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Model substances and their use in microwave heating studies.

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MODEL SUBSTANCES AND THEIR USE IN MICROWAVE HEATING STUDIES

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Introduction

Model substances must represent foods, but only with regard to *certain* properties. For microwave heating studies it is often sufficient that only the dielectric properties (the complex permittivity ε; $\varepsilon=\varepsilon'-j\varepsilon''$) is representative for those of the food, over a suitable temperature interval and at 2450 MHz.

The following factors can be different and facilitate the practical use:

Texture (or viscosity)

Optical transparency

Melting temperature

Coagulation or solidification

Colour change with temperature

Examples:

A gel is easy to cut and mould to an exact shape. A batter of suitable viscosity will not self-convect but can be shaped by a container. Colour change over a small temperature interval of an optically transparent gel helps in determination of hot or cold areas. Temperature indication can also be by melting or by coagulation; sculptured three-dimensional "isotherms" may be produced.

Solid model substances

A simple water-sugar gel is used as a defrosting test substance. Round pieces with about 25 mm diameter are made in a special mold. - Due to the shape of the small load items in this case, the permittivity is not crucial. - Some added substances cause the pH to be temperature-dependent; a suitable pH indicator is added so that the violet colour at low temperatures disappear over a temperature interval from about 15 to 20 °C, resulting in a colorless transparent gel at higher temperatures.

A water-glycerine-sugar mixture with some added salt has more similar dielectric data to those of compact non-frozen foods. It contains about 60% water, 20% glycerol and 15% white sugar, and some salts. (See Appendix). With addition of some particular chemical compounds which give a highly reproducible pH variation with temperature, an indicator and a gelling agent, a "reheating test gel" is obtained (dielectric data are given in *Figure A* and the composition in the Appendix).

Simple water-flour-sugar-egg batters are used for hot spot and edge overheating studies. They contain about 50% water and can be used with or without added salt; the recipe and other data are given in the Appendix. - The temperature dependence of the loss factor ε'' with temperature of the batter is strongly affected by the salt content (*Figure A*). Edge overheating phenomena cause weight loss by boiling. The phenomenon depends on both ε' and ε''.

Weight loss curves, made by data from fresh loads heated for different times, are shown in *Figure B*. The initial load mass was about 400 g and the only difference was the salt content. - The linear dependence of weight loss with time for the salty batter is important and makes it possible to design tests for microwave ovens.

<u>**Liquid model substances**</u>

Water often causes problems of representativity for foods, due to its high real permittivity ("dielectric constant"); $\varepsilon'=75$ at +30°C. The loss factor has a strong temperature dependence ($\varepsilon''=18$ at +5°C and only 4 at +60°C). The low loss tangent $\tan\delta$ ($=\varepsilon''/\varepsilon'$) at 15°C and above also increases the likelihood of internal resonances in a water load. The power penetration depth d_p is about 16 mm at 20°C. Typical d_p for compact non-frozen foods are 7 to 10 mm. - Data are shown in *Figure A*.

The same *water-glycerine-sugar mixture* as for the solid gel may be used in liquid form. No indicator or gelling agent is then added. The dielectric data are not changed by this.

1-octanol and 1-butanol may be used to simulate the dielectric properties of frozen foods. 1-octanol at +20°C and 2450 MHz has ε about 3,0-j0,30 and 1-butanol has ε about 3,5-j1,9. 1-octanol is used as a top layer substance in oven cavity mode analysis, to obtain the average equivalent TM-mode normalized wavelength. mode analysis; see Figure C.

APPENDIX

The text in this appendix is taken from the IEC proposal (Committee 59H; December 1992) for a reheating test for microwave ovens. The proposed container data are included for reference.

THE REHEATING GEL

General and ingredients

A normal kit makes a batch of about 1300 g ready liquid or gel. The only difference is that the liquid does not contain carrageenan (15 g). - The following substances are needed:

* Chemical powder (contains the pH agents, buffer and salts) - about 18½ g per kit/batch.

The full recipe will be given later. - The powder, carrageenan and the indicator solution are presently available through SIK (att. Ms K. Knutsson), Box 5401, S-40229 Göteborg, Sweden; direct fax +46-31-403980. They also have updated information about other sources of delivery.

