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PREVENTION OF SOILING OF HELIOSTAT SURFACES

FINAL REPORT

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OBJECTIVES

The goal of this program is to develop treatments for the glass surface of the heliostat or plastic dome covering the aluminized Mylar mirror of enclosed heliostats to prevent or minimize soiling and to facilitate cleaning.

Various antistatic and antisoiling agents were examined to determine which materials would produce the highest efficiency in the reduction of soiling on glass or plastic surfaces. These materials were either reactive with glass or plastic themselves, reactive with a coupling agent, such as a silane or titanate, or compatible with a carrier, such as weather-resistant coating.

The organic compounds known to be reactive with hydroxyl groups were attached directly to the glass surface. Other organic compounds were grafted to the plastic or glass surfaces using silane or titanate coupling agents. Antistats or soil-release agents which are compatible with weather-resistant coating vehicles, such as acrylics, or silicones, were blended with the carrier and coated on the glass or plastic surface.

Screening tests of the treated surfaces were conducted to determine the best agents for the reduction of soiling and whether or not the treatment process was economically feasible when compared to "standard" washing procedures. The testing procedures included determinations of clarity, hardness, abrasion resistance, antistatic properties, anti-soiling properties, and permanence.

ABSTRACT

The goal of this project was to develop methods for preventing or minimizing soiling of the surface of the glass-mirrored heliostat and the plastic dome over the aluminized Mylar mirror and also to facilitate the cleaning process. The substrates used in this project were float glass, Kynar, and Petra A polyester.

The two general classes of compounds which were being investigated were antistatic and antisoiling agents. The categories of antistatic agents used were amine derivatives, quaternary ammonium salts, phosphate esters, and polyethylene glycol esters. The soil-release agents were either hydrophilic ionic or hydrophilic nonionic in character. These compounds were attached to the substrate surface by silane or titanate coupling agents or as a mixture with a hard, weather-resistant coating. The silanol groups on the surface of glass provided suitable attachment sites; whereas, the plastic substrates required activation by various procedures. Another route to these objectives lay in direct reaction of an organic compound with a functional group in the glass surface.

Evaluation of the various coatings on the three substrates was accomplished by a sequential screening procedure. The tests were performed in the following order with ineffective materials eliminated at each step: (1) clarity, (2) adhesion, (3) antisoiling properties, (4) abrasion resistance, and (5) permanence. Dust was removed by a high velocity air stream, an air stream in conjunction with gentle brushing, or by small amounts of water at low pressure. Finally, a water wash apparatus was designed and examined for efficiency of dust removal.

INTRODUCTION

The solar central receiver system uses large surface areas of glass in the field of heliostats to collect and focus light. Any loss of reflectance as a result of dirt depositing on the mirror surface will cause a loss of power and require maintenance by washing. However, in desert areas where such systems will be constructed, the ecology places limitations on the volume of water which may be used in such washing procedures. The objectives of this project were to develop methods for preventing or minimizing soiling of the surface of the glass-mirrored heliostat and the plastic dome over the aluminized Mylar mirror and also to facilitate the cleaning process. The substrates used in this project were float glass, Kynar (polyvinylidene fluoride), and Petra A polyester.

There are two general approaches that will be used to provide a surface with dirt-repellant properties:

(1) Reaction of an antistatic or soil-release agent either directly with the surface or through an intermediate coupling agent.

(2) Binding of the additives to the surface through a polymeric coating.

The two general classes of compounds which have been investigated were antistatic and antisoiling agents. Previous experience in plastics, textile, and metal technology has proven the usefulness of these materials for preventing or minimizing soiling. The four general categories of antistatic agents are amine derivatives, quaternary ammonium salts, phosphate esters, and polyethylene glycol esters. Reagents from each category which we investigated are listed in Table 1. Soil-release agents are either hydrophilic ionic or hydrophilic nonionic in character. The soil-release materials studied are given in Table 2. These compounds were attached to the substrate surface by silane or titanate coupling agents or as a mixture with a hard, weather-resistant coating. Some additional materials are also available which react directly with the glass or plastic.

Commercially available silane coupling agents, which have two reactive functional groups, are quite effective in reactive polymer systems. Hydrolyzable alkoxy groups attached to a silicon atom react with the hydroxyl or other functional group on the surface of the substrate. Also attached to the silicon atom is an organo functionality such as an amino, mercapto, epoxy, vinyl, or methacryloxy group which can react with specific antistatic or antisoiling agent. The amino functionality is reactive with epoxy, phenolic, nylon, and vinyl polymers, and with some thermoset elastomers. The vinyl and methacryloxy silanes react with unsaturated polyesters and peroxide-cured polyethylene, for example. To be effective in any given system, the coupling agent must be reactive to some degree with both the polymer and the glass.

The silanes we examined are listed in Table 3.

Titanates also interact with and act as a bridge between the glass or plastic substrate and organic materials. They have three reactive pendant functional groups, and as with silanes they form a monomolecular layer on the surface. A typical reaction would be:

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                 RO                O
     Glass OH+RO-Ti-OR-- Glass -O- Ti-O-
                 OR                O
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The titanates screened in this study are listed in Table 4.

Another route is the dispersion or solution of the antistat or soil-release agents in a polymeric coating. Only three classes of coatings or their modifications are weather (UV) resistant: acrylics, silicones, and fluorocarbons .The expense of the fluorocarbons is prohibitive; therefore, we have examined the acrylics and silicones shown in Table 5. The antistatic and soil-release agents were dispersed in the organic coating and the coating was bonded directly to the glass or plastic in the case of the acrylics or through Dow Corning Q3-6060 primer with the silicones.

There are various antistatic organic compounds which react with silanol or hydroxyl groups; however, the resulting bond in many cases may be easily hydrolyzed. One way to avoid the hydrolysis problem is to react with glass or plastic, compounds which may function as antistatic agents, but which would be attached through a stable bond, (Table 6). An additional route to reaction with the hydroxyl group of glass or activated plastic lies in catalyzed grafting of organic polymers onto the surface.

Evaluation of the various coatings on the three substrates was accomplished by a sequential screening procedure. The tests were performed in the following order with ineffective materials eliminated at each step: (1) clarity, (2) adhesion, (3) antisoling properties, (4) abrasion resistance, (5) antistatic properties, and (6) permanence.

Visual clarity of a coating is evaluated initially. Materials which obviously produce cloudiness or a haze on the substrate are discarded. Percent transmission, normalized to solar energy wavelengths, is measured before and after soiling tests on treatments of interest.

Our determination of adhesion is essentially subjective. Glass coatings are rubbed with a plastic rod to determine if the coating can be defaced or removed. Since both plastic substrates are too soft for this approach, we rub them with cheesecloth for the same determination.

The soil release test is accomplished by sifting AC Fine Mix Test Dust (1) from General Motors onto a coated sheet. The sheet is placed horizontally in the path of air from a hand-held air gun. The approximate amount of dust removed is estimated. Percent transmission is measured on samples which appear to be staisfactory. Two other methods of dust removal are used; air gun plus brushing with a soft camel hair brush and washing with a stream of deionized water from a squeeze bottle.

Three types of dust were evaluated: dry (or regular dust), oily dust (dust mixed with 3% Nujol) and humified dust (the dusted slide is humidified for 24 hours at 80% relative humidity).

Abrasion was determined by the falling sand method. Ten pounds of sand is dropped through a tube 30 inches long to the sample which is placed at a 45° angle. This is followed by the soil-release test to determine if the coating has been removed.

The ability of the various coatings to dissipate an electrostatic charge was determined with a Simco Model E "Electrostatic Locator". The glass plate is placed between a metal ground panel and a mica insulator. The plates are charged for 5 minutes with 7 kilovolts D.C. The time for the charge to dissipate to 400 volts is measured.

Permanence is measured by outdoor exposure, Weather-Ometer, and the RS-4 Sunlamp.

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(1) Arizona Road Dust

DISCUSSION

GLASS

Direct Reaction Organic Compounds

In the attachment of reactants to float glass[1] it was essential that the "tin side" of the glass be identified. This is the side of the glass which was in contact with tin during manufacturing. The attachment of coupling agents to glass could possibly be inhibited by the presence of residual tin, therefore , it is necessary to identify the "non-tin" side for our studies. We have found that placing float glass under a short wavelength ultraviolet light causes fluorescence of the tin resulting in a bright glow from the tin side.

All studies were carried out on float glass cut to 1" x 3" size. All reactants were put on by dipping the glass slide in the reagent, draining and allowing to dry. Coatings were judged by optical clarity, uniformity the ease with which the coating was removed by gentle rubbing and ease of dry dust removal with an air gun.

The simplest system would be one in which a reagent molecule would react directly[2] with the hydroxyl group of the glass surface. Two materials are in this category:

- Permafresh LF-2 (Sun Chemical): Dimethylol dihydroxyethylene urea
- Cymel 303 (American Cyanamid): Hexamethoxymethylmelamine

An alternate route was the activation of glass with ceric ammonium nitrate followed by grafting of organic monomer to the surface and finally polymerization.

The monomers used in the grafting process were hydroxyethyl methacrylate (HEMA), methacrylic acid, methacrylamidopropyltrimethylammonium chloride, allyltrimethylammonium chloride, diacetone acrylamide, cetyl vinyl ether, vinyl isobutyl ether, and N-methylolacrylamide. Smooth, hard coatings were achieved

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(1) Float glass is used throughout this program unless stated otherwise.

(2) All reaction conditions will be in the Appendix.

with all of these materials. In a preliminary examination of dust removal from the coated glass slides the first group of materials in Table 7 gave what appeared to be reasonable dust removal. However, solar transmittance values of allyltrimethylammonium chloride, diacetone acrylamide; hydroxymethylmethacrylate and methacrylic acid, and Permafresh LF-2 treated slides after dust removal by air gun were only between 70 to 75 percent. It was found that these low values ,although due primarily to residual dust, were also caused by haze in the coating. In addition, simple rubbing of the glass slide removed the treatment.

This method of direct reaction with glass was dropped except for reaction with HEMA.

HEMA was the most promising of the direct reaction reagents. A slide is coated with HEMA then immersed in a solution of 4 mil triethyleneglycoldiacrylate in 96 mil 50/50 xylene/toluene for 30 minutes and finally crosslinked by oven heating[2]. Transmission of the coated glass slide after cleaning was 87%, after dry dust 83%, oily dust 85% and humidified dust 78%.

Coupled Systems

Considerable effort was focused on the attachment of silane and titanates to glass. These materials have the potential to act as antistatic and antisoiling agents themselves as well as functioning as coupling agents. The compounds examined are listed in Tables 3 and 4.

Aqueous solutions containing 1.0 percent of the agent were used for the silanes. Several of the Dow Corning samples were used both in acidified solution (pH 3.0 to 4.5) and also in methanol. The titanates were used at 1% in isopropanol. Glass samples were dip coated and dried at room temperature. The coatings were judged on the basis of their optical clarity, uniformity, and the ease with which they could be removed by wiping. The initial screening of these materials as antisoiling coatings was accomplished by sifting Arizona Road Dust onto the treated glass and directing an air stream across the glass.

Two silanes and two titanates were chosen as coupling agents for attachment of various antistatic and antisoiling agents to glass. Dow Corning XZ-2-2300 silane gave one of the best soil repelling coatings for the Arizona Road Dust; however, this coating was more easily removed than the other silanes. Dow Corning B-2080-200 and Pierce SurfaSil gave more permanent coatings and were chosen as the silane coupling agents. Kenrich KR37BS also provided fair soil release properties; this material is soluble with difficulty in virtually all solvents and must be applied as an emulsion. Consistent coatings are difficult with this material. Similar problems were encountered with Kenrich KR46B. DuPont Tyzor AA and Tyzor TE both provided good surfaces which appeared to adhere well to glass. As a result both of these compounds were chosen as the titanate coupling agents. None of these coupling agents were highly efficient at soil repellancy when used alone on glass. Therefore, they were subsequently used only as coupling agents for antistats and soil release materials.

It is essential that the reagents being attached or coated on the glass have minimal effect on transmission (%T). As indicated in Table 8 the materials used in this program, whether silane or titanate coupling agent have negligible, if any, effect on %T.

Following the selection of the two best silane and titanate coupling agents for glass, Dow Corning B-2080-200, Pierce SurfaSil, DuPont Tyzor AA, and DuPont Tyzor TE, we proceeded with the attachment of antistatic and soil release agents to commercial float glass. As previously indicated, we concentrated on the "non-tin" side of the glass.A number of antistatic agents were attached to glass using each of the four selected coupling agents. The antistatic agents included quaternary ammonium compounds, amine derivatives, phosphate esters, and polyethylene glycol esters. Antisoiling agents including both ionic polymers and nonionic polymers were also attached to glass with the same coupling[(1)] agents, (see Tables 1 and 2).

Untreated glass has a transmission of 87%. The silane and titanate coupling agents caused only a one percent loss in transmission. When the antistatic and antisoiling agents are combined with the coupling agents there may be small further loss in transmissions,depending on the system.

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(1) See Appendix for experimental details.

The silane, Pierce SufaSil, used alone gives a 1% loss; there is no further loss when it is combined with polyethylene glycol and Cyastat LS and only a 2% loss using Flexol Plasticizer TOF (Table 9).

Polyvinyl alcohol and casein coupled through the titanates, Tyzor AA and TE lose from 3 to 6% transmission. However, the quarternary ammonium compound Aston A25, and sodium carboxymethyl cellulose coupled to glass with titanates give only a 2% loss, only 1% more than Tyzor AA titanate used alone (Tables 8 and 9).

The direct reaction material HEMA (hydroxyethyl methacrylate) coated on glass as is and also crosslinked with triethylene glycol diacrylate gave no transmission loss; there is only 1% loss when coupled with Tyzor AA. HEC, hydroxyethyl cellulose, coupled through Tyzor TE produces the same %T as glass.

Using a broad variety of antistats and soil release agents with the four best coupling agents Arizona Road Dust was sifted onto the coated glass slide, tapped to remove excess dust and air blown with an air gun. Ease of removal was first judged qualitatively (Table 10) and then quantitatively on separate slides (Table 11). Qualitatively the most successful materials were Refined Onyx Aston 25, a quaternary ammonium compound, coupled with DuPont Tyzor AA; Flexol Plasticizer TOF coupled with Pierce SufaSil or Tyzor AA; sodium carboxymethyl cellulose, hydroxyethyl cellulose, and casein ionic polymers each coupled through either Dow Corning B-2080-200 silane, DuPont Tyzor AA, or DuPont Tyzor TE; polyvinyl pyrrolidone nonionic polymer coupled through Tyzor TE; and polyvinyl alcohol nonionic polymer coupled through Tyzor AA or Tyzor TE. Between 80 and 90 percent of all dust could be removed from these samples by the air stream. Additional transmission testing was then performed on some of the samples after dust removal. Dusted but untreated glass loses 5% transmission dropping from 87 to 82%. None of the coupled soil release agent or antistat systems effected any significant improvement.

Coatings

As with the evaluation of coupling agents the first step is to be certain that the coating does not interfere with %T. In Table 12 four acrylics and two silicones do not cause any loss of transmission and the silicone primer Q3-6060 only a very small loss. However, the GE SHC-1000 "silicate type" material causes a five percent reduction in %T. Although the SHC-1000 overcomes one of the problems with silicone coatings, i.e. insufficient hardness, it causes too great a drop in %T to be generally useful. However, it provides good abrasion resistance and soil repellant properties. The transmission problem may be haziness due to unsatisfactory solvents or inadequate curing. This material should be investigated further.

The acrylic coatings AT-51 and AT-56 gave relatively low transmissions on glass when dip coated from a 7% solids solution. Decreasing the solids in the dip coating solution to 4% raised the transmission to that of glass (Table 12). Preliminary work was begun on dispersing or dissolving antistatic and soil-release agents in organic coating materials and then bonding the coating to the glass directly or through a primer. Two acrylic coatings from Rohm and Haas, Acryloid AT-50 and AT-56, were each examined(1). The AT-50 sample contains a crosslinking agent(1). AT-56 requires the addition of either Uformite 27-802 or Cymel 325 crosslinking agent. Glass plates containing AT-51 mixed with either Flexol TOF or Santicizer 141 recorded transmission of 86% (Table 13). Transmission values equivalent to glass were found with all the coating mixtures shown in Table 13.

