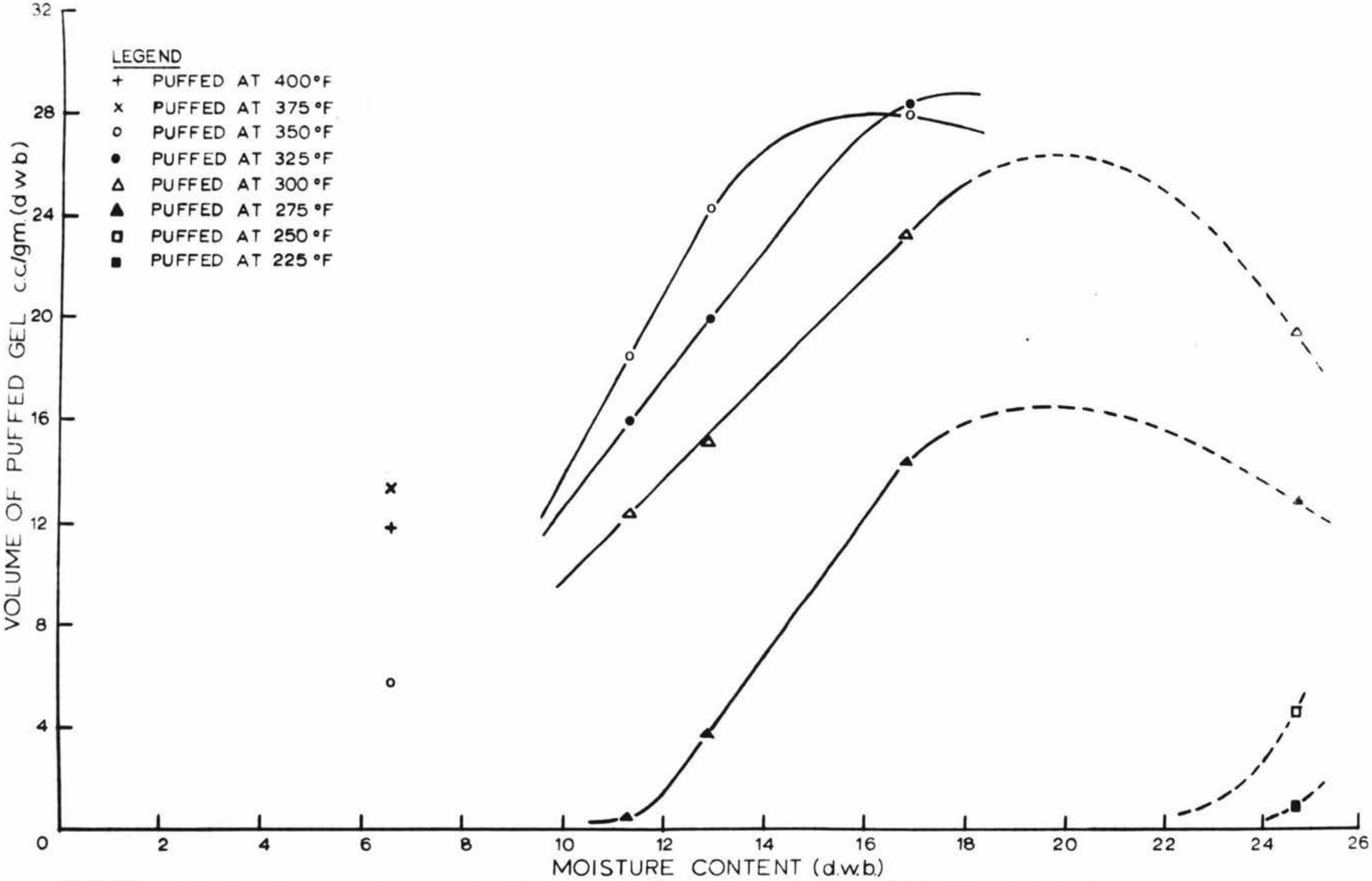


FIG 18 Graph of puffing vs. moisture content (before puffing) for 10% GELATINE gels. Each curve represents the relationship of moisture content vs puffing at a particular constant temperature. Gels were puffed at, 225, 250, 275, 300, 325, 350, 375, and 400°F.

II. EFFECT OF VARIABLES ON PUFFING OF A PROTEIN GEL.

It was decided to examine a non-starch gel to determine if the same or similar results would be obtained when moisture contents and frying temperatures were varied.

(a) Effect of Varying Moisture Content on Puffing of a Gelatine Gel.

(b) Effect of Varying Frying Temperature.

Both of these factors were studied by conducting a series of puffing experiments at different moistures and temperatures. The data, collected into Table (8), was plotted to obtain a family of curves similar to those drawn for Starch gels.

TABLE (8) Puffing of Gelatine Gels Over a Range of Temperatures and Moisture Contents.

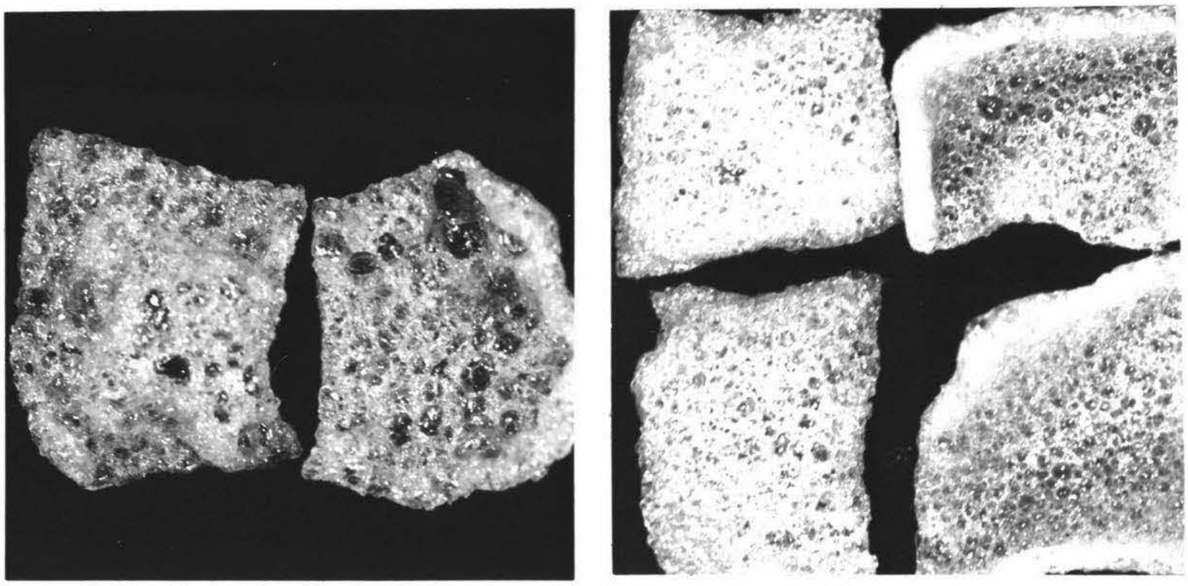
Moisture Content %(d.w.b.)	Puffing in c.c./gm. (d.w.b.) at Temperatures of -							
	225°F.	250°F.	275°F.	300°F.	325°F.	350°F.	375°F.	400°F.
6.6	-	-	-	-	-	5.75	13.4	11.9
11.3	-	-	0.55	12.4	15.9	18.4	-	-
12.9	-	-	3.73	15.2	20.0	24.3	-	-
16.8	-	-	14.4	23.4	28.4	28.0	-	-
24.6	0.9	4.6	13.0	19.6	-	-	-	-

The plots are shown in Fig. (18).

Some differences were seen between the puffing characteristics of Gelatine and Starch gels.

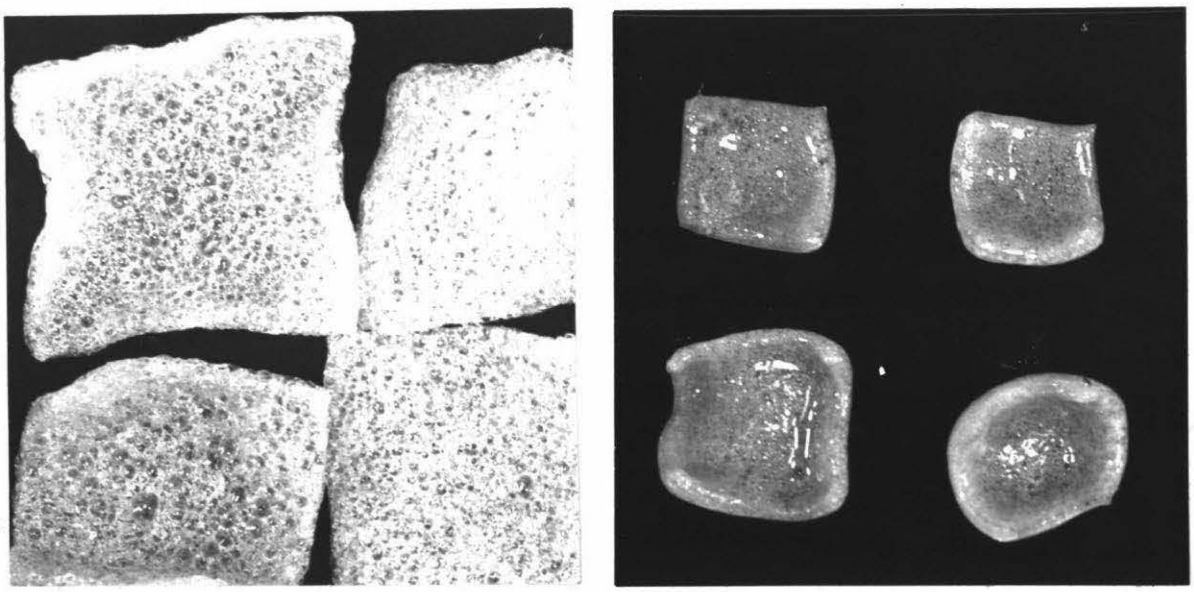
1. Maximum volumes obtained by puffing 10% Gelatine gels were far in

FIG 19



No 4 16·8 % Moisture

No 3 12·9% Moisture



No 2 11·3 % Moisture

No 1 6·6% Moisture

Puffing vs. moisture content of 10 % GELATINE GELS in fat at 350°F.

excess of those obtained by puffing 10% Starch gels.

2. Puffing also took place at lower temperatures and it was noted that gradients of the steep sections of curves decreased as the frying temperature was lowered. This was in contrast to the near parallel slopes of Starch curves.

Minor puffing was shown to occur in the low moisture content regions (below 8% for Gelatine). This was also so for Starch (below 6%) but because puffing took place above 500°F. no measurements of volumes were made.

However, the major characteristics are seen to be the same, i.e.

1. A minimum amount of moisture must be present to achieve any puffing at all for a particular frying temperature.
2. Above this level, puffing increases rapidly with increase in moisture content.. Puffing reaches a peak and then, as moisture content continues to increase, it begins to fall.

As for Starch gels, a series of photographs are shown. Figs.(19) and (20) show the effect of increasing moisture content at constant temperatures (350°F. and 275°F. respectively).

Fig. (19) - 350°F. Frying Temperature.

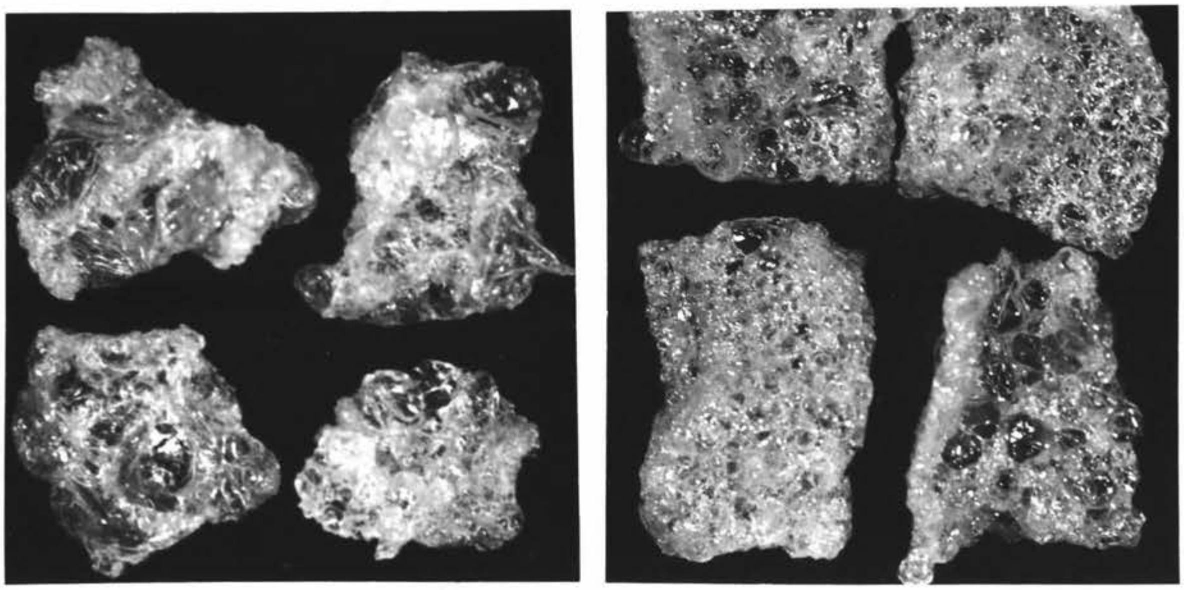
Trends in bubble size appeared to be reversed in gelatine gels. Bubble size was even at low moistures while at high moistures, extremely large bubbles may be present.

No.1 6.6% Moisture. Bubbles were very small as was volume increase when compared with Nos. 2, 3 and 4. The surface was shiny and smooth whereas in Nos. 2, 3 and 4, humps in the surface were caused by underlying bubbles.

Nos. 2, 3 and 4. 11.3%, 12.9%, 16.8% Moistures respectively.