* Carrageenan (Kappa-) powder (15,0 g per batch).
* Indicator solution (2 g cresolphthalein.ortho in 100 ml 99 % ethyl alcohol) - 4½ ml is taken per batch.
* Sugar (standard, white cane sugar) - 188 g is taken per batch.
* Glycerol, standard grade, 87%, neutral pH - 330 g is taken per batch.
* Water, potable - 749 g is needed per batch.

Consumption of about 100 g or more of the gel may cause temporary discomfort. As neither taste nor appearance are suspicious, information that it is not suitable for consumption should be given.

Preparation of the liquid

Dissolve the chemical powder in 749±3 g of cold potable water, in a glass or plastic beaker taking 1½ to 2 litres. - Add 330±2 g glycerol and stir. - Add 188±2 g sugar and stir until all is dissolved.

No indicator is needed, but can be added as a practical aid for recognition (violet colour).

Preparation of the gel

Dissolve the chemical powder in 749±3 g of cold potable water, in a glass or plastic beaker taking 1½ to 2 litres. - Mix the carrageenan with 50 g sugar and add the mixture slowly under stirring, until it has dissolved. - Add 330±2 g glycerol and stir. - Pour 4½ ml indicator solution into the solution and stir.

Put the beaker with solution into a 700 to 900 W microwave oven and operate at full power for 2½ minutes. - Add 138±2 g sugar and stir until all is dissolved. Seal the beaker with clingfilm and make some small holes in it so that vapour can escape. - Heat for another 2 to 3 minutes; the liquid should simmer and vigorous boiling should not occur.

An alternate procedure is to mix the ingredients in a saucepan and to heat it on a hot plate. More vigorous stirring may improve the result, but care should be taken to minimize evaporation during the preparation.

Take out the beaker, using a glove or similar. Stir, and pour the hot solution into tared plastic test containers on a balance. The gel weight should be 400±15 g in chilled condition. - Cover the containers with clingfilm and let stand until most of the gel has solidified and air bubbles dispersed. - Put into a refrigerator at (+5±2) °C.

Density, dielectric data etc

The density of the liquid at +20°C is 1134 kg/m^3. The same is valid for the gel. The nominal weight for 350 cm^3 becomes 400 g.

The gel is optically transparent and has a deep violet colour at room temperature. The intensity is strongly reduced at +40°C and the colour disappears near +50°C.

Nominal dielectric data at 2,45 GHz are:

+10°C: $\varepsilon'=49$ $\varepsilon''=26$ +20°C: $\varepsilon'=52$ $\varepsilon''=20$ +40°C: $\varepsilon'=51$ $\varepsilon''=17$
+60°C: $\varepsilon'=50$ $\varepsilon''=15$ +80°C: $\varepsilon'=45$ $\varepsilon''=14$

VISCOUS BATTER FOR EVAPORATION AND HEATING PATTERN TESTS

Recipe:

600 g (soft) wheat flour
200 g whole eggs, white and yolks thoroughly blended, without shell
60 g white sugar
12 g sodium chloride *[is included for the IEC test]*
500 g potable water

Powder made from reconstituted eggs may be recommended instead of whole eggs.

Mix flour, sugar and water thoroughly, with a mixer. Add eggs and mix into the batter, with minimum amount of air coming into it. Store in a refrigerator at +5±2 °C, for not more than 24 hours.
- Stir slowly, to even out any separated liquid, before use.

Density, dielectric data etc

The measured density and specific heat capacity, and the nominal mass for ≈350 cm^3 are:

Density 1180 kg/m^3 c_L 2780 J/(kg,K) mass 414 g

c_L varies within ±2 %, depending on the ingredients.

The salt concentration (≈2%) is chosen for minimum ε'' variation with temperature.

Nominal dielectric data at 2,45 GHz are:
+10 °C: $\varepsilon'=34,0$ $\varepsilon''=15,0$ +20 °C: $\varepsilon'=35,7$ $\varepsilon''=15,5$
+40 °C: $\varepsilon'=37,3$ $\varepsilon''=15,5$ +60 °C: $\varepsilon'=36,1$ $\varepsilon''=15,0$
+80 °C: $\varepsilon'=33,5$ $\varepsilon''=14,5$

Dielectric data show no significant difference between a "raw" batter at +20°C and a coagulated batter cooled down to +20°C. They do however vary somewhat due to varying egg composition.

