Optimization of an Industrial Chemical Cleaning Process for Glass Lenses

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ABSTRACT

The chemical cleaning of glass constitutes an extremely complicated problem, since its exposure to chemical attack by either water, acid, alkali salt solutions or even gases in the atmosphere may result in corrosion. In reality, corrosion generally occurs in a combination of ways simultaneously. This is particularly true with respect to industrial chemical cleaning of glass lenses, in which the absolute cleanliness (and spotlessness) of the surface of the lenses is the primary condition for further processing and/or fitness to the ultimate use. This paper presents data of a selected industrial field study (in vivo conditions) in which an application, optimization, and assessment of the chemical cleaning process (and its results) of glass lenses involving various surfactant-based formulations has been carried out. With a high level content of polyphosphates (i.e., sodium tripolyphosphates), the phosphate ester-based formulations were found to perform better than formulations based on other classes of surfactants (i.e., anionics and nonionics). The best results were achieved with 2.5–3.5% solutions of the formulation that contained ca. 3% of surface active agent. The optimal ratio of alkali-phosphate in the formulations was found to be in the range of 1:1.7–1:2.4. The results are discussed and conclusions with regard to the "real world" of such industrial processes have been drawn.

INTRODUCTION

Countless processes have been advocated for cleaning glass, and it appears that many people involved in glass cleaning treat the subject more as an art than a science (1). This state of affairs is probably due to two major factors. The first is associated with the not clearly defined physicochemical structure of glass of different types. The second is an unavoidable consequence of the lack of sufficient literature containing "hard" data on glass cleaning processes under specific well defined constraints with respect to the particular type of glass being cleaned, the specific working conditions employed, and the specifications of the final results required.

Indeed, glass is actually a physical state rather than a particular composition (2); it is a rigid transparent to translucent material with the extrinsic properties of a solid but with intrinsic properties more like those of a liquid. The regular crystal pattern that is typical of solids is missing in the glass state, so that the contained atoms are arranged in randomness typical for liquids. Besides these unique structural features, one should remember that today there are more than 600 different glasses available commercially. Typical compositions of some selected major glass types (lenses included) are summarized in Table I.

In view of the composition variability of the different types of available glasses, as well as the substantial chemical sensitivity (and/or reactivity) of a substantial portion of the glass components, the problems one has to cope with in cleaning glass surfaces are apparent. Moreover, matters are complicated by the fact that the inclusion of rather modest amounts of certain compounds in glass melt usually causes marked changes in its final physicochemical properties.

Indeed, the chemical cleaning of glass constitutes an extremely complicated problem, since exposure of glass to chemical attack by either water, steam, acids, bases, alkali salt solutions, surface active agents or even gases in the atmosphere may result in corrosion. The glass may either react with the corrosive materials to form new compounds on the surface, or be preferentially dissolved leaving a leached surface layer. In reality, corrosion occurs in a combination of these ways simultaneously.

The above is particularly true with respect to industrial

TABLE I

Typical Compositions of Selected Commercially Available Glass Types

	Chemical composition (%)												
Type	SiO_2	Na_2O	K_2O	Li_2O	CaO	MgO	ZnO	B_2O_3	Al_2O_3	ZrO_3	PbO	BaO	AgCl BrF
Ordinary lens (Corning 8361)	68.3	8.0	9.4		8.4		3.5		2.0				0.4
Photochrom lens	55.4	1.9		2.6				16.1	9.0	2.1	5.0	6.7	0.77
Bottles, windows (lime glass)	71.1	14.0			9.9	3.2			0.3				
Laboratory glass (borosilicate)	81.0	4.5						12.5	2.0				
Fiberglass (E type) (aluminosilicates)	54.5				17.5	4.5		10.0	14.0				
Table crystal (lead silicate)	56.0	2.0	13.0							29.0			

TABLE II

The Attack of Alkali on Different Types of Glass[a]

Type of glass		Loss of weight
(Corning No.)	Composition/category	(g/cm^2)
7900	95% silica	0.9
7740	Borosilicate	1.4
0010	Lead glass (electrical)	1.6
8870	High lead	3.6
1710	Aluminosilicate	0.35

[a]Conditions: 6 hr; NaOH 5% (aqueous solution); 100 C (after Hubbard and Hamilton [1941]).

chemical cleaning of glass lenses, where the cleaning process is being conducted under actual in vivo field conditions (3). Also, one should keep in mind that the classical formulations for cleaning processes traditionally contain, in addition to the surfactant(s), alkaline builders (i.e., silicates, condensed phosphates, etc.), chelating agents and several other ingredients, each of which is a potential corrosion initiator of the glass surfaces being cleaned in the aqueous solutions. Table II illustrates the attack of alkali on different types of glass.

