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PROPERTIES AND APPLICATION OF PAINTS AND VARNISHES USED IN THE FURNITURE INDUSTRY*

by

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Introduction

The aim of any manufacturer is to make a profit.

These notes have been prepared to enable furniture makers to choose the right furniture finish (cost|quality compromise) and to use it in the right way to achieve a profit.

A few basic principles (theory) will be stated. Ignorance of these, negligence and short cuts, will result in substandard work, or even waste and unnecessary repairing, thus in loss of money.

To make a profit, we must know, we must even be alert since all things (although inanimate) around us react, degrade, break down. We must know the properties of the substrates we are going to coat and the properties of the coating we are using and how to use these delicately formulated coatings efficiently.

We shall consider the following substrates (building materials):
- wood and derivatives (plywood, particle board);
- steel - black, galvanized and phosphated;
- aluminium;
- G.R.P. (glass reinforced polyester) also known as "fibreglass".

Wood

Since time immemorial wood has been a readily available and renewable material. In the furniture industry solid wood has become a means of expression, a cultural affair with an important emotional aura. Certain pieces and certain styles have even become collection items of high value.

A wide range of species is used for furniture manufacture, each specie of wood having different characteristics. Generally and approximately wood consists of the following:

A. Cellulose and hemicellulose: 40-50 percent - fibrous structure of wood.

Lignin: 20-27 percent - polymeric binding material.

Protein: 0.2-0.5 percent

Mineral matter and salt: 1.0-5.0 percent.

Water: 25-35 percent.

Colorants (flavones and quinones)and tannins: less than one percent

B. Wood is a non uniform hygroscopic material, which shrinks and swells according to its water contents.

C. Wood is susceptible to attack by various chemicals: eg. solutions of nitric acid, nitrates, chlorates, alkalis, phenol, calcium and zinc salts, salts of strong bases and weak acids, sulphuric acids, alkaline detergents and soaps.

Wood is porous and even smooth surfaces are very irregular when viewed under magnification.

Wood is attacked by fungi and insects.

Wood is bleached by the sunlight's ultra violet rays.

Wood burns.

Moisture transfer

There are various methods of restricting the excessive transfer of moisture between the wood surface and the surroundings, and thus reducing excessive shrinking and swelling and even splitting. The method used in the furniture industry is application of a surface coating.

According to the exposure conditions and the type of wood, the coating (whether a varnish or a paint) will have some flexibility to accomodate micro-movements in the wood, and will form a film that is supposed to resist various chemical and physical constraints. Depending on the requirements, a wide variety of coatings can be used (cost/quality).

The pores in the wood can also be filled with correclty formulated wood fillers or sealers, or putties for larger cracks and holes. Again depending on the requirements, a wide variety of materials can be used.

Wood degradation by fungi and insects can be retarded or stopped by a number of methods.

B. S. Standards relative to wood preservation

B.S. 144-1973: Coal tar creosote for the preservation of timber.

B.S. 913-1973: Wood preservation by means of pressure creosoting.

B.S. 1282-1975: Guide to the choice, use and application of wood preservatives.

B.S. 3051-1972: Coal tar creosotes for wood preservation (other than creosotes to BS. 144).

B.S. 4072-1974: Wood preservation by means of water borne copper/chrome/arsenic compositions.

B.S. 3452-1962: Copper/chrome water borne wood preservatives and their application.

B.S. 3453 1962 (1979): Fluoride/arsenate/chromate/dinitrophenol water borne wood preservatives and their applications.

B.S. 5056 1974 (1979): Copper naphtenate wood preservatives.

B.S. 5707: Solutions of wood preservatives in organic solvents.

Part I (1979): Specification for solutions for general purpose applications including timber that is to be painted.

Part 2 (1979): Specification for pentachlorophenol wood preservative solution for use on timber that is not required to be painted.

Part 3 (1980): Methods of treatment.

Many are not suitable to the furniture industry. A few that are suitable are listed below:

(WB) Water borne preservatives: These are salt solutions used to impregnate dry wood under high pressure. They are generally colourless and odourless, they can be formulated to improve the fire resistance of wood. When dry, they can be painted or varnished. However, being water soluble, they are liable to be leached out of timber under wet conditions. Among these are:

Copper/chrome salts
Tanalith process
BM process
Copper/chrome/zinc chloride process

(DS) Preservatives carried by organic solvents: Zinc naphtenate, copper naphtenate, pentachlorophenol.

Various high remanancy modern insecticides and fungicides (similar to those used in agriculture). Chlorinated naphtalenes and other chlorinated hydrocarbons. These are usually applied by brushing or cold dipping. They do not render the timber more inflammable than it originally was. Also there exist insecticidal paints and varnishes of various composition which, apart from protecting the wood from insect attack, kill by contact all insects which may walk on the surface. These products remain active for at least three years and should find application for interior coatings of furniture.

Fire

The resistance of wood to fire can be greatly improved in two ways:

1. By incorporating salt such as ammonium phosphate in the pressure impregnation process used to render the wood resistant to insects and fungi using water borne preservatives.
2. By using fire resisting and/or fire reacting intumescent paints and varnish. A number of brands are available on the international market.

The following standards, though they refer to tests on buildings and constructions, may also, if necessary, be used as guidelines if fire resistance of various pieces of furniture need to be assessed:

-ANSI/ASTM E 119-76: Standard methods of fire tests of building construction and materials.

-B.S. 476: Fire tests on building materials and structures.

Also in the French Legislation, there are two books worth mentioning in respect of safety against fire. Those are published by the "Journal Officiel de la République Française" 26, rue Desaix, 75727 Paris Cedex 15. Their respective titles are:

Sécurité contre l'incendie - Etablissement recevant du public.

Sécurité contre l'incendie - Législation et règlementation générales - Immeubles de grande hauteur - bâtiments d'habitation - établissement industriels et commerciaux divers.

Steel

The backbone of today's world, available in so many alloys, is unfortunately a non-renewable resource, which does not grow back like trees. It has got superb qualities but one main defect. It rusts, to achieve its original form of iron oxides and hydroxides.

For furniture, mild steel (carbon content below 0.2%) is mainly used in the form of sheets and tubes of various sections.

These can be protected from rusting in different ways, a few of which are listed below:

1. galvanizing
2. phosphating
3. application of surface coatings of a wide range of types by a wide range of methods.
4. chrome plating.

Methods 1 and 3 as well as 2 and 3 above can be combined to achieve a better protective/decorative aim.

As far as furniture is concerned, steel does not carry the same emotional connotation as wood and it is mainly used for furniture of the office type. In this context, and also because of its intrinsic structure, steel is a material much more easy to coat and protect than wood, as long as one bears in mind that the two main sources of corrosion are water and oxygen. Contact of the unprotected steel with these two must be avoided. Under special conditions steel furniture may be in contact with highly corrosive chemicals other than or in addition to water and oxygen. Special coatings can be formulated to protect steel under these specific conditions.

When steel (or iron) is placed in contact with water (containing dissolved salts) in the presence of another metal, an electrolytic cell is immediately formed. According to the electrode potential of the respective metals, one will become the anode and the other the cathode. Electrons will flow (from the anode to the cathode) and the anode will be corroded away.

In practice, the electrode potential of iron is -0,44 volt while that of mill scale is +0,3 volt. This means that in the presence of an electrolyte, an electrolytic corrosion cell will be formed whereby the iron will become the anode and the mill scale the cathode (electron acceptor). Thus the iron will corrode away (liberation of Fe^{++} ions) to form various oxides and hydroxides (rust).

The electrochemical or electromotive series of element expresses the electrode potential of various elements with respect to the hydrogen ion H^+. According to this classification, when any two elements will be placed in an electrolyte, the one element with the more negative electrode potential is the anode and goes into solution (is corroded away).

Element (ion)	Normal Electrode potential
Mg^{++} (Magnesium)	- 2,27
Al^{+++} (Aluminium)	- 1,76
Zn^{++} (Zinc)	- 0,76
Cr^{++} (Chromium)	- 0,60
Fe^{+++} (Iron)	- 0,44
Ni^{++} (Nickel)	- 0,22
Pb^{+++} (Lead)	- 0,12
H^{+} (Hydrogen)	0,00
Cu^{++} (Copper)	+ 0,34
Ag^{+} (Silver)	+ 0,80
Au^{+} (Gold)	+ 1,50

However, the galvanic series reproduced below is a more practical way of determining which material will be corroded away when placed in contact with another material in an electrolyte.

Corroded end (anodic or least noble)
Magnesium
Magnesium alloys
Zinc
Aluminium
Cadmium
Steel and Iron
Cast Iron
Chromium Iron (active)*
18/8 Chromium/Nickel/Iron (active)
18/8/3 Chromium/Nickel/Molybdenum/Iron (active)
Lead/tin solders
Lead
Tin
Nickel (active)
Inconel (active)
Brasses
Copper
Bronzes
Copper/Nickel alloys
Monel metal 60 Nickel/30 Copper
Silver Solder

Nickel (passive)**
Inconel (passive)
Chromium/Iron (passive)
18/8 Chromium/Nickel/Iron (passive)
18/8/3 Chromium/Nickel/Molybdenum/Iron (passive)
Silver
Graphite
Gold
Platinum
Protected end (cathodic or most noble)

N.B. *Activity (active)

A metal which has not received the passivation treatment.

**Passivity (passive)

A condition in which a ferrous self repairing oxide film protects the metal from further corrosion.

A property shown by iron, chromium and related metals, involving loss of their normal chemical activity in an electrochemical system or in a corrosive environment after treatment with strong oxidizing agents like nitric acid and when oxygen is evolved upon them during electrolysis, forming an oxide coating.

Galvanizing of steel

Galvanizing is a process whereby Zinc metal is deposited on the cleaned steel surface.

Zinc is less noble (more electronegative) than iron or steel; when both metals are in contact with an electrolyte the zinc becomes the anode while the steel is the cathode. Thus zinc corrodes away instead of the steel which is thus sacrificially protected by the zinc.

The following British Standards refer to galvanizing of various steel articles:

B.S. 2989-1982: Specification for continuously hot dip-zinc coated and iron, zinc alloy coated steel; wide strip, sheet/place and slit wide strip.

B.S. 3083-1980: Specification for hot dip zinc coated corrugated steel sheets for general purposes.

B.S. 729-1971: Hot dip galvanized coatings on iron and steel articles.
B.S. 443-1982: Specifications for testing zinc coatings on steel wire and for quality requirements.

For additional protection, the galvanized surface is usually coated with a paint system consisting of a primer/undercoat and finish coat. Depending on the requirements, many sorts of coating (more or less durable) can be formulated. However, after degreasing, etching, and washing, it is usual to apply a two pack etch primer (or wash primer) on the dry and clean surface to achieve good adhesion of the subsequent primer/finish coats.

Phosphating

The principle of phosphating is that the surface of a steel part becomes coated with a ferrous phosphate layer after immersion in a dilute phosphoric acid solution.

Of course, the chemistry and the practical application are much more involved. Depending on the type of steel used and the end product required, a large number of process and different phosphating baths or solutions are available.

Generally, the phosphate coating has found two major applications:

1. As a paint base to increase paint adhesion and fight corrosion;
2. To facilitate cold forming of metals (like a lubricating layer).

Phosphatinc can usually be classified as 'thin' or 'thick' coat. These processes are described in the flow charts indicated in Figs. 1 and 2 hereunder.

The British Standard with reference to phosphating is:

B.S. 3189-1973: Phosphate treatment of iron and steel.

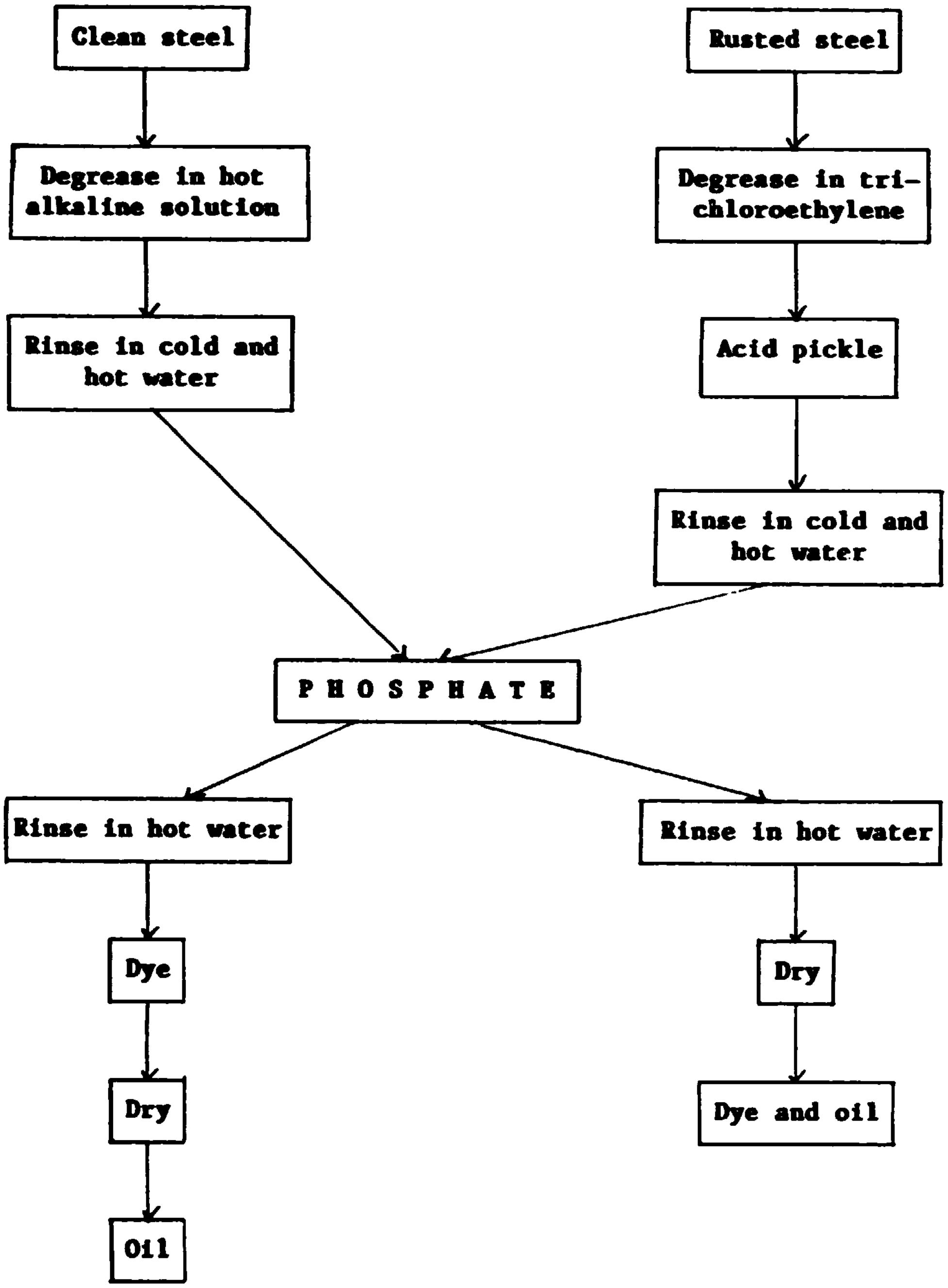


Fig. 1: Thin coat phosphating (suitable for overpainting).

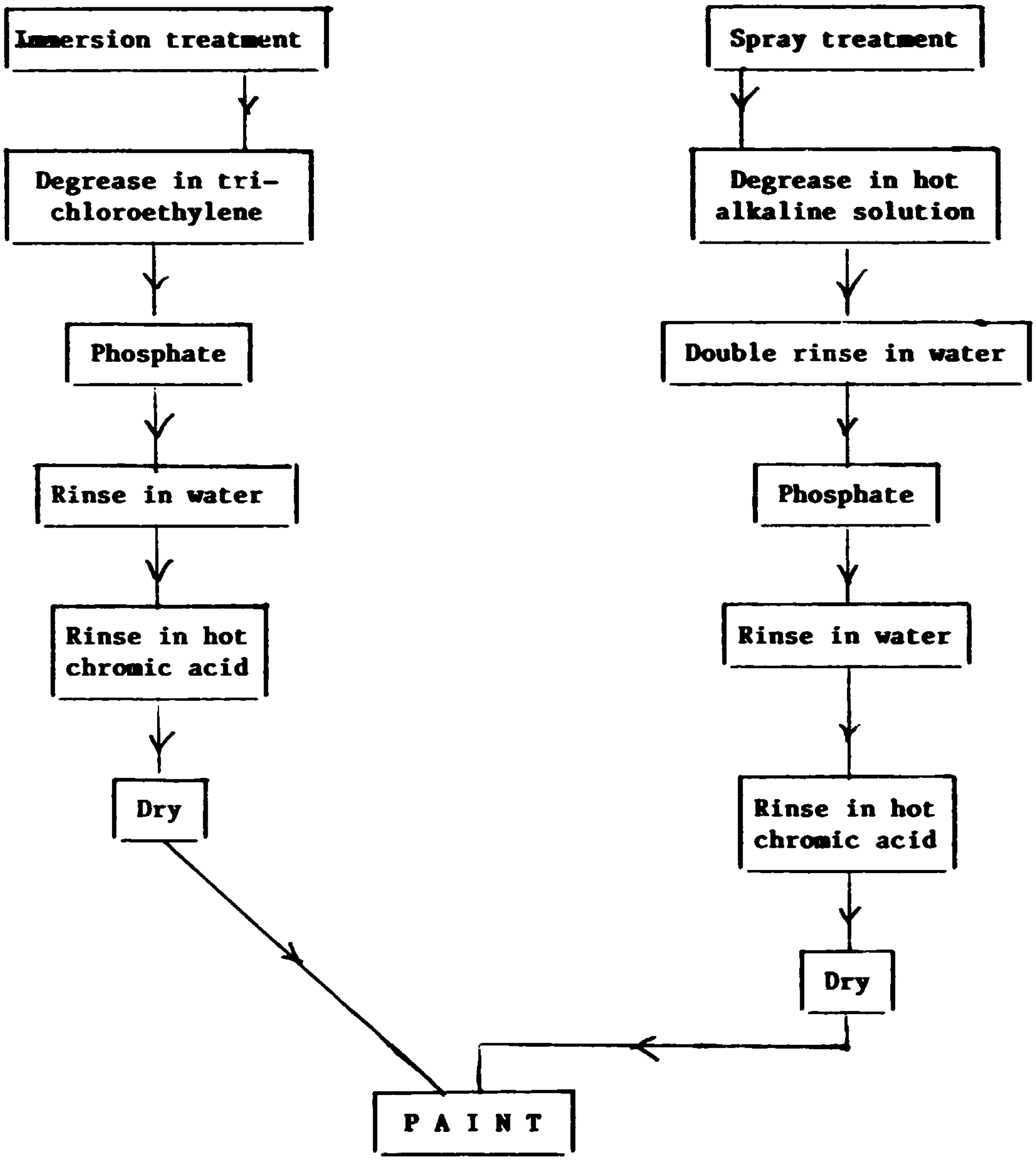


Fig. 2: Thin coat phosphating (suitable for overpainting).

Aluminium

One of the most widespread elements on earth (but unfortunately not widely available in easily extractable forms) is now available in a multitude of metallic alloys. Pure aluminium forms a protective aluminium oxide (Al_2O_3) layer under the action of oxygen.

Before application of a paint coating aluminium surfaces need to be cleaned. This is generally performed using chlorinated solvents such as methylene chloride or perchloroethylene. The surface can be etched with dilute sodium hydroxide solution, followed by acid neutralization and washing with water. Specific methods of degreasing and etching are recommended for specific alloys.

To achieve optimum adhesion, a two pack etch primer (or wash primer) is usually applied as a first thin, adhesion promoting coat. This is usually based on a polyvinyl butyral|phenolic resin blend with zinc tretraoxychromate as pigment and a phosphoric acid solution as catalyst. A wide variety of coatings can be applied on the cured primer. However, these coatings should be formulated to be somewhat flexible since the linear coefficient of thermal expansion of aluminium is of the order of $2.40 \times 10^{-5}\ {}^{o}C^{-1}$.

The coatings applied on the aluminium can be based on the following systems among others, thermosetting (convertible) or thermoplastic (non convertible) acrylic resins, polyurethanes, vinyls, alkyd|melamine combinations, alkyd|nitrocellulose combinations, chlorinated rubber.

Apart from application of a surface coating, aluminium surfaces can be anodized or electroplated.

Anodizing is a treatment whereby a relatively thick, hard, strongly adhering and protective coat of aluminium oxide is produced on the surface of the aluminium. The anodized aluminium can be overpainted if necessary.

Electroplating: Aluminium is sometimes plated with nickel or chromium. This is usually carried out in five steps:

1. degreasing
2. electrolytic cleaning
3. formation of undercoat
4. electroplating
5. polishing.

The following British Standards refer to aluminium and the various methods of protecting the metal:

B.S. 1615-1972: Anodic oxidation coatings on aluminium.

B.S. 3987-1974: Anodic oxide coatings on wrought aluminium for external architectural applications.

B.S. 5599-1978: Specifications for hard anodic oxide coatings on aluminium for engineering purposes.

B.S. 6161-1981|82 (parts 1-8): Methods of tests for anodic oxidation coatings on aluminium and its allows.

Glass reinforced polyester (G.R.P.)

This material consists of a plastic binder (an unsaturated polyester resin in a liquid form that may be pigmented to various shades) which is moulded with glass fibres in the form of 'mat' or 'roving cloth' of various characteristics). The curing is triggered by a catalyst such as Methylethyl Ketone peroxide (MEKP) and is accelerated by heat.

The fibres act as a reinforcement for the resin, which, when cured, produces a very hard, long-lasting and chemical resistant surface.

The combination of polyester resin and glass fibre reinforcement is used to manufacture boats, roofing sheets, aeroplane parts, storage tanks and pipes for water, petrol and various chemicals, electronic equipment, car bodies, and domestic articles such as motorcycle crash helmets and furniture such as tables, chairs, pots of various sizes and shapes and 'synthetic marble' sanitary ware and bathroom fixtures.

Furniture is usually made using moulds which need to be coated with a mould release agent to allow the piece to be removed after the initial curing.

The polyester resincan be already pigmented to the required colour before moulding so that the article already has the required colour built in from the mould. Otherwise, it will have to be painted

Before painting a new G.R.P. piece of furniture, the mould release agent has to be removed. This is done using any proprietary detergent composition combined with sanding with grade 300 paper.

After this sanding and washing operation an adhesion primer (which tends to bite into the polyester resin) is used, followed by a finishing system based on a two pack polyurethane or a one pack car refinishing enamel such as those based on a combination of nitrocellulose and so called synthetic resins (which can be a variety of short oil alkyd resins).

Also, after a few years of use, the G.R.P. furniture, if left outdoors (as may be the case for garden or beach furniture) will tarnish, its gloss will decrease and dents and scratches resulting from mechanical damage will need to be repaired.

Larger dents and cracks can be repaired with the original unsatured polyester resin (or a similar one) or using polyester car repair putty, or even two component epoxy putties.

In any case, before repairing the surface, loose and broken bits and pieces should be removed and the surface should be dry and clean before applying the putty or resin.

After the structural repairs the surface is smoothed down to its original contour. Surface preparation and painting are then carried on as for any new G.R.P. surface.

If only minor scratches are present, these can be repaired using car repair one pack 'nitroputty', followed by the usual surface preparation and painting systems.

Always ensure that the putties and fillers are well cured before painting, otherwise the paint may attack the fresh putty and filler and cause unsightly wrinkles in the surface thus ruining the purpose of the repair job.

