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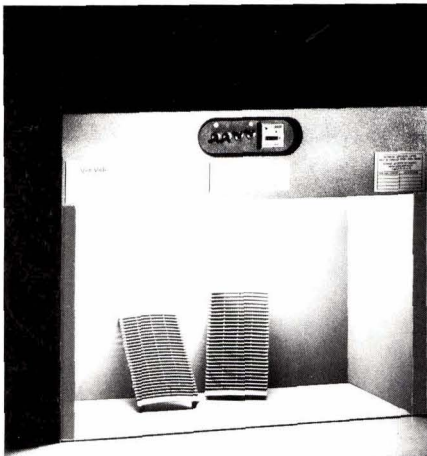


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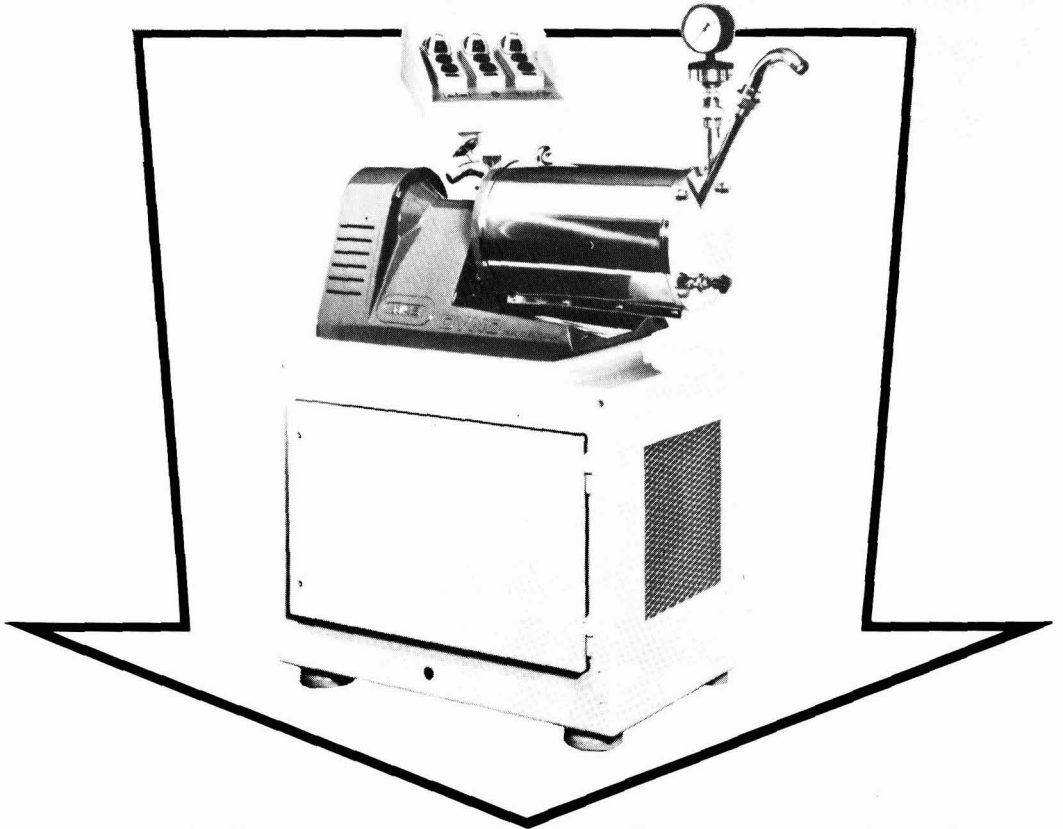
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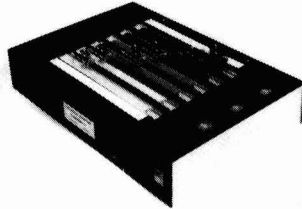
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Contents

Vol. 63 No. 3

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Transactions and Communications

| | |
|---|-----|
| OCCA Monograph No. 1 – Marine finishes. Part II | 93 |
| <i>T. A. Banfield</i> | |
| The relationship between glass transition and melting temperatures of natural resins | 101 |
| <i>D. N. Goswami</i> | |
| Evaporation and water-dilutable coatings | 103 |
| <i>L. O. Kornum</i> | |
| <i>Letters</i> | 124 |
| <i>OCCA Meetings</i> | 124 |
| <i>News</i> | 126 |
| <i>OCCA News</i> | 130 |
| <i>New Members</i> | 135 |
| <i>OCCA Diary</i> | 136 |

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OCCA Monograph No. 1 – Marine Finishes.