Although both the physicochemical parameters of glass and the conditions of the technological cleaning processes in industry vary considerably (and constantly), the absolute cleanliness (and spotlessness) of the glass surface of the lenses is the primary condition for further processing and/or fitness to the ultimate use. Spotting and filming performance in cleaning cycles of glass lenses are by far more crucial than they are in home glassware machine dishwashing.

Cleaning of any kind is a complex system problem dealing simultaneously with the object to be cleaned, the cleaning formula and the environment (or system) in which the first two will be brought to interact with one another. In fact, many of the determining factors in any particular "in vivo" cleaning process (under a real framework of constraints) are beyond the control of the formulator and/or the designer of the process or system. These include specific local conditions, the quality of water used, the nature, types and degree of dirt to be removed, the methods of work, the operator competence, and so on. As a result, the detergency and performance tests obtained in vitro (under controlled laboratory conditions), cannot be translated and applied with certainty in industry where realistic "in vivo" conditions exist (5).

The above limitations certainly apply to the case of industrial cleaning of glass lenses where actual constraints are rather crucial and demanding. Well accepted pragmatism is, therefore, the optimization of the industrial process in accordance with the particular local set of constraints, using results obtained in partial simulation under controlled laboratory conditions. This paper presents a study of this kind, the purposes of which are: (a) presentation of some selected in vivo experimental data concerning the effects of the type of surfactants, and their concentrations, as well as the alkali-phosphate ratio and the total concentration of the formulations used on the final results of the cleaning process; (b) optimization of the particular industrial process investigated as a first approximation model; (c) an attempt to draw some conclusions based on the collected data, so that they can be successfully implemented in actual industrial processes where similar systems are in operation.

The main purpose of this work was, therefore, pragmatic in nature: that is, to use the "in vivo" obtained results for the design of future optimal formulations and industrial processes for the cleaning of glass lenses.

Constraints and Methodology in the Optimization of the Cleaning Process of Glass Lenses

The problem one confronts in applying a surface active agent-based formula to an industrial cleaning process of glass lenses, in an attempt to meet the required absolute cleanliness and spotlessness of the glass surface, is threefold: (a) application of the available knowhow (mainly accumulated under controlled laboratory conditions) under the actual "in vivo" field conditions; (b) optimization of the industrial chemical process within the framework of these constraints; and (c) assessment of the final results, i.e., the degree of cleanliness of the lenses' surface after any change of the system parameters (within the optimization process) in terms of the required standards.

Of the three specified aspects, the third is probably the most problematic; namely, how to obtain meaningful data from field operations which are essentially uncontrolled experiments.

The available data, which is "buried" mainly in the patent literature, has been obtained almost exclusively under controlled laboratory conditions. However, almost no data are available on the cleaning of glass lenses under actual industrial conditions.

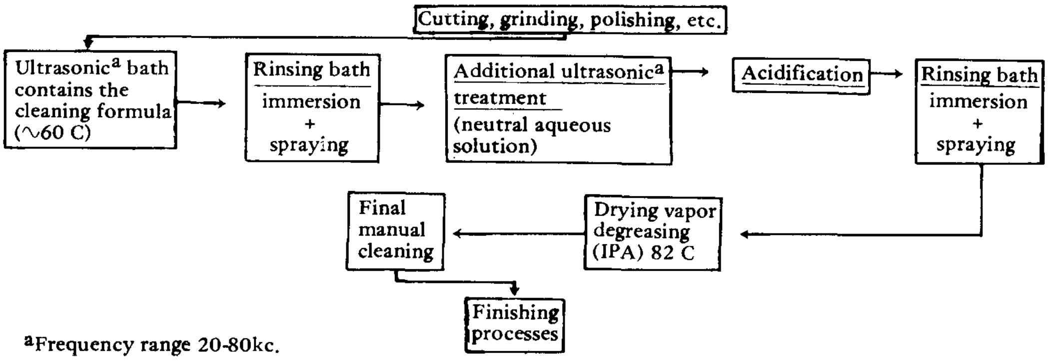
The following are some selected constraints in the optimization of an industrial cleaning process of glass lenses: (a) operating within a multivariant system, many parameters of which are uncontrollable (or changing constantly); (b) existence of intimate relationships between the technical-technological framework and the working method on the one hand, and the physicochemical performance of the cleansing formulation on the other hand; (c) absence of objective criteria for the evaluation of the results of the cleaning process; (d) lack of practical possibility to conduct a controlled experiment for the optimization of one lone component of the system at a time.