One pack 'nitroputties' are not meant to be applied in thick film since thy may shrink on drying, or when the piece of furniture is exposed to the sun. This shrinkage can be explained by the fact that 'one pack nitroputties' contain 10 - 15% solvent. This will be entrapped in thick coats and will eventually tend to go out when the article is exposed to the sun thus causing a shrinkage in volume in the putty. As a rule 'nitroputty' should not be applied in coats more than one millimetre thick.

Composition of polyester resin

An unsaturated polyester resin is the reaction product of polyhydric alcohols with a mixture of unsaturated dibasic acids or acids anhydrides.

Typical raw materials for general purpose polyester resin are as follows:

Typical raw materials for general purpose polyester resin are as follows:

A.	Propylene glycol	29.2	Alcohol
	[Maleic anhydride	22.8	Acid
	[Phthalic anhydride	17.2	Acid
B.	Styrene monomer	30.8	Reactive diluent containing stabilizers to achieve storage stability.

Part A is the reaction mixture from which the resin is cooked in a reaction vessel, the finished resin is then diluted with the styrene (Part B) to achieve the required viscosity and solid content for delivery.

During the curing procedure using a peroxide catalyst and an accelerator such as cobalt octoacte the styrene polymerises with the unsaturated polyester to yield the hard brittle and chemical resistant binder.

On curing a pure resin shrinks 5-8% depending on the type of resin and original solid percentage. The incorporation of pigments and extenders and the presence of the glass fibre reinforcement reduce the shrinkage. It should be noted that the curing of the polyester resins dissipates heat (exothermic reaction).

Typical physical properties of a glass mat laminate (glass content 30%) using a **general purpose unsaturated polyester resin** is as follows:

Tensile strength N|mm^2	110
Flexural strength N/mm^2	210
Modulus of elasticity in tension N/mm^2	9800

Composition of glass fibres

Glass fibre is made from molten glass of definite composition. The molten glass is quickly pulled into filaments and cooled.

These filaments, of diameter 5-20 micron, received a protective coating (binder) which tends to keep the filaments together in the strands and help the wetting of the glass by the resin.

Glass fibre possesses outstanding physical properties such as:

Tensile strength	175 - 280 N/mm^2
Modulus of elasticity	7000 N/mm^2
Density	2.55 g/mm^3

The strands can be assembled in various arrangements such as 'mat' and 'roving cloth'.

Mat : The strands are cut at length of 25-50 mm and randomly packed together. They are kept stuck by a binder which is soluble in the polyester resin.

Mats are described by their mass per metre square such as: 300, 450, 600, g/m^2

Roving cloth: The strands are woven in a uniform square pattern. The usual mass per square meter are: 300, 500 and 800 grammes.

Coating: General composition and main components with reference to the furniture industry

Now that we have briefly examined the substrates to be coated (the materials used to manufacture various pieces of furniture) we shall have a quick look at what is: a paint, a lacquer, a varnish, a primer, an undercoat, a filler, a stopper, a putty, a sealer, a dye, a stain and a thinner.

We shall glance through their constituents and we shall explain the main characteristics of a coating such as: solid content, adhesion, flexibility, drying (or curing), hardness, gloss, opacity, colour, sandability, chemical resistance, abrasion and impact resistance, resistance to weathering, compatibility amongst coatings systems.

Generally speaking, a coating consists of the following basic constituents:

Binders:

Also known as film formers, polymer resin, plastic material. These are the basic constituent of a coating and are responsible for adhesion, flexibility, gloss, imperviousness, resistance to all sorts of weathering conditions, see figs. 3, 4 and 5. Binders are available in solid and liquid form. They can be natural or synthetic in origin.

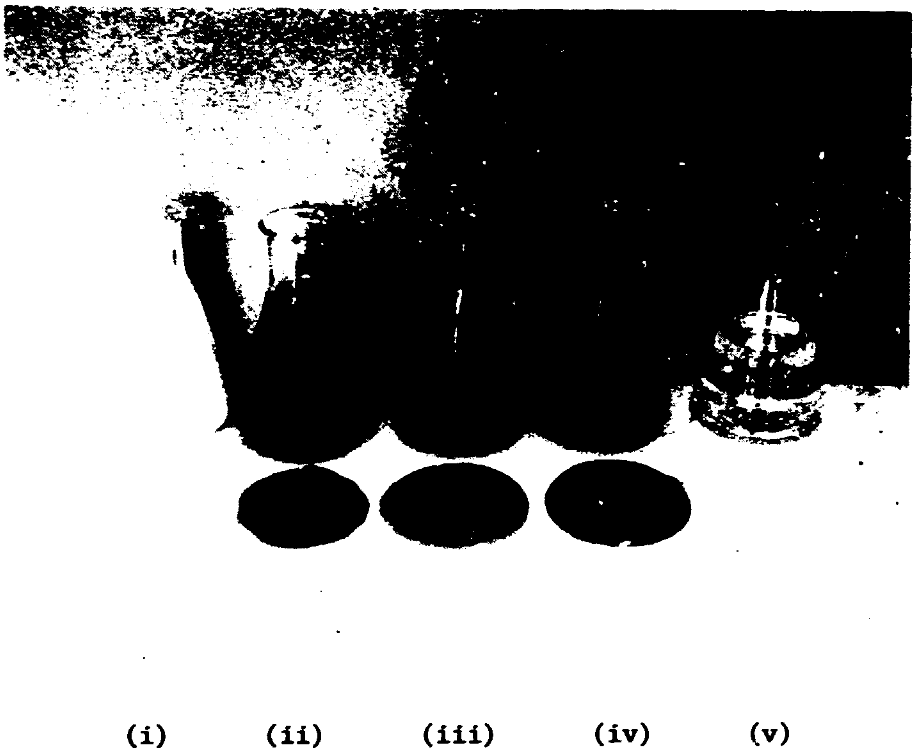


Fig. 3

Legend: (i) PVA/Acrylic dispersion (emulsion) in water, with water milky appearance. Used for water based paints.

(ii) Raw soya oil, as used in manufacture of long oil alkyd resins by the alcoholysis process (semi drying oil).

(iii) Boiled linseed oil (drying oil) - can be used in the manufacture of various oil based paints and primers - slow drying, soft film, which yellows.

(iv) Long oil alkyd resin for manufacture of primers.

(v) water white melamine resin as used in acid catalysed varnishes or baking enamels.

Fig. 4: Some binders in solid form.

Fig. 5: Some binders in solid form.

Plasticizers:

These are flexible or soft binders used to modify the flexibility and adhesion characteristics of a binder. They are available in either liquid or solid form.

Solvents:

These are used to dissolve solid resins or to dilute (reduce the viscosity of) highly viscous liquid resins. They are usually considered as the volatile part of the coating. They are compatible with the binder and are specific to certain binders (see figs. 6, 7 and 8). Apart from water and a few chlorinated solvents such as methylene chloride all solvents are inflammable. Also they are usually more or less toxic being narcotic (central nervous system depressant). Benzene (C_6H_6) has been classified as carcinogenic.

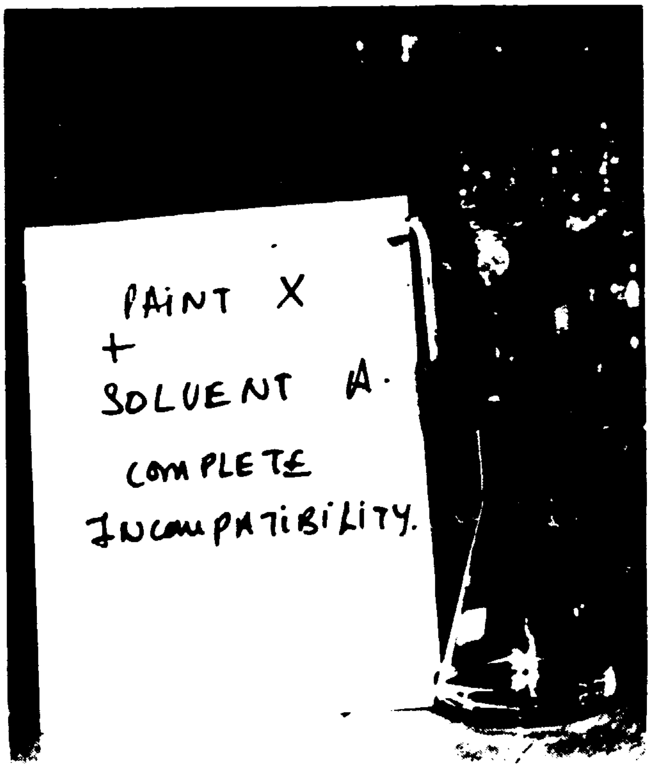


Fig. 6: Demonstration of paint to solvent incompatibility or compatibility

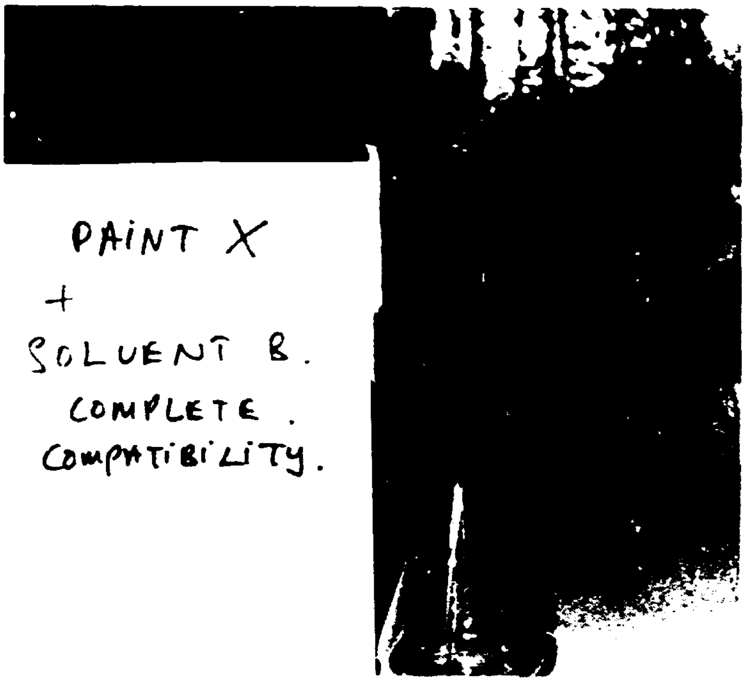


Fig. 7: Demonstration of paint to solvent incompatibility.

Fig. 8: Demonstration of paint to solvent compatibility.

Pigments:

These are coloured powders and are designed to be insoluble in the resin or resin/solvent solution in which they are dispersed (not dissolved). They confer colour and opacity to coatings. They tend to protect the resin component from the degradative influence of ultraviolet radiation (from sunlight). They can also confer specific properties to the coating, an example being the anticorrosive pigments (see Fig. 9).

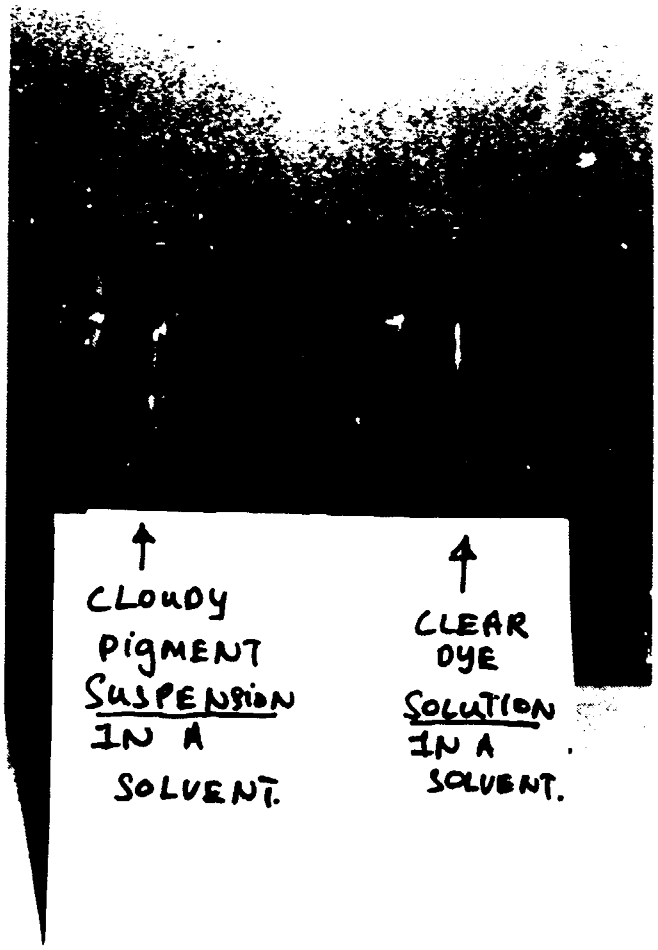


Fig. 9: Comparison between a pigment and a dye.

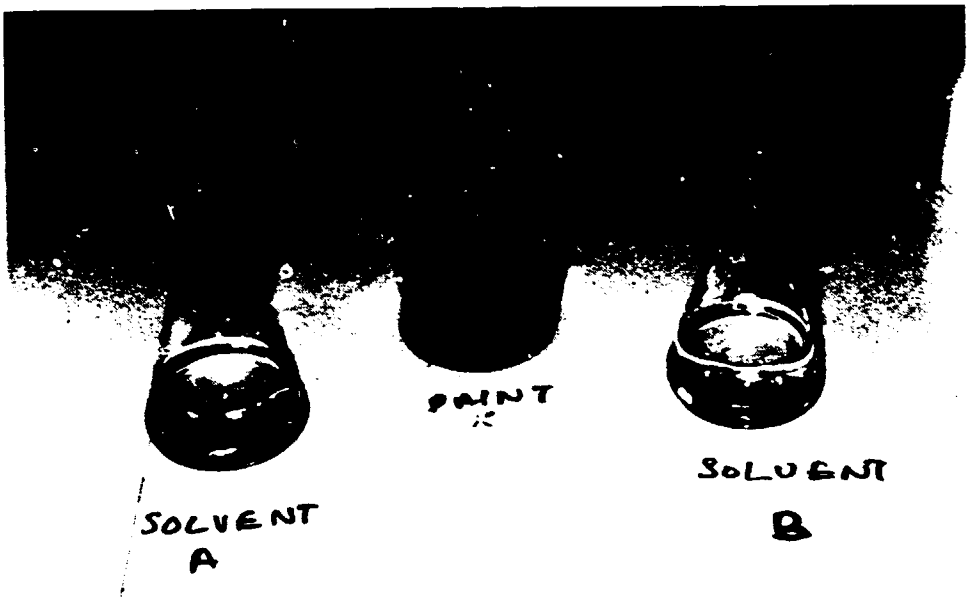


Fig. 10: Incorporating pigment in a resin solution using a cowles types dissolver.

Dyes:

These are coloured powders which are soluble in the resin or resin/ solvent or in water. Like the pigments they provide colour and usually because of their high transparency they are used to stain wood. They also tend to protect the binder from degradation and influence of ultra violet radiation.

Extenders:

These are powders which are insoluble in the resin or resin/solvent solution in which they are dispersed. They provide very little opacity to the system and they are used to modify certain properties of the coatings or to reduce cost. They are usually whitish powders.

Additives:

These are special chemicals which, when added in small amounts, (micro components) to a coating formulation have an important effect on the coating characteristics.

Binders:

These consist of a wide range of chemical families and thus have a wide range of properties. Various binders of different chemical families are compatible with each other and blends are often formulated to obtain intermediate properties.

However, binders can be classified into two broad groups according to thier curing (or drying) mechanism.

Group A - convertible binder (usually thermosetting)

These change in chemical composition when they cure. In the case of binders in solution, the curing mechanism renders them insoluble in their original solvent.

Examples are: two component epoxies, two component polyurethanes, air drying alkyds, unsaturated polyester, urea, melamine and benzoguamine/formaldehyde in combination with various other resins such as epoxies and alkyds, various acrylics, drying oils such as linseed, fish, tung, one pack polyurethane, epoxy esters modified alkyds.

Group B - non-convertible binders (usually thermoplastic)

These cure mainly by solvent evaporation and/or coalescence, without any chemical reaction taking place. Thus they keep their original chemical structure and remain soluble in their original solvent. They are said to dry physically. Heat will speed the rate of solvent evaporation and will thus shorten the drying time.

Examples are: chlorinated rubber, nitrocellulose resins, cellulose acetate buyrate (CAB), cellulose acetate proprionate (CAP), vinyl resins, thermoplastic acrylics, bitumen and tars, and coalescence (eg. polyvinyl acetate - PVA - dispersions, PVA/acrylic dispersions among others), waxes, shellac, coumarone resins, manillagum and damar.

Group A - convertible binder (and thus convertible coatings of which the form the basis)

These can cure by a large number of methods depending on their chemical constitution. In fact the same binder can be cured by different methods to yield the same end product, or a specific binder can be made tc yield very different end products by reacting with different reaction partners.

For a given binder (or coating) the curing method usually depends on the rate of production and manufacturing method of a given object. The reaction partner (thus formulation of the coatings) depends not only on the rate of production and manufacturing method but also on cost/quality compromise. Thus, various binders can be mixed or blended to formulate a coating adapted to the application method and having specific characteristics when cured. Thus, according to their curing mechanism, (dictated by the production method) we shall draw an arbitrary classification of convertible coating based on convertible binders.

N.B. It should be noted that in certain cases, a convertible binder can be blended with non-convertible bindres to achieve certain desired properties. In these cases, the curing mechanism is both chemical (change of chemical structure) and physical (solvent evaporation).

General characteristics of each family

1. Binders (coatings) which cure by reaction with a hardener (reaction partner):

Examples are:

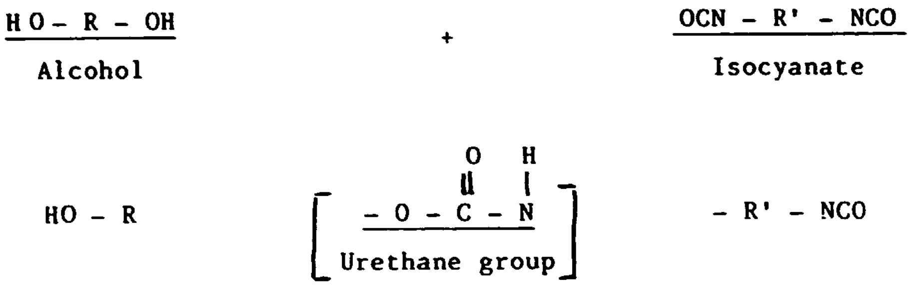
(i) Two-pack epoxies:

A usual reaction is between the terminal epoxide groups $(-\ \overbrace{CH - CH_2}^{O})$ in the epoxy resin and amine groups in polyamines and polyamido amides $(R - NH_2)$ and occurs at room temperature. This reaction is speeded up by increasing the temperature. Solvent free and solvent containing epoxy coatings are available to cure at room temperature.

(ii) Two-pack Urethanes:

A usual reaction is between the base resin which can be a polyalcohol which contains $-OH$ groups and the hardener (a polyisocyanate) which contains isocyanate groups. The reaction occurs at room temperature and is accelerated by heating.

Polyurethane curing reaction:



$$\underbrace{HO-R-OH}_{\text{Alcohol}} \quad + \quad \underbrace{OCN-R'-NCO}_{\text{Isocyanate}}$$

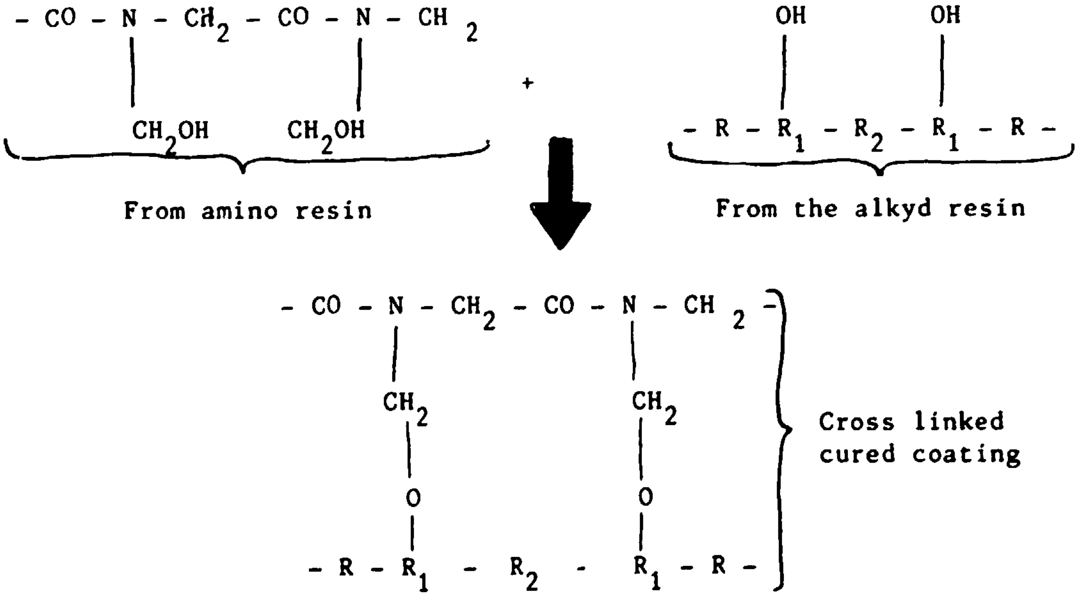
$$HO-R \quad \left[\underbrace{-O-\overset{\overset{O}{\|}}{C}-\overset{\overset{H}{|}}{N}}_{\text{Urethane group}}\right] \quad -R'-NCO$$

(iii)Two pack acrylics curing with isocyanates

2. **Reaction accelerated by a catalyst:**

(i) Acid catalysed varnishes and enamels:

These are based on urea formaldehyde or melamine formaldehyde resin plasticized by short oil, non-drying castor oil or coconut oil alkyds. The reaction occurs at room temperature in the presence of an acid catalyst such as an alcoholic solution of hydrochloric acid, or paratoluene sulphonic acid. The reaction (which can also take place at elevated temperature without catalyst) usually occurs between the methylol groups of the amino resins and residual hydroxyl groups in the alkyd resin.

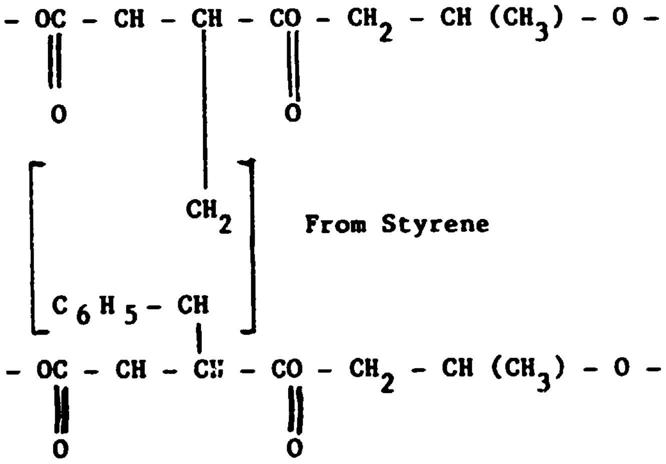


(ii) Unsaturated polyester fillers or coating

They are based on an unsaturated polyester resin which is the reaction product of unsaturated and saturated dibasic acids with polypols, (they are supplied as a solution in a monomer reactive diluant) such as styrene. The cross linking reaction can occur at room temperature when a catalyst (an initiator) and an accelerator are used. The reaction can also be carried out by ultra violet curing or electron beam curing.