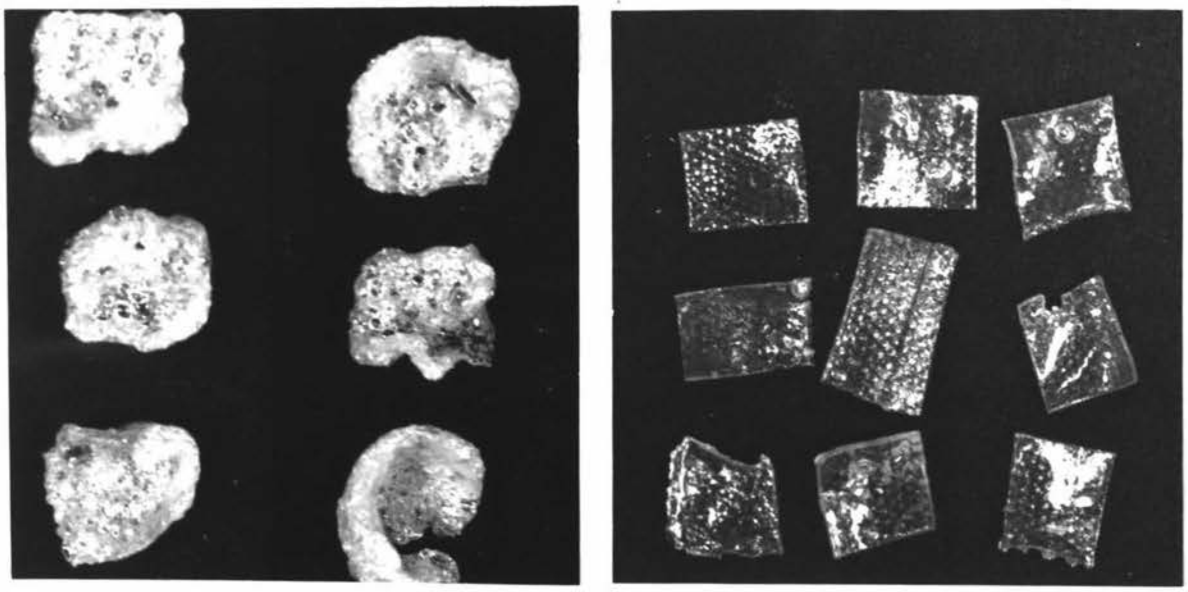
A marked increase in volume was noticed between Nos. 1 and 2 with

FIG 20



No 4 24·65% Moisture

No 3 16·8% Moisture



No 2 12·9% Moisture

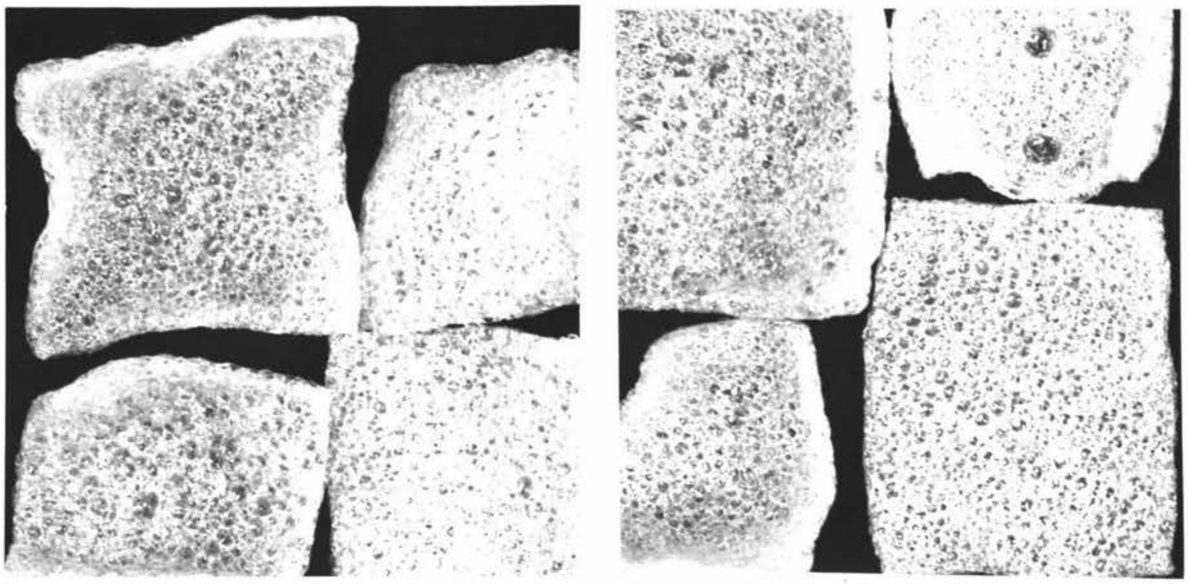
No 1 11·3% Moisture

Puffing vs. moisture content of 10% GELATINE GELS in fat at 275°F.

Scale

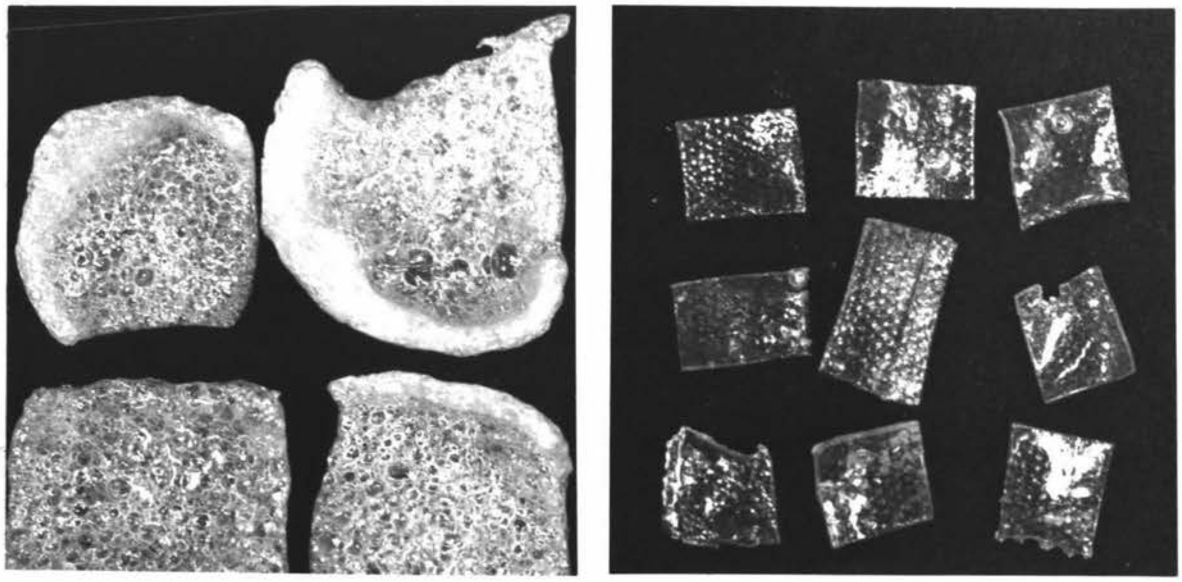
0" 1" 2"

FIG 21



No 4 350°F

No 3 325°F



No 2 300°F

No 1 275°F

Puffing vs. temperature of frying of 10 % GELATINE GELS at 11·3 % moisture (d.w.b).

Scale

0" 1" 2"

little apparent difference between Nos. 2, 3 and 4 although bubble size in No. 4 is larger than in Nos. 2 and 3.

Fig. (20) - 275°F. Frying Temperature

No.1 11.3% Moisture. No puffing took place and, in fact, the gel shrunk on heating to 275°F.

No.2 12.9% Moisture. Only slight puffing took place. Volume was 3.73 c.c./gm. (d.w.b.).

No.3 16.8% Moisture. Volume considerably increased on No. 2.

No.4 24.65% Moisture. Puffing volume was large.. However, structure contained a number of large bubbles and some shrinkage took place on cooling.

The effect of varying puffing temperatures at constant moisture is also shown by four photographs of a gel puffed at four different temperatures.

Fig. (21) - Moisture Content 11.3% (d.w.b.)

No.1 275°F. No puffing whatever had taken place. Volume after frying was 0.55 c.c./gm. (d.w.b.).

No.2 300°F. At a temperature only 25°F. higher than for No. 1, the sample puffed quite evenly to 12.4 c.c./gm.

Nos. 3 and 4 325°F. and 350°F. respectively. An increase in volume (15.9 and 18.4 c.c./gm. respectively) was shown over No. 2. Gels tended to have finer texture and smaller bubble size. Little difference was seen between Nos. 3 and 4.

These photographs show graphically the effect of increases in temperature within narrow limits of moisture content.

III. NATURE OF GEL FORMING BONDS AND THEIR RELATIONSHIP TO PUFFING.

According to Ferry (1948) gels fall into three major classes.

(a) Those gels formed by random non-localised secondary bonding between long chains, e.g. Starch gel.

(b) Those gels formed by localised secondary bonding; that is, bonding that takes place at specific sites on a long organic molecule, e.g. Gelatine.

(c) Those gels formed by primary chemical bonding and, unlike the above two, are not heat reversible gels, e.g. Calcium precipitated milk protein.

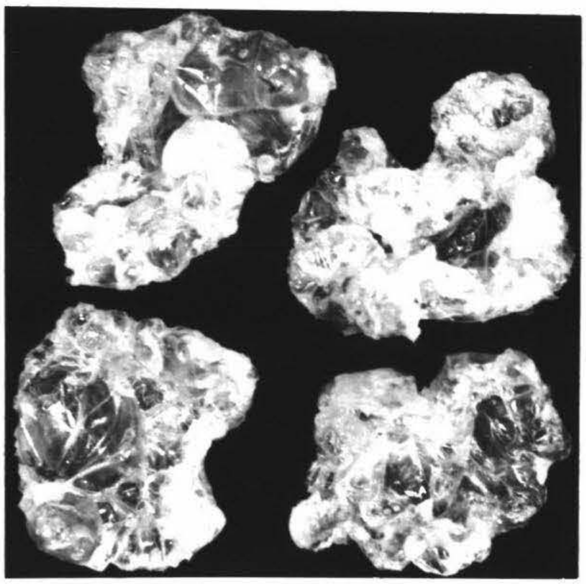
Gels of the first two groups were successfully puffed and to complete the picture, a gel in the third group was studied.

It was known that formaldehyde forms primary chemical bonds between and within gelatine molecules. By treating a 10% gelatine gel with formaldehyde, a gel containing primary chemical bonds was obtained.

10% Gelatine gels were placed in a desiccator above a concentrated formaldehyde solution at 86°F. (30°C.) for five days. A sample was removed at 24 hourly intervals and puffed at 350°F.

Photographs in Fig. (22) show that inhibition of puffing took place very rapidly, presumably as a result of surface tanning of the gelatine. The 48 hour sample showed this particularly well for the outside layer on one piece had split revealing puffed gelatine within. It was a considerable period before puffing was completely inhibited. After 96 hours, some areas still showed slight areas of

FIG 22



Effect of exposing 10% GELATINE gel to formaldehyde on puffing characteristics.

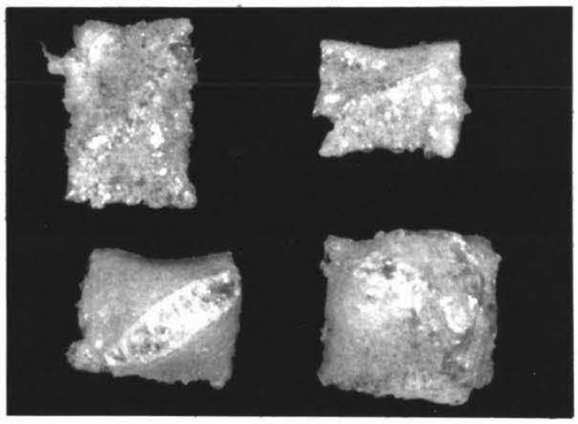
No1

0 hrs. 280°F

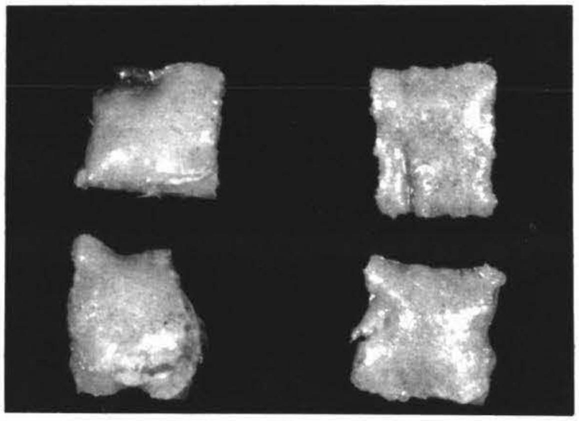
20% Moisture content.

scale

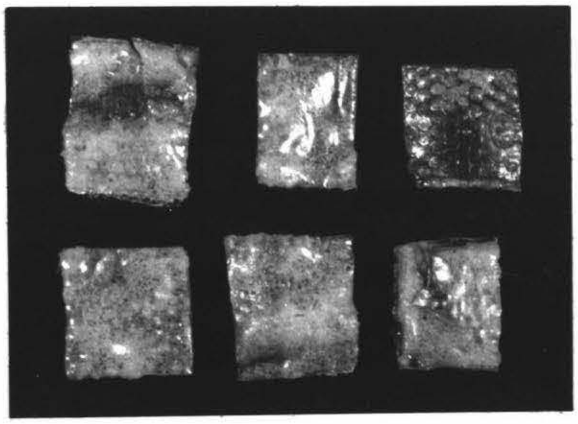
0" 1" 2"



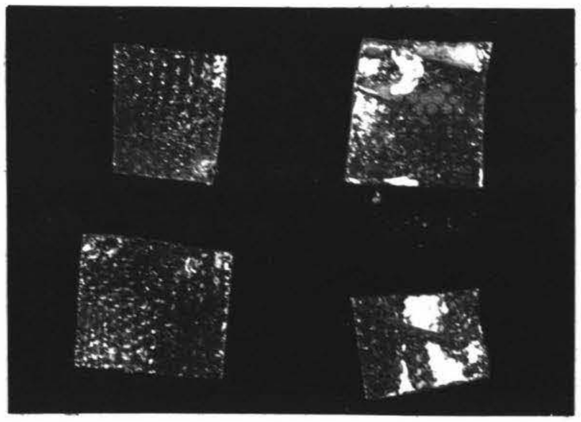
No2 48hrs. 350°F



No3 72 hrs. 350°F



No 4 96 hrs. 350 °F



No5 120 hrs. 350°F

puffing. However, after 120 hours puffing had been completely inhibited.

It would appear that extent of puffing had been related to formaldehyde penetration and the formation of primary bonds. It thus seems reasonable to suggest that gels incorporating secondary bonding only are suitable for puffing.

IV. RESIDUAL MOISTURES IN PUFFED GELS.

Interest at this point was aimed at finding out a little more about the moisture in low moisture content gels. It was apparent that moisture content below a certain percentage did not cause puffing below the "Critical Puffing Temperature". An experiment was designed to find out if this moisture was in fact removed during frying.

Residual moistures of two samples after puffing at 400°F. and 10% moisture, were 3.2% and 1.6%. Thus water was removed that would not cause puffing if present only in those amounts.

The table below shows the loss of moisture of two samples, at two temperatures, with time in minutes. Sample No. 1. did not puff while Sample No. 2. did.

TABLE (9) Loss of Moisture with Time During Frying in Fat.

Sample No. Frying Temp.	1 380°F.	2 400°F.
Time Mins.	Moisture Content %	Moisture Content %
0	7.55	8.8
0.5	-	1.98
1.0	2.52	1.32
2.0	1.99	1.07

Removal of moisture appeared to be slower in samples that did not puff. This may be due to a longer diffusion path in unpuffed samples. However, there can be no doubt that although a gel may not puff, the conditions were sufficiently rigorous to remove remaining moisture.