Our methodological approach to cope with the above was as follows: (a) "treatment" and changing the parameters of a selected component in the system for as long a period of time as was practically possible (under the local in vivo conditions); and (b) optimization of the process in accordance with the averaged, weighted results obtained which, in turn, were based on the subjective evaluation of the workers on location.

All of the above was conducted while keeping in mind the following fundamental demands in cleaning glass lenses with aqueous solutions of surface active agents: (a) the surface of the glass must remain absolutely clean and smooth at the end of the cleaning process; (b) any kind of corrosion of the glass should be avoided, including the diffusion of cations from the glass into the solution; (c) the complexing (during the cleaning process) of metal ions which are capable of exchange with the metal ions contained in the glass is a must; (d) the surface of the lenses must remain absolutely dry at the end of the process (otherwise, extra laborious and expensive manual drying will be required);

SCHEME 1

A "classical", conventional flowsheet of industrial cleaning process of glass lenses at Shaimar Optics, Israel.



^{a}Frequency range 20-80kc.

(e) the cleaning solution must be effective in as short period of operating time as possible; (f) the stability and original properties of the cleansing solution in the ultrasonic cleaning containers should be maintained over relatively long periods of time; and (g) the effectiveness of the cleaning solution should be maintained within a long range of changing parameters, under the practically uncontrollable in vivo conditions of the multivariant system in operation.

EXPERIMENTAL PROCEDURES

The optimization and all the related experiments have been conducted in a factory in which all kinds of glass lenses and possible combinations thereof are produced. The cleaning process is being carried out via a classical, conventional industrial design, the essence of which is represented in Scheme 1.

All the materials and formulations used in this study were industrial products meeting the specifications and standards commonly accepted in the detergent industry. Only the products of well known leading manufacturers were used. The required cleaning formulations which were prepared specifically for this study were industrial products meeting the specifications and standards commonly accepted in the detergent industry.

The required cleaning formulations were prepared specifically for this study on a small scale. Only conventional built detergent formulations (or compositions) have been used within the entire study since the decade to come will likely not bring dramatic changes in detergent technology (6). A prototype of such a formula for the cleaning of glass lenses is given in Table III.

Classical formulas of this type contain, among others, strong alkaline components, phosphates which are the most common builder for heavy duty detergent-based formulation (7), sequestering agents, dispersants, surfactants, and obviously, appropriate inhibitors. Some crucial and essential properties of such formulas are their alkalinity, water softening capability, low foam, saponification and emulsification power, capacity of complexing metal ions, and preventing the redeposition of soil (8).

The water used in the cleaning process was of medium hardness (ca. 100 ppm expressed as $CaCO_3$) unless otherwise stated. The same employees were responsible for the cleaning unit operation during the entire study and optimization.

TABLE III

A Prototype Formula for Glass Lenses Cleaning

Components	%
Alkaline base(s)	15–35
Phosphates (mainly polypohsphates)^a	20–45
Sequestrants and chelating agents^b	15–35
Silicates^c	10–20
Surface active agent^d	2–6
Inhibitors and/or other additives	0.5–4

^{a}Typically sodium tripolyphosphate (STP).
^{b}Typically EDTA.
^{c}Typically sodium metasilicate pentahydrate.
^{d}Anionic or nonionic (or a combination of both).