The catalyst (an organic peroxide such as benzoyl peroxide or methyl ethyl ketone peroxide) initiate free radicals when heated to its critical temperature or when in contact with an accelerator such as cobalt napthenate.

The polyester then copolymenizes with the styrene monoer to yield a cross linked structure as indicated below.



(iii) Two pack etch (wash) primers

These are usually based on a blend of polyvinyl butural and resol phenolic resins together with appropriate pigments and solvents. The catalyst is a phosphoric acid solution in various solvents.

Because of the methylol groups ($-CH_2OH$) they contain, resol resins can be catalysed by acid at room temperature to form polycondensates. These resols also polymerize when baked at 150-200°C.

3. Binders which cure by oxidation

(Oxidative polymerization accelerated by catalyst usually called driers which are incorporated in the formulation and not mixed in prior to use.)

(i) Drying oils such as linseed, tung and fish.

(ii) Long oil and medium oil alkyds based on drying oils or unsaturated fatty acids.

(iii) Modified alkyds such as styrenated alkyds, silicone modified alkyds.

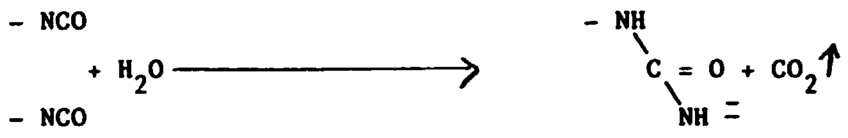
(iv) One pack epoxy esters.

(v) One pack oxidation drying polyurethanes.

The drying (polymerization) mechanism is explained by the hydroperoxide theory and the formation of free radical in the unsaturated fatty acid (except for conjugated fatty acids whose curing mechanism is via peroxide formation).

Binders which cure by reaction with ambient humidity

These are usually moisture cured 'polyurethane'. They consist of urethane prepolymers containing residual (excess), isocyanate groups which react with atmospheric humidity to cure as shown below:



$$\begin{array}{l}-NCO\\ \\ -NCO\end{array} + H_2O \longrightarrow \begin{array}{l}-NH\\ \quad C=O\\ \quad NH-\end{array} + CO_2\uparrow$$

Binders which cure under the action of heat (infra red radiation)

As we have seen, heat speeds up the rate of chemical reaction and the rate of solvent evaporation. Thus, most if not all coatings which cure at room temperature, would cure more rapidly if heated or warmed.

However, there are a few coatings which have been designed to cure only when heated. A few of these binder systems are listed below:

- Amino/alkyd combinations
- Amino/epoxy/alkyd combinations
- Phenolic (resol)/epoxy combination
- Epoxy/amino
- Epoxy/acrylics
- Amino/acrylic combination

- Thermosetting powder coatings/epoxy based (with a variety of curing agents such as cyanamides, acid anhydrides and both aromatic and aliphatic amines, epoxy/polyester blends, polyester/polyisocyanate.

These coatings are used in industry where continuous flow production exists.

For example: amino alkyd and amino acrylic are used in car finishes, Epoxy phenolic are used in inetrior drum and can coatings.
Epoxy/alkyd/amino used for domestic equipment and toys.
Acrylic/epoxy: domestic equipment and furniture.
Powder coatings: tubular furniture, industrial parts.
These powders contain the base resin and the hardener already intermixed in each powder grain. It is only when the powder is heated above a certain temperature that the reaction and curing takes place.

We shall not consider the individual reaction involved, nor the individual characteristics of these binder blends since so many combinations are possible to yield coatings with similar properties.

Ultra violet and electron beam curing

These high energy radiations shorten the curing time of convertible coatings considerably. Ultra violet is more common than electron beam curing.

Radiation of the order of 3000 to 4000 Ångstrom (10×10^{-10}m) is used to initiate free radical formation and thus polymerization in unsaturated polyester systems for wood coating. Thus an UV-cured system is mainly used with curtain coating application.

Electron beam curing has been used for curing unsaturated polyester coatings. It is faster than UV curing and permits line speeds in curtain coating of the order of 600 metres/minute. Like UV curing the process does not heat the substrate so that it is suitable for materials such as wool or wood derivatives which are sensitive to heat. The depth of penetration of the electron beams depends on the potential difference in the apparatus. This is of the order of 300 kV (300,000 V) and can be varied as necessary.

The reaction mechanism of the polyester curing is the same as that of catalytical cure at room temperature.

Group B: non-convertible binders

As we have seen these dry physically by solvent evaporation. Non convertible binders are often used in blend with convertible binders to achieve intermediate properties.

A few blends are:

Nitrocellulose/drying alkyd blends for furniture finishes.

Nitrocellulose/melamine/alkyd blend for acid catalysed furniture finishes or air drying car repair finishes.

Chlorinated rubber/drying alkyd blends for industrial maintenance paints.

Epoxy/tar combinations for industrial maintenance paints and marine coatings.

Plasticisers:

Examples are:

Various alkyds used to plasticize melamine resin, chlorinated rubber resins, nitrocellulose resins.

Chlorinated paraffins used in conjunction with chlorinated rubber resins.

Various esters such as dibutyl phtalate tricresyl phosphate used in conjunction with nitrocellulose.

Main groups of solvents used in coatings

Since solvents (thinners) are the only component (apart from hardeners and catalysts) which the user or applicator of a coating can add to the coating before its application, it is important that a few characteristics of more usual solvent be known, since adding the wrong solvent to a coating can completely ruin the product itself or cause early coating failure (breakdown).

Apart from its compatibility with the binder system - that is ability to dissolve or dilute a binder system (solvency)- other basic properties of solvents which must be known to users are evaporation rate, flash point and toxicity.

An important tool for choosing solvents that are compatible with the binder system is the solubility parameter concept, which is a numerical constant characteristic for each solvent and film forming material. To be of practical use the solubility parameter is linked to the degree of hydrogen bonding of the solvent and it has been found that a third dimension of solubility which is polarity or dipole moment (μ) helps to explain the solubility of a few more systems.

According to their hydrogen bonding, solvents can be grossly classified into the three following groups:

(1) Poorly hydrogen , includes aliphatic, aromatic, chlorinated and nitro hydrocarbons.

(2) Moderately hydrogen bonded , includes esters, ketones and ethers.

(3) Strongly hydrogen bonded,includes: alcohol, aminos, and acids.

Solubility parameters represent the force by which molecule solvent or a resin attract each other. Resins are dissolved by solvents whose solubility parameter are similar to their own, while they remain insoluble in solvents which have very different solubility parameters from their own.

Also substances that differ widely with respect to hydrogen bonding are immisible.

Finally, it has been found that solubility parameters and hydrogen bonding properties of mixtures of solvents are approximately proportional to the volume average of the components.

The following list mentions a few of the basic solvents used in paints and varnishes. However, since each coating manufacturer specifies special 'thinners' for their coatings the user should follow the respective manufacturer's recommendations and not try and prepare his own 'magic' solvent blend.

Alcohols

Methanol
Ethanol
Propanol
Butanol
Diacetone Alcohole

Esters

Ethyl acetate

Butyl Acetate

Ketones

Acetone

Methyl Ethyl Ketone

Methyl I.B.K. (Methyl iso butyl ketone)

Cyclohexanone

Isophorone

Chlorinated solvents

Methylene chloride

Perchloroethylene

Aromatic hydrocarbons

Toluol

Xylol

Styrene

Hydrocarbon solvent blends (both aromatic and aliphatic)

Various white spirits

Various Shellsols

Various Pegasols

Various Solvessos

Various Aromalsols

As determined by their boiling range. For aliphatic hydrocarbons their percentage of aromatics is stated.

Cycloaliphatic hydrocarbons

Cyclohexane

Miscellaneous solvents

Turpentine

Dipentine

Cellosolve

Cellosolve acetate

Polysolvan O

Texanol

Mono Ethylene Glycol

Butyl Diglycol

Tests on solvents

1. Boiling range (distillation range)
2. Refractive index
3. Flash point (various methods)
4. G.L.C. Analysis (gas/liquid/chromatograph analysis)
5. Aromatic content (for hydrocarbon solvents)
6. Water content (determination of water Karl Fischer method BS 2511-1970)
7. Specific gravity
8. Evaporation rate
9. Viscosity reduction power. Refers to the capacity of a solvent to dissolve various resins. For a given resin, at a given solution concentration and temperature the solvent which produces the lowest viscosity is the better solvent for that resin.
10. Copper corrosion test (to detect presence of sulphur in hydrocarbon solvents).

Pigments

They are an enormously large group of compounds with a wide range of composition and a wide range of characteristics. They are classified in the 'colour index' published by the Society of Dyers and Colourists with the collaboration of the American Association of Textile Chemists and Colourists.

For our use we should know that pigments can be simply classified as organic and inorganic.

Organic pigments are always synthetic, while inorganic pigments can be obtained from natural origin (although nowadays they are mostly synthetic).

Apart from their desired properties of colour, opacity and weather fastness, we should know that some pigments are toxic and that their use is restricted. Examples of toxic pigments are: those containing lead such as the lead chromates, white lead (basic lead carbonate), red lead (lead oxide) and calcium plumbate, the last two being used as anticorrosive pigments for metals.

When ingested, lead compounds accumulate in human beings and finally produce conditions known as 'peripheral neuropathy', whence the motor nerves of arms or legs are affected.

A few inorganic pigments of common use in paints are:

Titanium dioxide (white)
Lead chromates (lemon yellow, chrome yellow, oranges, yellowish red)
Iron oxides (brown, red, black, yellow)
Chrome oxides (dirty greyish green)
Molybdated lead chromates - solid solutions of lead molybdate, lead chromate and lead sulphate, molybdate orange (orange)
Cadmium pigments (yellow, orange, red to maroon)
(cadmium sulphide, cadmium sulphoselenide, cadmium mercurysulphide)
Various carbon blacks (various shades of black)
Micacious iron oxide

A few organic pigments of common use in paints are:

Azo yellow, red and violet of various shades, also a few blue, greens and browns.

Phthalocyamine blues and greens.

Toxicity of pigments

Apart from pigments containing lead, others such as antimony trioxide, and pigments containing heavy metals (eg. chrome) such as zinc chromate are also considered as toxic.

The purpose of mentioning the toxicity of pigments is that, for example, children's furniture should be coated with 'non-toxic' coatings so that in the event that part of the furniture is chewed and part of the coating swallowed no cumulative irreversible deleterious effect will be observed. It should be noted that all colours and shades are available with non-toxic pigments in non-toxic binders.

The British 'Toy (Safety)' Regulations of 1974 specifies the following maximum level of various heavy metals per million parts (ppm) of the dry paint film

METAL	PPM
Arsenic (soluble)	100
Lead (total)	2500 (0.25%)
Mercury (soluble)	100
Cadmium (soluble)	100
Chromium (soluble)	250
Antimony (soluble)	250
Barium (soluble)	500

The following pigments could be classified in either of the above two families but because of their specific use, we shall list them according to their uses:

Anticorrosive pigments: which actively take part in corrosion protection

1. Red lead (for iron and steel).
2. Calcium plumbate (for iron and steel) including galvanized surfaces.
3. Zinc chromate (for iron and steel) including galvanized surfaces.
4. Zinc phosphate (for iron and steel) including galvanized surfaces.
5. Metallic zinc dust (for iron and steel) inlcuding galvanized surfaces.

Metallic pigments: (used for decorative effects such as metallic finishes)

Aluminium powder and flakes of various grades (leafing or non leafing types and various particle sizes).

Bronze powder and flakes of various grades.

N.B. It is to be noted that aluminium flakes have many uses apart from their incorporation in metallic finishes of various shades - eg. their flaking properties make them useful in formulation in knot sealers for resinous woods.

Pigments in paint

Now that we have had a quick look at binders and pigments, we should state that a paint is basically a more or less stable system in which a pigment has been dispersed, i.e. intimately ground with the binder, so as to achieve the best cost/quality compromise in terms of storage stability (of the unused product) and durability (service life) of the applied product.

However, pigments and binders may react together (example: red lead which is an amphoteric oxide reacts with an acidic resin - such as a long oil alkyd - to form insoluble lead salts) and the product may gel in the can during storage. Also according to 'Stokes law' pigments will tend to separate out and settle on the bottom of the can during paint storage. This is specially true of heavy (high density) pigments such as red lead, calcium plumbate, zinc dust, titanium dioxide.

Furthermore, for colour matching purposes, pigments of very different families will have to be mixed and these may not be compatible with each other, hence the phenomenon of pigment floation or separation of colours on application of a coating.

Now let us have a quick look on the principles of colour mixing. Using five basic 'colour', namely black, white, blue, yellow, and red. we can prepare a large number of 'shades'.

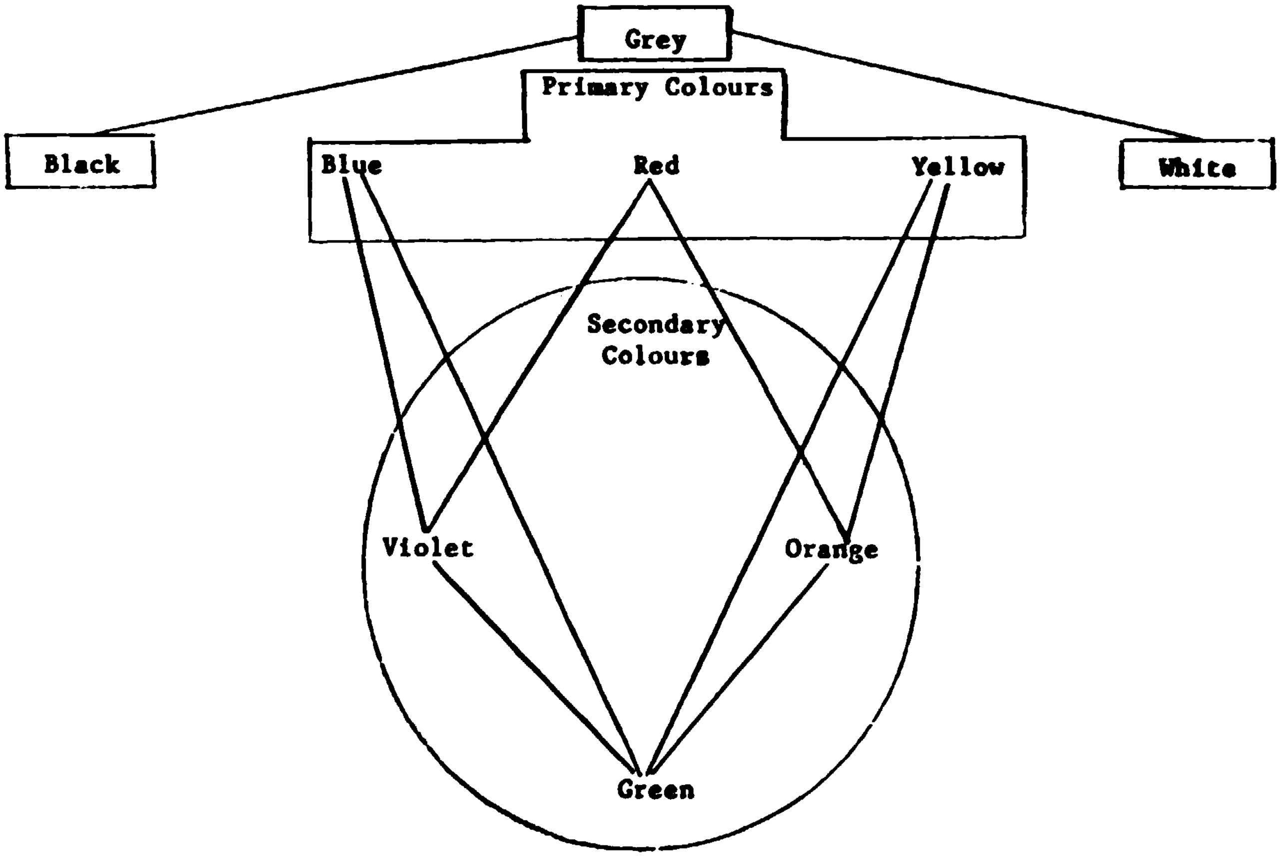


Fig. 11: Blending of colours.

This is what happens in practice in colour mixing or colour matching procedures. By mixing equal parts of a primary colour and a secondary colour, a tertiary colour is obtained. When two or more tertiary colours are mixed together, the result is a colour: grey.

Notes about colour matching

1. The substrate influences the colour of the coating unless a very good opaque film of paint is applied. Thus to compare colours ensure that the paint being matched is being applied on a similar substrate and in a similar thickness to the colour sample to be matched.
2. Due to the difference in aspect, it is tricky to obtain an exact match of the colour of a gloss coating to that of a mat finish (and vice versa).
3. When colour matching always ensure that the paint film is dry before comparing it to the standard (on drying the colour of the paint may change slightly.
4. It is advisable to use a constant illumination cabinet (see fig. 12) to obtain a constant quality of light to compare the specimens. Sunlight at various times of the day is not of the same composition or spectral distribution. Moreover, a fluorescent light and in incandescent light bulb also have different spectral emissivity. The fluorescent light has more of the blue component, while the filament bulb has more of the red component.

   Thus matching of the same colour under different illumination conditions may lead to metameric matching. This implies that paints matched as being of the same colour under one illuminant (say a filament bulb) will be seen as different under another light source such as a fluorescent tube. This phenomenon results form the use of different pigments in the original paint sample as compared to the freshly prepared paint.

   If no constant illumination cabinet is available it is reasonable to propose the use of natural diffuse day light as the light source for colour matching purposes.
5. When matching metallic colours based on aluminium powder pigment, one should remember that to achieve the same metallic effect as the standard the following conditions should be met:

a) That the aluminium pigment being used is very close or the same as the one in the standard paint. Aluminium pigments are available in a variety of particle sizes and shapes. Using pigment of different particle size will result in a different optical effect on the paint film, even if all other parametres are constant or at least similar. Thus, for the applicator, aluminium paint for colour matching purpose is classified as leafing or non leafing and leafing grades are further divided into 'fine', 'medium' and 'coarse' opalescents depending on the average particle size of the aluminium flakes.

b) At application of a metallic coating which is usually done by air spray (apart from the spray gun setting and air pressure) the viscosity of the paint, the film thickness and drying time are important to allow the aluminium flakes to orientate correctly in the paint film while the paint is drying and thus achieve an effect similar to the original.

c) When a patching up or touching up of a surface painted with metallic paint is effected, it is difficult to obtain an exact match to the original. This is even more true if the original colour has faded due to exposure to exterior conditions. The trick is then to apply the paint in such a way as to blend it gradually to the existing paint. Thus, working from the repainted patch one applies a film of decreasing thickness in a circular pattern around the patch. This will make any shade difference gradual and less noticeable.

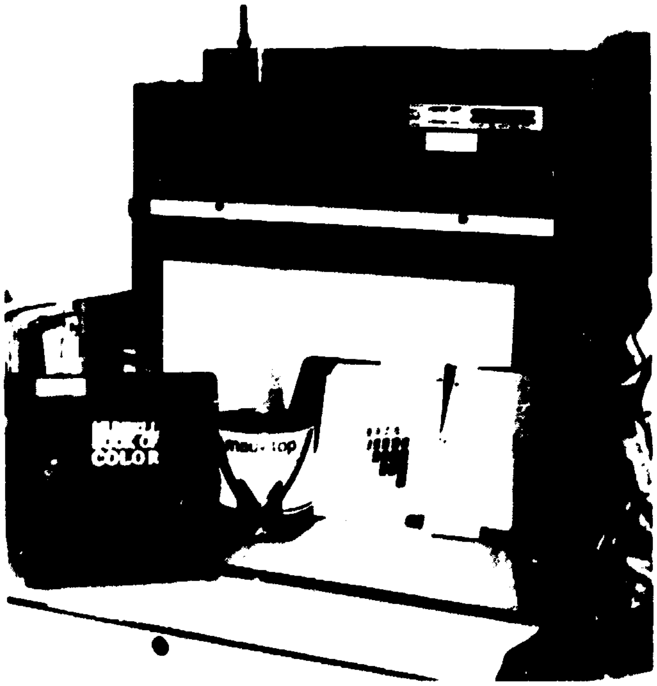


Fig. 12: Constant illumination cabinet. Ideal for colour matching purposes.

Notes on organic pigments

Before we list some of the main organic pigments used in the paint industry, it is necessary to have a few definitions.

Organic pigments can be classified into:

Pigment dyestuff: are entirely organic compounds which leave no ash on ignition and contain no salt-forming groups. They are a large class and include pigments with good light fastness.

Toners: are salts produced from:

a) soluble or partly soluble acid dyestuffs by precipitation with a heavy metal ion, and from

b) basic dyestuff by precipitation with acids.

Lakes: are formed by precipitation of a toner in the presence of a 'base' such as blanc fixe, alumina|blanc fixe, or alumina|china clay.

The colour producing group in an organic pigment is called the **chromophore.**

The most important chromophores are:

$-N = N -$	Azo Group
$-N = O$	Nitroso group
$-N O_2$	Nitro group

Acid and basic dyes also contain salt forming groups known as auxochromes, which are a radical or group of atoms, whose presence is essential in enabling a coloured organic substance to be retained on fibres.

Acids	Base
$- COO H$	$- NH_2$
$- SO_3 H$	$- NHR$
$- OH$	$- NR_2$

A molecule containing a chromophore but no auxochrome is known as a **chromogen.**

Azo group

Azo pigments constitute the largest group of organic pigments used in the paint industry. The various pigments containing Azo groups range in hue from yellow (all shades), red (all shades), violet (all shades) to a few blues, greens and browns.

Thus there are a large number of pigment structures which contain the Azo group, with more or less good fastness and good resistance properties. The Azo group is divided into monoazo, diazo, triazo, and tetrazo according to the number of - N = N - groups in the molecule.

Extenders

Some usual extenders are:

Calcium carbonate (various grades).
Talc (hydrated magnesium silicate).
Barytes (bariumsulphate).
Mica (hydrated aluminium silicate).
China clays (crystalline hydrated aluminium silicates).
Diatomaceous earths - siliceous remains of diatoms.
Silica sands.
Barium metaborate.

Extenders are cheaper than pigments and are often used to decrease the raw material cost of coatings, without reducing the solid content of the product. With reference to solid content, it is quite dicy (apart from cost consideration) to increase the proportion of pigment above a certain pigment/binder ratio. Organic pigments (Azo yellow for example) have higher oil absorption than calcium carbonate (for example) and too much pigment will result in a stiff paste, which is difficult to apply and will have poor weathering characteristics, whereas addition of the same mass of the extender will not have the same adverse effects and will increase the solid content to the same proportion.

A few other uses of extenders are as matting agents, as agents to assist in sandability of sealers, stoppers and putties, to increase hardness of coatings, as antiskid agents, to increase the compressive strength of putties to prevent deposition (and caking) of heavy pigments when products are stored, to provide certain flow properties to coatings, putties, fillers or stoppers, to aid in fire resistance properties of coatings, to improve resistance to fungi and pH stabilizers in certain emulsion system.

Additives

We have seen the large 'macro' constituent of coatings and putties (resins, plasticisers, solvents,pigments, extenders). These can be mixed together, dispersed, ground and adjusted to viscosity with the appropriate solvents. However, sometimes, things go wrong or special effects are required.

Examples are:

Oil paint and varnishes form a skin in the pot.

Colours separate (pigment floatation).

A coating sags on application.

Pigments settle on storage.

Certain coatings may foam on application.

Fungi grow on the coating.

To solve these problems certain chemicals (additives) are added in small amounts (1 percent and less) to the coating, at the manufacturing stage.

