

# WATER-SOLUBLE CELLULOSE DERIVATIVES\*

## USES AS PRIMARY EMULSIFYING AGENTS. PART II

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A study has been made of the effects of heat, acid and alkali, salts and alcohol on the stability of methyl-, methylethyl- and sodium carboxymethyl-cellulose emulsions of liquid paraffin. All were stable for 4 to 8 weeks at 40°, but at 80° deteriorated rapidly, the order of decreasing stability being methyl-, methylethyl- and sodium carboxymethylcellulose emulsions. Heating at 115° for 30 minutes decreased the stability of sodium carboxymethylcellulose, but not of methyl- and methylethyl-cellulose emulsions. Stability in the presence of added substances depended largely on the physical properties of the reaction products. The results are related to the behaviour under similar conditions of aqueous dispersions of the three derivatives, and the influence on emulsion stability of dehydration and degradation of the emulsifying agent is discussed.

In the first part of this work we showed that the emulsifying properties of the water-soluble cellulose derivatives depend upon the concentration, viscosity grade and type of derivative used<sup>1</sup>. The effects of heat and various added substances have now been examined.

### MATERIALS AND APPARATUS

Materials, apparatus, and the methods of preparing and assessing the emulsions were as previously described<sup>1</sup>. The disperse phase was liquid paraffin 25 per cent v/v. The chemicals were of A.R. quality. pH measurements were made on the Cambridge bench pH meter using a glass electrode and a saturated calomel reference electrode.

### EXPERIMENTAL AND RESULTS

#### *Repeated Gelling and Cooling of a Methylcellulose Emulsion*

An emulsion made with methylcellulose M20 (4.7 per cent in the aqueous phase) was divided into two samples. Each, after determination of their "H" values, was rapidly heated in a water bath to 50°, when they completely gelled. They were then removed and allowed to stand at room temperature for 24 hours to cool and revert to their original fluid state, briefly shaken, and their "H" values redetermined.

This procedure could be repeated six times without the emulsions deteriorating. After the seventh treatment some small oil globules were visible on the surface of the emulsions.

\* The subject-matter of this communication forms part of a thesis by one of us (R.E.M.D.) accepted by the University of Wales for the degree of Master of Pharmacy.

*Emulsions Stored at Elevated Temperatures*

Emulsions made with methylethylcellulose and low viscosity grades of methyl- and sodium carboxymethyl-cellulose were distributed into 10-ml. neutral glass ampoules which were sealed and then stored in hot air ovens at 40° and 80° for 6 months. The emulsions were examined initially, and, thereafter, at 1, 2, 4, 8, 12 and 24 weeks, being allowed to stand for 24 hours at room temperature after removal from the ovens. The results (Table I) show that: (a) All the emulsions deteriorated more rapidly at 40° than at room temperature. Nevertheless, at 40° they all remained stable for 4 to 8 weeks. (b) Emulsions stored at 80° deteriorated rapidly; within a week there was loss of viscosity, accompanied by creaming and oil separation. The order of increasing stability was sodium carboxymethylcellulose, methylethylcellulose and methylcellulose emulsions.

TABLE I\*  
STORAGE OF LIQUID PARAFFIN EMULSIONS AT ELEVATED TEMPERATURES

Derivative	40°		Remarks†	80°
	Value of "H"			
	Initial	Final		
Methyl M20 4 per cent	48.1	50.3 (8)	A thin film of oil appeared between 8 and 12 weeks. By 24 weeks the emulsion had become less viscous	Rapid creaming after 1 week's storage, when emulsion became very fluid. Oil separation began between 2 to 4 weeks. Surface of emulsion "browned" between 4 to 8 weeks
Methylethyl 3.5 per cent	25.5	24.5 (4)	Oil separation began between 4 to 8 weeks. A thin oil film covered the surface after 12 to 24 weeks	Oil separation began within a week, and a thin continuous oil film had formed after 2 weeks. Emulsion became very fluid
S.C.M.C. 3.25 per cent	53.9	53.4 (8)	Oil separation began between 8 and 12 weeks	Oil separation began within 24 to 48 hours. A continuous layer of oil formed between 72 to 96 hours, when sample creamed and darkened in colour. There was an obvious loss of viscosity after 1 week

† The appearances are those of the emulsions 24 hours after removal from the ovens.