The basic unit operations of the cleaning process are illustrated in Scheme 1. The lenses were initially washed in an ultrasonic bath (which contained the tested cleaning formula) at ca. 60 C. This major cleaning process was followed by rinsing and additional ultrasonic treatment (at gradually decreasing temperatures), acidification, and additional rinsing (at room temperature), and final drying and vapor degreasing (with isopropyl alcohol).

Both the wash and the rinsing times were within the range of 2-4 min, except for the final vapor degreasing step which was somewhat longer. The soil being removed from the lenses constituted a combination of some cutting oil, the grinding compound (cerium oxide), and grease (mixed with some glass grind).

Evaluations of the results (i.e., rating the cleanliness and the spotlessness of the cleaned glass lenses) of each variant of the cleaning process were made by the employees on location according to their own criteria and standards. Indeed, this evalution procedure is essentially the real evaluation of detergent products by the customer under actual conditions. The evaluations were classified and recorded using a five-scale basic questionnaire as follows: 1–excellent; 2–good; 3–fair; 4–unsatisfactory; 5–very bad.

The recorded data for each set of conditions is an average of dozens (and, in certain cases, even hundreds) of runs, in each of which a batch of several hundred lenses were cleaned, bringing the total number of lenses cleaned in each series to several ten thousands.

TABLE IV

The Effect of the Surfactant Type on the Results of the Cleaning Process for Glass Lenses

		Rating (%)					
Detergent	Type	1	2	3	4	5	f_s
D-2A	Anionic[a]	–	27	48	19	6	75
	[b]		33	22	33	11	55
E-PS[c]	Anionic	–	41	50	4.5	4.5	(91)
T-Q4	Anionic[a]	–	22	58	16	10	80
	[b]		47	40	13	–	87
T-Q1	Anionic	–	7	33	40	20	40
U-L	Not known	–	50	38	12	–	88
Q	An alternative commercial formula[d]	–	13	47	13	27	60

[a] Tap water (medium hardness).

[b] Soft water.

[c] Phosphate ester.

[d] Containing nonionic.

Working conditions: 2% aqueous solution of the cleaning formula and 2% of the surface active agent in the formula. Basic formula: polyphosphates, 38%; chelating agents, 22%.

SELECTED RESULTS AND DISCUSSION

The effect of the change of surfactant type in the cleaning formula on the film formation and spotting of the cleaned lenses was thoroughly investigated. The basic formula used in this series contained 38% polyphosphates, 22% chelating agents and 2% surface active agents.

Different types of anionic and nonionic surfactants were tried. These were: Dowfax 2A1 (D-2A)–the sodium salt of C_{12}-branched alkyl diphenyloxide disulfonate; Emphos PS-400 (E-PS)–a complex organic phosphate ester of the type $HO\text{-}P(O)[(OCH_2CH_2)_n]_2$; Triton QS-44 (T-Q4)–also an anionic phosphate ester compound; Triton QS-15 (T-Q1)–the sodium salt of an amphoteric surfactant. The type of Ultravon LX (U-L) is not known.

Washing results are given in Table IV and are summarized for each surfactant in terms of f_s. f_s is defined as the "factor of success" in which the cleanliness and spotlessness of the glass surface were rated at least as fair (3) or better. Thus, $f_s = 1+2+3$. Significantly, never in the above series where the results rated as excellent (1), could any meaningful trend be associated with the use of soft or medium-hardness water in the process. However, the best results under these particular working conditions were achieved when a phosphate ester-type anionic surfactant (i.e., E-PS) was used in the cleaning formula. Due to the good compatability of the phosphate ester-type surfactants with highly alkaline components, this result is not surprising. The results obtained in using a commercially available formula (Q) suggested by the producer for this purpose were found to be relatively poor and are included in Table IV (last row) for the sake of comparison. Interestingly, except for the amphoteric surfactant (i.e., T-Q1) and one anionic (D-2A) with soft water, the results of the cleaning process were evaluated as satisfactory.

The effect of the change in concentration of the surface active agent in the cleaning formula on the final results of the cleaning process is summarized in Table V.