They can be antiskinning agents (prevent skinning), dispersing agents (prevent pigment floatation) and improve 'wetting' of pigment by binder. Rheology agents provide a 'false body' and prevent sagging, antisetting agents, antifoam, fungicides and bactericides.

Again there are a very wide range of products available for each particular use.

Some important characteristics common to all paints, putties and varnishes:

1. Solid percent by volume and by mass.
2. Pigment volume concentration (P.V.C.).
3. Opacity.
4. Coverage.
5. Appearance of cured coating (glossy, mat).
6. Viscosity (consistency).
7. Drying time (touch dry and hard dry).
8. Various application/curing characteristics (as agreed between supplier and purchaser or as per specific standards).

The finished product that is purchased by the applicator has certain designed characteristics. Generally these are given and are mentioned to the customer via data or product specification sheets.

We shall now explain the meaning of these various characteristics, or how to read paint manufacturers' specifications.

The **type of binder** and the pigment are usually specified. (We have already seen these.)

Then the **solid content** of the liquid product **by mass** and **by volume** is specified. The solid content by mass simply means that in 100 kgs of product say 60 kgs are solid matter and remain in the film after 40 kgs of volatile constituents (solvents) have evaporated to the environment. Thus it is better (for a given viscosity) to purchase the coating which has more solid material.

However, this concept can be misleading; for example, if we use high density pigments in the formulation then the solid content by mass is bound to be high, although the percentage volume of solids can be low.

When we considered coating protection properties, these are dependant on the dry film thickness of the coating, the higher the film thickness the better the protection provided (all other components being constant).

Also when we purchase a can of paint we need to know what area we can cover this with paint.

Film thickness and area covered brings us to the concept of volume (area x thickness).

Thus, when we purchase a can of paint, we need to know the volume of solids in the paint so that we can calculate (within experimental error) what area we can cover and what average dry film thickness we are going to obtain with the paint we shall use.

When we need to choose between different brands of paint, the same type, with all other characteristics constant we should purchase the one with the higher volume of solids.

The volume of solids is specified on product specifications. It is directly related to the practical figure of coverage at specified average film thickness on a specified substrate. (**Coverage** is specified in terms of area covered per coat at a specified film thickness.)

Diagramatically we can represent volume of solids as in fig. 13 below:

A = total area covered
T = wet film thickness
A x T = Volume of wet paint
TV = thickness of volatile
TV x A = volume of volatile
TS = thickness of solids
TS x A = volume of solids

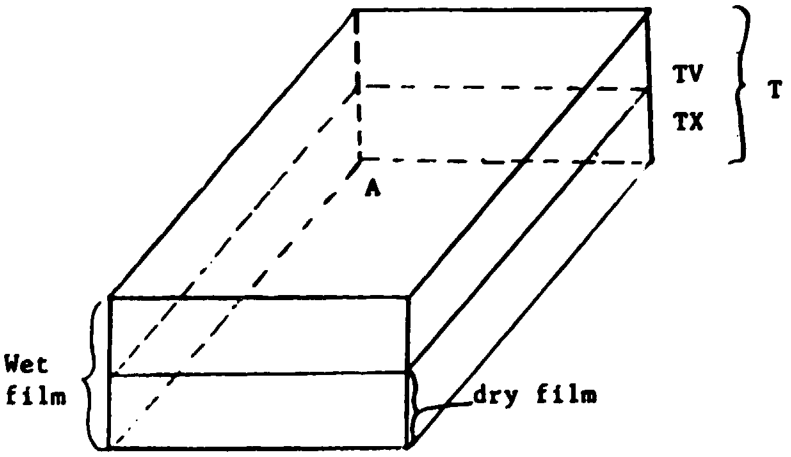


Fig. 13: Volume of solids.

When the solvent evaporates the film shrinks and we are left with TS which is the thickness of solids and with the volume of solids which is (TS x A).

N.B. Since solvents are toxic, dangerous, inflammable, non renewable, polluting, more and more expensive and require considerable calorific energy, which cannot be wasted, the trend is to formulate coatings with high solids or with water as the thinner.

High solids coatings are usually:

1. Two pack polyamine cured epoxies.
2. Two pack polyurethanes.
3. Unsaturated polyester (since the solvent styrene monomer, copolymerize with the polyester resin during curing).
4. Thermesetting (epoxies, polyester) powder coatings.
5. Thermoplastic powder coatings based on polyethylene and nylon,

Water based coatings can be divided into two groups

- **Emulsion binders**- in which the resin is in a state of dispersion (not solution) in water - this involves the use of emulsifiers and stabilizers, since the binder and water are not compatible.

Common example: 'Emulsion' binders used to manufacture decorating paints for buildings.

Many coatings are now available in emulsion form and are based on the following resins for exampls:

Polyvinyl acetate emulsion.
Polyvinyl acetate/acrylic emulsion.
Acrylic/acrylic copolymer emulsion.
Styrene/butadiene emulsion.
Styrene/acrylic emulsion.

It is also possible to emulsify two pack epoxy systems and bitumen for example.

- **Solution binders** - in which the binders have been modified to render them completely or partly soluble in water or just water dilutable:

These include:

Modified drying alkyds - for gloss paints and clear varnishes; also metal primers

Saturated polyester - for stoving enamels (in combination with melamine)

Thermosetting acrylics: for spraying and dipping, stoving enamels. (in combination with melamine).

Pigments volume concentration P.V.C. (of dry film)

This characteristic of a coating is a ratio of the volume of pigments to the total volume of solids in the dry coating; it is expressed as a percentage. P.V.C. (not to confuse with polyvinyl chloride) can be related to coating properties such as abrasion resistance, gloss, chalking resistance, stain resistance,flow among others.

Opacity:

This is the ability of a coating to obliterate the surface on which it is applied. It is directly dependant on the amount of pigment present in the formulation and to the type of pigment used. It can be measured under certain conditions and is expressed as contrast ratio at a certain dry film thickness between the reading observed on standard white and black surfaces. A contract ratio of 100% means complete opacity under the specified conditions.

Appearance of coating surface (glosses, satin or mat)

On a standard smooth surface such as gloss the appearance of the dry coating depends on the ratio between pigment extenders and binders.

The following diagrams illustrate the point:

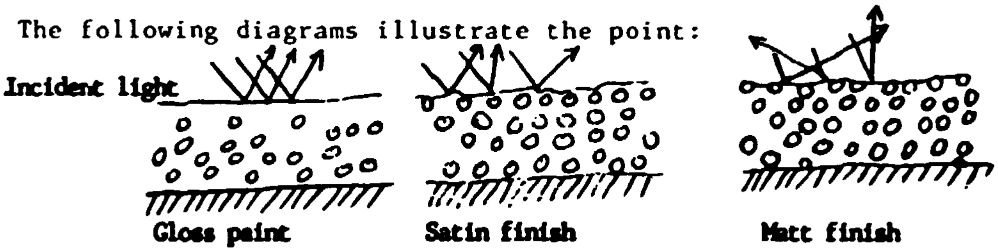


Fig. 14: Proportion of pigment to binder increases

Low (10-20) P.V.C. Mirror like finish which reflects incident light rays in an orderly fashion. A clear image of an object can be formed.	(subdued gloss) PVC (21-40) Satin like finish indicent light rays are reflected in a somewhat disorderly fashion such that an image of an object cannot be formed.	P.V.C. (41or more) Dull and completely non reflective finish.Incident light rays are partly absorbed and/or reflected in a disorderly fashion, no image of an object can be formed.

N.B. Each type of binder has a range of P.V.C. for which it is gloss, satin or mat - some binders in clear films may form a more glossy finish than others - i.e. not all binders are equal in thier ability to form glossy films. Gloss (reflection) at various angles of incident light can be measured using a glossmeter.

VISCOSITY

Viscosity (consistency) is related to the flow of various fluids (more or less thick). Fluids can be grossly classified into **Newtonian** (ideal) fluids, an approximation of which are water and certain oils (long oil, alkyd resins and many other binders in solution fall under this category) and **non-Newtonian.**

For **Newtonian fluids:** $\frac{\text{Stress}}{\text{Strain}}$ = Constant (which is viscosity)

These sort of fluids are said to have laminar flow: whereas the fluid in motion is considered to have an infinite number of planes which slide upon each other in an orderly fashion when a force (stress) acts upon them, and the flow (strain) is produced.

There are two conditions for a Newtonian Fluid.

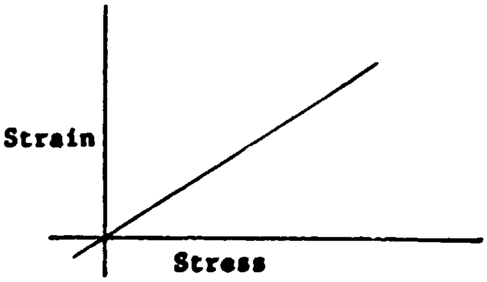
1. Flow is proportional to force
2. The least possible force produces some flow.

The unit of $\frac{\text{Stress}}{\text{Strain}}$ (i.e.viscosity) is the poise, an absolute unit of 1 gram per centimetre per second.

Another unit of viscosity the stoke is used when the density of the fluid needs to be taken into account.

$$\text{Stoke} = \frac{\text{Poise}}{\text{Density}}$$

Practically for Newtonian fluids a graph of strain (y axis) and stress (x axis) is represented by a straight line going through the origin.



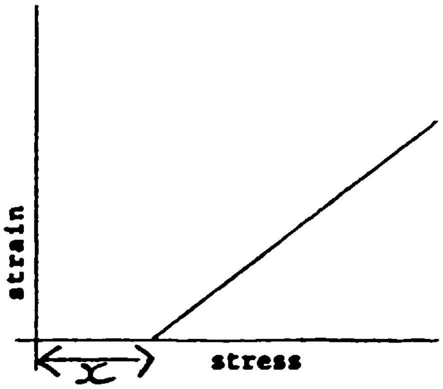
A simple way of measuring 'viscosity' or more rightly efflux time of Newtonian fluids is using an efflux cup such as Ford Cup No. 4 or various Zahn Cups.

N.B. Viscosity changes with temperature. Thus temperature must be stated whenever viscosity readings are taken.

Many fluids are not Newtonian fluids. They include solution of high molecular weight materials such as rubber and proteins and suspension of solid in liquids (emulsion type binders, and paint system where the properties of the binder solution is affected by the incorporation of various pigments, extenders and additives which all interact).

EXAMPLE OF NON NEWTONIAN FLUIDS

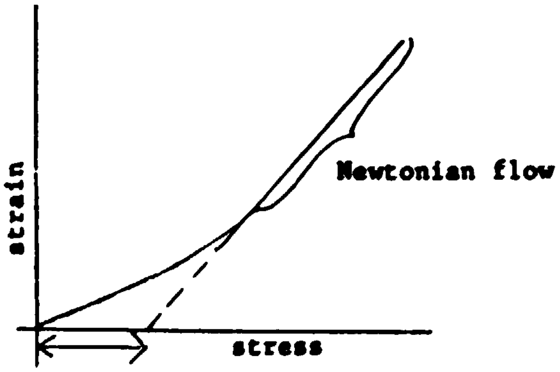
BINGHAM BODIES



The intercept X means that below a certain limiting stress no flow takes place. This limiting stress is called the 'yield value'. Above it stress is proportional to strain. Materials exhibiting this behaviour are called 'Bingham Bodies' and they are said to exhibit 'plastic viscosity'.

PSEUDOPLASTIC MATERIALS

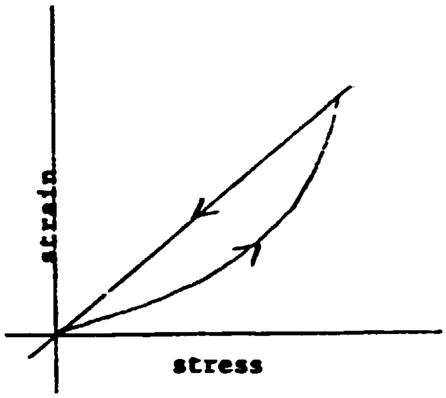
They have some degree of in built structure in the fluid so that at first there is no flow, (strain is low) but above a certain stress, there starts to have some flow (strain) and the strain/stress graph eventually straightens, to a straight line corresponding to Newtonian Flow.



THIXOTROPY

Some fluids posses structures which in contrast to pseudoplastic materials cannot be broken down and resumed immediately, i.e. they possess a certain resistance to the breaking down of their structure under shear and when the shear is stopped or decreased they take a substantial time before resuming their original structure.

This can be the case of certain coatings which although they seem to possess pseudoplastic properties, do not resume their original structure and are called 'Thixotropic materials'.



The stress is increased gradually to obtain constant flow at each level until point A is reached. Then the stress is suddenly decreased. It will be observed that the fluid requires a lower value of stress to produce constant flow. Thus the downward line with lower values of stress for equal values of strain can be drawn. An **Hysteris loop** (Hysteresis from the Greek 'lay behind') characteristic of thixotropic materials is thus formed.

Various apparatus have been designed to measure the amount of stress to be applied to produce a constant strain (flow) in various materials.

Since vistosity is $\frac{\text{Stress}}{\text{Strain}}$, then the larger the stress required to produce a given strain, the higher the viscosity.

Examples are: the Stormer paddle viscometer, the I.C.I. cone and plate viscometer the Brookfield viscometer (see fig.15). The **paddle type** viscometers works on the principle that a **constant strain** can be observed through a stroboscopic arrangement which certifies that a constant r.p.m. (revolution per minute) of a paddle immersed in the fluid has been achieved. To achieve this constant strain (rpm) the stress is varied through a system of weight and pulleys acting on the shaft of the paddle. The larger the weight (stress) needed to achieve constant strain (rpm) the higher the viscosity. Sometimes, for routine comparative control the reading is taken as the weight required to achieve constant strain (as denoted by achievement of the predetermined r.p.m.).

There exists another condition of fluid flow called **Dilatancy.**

In this case viscosity increases with increasing rate of shear, i.e. strain diminishes with increasing stress. This condition can occur in highly pigmented systems. (A common example is 'corn flour' solution.)

As can be seen viscosity is a very important property of coatings. Viscosity is temperature dependant. Normally, increasing temperature decreases viscosity. Addition of the right solvent will also reduce the viscosity of a coating. Viscosity is thus extremely important with reference to how a coating is to be applied.

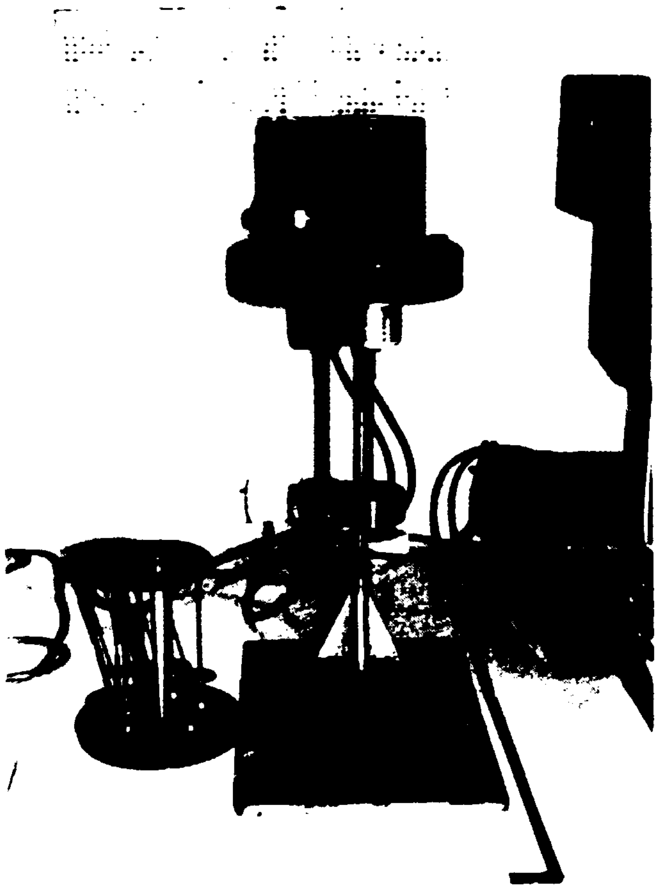


Fig. 15: Brookfield viscometer with various spindles.

DRYING TIME

In product specifications, it is usual to specify touch dry time, overcoating interval and hard dry time, under specific conditions. There exist standard methods to determine (and check) these properties. To the user drying time and curing schedule are very important, since they are directly related to production rate. In furniture manufacture quick drying coatings (one coat) are to be preferred since they increase output. Also quick drying systems have less chance of being soiled by environmental dirt; thus requiring further polishing. Drying time, as we have seen, is usually shortened by increasing ambient temperature.

OTHER COATINGS CHARACTERISTICS

These include:

- Storage stability -(of unused product)

- Pot life - of base/hardener mix in the case of two pack systems and of catalysed system (again increasing temperature increase the rate of reaction).

-Flexibility
-Adhesion
-Impact resistance
-Abrasion resistance
-Hardness
-Weathering resistance
-Colour fastness

of cured systems

RESISTANCE TO VARIOUS CHEMICALS

Electrical characteristics (insulating or conducting).

Water and water vapour absorption and transmission.

Resistance to wet and dry heat.

Characteristics of coatings can be tailor made to suit agreement (cost/quality) between the manufacturer and the purchaser or made to conform to certain official standards.

PAINT MANUFACTURING PRINCIPLES

PURPOSE

To produce a homogeneous and stable - more or less fluid - paste, which possesses drying and film forming properties, to protect and decorate a wide variety of substrates.

Pigments and extenders are mixed and 'dispersed' in the chosen binder (resin) or binder blend (various resins mixed together), adequate additives are added (see additives) and the viscosity (consistency) is finally adjusted with the appropriate solvent or solvent blend.

Various paint manufacturing equipment are used, depending on the type of pigment used (see pigments), the volatility of the solvents for the binder system and the degree of dispersion required.

Also various equipment can be used to manufacture the same end product. In this case the 'mill base' formulation is adapted to the equipment.

N.B. The 'mill base' is that part of the total paint formulation which contains some resins, additives, solvents and all the pigment to be dispersed. It is usually thicker and more viscous than the finished paint. It is more economical to process a small mass of mill base than the complete larger batch of paint.

The second part of the paint formulation to be added to the mill base is called the 'let down'. It consists of additional resin in solution (varnish) with various additives and solvents as necessary.

General paint formulation for a long oil alkyd enamel to be dispersed on a Tripple roll mill

75 % long oil alkyd	9.0	mill base
While pigment	29.0	
Dispersing agent	0.5	
Solvent	6.0	
75 % long oil alkyd	41.0	let down
Mixed driers	1.0	
Antiskinning agent	0.1	
Fungicide	0.4	
Solvent	13.0	
	100.0	

Manufacturing equipment used: Cowles type disperser/dissolver, triple roll mill.

Procedure

Weigh the resin and dispersing agent into the manufacturing vessel and start stirring, add the pigment and solvent to adjust the consistency and mix for about half an hour until a smooth paste is obtained. Scrape the side of the manufacturing vessel to ensure that all the pigment is mixed in.

After mixing for half an hour, the temperature of the paste may rise to 40-50°C.

Transfer the paste to the triple roll mill and proceed with the dispersion (see Tripple roll mill operation).

Check the dispersion with a grind gauge. If the grind is acceptable transfer the mill base into another manufacturing vessel containing the let down, and mix wiht a spatula.

When the dispersion is complete, fully homogenize the mill base/let down blend in the Cowles type dispenser/dissolver.

Check the viscosity. Adjust with appropriate solvent if necessary. Since viscosity is temperature dependant, it should be checked at a specified temperature say 25°C. A Ford Cup No. 4 is normally used to determine the 'efflux time' of alkyd enamels.

Proceed to full **quality control** before packing the paint.

In the case of a long oil alkyd enamel, apart from dispersion and viscosity, routine quality control (and comparison with the relevant standard) should include: specific gravity control, opacity, gloss and film.

Flexibility, adhesion and resistance to various exposure conditions should only be determined occasionally.

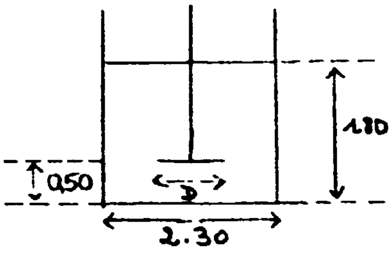
VARIOUS PAINT MANUFACTURING EQUIPMENT

Cowles type high speed dissolver/disperser

This is the basic paint manufacturing equipment and its use is widespread.

It is usually sufficient to achieve a reasonable dispersion for white emulsion based paints and various solvent based primers. It is not adequate to obtain a good gloss enamel or good dispersion of various pigments in water based or solvent based media.

In theory the various parameters to make optimum use of a high speed Cowles type dissolver/disperser are indicated in the sketch below.



Periperal speed of impeller
1000-1300 m/min.

D = Diameter of impeller

Fig. 16

A normal belt driven high speed Cowles dissolver/disperser is not suited to blend high viscosity paste such as offset inks or polyester fillers.

To improve dispersion and mixing various impeller types have been designed, for example:

Silverson type (cage) emulsifiers/dispersers (see fig. 16)

Star disperser/dissolver (Drais)

Twin shaft disperser/dissolver (Myers)

Variable impeller diameter (Vary Shear)

To handle **thicker pastes** hydraulic drive dispersers fitted with either **Cowles** or **Trifoil blades** (see fig. 17) have been devised.

Other paint/paste mixing equipments include:

Planetary mixers which handle very thick pastes (see figs. 18 and 19).

Dough mixers which handle medium to thick pastes (see fig. 20).

Z Blade mixer for very thick pastes (putty) also produces good dispersion (see fig. 21).

Edge runner mill for putty consistancy pastes. Produces good dispersion (see fig. 22).

Dispersion equipment includes:

Triple roll mills with mechanical or hydraulic setting

Pearl and sand mills

Attritor mills

Colloid mills

Ball mills

Triple roll mills (see fig. 23): Handle thick pastes with slow evaporating solvents. Mill bases containing fast evaporating solvents cannot be used on Tripple roll mill as the solvent will evaporate and the paste will dry out on the mill.

Sand and Pearl mills (see fig. 24): Handle thinner pastes (that can be pumped) with slow or fast evaporating solvent.

Attritor mills: Process paste with similar viscosity to Pearl and sand mills.

Colloid mills: Useful for small runs of water based dispersion.

Ball mills: Process pastes of similar consistencies to snad mills.

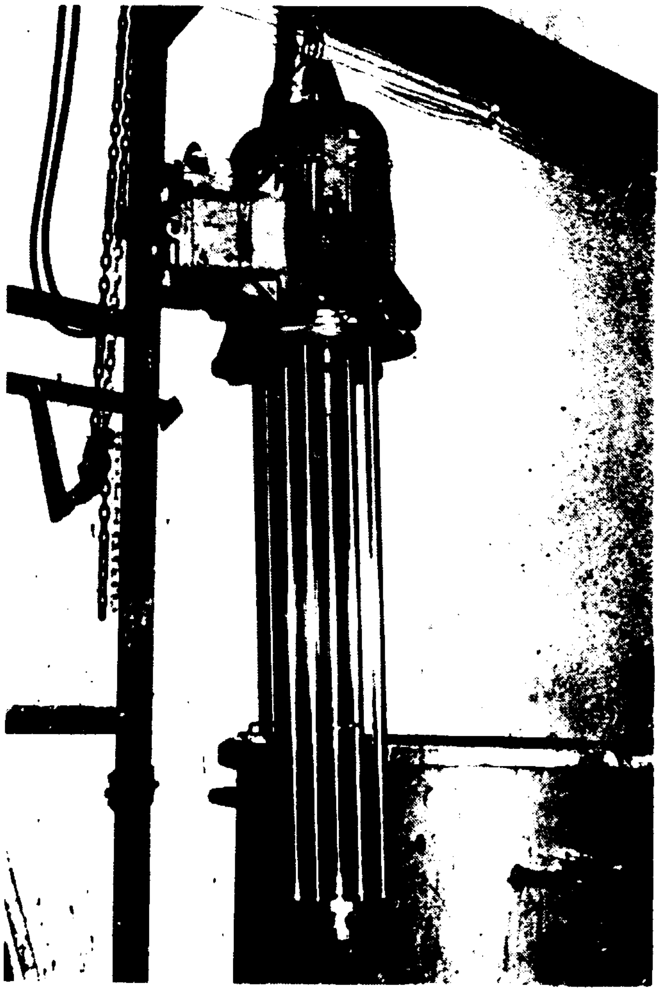


Fig. 16: Silverson type emulsifier/disperser.

