Phosphates as Energy Savers in Machine Dishwash Performance

R.P. LANGGUTH and **E.A. CASEY**, Monsanto Industrial Chemicals Company, Detergents and Phosphates Division R&D, St. Louis, Missouri 63166

ABSTRACT

A savings of 20% in the energy consumption of machine dishwashers to meet government guidelines requires a significant reduction in the amount of water used or in the temperature of the wash. Performance testing has shown that a reduction in wash temperature from 140 F to 100 F results in a significant increase in the spotting and filming of glassware. This performance loss to conserve energy can be reduced by increasing the sodium tripolyphosphate (STP) content of the machine dishwash formulation. A reduction in the STP content of the formulation from the typical 40-45% level that would be required to comply with restrictive phosphate (8.7% P) legislation coupled with a decrease in wash temperature for energy conservation results in extremely poor washing performance.

INTRODUCTION

Composition of high quality, proprietary machine dishwash detergents has undergone surprisingly little change over the past 25 years in spite of large market growth during this period. Enactment of legislation in a few areas of the country has limited phosphate level in machine dishwash detergents to 8.7% P. Sodium tripolyphosphate (STP) level has accordingly been reduced from the usual 40-50% range to the 25-33% level for products sold in these areas to comply with the legislation. Liss et al. (1) showed that this reduction in phosphate causes a readily apparent increase in the spotting and filming performance of the formulations. Consumer panel testing (2) showed that consumers could detect a performance loss due to this lower phosphate level. Also, panel results showed zero phosphate formulations to have such poor performance that housewives discontinued their use after only a few weeks.

In recent years the government has asked appliance manufacturers to make a significant reduction in energy consumed by machine dishwashers. A goal of 20% energy savings is now targeted for about 1980. Since 85-90% of the energy consumed in a machine dishwashing cycle is used to heat water, the only options available to meet this goal are (1) to use less water, or (2) to wash in cooler water. It is generally accepted by industry that any significant reduction in wash temperature from the usual 140-150 F will cause a large increase in spotting and filming performance of current machine dishwash formulations. Kaneko et al. (3) showed that an 80 F (27 C) wash temperature is too low to achieve acceptable spotting and filming performance from currently available formulations and that performance from these formulations is not as good at 100 F (38 C) as at 120 F (49 C).

The work reported in this paper was carried out to determine the extent of performance loss occurring from a reduction in wash temperature from hot 140 F (60 C) to warm 100 F (38 C) water, and establish if increasing the STP level of the formulation could be effective for offsetting or reducing performance loss, or as the title suggests, act as an energy saver. The effect of phosphate reduction in the formulation was also considered to establish the combined effect of temperature reduction for energy conservation and decreased phosphate level to comply with reduced-phosphate legislation that would include machine dishwashing products. This work covers the effect of these variables on soil redeposition on glassware as observed by spotting and filming – the criteria normally used in performance evaluations of machine dishwashing detergents.

EVALUATION PROCEDURE

The performance testing used in this study was based on visual appearance of glass tumblers after a multicycle wash in the specific formulation under study. The procedure is designed to show spotting and filming on glass tumblers in the presence of designated food soils.

The glass tumblers are prepared for the test by cleansing them thoroughly by hand using a standard concentration of an all-purpose liquid cleaner. Each glass is cleaned so that no "water-break" is evident when the tumblers are rinsed in distilled water. After thorough rinsing, the tumblers are dried and inspected for cleanliness prior to their use.

Test conditions are shown in Table I. Eight, 9" cafeteria style dinner plates are soiled with the desired weight of the designated soil type. The soiled plates are allowed to age ca. 1 hr before use. The soiled plates and eight clean glass tumblers are then distributed evenly within each machine. The dishwashers used in this study were 1975 "Superba" model Kitchen-Aids. The light soil cycle used for these tests provides a pre-rinse, single wash, two final rinses and drying.