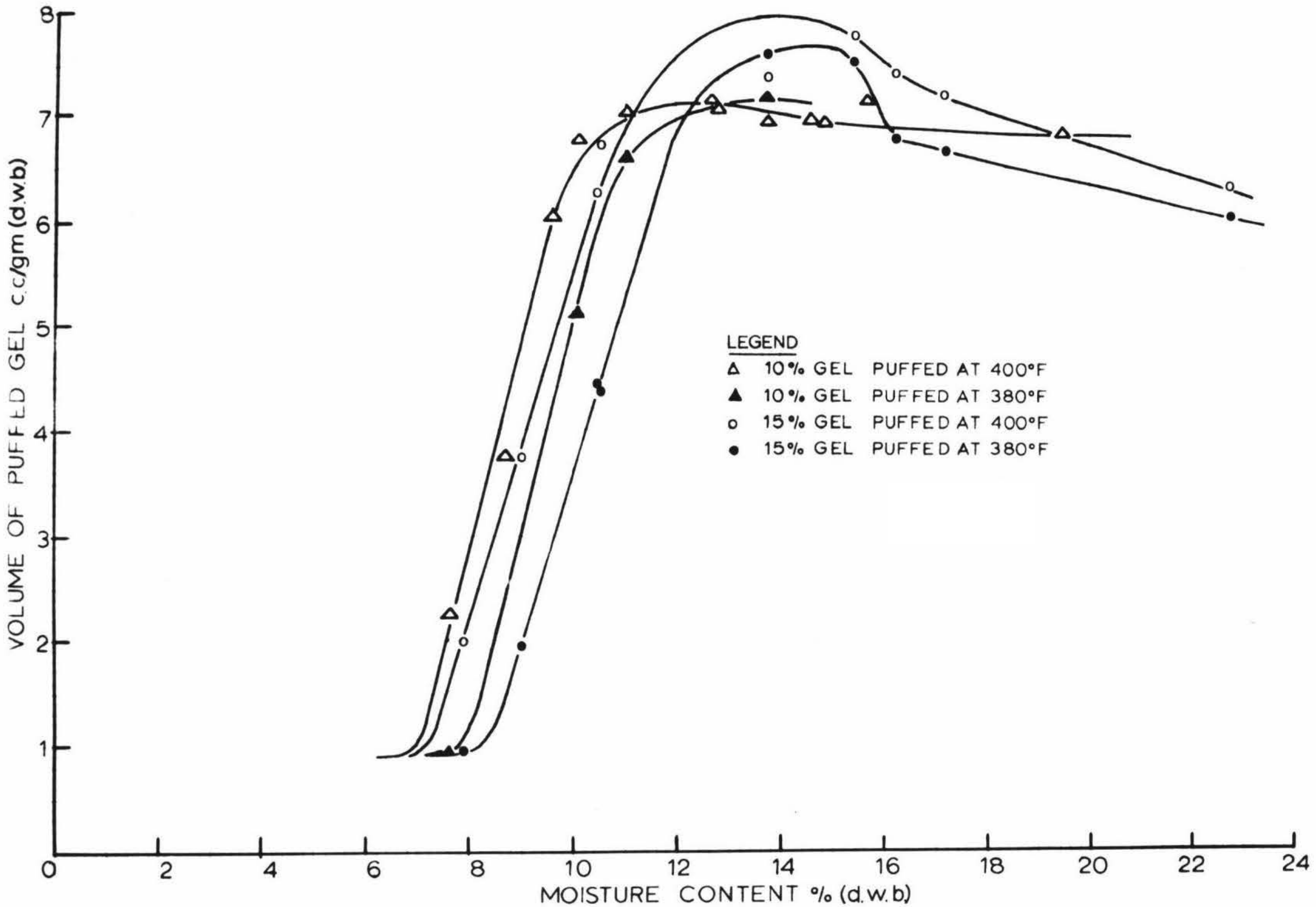


FIG 23 Graph of moisture content (before puffing) vs. puffing for two STARCH gels (10% and 15%) and at two frying temperatures (380°F and 400°F). The graph shows the effect of increasing the setting strength of the gel on its puffing characteristics.

V. EFFECT OF VARYING GEL SETTING STRENGTH ON PUFFING.

A previous experiment had shown that strength or chemical nature of gel forming bonds affected puffing. It seemed reasonable to suppose that an increase in the number of secondary bonds per unit volume would also affect puffing. To study this possibility, an experiment was conducted in which puffing characteristics of 15% Starch gels were studied at two frying temperatures. The results were compared with the puffing of a 10% Starch gel. Both gels were prepared in such a way as to make them of equal thickness when dried.

Results are tabulated in Table (10) and presented graphically in Fig. (23).

The following observations were made from the graph:-

(a) If a higher moisture content is required before the stronger gel begins to puff, the increase over that for a 10% gel is slight.

(b) The gradient of steep section of the graph decreases as gel strength increases.

(c) Peak puffing volumes are higher for gels of higher strength.

(d) Puffing for a stronger gel decreases more rapidly past the optimum moisture content.

TABLE (10) A Comparison of Puffing of 10% and 15% Starch Gels.

Moisture Content % (d.w.b.)	Puffing c.c./gm. (d.w.b.)			
	10% Starch Gel		15% Starch Gel	
	380°F.	400°F.	380°F.	400°F.
7.63	-	-	0.96	2.25
7.9	0.95	1.98	-	-
8.7	-	-	-	3.74
9.0	1.93	3.73	-	-
9.6	-	-	-	6.03
10.1	-	-	5.1	6.75
10.45	4.42	6.25	-	-
10.55	4.38	6.7	-	-
11.05	-	-	6.58	7.0
12.7	-	-	-	7.1
12.8	-	-	-	7.03
13.8	7.58	7.35	7.17	6.92
14.6	-	-	-	6.95
14.9	-	-	-	6.9
15.45	7.5	7.76	-	-
15.7	-	-	-	7.14
17.2	6.67	7.2	-	-
19.5	-	-	-	6.82
22.8	6.05	6.33	-	-

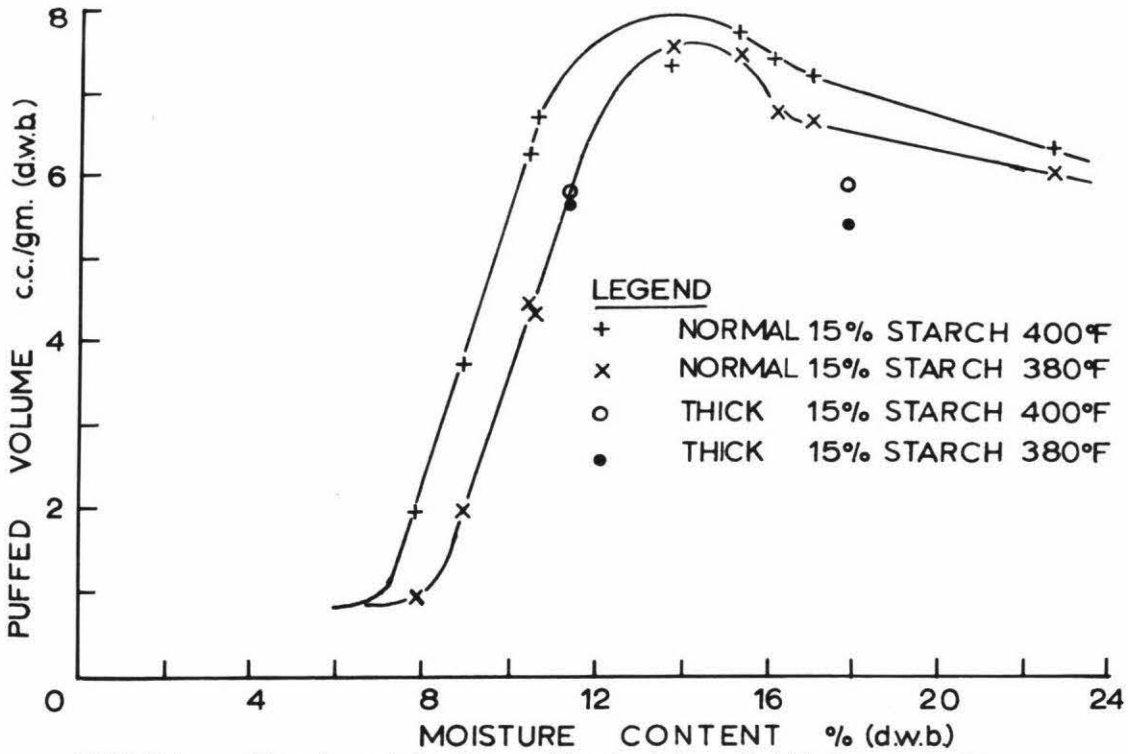


FIG 24 Graph showing effect of gel thickness on puffing.

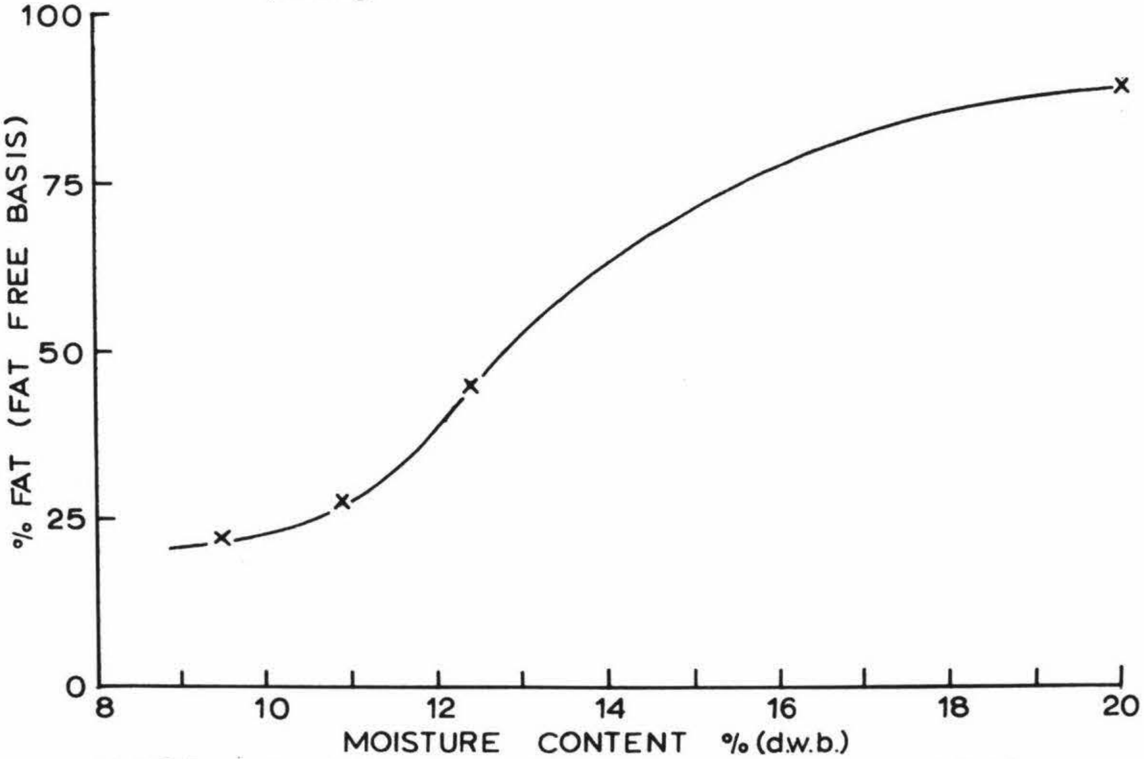


FIG 25 Graph of fat pick-up vs. moisture content (before puffing) during frying of 10% STARCH GEL at 380°F.

VI. EFFECT OF VARYING GEL THICKNESS ON PUFFING.

A comparison was made between two 15% Starch gels, each of different thickness. One was poured $^{9}/64$ in. thick and was the same as 15% Starch gels used in other experiments. The other was $^{12}/64$ in. thick. This latter gel was puffed at two moistures and two temperatures and the results are given in Table (11).

TABLE (11) Puffing of 15% Starch Gel Poured $^{12}/64$ in. Thick

Moisture Content % (d.w.b.)	Puffing c.c./gm. (d.w.b.) at -	
	380°F.	400°F.
11.4	5.66	5.8
18.0	5.4	5.88

The relationship of these four points to a graph of puffing against moisture content for a 15% Starch gel poured $^{9}/64$ in. thick can be seen in Fig. (24).

These meagre results are inconclusive. They showed, however, that the steep section of the curve was unchanged since the point 11.4% moisture and 5.6 cc./gm. volume at 380°F. for thick gel coincides with the graph at 380°F. for the thinner gel.

VII. FAT PICK-UP AS A RESULT OF DEEP FAT FRYING.

Four samples of Standard Starch Gel, each with a different moisture content, were prepared and weighed samples were fried in duplicate at 380°F. in hydrogenated oleo oil until puffing had been completed. Samples were shaken briefly and allowed to cool. Fat content of each sample was determined by Soxlet extraction and expressed as a percentage on a dry starch basis.

Results of fat pick-up are given in Table (12) and are shown graphically in Fig. (25).

TABLE (12) Fat Pick-up During Frying at Four Moistures.

Sample No.	Moisture Content % (d.w.b.)	Average % Fat (dry starch basis)
1.	9.5	22.1
2.	10.9	27.5
3.	12.4	45.0
4.	20.0	88.6

Fat pick-up has thus been shown to increase with moisture content. It would also be reasonable to expect fat pick-up to be related to surface area which increases enormously during puffing of the gel.

VIII. EFFECT OF DISSOLVED SUGARS AND DISPERSED FAT IN GELS ON PUFFING.

Four gels were prepared.

(a) A 10% Standard Starch Gel.

(b) A 10% Standard Starch Gel containing 10% sucrose.

(c) A 10% Standard Starch Gel containing 10% glucose.

(d) A 10% Standard Starch Gel containing 10% fat.

Each was coloured with a drop of food dye for identification purposes. The gels were dried and equilibrated together in the "Tumbler" for three days. Because they were equilibrated together, each sample will be in equilibrium with the same Relative Humidity. The starch fraction of each sample could be expected to contain the same percentage of moisture. Moisture content of the pure starch sample was 15.1% (d.w.b.).

One pice from each sample was fried in fat at 400°F. and photographed. A photograph of the four gels is shown in Fig. (26).

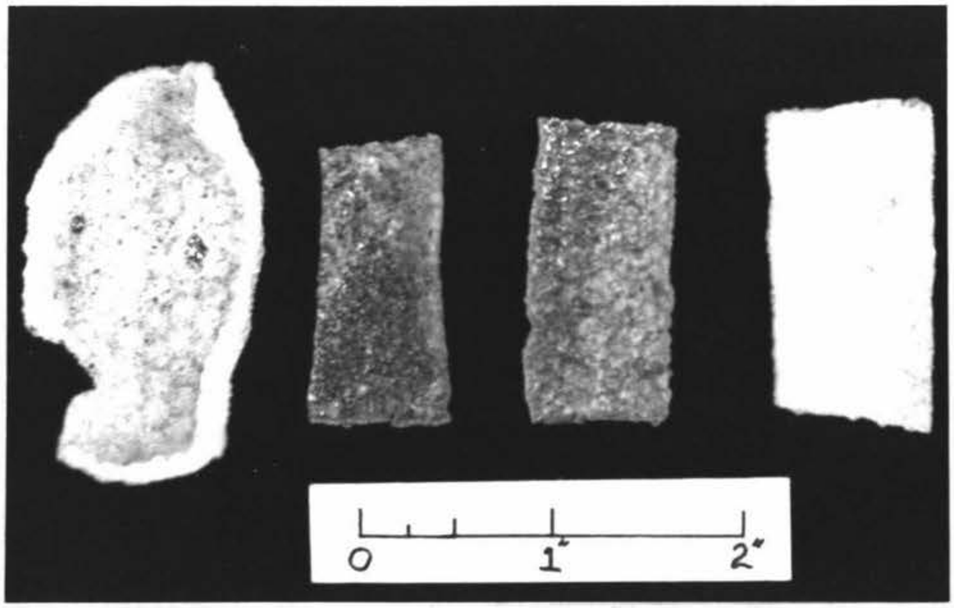


Fig. (26) Four gels after frying in fat at 400°F.
From left to right they are: 10% Starch, 10% Starch and 10% Sucrose, 10% Starch and 10% Glucose, 10% Starch and 10% Fat.

As can be seen, the soluble sugars almost completely inhibited puffing. Some bubbles did form but the texture was very hard and glossy. Some caramelization took place.

The sample containing fat puffed evenly. However, the volume expansion was considerably less than that for pure starch.