*Emulsions Heated and Subsequently Stored*

Emulsions made as above, after their "H" values had been determined, were distributed into 10-ml. neutral glass ampoules and heated in an

## EXPLANATORY NOTES

## \* TABLES I TO IV

*Concentrations.* These refer to the percentage w/v of derivative in the mucilage used to prepare the emulsions. (Emulsions contain 25 per cent v/v of oil.)

*Final value of "H."* Figures in parenthesis indicate stage, in weeks, of last globule count.

*Coefficient of variation.* Calculated on all globule counts made during the period of storage (see also previous note).

*Cream volume.* Figures in parenthesis indicate stage, in weeks, of observation. The volumes were assessed by means of a rule placed against the sides of the jars.

*Oil separation.* Unless otherwise stated, this refers to the separation of small isolated globules, visible to the naked eye, on the surface of the emulsion.

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autoclave at 115° for 30 minutes. They were re-examined 24 hours after heating, and at 4, 12 and 24 weeks. The results (Table II) show that: (a) The stability of methyl- and methylethyl-cellulose emulsions was not reduced by autoclaving. (b) The stability of sodium carboxymethylcellulose emulsions was reduced by autoclaving, gross deterioration becoming apparent within the first 4 weeks of storage.

TABLE II  
EMULSIONS OF LIQUID PARAFFIN HEATED FOR 30 MINUTES AT 115° AND  
SUBSEQUENTLY STORED

Derivative	Value of "H"		Coefficient of variation	Remarks
	Initial	Final		
Methyl M20 4 per cent	47.8	49.1 (24)	1.8	No oil separation after 24 weeks' storage. Creaming behaviour similar to unheated emulsion
Methylethyl 3.5 per cent	29.9	27.5 (24)	6.5	As above
S.C.M.C. (low) 3.25 per cent	51.3	53 (24 hours)	—	Oil began to separate within 4 weeks and increased over the storage period. The unheated control sample neither creamed nor showed oil separation

TABLE III  
STORAGE OF LIQUID PARAFFIN EMULSIONS MADE WITH MUCILAGES HEATED  
FOR 3½ HOURS AT 115°

Derivative	Sample	Efflux time of mucilage (secs.)	Value of "H" (initial)	Cream volume (per cent)	Stage of oil separation (weeks)	Remarks
Methyl M20 4 per cent	Unheated mucilage	360	48.6	95 (4, 24)	—	Thick, pourable
	Heated mucilage	270	50.4	85 (12, 24)	8-12	Less viscous than control sample
S.C.M.C. (low) 3.25 per cent	Unheated mucilage	400	56.9	0	8-12	Thick, pourable
	Heated mucilage	147	53.2	85 (4, 24)	0-4	Much less viscous than control. Traces of oil apparent within 36 hours of preparation. The volume of oil separating on storage was greater than in the control sample

*Emulsions Prepared with Heated Mucilages and Subsequently Stored*

Mucilages containing the low viscosity grades of methyl- and sodium carboxymethyl-cellulose were each divided into two portions, one of which was heated at 115° for 3½ hours to reduce its viscosity. The heated and unheated mucilages were used to make emulsions of liquid paraffin which were stored at room temperature for 6 months, being examined initially and, thereafter, at 4, 8, 12 and 24 weeks. The results (Table III) show that: (a) Although the efflux time, measured with a Redwood viscometer, of the methylcellulose mucilage had been reduced by 25 per cent, both

batches of emulsion had, initially, similar "H" values. That made with the autoclaved mucilage was less viscous and oil began to separate between the second and third month of storage, whereas the "control" sample remained stable. (b) Although the efflux time of the heated sodium carboxymethylcellulose mucilage had been reduced by over 60 per cent, both batches of emulsions had, initially, similar "H" values.

