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(54) Titre : TRAITEMENT D'HYDROFUGATION ASSURANT LA NON-MOUILLABILITE D'UNE SURFACE
(54) Title: AUTOPHOBIC WATER REPELLENT SURFACE TREATMENT

(57) **Abrégé/Abstract:**

A composition and method are disclosed to provide a substrate such as glass, plastic, metal, inorganic polymer coated substrate or inorganic coated substrate with a durable non-wetting surface. The composition includes a perfluoroalkylalkyl silane selected from compounds having the general formula $R_m R'_n SiX_{4-m-n}$ where R is a perfluoroalkylalkyl radical, R' is an alkyl or vinyl radical, m+n is not greater than 3, and X is selected from halogen, alkoxy or acyloxy radicals. The perfluoroalkylalkyl silane is in a solvent such as an alkane, alkene, aromatic hydrocarbons, ether, ketone or halogenated hydrocarbon which together form a composition which initially wets the surface. As the perfluoroalkylalkyl silane reacts with the surface, the remaining composition is repelled by the perfluoroalkylalkyl silane treated surface due to the difference between the surface tension of the solvent and the free energy of the treated surface, for expedient removal of the remaining composition from the treated surface.

ABSTRACT OF THE DISCLOSURE

A composition and method are disclosed to provide a substrate such as glass, plastic, metal, inorganic polymer
5 coated substrate or inorganic coated substrate with a durable non-wetting surface. The composition includes a perfluoroalkylalkyl silane selected from compounds having the general formula $R_mR'_nSiX_{4-m-n}$ where R is a perfluoroalkylalkyl radical, R' is an alkyl or vinyl radical, m+n is not greater
10 than 3, and X is selected from halogen, alkoxy or acyloxy radicals. The perfluoroalkylalkyl silane is in a solvent such as an alkane, alkene, aromatic hydrocarbons, ether, ketone or halogenated hydrocarbon which together form a composition which initially wets the surface. As the perfluoroalkylalkyl
15 silane reacts with the surface, the remaining composition is repelled by the perfluoroalkylalkyl silane treated surface due to the difference between the surface tension of the solvent and the free energy of the treated surface, for expedient removal of the remaining composition from the treated surface.

AUTOPHOBIC WATER REPELLENT SURFACE TREATMENT

BACKGROUND

The present invention relates generally to the art of surface treatment and, more particularly, to the art of producing a water repellent surface on various substrates, and most particularly to producing such a water repellent surface without applying excess material which must be removed.

U.S. Patent No. 4,724,022 to Armstrong discloses an improved method of preparing a glass release surface useful in the manufacture of anti-lacerative window assemblies by treating the glass surface with (heptadecafluoro-1,1,2,2-tetrahydrodecyl)-1-trichlorosilane.

European Patent Application No. 92107814.3 (Publication Number 0 513 690 A2) of Yoneda et al. describes a surface-treated substrate having at least two treated surface layers wherein the first outermost layer is obtained by treatment with a compound forming a surface having a contact angle of at least 70° against water and the second underlayer is obtained by treatment with at least one reactive silane compound selected from isocyanate silane compounds and hydrolyzable silane compounds.

U.S. Patent Nos. 4,983,459 and 4,997,684 to Franz et al. disclose an article and method respectively for providing a durable nonwetting surface on glass by treatment with a perfluoroalkylalkyl silane and a fluorinated olefin telomer.

5 U.S. Patent No. 5,308,705 to Franz et al. describe providing nonwetting surface properties to substrates other than glass by treatment with a perfluoroalkylalkyl silane and a fluorinated olefin telomer.

U.S. Patent No. 5,328,768 to Goodwin discloses a
10 glass substrate the surface of which is treated with first a silica primer layer and second a perfluoroalkylalkyl silane.

U.S. Patent No. 5,368,892 to Berquier describes a non-wettable glass sheet comprising a hydrophobic, oleophobic, UV resistant layer and a process for manufacturing the same,
15 which includes cleaning the glass, contacting the glass with a solution containing a fluorinated organosilane in a non-polar solvent system at a temperature ranging between -10°C and 25°C for at least 5 minutes, and rinsing.