Fig. 17: Trifoil type hydraulic drive dissolver/disperser to predisperse pigment pastes. This type of mixer handles thicker pastes than the Cowles type blades.

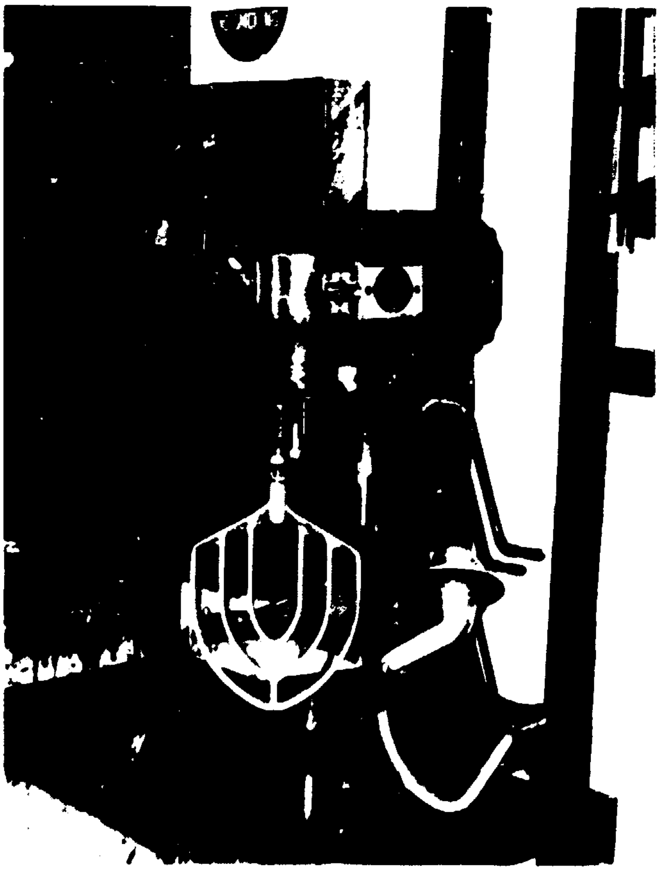


Fig. 18: Planetary mixer.

Fig. 19: Mixer with planetary action to handle thick pastes (putty consistency).

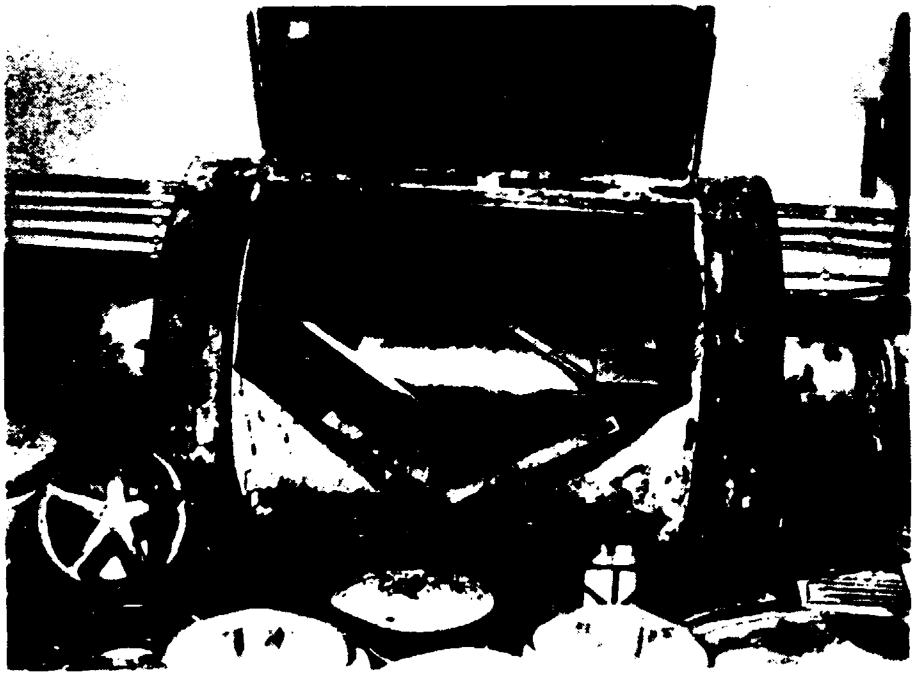


Fig. 20: Dough mixer/blender to handle thick pastes (putty consistency).

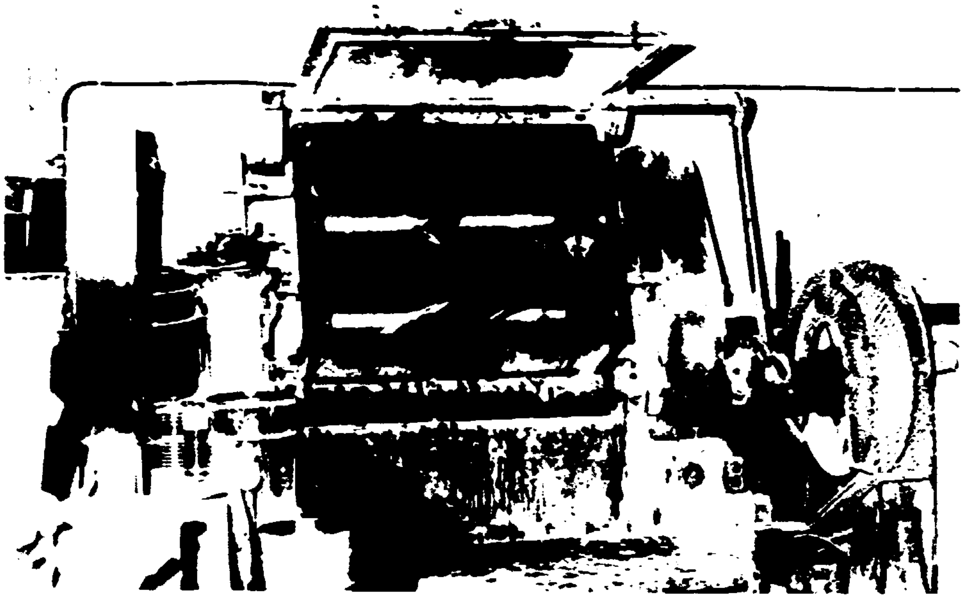


Fig. 21: Z blade mixer.

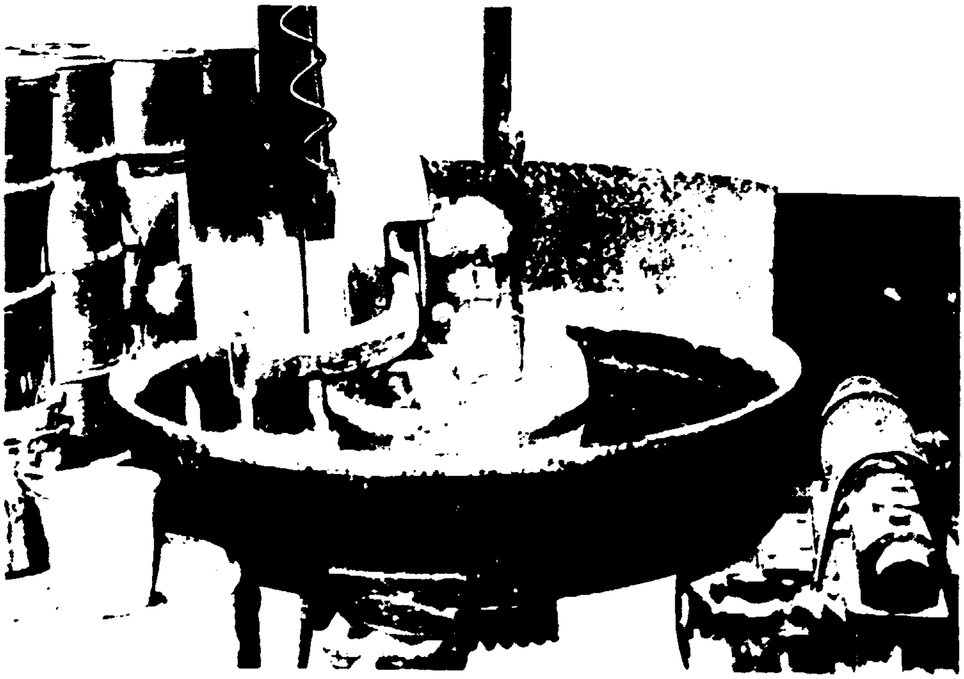


Fig. 22: Edge runner mill.

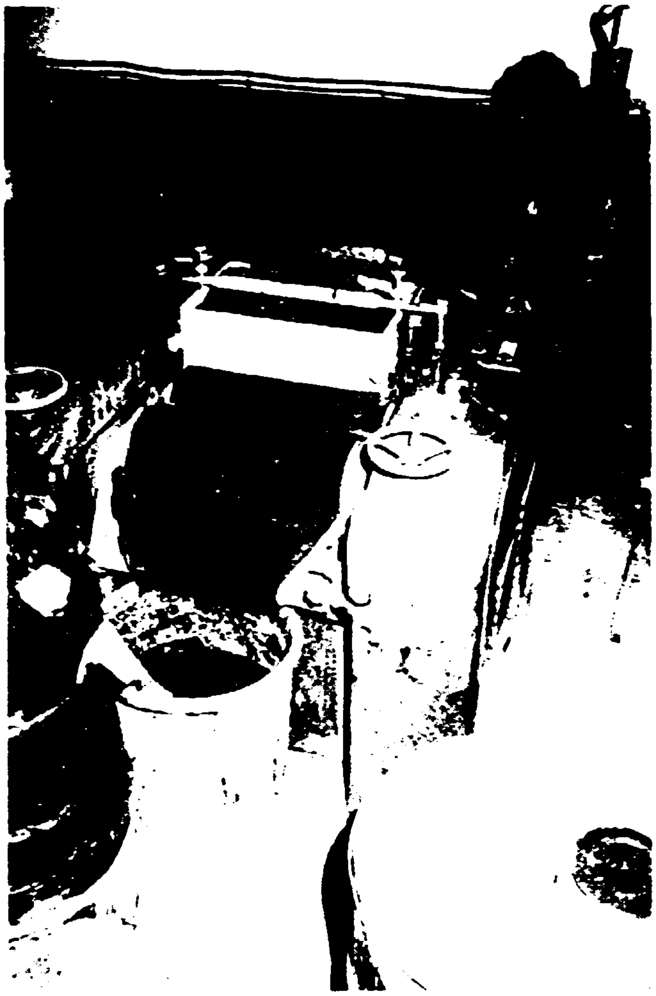


Fig. 23: Triple mix roll.

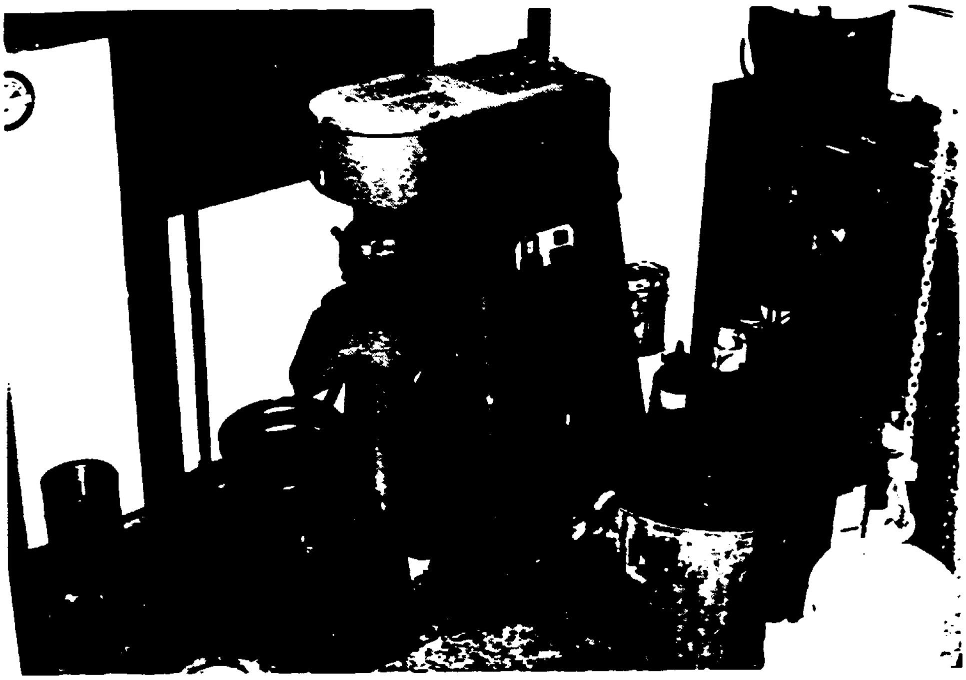


Fig. 24: Pearl and sand mills.

Various types of blades are shown in fig. 25.

Fig. 25: From left to right
Trifoil type blade
Cowles type blade
Impeller type blade

Simple test on liquid paint and cured paints films

The serious applicator must know the basic characteristics of the coatings he uses and he must be able to perform a few simple, inexpensive tests, on the paints he purchases to make sure that he receives a constant quality form his supplier, and in turn delivers a constant or improved quality to his customer.

Moreover, these simple testing procedures will help him to select the best cost and quality compromise from the manufacturers. He will have some facts to discuss with the different sales representatives when they come.

It is advisable that a record be kept of these testing procedures and that the batch number of the paint be noted on this record sheet. In turn each job he delivers to a customer should bear an identification number or mark which refers to a job card where,amongst other things, the batch of paint of varnish used for the job is noted, for future cross checking in the event of a customer complaint.

This procedure may seem tedious but being systematic and orderly helps to trace problems and solve them unemotionally when they occur. This approach definitely helps to raise the level of discussion and arguments and render them productive instead of dramatic and destructive. It also builds trust and mutual respect in the relations between supplier and customer.

Basic equipment required to perform simple tests on liquid or cured coatings

Property to be checked	**Equipment suggested**
Efflux time (Newtonian Viscosity)	Ford Cup No.4 (see fig. 26) Mercury bulb thermometer scale -10 ÷ 50°C
Wet film thickness	Erichsen Model 234 in accordance to ISO 2808, ASTM D1212, BS3900 (Part C5) or Erichsen Model 333 in accordance with ISO 2808 BS 3900 (part C5) (see fig. 27).

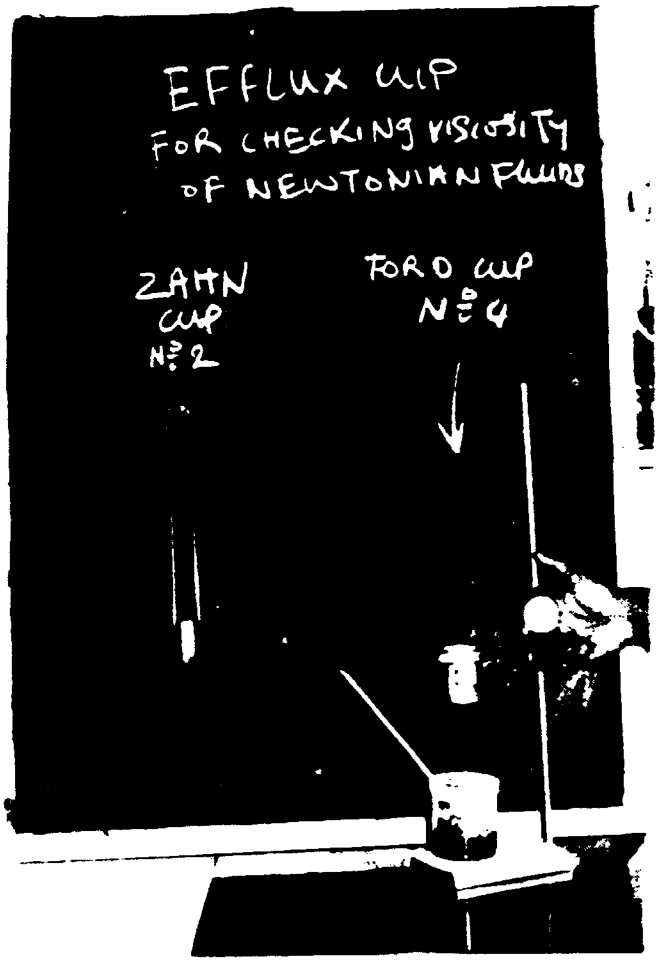


Fig. 26: Efflux cup for checking viscosity of Newtonian Fluids.

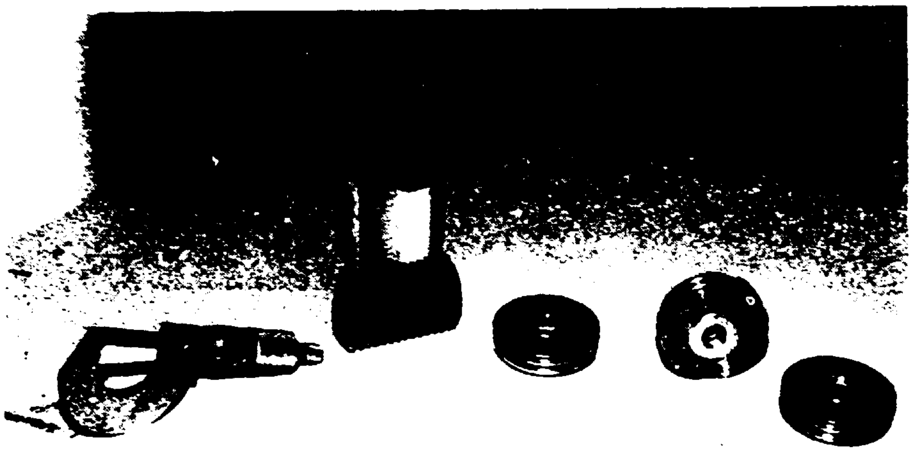


Fig. 27: Equipment for checking wet film thickness:
- Micrometer,
- Erichsen model 234,
- Erichsen model 333.

Dry film thickness	Micrometer reading to 0.001 millimeter or using a Leptoscole (see figs. 27, 28)

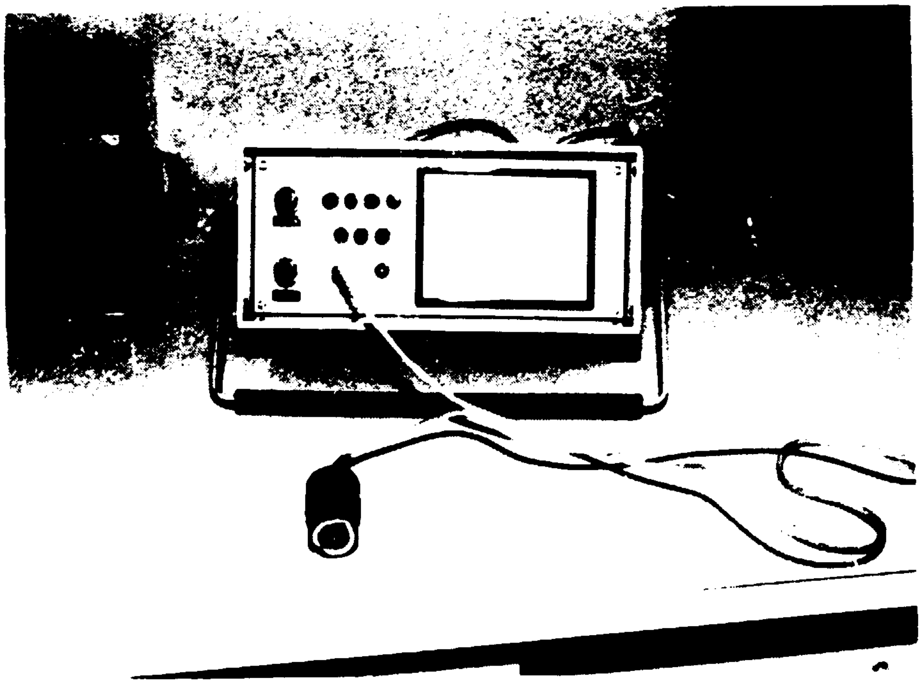


Fig. 28: Leptoscope to measure dry film thickness of non-magnetic coatings on magnetic substrates.

Coating hardness	Pencils of specified hardness ranging from 8B (softest) ro V, HV, H ro 8H (hardest) (see fig. 29).

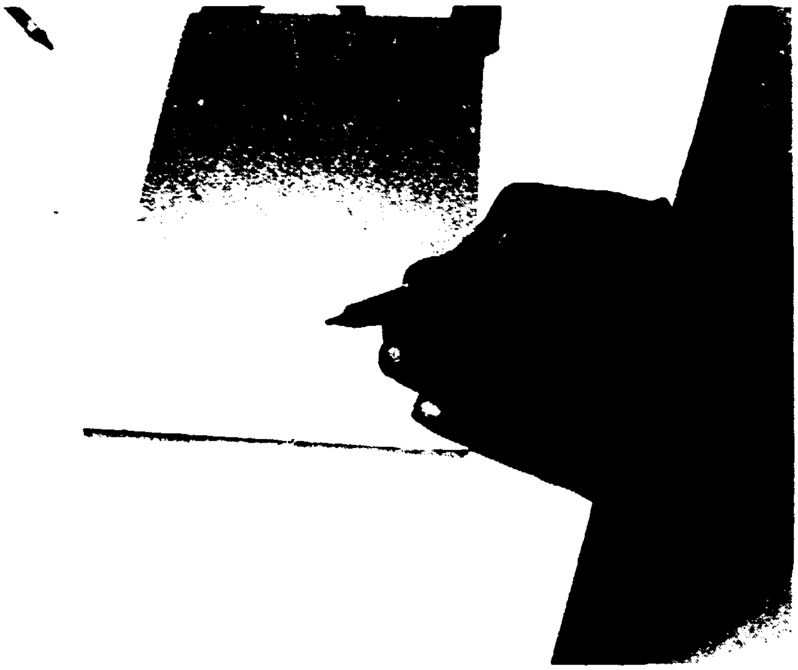


Fig. 29: Pencil hardness determination.