TABLE IV  
STORAGE OF LIQUID PARAFFIN EMULSIONS OF VARYING pH

Derivative	pH	Value of "H"		Coefficient of variation	Cream volume (per cent)	Stage of oil separation (weeks)	Remarks
		Initial	Final*				
Methyl M20 4 per cent	1.54	50.8	53.5	4.9	33 (4, 24)	—	Thick, pourable
	2.82	53.0	51.8	3.7	33 (12, 24)	—	As above
	4.66	54.8	51.6	3.4	As above	—	As above
	9.08	52.4	55.0	3.7	As above	—	As above
	12.8	52.0	52.1	4.7	As above	—	As above
Methyl-ethyl 3 per cent	1.52	20.3	19.5	6.4	33 (4) 50 (8, 24)	—	Readily pourable
	3.29	21.1	18.6	6.1	As above	—	As above
	4.94	22.1	20.9	5.2	As above	—	As above
	9.7	20.0	19.6	2.8	As above	—	As above
	12.9	17.5	16.3	5.8	50 (24 hours, 24)	—	As above
S.C.M.C. (low) 3.25 per cent	1.55	—	—	—	0	—	Thixotropic. No creaming or oil separation
	2.98	—	—	—	0	—	As above
	7.1	51.1	54.7 (4)	—	90 (24)	8-12	Thick, pourable
	8.88	53.1	56.2 (4)	—	50 (4) 33 (24)	4-8	As above
	12.5	55.8	—	—	50 (0) 33 (4, 24)	0-4	As above

\* Value of "H" after 24 weeks unless otherwise indicated.

The emulsion made with the heated mucilage was much more fluid, creamed more readily and oil separation was greater and occurred earlier than with the "control" sample.

#### *Storage of Emulsions of Varying pH*

Hydrochloric acid or sodium hydroxide solution was added to the emulsions to yield a range of pH values. Where necessary, water was also added so that each emulsion was diluted by the same amount. The emulsions were stored at room temperature for 6 months and examined at 24 hours, 4, 8, 12 and 24 weeks. The results (Table IV) show that: (a) The most acid methylcellulose emulsion creamed more rapidly than the other samples. (b) The most alkaline emulsion of methylethylcellulose creamed more rapidly than the other samples. (c) Although both the

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acidified emulsions of sodium carboxymethylcellulose were thixotropic, microscopically they appeared no different to the other samples, but they neither creamed nor showed any separation of oil. The three remaining samples creamed and oil separated on storage, the degree of deterioration increasing with the alkalinity of the sample. The most alkaline sample was the least viscous.

### *Storage of Emulsions Containing Sodium Chloride*

Emulsions made with low viscosity grades of methyl- and sodium carboxymethyl-cellulose were diluted with equal volumes of water containing varying concentrations of sodium chloride (0 to 30 per cent w/v), stored for 6 months at room temperature and examined at 1 day, 4, 8, 12 and 24 weeks. The results can be summarised as follows: (a) The stability of methylcellulose emulsions was unaffected by up to 5 per cent of sodium chloride. Emulsions containing 10 and 15 per cent of sodium chloride were thixotropic and did not cream; microscopically, they appeared similar to the other samples. None of the emulsions showed any separation of oil. (b) All the sodium carboxymethylcellulose emulsions creamed to the same extent. At the end of 6 months' storage, oil had separated from all the emulsions, but its volume decreased with increasing sodium chloride content.

### *Storage of Emulsions containing Other Chlorides*

Emulsions made with sodium carboxymethylcellulose (low) were diluted with equal volumes of water containing various monovalent and bivalent chlorides to yield a salt concentration of 0.2M in the emulsion. They were stored at room temperature for 6 months and examined at 1 day, 4, 8, 12 and 24 weeks.

Less oil separated from those emulsions containing salts than from the control samples.