Part II*

By T. A. Banfield, PhD, DIC, ARCS, FICorT, FTSC

Consultant, formerly with Berger Jenson and Nicholson Ltd

4. Marine paint systems

Refs. 2, 16, 24-26, 28-53

4.2 Exterior surfaces below the water-line

This is an area of ships which encounters conditions not met by structural steelwork ashore. Seawater is normally slightly alkaline (pH about 8.0-8.2) and, as already described in Section 2, the electrochemical corrosion reaction leads to the production of hydroxyl ions at cathodic areas which may give pH values of about 11 over localised areas. This is particularly the case when a cathodic protection system is fitted, and the entire immersed surface is made cathodic. Consequently, a primary requirement of paints for use on steel immersed in seawater is that they must withstand alkaline conditions, i.e. oil or alkyd media which are readily saponified are not suitable. The conventional paints used on steelwork ashore, including the traditional red lead in linseed oil primer, do not meet these requirements.

In addition to corrosion, ships' bottoms are also subject to fouling – the attachment and growth of marine plants and animals. The special paints used to combat this, called antifouling compositions, are a separate study forming the subject of paragraph 4.2.3. below.

4.2.1. Conventional protective paint systems

These are usually based on phenolic media, pitches and bitumens. Work by the Iron and Steel Institute's Marine Corrosion Sub-Committee and the British Iron and Steel Research Association²⁸ led to the introduction of "Admar 173" – a protective paint containing basic lead sulphate, white lead, burnt island red and barytes in a 1:2 modified phenolic/linseed stand oil medium. Later work²⁹ showed that the inclusion of aluminium powder and replacing half the linseed oil by tung oil improves the performance – this paint being known as Anticorrosive 655. Admar 173 and Anticorrosive 655 are used for underwater surfaces³⁰ on those British Naval vessels painted with conventional systems, and a number of proprietary underwater protective paints used on merchant ships are similar to 655. Another primer used widely on merchant ships is the bituminous/aluminium^{2,16} type, essentially aluminium powder in a solution of bitumen or pitch – sometimes a bitumen/stand oil medium, approximately 4:1. The pigment consists of a fine grade of aluminium flake, a high content ensuring that the films have a low permeability to water. Such conventional protective paints are normally applied at a dry film thickness of about 50-60 μm per coat, 4 coats being usual on ships' bottoms to give a total thickness of about 200 μm . On merchant ships these conventional protective paint systems are generally completed by a barrier coat applied between the primer and the finishing coat of antifouling composition. These barrier

coats, often still known by their old name "No. 1 Anticorrosive Composition", are essentially undercoats for antifouling compositions; their principal use is in repainting ships' bottoms in service, so as to seal the surface of the old antifouling before applying a new coat of antifouling. They do not contain rust-inhibiting pigments, usually consisting of red oxide and extenders in a bituminous or bitumen/rosin medium. These barrier coats are applied at a dry film thickness of about 50 μm ; one coat is normally used over a conventional ships' bottom primer or, on a ship in service, over an old antifouling composition.

4.2.2. High performance protective paint systems

The conventional underwater protective paints just described are still used mainly on smaller ships not fitted with cathodic protection. The operating costs of large ships are so high, however, that long periods in service with short maintenance periods are necessary for economical operation and so-called "high performance" coating systems are required. These are based on the newer types of non-saponifiable resins such as epoxies, vinyls and chlorinated rubber which resist the alkaline conditions associated with cathodic protection and are, in general, applied at a dry film thickness of at least 100 μm per coat.