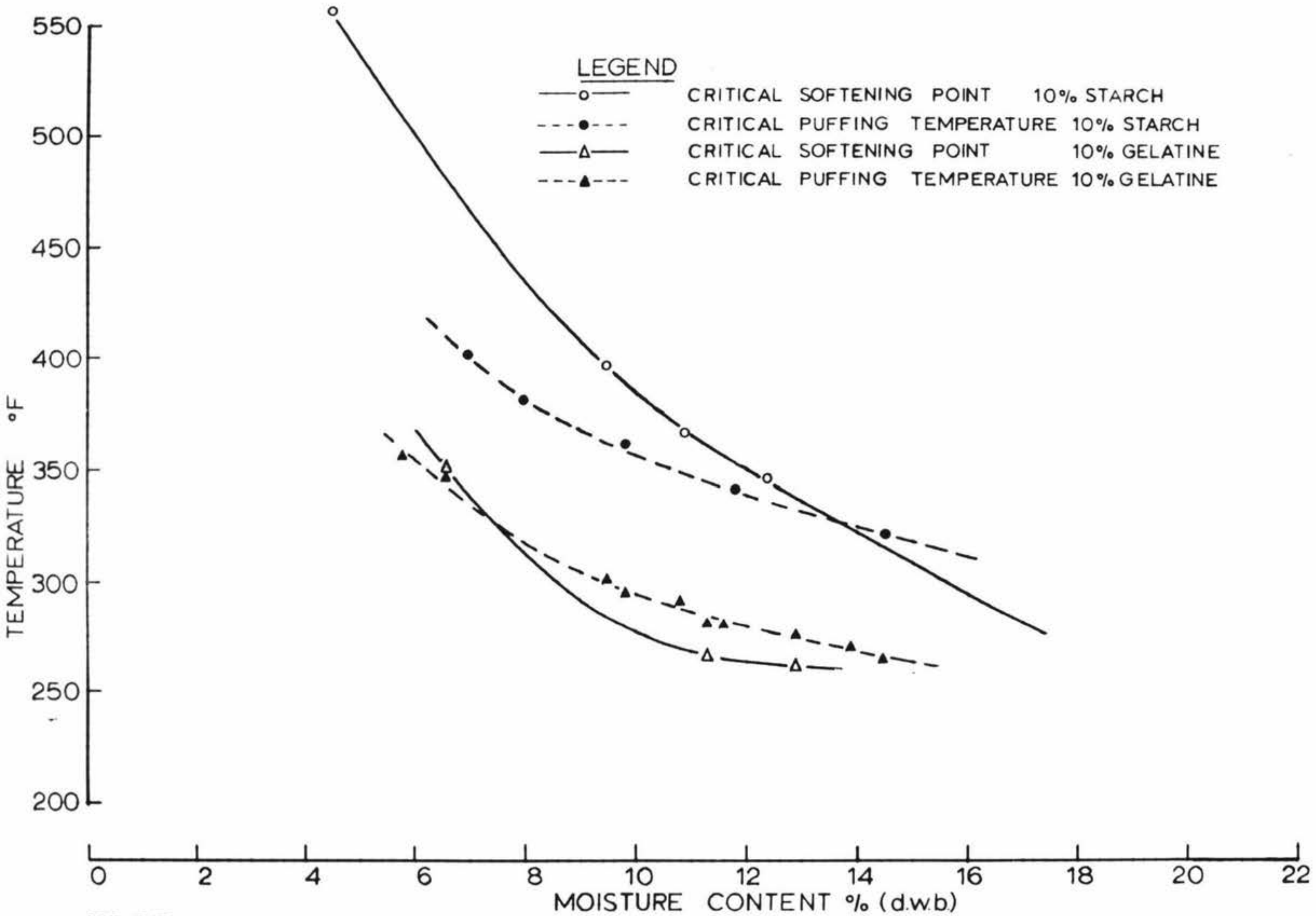


FIG 27 Graph showing Critical Puffing Temperature (C.P.T.) and Critical Softening Point (C.S.P.) for both 10% STARCH and 10% GELATINE GELS, and how it varies with moisture content. "C.S.P." of a gel is that point determined by the Thermoplastometer. "C.P.T." is that temperature at which a gel of given moisture content begins to puff.

IX. THERMOPLASTICITY OF A GEL.

It was thought that there could be some relationship between moisture content, puffing and softening of a gel as it was heated. To study this possibility, the thermoplasticity of 10% Starch and 10% Gelatine gels were determined.

The apparatus and method is explained in the section on "Analytical Methods and Experimental Techniques".

Also included in this study was the determination of "Critical Puffing Temperatures" of both 10% Starch and 10% Gelatine gels. Critical Puffing Temperature (C.P.T.) shows the relationship between puffing and moisture content, while Critical Softening Point (C.S.P.), determined with the Thermoplastometer, shows the relationship between moisture content and plasticity. The C.P.T.'s for gelatine were determined by finding the lowest temperature at which puffing was evident for a series of samples, each with a different moisture content. The C.P.T.'s for starch were obtained from Fig. (15). The moisture content at the base of the steep slope of each curve was taken as that moisture content at which that constant frying temperature became the Critical Puffing Temperature.

The results are tabulated in Table (13) and graphed in Fig. (27).

The curves of C.S.P. and C.P.T. appeared to show some relationship to each other. Each becomes steeper as moisture content approaches zero. It was also noted that the temperature at which the C.S.P. and C.P.T. curves cross (325°F.) is the same for both Gelatine and Starch gels.

TABLE (13) Critical Puffing Temperatures and Critical Softening Points for 10% Starch and 10% Gelatine Gels for a Range of Moistures.

Moisture Content % (d.w.b.)	10% Gelatine		10% Starch	
	C.P.T. °F.	C.S.P. °F.	C.P.T. °F.	C.S.P. °F.
4.55	-	-	-	555
5.8	355	-	-	-
6.6	345	350	-	-
7.0	-	-	400	-
8.0	-	-	380	-
9.5	300	-	-	395
9.8	295	-	360	-
10.9	290	-	-	365
11.3	280	265	-	-
11.6	280	-	-	-
11.8	-	-	340	-
12.4	-	-	-	345
12.9	275	260	-	-
13.9	270	-	-	-
14.45	263	-	-	-
16.8	250	-	-	-
19.2	-	-	-	250
20.0	-	-	-	240
20.6	240	-	-	-

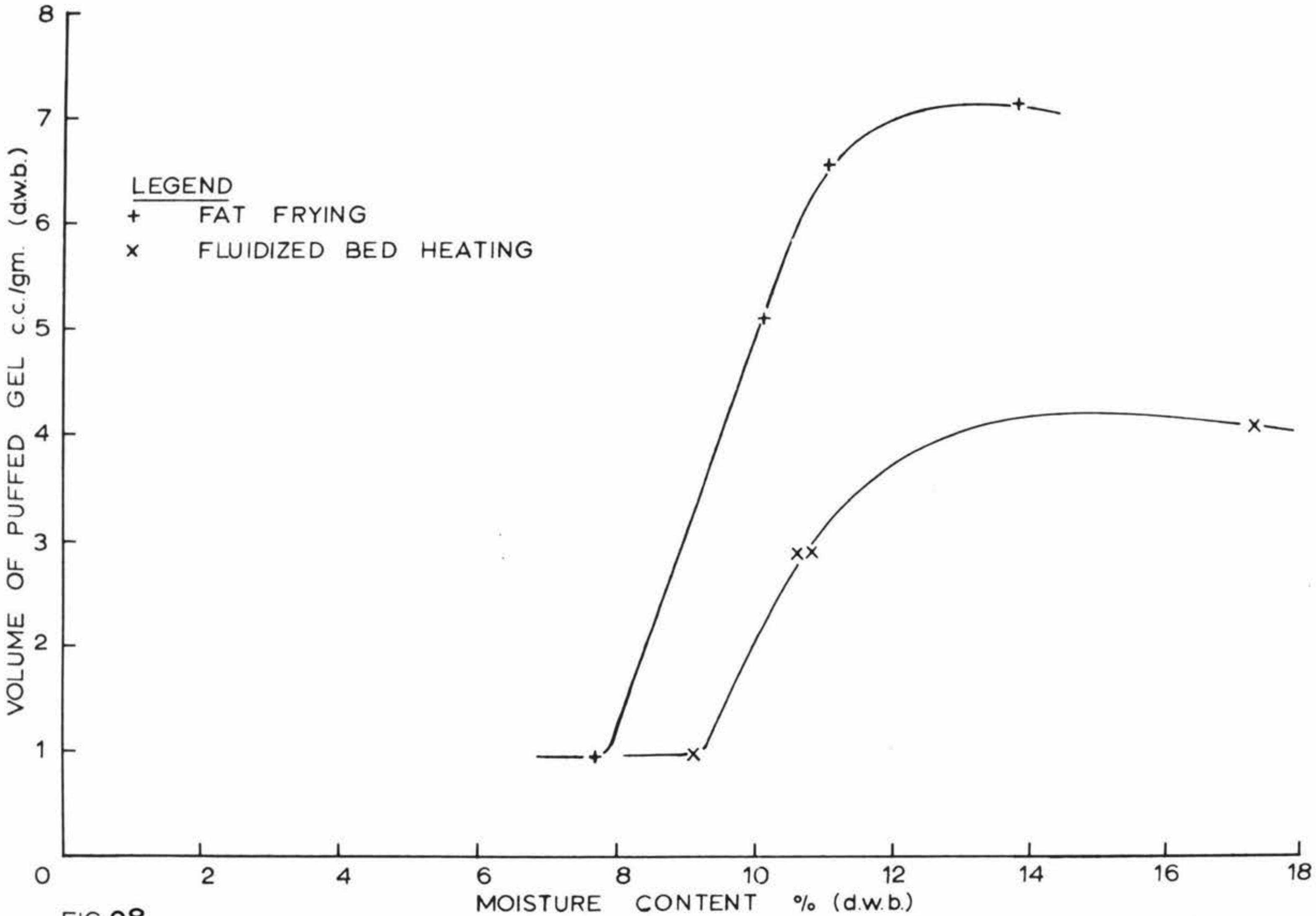


FIG 28 Graph shows the effect of different heating methods on puffed volume of 10% STARCH gel. Puffing was at 380°F.

X. EFFECT OF ALTERNATIVE HEATING METHODS ON PUFFING.

Two heating methods other than fat frying were tried in an endeavour to

(a) Overcome the problem of fat pick-up associated with fat frying.

(b) Get some measure of control on the extent of puffing of gels.

The first method studied was fluidized salt bed heating. Apparatus and experimental technique is discussed fully in the section on "Analytical Methods and Experimental Techniques".

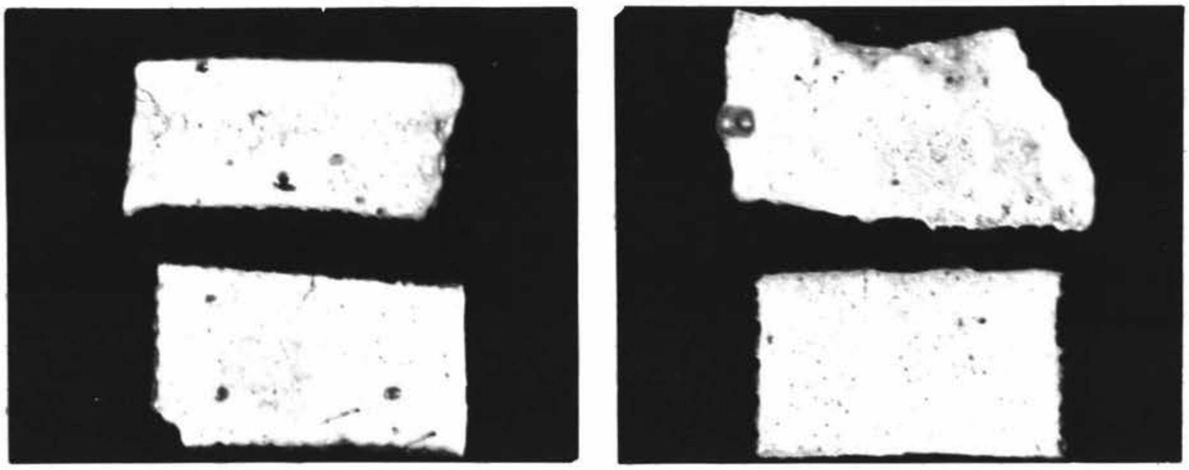
Five lots of Standard Starch Gel were equilibrated to five different moisture contents using the "Tumbler" method. A 10 gm. sample of each lot was heated at 380°F. by immersion in the fluidized salt bed until puffing had been completed. Puffed volumes were measured and the results compared with those volumes obtained by deep fat frying of similar gels. The results are tabulated in Table (14) below and represented graphically in Fig. (28).

No allowance has been made in the volumetric measurement for fat picked up in those samples fried in fat.

TABLE (14) Volumes of 10% Starch Gels Obtained by Puffing in Fat, in Fluidized Salt at 380°F.

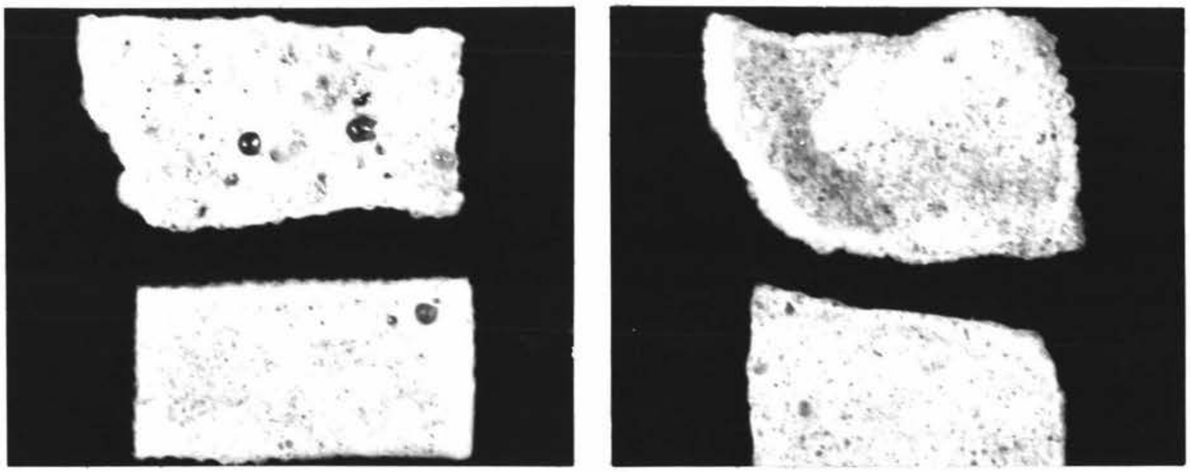
Moisture Content % (d.w.b.)	Deep Fat Frying 380°F. c.c./gm.(d.w.b.)	Fluidized Bed Heating 380°F. c.c./gm.(d.w.b.)
7.63	0.96	-
9.1	-	signs of puffing
10.1	5.1	-
10.6	-	2.9
10.85	-	2.91
11.05	6.58	-
13.8	7.17	-
17.3	-	4.13
27.2	-	3.46

FIG 29



No1 9·5% Moisture

No2 10·9 % Moisture



No3 12·4% Moisture

No4 20·0% Moisture

Effect of fat and salt heating on puffing volumes at different moistures (d.w.b.). Temperature of frying was 380°F. Fat fried sample in top, salt fried sample in bottom of each photograph.

scale

0" 1" 2"

As is shown by these results, puffed volumes obtained by heating in fluidized salt were about half those obtained by heating to the same temperature in fat.

In Fig. (29) there are shown photographs of samples fried by these two methods at the following four moisture contents:-

9.5%, 10.9%, 12.4% and 20.0% (d.w.b.)

The difference in puffed volumes at each moisture content as a result of the different heating methods can be clearly seen.

It has also been found that radiant heating can cause puffing. A Muffle Furnace was heated to 500°C. and samples of Gelatine, Starch, Gluten and other gels were placed inside for a few seconds. Care was necessary to ensure that the samples were removed before they charred. Satisfactory puffing was obtained although no volumetric or photographic records were kept.

DISCUSSION OF RESULTS.

It has been shown that if a gel of Starch or Gelatine is dried to a low moisture content a physical state is reached whereby when subjected to high temperatures, the gel expands to many times its original volume and becomes very porous. The structure on expanding consists of a large number of cavities with thin walls of gel material. This expansion has been called "puffing".

Moisture is lost by a dried gel during frying and this loss occurs even if puffing does not take place. This trend is shown in Table (9). If the moisture content of a particular dried gel when fried at a particular temperature is above a particular critical level, puffing does take place.

Puffing is shown in Fig. (15) to be related to both moisture content and frying temperature, and as the frying temperature increases so does the likelihood that a gel of particular moisture content will puff.

It would appear that this expansion is due to vaporization of portion of the moisture content. This steam so formed then expands forming a pocket or cavity within the gel. However, this only occurs above critical moisture and temperature levels where it would appear that the gel can no longer contain evaporating moisture, and it expands to accommodate it.

The system can be visualized as being in equilibrium under those conditions at which signs of puffing begin to occur. When either the temperature or the moisture content is increased above this equilibrium point a situation of dis-equilibrium can be said to ensue and the system expands to the point where equilibrium is once again established and expanding moisture vapour has been accommodated.