The same basis formula as in the previous series was used for anionic A_1, whereas a formula containing a high level of alkali ($\sim$50% w/w) was used for anionic A_2 and nonionic N. For the last two, cleaning solutions of higher concentration (i.e., 5%) have been used in the cleaning process. The only practical conclusion one can draw based on the obtained data (Table V) is that there is no advantage in using cleaning formulas containing more than 3% of surface active agent under the given set of the process constraints. As a matter of fact, a surfactant level of 2-3% in the formula appears to be optimal.

Since the industrial cleaning process is a multivariant system in which numerous factors interact with one another, it is not surprising that a drastic change in the content of the surface active agent in the cleaning formula (within the range of 1-6%) is not necessarily accompanied by a drastic change in the results of the cleaning process. It is interesting, however, that the system is much more sensitive to changes in the alkali-phosphate ratio in the cleaning formula, as can be seen in Table VI.

Significantly, keeping the alkali-phosphate ratio in the formula between 1:2.4 and 1:1.7 (total alkali and phosphates in the used formula in this series was kept at the 52% level) maintains essentially the same level of results in the process. However, decreasing the optimal ratio in favor of the alkaline component leads to a drastic change in performance. Further increase of the optimum alkali-phosphate ratio (in this particular case, 2:1) does not necessarily lead to significant changes in the results.

There are several possible explanations for these results. The most plausible would be that the increase of alkalinity (and evidently the pH of the cleaning solution) may result in corrosion of the glass surface (see Table II). The decrease in the level of the phosphates, on the other hand, may result (along with other possibilities) in reduced sequestering capacity of the formula with respect to the water hardness (Ca^{2+} and Mg^{2+}). The formation of films and spots on the glass surface is thus facilitated. Both effects (i.e., corrosion and spotting) are, consequently, being reflected in the final results of the cleaning process.

Finally, the effect of the cleaning formula concentration

TABLE V

The Effect of Surfactant Concentration in the Cleaning Formula on the Results of the Cleaning Process

Surfactant concentration (%)	Type[a]	Rating (%) 1	2	3	4	5	f_s
1	A_1	6.5	16	39	16	22.5	61.5
	A_2	–	33	34	33	–	77
	N	–	–	–	75	25	–
2	A_1	9	25	36	19	11	70
	A_2	–	–	–	–	100(?)	–
	N	–	–	50	50	–	50
3	A_1	–	50	28	11	11	(78)
	A_2	–	17	17	33	33	34
	N	–	–	86	–	14	(86)
4	A_2	–	–	34	33	33	34
5	N	–	18	29	18	35	46
6	A_1	10	37	29	13	11	76

[a] A_1, A_2, anionics; N, nonionic.

Working conditions: aqueous solution of the cleaning formula, 2% for A_1; 5% for A_2 and N.

TABLE VI

The Effect of Alkali Polyphosphate Ratios in the Cleaning Formula on the Results of the Cleaning Process

Alkali: phosphate ratio	No. of runs	Rating (%) 1	2	3	4	5	f_s
1:2.4	–	10	37	29	13	11	76
1:1.9	55	–	33	38	22	7	71
1:1.7	39	–	23	54	16	7	77
1:1	44	7	32	25	18	18	64
2:1	16	6	25	19	38	12	50
10:1	83	–	20	36	17	27	56

Basic formulation: alkali and phosphates, 52%; chelating agents, 24%; surfactant, 4%. Working conditions: aqueous solution of the cleaning formula, 4%.

TABLE VII

The Effect of the Concentration of the Cleaning Formula (in solution)[a] on the Results of the Cleaning Process

	Rating (%)										
	Formula Z[b]					Formula Q[c]					
Concentration (%)	1	2	3	4	5	1	2	3	4	5	f_s
0.55	–	25	25	–	50						50
0.85	4	8	48	16	24						60
1.25	–	–	40	40	20						40
1.7	6	25	19	38	42						50
2.0						–	13	47	13	27	60
2.5	–	60	40	–	–						100
3.5						–	43	29	14	14	72
4.0						–	17	49	17	17	66
5.0	21	33	26	21	–						47

[a] Tap water (medium hardness).

[b] A special formula designed for this study.

[c] A commercial product suggested for the cleaning of glass lenses.

in the aqueous cleaning solution (in the first ultrasonic bath of the process) was studied within the range of 0.5–5%. The results of this series with two different formulas are summarized in Table VII.