Slides were also coated with the silicone primer Q3-6060 followed by immersion in 1% Santicizer 141 in isopropyl alcohol. Again %T was high at 87%.

The best acrylic coatings appeared to be the solvent acrylics from Rohm and Haas AT50, 51 and 56. However, before we settled on these, other acrylics were explored.

We evaluated the Rohm and Haas WL-81 acrylic latex which has demonstrated optical clarity and abrasion resistance. Dust removal studies with this material, however, were unsuccessful. Insufficient dust was removed by our air gun to measure the percent transmission. We incorporated water soluble additives such as Santicizer 141, Aston 456, Aston OI, polyacrylic acid, polyvinyl alcohol, polyethylene glycol, methyl cellulose, and polyvinyl pyrrolidone into the WL-81 formulation but no distinct improvements were noted. The polyethylene glycol sample gave the best results; however, only 95 percent of the dust could be removed from this coating.

We examined several other Rohm and Haas solvent-based acrylics for dust resistance. These were AT-70, B-44, B-50, B-72, B-84, and B-99.

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(1) See Appendix for experimental details.

Approximately 95 percent of the dust was removed from glass coated with B-44, B-72 , or B-99. A significant amount of small dust particles did remain on the samples. The addition of Santicizer 141 to the three coatings failed to provide any improvements.

A new series of latex acrylics including B.F. Goodrich Hycar 256, Hycar 172, Hycar 138, Hycar 91, Valspar Acrylic Latex EB 9388, Celanese Solvent Coating ED25164, and Johnson Wax Permacote 62 were applied to glass and evaluated for dust removal. The best sample was Permacote 62 but this gave only 81 percent transmittance after dust removal.

The solvent acrylics AT50, 51 and 56 were still the most effective and were chosen for in-depth investigation.

The initial evaluation of soiling was carried out by qualitatively assessing the amount of dust removed by an air gun from a coated and dusted glass slide. The bulk of the work was carried out with systems based on the Rohm and Haas solvent acrylics AT-50, 51 and 56, and the silicone primer Q3-6060. A wide variety of antistats and soil release agents were incorporated into the acrylic coating (Table 14). With the silicone system the glass was primed first with the Q3-6060 and then topcoated with the reagents shown in Table 15. From this information plus coating uniformity, clarity and adhesion (as judged by rubbing), a few coatings were chosen for measurement of percent transmission (Table 16). Systems with the highest transmission were 650 silicone glass resin, Q3-6060/Santicizer 141 and to a lesser extent AT-50/Flexol 4GO. It is pertinent to note that the Owens Illinois silicone Glass Resin 650 does not require any secondary additives.

All dust removal studies up to this point have been carried out with dry dust. However, in many industrial areas the dust would be mixed with industrial oils or would be under conditions of high humidity.

Dust containing 3% Nujol was sifted onto coated glass slides. Coatings consisted of the direct reactant HEMA, two coupling agents systems, as well as silicone and acrylic coating systems. Two of the best systems were the same as with dry dust--650 Glass Resin and Q3-6060 primer followed by Santicizer 141 (Table 17). Other high efficiency materials were crosslinked HEMA, and hydroxyethyl celluose coupled with Tyzor TE.

The humidified dust was also removed from the coated glass with an air gun. Again Q3-6060 primer post coated with the phosphate ester plasticizer, Santicizer 141 gave the easiest soil removal. Other excellent coatings were crosslinked HEMA coupled with Tyzor AA and hydroxyethyl cellulose coupled with Tyzor TE (Table 18).

We attempted to verify our results from the air gun experiments with an air stream generated in a wind tunnel at Foster-Miller in Waltham, MA. We used coatings which included Acryloid AT-50, AT-50 containing Flexol 4GO, and Dow Corning Q3-6060 followed by Santicizer 141. The maximum measurable velocity in the wind tunnel is 24 mph. Very little dust was removed from any sample at this speed. Significantly higher air velocities generated at higher blower speeds did remove most all of the applied dust. The percent transmission readings on these samples were essentially the same as those obtained with the air gun. These results indicate that removal of dust from coated heliostats by wind only would be difficult at best (Table 19).

Abrasion

Since many of the heliostats will be in desert areas, abrasion from sand was considered to be a potential problem. Therefore we ran sand abrasion tests per ASTM 6191 which involves sand falling 30 inches through a pipe and striking the object angled at 45 degrees.

We began our abrasion studies on untreated float glass. Ten pounds of falling sand produced a drop in transmission from 87 to 73 percent (Table 20). As little as 0.5 lbs of sand lowers %T to 85%. One pound produces a decrease to 84 percent and two pounds gives value of 79 percent.

Many simple glass treatments or coatings give better abrasion resistance as measured by percent transmission than the unprotected glass. These including the silicone 650 Glass Resin as well as the acrylic coatings AT50, 51 and 56 and WL81. Our best results have been obtained with the Rohm and Haas latex acrylic WL-81. A glass sample coated with a five percent solids solution of WL-81 gave a transmission of 86 percent prior to abrasion and 85 percent after 10 pounds of falling sand (Table 21).

The above results with the Rohm and Haas solvent acrylics were obtained with a 4% solution in xylene and butanol. At seven percent solids abrasion resistance was worse. The AT-50 and AT-51 Acryloids from Rohm and Haas are too soft in their recommended form to provide proper dust removal and to withstand abrasion. Increasing the Cymel 325 crosslinker amount by 5 percent failed to provide the necessary hardness and 10 percent added cross-linker resulted in extremely brittle coatings which cracked and peeled off the glass. We found an additional 7 percent crosslinker to be a satisfactory compromise.

A study was made of the amount of falling sand required to remove the treatment from a glass surface(Table 22) . A variety of antistats and soil release agents coupled to glass with B-2080-200 silane or Tyzor AA or TE titanates were exposed to falling sand and the amount of sand required to remove the coating recorded (Table 22). The silane results were poor, however, systems with sodium carboxymethyl cellulose,Flexol Plasticizer TOF polyvinyl alcohol dip coated from a one percent solution gave coatings that were intact even after ten pounds of falling sand. The other samples were damaged with less than one pound of sand.

Percent transmission after abrasion with ten pounds of sand was measured on a wide variety of release agent systems either coupled to glass through silanes or titanates or bound to glass via an acrylic or silicone coating. Transmissions ranged from 67 to 81 percent. Polyvinyl pyrrolidone with either of the solvent acrylics AT51 or AT56 gave the 81 % transmission after abrasion. Other high transmissions were produced with the acrylic coatings using Santicizer 141 and Flexol TOF as well as with the titanate coupled systems containing hydroxyethyl cellulose and polyvinyl alcohol (Table 23).

Corning 7809 Glass

Samples of Corning 7809 glass, which were sent to us by Sandia, were treated with the coatings previously judged to be successful on float glass. We ran our basic series of tests on these samples to determine if any differences exist between them and the standard float glass samples. The regular dust samples were covered with AC Test Dust, the oily dust samples were covered with AC Test Dust containing 3 percent of Nujol, and high humidity samples were covered with AC Test Dust and stored for 24 hours at 80 percent relative humidity. In all cases, the dust was removed with our air gun. The results are given in Table 24. Only dust treated with Nujol could be readily removed from all samples even including the uncoated glass; however, overall performance was satisfactory only with 650 Glass Resin and the silicone primer Q306060 and Santicizer 141. Alternate dust removal methods proved to be effective with the uncoated glass. Regular dusted samples could be cleaned with either water wash or brushing while applying a stream of air. In both cases, the resulting solar transmission was 92 percent.

Sand abrasion tests were also performed on each of these samples. The results are given in Table 25. In each case, the transmission following abrasion is greater with the coated samples than with the untreated glass. The decrease in percent transmission with these samples is generally greater however than the decrease noted with the same coatings on regular float glass. Apparently, the coatings are not as strongly bound to the Corning glass as they are to soda-lime glass.

Corning 7809 glass samples coated were exposed over a constant temperature bath at 70°F to determine the effect of very high humidity (water vapor) on coating stability. Samples exposed included an uncoated control and glass slides coated with WL-81 (Rhom and Haas Rhoplex Latex Acrylic), 650 resin(a silicone from Owens-Illinois) and a combination of Q3-6060 primer (Dow Corning Silicone) and Santicizer 141 (phosphate ester, Monsanto). These coating systems were among the most successful on float glass. The data in Table 26 indicate that water vapor had no affect on the control or on the three coatings.

One of the possible routes to dust attraction and clinging to surfaces is static charge. Static attraction of dust is a well-known phenomenon and the use of antistatic agents to minimize this dust attraction is also well-known.

Assuming that static attraction implies the presence of an electrostatic charge we screened the various coatings for their ability to dissipate an electrostatic charge(1). The glass plates were charged for 5 minutes with 7 kilovolts D.C. The time for the charge to dissipate to 400 volts was measured (Table 27). Several samples dissipated the charge faster than the untreated glass control. Among the successful materials were American Cyanamid Cyastat LS,Refined Onyx Aston 25, sodium carboxymethyl cellulose, polyvinyl pyrrolidone, and casein. The casein samples which worked well were prepared in NaOH solutions. Residual sodium salts gave satisfactory results with this sample. These salts also lower light transmission. The same samples prepared in ammonium hydroxide solutions, which would not leave residual salts,

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(1) Using a Simco Model E Electrostatic Locator

were not as successful. There is not a good correlation between samples releasing soil and those which dissipate a static charge.

Glass Summation

Table 28 shows the best materials in each of the categories of dry, oily, and humid dust removal by air gun.

Four systems stand out in ease of dust removal:

- Q3-6060 Dow Corning silicone primer/top coated with Santicizer 141 (a Monsanto phosphate ester antistat)
- 650 Glass Resin (silicone from Owens Illinois)
- Flexol 4GO (Union Carbide polyethylene glycol ester) combined with AT-50 solvent acrylic from Rohm & Haas)
- Hydroxyethyl cellulose (ionic polymeric soil release agent) coupled through Tyzor TE (DuPont titanate coupling agent)

HEMA (hydroxyethyl methacrylate) offers possibilities but would require more work to prove it out. The acrylic latex WL-81 gives, by far, the best abrasion resistance.

PETRA A

Activation

Unlike glass, Petra A (thermoplastic polyester) does not have reactive functional groups on the surface. In order to attach coupling agents to this material it is necessary to activate the surface . Polyesters can be activated by hydrolysis of the ester linkage with a dilute sodium hydroxide solution (NaOH). The primary concern is to activate the surface without reducing the percent transmission of light through the material.

A Petra A sample immersed in a 10 percent NaOH solution overnight had a transmittance of 80 percent vs 83 percent for the unactivated control. Table 29 indicates the %T for a series of activation times in 10 percent NaOH. We have found that exposure of Petra A to a 10 percent solution of NAOH for two hours at room temperature caused no loss in transmission and this type of activation is used throughout all of our work with Petra A.

Using the same screening procedure as was used previously for glass, i.e. coating clarity, uniformity and adhesion after rubbing, we screened a wide variety of silane and titanate coupling agents (Tables 3 and 4). The coupling agents selected were Dow Corning Z-6020 and XZ-2-2300 silanes and DuPont Tyzor AA and Kenrich 46B titanates.

Again the first step is to analyze transmission after coating. It is noteworthy that a wide variety of systems single coatings of silicone and acrylic, combination systems of acrylic coatings or silicone (Q3-6060) primer with release agents or titanate coupled systems, gave a higher percent transmission than Petra A. This improvement ranged from 1 percent for several coatings to as much as 4 percent for 650 silicone glass resin (Table 30).

The first step in analyzing the efficiency of the coatings was to qualitatively assess the percent dust removed. Arizona Road Dust was sprinkled onto the Petra A and blown off with the air gun. Coating activated Petra A with Acryloids AT-50 and AT-51 produces samples which release at least 95 percent of applied dust. The addition of AT-56, however, only results in the removal of approximately 70 percent of the dust. Incorporation of Aston AP, Aston 456, hydroxyethyl cellulose, polyvinyl pyrrolidone, or methyl cellulose into AT-56 improves the release to at least 90 percent. All of these AT-56 samples, however, are quite hazy and appear to have an unacceptable percent transmission, indicating that qualitative estimate of dust removed is not an accurate technique (Table 31).

With Petra A only 50 percent of the dust was removed. As can be seen in Table 31 many types of coatings systems improve ease of dust removal. In fact, efficiency is so good that the data is probably suspect. Percent transmission is the only way to judge dust removal.

In Table 32 single coatings were applied to activated Petra A and dust was removed in three ways--air gun, air gun with brushing with a soft camel hair brush(coated with Santicizer 141 as an antistat), and a stream of deionized water from a laboratory squeeze bottle.

Before dusting, acrylic latex WL-81, Permacote 62 and 650 silicone Glass Resin improved percent transmission probably by improving sample smoothness. After dust removal by air gun or by air gun plus brush there was some loss in %T. However, the water wash returned the samples to their original transmission except for the unactivated or activated controls.

We continued the Petra A study by reacting vinyl isobutyl ether, hydroxyethyl methacrylate, and methacrylic acid directly to the surface. These monomers were polymerized using a certic ion catalyst. Both the hydroxyethyl methacrylate and methacrylic acid samples provided good soil repelling surfaces (Table 33). Direct reaction materials, Permafresh LF-2 and Cymel 303, were attached to the Petra surface also, but neither compound provided a suitable coating.

Several acrylics, AT-50, AT-51, B99 and Permacote 62 were used as carriers for the antistatic and antisoiling agents for activated Petra A. Before dusting %T was , in most cases, equal to or better than the control. After dusting and removal by air gun several systems Santicizer 141/AT50, and especially Santicizer 141 with B99 and Permacote 62 gave superior soil repellant properties. Petra A primed with Q3-6060 silicone and top coated with Santicizer 141 effected no improvement. In all cases the titanate coupled coatings were inferior to the controls.

Air gun plus brushing with a soft camel hair brush offered no benefits.

However, water washing with a squeeze bottle returned transmission in most cases back to that of the original. The principal exceptions were the coupled systems and the controls.

A dust removal study is not realistic or complete without evaluation of the ease of removal of oily and humidfied dust. Table 34 shows the results of air gun and air gun plus brush removal of oily dust containing 3 percent Nujol and humidified dust on coated, activated Petra A. The unactivated control after dusting with oily dust and removal by air alone gave a %T of 72 and for humid dust 74 percent. Brushing improved this somewhat to 76 and 77 percent respectively. Only about 50 percent of the oily or humidified dust could be removed from the Petra A unactivated control.

For oily dust the 650 Glass Resin sample had the highest value at 83 percent followed by B-99 and Permacote 62 acrylics, AT50/Aston 456 and two coupled systems Tyzor TC and TA/carboxymethyl cellulose (CMC).

More recent work with Petra A coated with mixture of B-99 Acrylic/ Santicizer 141 and separately primed with Q3-6060 silicone and top coated with Santicizer 141 gave %T's after oily dust removal by air gun of 79 and 80 percent respectively.

Coated Petra A with humidified dust (Petra A dusted and exposed 24 hours at 80 percent RH.) was more difficult to clean.

Petra A is easily abraded under the falling sand test. The AT-51 and AT-56 Acryloid coatings which had demonstrated abrasion resistance on glass were applied to Petra A. We tried both single and double coatings of these materials. Also, monomers such as methacrylic acid and hydroxyethyl methacrylate were polymerized to the activated Petra A surface. In each case, the surface was severely abraded with 0.5 pounds of sand. We feel the abrasion is due to the softness of the polyester surface which fails to provide sufficient support for the acrylic coatings.