### *Storage of Emulsions Containing Alcohol*

To emulsions made with low viscosity grades of methyl- and sodium carboxymethyl-cellulose were added quantities of industrial methylated spirit (74 o.p.) and, where necessary, sufficient water to dilute the emulsions by 50 per cent. The concentration of I.M.S. in the emulsions varied from 0 to 50 per cent. The emulsions were stored at room temperature for 6 months and examined at 1 day, 4, 8, 12 and 24 weeks. The results can be summarised: (a) Alcohol did not influence the creaming behaviour of methylcellulose emulsions but it did effect separation of traces of oil after 6 months' storage. With 50 per cent of alcohol the ether partially precipitated. (b) As little as 10 per cent of alcohol profoundly affected the stability of sodium carboxymethylcellulose emulsions and considerable oil separation occurred within 24 hours. Fifty per cent of alcohol precipitated the ether.

## DISCUSSION

### *Influence of Temperature*

When methyl- and methylethyl-cellulose sols are heated their viscosity gradually falls until a temperature is reached (about 50°) at which the

ether precipitates. At this point, depending on the concentration of the sol, either discrete gel particles or a continuous gel is formed, and, in the latter case, the viscosity rises sharply. The viscosity of sodium carboxymethylcellulose sols decreases progressively with rise in temperature. If the heating period is not prolonged and the temperature not excessive, both these changes are reversible and the sols regain their original viscosity on cooling. Prolonged heating at high temperatures, however, leads to irreversible viscosity changes<sup>2</sup>.

When a methylcellulose emulsion is heated to 50° only the reversible changes have to be considered. If 50° is reached rapidly, the possibility of aggregation and coalescence of oil globules during the brief pre-gelation period of lowered viscosity can be ignored. But when the particles of the emulsifying agent are dehydrated sufficiently to form a gel, it might be expected that changes would occur at the interface to alter the stability of the emulsion. As shown, however, the sol/gel/sol transformation can be accomplished without deterioration. Since the oil globules are immobilised while the emulsion remains gelled, two explanations suggest themselves: the first, that the interfacial film remains intact in its partially dehydrated state, or the second, that the film is disrupted as dehydration proceeds, but rapidly reforms as the system cools. In the latter instance, some coarsening of the emulsion would be inevitable unless there was close correlation between interfacial readsorption and break-down of the gel structure. The first explanation, therefore, seems the more likely. That the emulsion will not withstand repeated treatments of this kind indicates that in spite of the apparent rigidity of the film some points of weakness are induced by dehydration.

In the long-term storage tests, 40° was chosen in the expectation that for both the methyl- and methylethyl-cellulose emulsions it would be near the point of minimum viscosity (that is, just below gel point). Both emulsions gelled at this temperature, however, while the sodium carboxymethylcellulose emulsions became less viscous. The results show that methyl- and methylethyl-cellulose emulsions can be maintained in the gelled state for 4 to 8 weeks without deterioration. Some breakdown occurs eventually, indicating that prolonged dehydration weakens the interfacial film. The methylethylcellulose emulsion was the least stable of the two. Gels of the methylethyl- derivative are less rigid than those of methylcellulose and therefore coalescence is easier. Deterioration of the sodium carboxymethylcellulose emulsion results from the lowered viscosity which facilitates aggregation and coalescence of the disperse phase.

In the emulsions stored at 80° the effects of the irreversible viscosity changes became apparent. After storage for a week, emulsions of methyl- and methylethyl-cellulose creamed rapidly on cooling, indicating that the derivatives had undergone degradation. Although the reduced viscosity of the continuous phase must have contributed to the instability, degradation (and, in the case of the methyl- and methylethyl-cellulose emulsions, dehydration) of the derivative at the interface may be an equally important factor. As expected, sodium carboxymethylcellulose emulsions proved to be the least stable under these conditions.

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The results obtained after emulsions were autoclaved and then stored also agree with previous findings. The amount of degradation which the methyl- and methylethyl- derivatives underwent was too small to affect the viscosity of the continuous phase. Sodium carboxymethylcellulose, however, degrades far more readily.