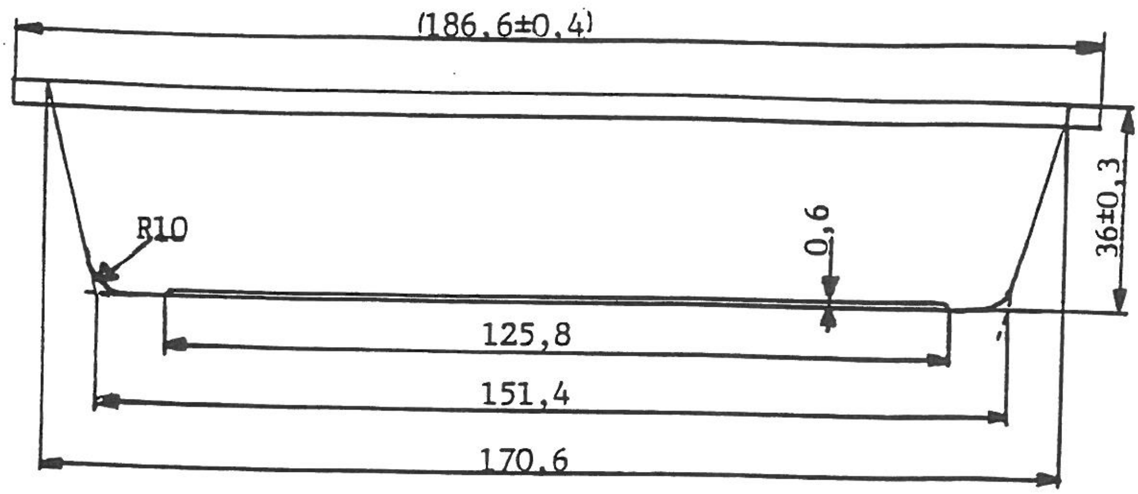
CONTAINER FOR THE TESTS

A thin-walled crystallized polyester (CPET) container is used. Its characteristic dimensions and weight data are:

- 165 x 115 mm nominal horizontal cross section at 20 mm height.
- 20 mm corner radius at 20 mm height
- 10 mm bottom edge radius
- side wall angles about 105°
- weight about 20 g, specified to be within ±1,5 g

Further dimensions, for a commercially available container, are given in the drawing below.

Containers fulfilling the specifications are manufactured by the company R. Faerch Plast A/S in Denmark, with type number 2187-1A. They are presently available through SIK (att. Ms K. Knutsson), Box 5401, S-40229 Göteborg, Sweden; direct fax +46-31-403980.