A summation of the most successful coatings on activated Petra A is shown in Table 35. Data is presented on transmission of the coated sample before dusting and after dusting with regular, oily and humidified dust and after removal by air gun and water(from a squeeze bottle). The 650 silicone Glass Resin is overall best. Four other systems are also possibilities.

- WL-81 latex acrylic (Rohm & Hass)
- Acryloid B99 solvent acrylic (Rohm & Haas)
- B99 mixed with Santicizer 141 (a phosphate ester antistat from Monsanto)
- Q3-6060 silicone primer from Dow Corning top coated with Santicizer 141.

KYNAR

Kynar has no functional groups on the surface that would promote reaction. Kynar may be activated by dehydrofluorination using a primary amine in a solvent such as methanol. In 10 percent butylamine in methanol there was a gradual decrease in percent transmission from 87 percent to 86 percent within the first three minutes. After approximately five more minutes, % T drops to 85 percent. After two hours %T is 85 percent and still slowly decreasing. We continued our study of the proper activation time for Kynar using butylamine. We achieved our most consistent results using an activation time of 5 minutes in a 10 percent solution of butylamine in methanol.

We attached the Q3-6060 silicone primer to activated Kynar. Dust repulsion studies indicated approximately 100 percent of the test dust was removed by the air stream.

Activation with butylamine results in dehydrofluorination giving a double bond in the polymer backbone. For attachment of many coupling agents or direct reaction compounds, further activation is necessary.

Other activation methods evaluated included ozonolysis, redox reactions, sulfonation and t-butyl peroxide in methanol. Ozonolysis, redox, and sulfonation were unsuccessful and peroxide activation was not reproducible.

We examined two more highly reactive peroxides for the activation of Kynar. These are acetyl peroxide and dicumyl peroxide which have 10 hour half-lives at 69°C and 115°C as compared to 119°C for t-butyl peroxide used previously. We have found that these peroxides can react directly with methanol at 65°C to provide methylol radicals which then react with untreated Kynar to provide alcohol groups on the polymer surface. However, reproducibility was still poor.

Finally, we placed samples of butylamine activated Kynar in refluxing methanol containing t-butyl peroxide, acetyl peroxide or methyl ethyl ketone peroxide. The peroxide decomposes into radicals which react with methanol molecules. The resulting methanol radicals react with the double bond of the polymer giving hydroxyl groups along the chain. Solar transmission measurements show no decrease in transmission resulting from this treatment.

Attachment of antistatic and antisoiling agents to t-butyl peroxide-activated Kynar gave poor results during dust testing. The methyl ethyl ketone and acetyl peroxide treated material, however, exhibited excellent dust repulsion when coupled with methyl cellulose or polyvinyl pyrrolidone. Slightly lower efficiencies were noted with Cyastat LS, IsoNoStat, and Velvamine ATS. Very good results were also obtained with Q3-6060 silicone primer, a mixture of Acryloid AT-56 and IsoNoStat, and hydroxyethyl methacrylate when these materials were reacted with peroxide-activated Kynar.

The best technique involved immersion in 10 percent butyl amine in methanol followed by reflux for two hours at 65°C in a 1.0% acetyl peroxide solution in methanol. Acetyl peroxide gave better results than either t-butyl peroxide or dicumyl peroxide.

To determine the best preferred pretreatment condition Kynar was pretreated for 5 and 10 minute periods in butyl amine in methanol followed by 1.0% acetyl peroxide in methanol at reflux for two hours. The activated Kynar was then coated with four of the best Petra A Coatings-650 Glass Resin, B-99, HEMA and Permacote 62. Samples were covered with dry dust and air blown. Three separate sets were coated (Table 36).

Of the four coatings only the 10 minute butyl amine pretreated Glass Resin coated Kynar gave a higher transmission after dusting and air removal than the unactivated and uncoated Kynar control. Whether this small difference is sufficient to justify the cost of coating, only further studies with oily and high humidity dust can determine.

For the uncoated control and Kynar coated with three of the four coatings the 10 minute butyl amine pretreatment gave higher transmission than the 5 minute pretreatment. Reproducibility of percent transmission of the coated Kynar is fair indicating that the dust is blown off reasonably consistently.

The effect of time of pretreatment and coating of Kynar on percent transmission before dusting is revealed in Table 37. On the coated samples there is no difference in percent transmission and on the uncoated only a slight difference between the five and ten minute pretreatment times. Thus, ten minutes butyl amine pretreatment was chosen as the preferred condition. Table 37 also indicates that the pretreatment and coating provides a higher transmission than the original Kynar, perhaps becuase of increased surface smoothness.

Kynar was activated by immersion in 10 percent butylamine in methanol for ten minutes followed by heating at 65°C in 1.0 percent acetyl peroxide in methanol for two hours. It was then coated with a variety of materials that were promising on Petra A and glass. The coated specimens were dusted with dry, oily and high RH (humidified) dust. Removal was by air gun, air plus brush and deionized water stream from a squeeze bottle.

Two tables present the data. In Table 38, the %T is arranged by the type of dust, and in the other, Table 39, by the method of dust removal. The latter contains only the better coatings.

With dry dust and all three methods of removal the coatings are best.

With oily dust 650 Glass Resin and Q3-6060/Santicizer 141 provide easiest removal with air alone or air plus brush. Several coatings, B99, HEMA, Permacote 62 and 650 Glass Resin, are effective with oily dust and water wash.

The pattern is somewhat different for high humidity dust. Coatings of B-99 , HEMA and Permacote 26 are about the same as the control. Coatings of 650 Glass Resin and Q3-6060/Santicizer 141 give a higher transmission after dust removal than does the control in most cases. In general 650 Glass Resin and Q3-6060/Santicizer 141 are best for all types of dust.

One conclusion clearly stands out. An efficient coating, e.g., 650 Glass Resin and perhaps Q3-6060/Santicizer 141 provides easy dust removal by all coating methods.

WATER WASH APPARATUS

Three methods of dust removal were used throughout this program:

- Air stream from an air gun
- Air gun while brushing with a soft destaticized (with Santicizer 141) brush .
- Washing with a stream of water from a laboratory, plastic squeeze wash bottle.

None of these are quantitative and precisely reproducible techniques. Therefore, in consultation with Sandia Livermore, we designed the apparatus shown in Table 40. It is basically a pressurized holding tank with a controlled orifice valve. Water is sprayed through the valve onto a sample holder. Variables are water pressure, valve orfice, spray time, distance of the sample from the valve, and specimen angle. All variables were fixed except for time and pressure.

Arizona Road Dust was sieved onto float glass mirrors through the usual 40 mesh sieve and the excess dust tapped off. The dusted samples were washed in the water wash apparatus at the pressures and times shown in Table 41 and percent reflectance measured. Reflectance before dusting varies from 71-75.

It is obvious that even at the lowest water pressure and shortest times, i.e. 2 psi and 7 seconds the dust is removed and reflectance returned to the original valve most cases. Dust that has not weathered on a substrate is not "cemented" and is, as shown above, easily removable. Therefore, this experiment is unrealistic. On the next section "Coating Permanence" in Tables 46 and 50 the Water Wash Apparatus is used on coated and uncoated dusted samples that have been exposed under the RS-4 sunlamp or weathered outdoors naturally. This data is discussed later.

COATING PERMANANCE

Although a number of coatings have proven effective in developing a surface for easier dust removal, the dust removal test has only been carried out once. What would be the effect, as would occur in practice, of many cycles of dusting and dust removal? Would the coating still be efficient? The best coatings were applied to each substrate as shown in Table 42.

To evaluate the effect of multiple dusting and dust removal coated glass, Petra A and Kynar substrates were dusted with Arizona Road Dust 12 times with air cleaning in between each one (Table 42). With repeated dustings the cleaning by air blowing became ineffective. There was a steady build-up of unremoved dust. Therefore, the approach was changed and washing with a lab wash bottle was introduced at the completion of 12 dust and air removal steps. This was considered as one cycle.

The glass control lost 8 %T after one cycle (one set of 12 dustings) but only 4 %T after two cycles. Only one coating, 650 Glass Resin, was distinctly superior to the control . There was essentially no loss in clarity even after two cycles.

With Petra A the control dropped from 83%T to 78%T and stayed at this level. All coatings were equal or superior with again 650 Glass Resin being best with no transmission loss.

Kynar presents a different picture. The uncoated control and both coatings are excellent.

A similar series was repeated on float glass mirrors (Table 43). Reflectance was measured after each cycle. Again a cycle is twelve dustings with Arizona Road Dust, each dusting followed by blowing with an air gun, and a water wash with a lab squeeze bottle after each set of twelve. Neither the control, nor any of the coated mirrors lost any percent reflectance even after "2 cycles".

A final study was made wherein coated float glass mirrors were dusted and worked with a lab squeeze bottle after each dusting (Table 44).

An uncoated control and two coatings-WL-81 acrylic latex and 650 Silicone Glass Resin- were examined. Duplicate runs were made.

In general, reproducibility was good. There was essentially no change in percent reflectance of the control or the two coatings even after six cycles. The coatings had not deteriorated through this number of cycles.

The previous multidusting and multicleaning cycle was carried out to analyze the effect of multiple dust removal on continued efficiency of the coating. The general conclusion was that under the conditions of testing there was no change in percent reflectance for any coating. Where transmission was measured 650 Silicone Glass Resin was effective on all substrates and superior to the uncoated control.

An even more significant aspect of coating permanence is the effect of weathering. A number of coatings on float glass were exposed under a General Electric RS-4 sunlamp for periods of 8 to 10 months. The %T after dusting and air removal of the unaged original is given in the 5th column (Table 45). Column 3 is the estimated percent dust removed by air gun after exposure; column 6 is the %T of the aged, coated glass which was dusted after aging and the dust removed with an air gun. This same specimen cleaned with an air gun was further cleaned by water wash with deionized water from a squeeze bottle.

The original dusted and air blown samples with the coatings below have a %T equal to or close to the original undusted. These good coatings were numbers 1, 2, 3, 6, 15, 18, 20, 22, 24, 25 and 26. After aging for the times shown percent dust removal was estimated qualitatively. Those samples with reasonable dust removal were measured for percent transmission (column 5). These included:

- Tyzor AA coupling agent/Flexol TOF
- Tyzor TE/CMC
- Tyzor AA/CMC
- Silicone Primer Q3-6060/IsoNoStat
- AT56 acrylic coating plus Flexol TOF
- Three systems based on 650 Glass Resin with varying concentrations of A1100 and A1152 silanes.

Of these 8 systems only the 650 group gave a high %T after the dusted and aged sample was air blown. However, after washing there were four additional coatings that gave high %T, either the same or very close to the original; however the 650 Glass Resin was still the best.

An additional RS-4 study was carried out with the RS-4 sunlamp using regular (dry), oily and humid dust exposed two and six weeks with dust removal using the water wash apparatus (Table 46). The purpose was to see the effect of aging on the three types of dust as well as to determine the efficiency of the water wash apparatus.

An uncoated control was compared to 650 Glass Resin coating. In <u>every</u> case the %T after aging and before washing was higher with the 650 Resin coated glass indicating that the 650 silicone Glass Resin is repelling dust.

After dusting and before removal %T of glass is 80 percent. After washing at 5 psi for 15 seconds all transmissions were back to the original value, including float glass, indicating that in this period of time (6 weeks) the dust had not cemented to the glass substrate.

The next three tables attempt to determine the effects of outdoor weathering at Hazardville, CT. (summer) on transmission. Float Glass, Petra A and Kynar were coated with a variety of "better" coatings and exposed on the roof at Hazardville, CT. during the summer of 1980 (Table 47). A record (Table 48) was kept of the weather conditions.

Transmission dropped the first two weeks and then in general either rose or stayed about the same between the 2nd and 4th week. There was no rain the first two weeks and then considerable rain in the 3rd and 4th week. Very heavy rains the 6th week correlated with further rise in transmission.

On glass 650 Glass Resin, WL-81 and AT-50/4GO were excellent, although not superior in this short time period to uncoated glass.

On Petra A at the 4th week 650 Resin was a bit superior to the control. At 6 weeks only WL-81 was equal or superior to the control.

On Kynar there was no effect on either the control or on the 650 Glass Resin coating.

Much longer exposure times are needed to analyze the effectiveness of these coatings.

The same four coatings were applied to glass mirrors, exposed for six weeks outdoors at Hazardville, CT. during the summer of 1980 (Table 49).

Percent reflectance was measured on a Schumacher Reflectometer. Float glass evidenced no change in reflectance nor did float glass coated with 650 Glass Resin. The other three coatings lost %T in varying degrees.

In a further effort to study the effects of outdoor aging as well as to evaluate the Water Wash Apparatus, float glass and 650 Glass Resin coated float glass were put outdoors on the roof at Hazardville, CT. Percent transmission was measured after 2 and 5 1/2 weeks, before and after washing (Table 50). Percent transmission was also measured on 2 week samples cleaned with an air gun. The 5 1/2 week air gun samples were toppled by a high wind and were unusable.

Ten individual glass slides were evaluated for %T after exposure but before cleaning. Duplicate slides of the 650 Glass Resin were exposed for 5 1/2 weeks and four float glass controls. Reproducibility was excellent.

After air gun cleaning or washing, %T of the glass control is the same as that of the coated but not-cleaned glass also exposed 2 or 5 1/2 weeks, i.e. washing has removed all of the dust. The back of the coated samples may have picked up something from the tar roof. The back of the slide is somewhat, unevenly spotted; this cloudiness is not removed by washing and these results should be considered anomalous.

COSTS

The ultimate criteria for judging the results of this work is cost-effectiveness of the coating systems. In the context of this program a technically effective coating would minimize the number of washings needed to remove dust.

The first step is to calculate the cost of coating glass heliostats, as well as the Petra A and Kynar domes[(1)]. Table 51 indicates the assumptions used in calculating the cost of coating heliostats including both variable and fixed costs. Allowing for losses calculations were made for 51,000 and 25,500 heliostats level is compared in Table 53. Coating cost for the Petra A dome is more than double glass mirror coating cost primarily because of the cost of activation. Activation of Kynar is even more complex and even more costly.

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(1) Details of costing are shown in the Appendix.

Table 53 also defines washing costs. An assumption of $1.50/heliostat and 26 washes/year=$39/heliostat/year or 39,000,000 for the cost of 50,000 heliostats over 20 years.

The ultimate judgement lies in the assumptions that the coating could reduce the number of washings to 1/2 or to 3/4. Comparisons are made with a coating life of 10 and 20 years. Column 1 of Table 54 gives the cost/over a 20 year period/heliostat, with washing costs at 26 times/ year at the top. The final column reveals that the savings with each of these assumptions varies from a low of $7,650,000 (10 year life, 1/4 of the washings eliminated because of the coating) to a high of $18,450,000 savings (20 year life, 1/2 of the washings eliminated). A 10 year coating life assumes that the coating will be replaced at the end of 10 years. Savings are based on a comparison with the cost of $39,000,000 for washing 26x per year for 20 years.

For example, on a full washing schedule of 26x/yr the cost/ heliostat/ 20 years is $780. If we assume only 1/2 the number of washings, the washing cost is $390 plus $20.80 coating cost or $411/heliostat. For 50,000 heliostats the total cost is $20,550,000. The savings are $39,000,000-20,550,000= $18,450,000.

PROBLEM AREAS

The principal problem lies in the determination of washing effectiveness for coated vs uncoated substrates where dust has accumulated under realistic outdoor conditions. At what rate does dust accumulate outdoors at various locations? How much less dust accumulates on specific coated substrates? How many fewer washings are necessary for specific coated substrates? In light of current theories that under the combined action of UV, moisture, and salts dust is "cemented" to the substrate ,will washing continue to remove all accumulated dust?

RECOMMENDED SOLUTIONS AND FUTURE WORK

The following are recommended approaches to solving the problems discussed above:

1. Determine dust accumulation rates at various locations.
2. Analyze washing effectiveness and number of washings needed for specific coated surfaces at various outdoor locations.