These results are gratifying in two respects: first, the best cleaning results are obtained when the concentration of the cleaning material in the aqueous solution is within the range of 2.5–3.5%. Lower or higher concentrations result in poorer performance as far as the surface of glass lenses is concerned. Second, although the optimization curves for both formulas tested present similar behavior, the performance of the formula Z, designed especially for this study, was found to be greatly superior when compared with existing commercial products. In spite of the problems associated with the subjective nature of the evaluation procedure used, it seems fair to conclude that the specially designed formula Z is indeed the formula of choice for this particular set of constraints.

It appears that in the system studied, an industrial cleaning process of glass lenses under in vivo conditions, the interplay between the various parameters contribute towards keeping the system in some sort of dynamic equilibrium with which the resultant formula effectiveness is directly correlated. However, the change in the type and/or the ratio, and/or the concentration of some selected components of the cleaning formula, within a certain range, does bring about changes in performance. Thus, it was found, that phosphate esters (ca. 3% in the detergent based formula) are the surfactants of choice for this process when the alkali-phosphate ratio in the formula is between 1:1.7 and 1:2.4 and the concentration of the cleaning compound in the solution is in the range of 2.5-3.5%. Also, a relatively high level of condensed phosphates (mainly sodium tripolyphosphate) and chelating agents was found essential for the success of the process. Optimization of the process in accordance with the particular set of local constraints was found to be economically rewarding.

Currently, the surfactant chemist or formulator can work with over 600 surface active agents manufactured by about 160 producers in the USA alone (9). The effective optimization of an industrial chemical cleaning process as well as the formula to be used in the process can be envisioned therefore, as an insurmountable problem. However, as is shown in this study, it can be and should be done. The data collected in one process can be creatively adopted and applied to the optimization of similar processes under a given set of local conditions. The economical benefits to the glass lenses' industry are apparent.

Heavy duty surfactant-based formulations used in the cleaning process of glass lenses (and glass in general), form a complex multivariant, self-contained, multipurpose system, which is capable of useful performance under a variety of working conditions. Therefore, from a practical point of view, a dialogue between the laboratory and the field is suggested to fill the gap between theory and practice as far as cleaning techniques and the performance of the surfactant-based formulations are concerned.

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REFERENCES

1. Holland, L., The Properties of Glass Surfaces, Chapman & Hall, London, 1966.
2. Kolb, D., and K.E. Kolb, J. Chem. Educ. 56:604 (1979).
3. Zoller, U., Tenside Deterg. 16:135 (1979).
4. Langguth, R.P., and E.A. Casey, JAOCS 56:909 (1979).
5. Matson, T.P., and M. Berretz, Soap, Cosmet. Chem. Spec., 36, January (1980).
6. Schneider, M.J., Ibid. 40, March (1977).
7. Lowe, E., A. Johnston, and E. Johnston, JAOCS 55:32 (1978).
8. Davis, R.C., in Detergency-Theory and Test Methods, edited by W.G. Cutler and R.C. Davis, Marcell Dekker, Inc., New York, NY, 1972.
9. Bluestein, B.R., R.D. Cowell, and M.L. Mausner, JAOCS 58: 173 (1981).

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ERRATUM

In the article "Synergism in Binary Mixtures of Surfactants: II. Some Experimental Data" appearing in the December issue of *JAOCS* (Rosen and Hua 59:582 [1982]), five lines were misplaced. The last five lines on page 583 ("systems showing synergism . . . i.e., the cmc, area") should be omitted, and inserted at the bottom of page 584. The last paragraph on page 584, continuing on page 585, should then read "Currently, there are almost no data in the literature from which calculations of β, β^M, X_c, and X^M can be made on systems showing synergism in this respect. Table III lists some data for the system: $C_{12}H_{25}SO_3K/C_{12}H_{25}N(CH_3)_2O$ (6) in which this type of synergism is present. It also includes data for some hypothetical systems in which the values of C_1^M, C_2^M, A_1°, A_2°, γ_1^M, and γ_2^M (i.e., the cmc, area per molecule and surface tension at the cmc for the individual surfactants) and the value of β^M are identical with those in the real system, while the value of β is changed."