St. Louis tap water, which during these tests ranged from 90-110 ppm $CaCO_3$ hardness, was used for the low hardness level, and spiked with a synthetic hard water concentrate for higher water hardness levels. Water hardness was controlled during a given run to a fixed level in all of the wash and rinse cycles. Twenty-five grams of detergent, which is equivalent to 0.25% use-concentration, was added to the machines in solution form at the time in cycling just prior to the wash when detergent dispensers opened.

The procedure used in this study calls for four wash cycles with the glass tumblers allowed to cool to room

TABLE I

Test Conditions

Number of plates	–	8
Number of tumblers	–	8
Machine	–	Kitchen-Aid, Superba model
Wash cycle	–	Light soil
Detergent concentration	–	0.25%
Number of wash cycles	–	4
Soil weight	–	40 g (heavy loading) 10 g (medium loading) 5 g (light loading)

TABLE II

Rating Scales for Spotting and Filming Evaluations

Numerical rating	Subjective description: Spotting	Filming
1	None	None
2	Few	Light
3	¼-½ Covered	Moderate
4	½-¾ Covered	Heavy
5	> ¾ Covered	Very heavy

TABLE III

Composition of Standard Detergent

Ingredient	% by Weight
Sodium tripolyphosphate (anhydrous)	40
Liquid sodium silicate (42% solids, SiO_2/Na_2O=2.8)	24
Plurafac RA-43	2
Chlorinated trisodium phosphate	24
Sodium sulfate	10
Total	100

temperature between cycles by opening the machine door at the end of the drying cycle and pulling the trays out. All eight tumblers were rated for spotting and filming after the fourth wash using a viewer equipped with fluorescent lights. The rating scales used are shown in Table II. An average spotting and filming rating are calculated from the values for the eight tumblers. The rating scale ranges from a low value of 1, which means essentially no change over a clean, unwashed tumbler, to a high value of 5, which is never observed with phosphate-built formulations. Values for high performance proprietary products normally range from 1.5-2.0 for either spotting or filming with the standard margarine/nonfat milk solids test soil under nonstressed conditions. Ratings greater than 2.5-3.0 would most probably lead to complaints about the performance of the product. A difference of ± 0.4 of a unit in average ratings is statistically significant at the 95% confidence level.

The composition of the detergent used as the standard throughout this study is given in Table III. For the reduced phosphate formulation, an STP level of 25% was chosen so that the total P content from the STP and chlorinated trisodium phosphate was the 8.7% P level required by legislation in some areas. In this case the STP removed from the formulation was replaced with sodium sulfate. A level of 55% STP was selected for an increased P content, which meant that the 10% sodium sulfate was completely removed from the formulation and both the sodium silicate liquid and chlorinated trisodium phosphate were reduced by 2.5 percentage points.

RESULTS

Spotting Performance

The effect of reducing the wash temperature from 140 F (60 C) to 100 F (38 C) on glassware spotting is shown for three different soil loadings (40, 10 and 5 g/wash) in Figure 1. The soil used in these tests is the 80:20 oleomargarine/nonfat dried milk solids given in the standard CSMA dishwasher test for spotting and filming (4). The high soil loading level of 40 g/wash in the CSMA test is an excessive loading that represents an aggravated condition for quick screening purposes. Lower soil loading would be considered more in line with actual household conditions, and in situations where there is some prerinsing of dishes before placing them in the dishwasher, the soil loading would be very low. For this reason, lower levels of soil loading were also considered in this work.

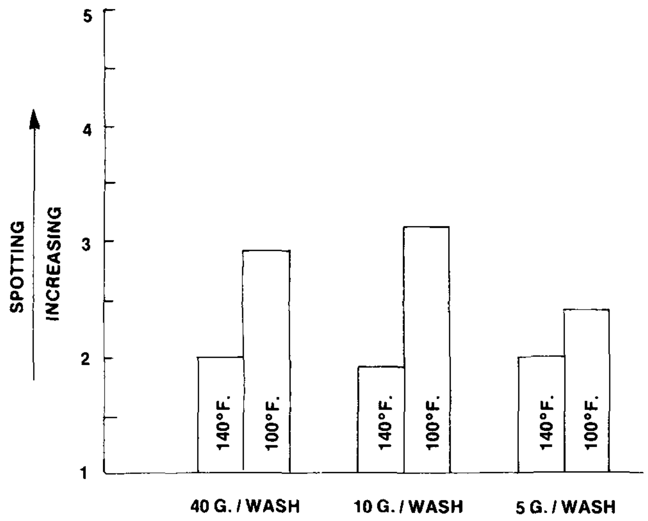

FIG. 1. Effect of loading and temperature on spotting using St. Louis tap water.