20 DESCRIPTION OF THE DRAWING

Figure 1 illustrates the contact angle of a liquid drop as a function of solvent surface tension in dynes per centimeter on substrates having various surface free energies, measured in dynes per centimeter.

25 Figure 2 illustrates the contact angle of a liquid drop as a function of surface free energy in dynes per centimeter of various fluids, the surface tensions of which are measured in dynes per centimeter.

30 SUMMARY OF THE INVENTION

The present invention provides a substrate surface with high water repellency and high lubricity. Durable water

and dirt repellency of a substrate surface are provided by applying to the substrate surface a composition comprising a perfluoroalkylalkyl silane compound and a solvent which renders the surface treatment autophobic, i.e. the composition initially wets the substrate surface, and as the substrate surface becomes treated with the perfluoroalkylalkyl silane, the composition is repelled by the treated substrate surface. The composition comprises at least one solvent for the perfluoroalkylalkyl silane. The composition comprises at least one solvent having a boiling point sufficiently high to prevent complete evaporation of solvent upon application of the perfluoroalkylalkyl silane, and a surface tension at least 5 dynes per centimeter higher than the surface free energy of the perfluoroalkylalkyl silane treated surface. The composition may comprise a single solvent or a mixture of solvents.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A composition comprising perfluoroalkylalkyl silane and solvent in accordance with the present invention is applied to the surface of a substrate to produce a surface treatment article. The perfluoroalkylalkyl silane and solvent composition is preferably employed as a suspension or solution, preferably in a solvent for the perfluoroalkylalkyl silane. The preferred solution of the present invention is applied to a substrate surface by any conventional technique such as dipping, flowing, wiping or spraying. The composition initially wets the surface, usually for about 0.2 to 2 seconds until the treated surface becomes sufficiently nonwetting to repel the remaining composition. As the perfluoroalkylalkyl silane reacts with the surface, and the treated surface repels the remaining composition, any excess composition can be

easily removed, for example by wiping, without deposition of any excess silane as a thin hazy film which is difficult to remove and requires significant effort to eliminate.

Preferred perfluoroalkylalkyl silanes have the general formula $R_mR'_nSiX_{4-m-n}$, wherein R is a perfluoroalkylalkyl radical; m is typically one, n is typically zero or one, and m+n is not greater than 3, i.e. each of m and n is zero, one, two or three; R' is a vinyl or alkyl radical, preferably methyl, ethyl or propyl; and X is preferably a radical such as halogen, acyloxy and/or alkoxy. Preferred perfluoroalkylalkyl radicals preferably comprise perfluoroalkyl moieties which range from CF_3 to $C_{30}F_{61}$, preferably C_6F_{13} to $C_{16}F_{33}$ or $C_{18}F_{37}$, and most preferably C_8F_{17} or C_6F_{13} to $C_{10}F_{21}$ or $C_{12}F_{25}$. The alkyl moiety of the perfluoroalkylalkyl radical

is preferably ethyl. Preferred radicals for X include chloro, bromo, iodo, methoxy, ethoxy and acetoxy radicals. Preferred perfluoroalkylethylsilanes in accordance with the present invention include perfluoroalkylethyltrichlorosilane, perfluoroalkylethyltrimethoxysilane, perfluoroalkylethyltriacetoxysilane, perfluoroalkylethyldichloro(methyl)silane and perfluoroalkylethyldiethoxy(methyl)silane.

These perfluoroalkylethylsilanes appear to react with bonding sites at the substrate surface on a molecular basis. Strong surface bonding of the perfluoroalkylethylsilanes produces a durable substrate surface which exhibits a high contact angle with a drop of water, indicating high water repellency. The perfluoroalkylalkyl silane composition may further comprise a hydrolyzable silane capable of hydrolytic condensation to form a silica gel which acts as an integral primer. Preferred hydrolyzable silanes include fully hydrolyzable organosilanes, such as tetrahalosilanes, particularly tetrachlorosilane, $SiCl_4$.