3. Assess the necessity of coatings on a low energy fluorocarbon surface such as Kynar?

4. Expose coated surfaces to both accelerated and outdoor (45° angle and EMMAQUA) weathering to see if the coatings retain their efficiency over a long time period.

5. Explore other acrylics and silicones bearing a structural resemblance to the ones that have proven successful in the current program.

6. Optimize the best coating systems (e.g. silicone Glass Resin 650, WL-81 acrylic latex, Q3-6060 silicone primer followed by Santicizer 141 etc.) with respect to the coating thickness, type of primer, type of coupling agent blended into the coating, synergistic combinations of antistats, hydrophilic or hydrophobic release agents and chemically unique silanes or titanates.

7. Using coated surfaces which have been "aged" outdoors with natural dust accumulation explore the efficiency of the water wash apparatus.

8. The effect of pollutants-SO_2, NO_x, especially in the presence of UV and moisture - on the coatings, on dust accumulation and on ease of dust removal should be studied.

9. Applications of "best" coatings should be examined on other types of glass.

10. Improved abrasion resistant coatings should be developed.

11. Costing should be refined for optimized systems using realistic wash efficiency data developed during outdoor exposure.

TABLE 1

ANTISTATIC AGENTS[1]

Quaternary Ammonium Compounds

Cationic Softener X (Refined Onyx) (0.1% in H_2O)[2]

Aston 25 (Refined Onyx) (0.1% in H_2O)

Velvamine ATS (Refined Onyx) (0.1% in H_2O)

IsoNoStat (Isochem) (0.1% in Methanol)

Amine Derivatives

Aston AP conc. (Refined Onyx) (0.1% in H_2O)

Aston 456 (Refined Onyx) (2% in H_2O)

Aston OI conc. (Refined Onyx) (1% in H_2O)

Cyastat LS (American Cyanamid) (1% in H_2O)

Phosphate Esters

T-butylphenyldiphenylphosphate (Monsanto 154)	--1% in IPA
Triphenyl phosphate (Monsanto)	
Santicizer 141 (Monsanto)	
Flexol Plasticizer TOF (Union Carbide)	

Polyethylene Glycol Esters

Flexol Plasticizer 4 GO (Union Carbide)	-- 1% in Xylene
Tween 20 (Union Carbide)	
Tween 60 (Union Carbide)	
Polyethylene glycol 600 distearate (Polysciences)	

(1) All are used at 1% in water, unless stated otherwise. Samples are immersed for 10 seconds, allowed to drain 5 seconds and dried at room temperature.

(2) Deionized water (H_2O) used.

TABLE 2

SOIL-RELEASE AGENTS (1)

Ionic Polymers

Sodium carboxymethyl cellulose(CMC)(1% in 0.2N NH_4OH)
Hydroxyethyl cellulose (HEC) (0.1% in IPA)
Ammonium salt of polyacrylic acid (1% in H_2O)
Casein (1% in 0.2N NH_4OH)

Nonionic Polymers

Polyvinyl alcohol (PVA) (1% in H_2O)
Polyethylene glycol (1% in H_2O)
Methyl cellulose (1% in H_2O)
Polyvinyl pyrrolidone (PVP) (1% in H_2O)

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(1) All are used at 1% in water, unless stated otherwise. Samples are immersed for 10 seconds, allowed to drain 5 seconds and dried at room temperature.

TABLE 3

SILANE COUPLING AGENTS(1)

- 3-(trimethoxysilyl) - propyloctadecyl dimethyl ammonium chloride (Dow Corning Q9-5700).
- Alpha-(trihydroxysilyl) - propylisothiouronium chloride (Dow Corning Z-5456).
- Azidosilane (Hercules Coupling Agent S3076S).
- Blend of dimethyldichlorosilane and methyltrichlorosilane (Dri-Film SC-77, Silar Laboratories) (used as is).
- Polymeric silicone fluid containing unhydrolyzed chlorine-silicone bonds (Pierce SurfaSil) (in Heptane).
- N-(p-aminoethyl) - alpha-aminopropyl trimethoxy silane (Dow Corning Z-6020).
- A quarternary methacrylate functional ester (Dow Corning Z-6031)
- An anionic copolymer of maleic anhydride (Dow Corning B-2080-200).
- A zwitterion type silane having both anionic and cationic functions (Dow Corning B-2014-25).
- Octadecyldimethyl [3-(trimethoxysilyl)-propyl] ammonium chloride (Dow Corning XZ-2-2300).
- Experimental silane (Dow Corning XZ-8-5061).
- Aqueous mixture of mixture of quaternary ammonium compounds (Analytical Chemical Labs Staticide).

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(1) All are used at 1% in water, unless stated otherwise. Samples are immersed for 10 seconds, allowed to drain 5 seconds and dried in a circulating air oven in Aluminum foil cups for 30 minutes at 90°C.

TABLE 4

TITANATE COUPLING AGENTS[1]

- Triethanolamine titanium chelate (DuPont Tyzor TE) (1% in IPA).
- Acetyl acetonate titanium chelate (DuPont Tyzor AA) ((1% in IPA).
- Isopropyl, di-(4-aminobenzoyl) isostearyl titanate (Kenrich KR-37BS) (1% in Cellosolve)
- Isopropyl, tri(dioctylpyrophosphato) titanate (Kenrich KR-38S) (1% in IPA).
- Tetraoctyl oxytitanium di(dilauryl phosphite) (Kenrich 46B) (1% in IPA).
- Triisostearic isopropyl titanate (Kenrich KR-TTS) (1% in Xylene).
- Isopropyl, tri(dioctylphosphato) titanate (Kenrich KR-12S) (1% in Xylene).
- Titanium di(dioctylohosphate) oxyacetate(Kenrich KR-122S). (1% in Xylene).
- Di(dioctylphosphato)ethylene titanate (Kenrich KR-212S). (1% in Xylene).

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(1) All are at 1% in solvent shown. Samples are immersed for 10 seconds, allowed to drain 5 seconds and dried in a circulating air oven in Aluminum foil cups for 30 minutes at 90°C.

TABLE 5

POLYMER COATINGS

Acrylics

Rohm & Haas Acryloid AT-50
Rohm & Haas Acryloid AT-51
Rohm & Haas Acryloid AT-56
Rohm & Haas Rhoplex WL-81
Rohm & Haas Acryloid B-99
Johnson Wax Permacote 62

Silicones

General Electric SHC-1000
Dow Corning Q3-6060
Owens-Illinois 650 Glass Resin
Repcon

TABLE 6

DIRECT REACTION ORGANIC COMPOUNDS

- Cymel 303[1] (American Cyanamid)
- Permafresh LF-2[2] (Sun Chemical)
- Hydroxyethyl methacrylate (HEMA)
- Methacrylic acid
- Methacrylamidopropyltrimethylammonium chloride
- Allyl trimethylammonium chloride
- Diacetone acrylamide
- Cetyl vinyl ether
- Vinyl isobutyl ether
- N-methylolacrylamide

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(1) Hexamethoxy methylmelamine

(2) Dimethyloldihydroxy ethylene urea

TABLE 7

DIRECT REACTION OF ORGANIC COMPOUNDS ON GLASS

Successful at Dust Repulsion

Permafresh LF-2 (Sun Chemical)

Hydroxyethyl methacrylate (HEMA)

Methacrylic acid

Allyl trimethylammonium chloride

Diacetone acrylamide

Unsuccessful at Dust Repulsion

Cymel 303 (American Cyanamid)

Methacrylamidopropyltrimethylammonium chloride

Cetyl vinyl ether

Vinyl isobutyl ether

N-Methylolacrylamide

TABLE 8

PERCENT TRANSMISSION
OF
COUPLING AGENTS ON GLASS

Coupling Agent	% Transmission
Untreated Glass	87
Tyzor AA	86
Tyzor TE	86
Pierce SurfaSil	86
B-2080-200	86

TABLE 9

PERCENT TRANSMISSION

OF COUPLED SYSTEMS ON GLASS

Release Agent	Coupling Agent	% Transmission
Untreated Glass	--	87
Polyvinyl alcohol	Tyzor AA	84
Polyvinyl alcohol	Tyzor TE	83
Casein	Tyzor AA	83
Casein	Tyzor TE	81
Flexol Plasticizer TOF	Pierce SurfaSil	85
Flexol Plasticizer TOF	Tyzor AA	84
IsoNoStat	Pierce SurfaSil	84
Polyethylene glycol	Pierce SurfaSil	86
Cyastat LS	Pierce SurfaSil	86
Polyvinyl Pyrrolidone	Tyzor TE	84
Hydroxyethyl cellulose	B-2080-200	85
Aston 25	Tyzor AA	85
Sodium carboxymethyl cellulose	Tyzor AA	85
Sodium carboxymethyl cellulose	Tyzor TE	85
Sodium carboxymethyl cellulose	B-2080-200	85
HEC	Tyzor TE	87
HEMA	Tyzor AA	86

TABLE 10

COUPLING AGENT SOIL RELEASE STUDY ON GLASS :
EFFICIENCY OF DUST (1) REMOVAL BY AIR GUN

Release Agent	Silane		Titanate	
	DC- B-2080-200	Pierce SurfaSil	Tyzor AA	Tyzor TE
Aston 25		F(2)	G	
IsoNoStat		G		
Aston AP Conc.		G		
Aston 456		F	F	
Aston OI Conc.		G		
Cyastat LS		E	F	
Monsanto 154		E		
Triphenylphosphate		G		
Flexol Plasticizer TOF		E	G	
Flexol Plasticizer 4GO		E		
Tween 20		F		
Polyethylene glycol 600 distearate		G		
Sodium CMC	G		G	G
Hydroxyethyl cellulose	G		G	G
Casein	G		G	G
Polyvinyl alcohol			G	G
Polyvinyl pyrrolidone				G
Santicizer 141		E		

(1) Unless specified otherwise "Dust" means dry dust.

(2) E- Excellent

G- Good

F- Fair

TABLE 11

PERCENT TRANSMISSION OF COUPLING AGENT SYSTEMS ON GLASS (1) AFTER DRY DUST (2) REMOVAL WITH AIR GUN

Release Agent	Coupling Agents	% Transmission
IsoNoStat	Pierce SurfaSil	77
Cyastat LS	Pierce SurfaSil	82
Sodium carboxymethyl cellulose	Tyzor AA	74
Sodium carboxymethyl cellulose	Tyzor TE	73
Hydroxyethyl cellulose	Tyzor TE	84
Hydroxyethyl cellulose	Tyzor AA	83
Casein	Tyzor AA	74
Flexol TOF	Tyzor AA	83
Crosslinked HEMA	Tyzor AA	79

(1) Transmission of untreated and undusted glass is 87% (five identical readings on three slides). Untreated but dusted glass (before dust removal) has a %T of 80% . This is an average of two readings per slide on three slides with a spread from 79-81%.

(2) Arizona Road Dust is sieved onto the glass through a 40 mesh screen and the glass slide tapped to remove excess dust.

TABLE 12

PERCENT TRANSMISSION AFTER APPLICATION OF ACRYLIC, OR SILICONE COATINGS ON GLASS

Coatings	% Transmission
AT-50 Acrylic	87
AT-51 Acrylic	87
AT-56 Acrylic	87
Repcon Silicone	86
WL-81 Acrylic	87
650 Glass Resin Silicone	87
Q3-6060 Silicone	85
GE SHC-1000 Silicone	82

TABLE 13

PERCENT TRANSMISSION OF COATING SYSTEMS
ON GLASS

Release Agent	Coatings	% Transmission
Untreated Glass		87
Santicizer 141	Q3-6060	87
Santicizer 141	AT-50	87
Flexol TOF	AT-56	87
Flexol 4GO	AT-50	86

TABLE 14

ACRYLIC COATING SOIL RELEASE STUDY ON GLASS: APPROXIMATE PERCENT DUST REMOVED BY AIR GUN(1)

Release Agent	Rohm & Haas Acrylic Coatings AT-50	AT-51	AT-56
Aston 25	75	0	100
Velvamine ATS	100	95	20
IsoNoStat	95	100	100
Aston AP Conc.	75	20	80
Aston 456	95	5	75
Aston OI	25	10	95
Cyastat LS	50	30	95
Monsanto 154	95	75	60
Monsanto 141	90	100	90
Triphenylphosphate	80	100	100
Flexol Plasticizer TOF	80	100	50
Flexol Plasticizer 4GO	100	50	95
Tween 20	95	25	35
Tween 60	100	25	10
PEG 600 distearate	95	50	5
Hydroxyethyl cellulose			
Polyvinyl alcohol			
PEG	70	85	70
Polyvinyl pyrrolidone		80	95
Methyl cellulose	80		

(1) The air gun is a Lab heat gun operated at room temperature, held at a 45° angle and approximately one inch away from the sample.

TABLE 15

SILICONE COATING SOIL RELEASE STUDY ON GLASS: APPROXIMATE PERCENT DRY DUST REMOVED BY AIR GUN - DOW CORNING Q3-6060 PRIMER (1)

Release Agent	% Removed
Santicizer 141	100
Flexol Plasticizer TOF	100
Flexol Plasticizer 4GO	100
Polyvinyl alcohol	100
Aston 25	95
IsoNoStat	95
Triphenyl phosphate	95
Polyvinyl pyrrolidone	95
Aston 456	90
Velvamine ATS	85
Polyethylene glycol 600 distearate	85
Aston OI conc.	50
Polyethylene glycol	30
Cyastat LS	15
Monsanto 154	10
Aston AP conc.	5
Casein	5
Tween 20	2
Tween 60	2
Polyacrylic acid, NH_4^+ salt	0

(1) All additives were unsuccessful with General Electric RTV 615 primer.

TABLE 16

PERCENT TRANSMISSION OF COATINGS ON GLASS AFTER DRY[2] DUST REMOVAL WITH AIR GUN

Release Agent	Coatings	% Transmission
Untreated Glass[1]	--	82
None	650 Glass Resin[1]	86
None	Repcon[1]	73
None	AT-50	78
None	AT-51	83
None	AT-56	75
None	WL-81[3]	76
Santicizer 141	Q3-6060[1]	86
Flexol 4GO	AT-50[2]	84
Santicizer 141	AT-50	81
Flexol TOF	AT-56	72

(1) The transmission of the original, undusted glass is 87%.

(2) Also called regular dust.

(3) Rohm & Haas acrylic latex.