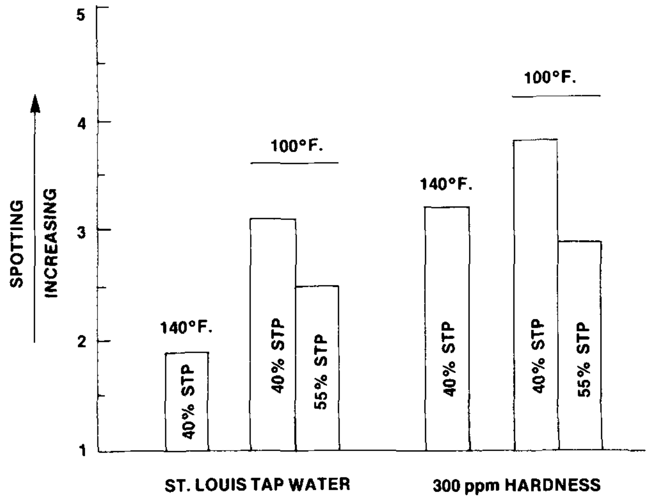

FIG. 2. Effect of STP content on spotting for 10 g/wash soil loading.

The results in Figure 1, obtained using St. Louis tap water, show a marked increase in the average spotting results from 2.0-3.0 for a 40 F (22 C) drop in wash temperature using either 40 g/wash or 10 g/wash soil loadings. When the soil loading is reduced to 5 g/wash, spotting results are not statistically different for the two wash temperatures. In light of these results, it was decided to use soil levels of 10 and 40 g/wash for studying the effects of STP content of the formulations on spotting at a reduced washing temperature. These soil levels produce a significant spotting difference between the two wash temperatures and should adequately cover the amount of soil encountered in home units.

The increase in spotting observed in Figure 1 for the 40 F (22 C) decrease in temperature undoubtedly results from the fact that more of the fatty components of the soil will be in a solid state at 100 F (38 C) than at 140 F (60 C). Since the polyphosphates are excellent dispersants for solid particles (5) and also improve the emulsification of liquid fats, it is reasonable to think that the STP content of the formulation might affect its spotting performance.

The effect on spotting at the 100 F (38 C) wash temperature from increasing the STP content of the formulation from 40% to 55% for the 10 and 40 g/wash soil loadings are shown in Figures 2 and 3, respectively. At 300 ppm $CaCO_3$

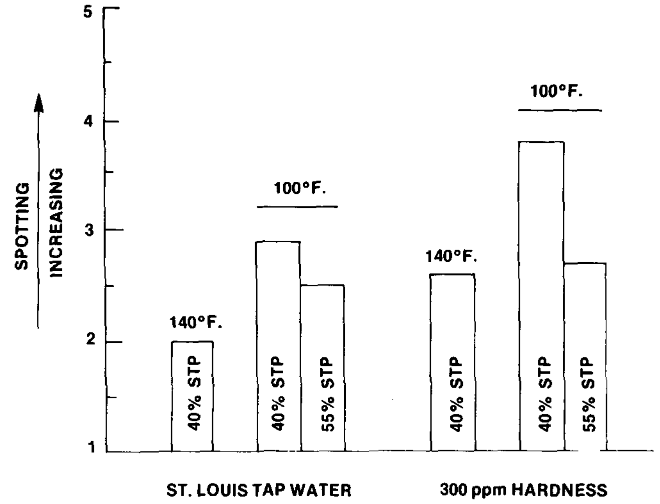

FIG. 3. Effect of STP content on spotting for 40 g/wash soil loading.