The coatings depend mainly on their high film thickness for their protective properties and to provide resistance inhibition, chemical inhibitive properties being of secondary importance; typical systems have a total dry film thickness of 300-400 μm , and are obtained by airless spraying in 3 or 4 coats. The paints must, therefore, be formulated and manufactured to permit airless spray application of coats with a wet film thickness of 200 μm or more, that do not sag or run on vertical surfaces. Additives such as treated bentonite clays, castor oil derivatives or fumed silicas are included to confer thixotropic properties, and the viscosity, measured on a cone and plate rotational viscometer³¹, is adjusted to about 6-10 poises at 25°C at a shear rate of 10,000 sec^{-1} . The method of manufacture must be such as to develop the thixotropic structure – for example with some castor oil derivatives it is necessary to attain a temperature between 40°C and 60°C when milling – and the paints must be sieved at the filling point to remove oversize particles that could block airless spray nozzles.

Cold-cured epoxy paints formulated similarly to those described in section 4.1.2, have been used as protective paints on ships' bottoms, but their excellent oil and chemical resistant properties are not essential for the service and the more economical coal tar pitch modified epoxy resin paints are generally used³². Their black colour is not a disadvantage on ships' bottoms and they may be regarded as combining the water impermeability of coal tar pitch with the adhesion, toughness and water

*Part I of this Monograph appeared in the February issue of JOCCA.

resistance of epoxies. The proportions of epoxy resin and coal tar may be varied³³ over a fairly wide range; typically³⁴ the non-volatile vehicle contains 35-40 per cent cured epoxy resin (i.e. epoxy resin plus curing agent), the balance being coal tar. The coal tar³⁵ requires careful selection – it is generally of the “high aromatic” type and must, of course, be compatible with the epoxy resin. Inert fillers and pigments such as talc, barytes or red oxide are used, and the solvents are essentially aromatic hydrocarbons with additions of glycol ethers, alcohols or ketones. Solutions of coal tar pitch with epoxy resins are not stable on storage, indicating some reaction between these materials, so the two components of the paint generally consist of (a) pigments and fillers in a solution of coal tar pitch and polyamide resin, and (b) epoxy resin solution. It may be noted that when formulating these paints, the quantity of curing agent used is the full amount required to react with the epoxy resin, any reaction between the epoxy resin and the coal tar being ignored. The two components are normally packed in the separate compartments of a dual-pack drum and mixed at the time of use – this ensures that the correct quantities of each are used. The paints are sprayed from an airless gun to give dry film thicknesses of 100-150 μm per coat, three coats with a total thickness of 300-400 μm being a typical requirement. As with pure epoxy paints (section 4.1.2 above) the curing of coal tar epoxies is dependent on temperature, the lowest practical recommendation being about 10°C, and best intercoat adhesion is secured by applying successive coats before the previous coat has fully cured. In practice, this involves maximum as well as minimum overcoating intervals, both varying with temperature; a table of recommended overcoating intervals may be drawn up as follows:

| Temperature | Recommended overcoating interval | |
|-------------|----------------------------------|---------|
| | Minimum | Maximum |
| 5°C | 32 hrs | 10 days |
| 10 | 22 | 7 |
| 15 | 16 | 5 |
| 20 | 11 | 3½ |
| 25 | 8 | 2½ |
| 30 | 5½ | 42 hrs |
| 35 | 4 | 30 |
| 40 | 3 | 21 |

These times are approximate, and are typical of commercial epoxy or coal tar epoxy paints used on ships.