TABLE 17

PERCENT TRANSMISSION OF COATINGS ON GLASS AFTER OILY[1] DUST REMOVAL WITH AIR GUN

Release Agent	Coupling Agent or Carrier	% Transmission
Untreated Glass	--	81
HEC	Tyzor TE[3]	84
Flexol TOF	Tyzor AA[3]	83
None	650 Glass Resin[2]	85
Santicizer 141	Q3-6060[1]	86
HEMA	--	85
Santicizer 141	AT-50	76
Flexol 4GO	AT-50	83
Flexol TOF	AT-56[4]	82

(1) Dust contains 3% Nujol

(2) Silicone coating

(3) Titanate coupling agent

(4) AT-solvent acrylic coatings from Rohm & Haas

TABLE 18

PERCENT TRANSMISSION OF COATINGS ON GLASS
AFTER HUMIDIFIED[1] DUST REMOVAL WITH AIR GUN

Release Agent	Coupling Agent or Carrier	% Transmission
Untreated Glass	--	74
HEMA	--	78
Santicizer 141	Q3-6060[2]	86
Crosslinked HEMA	Tyzor AA[3]	84
Flexol TOF	Tyzor AA	81
HEC	Tyzor TE	83
None	650 Glass Resin[2]	80
None	AT-51[4]	82
Flexol 4GO	AT-50	79
Santicizer 141	AT-50	75
Flexol TOF	AT-56	66

(1) Samples stored for 24 hours at 80% relative humidity after dusting

(2) Silicone coating

(3) Titanate

(4) Acrylic

TABLE 19

PERCENT TRANSMISSION OF COATINGS ON GLASS AFTER DRY DUST REMOVAL: CORRELATION BETWEEN AIR GUN AND WIND TUNNEL

Coating System	Air Gun	% Transmission Wind Tunnel		
		Low	Medium	High
AT-50	78	--	--	83
Flexol 4GO + AT - 50	84	--	--	82
Santicizer 141 + Q3-6060	86	--	--	83

Low = 15 mph

Medium = 24 mph

TABLE 20

PERCENT TRANSMISSION OF FLOAT GLASS
AFTER ABRASION WITH SAND

Weight of Sand, Pounds	% Transmission
0	87
0.50	85
0.67	84
0.75	86
1.0	84
2.0	79
3.0	80
5.0	80
10.0	73

TABLE 21

PERCENT TRANSMISSION OF COATED GLASS
AFTER ABRASION WITH 10 POUNDS OF FALLING SAND

Surface Modification	% Transmission
Untreated Glass	73
Coupling Agent	
Tyzor TE	74
Coating	
WL 81	85
AT 50	75 (1)
AT 51	79 (1)
AT 56	80 (1)
Repcon	74
Q3-6060	67
650 Glass Resin	76
Direct Reaction Monomer	
Crosslinked HEMA	74

(1) 4% solids solution

TABLE 22

SAND ABRASION[1] OF REAGENTS COUPLED TO GLASS

Release Agent	COUPLING AGENT	Sand Required to Remove Surface, Lbs.
Sodium carboxymethyl cellulose (1.0%)	Tyzor AA	> 10
Sodium carboxymethyl cellulose (0.1%)	Tyzor AA	0.75
Sodium Carboxymethyl cellulose	Tyzor TE	> 10
Flexol Plasticizer TOF	Tyzor AA	> 10
Polyvinyl alcohol	Tyzor AA	> 10
Polyvinyl alcohol	Tyzor TE	> 10
Hydroxyethyl cellulose (0.1%)	Tyzor AA	< 0.25
Hydroxyethyl cellulose (0.1%)	B-2080-200	1.00
Casein	Tyzor AA	< 0.25
Casein	Tyzor TE	0.50
Casein	B-2080-200	0.75
Polyvinyl pyrrolidone	Tyzor TE	0.50

(1) ASTM 6191

TABLE 23

PERCENT TRANSMISSION OF COATING SYSTEMS ON GLASS AFTER ABRASION WITH 10 POUNDS OF FALLING SAND

Release Agent	Coupling Agent or Carrier	% Transmission
IsoNoStat	Pierce Surfacil	76
IsoNoStat	Q3-6060	72
IsoNoStat	AT 51	68
IsoNoStat	AT 56	76
Cyastat LS	Pierce Surfacil	69
Santicizer 141	Q3-6060	73
Santicizer 141	Pierce Surfacil	67
Santicizer 141	AT 50	77
Santicizer 141	AT 51	78
Flexol Plasticizer TOF	Pierce Surfacil	67
Flexol Plasticizer TOF	Tyzor AA	70
Flexol Plasticizer TOF	Q-3-6060	72
Flexol Plasticizer TOF	AT 56	81
Flexol Plasticizer TOF	AT 51	73
Hydroxyethyl Cellulose	Tyzor TE	78
Hydroxyethyl Cellulose	Tyzor AA	77
Polyvinyl Alcohol	Tyzor AA	78
Polyvinyl Alcohol	Tyzor TE	79
Polyethylene Glycol	Pierce Surfacil	74
Sodium CMC	Tyzor AA	77
Sodium CMC	Tyzor TE	74
Polyvinyl pyrrolidone	AT-51	81
Polyvinyl pyrrolidone	AT-56	81

TABLE 24

CORNING 7809 GLASS

PERCENT TRANSMISSION FOLLOWING DUST

REMOVAL WITH AIR GUN

Coating	Prior to Dusting	After Dust Removal		
		Regular Dust	Oily Dust	High RH Dust
None	92	< 70	87	< 70
WL-81	91	< 70	86	< 70
AT-50 + 4GO	91	< 70	83	< 70
650 Glass Resin	92	89	91	87
Q-3-6060 + Santicizer 141	90	89	89	90

TABLE 25

CORNING 7809 GLASS
PERCENT TRANSMISSION FOLLOWING SAND
ABRASION TESTS

Coating	Prior to Abrasion	After 5 lbs Sand	After 10 lbs Sand
None	92	79	75
WL-81	91	82	78
AT-50 + 4GO	91	82	78
650 Glass Resin	92	84	79
Q3-6060 + Santicizer 141	90	87	76

TABLE 26

CORNING 7809 GLASS

PERCENT TRANSMISSION AFTER EXPOSURE

TO STEAM

Coating	% Transmission Before Exposure	After Exposure
Uncoated	86	86
WL-81 (1)	85	84
Q3-6060 Primer (2) + Santicizer 141 (3)	85	85
650 Glass Resin (4)	87	87

(1) Rohm & Haas Rhoplex latex acrylic

(2) Dow Corning silicone

(3) Monsanto phosphate ester

(4) Owens Illinois silicone resin

TABLE 27

GLASS COATINGS STATIC CHARGE DISSIPATION[1]

Release Agent	Coupling Agent	Initial Charge, Volts	Time to Discharge To 400 Volts, Min.
Untreated Glass		800	5.00
Casein (NaOH)	Tyzor AA	400	0
Cyastat LS	Tyzor AA	400	0
Casein (NaOH)	Tyzor TE	450	0.25
Sodium carboxymethyl cellulose	Tyzor TE	525	0.50
Casein (NaOH)	B-2080-200	600	1.25
Aston 25	Tyzor AA	950	3.15
Polyvinyl pyrrolidone	Tyzor TE	1645	4.80
Aston 456	Tyzor AA	1300	5.00
Sodium Carboxymethyl cellulose	Tyzor AA	1200	5.00
Hydroxyethyl cellulose	Tyzor TE	1500	5.00
Hydroxyethyl cellulose	Tyzor AA	1600	4.75
Hydroxyethyl cellulose	B-2080-200	1850	8.25
Polyvinyl alcohol	Tyzor AA	2050	8.15
Casein (NH_4OH)	Tyzor TE	2000	8.50
Casein (NH_4OH)	Tyzor AA	1200	8.50
Polyvinyl alcohol	Tyzor TE	2300	10.00
Polyvinyl pyrrolidone (1.0%)	Tyzor TE	2500	16.00

(1) Sample charged for 5 min. at 7KV

TABLE 28

BEST COATING SYSTEMS ON
GLASS PERCENT TRANSMISSION
AIR GUN REMOVAL

Coating System	Dry Dust	Oily Dust	High R.H. Dust	Abrasion Resistance %T After 10 lbs of Falling Sand
Untreated Glass(1)	82	81	74	73
Q3-6060/141	86	86	86	73
Glass Resin 650	86	85	80	76
Flexol 4GO/AT-50	84	83	-	-
HEC/TE	84	84	83	78
Crosslinked HEMA	-	85	-	74
Crosslinked HEMA/AA	-	-	84	-
WL-81	80	-	-	85

(1) After dusting and before dust removal %T is 80% for dry dust.

TABLE 29

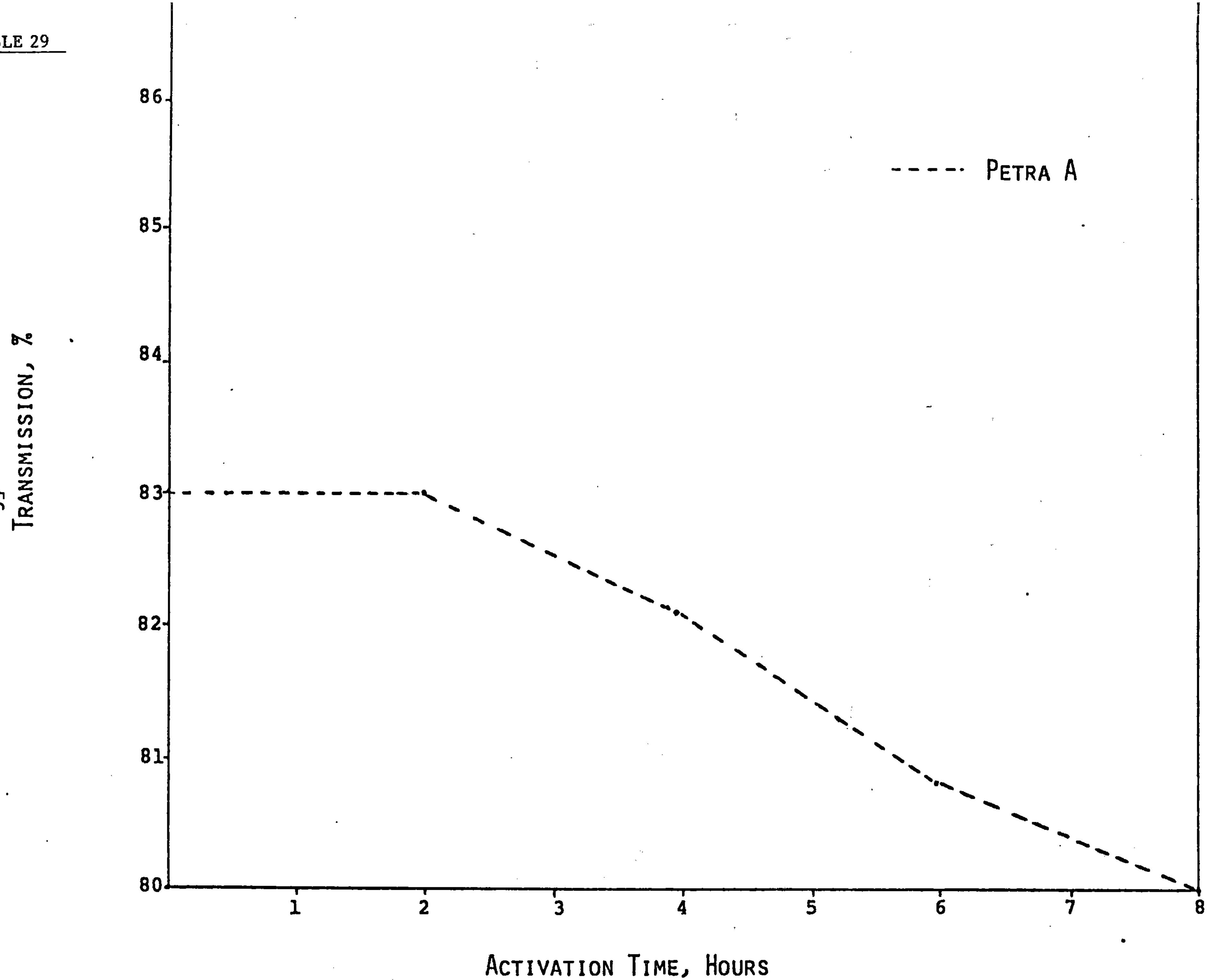

Petra A
Transmission, %
86
85
84
83
82
81
80
1
2
3
4
5
6
7
8
Activation Time, Hours

TABLE 30

PERCENT TRANSMISSION OF COATED PETRA A

Coating	Release Agent	% Transmission
Unactivated Petra A	-	83
Activated Petra A*	-	83
650 Glass Resin	None	87
WL-81	None	85
Permacote 62	None	85
AT-51	Monsanto 154	85
Q3-6060	Santicizer 141	84
AT-50	Santicizer 141	84
Tyzor TE	CMC	84
Tyzor AA	CMC	84
Tyzor AA	Polyacrylic Acid	84
AT-51	Isonostat	83
Tyzor AA	Polyvinyl Pyrrolidone(s)	81

* Activated for two hours in 10% Aqueous NaOH

TABLE 31

AMOUNT OF DUST REMOVED BY AIR GUN
FROM COATED PETRA A[1]

Release Agents	Coupling Agent or Carrier	% Dust Removed
Unactivated Petra A	--	50
Coatings		
Monsanto 154	AT-50	100
Aston 456	AT-50	98
IsoNoStat	AT-51	98
IsoNoStat	AT-56	95
Velvamine ATS	AT-50	95
HEC	AT-56	95
Flexol TOF	AT-50	95
Monsanto 154	AT-50	93
Tween 60	AT-50	93
Coupling Agent Systems		
Polyacrylic Acid, NH_4 Salt	Tyzor AA	95
Polyvinyl Alcohol	Tyzor AA	95
Direct Reaction		
Hydroxyethyl methacrylate	-	95
Methacrylic Acid	-	95

(1) All work is on activated Petra A

TABLE 32

PERCENT TRANSMISSION OF COATED PETRA A
AFTER DUST REMOVAL WITH AIR GUN

Release Agent	Coating	Percent Transmission: Before Dusting (1)	Removal By Air Gun	Air Gun Plus Brushing	Squeeze Bottle Washing
Unactivated Petra A	--	83	-	-	81
Activated Petra A	--	83	78	82	80
	650 Glass Resin	87	80	80	87
	Repcon	83			
	Permacote 62	85	81	73	86
	B99	83	81	-	85
	WL 81	85	80	80	85
	Crosslinked HEMA	82	-	79	-

(1) After dusting and before washing %T is 76

TABLE 33

PERCENT TRANSMISSION OF COATED PETRA A
AFTER DUST [1] REMOVAL

Release Agent	Coating or Coupling Agent	Percent Transmission: Before Dusting	After Removal By: Air Gun	After Removal By: Air Gun Plus Brush [2]	After Removal By: Water [3]
Coating Systems					
Santicizer 141	AT 50	84	79	-	83
4 GO	AT 50	81	78	-	78
Velvamine ATS	AT 50	81	-	-	81
Aston 456	AT 50	82	75	71	82
IsoNoStat	AT 51	83	-	-	83
154	AT 51	85	-	-	82
Santicizer 141	B99	84	80	-	86
Santicizer 141	Permacote 62	85	81	73	86
Santicizer 141	Permacote 62	85	-	-	86
Santicizer 141	Q3-6060	84	78	-	85
Coupling Agent Systems					
HEC	Tyzor TE	83	-	71	79
CMC	Tyzor TE	84	76	74	81
CMC	Tyzor AA	82	74	77	79
PVA	Tyzor AA	84	70	-	79
PVP	Tyzor AA	81	74	-	-
Unactivated	Petra A	83	76	-	81
Activated	Petra A	83	78	82	80
HEMS	--	84	78	-	-
Methacrylic Acid	--	83	76	-	-

(1) Regular dust

(2) Brush is coated with Santicizer 141

(3) From a squeeze bottle

TABLE 34

TRANSMISSION OF COATED PETRA A TREATED WITH OILY AND HUMID DUST AFTER CLEANING WITH AIR GUN OR AIR GUN WITH BRUSHING

Coating	Prior to Dusting	Air Only		Air and Brush	
		Oily Dust (1)	High RH (2)	Oily Dust	High RH
Unactivated Petra A	83	72	74	76	77
Activated	83	77	77	82	80
Coating Systems					
650 Glass Resin	87	83	81	83	85
WL-81	85	81	-	-	-
B-99	83	81	< 70	76	<70
Permacote 62	85	80	< 70	83	77
AT50/Santicizer 141	84	73	-	-	-
AT 50/4GO	81	75	-	-	-
AT 50/Velvamine ATS	81	78	-	-	-
AT 50/Aston 456	82	81	-	-	-
AT 51/154	85	77	-	-	-
AT 51/IsoNoStat	83	73	-	-	-
Coupling Agent Systems					
Tyzor TE/CMC	84	80	-	-	-
Tyzor TE/HEC	83	79	-	-	-
Tyzor AA/CMC	82	81	-	-	-
Tyzor AA/PVA	84	75	-	-	-
Tyzor AA/PVP	81	77	-	-	-
Direct Reaction					
Crosslinked HEMA	82	80	-	-	-

(1) Dust containing 3% Nujol
(2) Dusted sample stored 24 hours at 80% relative humidity.