Suitable solvents include those with relatively high boiling points, preferably above 65°C, and surface tensions greater than the surface free energy of the perfluoroalkyl-alkyl silane treated substrate surface by at least 5 dynes per centimeter (dynes/cm). The solvent may be a single solvent or a mixture of solvents, comprising at least one solvent for the perfluoroalkylalkyl silane and at least one solvent having the above properties. Also suitable are solvent mixtures which have at least one component which has a high boiling point, and either have fluid surface tensions which are at least 5 dynes/cm greater than the perfluoroalkylalkyl silane treated substrate surface, or change by selective evaporation during treatment of the substrate surface until the surface tension of the fluid is at least 5 dynes/cm greater than the free energy of the perfluoroalkylalkyl silane treated substrate surface. Preferred solvents and solvent systems include those which are aprotic, i.e. without -OH, -NH or -SH which can react with hydrolyzable groups on the perfluoroalkylalkyl silane, and have surface tensions greater than the surface free energy of the treated surface or are capable of selective evaporation to form a solvent system with a surface tension greater than the surface free energy of the treated surface.

Suitable solvents include high boiling, high surface tension solvents in the following families: normal, cyclic, and isoparaffinic alkanes such as hexane, heptane, cyclohexane, octane, hexadecane, and mixtures such as mineral spirits and IsoparTM solvents (product of Exxon); alkenes such as limonene; aromatic hydrocarbons such as toluene and xylenes; high boiling ethers such as n-butyl ether; ketones such as cyclopentanone, cyclohexanone, and methyl isobutyl ketone; halogenated hydrocarbons such as trichloroethane and chlorobenzene. Suitable solvents, particularly in solvent

mixtures, may include isopropanol, ethanol, hexane, heptane, mineral spirits, acetone, toluene, and naphtha. Preferred solvents are high boiling alkanes, such as octanes, decanes, dodecanes and mixtures thereof; halogenated hydrocarbon solvents such as trichlorotrifluoroethane and methylene chloride; and perfluorinated organic compounds such as perfluorocarbons. Preferred solvents, for shipping considerations, are those without flash points or with flash points above 140°F (60°C). Preferred solvents include 1,1,1-trichloroethane, alkanes such as dodecane and hexadecane, and commercially available mixtures such as IsoparTM solvents, grades L, M, and V, from Exxon Corp. In all cases, the solvent or one component of the solvent mixture, preferably at least 1 percent in concentration, is of sufficiently high boiling point so as not to evaporate within about one minute of coating application.

Some suitable solvents, along with their surface tension, boiling temperature and flash point properties are listed in the following Table.

Suitable Solvents	Surface Tension (Dynes/cm)	Boiling Point or Range (°C)	Flash Point (°F)
hexane	18.4	69	-10
heptane	19.7	96	30
cyclohexane	25.5	81	-1
octane	21.8	126	60
mineral spirits	25.3	177	~135
VM&P naphtha	22	127	
dodecane	25.4	216	160
hexadecane		287	275
Isopar TM C	21.2	98-104	19
Isopar TM E	22.5	118-137	45
Isopar TM G	23.5	160-174	106
Isopar TM H	24.9	178-188	129
Isopar TM K	25.9	177-197	135
Isopar TM L	25.9	191-207	147
Isopar TM M	26.6	223-252	196
Isopar TM V	30.8	273-311	264
limonene		178	119
toluene	28.5	110	40
o-xylene	30.1	144	90
n-butyl ether	22.9	142	77
cyclopentanone		131	87
cyclohexanone	35.2	155	116
methyl isobutyl ketone	24.5	115	56
1,1,1- trichloroethane	25.8	74	none
chlorobenzene	33.6	132	75

If the perfluoroalkylalkyl silane comprises readily hydrolyzable groups, such as chloro, the solvent preferably excludes water and alcohols such as ethanol and isopropanol, which can react with the perfluoroalkylalkyl silane, leaving it less capable of reacting with the substrate surface. For the particularly preferred perfluoroalkylalkyl silanes, such as the perfluoroalkylalkyl dichloro- and trichloro-silanes, the solvent or solvent mixture is preferably anhydrous. Solvents may be passed through conventional drying agents such

as anhydrous, magnesium sulfate or silica gel. Various preferred solvents, such as the high boiling alkanes, may include a reactive drying agent, such as thionyl chloride, to remove any trace of water which would otherwise react with the
5 perfluoroalkylalkyl silane.