Vinyl resin solution paints similar to those described in section 4.1.2. for above water are also used on ships' bottoms, the only real difference being that the finishing coats have antifouling properties. The paints may also be modified with coal tar³⁶, combining the low water permeability and low cost of coal tar with the toughness of vinyls. The vinyl:coal tar ratio is generally between 1:1 and 1:2. The maleic acid modified (i.e. carboxylated) type of vinyl resin is generally used, ensuring good adhesion to metals. Inert pigments and fillers are used, and the paints are formulated as thixotropic high build types capable of airless spray application at dry film thicknesses of about 100-125 μm per coat. Three coats would normally be applied to a ship's bottom to give a total dry film thickness of 300-350 μm , before application of an antifouling coat to those areas requiring protection against fouling. Being single-pack solution type paints, there are no problems with mixing at the time of use, no limitations of pot life, no critical overcoating intervals, no intercoat adhesion problems and drying is not greatly affected by temperature – practical advantages over cold-curing epoxies.

Chlorinated rubber paints as described in section 4.1.2. are also suitable for use on ships' bottoms, a typical protective system consisting of one coat aluminium primer at a dry film thickness of about 50 μm and two coats high build intermediate coat, pigmented with red oxide and extenders, at about 125 μm per coat; note that the first two coats are the same as suggested for use above water, and this simplifies the application procedure since these two coats are applied over all the exterior hull. On the underwater areas an additional coat of high build would then be applied, followed by antifouling where required. As with epoxies and vinyls, chlorinated rubber may be modified with coal tar for use on ships' bottoms where colour is unimportant. The modified coatings combine the low water permeability and low cost of coal tar with the toughness of chlorinated rubber. The coal tar must be compatible with chlorinated rubber, grades from the high temperature carbonisation of coal and containing few phenolic or other reactive groups generally being suitable. The ratio of coal tar to chlorinated rubber plus plasticiser may be varied between about 1:2 and 2:1, typical commercial paints being about 1:1. As before, inert pigments and fillers are used, it being possible to modify the colour between black, dark brown and dark grey to distinguish between successive coats, and the paints are formulated as thixotropic high build types capable of airless spray application at a dry film thickness of 100-125 μm per coat. On a ship's bottom a typical protective system would consist of one coat chlorinated rubber aluminium primer at about 50 μm followed by two coats high build chlorinated rubber/coal tar at about 100-125 μm per coat – to be followed by chlorinated rubber antifouling on those areas requiring protection against fouling. As with the other single-pack solution type paints, chlorinated rubber/coal tars have practical advantages over cold-curing epoxies, viz there are no mixing problems at the time of use, no limitation of pot life, no critical overcoating intervals, no intercoat adhesion problems and the drying rate is hardly affected by temperature. In addition, chlorinated rubber and coal tar modified paints use mainly aromatic hydrocarbon solvents which are cheaper and have a less objectionable odour than the aromatic hydrocarbon/ketone/ester type blends required for vinyls.

As already mentioned for surfaces above the water line (section 4.1.2.) these high performance underwater paint systems may be applied over a zinc silicate priming system, all being based on non-saponifiable media that resist the alkaline nature of some zinc silicates. In a few special cases zinc silicates may be used on ships' bottoms without being overcoated, e.g. in fresh water service where the growth of fouling is not significant.

The normal period in service between drydockings of a ship protected with conventional underwater paint systems is about 9-12 months. If, however, a high performance coating system is used this period may be extended. Lloyds Register of Shipping and other classification societies permit drydocking to be deferred for up to 24 years provided an approved automatically controlled impressed current cathodic protection system is fitted and an approved high performance paint system applied immediately to a blast cleaned surface, or to a blast cleaned surface immediately blast primed. The bottoms of most large ships are so protected.

4.2.3. Antifouling compositions

The underwater areas of ship's hulls are protected against corrosion by the paint systems described in the preceding