Above the minimum amount, puffing increases rapidly as moisture content increases. The volume of a 10% Starch gel reaches a peak after puffing at from 3 - 4% moisture content above the minimum amount. An example may be taken from Fig. (15) for the puffing of a 10% Starch gel. The critical moisture content for puffing at 400°F. is 7.0%. Puffing reaches a peak at 11.0% where the volume of puffed gel is 7 c.c./gm. (d.w.b.).

It would appear from the above discussion that -

(a) Puffing is due to the evaporation of moisture present in the gel.

(b) Only a part of the total moisture content plays a part in volume increase.

It is conceivable that, as puffing occurs only at temperatures above the boiling point of free water at atmospheric pressure, the moisture in the gel must evaporate under pressure. The gel must then expand because it is subjected to internal steam pressures developed by frying at high temperatures.

It was mentioned during the presentation of results that just above minimum puffing conditions, as shown in Fig. (15), the puffing curves rise steeply, the gradients being fairly similar for each curve representing a different temperature.

If it is assumed as was suggested previously that expansion is due only to evaporation of that moisture above the critical level, it is possible to calculate the volume occupied by this moisture when present as saturated steam at the frying temperature. These calculations may then be compared with the experimental volume increase as obtained from those gradients mentioned in the preceding paragraph.

The pressure of saturated steam at 400°F. is 250 p.s.i. and occupies 1.8438 $ft.^3/lb.$ - Perry (1963)

$$1 \text{ lb.} \equiv 454 \text{ gm.}$$

$$1 \text{ ft.}^3 \equiv 28,200 \text{ c.c.}$$

Thus 1 gm. of water occupies -

$$\frac{28,200}{454} \times \frac{1.8438}{1} \text{ c.c.}$$

Volume of vapour = 115 c.c./gm.

Thus the "Theoretical Volume Increase Percent" of the gel at this temperature is 1.15 c.c./gm./% moisture.

Likewise, the Theoretical Volume Increase Percent of gels fried at -

380°F. is 1.41 c.c./gm./% moisture
360°F. is 1.86 c.c./gm./% moisture
340°F. is 2.31 c.c./gm./% moisture

To obtain the actual experimental volume increase of gels, the gradient of each curve representing puffing at 400°F., 380°F., 360°F. and 340°F. in Fig. (15) was determined. The gel studied was 10% Starch gel.

For example, the gradient of the curve representing puffing at

400°F. is as follows:-

At 1 c.c./gm., moisture content = 7% (d.w.b.)

At 7 c.c./gm., moisture content = 10% (d.w.b.)

Slope of curve $= \dfrac{6 \text{ c.c./gm.}}{3\% \text{ moisture}}$

$= 2$ c.c./gm./% moisture

Other gradients are:-

380°F.	2 c.c./gm./% moisture
360°F.	1.79 c.c./gm./% moisture
340°F.	1.67 c.c./gm./% moisture

Likewise, slopes of the curves representing puffing of 15% Starch gel in Fig. (23) are as follows:-

400°F.	1.67 c.c./gm./% moisture
380°F.	1.58 c.c./gm./% moisture

All of the above information is tabulated in Table (15).

TABLE (15) Actual and Theoretical Volume Increase per Percent Moisture at Different Temperatures for 10% and 15% Starch Gels.

Frying Temperature °F.	Theoretical Volume Increase c.c./gm./%	Actual Volume Increase	
		15% Starch c.c./gm./%	10% Starch c.c./gm./%
400	1.15	1.67	2.00
380	1.41	1.58	2.00
360	1.86	-	1.79
340	2.31	-	1.67

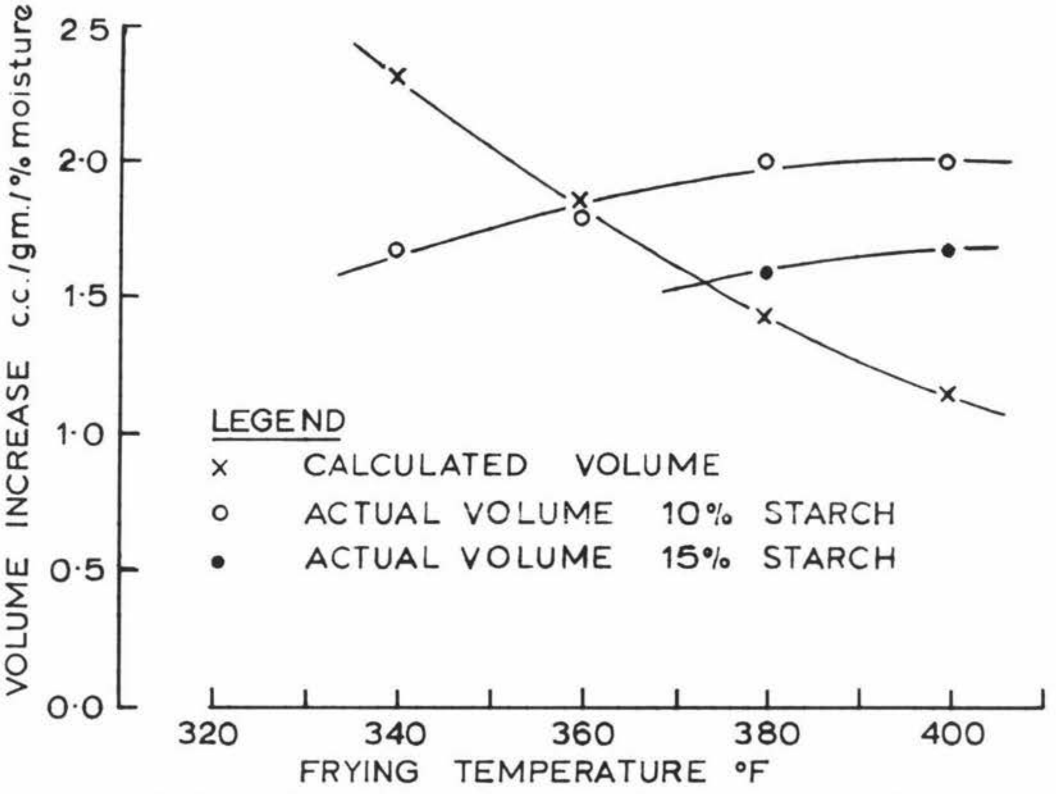


FIG30 Graphs of actual and theoretical puffing increase with increase in temperature.

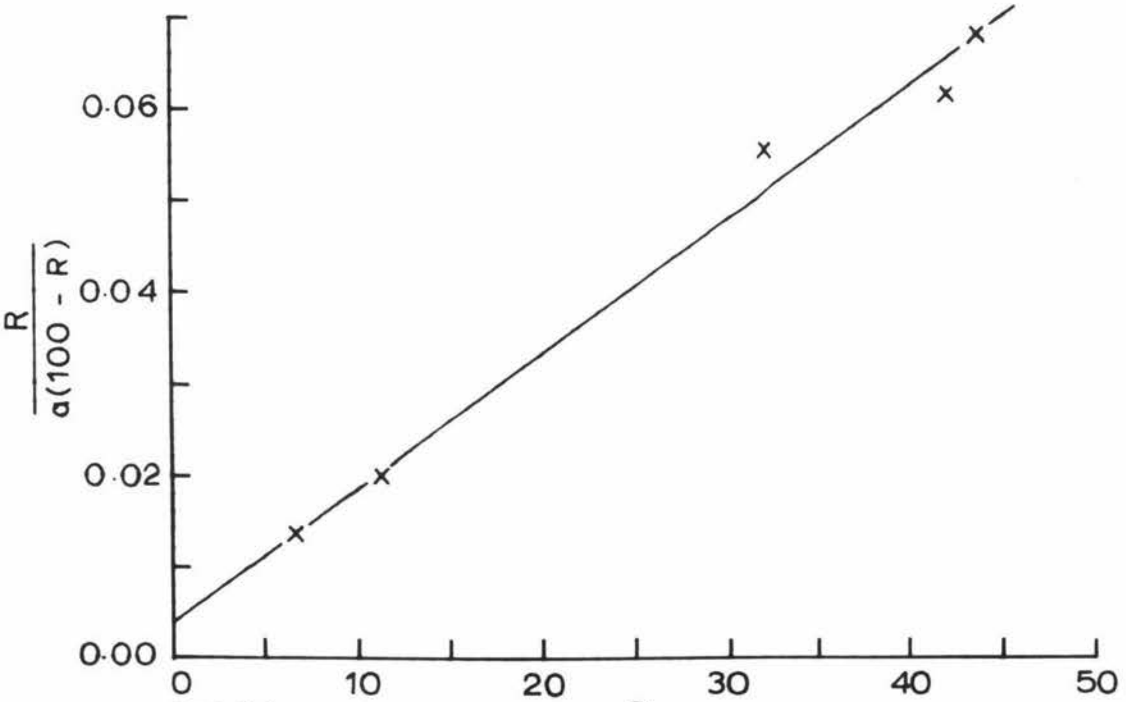


FIG 31
Graph for monolayer calculation 10% STARCH.

In the theoretical calculations it is assumed that the cavity filled with steam does not weaken as it increases in size. However, as it expands, the surrounding film of gel is drawn into a thinner and thus weaker layer. Surface area, and thus the stress exerted at a particular pressure, increases as r^2 increases (r = cavity radius). Strength of the corpuscle decreases as r increases. As puffing takes place, the corpuscle becomes weaker, expanding to a larger volume which in turn causes further weakening allowing a drop in pressure. This permits some moisture to vaporize that would not otherwise have done so. It would appear that once a gel begins to puff the resultant puffed volume could be in excess of the calculated volume because of the above factors.

A graph of theoretical and actual volumes as tabulated in Table (15) is shown in Fig. (30) and it shows that, as suggested, actual experimental results tend to be higher than the calculated ones. Nevertheless, theoretical and actual results show considerable agreement. The 15% gel, perhaps because of its increased density of bonds and thus increased strength, does not exceed theoretical values as much as the weaker 10% gel.

It is clearly apparent that, as theoretical calculations based on saturated steam volumes agree so closely with experimental results, it is steam under pressure that is causing volume expansion and not entrapped gas or some other cause.

Because it is necessary for a gel to expand during puffing the type of gel-forming bond may play some part in determining its puffing characteristics.

The effect of bond type on puffing was shown in Section III. of the "Results". It was shown that only those gels formed with localized secondary bonds, such as Gelatine, or non-localized secondary bonds, such as Starch, puff when dried to a suitable moisture content.

Gels formed with primary chemical bonds such as formaldehyde treated gelatine, are apparently so strong that steam pressures obtainable by frying are not sufficient to disrupt them and no puffing occurs.

Up to this point it has been shown that -

(a) Puffing in dried gels is due to the vaporizing of part of their residual moisture content.

(b) Steam pressures required for puffing are substantial, being 250 p.s.i. at 400°F., 200 p.s.i. at 380°F., 155 p.s.i. at 360°F. and 120 p.s.i. at 340°F. when saturated.

(c) Only those gels relying on secondary bonding for gelation can be puffed.

It would appear that there is some physical characteristic of dried gels which permits the development of high internal pressures. It is noted that these pressures are not sufficient to puff a gel with moisture content below a particular level and above this level only that moisture in excess takes part in volume expansion. The system appears to be in equilibrium at the critical moisture content, and at higher levels the excess moisture is evaporated until the equilibrium conditions are once again attained. It has been shown that this evaporation takes place under pressure.

It was known that gels increased in plasticity as either -

(a) moisture content was increased, or

(b) temperature was increased.

Thus it is believed that "thermoplasticity" and/or "hygroplasticity" of a gel may be the other major factor determining the puffing characteristics of gels dried to low moistures.

To study this factor, the Thermoplastometer was developed and its use is described in "Analytical Methods and Experimental Techniques". The results obtained with this instrument are in the appropriate section. (See Fig. 27).

A study was made, using 10% Starch and Gelatine gels, of how two points moved in relation to each other as moisture content of the gel was varied. The first of these points is the Critical Softening Point (C.S.P.) and is that point measured by the Thermoplastometer. This value is a fixed plasticity. At any point on the C.S.P. curve the gel has the same plasticity and the curve shows how this plasticity is affected by temperature and moisture. As moisture content decreases, the same plasticity is obtained at a higher temperature. Likewise, as temperature decreases, the same plasticity is obtained at higher moistures.

The other point to be discussed is the Critical Puffing

Temperature (C.P.T.). This point is defined as "that lowest temperature at which a gel of particular moisture content shows signs of puffing" and is the point at which all factors affecting puffing are in equilibrium with each other. Whereas the first point measures the position of a constant, the second point measures the position of two variables. As the point moves up the curve to a higher temperature so the internal pressure exerted by vaporizing moisture increases. The other variable, to be called "resistance to puffing" at this stage, also changes as temperature increases. As temperature increases, steam pressure increases and thus, to maintain the equilibrium conditions (of which C.P.T. is a plot) the "resistance to puffing" increases. Likewise, as temperature is decreased, internal pressures are reduced and equilibrium is obtained with reduced "resistance to puffing".

At any particular temperature, it is possible to read off the curves of C.S.P. the moisture contents at which Starch and Gelatine gels have the same plasticity. Also, at any particular temperature the moisture contents of the two gels may be obtained from the C.P.T. curves at which the pressure of vaporizing moisture and, likewise, the "resistance to puffing" is the same.

At 325°F. the C.S.P. and the C.P.T. curves for both Starch and Gelatine gels intersect each other. The respective moisture contents are 13.7% and 7.5% (d.w.b.). As mentioned in the preceding paragraph, the pressure developed by saturated moisture vapour at this temperature can be assumed to be the same in each gel. The pressure is 95 p.s.i. Abs. Perry (1963). That steam under pressure causes puffing has already been shown. At this point the "resistance to puffing" must also be the same for it is just preventing the expansion of steam under the same pressure. It is noted that this factor called "resistance to puffing" is modified in the same way, by temperature and moisture content changes, as the C.S.P. Because of this relationship, and as it has been shown that the "resistance to puffing" must change to counteract altering pressures, when these two curves meet, the "resistance to puffing" equals that plasticity measured by the plastometer. Also, this point coincides for two unlike gels at the same temperature, and thus the same pressure.

This is convincing evidence that the Thermoplastometer measures that particular gel texture characteristic which constitutes one of the two major factors determining the puffability of a gel. The other factor, of course, is steam pressure. It should be realised that this C.S.P. curve is but one of a family of curves, each measuring a different plasticity which will be equal to the "resistance to puffing" at a different temperature, and thus equal to a different steam pressure. This particular plasticity is equal to the "resistance to puffing" at a steam pressure of 95 p.s.i. Abs.

Thus puffing is controlled by a combination of plasticity and steam pressure. When internal pressures exceed the plastic strength it puffs. When internal pressures are less than, or equal to, the plastic strength, no puffing occurs. Pressure is temperature dependant and the plastic strength, necessary to be in equilibrium with pressure, is dependant on temperature, moisture content and internal pressure.

The relationship between pressure (P), temperature (T) and plasticity (K) is more readily represented as equations.

Allow a gel to be fried at two temperatures. At T_1 the gel puffs, and at T_2 the gel does not puff.

$$\text{Thus } T_2 < T_1$$

and as T_2 tends to T_1, K_2 tends to K_1

$$\text{where } K_2 > K_1$$

As T_2 tends to T_1, P_2 tends to P_1

$$\text{where } P_2 < P_1$$

At T_1 puffing occurs, so therefore

$$P_1 > K_1$$

At T_2 puffing does not occur, so therefore

$$P_2 < K_2$$

At some Temperature T in between T_1 and T_2 only initial signs of puffing will be seen at which point $P = K$ and the system is in equilibrium.