Thionyl chloride (SOCl_2) is a member of a class of reactive drying agents. Most drying agents work by complexing water present in the solvent. The water is still present in systems that rely on complexation. Reactive drying agents,
10 for the instant invention, are those that react with the water to form other compounds which do not contain water and preferably do not produce other -OH containing moieties that are reactive with chlorosilanes. Other reactive drying agents include sulfur monochloride (S_2Cl_2), phosphorus pentachloride
15 (PCl_5) sulfuryl chloride (SO_2Cl_2), and phosphorus trichloride (PCl_3).

Concentrations of about 0.005 to 50, preferably about 0.05 to 5, percent of perfluoroalkylalkyl silane in the solvent or solvent mixture are preferred. The composition is
20 preferably applied to the substrate surface by wiping, dipping or spraying followed by removal by air blow off, gravity draining or wiping while some of the composition remains on the treated surface in a form which is repelled by the treated surface due to the remaining solvent having a significantly
25 higher surface tension, preferably at least 5 dynes/cm greater, than the surface free energy of the treated surface. This retraction of the solvent from the treated surface provides for easy pickup and removal of the remaining composition without deposition of a thin film of excess
30 perfluoroalkylalkyl silane component which forms a haze which may be difficult to remove, and which may require more time

and effort to remove than the time required for application of the composition.

After any remaining solvent is evaporated, preferably simply by drying in air at ambient temperature, the
5 perfluoroalkylalkyl silane may be cured to form a more durable coating. Preferably, curing is accomplished by heating the perfluoroalkylalkyl silane treated surface. Typically, curing temperatures of at least 150°F (about 66°C) are preferred, particularly above 200°F (about 93°C). A cure cycle of about
10 200°F (about 93°C) for about 30 minutes is suitable. Higher temperatures and shorter heating times may be more efficient. A cure cycle of 2 to 5 minutes at 400 to 500°F (about 204 to 260°C) may be preferred, particularly about 3 minutes at about 470°F (about 243°C).

15 The contact angles recited herein are measured by the sessile drop method using a modified captive bubble indicator manufactured by Lord Manufacturing, Inc., equipped with Gaertner Scientific Goniometer optics. The surface to be measured is placed in a horizontal position, facing upward, in
20 front of a light source. A drop of water is placed on top of the surface in front of the light source so that the profile of the sessile drop can be viewed and the contact angle measured through the goniometer telescope equipped with circular protractor graduation.

25 Figure 1 shows that fluids with very low surface tension, such as perfluorocarbons, can easily wet the treated surfaces, even the most repellent. During the application of perfluoroalkylethyltrichlorosilane coatings by wiping, the surface free energy is generally lowered from about 73
30 dynes/cm for the glass surface to about 12 dynes/cm for the perfluoroalkylalkyl silane treated glass surface. During this time, a solvent system with a constant surface tension of

about 20 to 70 dynes/cm shows initial wetting of the surface followed by de-wetting after the surface has been partially coated. Figure 1 illustrates that by choosing a solvent surface tension and moving from the x-axis upward, as the coating is applied and the surface free energy is lowered, the contact angle of the solvent on the coating increases.

Figure 2 illustrates more clearly that for a surface modified to be more repellent, fluids with surface tension greater than about 20 dynes/cm become repelled by the surface, while fluid with a surface tension of about 15 dynes/cm still have a low contact angle. Higher contact angles reduce the evaporation rate of solvents due to "beading up" which reduces the surface area of the drop which, in turn, reduces the evaporation rate of the solvent. Also, as the solvent beads, the surface repels the solvent more, which allows a paper towel to remove the solvent cleanly from the surface.

The present invention will be further understood from the descriptions of specific examples which follow.

EXAMPLE 1

A first coating solution is prepared comprising 1.2 percent by weight perfluoroalkylethyltrichlorosilanes, wherein the alkyl comprises primarily C₆ to C₁₈ chain lengths, in a solvent system comprising equal weights of Freon[®] TF trichlorotrifluoroethane (Freon is a registered trademark of DuPont) and hexadecane. A second coating solution is prepared as above except that the solvent consists entirely of Freon TF. These two solutions were used to render float glass samples water repellent by a simple wiping procedure. During application of the two solutions, the second coating solution wiped onto the glass surface like wax, and left a film of excess material, while the first coating solution, within a

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short time of application, was repelled from the treated surface sufficiently to cause the solution to "bead up"; the hexadecane did not readily evaporate due to its high boiling point. The "beaded up" first solution was readily removed by simple wiping. Removal of the excess material from the second coating solution required solvent, extra towels and considerable buffing effort.