Coating Flexibility	Mandrel Rack. Mild steel panels with Mandrel diameters ranging from 4mm to 20 mm, (2mm increments) (see fig . 30)

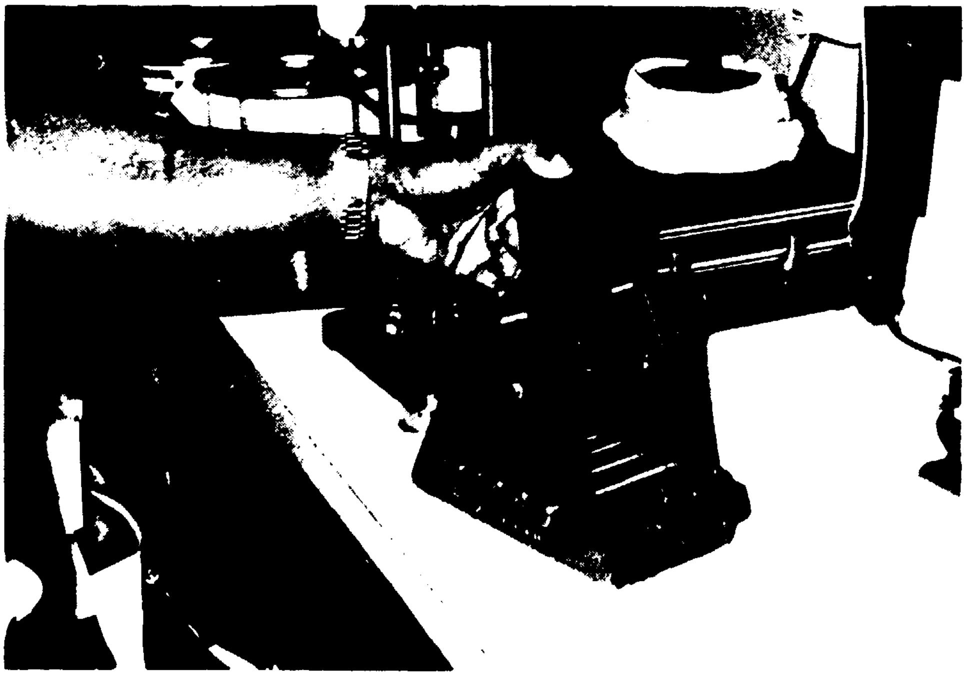


Fig. 30: Testing flexibility of a coating on known film thickness applied on a metal sheet using the mandrel rack
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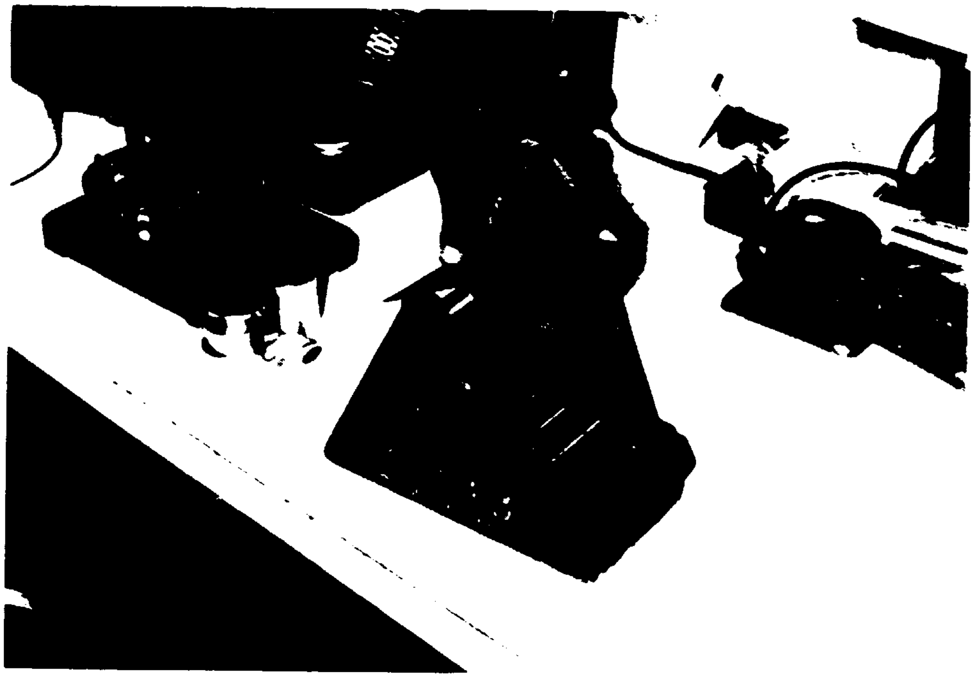


Fig. 30(b): Bending of painted puls on the mandrel.

Adhesion	Cutter, steel ruler, mild steel panels, glavanized steel panels, aluminium panels or other relevant substrate, adhesive tape of constant quality (see fig. 31).

Fig. 31: Simple apparatus used to determine adhesion of coatings on metal panels.

Impact resistance	Various simple comparative checks can be performed. For example dropping a steel sphere from a certain height on the surface of the two coatings to be compared and observing the result. A more drastic test would be to hammer a spherical steel punch on the coating applied on a standard mild steel surface of say 0.75 mm thickness and comparing the results the coatings to be compared. This second test would combine impact and deformation. Fig. 32 represents a laboratory equipment where a weight with a spherical impact point can be allowed to fall from various heights unto a coating applied on metallic plates of standard thickness.
Drying time	This is a comparative test between various coatings applied with similar film thickness on similar substrates, or the data can be absolute if constant ambient conditions can be assured: Touch dry time can be determined by comparative touch with the finger or spreading calibrated Balotinni beads on the surface and sweeping them away with a soft paint brush. If they stick to the paint film then the paint is not touch dry. Also there exist equipment such as B.K. drying time recorder (see fig. 33) which automatically records the time taken by a wet paint film of definite thickness to dry. A needle travelling along the paint film leaves a mark until it reaches dry paint and the mark stops. The needs travels at a constant speed and a reading is taken directly in hours where the mark stops.
Sandability	Sand paper of various grades.

Fig. 32: Falling weight impact tester

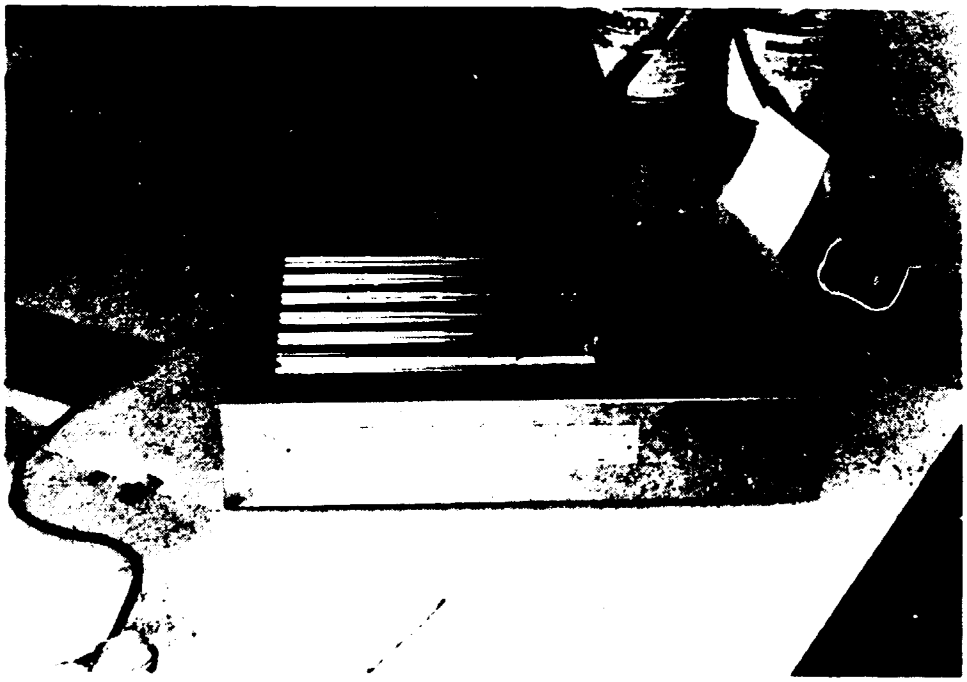


Fig.33: B.K. drying time recorder

Weathering resistance and colour fastness

Exposure racks can be made inclined at 45° and facing North (for the Southern Hemisphere) and inclined at 45° and facing South (for the Northern Hemisphere). Panels can be 30 cm long by 15 cm wide (see fig. 34).

Accelerated weathering conditions are produced in various proprietary equipment. They are meant to simulate and speed up the 'natural' break down of the coating so that results can be made available sooner than for outdoor weathering. These facilities are generally available in large research or control laboratories.

Fig. 34: Painted panels exposed to exteriour conditions to test the weather fastness of various coatings.

Gloss

Gloss of coatings can be visually checked by comparing the clarity of the reflection of an object on the surface of the dry coatings. The coating giving the clearer reflection is the one which has more gloss. Lab equipment for measuring gloss include reflectometers such as the one illustrated in fig.35

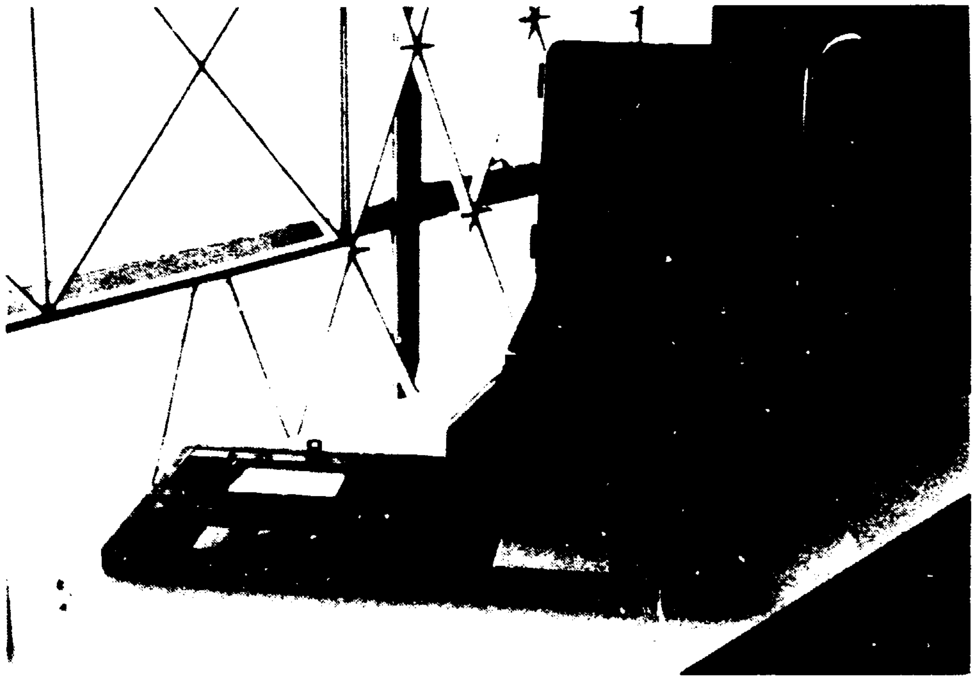


Fig. 35: Glossmeter used to measure the gloss of coatings

Resistance to chemicals

Allow the coating to cure according to the manufacturer's recommendation. Place the chemicals concerned in contact with the cured coating and assess for actual coating, colour change or breakdown at different moments in time. If the chemicals are volatile they can be covered with a watch glass or a petri dish, or even an ordinary drinking glass (see fig. 36).

N.B. A spray gun is used to apply the coatings on the panels to perform the above tests.

The tests suggested are not exhaustive nor are they meant as substitutes for various precise official methods such as the British Standard test methods. They are suggested as simple test that can be easily performed in furniture factories.

The equipment shown in figures 28, 33 and 34 are more expensive equipment found at paint factories or various official testing laboratories. They have been inlcuded in the text for academic interest.

Annex I lists British Standards referring to testing methods for various characteristics. Reading these standards is highly recommended. They can be obtained at the National Standard Bureaus or they can be purchased through the

British Standard Institution
2 Park Street
London W1 A 2BS
Great Britain

Other standards include:

ISO: International Standards Organization
ASTM: American Society for Testing of Materials
DIN: Standards of the Federal Republic of Germany
AFNOR: French Standards.
JIS: Japanese Standards
IS: Indian Standards
AS: Australian Standards

A list, and details of these have not been included due to lack of space.

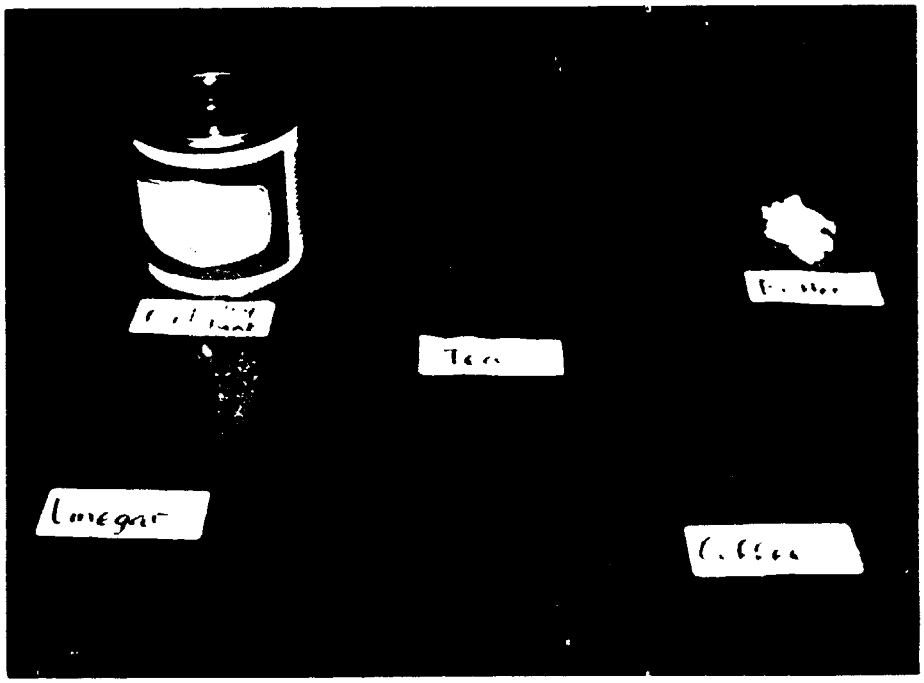


Fig. 36: Test of the resistance of an acid catalysed varnish to various household chemicals.

Notes on safety principles for paint factories.

1. Building and factory layout should comply to local safety regulations.
2. Adequate ventilation and air renewal should be provided by allowing air entries fitted with dust filters and forced air exits being flame-proof extractor fans.
3. Adequate fire extinguishers and fire fighting facilities should be made available - according to local legislation.
4. No smoking should be allowed in the factory.
5. All electric motors, fittings, lighting and wires should be flame and explosion proof.
6. All manufacturing equipment should be properly grounded (electrically earthed) to prevent static electricity sparking in dry weather conditions which could initiate a fire or explosion. This is particularly important when using a Cowles dissolver/disperser to dissolve nitrocellulose resin in volatile esters and ketone solvent and low boiling aromatic diluents such as toluol. Sparking due to static build-up may occur between a sharp edge on the rotating shaft and the metallic manufacturing vessels thus both the Cowles mixer and the manufacturing vessel should be properly grounded (earthed).

7. Adequate safety equipment should be provided to the work force.
   (a) Respiratory masks when spray painting and handling toxic pigments (see paragraph on pigments) (see fig.
   (b) Protective goggles, aprons, gloves and boots should be worn when handling corrosive or poisonous liquids.
   (c) Protective (industrial) boots should be worn at all times in the factory.
   (d) No loose clothes, belts, ties, hair hat, should be allowed on workers operating machinery.
8. The factory floor should always be kept clean, dry and not slippery.
9. No moving parts, gear, flywheels, etc. should be left without a proper guard.
10. All waste (washing) water should be safely disposed of, since inflammable solvent and paint residue may be present.
11. When using Cowles or trifoil dissolvers, all manufacturing vessels must be properly secured before starting the mixer.

Fig. 37: Spray painter wearing an adequate respiratory mask for paint dust.

Paint application

Paint and varnishes can be applied in a large number of ways, depending on the end product required, the output required and the final characteristics of the cured coating.

The usual coating application methods are listed below:

Brush (manual application)
Roller (")
Knife filling and stopping (")
French polishing (")
Waxing (")
Air spray
Pressure fed air spray (hot/cold)
Airless spray
Hot airless spray
Electrostatic spraying (of liquid paints)
Automatic spraying (of any one of the above methods)
Spray application of two component materials
Dip coating
Barelling (Tumbling)
Flow coating
Roller coating
Curtain coating
Powder coating (fluidized bed and electrostatic spraying)
Electrodeposition.

Brush application

The paint brush is made of natural (animal) bristles (pig or horse) or of synthetic bristles such as nylon.

The paint is taken up in between the bristles when the brush is dipped into the paint. In fact each bristle is somewhat fibrous and paint droplets are also taken by the bristle themselves.

When the brush is pressed on the surface, paint is forced out from the brush onto the surface.

The brushing action has the advantage of improved wetting of the surface by the paint which results in improved adhesion and paint protection.

Beautiful 'lacquered' finishes can be obtained by correct use of a good paint brush and judicious thinning of long oil alkyd enamels (for example: which has a near Newtonian flow).

The important thing with a brush is that the paint flows after the brushing action. Quick drying paints and paint having pseudoplastic characteristics (see viscosity) do not produce beautiful smooth and glossy finishes with brush application since they do not level out properly once the brushing action (shear) is stopped.

Brush application is cheap in material investment but time consuming (slow) and labour intensive. It is not suited for in line high rate production of furniture items for example.

Roller application

A roller can be considered as a cylindrical brush, but it has less 'brushing action' than a brush.

Roller application seldom achieves the quality finish that can be obtained with good brushing practice.

Roller application is much more rapid than brush application and is suited for application of decorative coatings for interior and exterior of buildings, and or protective coatings of ships' hulls and various other large surfaces.

Various sorts of rollers with long and short hair or bristles, of natural (lambs wool) or synthetic origin (acrylic or nylon) are available. There are also 'sponge' and 'rubber rollers' with various designs in relief on the surface. Each sort of roller is suited to a specific purpose, the sponge rollers being used for the application of textured coating on buildings while the 'rubber stamp' rollers can print various design on a surface.

Certain rollers are made to be resistant to various strong solvents which are present in certain coatings.

A roller is used with a tray (to pick up the paint). Rollers can be fitted with 'man helps' of various length. These are light poles fitted to the handle of the rollers. They give access to high surfaces without the use of expensive scaffolding.

Knife filling and stopping

This is the use of the various 'painters' knives' to apply various putties and fillers into holes, cracks and various imperfections found on the surfaces to be coated.

A large spatula can also be used to apply a high solids filler paste on porous wood or concrete surfaces. This minimises the use of many coats of primer and undercoats. High solid filler paste can be formulated to be quick (air drying) and possessing excellent dry sanding characteristics (i.e. they do not require water for sanding down, and the dust produced in sanding does not clog the sand paper).

These fillers are useful for 'one off' or short series production of lacquered wood, plywood or particle board furniture. Their dry sanding characteristics avoid wetting of the wood, they dry quickly and if used correctly can be overcoated directly with the finish coat.

Putties and fillers for the furniture industry consist of:

Adhesive/wood dust mix: These are usually prepared on site by mixing the appropriate wood dust with the adhesive such as Polivinyl acetate (white glue), urea formaldehyde glue, various animal glues, two pack epoxy glues. Resorcinol/formaldehyde glues are dark coloured and cannot be tinted and filled with wood dust to make a filler composition, moreover they are too expensive for this use.

Two pack polyester fillers: They are catalized with a peroxide and accelerated if necessary with a metal salt such as cobalt napthenate.

These are solvent free and contract very slightly on using (maximum 2%), thus they can be applied in thick coats without the risk of 'crater' formation or cracking when fully cured. They are available off the shelf pretinted to match various commonly used species.

They are usually quite cheap since they are heavily filled with extendiers. They have good dry sanding characteristics and are compatible (are not softened) with most (if not all) usual top coats when cured.

They are also available for use on metallic furniture where they exhibit good adhesion. Depending on the formulation, they also support baking procedures. They can be formulated to have a certain degree of flexibility.

They are very suitable for filling imperfection on G.R.P. (glass reinforced polyester) surfaces. Depending on the resin used in their manufacture, unmixed polyester fillers can gel on long storage in tropical conditions.

Two pack epoxy fillers: These are quite expensive but possess excellent anticorrosive characteristics coupled with great chemical inertness and excellent adhesion to various substrates.

When cured, they can be machined (turned, polished) to very smooth surfaces.

Their use is tricky since the recommended hardner/base mixing ratio should be strictly observed. This often necessitates the use of a scale (balance). Also the 'pot life' of the base/hardener mix is usually quite short (of the order of a few minutes for 100 g of mix at 25°C). Longer pot life can be obtained by choosing different base/hardener combinations, but this implies longer curing times.

Epoxy fillers are solvent free (100% solids) and exhibit practically no contraction in volume when curing. The curing reaction is exothermic (dissipates heat) and if a certain amount (say 1 kg) of unused base/ hardener mix is left it will react and heat up. For high reactive clear resin/hardener mix, the mixture may even start boiling. However, in filler composition due to the presence of various extenders the heat dissipation is less. Unmixed epoxy base/hardner are usually very stable on storage. Two pack epoxies can be baked at temperatures up to 140°C for a few minutes.

One pack quick drying nitroputties: These are based on a blend of Nitrocellulose alkyd resins. Other resins and plasticisers are also incorporated. The finished products usually contain 75-85% solids, and are available in various shades to match common species. They must not be applied in thick film in excess of one millimeter, since they will crack and craze on drying due to reduction in volume resulting from solvent loss. When dry (overnight) they can be overcoated with most usual furniture finishes. However, some coatings containing strong solvents may soften these nitro putties (so better check with the supplier).

These products are also formulated for application to metallic surfaces and G.R.P. surfaces. However they have the same limitation as those for wood surfaces.

They can be formulated to have as good dry sanding characteristics as polyester or epoxy fillers.

They are not recommended for baking conditions in excess of 100°C. If the subsequent finish needs to be 'low baked' it should be ensured that the putty is hard (dry) to prevent bubble formation from entrapped solvent.

Miscellaneous filler compositions: Apart from mixing wood dust with adhesive, fillers are also sometimes prepared by mixing various paints and varnishes and drying oils with wood dust, whiting, iron oxide or pigments available on the retail hardware market. Depending on the finishing system he is using, each tradesman has his own filler 'recipe' apart from those ready made we have just mentioned.

These personal 'recipes' are mostly used on solid wood, plywood or particle board trade, not for metallic furniture, Usually they are not suited for industrial serial production or for baking procedures.

French polishing

This old time and effort consuming finishing method is based on the use of alcohol soluble shellac (secreted by the insect Tanifer tana and deposited on the twigs of trees in India) varnish. The varnish is easily prepared by dissolving the shellac in alcohol (methylated spirits). Various grades of shellac (more or less refined) are available.

The process consists of applying with a dabber a large number of successive coats of the varnish.

The dabber consists of cotton wool enclosed in a fluff free cotton cloth. The wood is soaked with varnish and a circular motion of the hand is used to apply the varnish.

To seal the pores of the wood, powdered pumice stone or talc or fine silica is usually incorporated in the varnish or sprinkled and rubbed on the varnished surface. Excess is wiped and/or snaded off before applying further varnish. Too much powder will cause unisghtly whitish streaks and spots in the finished job. (Apart from their sealing properties, these various powders also produce a polishing action when rubbed on the varnish surface).

To give the final luster, the fully dry varnish system is wiped with a clean dabber moistened with alcohol (methylated spirits).

French polishing provides a good wetting of the wood surface and a superb finish having 'depth'. It is suited to the restoration of antiques, or the finishing of high quality reproduction furniture.

It is coupled with various processes of dying and colouring the wood. Also various dyes, colorants or pigments can be incorporated to the varnish to achieve desired shades.

Tradesmen use various iron oxides and lamp black. They sometimes obtain their lamp black by collecting the soot produced from the incomplete combustion of oil, kerosene or candles.