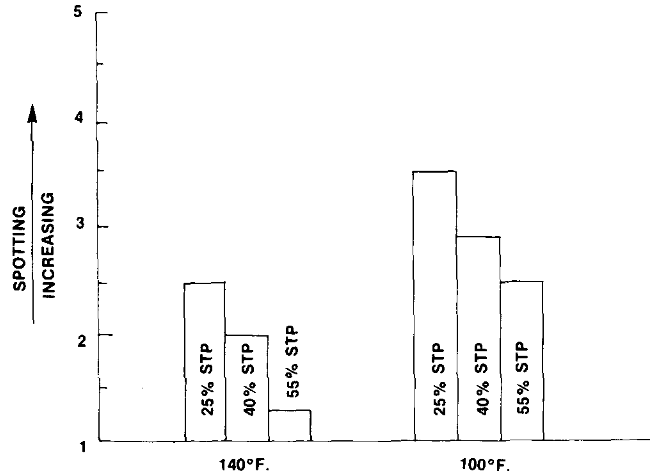

FIG. 4. Effect of STP content on spotting for 40 g/wash soil loading.

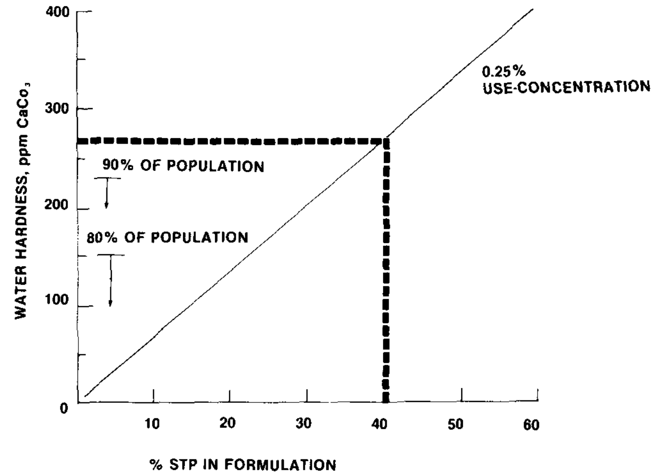

FIG. 5. STP level required in a machine dishwash detergent for hardness control at various water hardness levels.

hardness, an increase in the STP content of the formulation to the 55% level results in decreased spotting. With the St. Louis tap water, there is the indication of decreased spotting with increased STP content, although the difference is not statistically significant. At the high hardness level, the increased amount of STP offsets the spotting increase due to the 40 F (22 C) drop in wash temperature, but with the lower hardness St. Louis tap water, the increased spotting from the lower temperature appears to be only partially overcome.

The effect on spotting at the 140 F (60 C) and 100 F (38 C) wash temperatures with St. Louis tap water from a reduction in STP to the 25% level is shown in Figure 4. An increase in spotting results at both wash temperatures from the phosphate reduction. If the STP reduction, which would be necessary to meet the 8.7% phosphorus limitation in areas with legislation, is coupled with a decrease in wash temperature to conserve energy, then a large increase in spotting – from a 2.0 rating for the standard 40% STP formulation at 140 F (60 C) to a 3.5 rating for the 25% STP formulation at 100 F (38 C) – is observed. This 3.5 rating is a very poor performance level and would not be acceptable to the housewife.

The data in Figure 4 also clearly show that the spotting of glassware can be affected by the STP content of the formulation. The trends show 40% STP gives less spotting than 25% STP, and 55% STP is better than 40% at both wash temperatures. This means that the spotting problem resulting from cooler wash temperatures can be reduced by increasing the quantity of STP in the formulation, although the increased phosphate content does not completely offset the increased spotting due to the 40 F (22 C) temperature drop under all conditions. The increase in spotting over the standard conditions from the 40 F (22 C) drop in wash temperature is greater than that from a 15% reduction in phosphate to 25% STP at the standard conditions. The trend in the data, however, suggests that phosphate levels higher than 55% might overcome the spotting difference. Such formulations would require a change in the chlorine source to make room for the phosphate, and this could be accomplished by substituting the chlorinated isocyanurates for a portion or all of the chlorinated trisodium phosphate depending on the level of STP needed. This and formulation modifications such as the use of solid phase dispersants or emulsifiers for fatty substances conceivably could overcome this performance gap in spotting created by the use of lower temperature water.