TABLE 35

MOST SUCCESSFUL COATINGS:
PERCENT TRANSMISSION OF DUSTED
AND CLEANED COATED PETRA A[1]

Coating	Prior to[1] Dusting	Regular	Air Only Oily Dust	Air Only High RH	Water Wash Regular Dust
Control	83	78	77	77	81
650 Glass Resin	87	80	83	81	87
B-99	83	81	81	< 70	85
WL-81	85	80	81	-	85
B-99 Mixed with Santicizer 141	84	80	79	-	86
Q3-6060 Primer/ Santicizer 141 Top Coat	84	78	80	-	85

(1) %T of dusted but uncleaned Petra A is 76%

TABLE 36

PERCENT TRANSMISSION OF COATED KYNAR

AFTER DUST REMOVAL WITH AIR GUN vs ACTIVATION TIME

Coating	Pretreatment (1) Time in Min. In Butyl Amine Methanol Solution	Specular % Transmission After Dust Removal with Air Gun:
650 Glass Resin	5	81
650 Glass Resin	10	84
B99 (1)	5	79
B99	10	75
HEMA	5	73
HEMA	10	77
Permacote 62	5	77
Permacote 62	10	80
Activated Kynar	5	70
Activated Kynar	10	75
Kynar (2)	-	81

(1) Immerse in 10% butyl amine in methanol followed by 1.0% acetyl peroxide in methanol at 65°C Reflux for 2 hours.

(2) %T of Kynar is 86%; after dusting and before dust removal %T is 66%.

TABLE 37

PERCENT TRANSMISSION OF COATED KYNAR vs ACTIVATION TIME

Coating	Pretreatment Time in Min. in Butyl Amine Methanol Solution	% Transmission
650 Glass Resin	5	88
650 Glass Resin	10	88
B99	5	86
B99	10	86
HEMA	5	86
HEMA	10	85
Permacote 62	5	87
Permacote 62	10	86
Activated Kynar	5	88
Activated Kynar	10	85
Kynar	-	86

TABLE 38

PERCENT TRANSMISSION OF
COATED KYNAR AFTER DUST REMOVAL

TYPE OF DUST

Coating System	Before Dusting	After Dusting: Air Only			After Dusting: Air and Brush			After Dusting: Water Wash		
		Dry Dust	Oily Dust	High RH Dust	Dry Dust	Oily Dust	High RH Dust	Dry Dust	Oily Dust	High RH Dust
Kynar	86	78	79	75	80	80	75	84	70	84
Activated Kynar	85	80	80	83	80	–	–	83	–	–
B99	85	75	70	74	–	< 70	76	–	78	82
HEMA	83	77	81	75	–	83	78	–	77	82
Permacote 62	86	80	81	73	–	75	70	–	79	84
650 Glass Resin	87	84	85	76	87	85	80	87	81	86
Q3-6060 Primer + 141	82	85	85	86	86	81	80	83	74	81
AT50/4GO	84	76	78	66	61	60	69	80	69	79
AT50/Aston 456	83	68	66	70	66	61	74	76	69	76
Tyzor AA/PVP	81	< 60	61	< 60	64	64	63	75	72	71

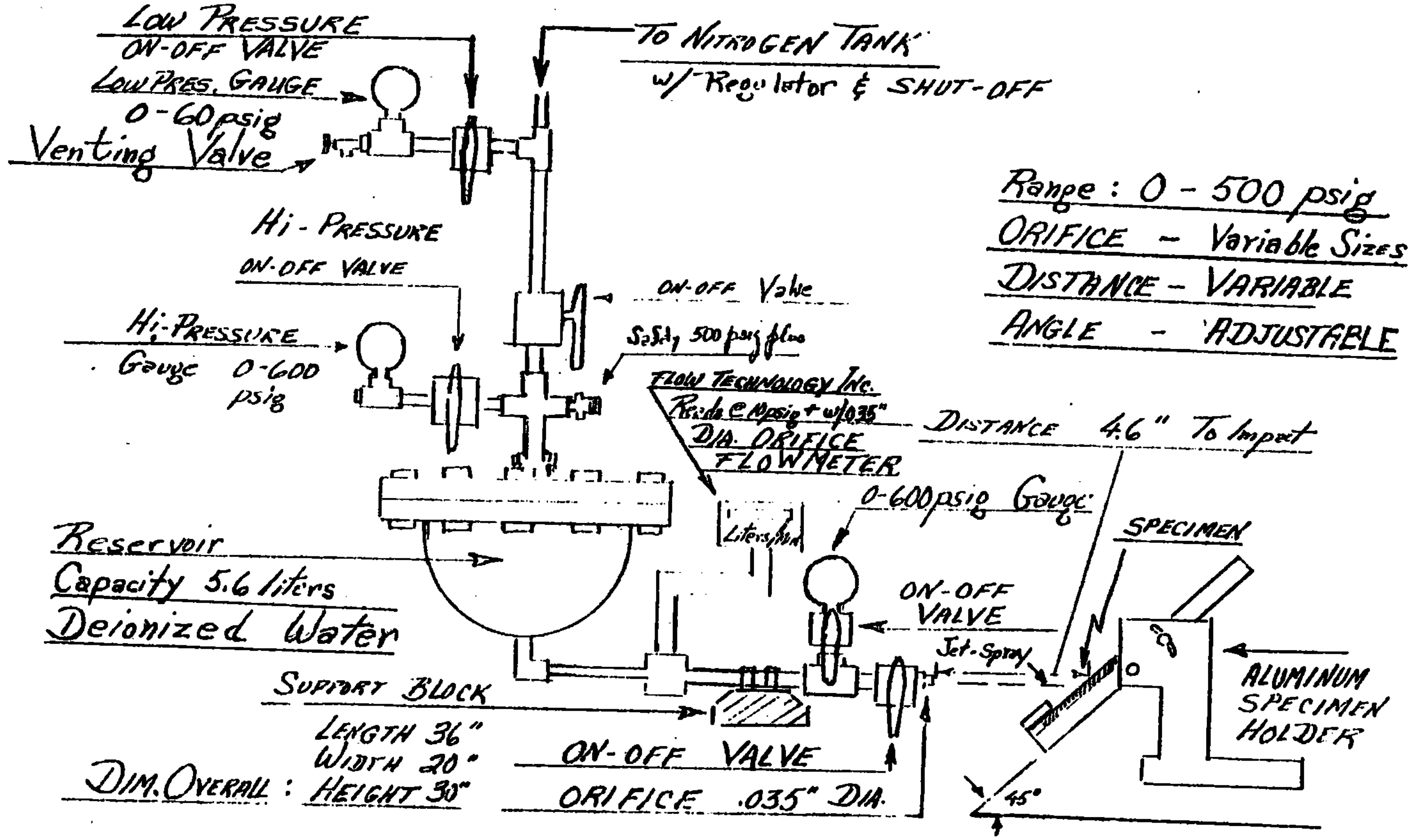
TABLE 39

PERCENT TRANSMISSION OF COATED KYNAR AFTER DUST REMOVAL

METHOD OF REMOVAL

Coating System	Before Dusting	After Dusting: Dry Dust: Air	Dry Dust: Air & Brush	Dry Dust: Water	Oily Dust: Air	Oily Dust: Air & Brush	Oily Dust: Water	High R.H. Dust: Air	High R.H. Dust: Air & Brush	High R.H. Dust: Water
Kynar	86	78	80	84	79	80	70	75	75	84
Activated Kynar	85	80	80	83	-	-	-	-	-	-
B-99	85	75	-	-	70	<70	78	74	76	82
HEMA	83	77	-	-	81	83	77	75	78	82
Permacote 62	86	80	-	-	81	75	79	73	70	84
650 Glass Resin	87	84	87	87	85	85	81	76	80	86
Q3-6060 Primer + Santicizer 141	82	85	86	83	85	81	74	86	80	81

TABLE 40



WATER - WASH APPARATUS

Springborn Labs Inc

TABLE 41

EFFECT OF WATER PRESSURE & TIME
CYCLE ON DUST REMOVAL FROM MIRRORS

Before Dust Original % Reflectance	Water Pressure (psi)	Time(Sec)	Reflectance %(1) After Washing
73	1	15	72
71	1	15	70
71	2	15	71
72	2	15	72
72	3	15	72
72	3	15	72
75	5	15	74
71	5	15	71
72	7	15	72
72	7	15	72
71	15	15	70
72	15	15	71
74	2	7	73
72	2	7	72
71	5	7	71
72	5	7	70
72	10	7	71
72	10	7	71
74	15	7	74
72	15	7	71
72	30	5	72
72	30	5	72
73	50	5	72
72	50	5	72

(1) By Schumacher Reflectometer

TABLE 42

PERCENT TRANSMISSION AFTER MULTIPLE DUSTINGS

SUBSTRATE	COATING	% Transmission(1) Original	After One Cycle(2)	Two Cycles
Glass	Rhoplex WL-81	87	80	76
	Acryloid AT50+ Plasticizer 4G0	87	55	52
	650 Glass Resin	87	85	86
	Q 36060 Primer & Santacizer 141	87	74	76
	Uncoated Control	87	79	83
Petra A	650 Glass Resin	87	86	88
	Rhoplex WL-81	85	81	78
	Acryloid B-99	83	73	81
	Uncoated Control	83	78	78
Kynar	650 Glass Rosin	87	86	86
	Q36060 Primer & Santacizer 141	86	86	87
	Uncoated Control	86	85	86

(1) Measured from 350 to 900 nm (Direct)

(2) 12 Dustings with air removal in between each dusting with final water wash using a Lab. squeeze bottle.

TABLE 43

EFFECT OF MULTIPLE DUSTING AND WASHING
ON
REFLECTION OF COATED FLOAT GLASS MIRRORS

Coating	Percent Reflectance[1] Before Dusting	After 12 Dustings & One Rinse[2]	After 24 Dustings & 2 Rinses
Uncoated Control	65	65	63
WL-81	64	62	62
Q3-6060 + Santicizer 141	61	60	63
AT50 + 4GO	60	58	60
650 Glass Resin	61	60	63

(1). Using the Schumacher Reflectometer.

(2) See Footnote "2" Table 42.

TABLE 44

MULTIPLE DUSTING & WASHING
STUDY ON FLOAT GLASS MIRRORS

Coatings		Percent Reflectance (1)						
		Original	1 Cycle	2 Cycles	3 Cycles	4 Cycles	5 Cycles	6 Cycles
Uncoated	Sample 1	74	71	71	71	71	71	72
	Sample 2	71	71	71	70	69	70	69
WL-81	Sample 1	72	71	72	70	69	69	69
	Sample 2	71	69	71	69	69	69	69
650 Glass Resin	Sample 1	72	72	72	71	69	70	69
	Sample 2	72	72	72	71	70	69	70

(1) By Schumacher Reflectometer

TABLE 45

EFFECT OF RS-4 SUNLAMP ON DUST(1) REMOVAL FROM COATED FLOAT GLASS(4)

Number	Coatings on Glass	RS-4 Exposure Time	% Dust Removal By Air Gun After Exposure (Qualitative)	% Transmission			
				Original	Original Dusted (2)	Dusted (2) & Aged	Dusted, Aged & Washed (3)
1	Santicizer 141 & Primer Q36060	10 Months	20	83	80	-	-
2	Hex & Tyzor TE		25	85	87	-	-
3	Flexol TOF& Primer Q36060		30	84	81	-	-
4	PVA & Tyzor TE		50	86	72	-	-
5	Flexol TOF & Surfacil		0	81	73	-	-
6	Flexol TOF & Tyzor AA		70	85	83	65	80
7	PVA & Tyzor AA		60	86	83	-	-
8	HEX & Tyzor AA		50	86	77	-	-
9	Polyethyleneglycol & Surfacil		40,50	85	57	-	-
10	CMC & Tyzor TE		85	78	63	44	78
11	CMC & Tyzor AA		70,60,87,70	75	58	19	75
12	IsoNoStat & Surfacil		40,40	81	73	-	-
13	IsoNoStat & Primer Q36060		90	83	67	42	81
14	Cyastat LS & Surfacil		50,60,60	83	50	-	-
15	Hydroxyethylmethacrylate		70	86	84	-	-
16	Surfacil & Santicizer 141		40,30	85	79	-	-
17	Flexol TOF & AT 51		0,10	84	68	-	-
18	IsoNoStat & AT51		50	83	81	-	-
19	HEC & AT56		40,20,50	80	68	-	-
20	IsoNoStat & AT 56		50	75	75	-	-
21	HEC & AT 50		50	81	71	-	-
22	Santicizer 141 & AT 50	9 Months	30,30,5	84	82	-	-
23	Flexol TOF & AT56		70,80	84	74	61	68
24	650 Glass Resin + .1 A1100	8 Months	90,90	87	83	82	84
25	650 Glass Resin + .5 A1100		95,80	87	80	82	83
26	650 Glass Resin + 1.0 A1152		95	87	80	81	83

(1) Arizona Road Dust
(2) Dust removed with an air gun and %T measured by direct transmission.
(3) Dust removed with a wash bottle.
(4) %T uncoated glass is 87%

TABLE 44

MULTIPLE DUSTING & WASHING
STUDY ON FLOAT GLASS MIRRORS

Coatings		Percent Reflectance (1)						
		Original	1 Cycle	2 Cycles	3 Cycles	4 Cycles	5 Cycles	6 Cycles
Uncoated	Sample 1	74	71	71	71	71	71	72
	Sample 2	71	71	71	70	69	70	69
WL-81	Sample 1	72	71	72	70	69	69	69
	Sample 2	71	69	71	69	69	69	69
650 Glass Resin	Sample 1	72	72	72	71	69	70	69
	Sample 2	72	72	72	71	70	69	70

(1) By Schumacher Reflectometer

TABLE 45

EFFECT OF RS-4 SUNLAMP ON DUST(1) REMOVAL FROM COATED FLOAT GLASS(4)

Number	Coatings on Glass	RS-4 Exposure Time	% Dust Removal By Air Gun After Exposure (Qualitative)	% Transmission Original	% Transmission Original Dusted (2)	% Transmission Dusted (2) & Aged	% Transmission Dusted, Aged & Washed (3)
1	Santicizer 141 & Primer Q36060	10 Months	20	83	80	–	–
2	Hex & Tyzor TE		25	85	87	–	–
3	Flexol TOF& Primer Q36060		30	84	81	–	–
4	PVA & Tyzor TE		50	86	72	–	–
5	Flexol TOF & Surfacil		0	81	73	–	–
6	Flexol TOF & Tyzor AA		70	85	83	65	80
7	PVA & Tyzor AA		60	86	83	–	–
8	HEX & Tyzor AA		50	86	77	–	–
9	Polyethyleneglycol & Surfacil		40,50	85	57	–	–
10	CMC & Tyzor TE		85	78	63	44	78
11	CMC & Tyzor AA		70,60,87,70	75	58	19	75
12	IsoNoStat & Surfacil		40,40	81	73	–	–
13	IsoNoStat & Primer Q36060		90	83	67	42	81
14	Cyastat LS & Surfacil		50,60,60	83	50	–	–
15	Hydroxyethylmethacrylate		70	86	84	–	–
16	Surfacil & Santicizer 141		40,30	85	79	–	–
17	Flexol TOF & AT 51		0,10	84	68	–	–
18	IsoNoStat & AT51		50	83	81	–	–
19	HEC & AT56		40,20,50	80	68	–	–
20	IsoNoStat & AT 56		50	75	75	–	–
21	HEC & AT 50		50	81	71	–	–
22	Santicizer 141 & AT 50	9 Months	30,30,5	84	82	–	–
23	Flexol TOF & AT56		70,80	84	74	61	68
24	650 Glass Resin + .1 A1100	8 Months	90,90	87	83	82	84
25	650 Glass Resin + .5 A1100		95,80	87	80	82	83
26	650 Glass Resin + 1.0 A1152		95	87	80	81	83

(1) Arizona Road Dust
(2) Dust removed with an air gun and %T measured by direct transmission.
(3) Dust removed with a wash bottle.
(4) %T uncoated glass is 87%