This factor, plasticity, it would appear, dictates a gel's puffing characteristics more than any other single factor. As mentioned previously, the C.S.P. curve measures but one plasticity which equals the "resistance to puffing" at a particular temperature. A series of C.S.P. curves could be drawn which would indicate other points at which a different plasticity is equal to other "puffing resistances". If it is assumed that these curves lie fairly parallel to each other, puffing characteristics of a gel can easily be predicted.

If the C.S.P. and C.P.T. curves are steep, (as for Starch gel) puffing will not be extensive for strength rapidly increases as puffing takes place and moisture is converted into vapour. Also, if the curves are positioned at a lower temperature for the same moisture content, puffing will be more extensive. At lower temperatures pressures are lower and thus volumes occupied by the same amount of moisture vapour are larger.

The C.S.P. curve for Gelatine gel is positioned at a lower temperature than the C.S.P. curve for Starch gel. Also, in the puffing of 10% Gelatine gels the C.S.P. curve above 10% moisture is almost horizontal indicating that plasticity does not change during puffing as moisture is lost down to this level. Moisture may be vaporized down to 10% without significant change in internal pressures. The C.S.P. for 10% Starch is, on the other hand, fairly steep.

Under these conditions greater volume per gram of dry gel would be expected for Gelatine gels than for Starch gels. This is so. Starch has been puffed to a maximum volume of approximately 7 c.c./gm. whereas Gelatine gels have been puffed to as high as 28 c.c./gm.

Gels puffing at high pressures require a greater wall thickness to retain this pressure than gels puffing at lower temperatures and pressures. Thus corpuscles expanding under high pressures may burst while the wall is still fairly thick. Corpuscles expanding under low pressures are able to expand until the walls are very thin and still contain internal pressures. The higher the C.S.P. curve above 212°F. the lower the maximum obtainable puffed volume.

It has been noted that the addition of sugars to a Standard Starch Gel affects its puffing characteristics. Fig. (26) illustrates four Starch gels with different additions in three of them. One is a control. All four samples were equilibrated in the same jar. Moisture content of the control was 15% (d.w.b.) which, according to Fig. (11), is in equilibrium with 63% Relative Humidity.

According to the method of Grover (1947) the concentration of a sucrose solution in equilibrium with 63% R.H. is 5.5 gm./gm. water. Such a solution contains 85% solids and if all the sugar is present in the dissolved or non-crystalline state, it will be a very highly supersaturated solution. Normally, sucrose solutions begin to crystallize at a concentration of 66% solids.

Supersaturated sugar solutions form glasses on drying. These glasses are very "tough" and if present in a dried gel, they could be expected to inhibit puffing. This effect could be more noticeable as moisture content decreased during puffing due to diffusion and vaporization.

A graph of C.S.P. against moisture content for gels containing an appreciable amount of sugar may be predicted to rise steeply as moisture content decreases, allowing only minor expansion during puffing.

The above reasoning is borne out in practice. When gels containing sucrose and glucose were fried, puffing was slight, as shown in Fig. (26). The product was very hard and glassy, being quite unpalatable.

Puffing has been shown to occur when a gel is sufficiently plastic and internal pressures are sufficiently high. Moisture is vaporized to develop these high pressures. Moisture also affects the plasticity of a gel at a particular temperature, as is shown by the C.S.P. curves. It is also known that the mode of adsorption of water onto gel molecules differs at different moisture contents and it is reasonable to suppose that the mode of binding of this moisture may have a distinct relationship to the way it affects plasticity and the gel's puffing characteristics. At very low moisture contents water is strongly held by hydrophilic groups. At higher levels it is present in a more free form, forming polymolecular layers on top of the strongly held monomolecular layer.

From information available in Table (16) it was possible to calculate how much moisture is strongly held by hydrophilic groups, as a monolayer. This calculation, devised by Brunauer, Emmett and Teller (1938) has become known as the B.E.T. Theoretical Monolayer, and is here calculated for a 10% Starch gel.

The modified graphical method of Salwin (1959) was used where R is graphed against $\frac{R}{A(100 - R)}$.

R = % Relative Humidity

I = y axis intercept

S = Slope of the straight line

$A_1 = \frac{I}{I + 100S}$

= gms. of water to fill the monolayer in 100 gms. of solids.

A = gms. water absorbed.

Only data up to 45% R.H. was plotted for it is known that above this level the graph deviates from the straight line.

The data plotted in Fig. (31) is as follows:-

TABLE (16)

R	100 - R	A	A(100 - R)	$\frac{R}{A(100 - R)}$
6.5-7	93.5	5.15	482	0.0135
11.1	88.9	6.3	560	0.0198
32.0	68.0	8.5	578	0.0553
42.0	60.0	10.88	648	0.0617
43.6	56.4	11.45	647	0.0674

Reading from the graph in Fig. (31) -

$$I = 0.004$$

$$S = 0.00143$$

Thus $$A_1 = \frac{1}{0.147}$$

$$= 6.75 \text{ gm./100 gm. solids.}$$

According to this calculation the moisture required to form a theoretical monolayer in gelled starch is 6.75 gm./100 gm. of dry starch.

The theoretical monolayer for gelatine according to Bull (1944) is 8.73 gm. of moisture/100 gm. of dry gelatine.

These moisture contents coincide with a point part way up the steep section of each C.S.P. curve. This point is approximately 2% moisture content lower than that point at which the gradient begins to increase. It can be said that the C.S.P. curve is virtually linear at moisture contents above monolayer moisture, but in the monolayer region of absorption the gel increases rapidly in rigidity. The margin between these two regions is, however, not a clear-cut one.

The effect of mode of moisture absorption is more clearly seen in the families of curves for the puffing of Starch and Gelatine gels, as shown in Figs. (15) and (18) respectively.

In frying 10% Starch gels no puffing was recorded below 7% moisture for temperatures up to 440°F. The curves for 440°F., 420°F. and 400°F. can be extrapolated to the base line of 1 c.c./gm. where they meet each other at 7% moisture. This point is just above the monolayer value of 6.75%. Puffing does occur at extremely high temperatures (550°F.) and low moistures (4.45%) but, like gelatine, the volume increase is not large in this region of puffing.

The family of curves representing the puffing of 10% Gelatine gels also appear to show some relationship to this theoretical monolayer value. Puffing at 6.6% moisture, a content below the monolayer value, occurs only above 345°F. The 350°F. and 325°F. curves at higher moistures when extrapolated to lower moisture contents meet at the moisture content corresponding to a theoretical monolayer. However, no puffing occurs at 325°F. at a moisture content of 8% and this curve must make a slight downward plunge. The 350°F. curve must, however, flatten out to meet the point 6.6% moisture and 5.75 c.c./gm. puffed volume. No puffing occurs at this temperature when the moisture content is as low as 6.2% so the curve must drop very suddenly.

(Note:- The values at which Gelatine gels do no puff were read off the C.P.T. curve for 10% Gelatine gels in Fig. (27)).

It is certain that the way moisture is bound in a gel plays an important part in the puffing phenomenon of dried gels. Its effect could take either or both of two forms -

(a) The gel's hydrophilic character may make it more difficult for water to be vaporized, and thus reduce steam vapour pressure below that which is obtainable with free water. Steam in this state would be below saturation and contain a few degrees of superheat.

This effect, if it did exist, would be strongest at a moisture content below the theoretical monolayer value. Frying temperatures are sufficient to remove all moisture at atmospheric pressure.

(b) The thermoplasticity of a gel is strongly related to moisture content and the same plasticity is only obtained in the monolayer region at substantially higher temperatures. It is suggested that moisture bound firmly to hydrophilic groups is not able to act as a "lubricant" between long molecular chains, whereas the lightly bound water molecules absorbed on top of the monolayer are more able to do so.

The effect of steam pressure depression seems to be small for it will be recalled that in Fig. (27) the C.S.P. curve crosses the C.P.T. curve at the same temperatures for both Starch and Gelatine gels. The moisture contents at which this event occurs, lie in two different adsorption regions. Moisture content of the Starch gel is 13.7%, i.e. more than double the monolayer value, whereas the moisture content of the Gelatine gel at 7.5% lies below the monolayer value. Nevertheless, this effect, although small, may not be insignificant.

The effect mode of moisture absorption has on plasticity is undoubtedly the major factor of these two.

The rate of heating of a gel was shown in Section X. of the "Results" to affect its puffed volume. A comparison of fat frying and fluidized salt bed heating was made. The heat transfer coefficient of a fluidized salt bed, although quite high, could be expected to be lower than the heat transfer coefficient obtained by direct contact with fat in a deep fat fryer. Heat transfer coefficients in fluidized beds range from 20 - 100 B.T.U./hr.ft.^{2} ^{o}F., Frantz (1962). Because conditions of agitation are uncertain in a fat bath no accurate estimation of rate of heat transfer can be made. However, as a guide, an example is taken from Perry (1963) of the heat transfer coefficient of a light oil flowing in a pipe. Pipe diameter is 1 in. and the oil is flowing at a mass velocity of 8 lb./sec.ft.^{2} at 400^{o}F. The heat transfer coefficient is 200 B.T.U./hr.ft.^{2} ^{o}F.

Results of puffing experiments show that the volume obtained by frying 10% Starch gels in fluidized beds is only half that obtained by frying in fat at the same temperature. This effect may once again be an indirect one. A slow heating rate would allow more moisture to diffuse to, and evaporate from, the surface before the gel had reached puffing temperature. A slowly heated gel would then puff to a smaller volume. Presumably, if the heating rate was slow enough to be counterbalanced by heat lost from the gel as diffusing moisture took up latent heat at the surface, no puffing whatever would occur.

CONCLUSIONS.

The studies show that the puffing phenomenon of low moisture gels when subjected to high temperatures is affected by five factors.

(a) Gel character
(b) Gel thermoplasticity
(c) Moisture content before frying
(d) Frying temperature
(e) Rate of heating

Gelation must occur by the formation of secondary localized or non-localized bonding between long molecular chains. Gels formed by primary chemical bonding between such chains do not puff.

The gel must have a satisfactory relationship between thermoplasticity and -

1. moisture content,
2. temperature of frying.

If the C.S.P. curve is too steep, puffing will be severely restricted. Likewise, if puffing occurs only at very high temperatures it will be severely restricted.

The gel must be heated to a suitable temperature at a suitable moisture content above the critical conditions. These two factors are related directly to thermoplasticity.

Finally, the rate of heat transfer must be sufficient to heat the gel to puffing temperatures before appreciable quantities of moisture are lost by diffusion to, and evaporation from the surface.

TECHNOLOGICAL STUDIES

RESULTS

INTRODUCTION

A number of pure, or near pure gels were studied to substantiate the postulate made under "Discussions of Results" in the preceding section of this Thesis. That is, "any material that can be induced to form a gel with secondary chemical linkages between long polymolecular chains will puff when subjected to high temperatures at a suitable moisture content".

This is followed by some developmental work to show some of the commercial possibilities of this process. The particular possible products developed were not chosen specifically for utilisation of local raw material or economic utilisation of waste materials produced by some food factories, but simply as typical applications in major commodity groups.

An attempt was made to cover as wide a range of gel structures as possible and also to demonstrate a wide range of product versatility. In a succeeding section, possible products and markets are suggested for those products puffed.

The final section deals with production of these puffs and the product and market potential of this puffing and dehydration process.

I. THE PUFFING OF PURE AND NEAR-PURE GEL SYSTEMS.

(a) Starch.

The preparation and puffing of Starch gels has been studied in the section "Fundamental Studies". A 10% Starch gel was in fact used as the standard gel for studying all the variables affecting puffing. To make this section complete a Starch gel is shown in Fig. (32) which has been puffed at 380°F. in fat. The moisture content before puffing was 20.0% (d.w.b.).

(b) Gelatine.

The preparation and puffing of a 10% Gelatine gel was also studied in some detail in the "Fundamental" section. Comparisons were made between Starch and Gelatine gels to show the effect of gel structure on puffing.

The puffed 10% Gelatine gel shown in Fig. (33) was fried in fat at 325°F. and had a puffed volume of 15.9 c.c./gm. Moisture content before frying was 11.3% (d.w.b.).

(c) Gluten.

Gluten, when suitably prepared, was also found to puff in the dried state. Commercial powdered wheat gluten was obtained from a local bakery and prepared in the following manner.

Sufficient water was added to the gluten to form a dough. This dough was worked by hand to form a cohesive mass and then rolled into a sheet $\frac{1}{8}$ in. to $^3/16$ in. thick. The sheet was

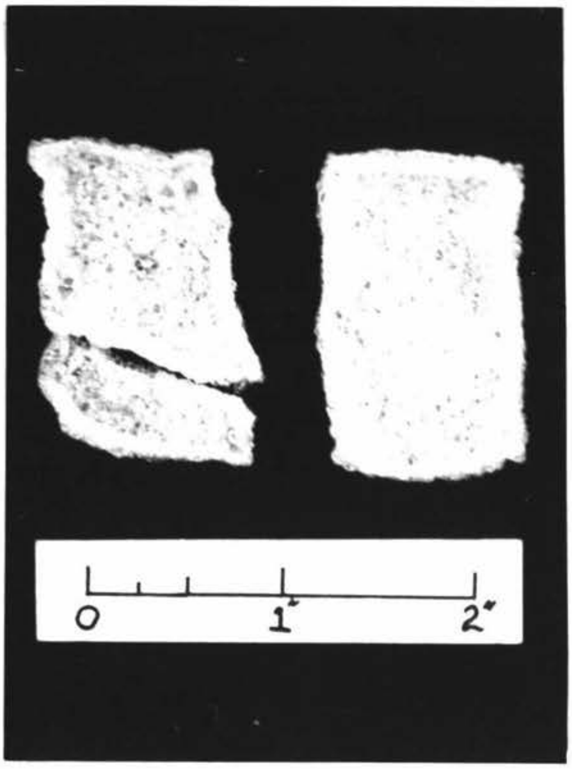


Fig.(32) Puffed Starch Gel.

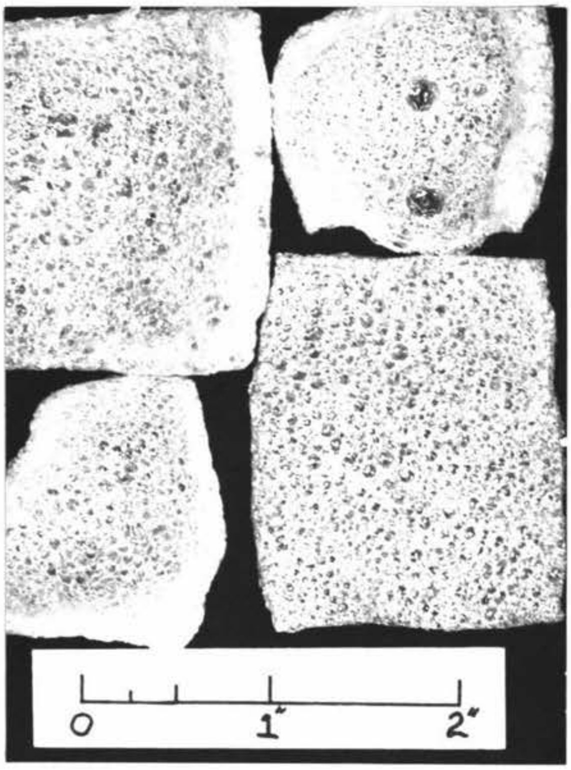


Fig.(33) Puffed Gelatine Gel

Fig.(34) Dried Gluten Gel before puffing at 380°F.