Filming Performance

The importance of sodium tripolyphosphate for the prevention of glassware filming through sequestration of hard water cations is well documented (1,2,6). Its function, of course, is to prevent the formation of hardness precipitates which can deposit on glassware as an opaque film.

The quantity ot STP required in a formulation to control hardness – assuming that 1 mole of STP is required per mole of hardness cation sequestered – is shown in Figure 5 for the 0.25% detergent concentration used in this testing. These data show that 40% STP used in the standard formulation should be sufficient to control the hardness levels experienced by more than 90% of the households, unless the detergent is underused. The assumption for arriving at these numbers does not take into consideration any change in solubility of the precipitates with temperature. The precipitates that could be involved include those from the interaction of hardness ions with the ingredients in the detergent formulation, or with the various proteinaceous and fatty acid soils.

Before conducting performance testing to establish the effect of temperature on glassware filming, hardness tolerance tests were run on solutions containing the formulation alone, or with milk solids or fatty acid soil present to determine the effect of the temperature variable on the solubility of the hardness precipitates. In this test, detergent solution is brought to the desired temperature, and an

TABLE IV

Hardness Levels Required for Precipitation

Conditions	% Conc.	ppm $CaCO_3$ hardness for precipitation 140 F	100 F
Detergent solution only	0.25	266	264
Detergent solution + nonfat milk solids[a]	0.25		
	0.04	266	270
Detergent solution + sodium oleate[b]	0.25		
	0.001	276	220

[a]Equivalent to NFMS concentration in machine using CSMA test soil loading.
[b]Equivalent to 0.3% free fatty acid in 32 g of fat in CSMA test soil loading.

immersion type turbidity probe is placed in the solution. The instrument monitors the lack of turbidity as the stirred solution is titrated with stock solution of mixed calcium and magnesium hardness in a 3:2 mole ratio. A sharp break in the readings is obtained at the onset of precipitation which is taken as the end point of the titration. The hardness level is calculated from the number of milliliters added to the break in the titration curve. The hardness tolerance values are considered to be good to ± 10 ppm $CaCO_3$ in the 200-400 ppm hardness range.

Table IV shows the hardness levels at which precipitation was first observed when titrating the detergent solutions, with and without milk and fatty acid soils, at 100 F (38 C) and 140 F (60 C). The detergent solution, which when used at a 0.25% concentration contains 1000 ppm STP, precipitates when the hardness reaches ca. 265 ppm $CaCO_3$. Reducing the temperature does not change the hardness level at which the precipitate forms. This value of 265 compares with a theoretical value of 272 ppm $CaCO_3$ hardness for a solution containing 1000 ppm STP.

The addition of nonfat dried milk solids at a level of 0.04%, which is the concentration in the dishwasher with the 40 g/wash soil loading referred to earlier in this paper, does not change the hardness level at which precipitate first forms. Again decreasing the temperature has no significant effect on the hardness level required for precipitation. These data suggest that hardness salts of the milk are more soluble than those of the formulation ingredients, since the same values are obtained as for the detergent formulation above.

When sodium oleate is added to the detergent solution at a level of 0.001%, which is equivalent to only 0.3% free fatty acid in the margarine fatty used in 40 g/wash soil loading, precipitate is formed at the 100 F (38 C) temperature at a significantly lower hardness (220 ppm) than at 140 F (60 C). This means that the hardness precipitate of the fatty acid is more insoluble at the lower temperature than the hardness precipitate of the formulation ingredients.