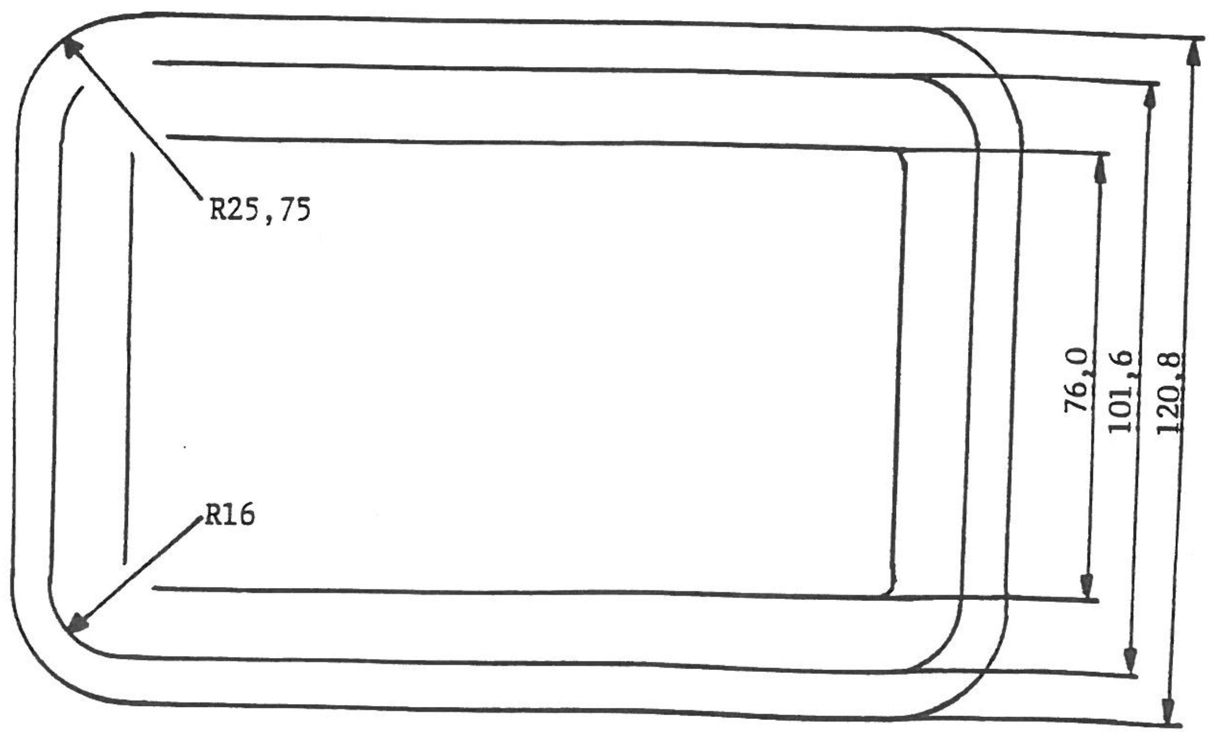


FIGURE A

DIELECTRIC DATA FOR SOME SUBSTANCES, AS A FUNCTION OF TEMPERATURE, AT 2,45 GHz

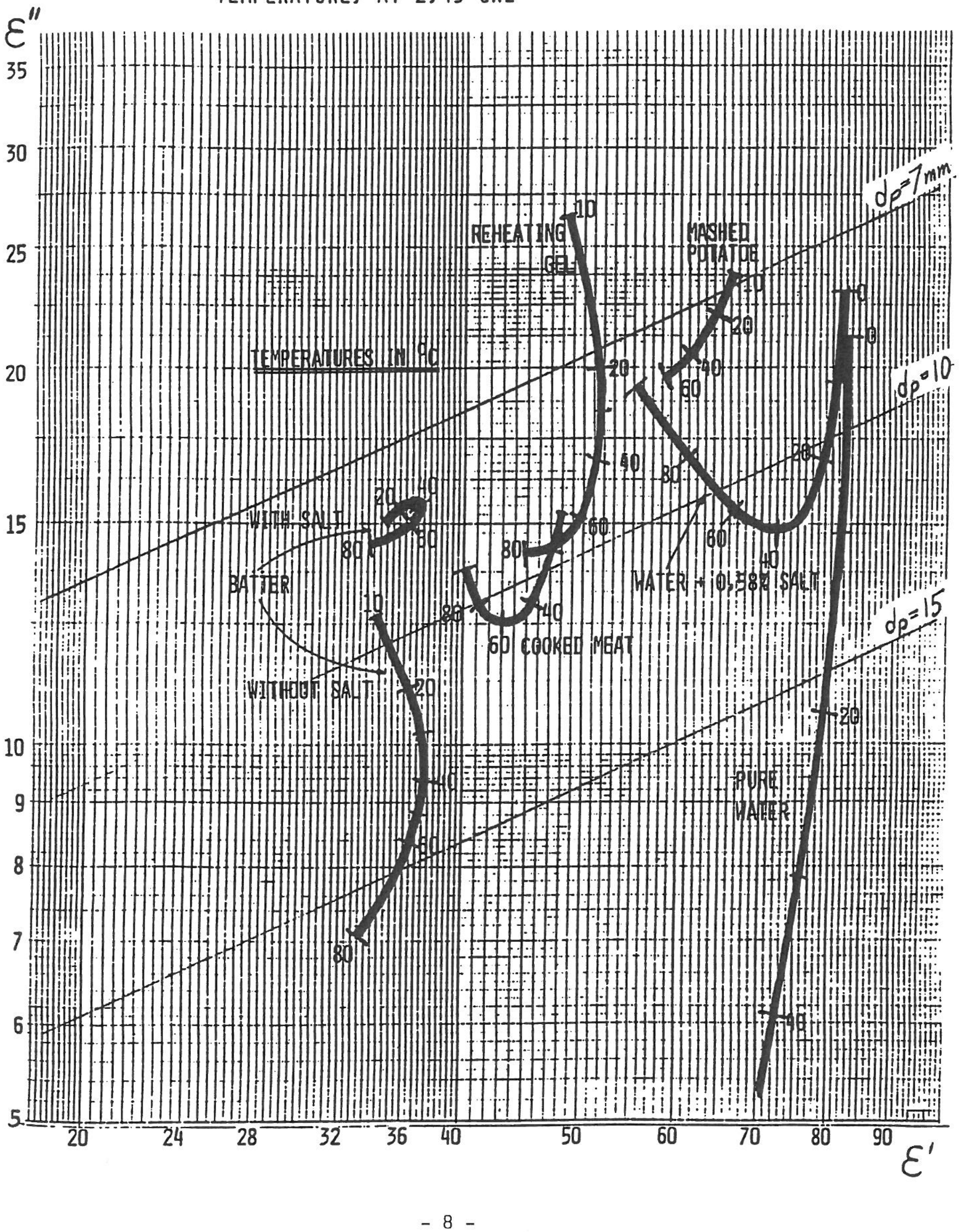


FIGURE B

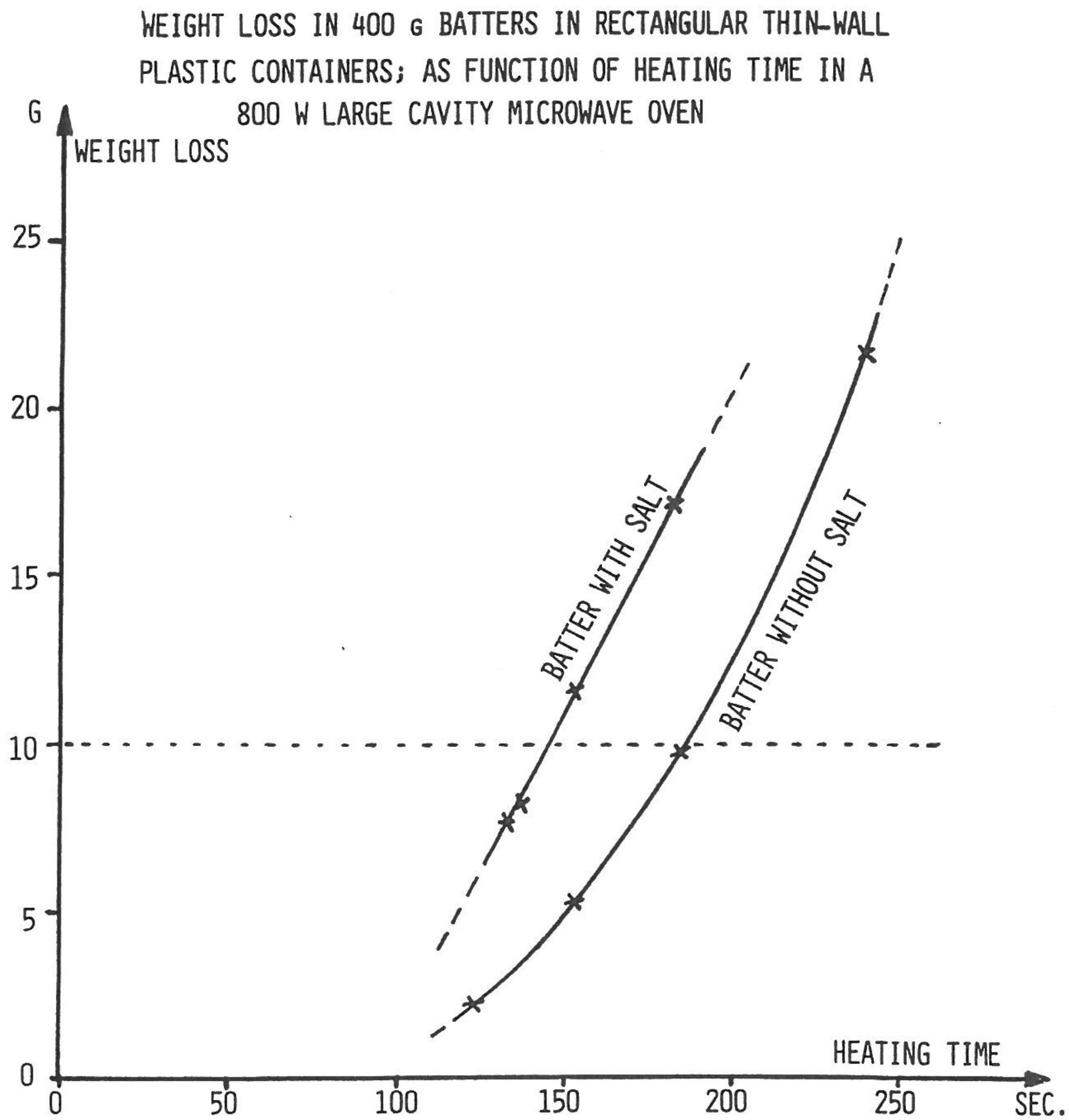

WEIGHT LOSS IN 400 G BATTERS IN RECTANGULAR THIN-WALL PLASTIC CONTAINERS; AS FUNCTION OF HEATING TIME IN A 800 W LARGE CAVITY MICROWAVE OVEN
G
WEIGHT LOSS
25
20
15
10
5
0
BATTER WITH SALT
BATTER WITHOUT SALT
HEATING TIME
0
50
100
150
200
250
SEC.

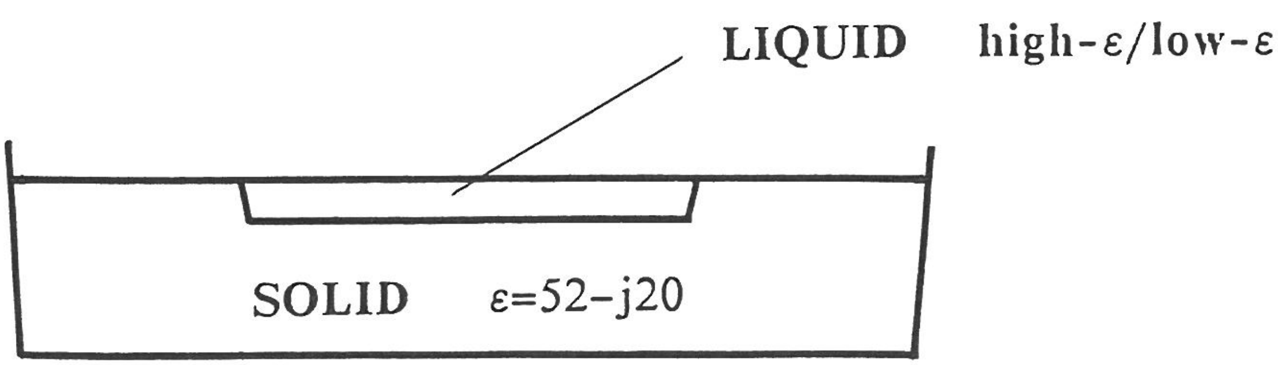
FIGURE C

Load for investigations of oven modes

The gel is molded into a large plastic container; the load height is 20 to 25 mm. A glass beaker is held by a tripod, to make a centre circular depression of about 5 mm depth. The solidified "base gel" is cooled to about +10 °C, as are gel liquid and another liquid, for example octanol. - The start temperatures of the base gel and liquid is measured before each heating operation.

The solidified depression is covered with clingfilm before a predetermined amount of liquid (by weight) is poured into it. After the heating, the film is lifted by its corners and the temperature of the liquid in the resulting "bag" is measured.

The quotient between the low-ε and the high-ε liquid temperature rises is recorded. It can be used to characterize oven cavity modes and gives vital information about for example the intensity of the edge overheating effect in typical food loads.



RAPPORT

Modellsubstanser för att testa mikrovågsvärmning.

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Det är vid fysikaliska undersökningar ofta fördelaktigt att använda väl specificerade substanser i stället för vanliga livsmedel. Detta gäller också vid testning av mikrovågsugnar och vid studier av mikrovågors värmningsförlopp. SIK har under många år använt speciella modellsubstanser för dessa ändamål. Vi har under de senaste åren ytterligare utvecklat sådana substanser för användning vid ugnstestning. SIK intar på detta område en ledande ställning.

Denna rapport behandlar kortfattat nuläget i vårt arbete och ger fysikaliska och dielektriska data för två modellsubstanser, varav en – den s k återuppvärmningsgelen – är optiskt transparent och ändrar färg med temperaturen. SIK säljer satser av koncentrat för denna gel.

Rapporten är på engelska.

SIK

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