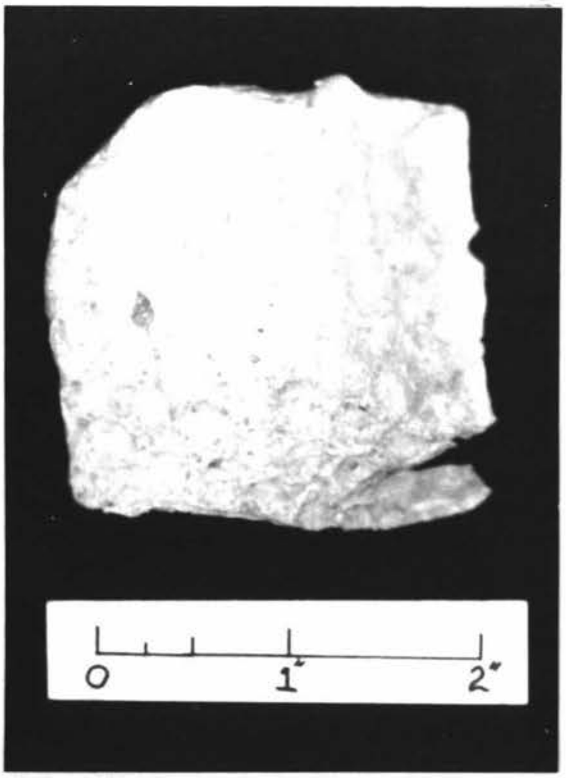


Fig.(35) Dried Gluten Gel after puffing at 380°F.

placed on a punched metal tray and dried at 110°F. for 20 hours. Moisture content of the flake so obtained was 8.1% (d.w.b.).

An extremely large volume increase was obtained by frying this Gluten in fat at 380°F. The volume of puffed gel was 13.45 c.c./gm. which is a puffed volume double that obtainable with 10% corn starch gels under optimum conditions.

Photographs of a Gluten gel before and after puffing in fat are shown in Figs. (34) and (35) respectively. Fig. (35) shows the gel seen in Fig. (34) after is has been fried in fat at 380°F.

(d) Agar.

An Agar gel was prepared by heating 5 gm. of Agar powder in 100 ml. of water. This solution was then allowed to cool and set in a sheet $\frac{1}{8}$ in. to $^3/16$ in. thick, and then dried at 110°F. for 20 hours.

The dried gel was fried at 400°F. in fat. No measurement of volume or moisture content was made. However, photographs of the gels before and after puffing are shown in Figs. (36) and (37) respectively, and some indication of the extent of puffing can be obtained from them. This puffing could well be taking place under conditions far removed from optimum but does, however, serve to show that Agar gels do puff.

(e) Pectin.

Pectin preparations set with sugar solution do not puff when dried and then fried at high temperature. This failure to

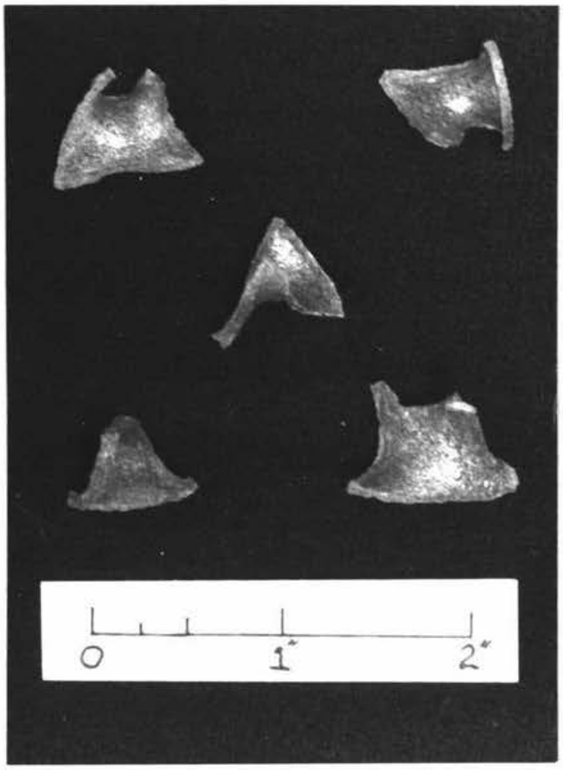


Fig.(36) Dried 5% Agar gel before puffing in fat at 400°F.

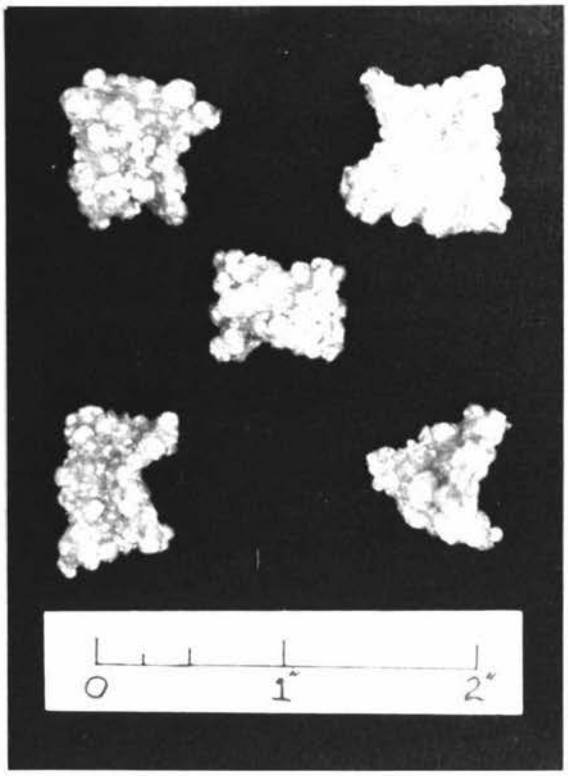


Fig.(37) The same gel after frying in fat at 400°F.

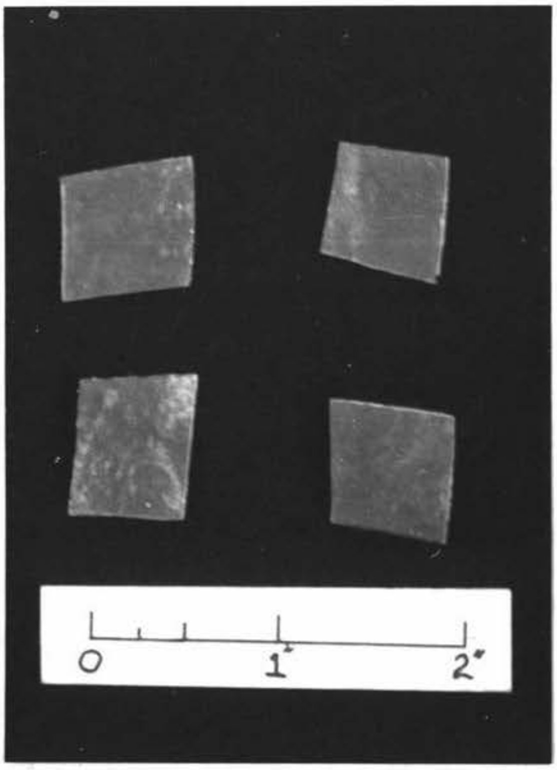


Fig.(38) A dried non-sugar Pectin gel.

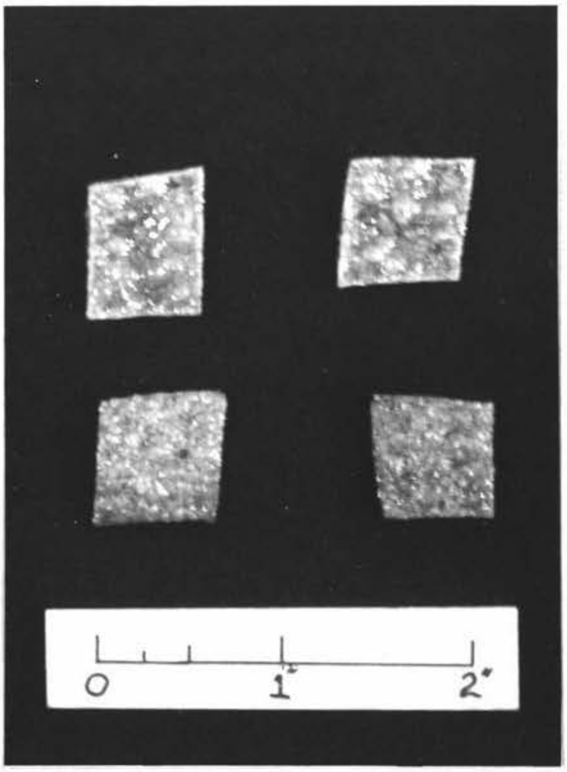


Fig.(39) Dried Pectin gel after frying in fat at 400°F.

puff is undoubtedly due to glass formation which is suggested as a suppressor of puffing in the section on "Fundamental Studies".

Some degree of puffing was obtained with a Pectin gel prepared in the following manner.

An apple pectin preparation, available commercially for use in home preserves, was made into a gel by adding water. No sugar, acid, calcium ion, or any setting agent whatsoever was added. The pectin concentration was very high, sufficient being added to form a strong gel. The gel was dried at 110°F. for 20 hours. Moisture content after drying was 15.65% (d.w.b.).

Figs. (38) and (39) show this gel before and after frying at 400°F. in fat. Volume increase was not large but puffing nevertheless did take place.

(f) Milk Protein.

A skim milk cheese contains little fat or lactose, and consists principally of milk caseins and water. This cheese, when matured, appears already to be in a gelated condition and requires no further treatment.

Skim milk cheddar cheese was sliced into thin layers and dried to 10.75% (d.w.b.) moisture in an oven at 110°F. This cheese puffed very well at 380°F. in fat and Figs. (40) and (41) show this cheese just before and just after puffing, respectively. Volume increase was 2.88 c.c./gm. (d.w.b.)

Larger volume increases have been obtained with dried skim cheddar cheese but it is not known if this was due to stage of maturity or to moisture content of the flake before frying.

Fig.(40) Sliced dried skim milk cheese before puffing in fat.

Fig.(41) Skim milk cheese shown in Fig.(40) after frying in fat at 380°F.

Puffing has thus been demonstrated to take place in a wide range of dried gels when heated to high temperatures.

Polysaccharides puffed were -

(a) Starch
(b) Pectin
(c) Agar

Proteins puffed were -

(a) Gluten
(b) Gelatine
(c) Milk Proteins

The above studies show conclusively that the puffing phenomenon is not related to Starch gels as traditionally used, but that in fact any gel fulfilling certain requirements, as regards bond energy, moisture content and nature of impurities, will puff.

This means that the range of food materials that can be puffed after suitable preparation is limited only to the ones in which gels of a suitable nature can be induced to form.

II. THE PREPARATION AND PUFFING OF GELS WITH COMMERCIAL AND PRODUCT POTENTIAL.

The application of this puffing mechanism to produce new food forms and as a new processing technique shows exciting commercial possibilities.

This process may make it possible to present a traditional food in a new form (for Europeans) or a new food in a traditional form (for Asians). It also shows promise as a unit operation in a process designed to obtain foods with better properties of reconstitution, better properties for application as an instant food, or perhaps to obtain a physical structure suitable for powdering. The production of powdered flavouring by incorporating that flavour in a neutral gel, puffing and then grinding it, may have some application. Powdering of flavourful gels, such as cheese, may also have some application.

With these views in mind, some products were partly developed to show the possibilities of application of this process to various fields of food processing and marketing.

(a) Cheese.

Only low fat or defatted cheese puffs satisfactorily. Cheese may be prepared for puffing by either of two methods.

1. Skim milk cheese may be sliced and dried.
2. Cheese may be defatted, using a fat solvent, if the fat content is high, and then heated until it becomes a viscous liquid. This may then be poured and rolled into a sheet and dried.

Cheese prepared by the first method and puffed in fat is discussed in the section on puffing of pure gels, and is shown in Fig. (41).

(b) Tapioca.

The cooking of tapioca puddings is normally a long, slow process due to slow hydration and gelation in the oven.

The use of this puffing phenomenon in the preprocess preparation of this starchy food appears to show some promise.

Puffed tapioca was prepared by the following procedure:- Tapioca in the granulated form was soaked in water for up to 3 hours and then spread in a thin layer on punched metal trays. An attempt to separate each "granule" from its neighbours was made. The tapioca was then steamed for from 1 - 2 minutes, or until gelation was complete. The tapioca, now in a gelled form, was dried at 110°F. for 20 hours, after which time it was removed and stored in air tight jars.

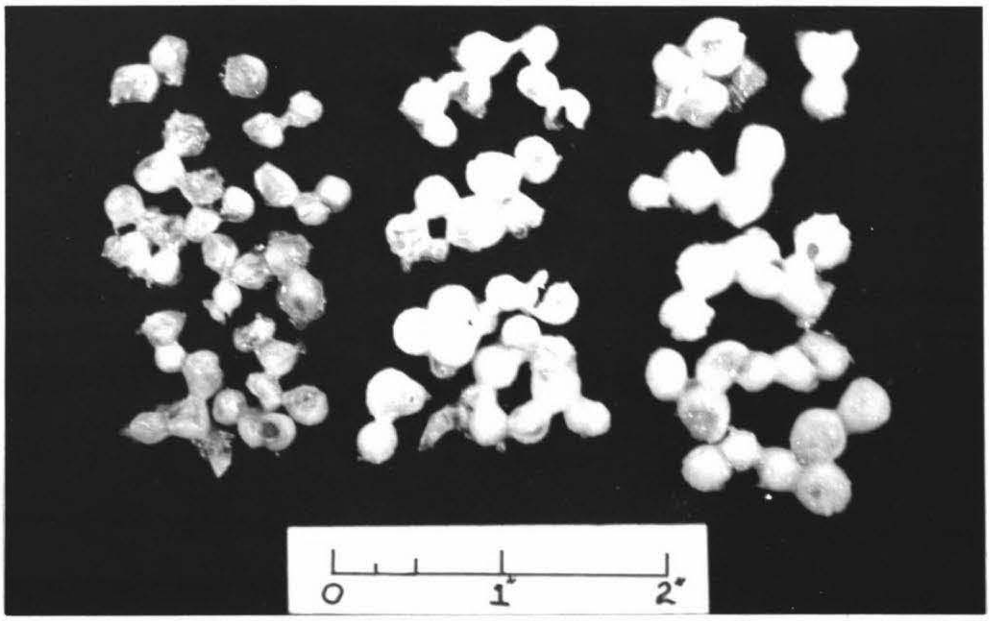


Fig.(42) Tapioca samples, from left to right:-
1. Gelled, dried and unpuffed Tapioca.
2. Tapioca after frying in salt at 380°F.
3. Tapioca after frying in fat at 380°F.

Samples dried in this fashion were subsequently puffed in fat and in a fluidized bed. Fig. (42) shows tapioca -

1. Before puffing.
2. After puffing in fluidized salt.
3. After puffing in fat.

Temperature of puffing in both cases was 380°F.

Moisture content before puffing was 9.0% (d.w.b.).

Volume after puffing was measured only for the sample puffed in salt. It was 2.1 c.c./gm. (d.w.b.). However, as can be seen in the photograph, volume increase was substantially larger for the fat fried gel. This trend is to be expected, for it has been shown to occur in the puffing of 10% Starch gels at these temperatures. (See Part X. of "Results" in the section "Fundamental Studies").

A study was made on the rate of rehydration of puffed tapioca, and a comparison made with normal cooking procedures.

Water was brought to the boil and samples dropped in.

Raw tapioca when dropped into boiling water took more than an hour to hydrate and gel completely, whereas puffed samples rehydrated completely in 10 minutes.

Some differences were seen between the rehydration rates of samples puffed in fat and in salt. In 3 minutes both samples were soft, although still aerated. The sample rehydrating faster at this point was the fat fried sample. At 8 minutes parts of each sample had been completely rehydrated and air removed. At 10 minutes all air had been expelled and the whole of both samples completely rehydrated.

Tapioca took on the gelled form it had before drying, showing few ill effects from the volume expansion it underwent during puffing. Texture, after rehydration, of the gel puffed in salt was the firmest and most closely resembled normal tapioca. The tapioca puffed in fat appeared to show some signs of collapsing on rehydration and was much softer in texture than normal tapioca. This effect was probably due to the much larger volume expansion obtained in fat as compared to that obtained in fluidized salt.

It was observed that rehydration of the sample puffed in fat was just as fast as the other sample in spite of its covering of fat picked up during frying. A layer offat would normally be expected to inhibit water uptake. Fast rehydration of this sample may be directly related to the more porous structure as a result of a greater puffed volume.