These titration data suggest that glassware filming should not be markedly affected by a reduction in wash temperature when the precipitates causing the filming are related to the detergent ingredients in the formulation. However, when small amounts of oleic acid are present in the wash water from fatty soils, a reduction in wash temperature would be expected to increase glassware filming. Dishwasher tests were conducted to confirm the findings from this turbidity study.

Figure 6 shows glassware filming results from the standard dishwash formulation with no soil present using water ranging from 100-400 ppm $CaCO_3$ hardness. These performance results are in good agreement with the turbidity data in that there is no filming difference between the two wash temperatures, and filming shows a large increase between 200 and 300 ppm $CaCO_3$ hardness where sequestration capacity of the STP is exhausted and precipitation of hardness salts of the detergent formulation occurs.

A similar test to that described above was conducted, but 4 g of nonfat dried milk solids in addition to the detergent were added to the machines prior to the wash cycle. The results were essentially the same as those with detergent only. There is no significant difference in filming

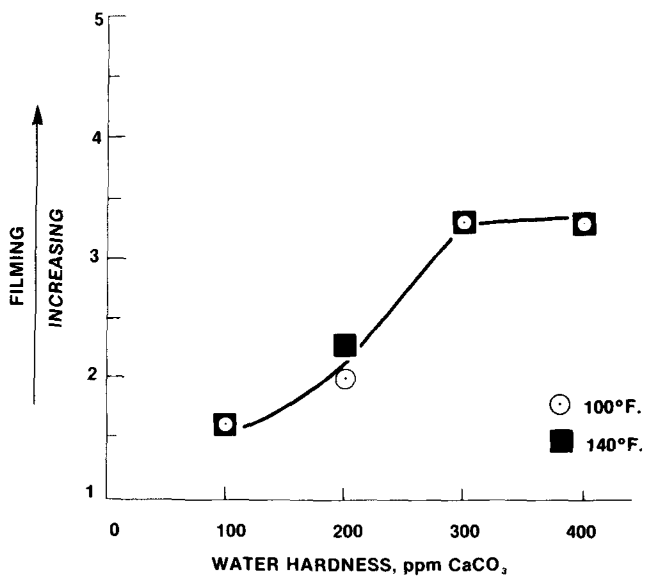

FIG. 6. Filming by detergent formulation only.

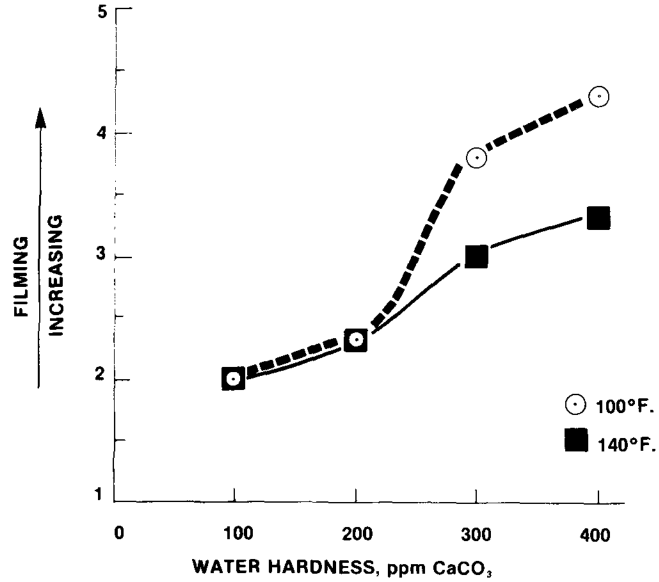

FIG. 7. Filming by sodium oleate and detergent formulation.