The surface treated glass coupons were exposed to condensing humidity in the Cleveland Condensing Cabinet (CCC), constantly condensing water vapor at 140°F (60°C). The efficiency of the treatment is measured by the contact angle formed by a drop of water on the surface. The results are reported in the following table.

CCC (hours)	Contact Angle (°)	
	First Solution	Second Solution
0	103	105
48	106	103
119	109	107
377	112	110
544	106	107
783	98	102
948	81	89
1138	75	82

15

The above results indicate similar durability of the coating provided by the two formulations. However, the first solution was significantly easier to apply due to the repellent nature of the treated surface once the low surface tension, low boiling component (Freon TF) evaporated.

20

EXAMPLE 2

Several glass coupons were coated with coating solutions to render the glass hydrophobic. Each coating

solution was based upon the same perfluoroalkylethyltrichlorosilanes as used in Example 1, but solvents and concentrations were varied. Some of the samples were weathered in outdoor Pittsburgh exposure inclined 45° to horizon, facing south. The treated coupons were evaluated by the contact angles of various solvents on these treated surfaces. The surface free energy (SFE) was calculated by the use of the contact angles of methylene iodide and water for each glass surface, as described by Owens and Wendt (J. Appl. Poly. Sci. 1969, 13, 1741). The most repellent treated surfaces are those represented by low surface free energies, such as 12.6 dynes/cm. The most weathered treated surface has the highest surface free energy, 47.3 dynes/cm; this treated surface is still significantly repellent to water, exhibiting a contact angle of 56°. The contact angle data are illustrated in Figures 1 and 2.

EXAMPLE 3

Four solutions were prepared as follows. Solution A was prepared by dissolving 0.5 weight percent each of silicon tetrachloride and perfluorooctylethyltrichlorosilane in Isopar L solvent, a mixture of hydrocarbons available from Exxon Corp., which has a surface tension of 25.9 dynes/cm and a boiling temperature range of 191 to 207°C. Solution B was prepared by dissolving 0.5 weight percent each of silicon tetrachloride and perfluorooctylethyltrichlorosilane in FluorinertTM FC-77, a fluorinated solvent available from 3M Corp., which has a surface tension of 15.0 dynes/cm and a boiling point of 97°C. Solution C was prepared by dissolving 0.5 weight percent perfluorooctylethyltrichlorosilane in IsoparTM L, and Solution D was prepared by dissolving 0.5 weight percent perfluorooctylethyltrichlorosilane in FluorinertTM FC-

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77. Each solution was wiped on glass coupons, which had been polished with an alumina polishing agent to obtain a clean surface, at 63°F (17°C) and approximately 70 percent relative humidity. The amount of haze was measured with a Pacific Scientific XL211 Hazegard System. Haze levels of 0.0 to 0.1 percent are generally not observable with the unaided eye, and treated substrates with this level of haze can be considered clear for normal viewing purposes. The haze values of glass treated with the four solutions are listed below:

10

Solution	SiCl ₄ (weight %)	C ₈ F ₁₇ C ₂ H ₄ SiCl ₃ TM (weight %)	Solvent (weight %)	Solvent	Haze (%)
A	0.5	0.5	99	Isopar L	0.1
B	0.5	0.5	99	FC-77	8.1
C	0	0.5	99.5	Isopar L	0.0
D	0	0.5	99.5	FC-77	11.8

As can be seen from the above data, solutions B and D which used low boiling point fluorocarbon solvent (Fluorinert FC-77) had significant haze levels, while solutions A and C which used high boiling point hydrocarbon solvent (Isopar L) did not. The higher boiling point and higher surface tension of the hydrocarbon solvent (Isopar L) resulted in this significant difference in haze.