Waxing

Some furniture styles and some woods do not lend themselves to varnishing or lacquering. The finishing method used in this case is waxing which may be used in conjunction with a clear or tinted sealer coat. The wood can be bleached or tinted before the sealer coat. The wax can be used clear or tinted.

The sealer coat is usually based on a drying oil such as boiled linseed oil or a long oil alkyd or air drying polyurethane oil (quicker drying) containing various extenders to make it mat and increase its solid content thus improving its sealing properties. These sealers are formulated to have good dry sanding properties.

Waxes generally used are:

Beeswax: which is available in various grades (bleached or raw). Melting range 62-65°C, and is slightly soluble in alcohol and soluble in oil among others.

Ozocerites: which are a mineral wax of fossil origin. Grades vary from yellow brown to black green. They are soluble in Kerosene and turpentine among others (melting range 55-110°C).

Ceresins: which are purified ozocerites.

Carnabua: which is the hardest most expensive commercial wax available. It is in the form of yellow to greenish brown lumps. It is produced by the leaves of a Brazilian tree (Copernica cerifera). It is soluble in boiling alcohol among other solvents. (Melting range 84-86°C).

Paraffin wax: White transluscent, tasteless and odourless solid derived from crude petroleum cracking. It is soluble in benzene (C_6H_6), warm alcohol and turpentine. Melting range 45-65°C.

Depending on the formulation the waxes (or wax polishes) can be applied hot in the molten form, dissolved in an appropriate solvent or in emulsion.

Wax based finishes can be modified with various compatible resins or drying oil to yield products with intermediate characteristics.

Waxing is not suited to mass production and furniture coated in this way must be regularly maintained by polishing (with an adequate polish composition) to maintain its original lustre.

Air spray

The principle of air spraying is: when a fast flow of air passes over a capillary tube filled with a liquid, a vacuum is produced on top of the capillary tube which causes the liquid to be sucked up and vaporize (atomize) in the air flow.

An air spray gun in an improved version of this atomization principle.

According to the way in which the paint is fed to the atomization area, air spray guns can be classified as:

- suction fed,
- gravity fed,
- pressure fed.

Depending on the way in which the paint is atomized at the tip (air cap) of the spray gun, two types of air caps are available namely:

- internal mix air caps used only on pressure feed guns,
- external mix air caps used on suction feed guns

Fig. 38 illustrates the working principle of a suction feed spray gun with an external mix air cap.

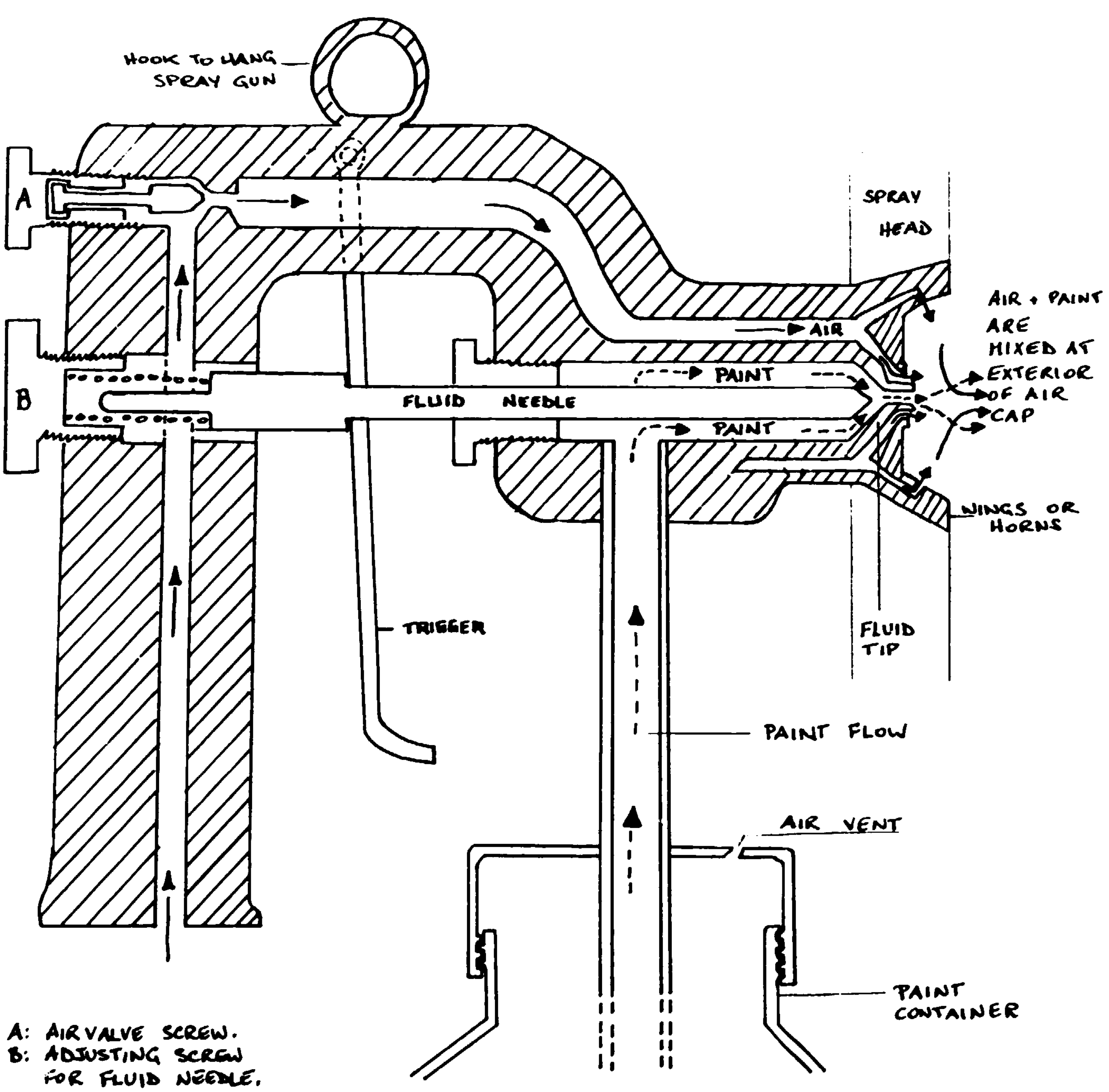
Fig. 39 to 40 show some of the spray guns available.

Considerable details on air spray gun construction, operation and characteristics are available in the trade literature.

Prices for 'similar' spray guns can vary enormously but one usually gets what one pays for.

Apart from the spray gun itself, the following pieces of equipment are essential for spray painting:

- air compressor
- air transformer
- air lines
- pressure regulator.



A: AIRVALVE SCREW.
B: ADJUSTING SCREW FOR FLUID NEEDLE.

Fig. 38: Simplified cross-section through a suction-fed spray gun.

Fig. 39: Suction fed air spray gun.

Fig. 40: Pressure fed air spray gun.

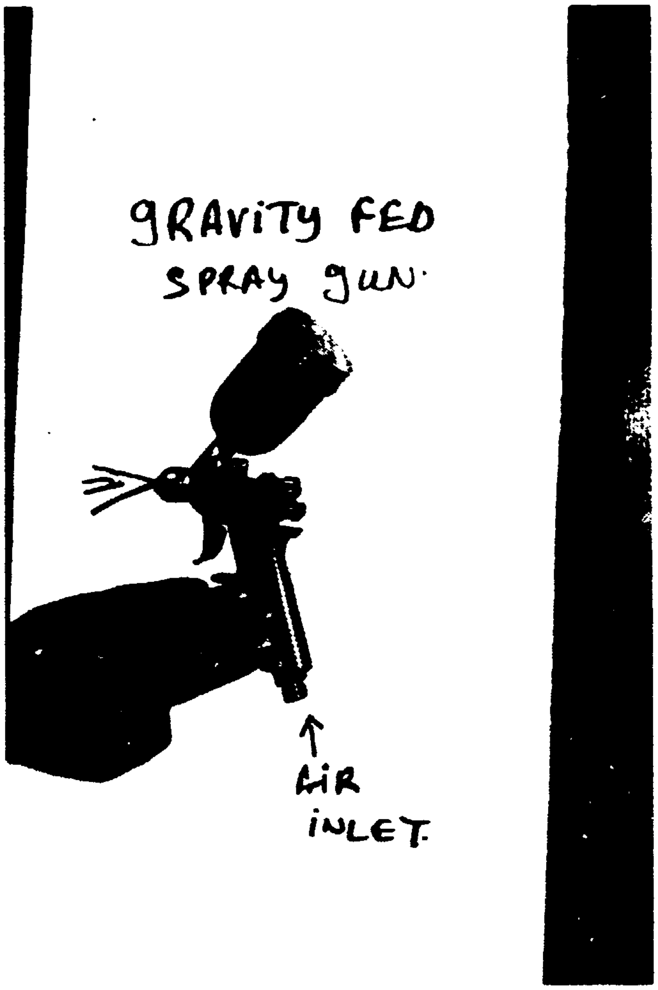


Fig. 41: Gravity fed air spray gun.

Safety measures

Since air spray painting produces air pollution and involves highly volatile, toxic and inflammable materials, a number of safety measures need to be taken.

Painters need to wear an appropriate respiratory mask and even goggles in certain instances (see fig. 37). Painting is best performed in spray booths or chambers which must be provided with flame and explosion proof electrical fittings, with flame proof extractor fans and with a fibre glass (or other type of) air filter unit (dust extractors) to minimize air pollution.

Also no smoking should be allowed when and where spray painting is being performed. Apart from the fire hazard, the heat of the cigarette may decompose various solvents and paints into toxic products, which will then be inhaled. Fire extinguishers should be present (Appendix II gives a list of British Standards, some of which refer to safety conditions.)

Air compressors

A large number of makes and a large number of types of air compressors are available, some are huge fixed machines for continuous industrial operation; others can be rolled around, some can be transported at arm length and still others, suitable for the do-it-yourself - amateur - market, are available as an accessory to 'power tool' hand drilling machines.

Principles of operation

Two main types of compressors exist: piston (reciprocating) compressors and centrifugal (rotary) compressors.

Both types need to be driven either by an electric motor or by an autonomous internal combustion engine (two or four strokes, gasoline, diesel or even kerosene fired).

Piston type compressors

These are the ones most commonly encountered for spray painting. They are available as single stage with or without compressed air storage tanks and multi-stage with compressed air storage tanks. For multi-stage, high capacity and high pressure compressors, a water or air cooled heat exchanger is fitted to the compressor since compressing air produced heat which must be removed before the compressed air is stored or utilized.

The compressed air, from the compressor needs to be supplied to the spray gun at a specified pressure, thus a pressure regulator needs to be fitted between the compressor and the spray gun, to step down to the utilizable level and a manometer needs also to be fitted after the regulator to be able to determine (read) the actual air pressure being supplied.

The 'low pressure' compressed air from the pressure regulator is not 'clean air'. It contains various contaminants such as oil from the compressor and water from the moisture in the air. These are mixed with the paint when sprayed and will cause various paint defects.

Thus, an air transformer is fitted (see fig. 42) on the air line before the spray gun. This equipment filters the air and separates out any moisture present which can then be bled off. Various designs of air transformers are available, some are fitted with air regulators and one or two manometers to be able to determine the air pressure before entering and after leaving the air transformer. Such an air filter without manometers and regulator is called an air condenser.

From the compressor to the air transformer, there is usually a metallic non flexible, fixed air line.

Form the air transformer to the spray gun, the compressed air is carried by a flexible line of variable length and variable cross section.

The longer the air line and the smaller its internal diameter, the higher will be the pressure drop from the air transformer to the spray gun, due to increased resistance to air flow encountered in long pipes of small internal cross section.

Fig. 42: Air transformer fitted between compressor and spray gun to remove water and oil from compressed air.

Air spraying techniques

Spray gun settings

It is assumed that the compressed air reaching the spray gun is free from moisture and oil, that the paint is of the correct viscosity (as can be checked with a Ford cup No. 4 for example, see fig. 47), and that the compressed air pressure is constant.

Referring to Fig. 39, (suction feed air spray gun), it can be seen that there are at least four settings that can be varied in this type of spray gun.

1. The air valve screw A can be opened more or less to allow more or less compressed air in per unit time.
2. The fluid needle adjusting screw B which controls the maximum movement allowed to the fluid needle and thus control the volume of paint allowed in or atomized per unit time.
3. The trigger movement which controls the actual movement of the fluid needle and thus at any moment in time the volume of paint that passes through the fluid tip and is atomized in the air cap.
4. The direction of air cap i.e. whether the two 'horns' at either side of the air cap are directed in a vertical or horizontal plane with respect to the fluid needle axis.

Direction and patterns of spray cone

In actual spray guns, the air cap and fluid tip are not cast as one piece but are separate parts fitted (screwed) to the core of the spray gun. Thus the air cap and its two 'horns' (in an external mix air cap) can be swivelled around the axis of the fluid needle to provide various spray patterns, thus changing the direction of the spray cone. Thus, when the operator holds the spray gun so that the spray head points away from him, if the air horns of the air cap are in a vertical plane, the spray pattern is horizontal (see fig. 43), whilst if the air horns are in a horizontal plane, the spray pattern is in a vertical plane (see fig. 44).

In the first case (vertical air horns and horizontal spray pattern) the painting motion is in a vertical plane, while for the second case (horizontal air horns and vertical spray pattern) the painting motion is in a horizontal plane.

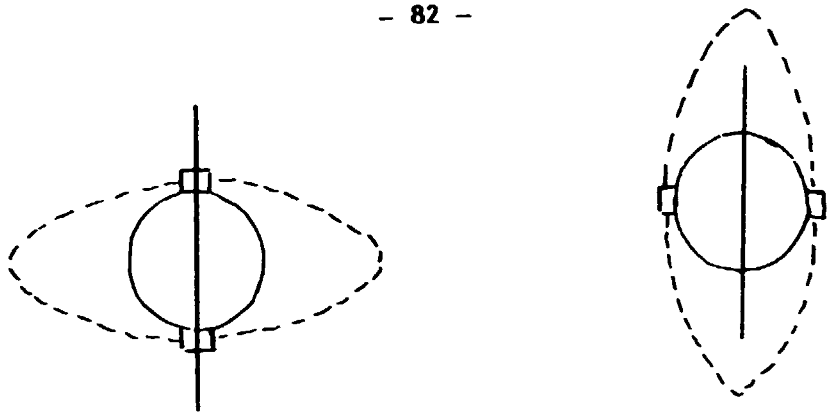


Fig. 43: Air horns vertical Fig. 44: Air horns horizontal

Effect of direction of air horns with respect to spray pattern

Various spray patterns defects are shown in fig. 45 (a,b,c,d, e and f). They may result from problems such as clogging of one or more of the various air vents on the air cap horns or clogging of various parts of the fluid tip and fluid needle.

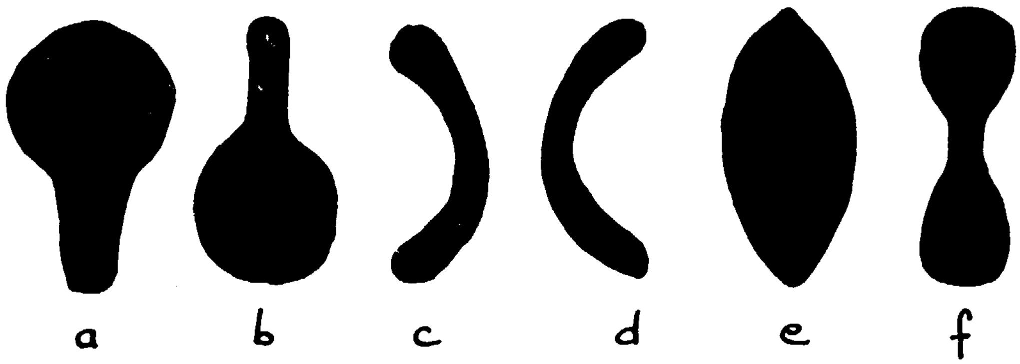


Fig. 45: Legend:
(a) top heavy; (b) bottom heavy; (c) heavy rightside;
(d) heavy left side; (e) heavy center; (f) split-spray

Apart from the four settings metnioned above, a specific spray gun can be fitted with different air caps, fluid tips and fluid needles to suit a variety of uses.

As a general rule, to minimize overspray and paint dust formation, paint should be sprayed at the lowest air pressure possible (other factors remaining constant).

Tables of data concerning the air pressure drop along air line of various cross section are a useful aid to estimate actual air pressure at the spray gun. A few indicative figures are given in Table 1.

Table 1: Indicative figures for spray gun operation.

	Air-pressure drop at spray gun, psi					
Inside Diameter	5-ft length	10-ft. length	15-ft. length	20-ft. length	25-ft. length	50-ft. length
1/4 in.						
At 40 psi	6	8	9½	11	12 3/4	24
At 50 psi	7½	10	12	14	16	28
At 60 psi	9	12½	14½	16 3/4	19	31
At 70 psi	10 3/4	14½	17	19½	22½	34
At 80 psi	12¼	16½	19½	22½	25½	37
At 90 psi	14	18 3/4	22	25¼	29	39½
5/16 in.						
At 40 psi	2¼	2 3/4	3¼	3½	4	8½
At 50 psi	3	3½	4	4½	5	10
At 60 psi	3 3/4	4½	5	5½	6	11½
At 70 psi	4½	5¼	6	6 3/4	7¼	13
At 80 psi	5½	6¼	7	8	8 3/4	14½
At 90 psi	6½	7½	8½	9½	10½	16

Paint characteristics for air spraying

The paint viscosity must be such that it can be sucked up (in a suction feed spray gun) that it can flow down (in a gravity feed spray gun) and can be pressed into (in a pressure feed system) the adequate spray gun.

Gravity feed and suction feed spray guns can atomize paint of lower viscosity than pressure feed spray guns. Since the paint, primer, sealer or varnish is usually supplied at a viscosity higher than that required, the paint has to be diluted with adequate thinners before use. Thus some means of measuring the extent of dilution or the effect of adding thinners on the viscosity of the paint is needed. Since many paints have a near Newtonian flow at spraying viscosity a Ford cup or sometimes a Zahn cup (both are efflex cups) are used to measure the viscosity at a specific temperature (since viscosity decreases with increase in temperature). See fig. 26 for use of a Ford cup No. 4.

Spraying flat surfaces (eg. table tops)

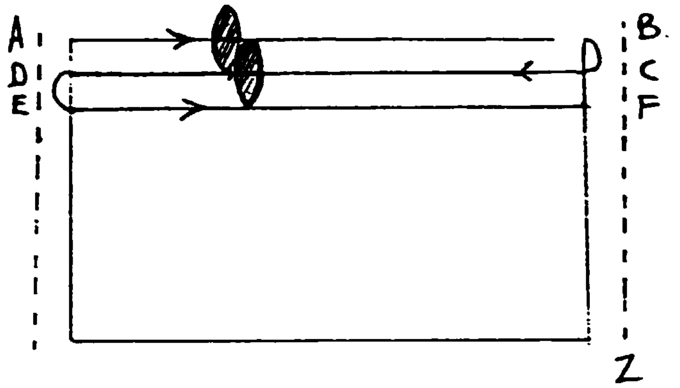


Fig. 46

Spraying of flat surface with horizontal movement of the spray gun and 50% overlap of the spray cone pattern between successive coats.

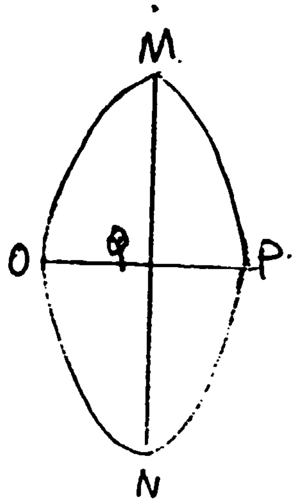


Fig. 47

Vertical spray cone pattern

MN: Vertical diameter of spray cone pattern obtained at surface being coated when spraying distance is 20 cm.

OP: Horizontal diameter of same

Start the spraying stroke at A (see fig. 46) such that half or part of the spray gun cone pattern falls outside the flat surface being coated. Continue the stroke at the correct spraying distance of 20 cm between the spray gun tip and the surface until the spray fan pattern falls outside of the surface and meets line BZ.

Bring the spray gun down a distance which is equal to half the vertical diameter of the spray cone pattern (see fig.47) and starting from C (which lies along the vertical line BZ) spray a continuous stroke (at the right spraying distance) along line CD and until D is reached.

This procedure is repeated until all the surface has been coated. This technique has two main characteristics:

(i) The spraying stroke is started outside the panel so that good covering of the edges are obtained.

(ii) A 50% overlap is obtained between successive parallel strokes. This allows good coverage and uniform film thickness of the coating to be achieved.

When successive coats are needed to achieve the required finish the second coat should be applied so that the spraying strokes are at right angle to those of the first coat. The same overlapping technique is used for each coat as for the first coat.

To reduce overspray the technique described above can be modified into what is known as the **banding technique.**

Instead of starting the horizontal strokes along the AX and BZ (see fig. 46), a vertical stroke is sprayed along both vertical edges and the horizontal spraying pattern as described above is performed except that the horizontal strokes are started at one edge of the surface and stopped at the other edge (instead of starting along AX and stopping along BZ).

To perform the spraying method described above, it is recommended that the flat surface be held inclined on a rack at a sharp angle for easy access, since as a general rule, it is better practice to incline the surface to be painted than the spray gun.

Spraying a level surface (such as a table top resting on its base)

When spraying such surfaces, start on the side nearest to you and using the technique described above move to the far side. This allows the overspray (dry spray) to fall on the part of the surface which is still uncoated and thus does not damage the appearance of the coated portion.

When performing such work, it is necessary to tilt the spray gun so as to try and obtain as much as possible a right angle (90°) between the spray gun axis and the surface being coated.

N.B. When tilting the spray gun, it should be remembered that it is not advisable to tilt suction fed or gravity fed spray guns (see figs. 39 and 41 respectively), since the coating may spill through the vent hole. Pressure fed guns which do not have vent holes (refer to Fig. 40) are more appropriate when tilting the spray gun cannot be avoided.

Spraying outside corners

To spray the outside corners of a box or square piece of furniture, the gun is held vertically opposite to the corner and a vertical spraying stroke is performed thus coating both sides of the corner.

Form the corner edge and following the banding technique described above, the flat surfaces from the corner are coated with successive horizontal strokes allowing as usual 50% overlap.

To spray the edge of a table top the spray gun is directed towards the edge so that a straight line from the edge and through the spray gun axis makes an angle f 45° both to the horizontal table top and to its vertical edge.

When spraying in this fashion, both the vertical cross section and the horizontal outer edge of the table top are sprayed in one go.

Spraying inside corners

For a quick spraying of inside corners, the spray gun is held vertically opposite to the vertical edge of the corner and a vertical stroke is performed. This method has the disadvantage of producing a thin coating at the tip of the corner and a thicker coat of paint at either sides adjacent to the corner.

Another method consists of spraying each side of the corner in a vertical stroke, the spray gun travelling in a parallel plane to that of the surface adjacent to the one being coated.

From this vertical stroke the rest of the panel is coated with overlapping horizontal strokes in the usual manner.

Spraying table legs

First an adequate spray cone pattern should be used. It should be of a size sufficient to cover the job but small enough to avoid excessive overspray.

Table legs or other slender work are better sprayed with a horizontal spray pattern while the legs are held vertical and the spray gun also travels in a vertical plane.

Depending on the diameter of the work,several vertical overlapping strokes may have to be performed.

Spraying large cylindrical shapes

Large vertical cylinders are usually sprayed like flat surfaces except that the horizontal strokes are short.