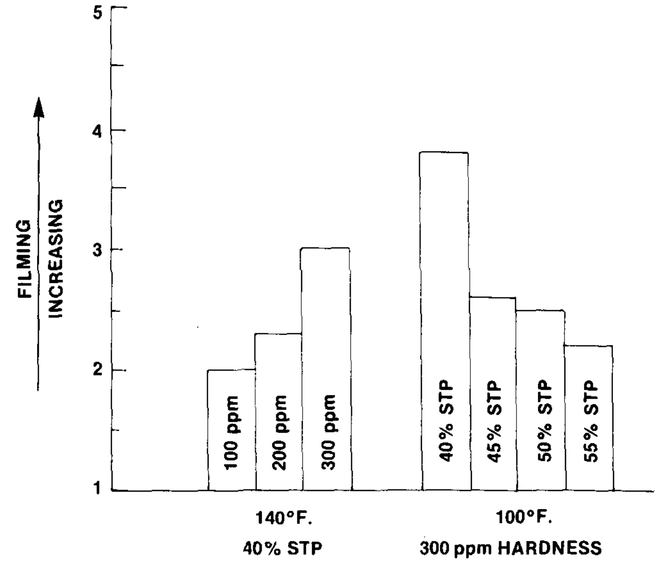

FIG. 8. Effect of STP content on filming with sodium oleate present.

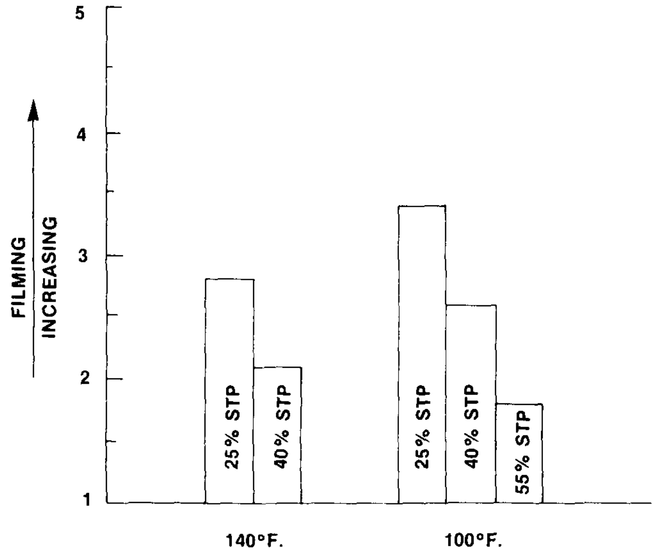

FIG. 9. Effect of STP level on filming for 40 g/wash soil loading using 300 ppm water hardness.

between the two wash temperatures, and the greatest filming occurs at hardness levels in excess of the sequestration capacity for the STP.

The effect on glassware filming from 0.108 g of oleic acid (equivalent to 0.3% free fatty acid as oleic acid in a 40 g/wash soil loading where the soil contains 36 g of margarine and 4 g nonfat dried milk solids) is shown in Figure 7. The detergent formulation was used at its customary 0.25%. In this case increased filming was noted at the lower wash temperature as expected from the hardness tolerance results.

Figure 8 shows the effect on glassware filming from increasing the STP content of the formulation from 40-55% in 5% increments with 300 ppm $CaCO_3$ hardness and a 100 F ((38 (38 C) wash temperature in the presence of the oleic acid and detergent. The data show that an increase in the STP content of the formulation to the 45% level overcomes the increased filming problem with this soil at 300 ppm hardness due to the 40 F (22 C) wash temperature drop. The 55% level of STP which is effective in reducing glassware spotting at the lower wash temperature reduces the filming at 300 ppm and 100 F (38 C) comparable to that from 40% STP at 140 F (60 C) and 100 ppm $CaCO_3$ hardness.

Glassware filming results from a 40 g/wash soil loading of the standard soil (36 g of margarine and 4 g nonfat dried milk solids) are given in Figure 9. The data show the same trend as Figure 8 in that a 55% STP level at the lower wash temperatures gives less filming than 40% STP at 140 F (60 C) when compared at the 300 ppm $CaCO_3$ hardness level. These results also show a significant increase in filming will occur at either temperature if the STP content of the formulation is reduced to 25%. A combined phosphate reduction and drop in wash temperature will result in a large increase in filming over the 40% STP standard at 140 F (60 C). The increase in filming over the standard conditions (40% STP and 140 F) from the drop in wash temperature is about the same as that observed from a 15% reduction in the STP content of the formulation when compared at the 140 F (60 C) wash temperature.

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