As previously mentioned<sup>1</sup>, the emulsions made with heated mucilages were less stable than similar emulsions made with unheated mucilages. This instability is largely due to the reduced viscosity of the continuous phase, although other factors, such as the ability of the degraded derivative to form a stable interfacial membrane, may also be involved.

### *Influence of Acid and Alkali*

The behaviour of methyl- and methylethyl-cellulose emulsions in the presence of acid and alkali can also be directly related to that of the mucilages under similar conditions<sup>2</sup>. Thus, creaming was most rapid in the most acid methylcellulose emulsions and the most alkaline methylethyl-cellulose emulsions. The behaviour of sodium carboxymethylcellulose preparations, however, is paradoxical. When sufficient acid was added to the mucilages to precipitate carboxymethylcellulose the viscosity fell immediately; but when precipitation occurred in the emulsion a product with thixotropic properties was formed which neither creamed nor showed oil separation. The other emulsions in this group behaved as expected, with stability declining with degree of alkalinity.

### *Influence of Salts*

Work on the mucilages<sup>3</sup> suggested that the main effects of electrolytes on methylcellulose emulsions would be those due to dehydration, and this was so. Thus, concentrations of sodium chloride too low to affect the viscosity of mucilages had no effect on emulsions, while concentrations sufficient to cause the mucilage to gel rendered the emulsions thixotropic. The behaviour of sodium carboxymethylcellulose emulsions was not predictable, for salts which reduced the viscosity of its mucilages appeared to enhance the stability of its emulsions. However, the addition of salts to systems containing anionic dispersing agents can result in a lowering of interfacial tension<sup>4</sup>, and here the effect on stability of a reduction in the viscosity of the continuous phase may be more than counterbalanced by a closer packing of the emulsifying agent at the interface.

### *Influence of Alcohol*

Alcohol added to mucilages of the cellulose derivatives first led to a progressive dehydration of the particles and a thickening of the system; larger volumes precipitated the derivatives without gel formation. This explains why, in contrast to the effect of strong solutions of salts, alcohol decreased rather than enhanced the stability of methylcellulose emulsions. Sodium carboxymethylcellulose emulsions were particularly sensitive to alcohol, precipitation of the derivatives being accompanied by syneresis as well as oil separation.

## GENERAL OBSERVATIONS

An attempt has been made to relate alterations in emulsion stability to changes which occur under similar conditions in aqueous dispersions of the emulsifying agent, and which are made manifest by variations in viscosity<sup>2,3</sup>. This has been done because the viscosity of the continuous phase is an important factor in emulsion stability, and because a change in viscosity signifies an alteration in the state of the emulsifying agent, and may therefore be indicative of simultaneous but less obvious changes in the properties of the interfacial film. While recognising the complexity of these reactions, it seems reasonable to draw the following conclusions from the results.

(i) Interfacial films of methyl- and methylethyl-cellulose withstand short periods of dehydration without disruption, but prolonged dehydration weakens the film.

(ii) When dehydration is accompanied by degradation of the derivative the instability of the emulsion is increased. This is because the reduction in viscosity of the continuous phase permits the dispersed oil globules to aggregate, and, if the interfacial film has been sufficiently weakened, to coalesce. Degradation may also affect the ability of the derivative to form stable films at the interface.

(iii) When dehydration is effected by a dehydrating agent, the stability of the emulsion depends on the physical properties of the reaction product. If the derivative forms a gel the emulsion will remain "stable", because the globules are immobilised.

(iv) Because sodium carboxymethylcellulose undergoes degradation more readily than do the two other derivatives, emulsions containing it are less stable to heat. This is due not only to the high irreversible viscosity losses in the continuous phase, but also to the fact that the reversible change on heating is not from sol to "stabilising" gel but to a more fluid preparation.

(v) As with methyl- and methylethyl-cellulose, the stability of sodium carboxymethylcellulose emulsions in the presence of other substances appears to depend largely on the physical properties of the product of the reaction.

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