20

EXAMPLE 4

A solution was prepared comprising 99 grams of high boiling point hydrocarbon solvent (Isopar L), 0.5 grams of thionyl chloride (SOCl₂), and 0.5 grams of perfluoroalkylethyl-trichlorosilanes, wherein the perfluoroalkyl moiety comprises primarily C₆F₁₃ to C₁₈F₃₇. This solution was used to render float glass water repellent by a simple wiping procedure. During application of the solution, the solution was repelled sufficiently to cause the solution to "bead up" and be easily

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removed from the surface without deposition of observable excess siloxane material. The thionyl chloride was used to dry the hydrocarbon solvent. The surface treated glass coupons were exposed to condensing humidity in the Cleveland
 5 Condensing Cabinet (CCC), constantly condensing water vapor at 140°F (60°C), and also exposed to cyclic UV light and humidity in a QUV Tester, with cycles of 8 hours UV at low relative humidity at a black panel temperature of 65°C followed by 4
 10 hours of near 100 percent relative humidity at 50°C. The efficiency of the perfluoroalkylalkyl silane surface treatment is measured by the contact angle formed by a drop of water on the treated substrate surface. The results are reported in the following table:

CCC Exposure (hours)	Contact Angle (°)	
	Tin Surface	Atmosphere Surface
0	117	117
188	80	86
355	72	76

15

QUVB-313 Exposure (hours)	Contact Angle (°)	
	Tin Surface	Atmosphere Surface
0	118	118
185	109	114
351	101	113

The above examples are offered to illustrate the present invention. Various perfluoroalkylalkyl silanes, organosilanes, solvents and concentrations may be applied by
 20 any conventional technique, and optionally cured at suitable temperatures for adequate times to provide durable non-wetting surfaces to any of a variety of glass and plastic substrates, as well as other inorganic surfaces such as metals, ceramics, enamels, and metal or metal oxide films. The treated
 25 substrates of the present invention are especially suitable in

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automobile and other vehicle, including aircraft, parts, as well as in building components, antireflective lenses and CRT cover plates.

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CLAIMS:

1. A method of producing a non-wetting surface on a substrate by contacting at ambient temperature the surface with a composition comprising:

(i) a perfluoroalkylalkyl silane selected from compounds having the general formula $R_mR'_nSiX_{4-m-n}$, wherein R is a perfluoroalkylalkyl radical, R' is an alkyl or vinyl radical, m is 1, n is 0 or 1, and X is selected from the group consisting of halogen, alkoxy and acyloxy radicals; and

(ii) at least, one aprotic solvent having a surface tension at least $5 \cdot 10^{-5}N$ (5 dynes) per centimeter higher than the surface free energy of the perfluoroalkylalkyl silane treated substrate surface and a boiling point of at least $65^\circ C$ and the solvent is selected from the group consisting of alkanes, alkenes, aromatic hydrocarbons, ethers, ketones, halogenated hydrocarbons, perfluorocarbons or mixtures thereof, and the solvent or one component of a solvent mixture at least one percent in concentration is of sufficiently high boiling point so as not to evaporate within about one minute after application of the composition, with the proviso that the solvent is not toluene,

until the treated surface becomes sufficiently non-wetting to repel the remaining composition and removing an excess of the composition and evaporating any remaining solvent.

2. The method of claim 1, wherein the perfluoroalkylalkyl silane is cured by heating the treated surface to a temperature of at least $66^\circ C$ ($150^\circ F$).

3. The method according to claim 1 or 2, wherein contacting and wetting of the substrate surface with the composition is done for 0.2 to 2 seconds to repel the remaining composition.

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4. The method according to claim 1, 2 or 3, wherein the perfluoroalkyl moiety of said perfluoroalkylalkyl radical of the silane is selected from the group consisting of CF_3 to $\text{C}_{30}\text{F}_{61}$.
5. The method according to claim 4, wherein said perfluoroalkyl moiety is selected from the group consisting of C_6F_{13} to $\text{C}_{18}\text{F}_{37}$.
6. The method according to claim 5, wherein said perfluoroalkyl moiety is selected from the group consisting of C_8F_{17} to $\text{C}_{12}\text{F}_{25}$.
7. The method according to any one of claims 1 to 6, wherein R' of the silane is selected from the group consisting of methyl, ethyl, vinyl and propyl.
8. The method of any one of claims 1 to 7, wherein X of the silane is selected from the group consisting of chloro, bromo, iodo, methoxy, ethoxy and acetoxy.
9. The method of any one of claims 1 to 8, wherein the composition further comprises a fully hydrolyzable organosilane capable of hydrolytic condensation to form a silica gel.