TABLE 46

EFFECT OF RS-4 SUNLAMP AGING ON SOILING

Sample	Period of Exposure (2)	Type of Dust (3)	% Transmission Before[4] Washing	% Transmission After (1) Washing
650 Resin on Glass	2 Weeks	Regular Dust	87	89
650 Resin on Glass	6 Weeks	Regular Dust	85	88
650 Resin on Glass	2 Weeks	Oily Dust	83	85
650 Resin on Glass	6 Weeks	Oily Dust	85	87
650 Resin on Glass	2 Weeks	High Humidity Dust	84	87
650 Resin on Glass	6 Weeks	High Humidity Dust	81	89
Glass Control	2 Weeks	Regular Dust	71	85
Glass Control	6 Weeks	Regular Dust	79	86
Glass Control	2 Weeks	Oily Dust	72	86
Glass Control	6 Weeks	Oily Dust	82	87
Glass Control	2 Weeks	High Humidity Dust	73	87
Glass Control	6 Weeks	High Humidity Dust	80	87

(1) Washed at 5 psi for 15 seconds

(2) Dry RS-4 Sunlamp

(3) Arizona road dust put on before aging

(4) %T of coated sample after exposure time shown

TABLE 47

EFFECT OF OUTDOOR WEATHERING ON TRANSMISSION

Substrate	Coating	% Transmission (1) Original	2 Weeks	4 Weeks	6 Weeks
Float Glass	WL-81	87	84	82	85
	AT50+4GO[2]	87	85	80	86
	Q36060/141	87	82	77	78
	650 Resin	87	86	85	87
	Uncoated	87	85	84	87
Petra A	WL-81	85	75	78	85
	B-99	83	65	76	72
	650 Resin	87	64	81	79
	Uncoated + unactivated	83	82	79	83
Kynar	650 Resin	87	85	85	85
	Q36060/141	86	78	83	82
	Uncoated + Unactivated	87	86	81	85

(1) From 350 to 899 nm

(2) Mixture of Flexol 4GO with AT-50 Acrylic

(3) Substrate primed with Q3-6060 Silicone post coated with Santicizer 141

TABLE 48

WEATHER CHART FOR ROOF SAMPLES

Summer 1980

	Date	Rain	Winds
1st Week	6/16	None	Calm
	6/17	None	Calm
	6/18	None	Calm
	6/19	None	Calm
	6/20	None	Calm
	6/21	None	Windy
	6/22	None	Calm
2nd Week	6/23	None	Calm
	6/24	None	Calm
	6/25	None	Calm
	6/26	None	Windy
	6/27	None	Windy
	6/28	None	Calm
	6/29	None	Windy
3rd Week	6/30	None	Calm
	7/1	Heavy	Moderate
	7/2	None	Calm
	7/3	None	Calm
	7/4	None	Calm
	7/5	Moderate	Moderate
	7/6	None	Moderate
4th Week	7/7	None	Moderate
	7/8	Heavy	Moderate
	7/9	None	Calm
	7/10	None	Calm
	7/11	Moderate	Moderate
	7/12	Heavy	Moderate
	7/13	None	Calm
5th Week	7/14	None	Calm
	7/15	None	Calm
	7/16	Moderate	Moderate
	7/17	Moderate	Moderate
	7/18	None	Moderate
	7/19	None	Moderate
	7/20	Heavy	High
6th Week	7/21	None	Moderate
	7/22	Heavy	Moderate
	7/23	Heavy	High
	7/24	Heavy	High
	7/25	None	Calm
	7/26	None	Calm
	7/27	Heavy	Moderate

TABLE 49

PERCENT REFLECTANCE[1] OF
COATED FLOAT GLASS MIRRORS
AFTER OUTDOOR EXPOSURE[2]

Coating	% Reflectance Original	4 Week	6 Week
Control	74,74[3]	71, 72	70, 71
Rhoplex WL-81	72, 72	61, 63	62, 63
Acryloid AT-50+4GO	72, 72	43, 43	53, 55
Primer Q36060+141	70, 71	61, 65	68, 66
650 Glass Resin	72, 72	70, 70	69, 70

(1) Schumacher Reflectometer

(2) Hazardville, CT.

(3) Duplicate Runs

TABLE 50

EFFECT OF OUTDOOR EXPOSURE[1] ON SOILING

Sample	Period of (1) Outdoor Exposure	Cleaning Method	% Transmission Before Cleaning	% Transmission After Cleaning
Glass Control	2 Week	Air Gun[2]	85	85
Glass Control	2 Week	Water Wash[3]	85	86
Glass Control	5-1/2 Week	Water Wash	85	85
Glass Control	5-1/2 Week	Water Wash	85	86
Glass Control	5-1/2 Week	Water Wash	85	86
Glass Control	5-1/2 Week	Water Wash	84	87
650 Resin on Glass	2 Week	Air Gun	82	80[4]
650 Resin on Glass	2 Week	Water Wash	87	86[4]
650 Resin on Glass	5-1/2 Week	Water Wash	86	84[4]
650 Resin on Glass	5-1/2 Week	Water Wash	6	82[4]

(1) Southern exposure at Hazardville, CT.

(2) Air gun is held at a 45° angle and approximately 1" away from sample.

(3) Washed at 5 psi for 15 seconds in Water Wash Apparatus.

(4) Front washed and is clean; back cloudy; coated by dipping; back won't wash off with water.

TABLE 51

METHOD OF CALCULATING COST OF

COATING HELIOSTATS

OPERATING COSTS	ANNUAL $	$ PER HELIOSTAT
VARIABLE		
Raw Materials		
Direct Labor	$6.00/hr 1920 3 Men	
Fringes on Direct Labor	35%	
Utilities	Steam, Gas	
Freight in and out	$0.01/lb	
Packaging	Not Responsible	
Maintenance Supplies	1% Capital Investment	
Maintenance Labor	1% Capital Investment	
Other Supplies	2% Raw Materials	
By Products Credits	None	
TOTAL VARIABLE		
FIXED		
Indirect Labor	100% Direct Labor	
Fringes on Indirect Labor	35%	
Depreciation	Equipment- 7 yrs	
Insurance & Taxes	3% Investment	
Maintenance Supplies	1% of Capital Investment	
Maintenance Labor	.1% of Capital Investment	
SPACE CHARGE	$6-6 1/2% per sq.ft/year	
TOTAL FIXED		
MANUFACTURING COST		
ROI BEFORE TAX AT 20% ON CAPITAL INVESTMENT		
MANUFACTURING COST & ROI		

CAPITAL EQUIPMENT AND BUILDINGS

TABLE 52

51,000 HELIOSTATS

OPERATING COSTS	ANNUAL $	$ PER HELIOSTAT
VARIABLE		
Raw Materials [1]	783,447	15.36
Direct Labor 6x4x1920	46,080	
Fringes on Direct Labor	16,128	
Utilities	1,920	
Freight in & out	5,400	
Packaging not Responsible	0	
Maintenance Supplies	1,670	
Maintenance Labor	1,670	
Other Supplies	15,669	
By Products Credit	0	
TOTAL VARIABLE	871,984	
FIXED		
Indirect Labor	46,080	
Fringes on Indirect Labor	16,128	
Depreciation	23,841	
Insurance & Taxes	5,010	
Maintenance Supplies	1,670	
Maintenance Labor	1,670	
Space Charge 10,100	60,600	
TOTAL FIXED	154,860	
MANUFACTURING COST	1,026,844	
ROI BEFORE TAX AT 20%	33,377	
MANUFACTURING COST & ROI	1,060,221	20.80

(1) 650 Glass Resin coating from Owens Illinois.

TABLE 53

COATING[1] COST/HELIOSTAT

	25,000	50,000
Glass Mirrors	22.13	20.80
Petra A Dome	50.35	46.20
Kynar Dome	57.00	54.20

WATER WASH COST

\$1.50/Heliostat x 26 times/yr

=\$39/Heliostat/yr

x 20 Years = \$780

x 50,000 Heliostats

= \$39,000,000

(1) Coated with Silicone 650 Glass Resin from Owens Illinois.

TABLE 54

GLASS HELIOSTAT COMPARISON COSTS: WASHING

vs

COATING WITH REDUCED NUMBER OF WASHES

ASSUMPTION[(1)]	\$ Costs[(3)]/20 years Per Heliostat	\$ Savings Over 20 Years (5)
Washing Only No Coating	780[(4)]	-
1/2 as Many Washes-20 Yr Coating Life	411	18, 450,000
1/2 as Many Washes-10 yr[(2)] Coating Life	432	17,400,000
3/4 as Many Washes-20 yr. Coating Life	606	8,700,000
3/4 as Many Washes-10 yr[(2)] Coating Life	627	7,650,000

(1) 50,000 Heliostats/year

(2) Two coatings/20 years

(3) Rounded off to nearest dollar

(4) 26 washings/year at \$1.50 washing/heliostat

(5) Compared to \$780/heliostat x 51,000 heliostats or \$39,000,000/20 years

APPENDIX A

CONCENTRATIONS AND CONDITIONS OF APPLICATION

Tables 1 through 6 in the body of the report show the concentration of solutions used and the conditions of application for silane (Table 1) and titanate (Table 2) coupling agents, antistats (Table 3), and soil release agents (Table 4).

The direct reaction organic compounds are listed in Table 5. HEMA is made up as 10 ml HEMA, 5 ml ceric ammonium sulfate at 0.1 percent in water and 85 ml water. Crosslinked HEMA is 10 percent HEMA, 5 percent ceric ammonium sulfate (1% in water), 0.5 percent triethylene glycol diacrylate all in methanol. Specimens are immersed for 30 minutes, drained and cured at 90°C in an oven for 30 minutes.

For all reagents samples were immersed 30 minutes in the monomer drained dry and cured 30 minutes at 90°C.

To activate the glass surface it was activated by immersion in 1 percent aqueous ceric ammonium sulfate, chromic acid, or exposure to ozone or UV. The "activated" glass was then immersed in the monomer to effect grafting and cured as above. Experiments were repeated using a solution of ceric ammonium sulfate similar to that used for HEMA mixed with 10 percent monomer in methanol.

Five monomers (Table 5) effected some dust repulsion but only HEMA was successful, i.e. provided significantly improved transmission.

The polymers used for coatings are listed in Table 6. These acrylics are made up as follows:

- AT-50
  12.5 ml (50% solids AT-50)
  4.0 ml Cymel 325 (as a crosslinker)
  225 ml Solvent (Xylene-60% n-Butanol 22% and Cellosolve 18%)

- AT-51 and 56 are made as above except solvents are:

AT-51	AT-56
Xylene-78%	Xylene-90%
Butanol-22%	Butanol-10%

- Rhoplex WL-81
  10% WL-81 latex (50% solids) in deionized water.

- Acryloid B-99
  This comes as 50% solids in 50/50 toluene/xylene. It is used at 5% solids i.e.(10 ml B-99 in 90 ml toluene/xylene) (50/50).

- Permacote 62

  (No longer made- but they have a substitute (BP-99) we have not examined). This comes as 14% solids in xylene. We use it at 5% solids in xylene.

Coupled systems were prepared by immersing the substrate in 1 per cent coupler (see Tables 1 and 2), drying 30', 90°C and then immersing in the second reagent, e.g. 1 percent Flexol 4GO in xylene or 1 percent Santicizer 141 in isopropanol followed by drying 30 minutes at room temperature.

The following describes the application of the silicones:

- Q3-6060 primer was spread on one side of the substrate using a cheese cloth containing a few drops of the Q3-6060. This was followed by Santicizer 141 or other reagent per Tables 3 and 4.
- Glass Resin 650 was applied by dipping the substrate in a 5 percent solution in isopropyl alcohol.
- Repcon was applied by wiping with a cheese cloth containing several drops of Repcon.
- The GE SHC-1000 "silicate type" coating was applied per the manufacturers data that follows:

(1) In a well ventilated area, preferably having a filtered (dust free) air supply, apply a 4% (solids) SHP-100 primer solution to the part(s) by dip or flow coating. Use caution because the primer solvent(s) may be hazardous.

(2) Primer should drain and air dry for 20-30 minutes. Be sure to remove dip tank or tray as soon as primer is applied. Do not expose uncured primer films to solvent vapors.

(3) Cure primer coat for 30 min. at 120-125°C. Use an oven having strong mechanical (forced) air circulation and fast heat recovery.

(4) Remove samples(s) and cool to room temperature before applying SHC. This is a critical step--do not coat parts warm as optical defects can result.

(5) Using the same ventilated area* as in Step 1, dip or flow coat the parts with Silicone Hard Coat (SHC). Use caution because SHC's solvents (methyl alcohol and iso-butylalcohol) are hazardous.

(6) Coating should drain and air dry for 10-30 minutes. Be sure to remove dip tank or tray as soon as coating is applied. Do not expose uncured Hard Coat films to solvent vapors.

(7) Cure the SHC resin for 30-60 minutes at 120-125°C. Use the same oven type as in Step 3.

(8) Cool to room temperature. Parts prepared with Silicone Hard Coat are ready for service.

The material supplied is a silicone resin which yields a clear abrasion resistant film when applied to a suitable prepared plastic or metal substrate. It can be flow or dip coated. The recommended cure cycle is 10-30 minutes air dry and 30-60 minutes at 250°F(120°C) or equivalent.

Solution	
Solids Content (Wt.)	20%
Solvent	Methanol-isobutanol (1)
Flash Point	74°F (23°C)
Density	7.6 lbs/gal
pH	7.5
Shelf Life	Below 39°F (4°C) (6 mos)
Viscosity	4-10 ctks
Cured Film (2)	
Specific Gravity	1.45
Film thickness, flow coat 20% solids	0.2 mil
Tabor Abrasion, 500 cycles	2.0 - 4.0% haze
500 g on primed BPA polycarbonate (CS 10F wheel)	
Water Immersion - 65°C	4+ days (3)
Boiling Water Immersion	2 hrs (3)
QUV (Primed Polycarbonate)	200-400 hrs (3)
Humidity Oven (120°F-100% R.H.)	4 + weeks (3)

(1) Potentially hazardous
(2) All data for primed Lexan
(3) To crosshatch adhesion failure. Failure is any observed delamination.

* Relative humidity in the coating area should not exceed 50% R.H.

A P P E N D I X   B

DUSTS

Dry or regular dust is Arizona Road Dust of the following particle size ranges sieved through a 40 mesh sieve onto a substrate which is tapped to remove the excess.

ARIZONA ROAD DUST(1)

Fine Air Cleaner Test Dust

Specification(2)	
0-5 Microns	39± 2%
5-10 "	18± 3%
10-20 "	16± 3%
20-40 "	18± 3%
40-80 "	9 ± 3%

(1) Classified from Natural Arizona Dust prepared by AC Spark Plug Div., General Motors Division Corp., Flint, Michigan

(2) Particle size distribution by weight as measured with a Roller Analyzer.

Oily dust is prepared by blending 3 percent Nujol with the dust in a Waring Blender for five minutes.

High humidity dusted slides are prepared by placing the dry dusted substrate in a 80 percent R.H. chamber (26.3 g ammonium chloride in 100 g water) for 24 hours.

A P P E N D I X C

PERCENT TRANSMISSION

Transmittance was direct transmittance determined per ASTM E424-71over the visible spectrum 350 - 900 nm. An example of the calculation follows for 650 Glass Resin coating on float glass.

EXAMPLE OF DIRECT PERCENT TRANSMISSION CALCULATION (1)

		650 on Glass	
X(nm)	Relative Energy	%T at Every 50 (nm)	Energy Transmittance
350	1.7	72 (2)	1.22
400	4.41	86	3.79
450	9.55	88	8.40
500	11.56	88	10.17
550	11.31	90	10.18
600	11.10	89	9.88
650	11.17	87	9.72
700	10.57	87	9.20
750	8.61	86	7.40
800	8.13	84	6,83
850	7.94	81.5	6.47
900	4.50	80	3.60
.%T over range 350-900 nm			86.9 %

(1) Multiply the % Transmission at a specific wavelength times the corresponding relative energy value.