Vertical cylinders of smaller diameter can be sprayed like table legs with overlapping vertical strokes.

Drying time

Very fast drying paints (containing very fast evaporating solvents)_ cannot be sprayed since they may form 'spider webs' from the spray gun or they will not have enough time to flow evenly on the surface after spraying and thus cause 'dry spray'.

In very humid conditions, some fast drying paints , when sprayed on metallic surfaces, exhibit the phenomenon of blushing or blooming. This can be explained when we know that solvents (thinners) in the liquid state need to obtain the latent heat of evaporation from the substrate and surroundings to evaporate. Quick evaporating solvents on metallic surfaces take their heat of evaporation quickly from the metallic surface (which is a good conductor of heat). This cools the metallic surfaces and the paint below dew point for the ambient humidity conditions. Thus moisture condenses on the paint film (which acts as a barrier between the metal and the surroundings) and the result is a whitish discoloration of the paint film due to precipitation of the binder (known as blooming or blushing).

This phenomenon can be prevented by using a slower evaporating thinner (retarder) when spraying in very humid conditions, or by warming up the surface to be painted using for example infra-red lamps.

Paint straining:

Although paint makers take great care to ensure that the paint they supply is dirt free, it is recommended to strain the diluted paint through a muslin cloth before spraying.

Spraying distance and a few tricks of the trade

The spray gun should be held at a certain distance, usually twenty centimeters (about eight inches) from the tip of the spray gun to the surface being painted. Furthermore, the axis of spray gun (along the fluid needle) should be kept at an angle of ninety degrees (both in the horizontal and vertical planes) to the surface being painted.

If the spray gun is held too far from the surface, the paint will be deposited in droplets and in a 'close to dry' stage, thus flow on the surface and adhesion (in extreme cases) will be impaired. This defect is referred to as 'dry spray' (the same effect may be observed when the pressure of the compressed air is too high or when the thinners used evaporate too fast).

If the spray gun is held too close to the surface, too much paint in a very 'wet' stage will be deposited on the surface and sagging or weeping of the paint will result.

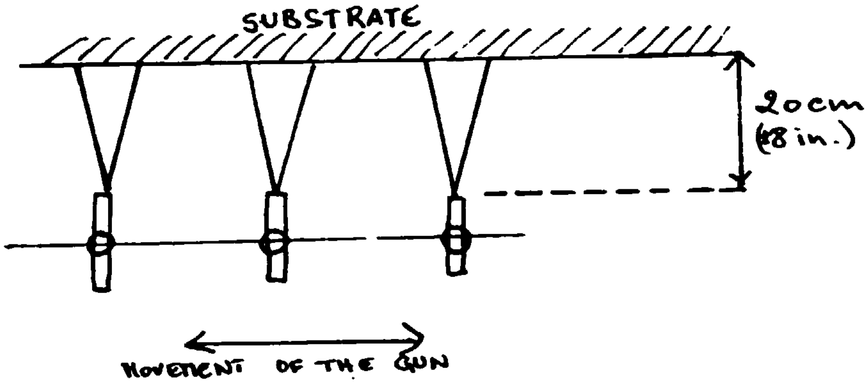


Fig. 48: Correct spray motion

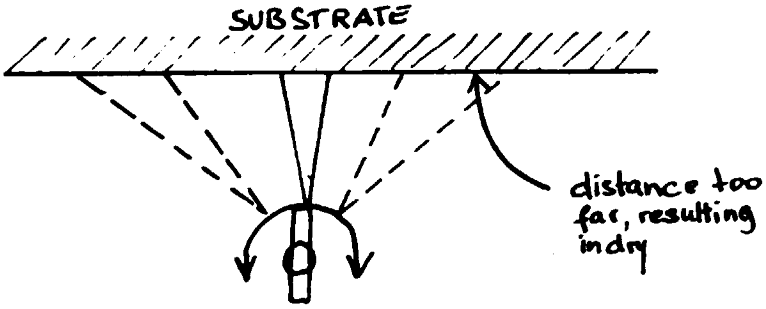


Fig. 49: Incorrect spray motion

Pressure fed spray guns

Their advantage is that paints of higher viscosities can be used, and thus savings are achieved both on solvents and the number of coats of paint to be applied.

Solvents are toxic, inflammable, expensive, a source of pollution and are lost when they evaporate form the coating.

When paints need to be diluted for application with an air spray their solid content is reduced, the film deposited is thus thin, this necessitating a larger number of coats thus increased labour cost and longer production time.

The disadvantage of pressure fed spraying compared to air spraying is that the initial capital outlay for equipment is usually larger.

Principle of operation

Apart from the air cap, (pressure fed guns have internal mix air caps) the spray gun itself is similar to non-pressure fed air spray guns.

If the paint container is attached to the spray gun, then it is completely air tight as compared to the paint container of non pressure fed guns which have an air vent so that the paint may be sucked up.

A certain maximum air pressure is specified for pressure fed guns with paint container attached. Exceeding this pressure will tend to blow or inflate the paint container.

For continuous in line production, the paint container of pressure fed guns is separated from the gun itself.

This container usually has a capacity in the range of five to twenty five litres as compared to the one liter capacity normally available when then paint container is attached to the spray gun.

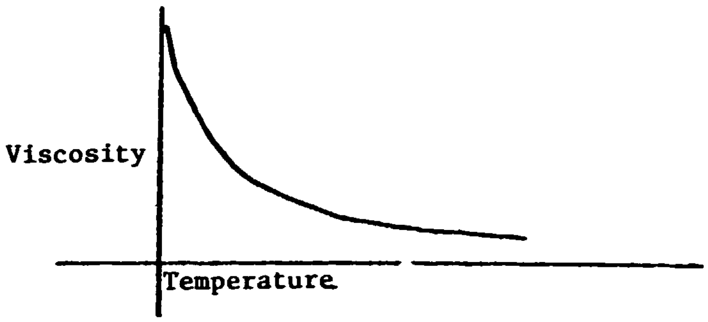
The remote container is avaialble with a stirrer usually air driven, if there is a tendency for certain heavy pigments to settle out from the paint, such as zinc powder in zinc rich primer, or aluminium and bronze powders or flakes in certain metallic or hammer finish paint formulations.

Figure 40 shows pressure fed spray gun with an attached container. It is rated to work at a maximum pressure of 50 psi. As can be observed from the photograph, this pressure has been exceeded since the paint container is swollen at its base.

To achieve an air tight seal this container is screwed to its cover whereas for non-pressure fed spray gun the container is of the clamp on type.

Hot air spraying (pressure fed)

Increasing the temperature of a paint (up to a certain limiting temperature, lower part of the curve) reduces its viscosity.



Instead of reducing the viscosity of a paint by diluting it with adequate thinners, the paint can be warmed or heated to a specific temperature.

Some advantages of hot air spraying are:

- No need for thinners with all their disadvantages (already mentioned).
- Less coats of paint (since the heated paint is sprayed at higher solid content).
- No blushing on cold metallic surfaces in conditions of high ambient humidity (since there is less thinner and the thinner which is present has a higher boiling point and the paint itself warms the surface so that the dew point is not reached).
- Better flow of paint and reduced 'orange peel' and dry spray. It is high temperature and not thinner that is responsible for the flow of paint. When fast evaporating thinners are used the paint sometimes reaches the surface as dry spray (if the air pressure is too high, or there is too much air for atomization, or the spray gun is held too far from the surface) and thus does not flow.
- Quicker setting of the paint when it hits the cool surface, thus reducing sagging and weeping tendencies when thick films are applied.
- Constant paint temperature keeps spraying viscosity constant.

Principle of operation

A paint heater is incorporated between the storage tank and the spray gun. From the heater to the spray gun, the paint is carried in a special lagged line to reduced heat loses.

The paint is usually heated by passing thorugh a heat exchanger that itself contains circulating hot water that is heated electrically in another heating tank.

This process ensures that the paint itself is not in direct contact with heating elements, thus reducing risks of localized overheating of the paint and also fire risks.

Electrostatic spraying

This method of spraying can be used to apply both certain 'powder coatings' and specially formulated liquid paints.

The principle resides in the fact that particles with similar electric charges repel, and that these same particles can be attracted to an object bearing an opposite electrical charge.

Thus by providing an electric charge to atomized liquid paint particle (as those produced in normal air spray) and providing an opposite charge to the object to be sprayed, the paint particles will ideally be attracted to the oppositely charged object and will be deposited in a uniform film.

A number of methods of charging the atomized paint particles either in air or airless spraying or the powdered point have been devised for both automatic and manual spray guns.

The Ransburg No. 1 process developped before the second world war was the original application of the electrostatic principle.

Basically, it consisted of a conventional air spray gun, automatically triggered and spraying a mist of paint droplets into a powerful electrostatic field produced by charging a grid (or series of wires) arranged on each side of an earthed conveyor carrying the object to be painted. The static potential then produced was of the order of 100,000 to 130,000 volts.

In this process the paint is atomized at a minimum air pressure so the velocity of the paint particles is kept as low as possible. The object to be painted could be rotated while passing through the charged paint mist.

In the Ransburg No. 2 process compressed air and the conventional spray gun are eliminated.

Paint, diluted to about 15 seconds Ford Cup 4, is carefully metered (pumped) into the spray gun whose tip consists of a rotating metal bell whose outer sharp edge is charged to a potential of 90,000 to 100,000 volts. The bell is rotated by an electric motor at speeds of the order of 1,000 rpm. This rotation causes the paint to spread centrifugally towards the charged tip, where it is charged and atomized to a fine mist. With the bell the spray pattern obtained is in the form of an annulus.

Based on the above principle, many devices have been produced by spray equipment manufacturers. Each manufacturer claims to combine specific advantages with minimum disadvantages.

A few advantages usually attributed to electrostatic spraying compared to conventional spraying methods (air spray, pressure fed, airless) are:

- Great paint savings due to the 'wrap around' effect of the charged paint mist which deposits itself on the earthed object, instead of being wasted due to overspray (specially important for objects like expanded metal tubular steel work).
- Better coverage, more uniform deposition of the paint on the object being painted.

Paints suitable for electrostatic spraying

Most paints are suitable or can be rendered adequate for electrostatic spraying. Although no hard and fast rule applies, the resistance of the paint should lie between 100,000 to 1,000,000 ohms. Resistance of paints can be adjusted using appropriate solvents. Addition of polar solvents such as methyl iso butyl ketone (M.I.B.K.), butanol, or di-acetone alcohol reduces the resistance of the paint.

There exist in the trade 'paint resistance meters' which provide a direct reading of the resistance of a given paint by immersing an electrode into the paint.

Apart from its electrical resistance, characteristics of the paint such as viscosity and evaporation rate of the solvents are important for spraying performance.

Electrostatic powder spraying

Similarly to liquid paint spraying, the aerated powder is fed to the spray gun where the powder is charged by various means and carried towards the earthed article to be painted. According to the type of powder being used, a positive or negative charge potential can be used. Epoxy based powder generally give better results with a negative potential, while thermoplastic powders such as nylon give a better result with a positive potential difference.

The article to be coated can either be warmed (hot) or cold. Hot articles will result in a thicker final film, all other parameters being constant.

Airless spraying

In the search for applying high solids coatings quickly, to increase output, an improved spraying method was designed.

This spraying method is not based on the air atomization principle. No air is required and the thick paint is pumped directly from the container through a strainer and into the spray gun at a pressure of the order of 3,000 psi where the paint is atomized through a specially designed tungsten carbide tip.

Since no air is required this system is called airless spraying.

It is well suited for mass production to apply a wide variety of coatings at thick film thickness, (one coat high build systems) on a wide variety of substrates.

Since the atomization pressure is very high, paint particles impinge on the surface with high energy which favours good wetting of surfaces being painted.

Airless sprays can be fitted with pole guns of up to six feet in length. These allow painting of ceilings or inaccessible surfaces without the use of expensive and cumbersome scaffoldings.

A few limitations and disadvantages of electrostatic spraying are:

High static charge which may be dangerous or cause inconvenience to operators.

Unsatisfactory coating of inside surfaces or recesses, and holes of surfaces due to the 'Faraday cage' effect implying that 'no electrostatic charge can exist inside a hollow conductor, the charge immediately passing to the outside of the conductor'.

Up to now electrostatic spraying of metallic (electrically conductive) objects have been considered. However, non-conducting material such as wood, plastic and glass can be sprayed. In that case, the surface is rendered conductive by a thin film of moisture.

APPENDIX I

LIST OF BRITISH STANDARDS TEST METHODS FOR VARIOUS COATINGS

BS 3900: Methods of test for paints

3900: General Introduction (1969)

Group A: Tests on liquid paints (excluding chemical tests)

3900 - part A1: (1984) Sampling.

3900 - part A2: (1983) Examination and preparation of samples for testing.

3900 - part A3: (1970) Standard panels for paint testing.

3900 - part A5: (1968) Large scale brushing test.

3900 - part A6: (1983) Determination of flow time by use of flow cups.

3900 - part A7: (1968) Determination of the viscosity of paint at a high rate of shear.

3900 - part A8: (1976) Determination of the danger classification by flashpoint closed cup method.

3900 - part A9: (1973) Determination of flashpoint closed cup method.

3900 - part A10: (1976) Determination of volume of dry coating (non-volatile matter) obtained from a given volume of liquid coating.

3900 - part A11: (1974) (1979) Small scale test for combustibility.

3900 - part A12: (1975) (1984) Determination of density.

3900 - part A13: (1978) Rapid test for determination of danger classification by flashpoint.

3900 - part A14: (1978) Rapid test for determination of flashpoint.

3900 - part A15: (1976) Determination of quantity of material in a container.

Group B: Tests involving chemical examination of liquid paints and dried paint films.

3900 - part B1: (1965) Determination of water by the Dean and Stark method.

3900 - part B2: (1970) (1984) Determination of volatile matter and non-volatile matter.

3900 - part B3: (1983) Determination of 'soluble lead' in the solid matter in liquid paints.

3900 - part B4: (1967) (1983) Determination of lead in low-lead paints and similar materials.

Group C: Tests associated with paint film formation

3900 - part C1: (1965) Wet edge time.

3900 - part C2: (1971) (1983) Surface drying test (Ballotini method).

3900 - part C3: (1971) (1983) Hard-drying time.

3900 - part C5: (1975) Determination of film thickness.

3900 - part C6: (1970) Determination of fineness of grind.

3900 - part C7: (1974) Pressure test for stackability.

3900 - part C8: (1978) Print free test.

3900 - part C9: (1982) Methods for evaluation of the compatibility of a product with a surface to be painted.

Group D: Optical tests on paint films

3900 - part D1: (1978) Visual comparison of the colour of paints.

3900 - part D4: (1974) (1984) Comparison of contrast ratio (hiding power) of paints of the same type and colour.

3900 - part D5: (1980) Measurement of specular gloss of non-metallic paint films at 20°, 60° and 85°.

3900 - part D6: (1982) Determination of contrast ratio (opacity) of light coloured paints using polyester film.

3900 - part D7: (1983) Determination of hiding power of white and light-coloured paints (Kubelka-Munk method).

Group E: Mechanical tsts on paint films

3900 - part E1: (1970) Bend test (cylindrical mandrel).

3900 - part E2: (1970) Scratch test.

3900 - part E3: (1973) (1979) Impact (falling weight) resistance.

3900 - part E4: (1976) (1983) Cupping test.

3900 - part E5: (1973) (1979) Pendulum damping test.

3900 - part E6: (1974) (1983) Cross-cut test.

3900 - part E7: (1974) Resistnace to impact (falling ball test).

3900 - part E8: (1974) (1979) Resistance to impact (pendulum test).

3900 - part E9: (1976) (1983) Buchholz indentation test.

3900 - part E10: (1979) (1983) Pull-off test for adhesion.

Group F: Durability tests on paint films

3900 - part F1: (1966) Alkali resistance of plaster primer-sealer.

3900 - part F2: (1973) (1983) Determination of resistance to humidity under condensation conditions.

3900 - part F3:	(1971) (1979) Resistance to artificial weathering (enclosed carbon arc).
3900 - part F3, Add.1:	(1978) Notes for guidance on the operation of artificial weathering apparatus to BS 3900 part F3 (1971).
3900 - part F4:	(1968) Resistance to continuous salt spray.
3900 - part F5:	(1972) Determination of light fastness of paints for interior use exposed to artificial light sources.
3900 - part F6:	(1976) (1984) Notes for guidance on the conduct of natural weathering tests.
3900 - part F8:	(1976) Determination of resistance to humid atmospheres containing sulphur dioxide.
3900 - part F9:	(1982) Determination of resistance to humidity (continuous condensation).

Group G: Environmental tests on paint films (including tests for resistance to corrosion and chemicals).

3900 - part G5:	(1976) (1984) Determination of resistance to liquids.
3900 - part G7:	(1976) Determination of the effect of heat.

Group H: Evaluation of paint and varnish defects.

3900 - part H1:	(1983) Designation of quantity and size of common types of defects: general principles and rating schemes.
3900 - part H2:	(1983) Designation of degree of blistering.
3900 - part H3:	(1983) Designation of degree of rusting
3900 - part H4:	(1983) Designation of degree of cracking.
3900 part H5:	(1983) Designation of degree of flaking.

BS AU:148 - Methods of test for motor vehicle paints

Part 2	(1969) (1984) Resistance to continuous salt spray.
Part 3	(1969) (1984) Flexibility and adhesion.
Part 4	(1969) (1984) Resistance to abrasion.
Part 5	(1969) (1984) Gloss measurement.
Part 6	(1969) (1984) Hardness

N.B. The following have been withdrawn:

3900 - part A4 (1979)
3900 - part C4 (1965)
3900 - part D2 (1967), D3 (1975)
3900 - part F7 (1973) (1979)
3900 - part G1 (1965), G2 (1965), G3 (1973), G4 (1967) (1979)

Part 9	(1969) (1984) Resistance to dry heat.
Part 10	(1969) (1984) Resistance to heat and corrosion.
Part 11	(1969) (1984) Resistance to blistering.
Part 12	(1969) (1984) Resistance to accelerated weathering.
Part 13	(1969) (1984) Resistance to deterioration by contact with other materials.
Part 14	(1969) (1984) Resistance to outdoor exposure.
Part 15	(1969) (1984) Resistance to chipping.

Note: AU:148 Parts1, 7 and 8 have been withdrawn.

BS 3962 - Methods of test for finishes for wooden furniture

Part 1	(1980) Assessment of low angle glare by measurement of specular gloss at 85^{o}.
Part 2	(1983) Assessment of surface resistance to wet heat.
Part 3	(1983) Assessment of surface resistance to dry heat
Part 4	(1980) Assessment of surface resistance to cold liquids.
Part 5	(1980) Assessment of surface resistance to cold oils and fats.
Part 6	(1980) Assessment of resistance to mechanical damage.

BS:5910 - Methods of test for surface finishes for furniture

Part 1	(1980) Assessment of surface resistance to cold liquids.

APPENDIX II

A FEW BRITISH STANDARDS RELATING TO FIRE EXTINGUISHERS AND SAFETY OF ELECTRICAL EQUIPMENT FOR EXPLOSIVE ATMOSPHERES

BS: 889	(1965) (1982) Flame proof electric lighting and fittings.
BS:5306	Code of practice for fire extinguishing installations and equipment on premises.
BS:5306 Part 1	(1976) Hydrant systems, hose reels and foam inlets.
Part 2	(1979) Sprinkler systems.
Part 3	(1980) Portable fire extinguishers.
Part 4	(1979) Carbon dioxide systems.
Part 5,section 5.1	(1982) Halen 1301 total flooding systems.
BS:5423	(1980) Specifications for portable fire extinguishers.
BS: 229	(1957) + Various amendments - Flame proof enclosure of electrical apparatus.
BS:4683	Electrical apparatus for explosive atmospheres.
Part 1	(1971) Classification of maximum surface temperature.
Part 2	(1971) The construction and testing of flame-proof enclosures of electrical apparatus.
Part 3	(1972) Type of protection N.
Part 4	(1973) (1979) Type of protection 'e'.
BS:1259	(1958) + various amendments - Intrinsically safe electrical apparatus and circuits for use in explosive atmospheres.
BS:5345	Code of practice for the selection, installation and maintenance of electrical apparatus for use in potentially explosive atmospheres (other than mining applications or explosive processing and manufacture).
Part 1	(1976) Basic requirements for all parts of the code.
Part 2	(1983) Classification of hazardous areas.
Part 3	(1979) Installation and maintenance requirements for electrical apparatus with type of protection 'd' flame proof enclosure.
Part 4	(1977) Installation and maintenance requirements for electrical apparatus with type of protection 'i'. Intrinsically safe electrical apparatus and systems.
Part 5	(1983) Installation and maintenance requirements for electrical apparatus protected by pressurization including continuous dilution and for pressurized rooms.

Part 6	(1978) Installation and maintenance requirements for electrical apparatus with type of protection 'e'. Increased safety.
Part 7	(1979) Installation and maintenance requiremetns for electrical apparatus with type of protection 'N'.
Part 8	(1980) Installation and maintenance requirements for electrical apparatus with type of protection 's'. Special protection.
BS:5501	Electrical apparatus for potentially explosive atmospheres.
Part 1	(1977) General requirements
Part 2	(1977) Oil immersion 'o'.
Part 3	(1977) Pressurized apparatus 'p'.
Part 4	(1977) Powder filling 'q'.
Part 5	(1977) Flame proof enclosure 'd'.
Part 6	(1977) Increased safety 'e'.
Part 7	(1977) Intrinsic safety 'i'.
Part 9	(1982) Intrinsically safe electrical systems 'i'.
BS: 3116	Automatic fire alarm systems in buildings.
Part 4	(1974) Control and indicating equipment.
Note	Part 1 withdrawn, parts 2 and 3 not issued yet.
BS:5445	Specification for components of automatic fire detection systems.
Part 1	(1977) Introduction.
Part 5	(1977) Head sensitive detectors. Point detectors containing a static element.
Part 7	(1984) Specification for point type smoke detectors using scattered light, transmitted light or ionization.
Part 8	(1984) Specification for high temperature heat detectors.
Part 9	(1984) Methods of test of sensitivity to fire.
Note	Parts 2, 3, 4 not yet issued.

Code of practice - CP 1003

Electrical apparatus and associated equipment for use in explosive atmospheres of gas or vapour other than mining application.

Part 1	(1964) + various amendments - Choice, installation and maintenance of flame proof and intrinsically safe equipment.

Part 2	(1966) Methods of meeting the explosion hazard other than by the use of flame proof or intrinsically safe electrical equipment. (Deals with the follwoing methods of meeting the explosion hazard: segregation, ventilation and pressurization).
Part 3	(1967) Division 2 areas. Considerations affecting the choice, use and installation of apparatus in Division 2 areas (i.e. areas in which flammable and explosive substances are so well under conditions of control that a hazard is likely only under abnormal conditions).

Public authority standards

BS: 6016	(1980) Specification for filtering face piece dust respirators.

APPENDIX III

CLASSIFICATION OF ABRASIVE CLOTH

	Standard rating	Emery scale
Very fine	600	12/0
	500	11/0
	400	10/0
	360	
	320	9/0
	280	8/0
	240	7/0
	220	6/0
Fine	180	5/0
	150	4/0
	120	3/0
Medium	100	2/0
	80	1/0
	60	½
Coarse	50	1
	40	1½
	36	2
Very coarse	30	2½
	24	3
	20	3½
	16	4
	12	4½

BS 871 (1981) Specifications for abrasive papers and cloths.

BS2992 (1970) Painters and decorators brushes for local authorities and public institutions (excluding quality of fillings.