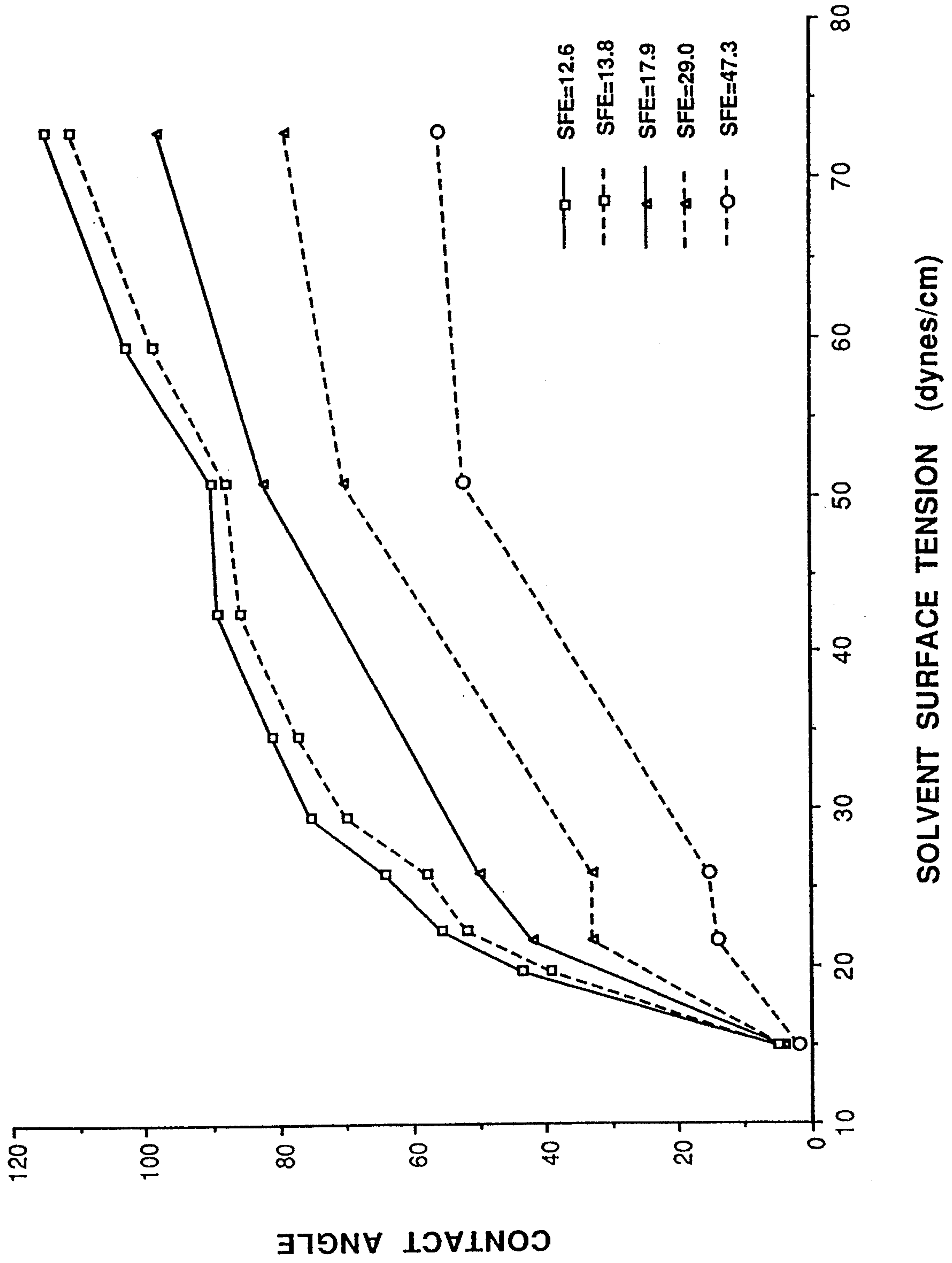
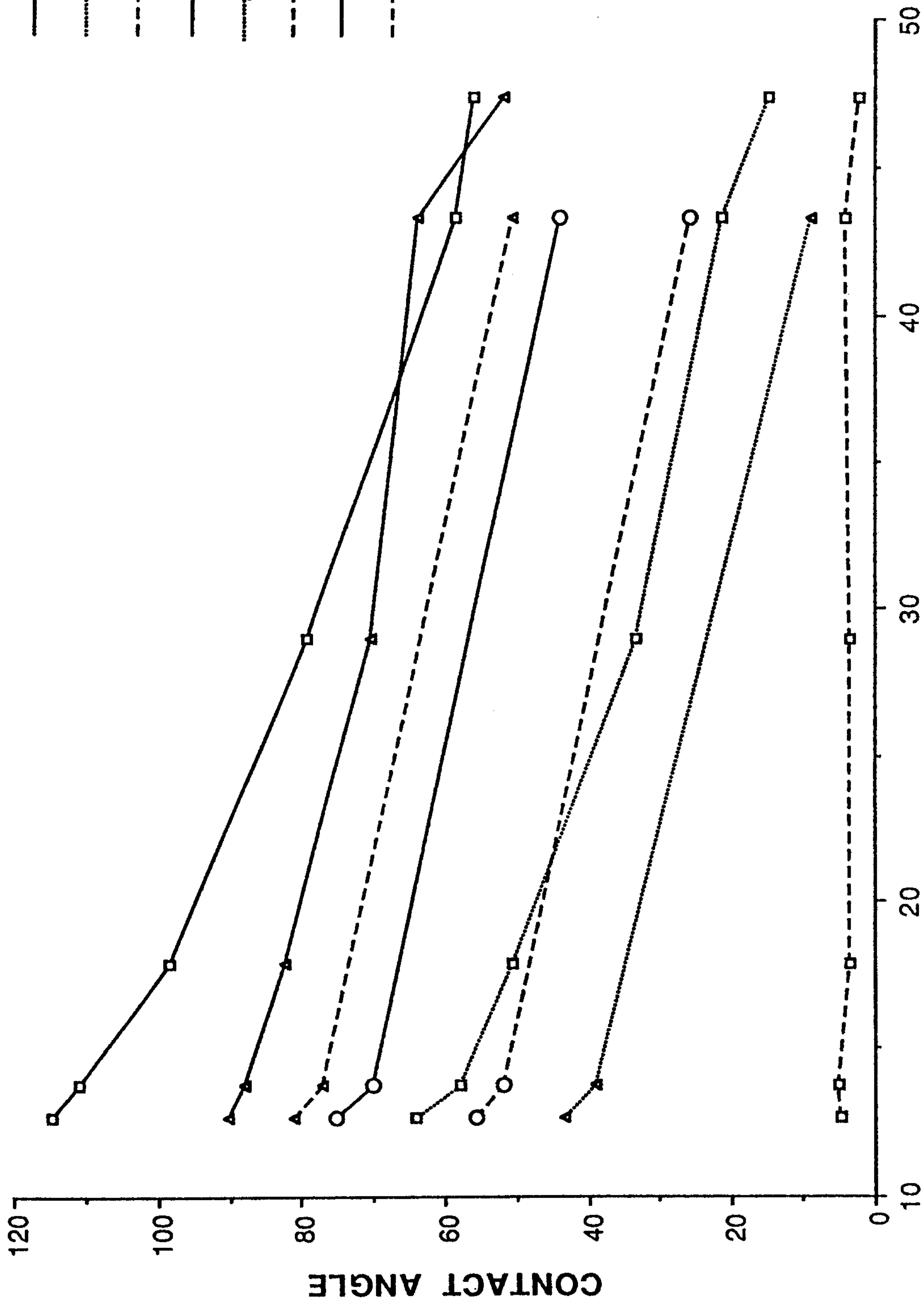


FIG.1



Fluid_surface_tension_(dynes/cm)

- Water (72.8)
-□..... Isopar L (25.9)
- - -□- - FC-77 (15.0)
- ▲— CH2I2 (50.8)
-▲..... Heptane (19.7)
- - -▲- - 46% Ethanol (34.7)
- 65% Ethanol (29.5)
- - -○- - Ethanol (22.3)



SURFACE FREE ENERGY (dynes/cm)

FIG. 2