It may be considered by some as unfair to compare times of rehydration of puffed tapioca with the time required for cooking unsoaked raw tapioca. However, the study was conducted to examine the possibility of developing it as an "instant" food, and the housewife must start with the material in dried form. A food cannot be regarded as instant if it requires soaking.

The puffed material appears to have one disadvantage. For the majority of the rehydration time, it floats. In such puddings as tapioca custard this would be a disadvantage for the tapioca would then all be at the top supported by set custard underneath. Some special preparation techniques, such as boiling for 8 minutes before adding to the custard mix, may have to be devised to overcome such problems.

(c) Carrots.

The following techniques were employed in an attempt to induce gelation in carrots. Carrots of good quality were brought from local fresh markets as required.

1. Carrots were sliced transversely into discs up to $\frac{1}{8}$ in. thick, blanched in water for 2 minutes and then dried at 110°F. for 20 hours.

2. Carrots were sliced, blanched and then pulped in a food blender in an attempt to destroy the cellulose structure. The pulp was then dried in a thin sheet at 110°F.

3. Carrots were sliced, blanched and then gently boiled in a 5% starch solution for 1 hour. Slices were washed and then dried.

   It was thought possible by the use of this technique to form a continuous starch gel in the carrot slice.

4. Sliced and pulped carrots were each treated with the enzyme Cellulase. It was hoped that the enzyme would destroy some of the puffing inhibiting cellulose. In the process some starch-like molecules would be produced which would help form a continuous gel network.

5. Carrot juice was extracted and a gel was prepared using 5 gm. corn starch and 100 ml. of carrot juice.

It was found that all sliced carrots showed some signs of puffing. The carrot juice starch gel also puffed quite well.

The sample showing most promise was No. 3, and study was directed towards this method. It was subsequently shown that, contrary to expectations, it was not penetration and gelation of starch but the leaching of soluble solids during boiling that was the principal factor in the improvement of puffing characteristics.

An experiment was conducted to study this factor. Carrots were sliced and blanched in boiling water for 5 minutes and then placed in a bucket into which ran fresh water continuously. At hourly intervals, a sample was removed and dried at 110°F. for 20 hours. The dried samples were fried in fat at 400°F.

Fig. (43) shows samples fried after 1, 2, 3 and 4 hours leaching.

Sample 1. has puffed in parts but there are also extensive areas where no puffing has taken place. Puffing was completely uniform in Samples 2. and 3. which were leached for 2 and 3 hours respectively. Sample 4., leached for 4 hours, puffed well but shrivelled slightly after puffing.

Moisture content just before frying of the sample leached for 2 hours was 16.65% (d.w.b.). Puffed volume after frying at 400°F. in fat was 5.8 c.c./gm. (d.w.b.).

The puffed texture of this carrot was very fine and appears to be intra-cellular. It appears that the gel matrix responsible for puffing is the pectin in cell walls with possibly some assistance from intra-cellular starch.

Inhibition of puffing of unleached samples is almost certainly due to the presence of soluble sugars. It is unfortunate that carrots must be leached before puffing for this also removes all water soluble vitamins and other materials.

Fig. (43) Dried carrot slices leached for 1, 2, 3 and 4 hours, and puffed in fat at 400°F.

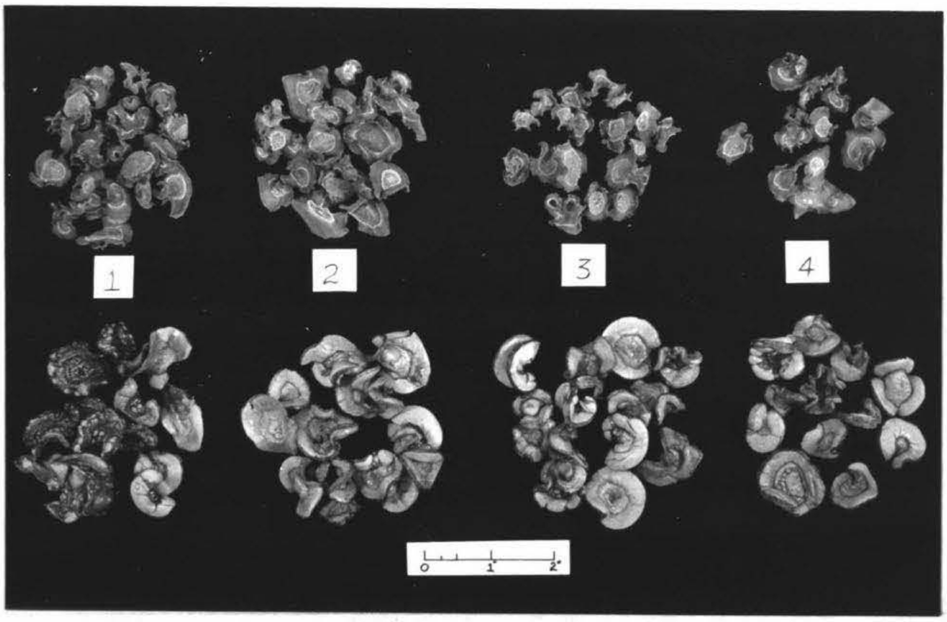


Fig. (44) Dried carrot slices before (top) and after (bottom) puffing. Numbers indicate number of hours samples were leached in running water before drying.

The problem may be overcome in two ways:

1. By using a carrot naturally low in sugars.
2. By extracting the sugars by counter-current extraction, drying the liquid in a suitable drier, and adding the powder of sugars and other nutrients to the dried pack. A Spray Drier may be suitable for drying the liquid.

(d) Tripe.

Tripe consists almost entirely of protein in the form of connective tissue with some muscle tissue present.

Boiling appears to convert tripe into a gel-like form. Some tripe was boiled and then dried at 110°F. for 20 hours. On frying in fat, the dried tripe puffed well in some areas. In others, high in muscle tissue, puffing was inhibited.

Although the "puffability" of tripe has been established, more work is necessary before a satisfactory product can be produced.

(e) Fish.

Gurnard was subjected to a number of techniques aimed at -

1. Inducing gelation.
2. Disrupting inhibition to puffing caused by muscle fibres.

The only successful technique discovered during a short study was as follows:-

Raw Gurnard flesh was minced and the minced flesh blended with water in a food blender until a watery paste was obtained.

This was then poured onto metal trays and dried at 110°F. for 20 hours. Gelation was assumed to take place during the drying cycle.

The flake so obtained was fried in fat at 400°F. and is shown in Fig. (45) in the puffed and unpuffed state. As can be seen, volume increase was quite large. The product was very porous and crisp.

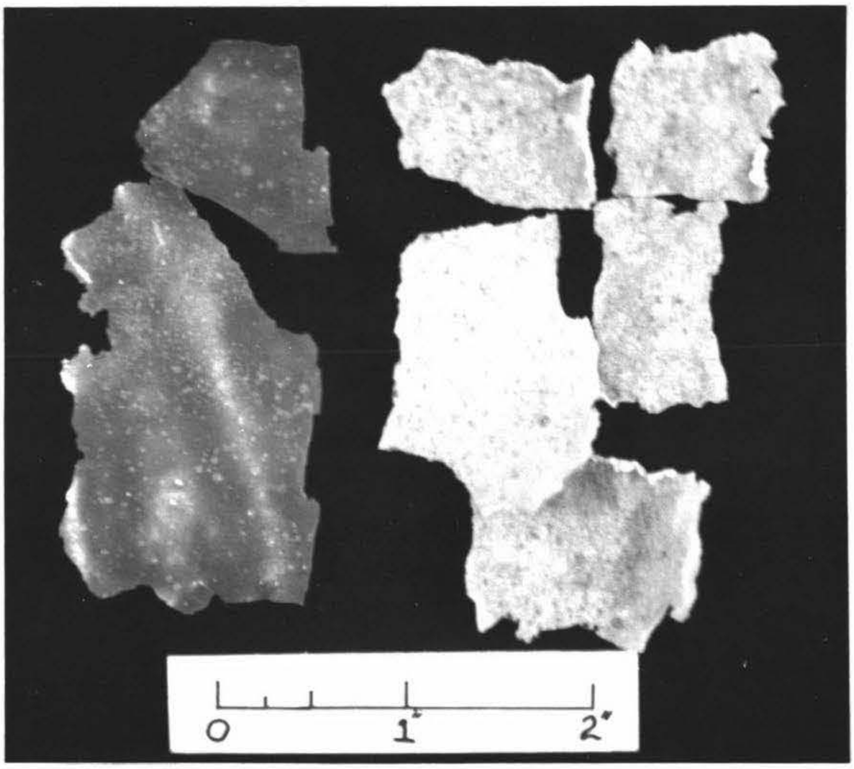


Fig. (45) Dried fish flake. Unpuffed sample on left. Puffed sample on right.

It would appear from this preliminary study that puffing is unobtainable unless the fibrous structure has been completely disrupted.

DISCUSSION OF RESULTS.

New Zealand has in recent years made some effort to develop a market for its dairy products in South East Asia,

Programmes for supplying skim milk, butter milk and whole milk, normally in reconstituted form, have been undertaken to supplement protein deficient diets of these nations. Such organisations as W.H.O. have been particularly interested in the improvement of nutrition in such underdeveloped areas.

Certain dehydrated foods, when fried, puff to an edible form and these foods play an important part in the national diet of these people.

It would appear more reasonable to supply protein rich foods in the form people are used to rather than in the more usual form which is, often enough, unfamiliar to them. Such a food could be puffed skim milk cheese.

Cheeses could be prepared from skim milk, dried and shipped in the dried state. Shipping charges should be low, for little moisture is exported and no special storage conditions requiring chill rooms are necessary. The dried cheese could be sold in the unpuffed form and puffed just before consumption (usually in the home).

There are also other potential fields of application.

Dehydration of cheese flakes should adequately stop maturation and further development of flavour enabling flavour to be standardized. Storage time would be limited by oxidation of residual fat in the dried cheese. Flakes could then be first, puffed, and then rehydrated to be used in the preparation of "processed cheese".

Production of a powdered cheese should be simple and cheap. The puffed flake could be ground in a mill. Cheese powder may be used in cheese flavoured biscuits, dehydrated soup mixes, or as a source of cheese flavour for food canners and general manufacturers. There is potential in the snack food industry for cheese flakes as a party snack, and could be eaten in every situation where pretzel sticks and potato chips are used. Cheese flakes could find favour with diet conscious people for they are high in protein whereas potato chips and pretzel sticks are high in starch.

Use could be made of tripe to make an edible puffed flake for protein supplementation of deficient diets. New Zealand does not utilise fully all tripe that is produced as a byproduct of the freezing works. Much of it is rendered and dried as meat meal.

Production of dehydrated fish flakes from New Zealand's "apparent" supply of low quality, uneconomic fish varieties could be an economic outlet for such fish. Like cheese and tripe, it could be used as a protein supplement in deficient diets. Production costs may be high because of the cost of blending into a fine paste.

Baked starch puddings such as tapioca, sago and rice take as long as 3 hours to cook and thus their preparation is time consuming and laborious. Such an "instantising" process as is suggested could be applied to all three of these materials. It may also be applicable to all noodle products. If cooking times for these puddings were only 20 minutes, as appears feasible by the use of this process, such desserts could find a better market acceptance. Note is made of the recovery of the potato industry in U.S.A. which was partly due to the development of "Instant Mashed Potatoes".

Puffing of carrots was also achieved. Due to the finely porous structure, which could be regarded as similar to that obtained by freeze drying, rehydration is very rapid. Application for this product may be found in instant soup mixes or as an instant food in its own right, e.g. instant diced carrots.

It would appear that this technique could be applied to most root vegetables. The major problem may be in obtaining raw material low in soluble sugars, or finding some technique of overcoming the undesirable side effects of leaching.

PRODUCTION TECHNIQUES AND THE PRODUCT AND MARKET POTENTIAL FOR PUFFED DEHYDRATED FOODS.

I. PRODUCTION TECHNIQUES

No process may be laid down as being typical for the production of puffed flakes.

The three main stages are, however -

(a) Formation of a gel.

(b) Dehydration to a suitable moisture content.

(c) Rapid heating to high temperatures.

(a) The Formation of a Gel.

One or more of the following techniques may be used:-

1. Formation of a gel within the raw material using one or more of its natural ingredients.

2. The incorporation within the raw material of a gelling agent, not a normal ingredient, either by soaking in a solution of that agent or by using a stitch pumping technique as is used in the meat industry for pumping curing brines into hams.

3. The raw material may be pulped and incorporated in a pure gel. Use may be made of a number of gelling agents to get characteristics required.

The formation of a gel does not guarantee that it will puff when fried at low moistures. The removal of some puffing inhibiting compounds such as sugars, may be necessary and such techniques as leaching or the use of enzymes may need to be used for this purpose.

(b) Dehydration to a Suitable Moisture Content.

The method of dehydration will obviously depend to a large degree on the nature of raw materials.

A form of drum drying may be found satisfactory for some paste-like materials. Tunnel driers appear to be the most suitable. Pastes could be extruded on to a moving belt that passes through a tunnel, the drying conditions of which are adjusted so that the product leaves with a moisture content suitable for puffing.

A material that had been gelled in situ could be sliced and dried, either in a moving belt or truck-and-tray, tunnel drier. Full advantage should be made of the fact that specialised driers such as fluidized driers, vacuum driers, etc. need not and, in many cases, cannot be used. Dehydration may be accomplished by the simplest of driers. Even sun drying may be used where suitable climates exist.

(c) Rapid Heating to High Temperatures.

Frying may be undertaken at the factory of production or it may be found more convenient and profitable to allow the frying to be done just prior to eating by the consumer. In other circumstances, it may be necessary for the manufacturer to undertake frying, particularly in the production of "instant" foods and where heating methods other than fat frying are used.

Fat frying and fluidized bed frying have been studied and it has been shown that each has its advantages. Fat frying results in a larger volume increase whereas in fluidized bed frying, the problem of fat pick-up is overcome and the reduced volume increase may be an advantage where "instant" or rehydratable type foods are being produced.

Because of the machinery necessary, fluidized bed frying must be done in factories suitably equipped.

It is suggested also that infra-red, dielectric and radio-frequency heating may all be satisfactory ways of puffing, and each may have special advantages.

II. PRODUCT POTENTIAL.

(a) For Rehydration.

This process can give certain products a porous structure similar to that obtained by freeze drying, and thus have similar advantages in the rapid uptake of water during rehydration. Examples which were previously discussed are puffed carrots and puffed tapioca.

(b) As a Snack.

The process undoubtedly has wide application in the Snack Food Industry. This process may be used for the production of flakes of high volume and low bulk density with a crisp texture. A snack food of high consumer appeal could be produced.

(c) In Powder Preparation.

This process could be a unitoperation in a production line producing powders. There are two major fields of application.

1. As a flavour:-
    - (i) An inert base such as starch may be used to carry flavourings and spices. The dried gel may be puffed and then ground to a powder.
    - (ii) The gelling substance itself may be flavourful (e.g. cheese) and a powder with that flavour may be prepared by drying the gel and then grinding it after puffing.
2. For producing rapidly rehydrating powders for applications, such as soup mixes.

III. POTENTIAL MARKETS FOR PUFFED PRODUCTS.

The process may be used for -

(a) Producing products for the growing snack food market in developed countries.

(b) Producing products to join the ever increasing "instant" food market. This market exists where an average to high standard of living is maintained.

(c) Producing gelled flakes from non-utilised raw material in developed countries which might be used for the supplementation of protein deficient diets of nations with a lower standard of living.

In conclusion, it would appear that this technique, although only partly developed and little used outside Asian countries, has considerable advantages as a process for modifying texture of dehydrated gels. The process has been confined to Starch gels in the past.

This process can be expected to find a place in the future alongside established food processing methods in highly developed countries. It could be put to a wide variety of uses and to the production of a wide range of commodity products not already established.

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