<u>Example</u>	<u>Energy Transmittance</u>
at 350 nm 1.7 x 72% =	1.22

Add together all the energy transmittance values to obtain the % T.

(2) These values are taken off chart paper from Spectrophotometer. They represent % transmission at every 50 nm.

A P P E N D I X D

SPRAYING WITH AQUEOUS SUSPENSION
OF
ARIZONA ROAD DUST

The Water Wash Apparatus removed all dust at very low pressures and short times.As a check on the effectiveness of this appartus Arizona Road Dust was suspended in water and sprayed onto float glass. The assumption is that an aqueous suspension of dust would "cement" to the glass and not be so easily removed.

The following table shows this to be true. The water was sprayed for 15 seconds at increasing pressures from 5 psi to 200 psi and percent transmission was measured in duplicate. Between 5 and 30 psi %T was about 72 percent. From 50 psi and up %T began to rise and reached 78-79 percent at 200 psi.

PERCENT REFLECTANCE AFTER WATER WASH
OF MIRRORS SPRAYED WITH AN AQUEOUS
SUSPENSION OF ARIZONA ROAD DUST

Water Wash Pressure	% Reflectance After Washing
5 psi	72, 72
10 psi	71, 72
15 psi	71, 72
20 psi	72, 73
30 psi	72, 70
50 psi	73, 75
100 psi	75, 77
200 psi	78, 79

---

(1) Original reflectance is 77-79%; after spraying the Float Glass Mirror with 10 grams Arizona Road Dust/200 ml deionized water reflectance is 6-15%.

(2) Two samples each test

A P P E N D I X E

COST DETAILS

The information that follows contains the cost details for the results that are summarized in the body of the report.

1. Coating 51,000 Heliostats with Glass Resin 650 Solution

Solution:

5% 650 glass resin, 95% isopropanol, 95% purity.

Final Film Thickness:

0.2 mil, need 4 mil solution thickness. Assume 2% breakage of mirrors, therefore 51000 mirrors used. Heliostat consists of twelve 12' x 4' mirrors.

Heliostat Area:

$4' \times 12' \times 12 = 576\ ft^2$

Amount of solution needed per year:

$576 \times 51000 \times 3.33 \times 10^{-4} = 9782\ ft^3 = 73210$ gal

4.5% excess used. Gallons used in calculation = 76,504

Density 95% alcohol = 6.70 lbs/gal = 512,574 lbs alcohol

Lbs/.95 = 539,551 lbs total solution

5% 650 Resin = 26,977 lbs

Chemical Costs as of August 21,1980 :

Cost of 650 resin = $23.00 /lb x 26,977 = $620,494

Cost of isopropanol= 2.13/gal x 76504 = $162,953

Total $783,447

Process:

Conveyor belt into spray cabinet, 3 sprayers, then into oven 2 minutes to remove isopropanol.

Capital Equipment:

Cost calculations. For all calculations assume 1920 working hours/ year. Use $X^{0.7}$ as equipment cost scale factor, where X is the number of units over that used for 25,000 units.

$2^{0.7} = 1.62$

$4^{0.7} = 2.64$

Ovens- 2 needed

$576 \frac{ft^2}{\text{heliostat}} \times 25500 \text{ heliostats} \times 2 = 2{,}937{,}600\ ft^2/\text{year}$

or

15300 ft^2/hr. 15300/48 = 318 twelve foot mirrors/hr.

Use two 161 ft long, 5 ft, wide ovens.

Cost= $50/$ft.^2$ x 5 x 161 x1.62 = $65,205

. Conveyors - 2 needed

Assume 15 ft before oven + 15 ft. spray cabinet + 161 ft oven + 24 ft. after oven =215 ft long x 4 ft wide = 860 ft^2

Cost = 860 ft^2 x $10/$ft.^2$ x 1.62 = $13,932

. Mixing Tank	
1000 gal $1.00 gal	$ 1,000
. Spraying Tank	
1000 gal $1.00 gal	$ 1,000
. Stirrer for 1 Tank	
0.50 gal	$ 500
· Covers for 2 Tanks	
0.25 gal	$ 500
. Spray Booths	
2 needed; 3 sprayers each	
$50,000 x 1.62	$ 81,000
. Storage Tank	
6000 gal for isopropanol	
$0.50/gal	$ 3,000
. Tank Cover	
$0.25/gal	$ 750

Total Capital equipment $166,887

ROI before taxes at 20% (See Table 52) $ 33,377

2. <u>Kynar Coated with Glass Resin 650 Solution Encasing 51,000 Reflectors</u>

· Amount of Kynar, square feet, needed for 1 heliostat calculated using study, " Feasibility Study of Solar Dome Encapsulation of Photovoltaic Arrays ", by Donald Zimmerman. JPL Contract No. 954833, Dec. 1978.

Page 105-53,600,000 ft^2 polyester film required

Page 107- 2,140,000 m^2 or 23,023,000 ft^2 solar cells

Therefore: 2.33 ft^2 polyester for 1 ft^2 reflector.

Assume Kynar 5 ft. wide. 2.33 ft^2 Kynar required

576 ft^2 x 2.33 = 1342 x 51000 = 68,442,000 ft^2

add 100,000 ft excess = 68,542,000/1920 x 5 = 7140 ft/hr.

has to be activated.

• Calculations for 10% butylamine in methanol tank 14 ft. long, 6 ft high, 7 ft. wide, 5 ft solution, 490 ft^3 solution. Assume 10% excess and 25% loss due to evaporation.

490 ft^3 = 3667 gal x 2 = 7334 gal + .35 (7334) = 9901 gal

Tributylamine 990 gal = 6098 lbs x 1.00/lb	= $6,098
Methanol 8911 gal x 0.96 gal	= 8,554
	$14,652

• Calculations for 1% acetyl peroxide in methanol:

Tank 75' x 13' x 6', 2.5 ft.solution, Depth = 2,438 ft^3

2438 ft^3 = 18,246 gal.acetyl peroxide solution.

Assume 10% excess, 25% replacement for each chemical and add 100 gal acetyl peroxide for decomposition per tank.

For 4 tanks :

Acetyl peroxide, 25% in dimethylphthlate 1382 gal = 13474 lbs

$3.70/lb	= $49,854
Methanol 97524 gal	= 93,624
	$143,478

. Cost of Glass Resin 650 Solution:

$68{,}542{,}000 \times 3.33 \times 10^{-4} = 22824\ ft^3 = 170{,}818$ gal + 4.5 % excess

Total gallons used in calculations = 178,500.

Density 95% isopropanol =	670 lbs / gal	= 1,195,950 lbs.
	lbs/.95	= 1,258,894
	5% 650 Resin	= 62,944 lbs
Cost of 650 Resin		= $1,447,712
Cost of isopropanol 2.13/gal		380,206
	Total	$1,827,918
Cost of Isopropanol for Rinse:		$ 1,200
Total Chemicals Cost		$1,987,248

. Processes for Kynar Film:

Activation steps and 650 Glass Resin solution application.

Kynar is fed on rollers through butylamine-methanol solution for 5 minutes and then is fed on rollers into 1% acetyl peroxide-methanol solution, which is at 50°C, for 1 hour. The film is passed into an isopropanol rinse tank and is driven through pinch rollers into spray booths of 650 resin solution. The required thickness of 650 resin solution film is obtained using a doctor blade. The isopropanol is evaporated in ovens and the processed film is rewound.

Capital Equipment

. 2 Unwind stands, 25,000 x 1.62	$ 40,500
. 2 Rewind stands, 75,000 x 1.62	121,500
. 2 Tanks for butylamine-methanol solution, 14' x 6' x 7' = 4400 gal, $0.50/gal $2200 x 1.62	3,564
. 2 Covers, $0.25 gal x 4400	1,100
. 75 Rollers- 2" diameter $100/roller, $7500 x 1.62	12,150
. 2 driver rolls to convey film to acetyl peroxide tanks, $25,000 x 1.62	40,500
. 4 Tanks for acetyl peroxide-methanol solution, 75' x 13' x 6' = 43,781 gal x $0.50 x 2.64	57,790
. 446 Rollers-2" diameter, $100/roller x 2.64	117,744

. Steam lines for tanks, 57,790 x $.25	$ 14,500
. Covers for tanks	14,500
. Mixing tank, stirrer, cover, 1000 gal for butylamine-methanol	1,500
. Mixing tank, stirrer, cover, 3000 gal, 0.75 gal for acetyl peroxide-methanol	3,375
. Storage tank-butylamine, 1000 gal, cover	1,250
. 4 driver rolls for taking film from peroxide tanks to isopropanol tanks, $25,000 x 2.64	66,000
. 4 isopropanol tanks, 404 gal x $1.00/gal	1,616
. 4 covers, $0.50 x 1616	808
. 1 still to recover isopropanol	2,500
. 4 driven pinch rolls to 650 solution, $25,000 x 2.64	66,000
. 4 conveyors, each 72' long x 6' wide, 432 x $10 ft^2 x 2.64	11,405
. 4 spray booths- 6' x 6', 3 sprayers. $50,000 x 2.64	132,000
. 4 rolls and 4 doctor blades, $25,000 x 2.64	51,480
. Storage tank and cover, methanol, 6,000 gal	3.750
. Storage tank and cover, isopropanol, 6,000 gal	3,750

Total Capital Equipment $840,282

3. Petra A Coated Polyester with Glass Resin 650 Solution Encasing 51,000 Reflectors.

. Calculations for amount of Petra A is the same as for Kynar. 2.33 ft^2 required per ft^2 reflector. Petra A- 5 ft. wide.

Petra A = 68,542,000 $ft.^2$ = 7140 ft/hr. has to be activated.

. Calculations for 10% sodium hydroxide solution tank , 75 ft. long , 7 ft. wide 6 ft. high. 5 ft. solution= 2625 $ft.^3$.

Assume 10% excess and 25% makeup:

19646 gal. x 0.35 (19646) = 26,515 x 2 = 53,030 gal. for two tanks.

Sodium Hydroxide	=	5,304 gal
Use 50% NaOH solution	=	10,608 gal
Tap Water	=	42,422 gal

50% NaOH- 10,608 gal x 12.72 lbs/gal= 134,934 lbs x $0.112/lb.	$15,112
Tap water 42,422 gal. x $4 x 10^{-4}/gal	16
	$15,128

. Calculations and Cost of 650 Resin Solution is the same as for Kynar. $1,827,918

. Process for Petra A Polyester Film:

Activation and 650 glass resin solution application

Petra A polyester film is fed on rollers through sodium hydroxide solution for 0.5 hours at room temperature. The film is rinsed with deionized water and blown dry with hot air. It is then driven through pinch rollers into spray booths of 650 resin solution. The required thickness of 650 resin solutions film is obtained using a doctor blade. The isopropanol is evaporated in ovens and the processed film is rewound.

Capital Equipment

. 2 unwind stands, $25,000 x 1.62	$ 40,500
. 2 rewind stands, $75,000 x 1.62	121,500
. 2 tanks for sodium hydroxide: 75' x 7' x 6' = 23,574 gal, $0.50/gal. $11,787 x 1.62	19,095
. Cover for tank, $11,787 x 2 x .25	5,894
. 437 rollers- 2" diameter $100 / roller x 1.62	70,794
. 2 drive rolls to convey film to wash tank, 25,000 x 1.62	40,500
. 2 wash tanks, 404 gal x $1.00 gal	808
. 3 rollers each tank	600
. Water take off in tanks	404
. Neutralization of NaOH. HCl and pH meter, 0.5 x 808	404
. 2 sprayers 5 gal/min deionized water 3 sprayers per side of film, $10,000 x 1.62	16,200
. Water deionizer	22,000
. 2 hot air blowers , $5,000 x 1.62	8,100
. 2 pinch rolls, $25,000 x 1.62	40,500
. 2 spray booths - 6' x 6', 3 sprayers $50,000 x 1.62	81,000
. 2 rolls and 2 doctor blades $25,000 x 1.62	40,500
. 2 tanks for 650 solution and covers, 1,000 gal	5,000
. 2 conveyors, 132' long x 6' wide x $10/ft^2 x 1.62	12,800
. 2 ovens, 125' x 6' x $50 ft^2 x 1.62	45,000
. Storage tank, NaOH 1500 gal, stirrer and cover, 1,000 gal	2,250
. Storage tank, isopropanol and cover, 6000 gal.	3,750

Total Capital Equipment $577,600

4. Costs for 25,500 Heliostats[a]

Substrate	Chemical Costs	Capital Equipment Costs
Glass	$ 391,724	$104,100
Kynar	993,624	516,870
Petra A	921,523	373,442

Chemical Costs are half that of 51,000 heliostat calculations.

Capital Equipment Costs can be derived by dividing the scale factor into the equipment cost. For example in the Kynar process four sets of 446 rollers cost $117,744. One set of rollers costs $\$117,744/4^{0.7}$ and the two sets of rollers used for the acetyl peroxide tanks would cost $\$44,600 \times 2^{0.7} = \$72,252$.

(a) Assumes 2% breakage on 25,000 mirrors and/or enclosures,

5. Coating Heliostats with WL-81 Resin

The solution is 90% deionized water, 10% WL-81 by volume.

The amounts of solutions are the same as calculated for the 650 resin solutions.

	25,500	51,000
Total gallons required	38,252	76,504
Deionized Water, gal	34,427	68,854
WL-81, gal	3,825	7,650
WL-81, lbs	33,048	66,096

Costs :

	25,500	51,000
Tap water $\$4x10^{-4}$/gal	$ 14	$ 28
Deionized Water-$0.05/gal	1,721	3,442
WL-81-$0.5675 /lb	18,754	37,508
Total Cost	$ 20,489	$ 40,978
Cost per Heliostat	$ 0.44	$ 0.44

6. Use of WL-81 Resin on Petra A Polyester Film

The amounts of solution are the same as calculated for the 650 resin solution.

	25,500	51,000
Total Gallons required	89,250	178,500
Deionized Water, gal.	80,325	160,650
WL-81 gal.	8,925	17,850
WL-81 lbs.	77,112	154,224

Costs:

	25,500	51,000
Tap Water- $\$4 \times 10^{-4}$/gal	$ 32	$ 64
Deionized Water 0.05/gal	4,016	8,032
WL-81 $0.5675/lb	43,761	87,522
Cost of Sodium Hydroxide Solution	7,564	15,128
Total Cost	$ 55,373	$ 110,746
Cost per Heliostat	$ 2.17	$ 2.17

Assume Capital Equipment Costs and Fixed Costs are the same as for the 650 glass resin. The only changes in the operating costs are the variable costs.

Costs of Coating Mirrors

Operating Costs				
Variable:	25,500		51,000	
Raw Materials	$20,489		$40,978	
Other Supplies, 2% Raw Material	410		820	
All Other Variable Costs	52,398		72,868	
Total Variable Costs		$73,297		$114,666
Total Fixed Costs		91,642		154,860
Manufacturing Costs		165,000		269,526
ROI before Tax at 20% Capital Equipment		20,820		33,377
Total Manufacturing Cost + ROI		$ 185,820		$ 302,903
Cost per Heliostat		$ 7.29		$ 5.93
Capital Equipment Cost		104,100		166,887

Costs of Coating Petra A Polyester Film

Operating Costs	25,500		51,000	
Variable				
Raw Materials	$ 55,373		$ 110,746	
Other Supplies, 2% Raw Materials	1,107		2,214	
All Other Variable Costs	93,000		105,780	
Total Variable Costs		$149,480		$218,740
Total Fixed Costs		154,937		255,693
Manufacturing Costs		$ 304,417		$ 474,433
ROI before tax at 20% Capital Equipment		74,688		115,070
Manufacturing Cost + ROI		$ 379,105		$589,503
Cost per Heliostat		$ 14.87		$ 11.56
Capital Equipment Cost		$ 371,942		$ 577,600

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