paragraphs 4.2.1. and 4.2.2. These areas are also subject to fouling³⁷ – the attachment and growth of marine plants and animals – which can seriously affect the roughness of ships' bottoms and lead to a considerable increase in resistance to movement through the water. This increase leads either to a reduction in speed, or to an increased fuel consumption in order to maintain the normal operating speed – in either case the ship operating costs are increased. In the case of large supertankers or bulk carriers, speed losses are very expensive because of the high running cost – a loss of 0.1 knot on a service speed of 16 knots is equivalent to a loss of more than 2 days a year in service, and at £40 000 a day this amounts to over £80 000 a year³⁸. Various methods of preventing marine growths on ships' bottoms have been proposed and used. Up to the Middle Ages it was the practice to careen ships at intervals to clean the underwater bottom, or to beach them for a more thorough job. Copper sheathing of wooden vessels was used, being effective in preventing attack on the wood by marine borers and also reducing fouling by marine growths. When iron ships were first built in the early years of the 19th century attempts were made to fit copper sheathing to reduce fouling. The copper sheets had to be insulated from the hull to prevent galvanic attack on the iron, but the practical problems of ensuring continued insulation proved insuperable and attention was directed to the use of special paints. In more recent years ultrasonic methods of preventing attachment of growths have been developed and used on a trial basis, and also processes involving the release of solutions of poisonous compounds from perforated pipes fitted to ships' bottoms, the electrolytic generation of chlorine gas and the application of radioactive compounds, but these have not been successful commercially. Only the special paints known as "antifouling compositions" have proved successful in keeping ships' bottoms free from marine growths. These paints contain chemicals poisonous to the settling stages of marine plants and animals, the poisons being released into the seawater at a rate sufficient to maintain a thin layer of water next to the hull in which the small spores and larvae of the organisms cannot survive – thus preventing attachment and further growth of the plants and animals. At first, antifouling compositions were formulated empirically, but the biology of ship fouling has been studied since the early years of the 20th century and modern antifouling compositions are formulated on more scientific lines. Little information on the subject was published before the 1940's, but during the last 30-40 years the results of a considerable amount of work have been published^{37,39,40,41,42}. Marine animals found on ships included barnacles, tubeworms (often incorrectly called coral), mussels, polyzoa, hydroids, ascidians, sponges and anthozoa (sea anemones) – barnacles being the major problem. These animals do not require sunlight for growth and may, therefore, settle on the flat bottoms of ships as well as on the vertical sides – see fig 4.

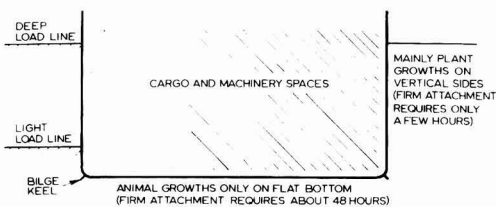


Figure 4. Section across a large vessel showing incidence of fouling settlement

Marine plants found on ships include a variety of green, brown and red seaweeds, the most common being *enteromorpha*, whose long green filaments grow rapidly under favourable conditions – it is often called "grass" when seen on the side of vessels. Green seaweeds need plenty of light for their growth so are found only on the vertical sides of ships, but brown and red weeds can grow with less light and may be found on the lower sides or even on flat bottoms. The most common brown fouling plant is the richly branched *ectocarpus*.

Animal fouling organisms reproduce themselves by releasing larvae which go through a free-swimming or motile stage, but eventually cement themselves to a firm substrate and change to the adult form. Plant fouling organisms reproduce by releasing spores, some being motile, which attach themselves to a firm surface. The function of antifouling compositions is to prevent attachment of larvae or spores to the bottoms of ships by releasing chemicals that are poisonous to these small organisms. For many years copper compounds have been the principal poisons used in antifouling – this followed from the knowledge that copper sheathing prevented fouling of wooden vessels. Cuprous oxide (red) is the most widely used compound, but when different coloured antifouling are required for yachts, cuprous thiocyanate (white), copper acetoarsenite (green) or copper flake (copper bronze) may be used. These copper compounds are effective against most marine fouling organisms but their action, against some plants in particular, may be reinforced by other poisons, e.g. compounds of mercury, arsenic, tin, lead or zinc. In the cases of arsenic, tin and lead their inorganic compounds have no useful antifouling properties, but certain organometallic compounds of these elements are used. Hundreds of purely organic compounds have been examined as possible antifouling poisons and although some have proved effective against specific organisms (e.g. the insecticide DDT is selectively effective against barnacles), none has yet been found which is so poisonous to a wide range of organisms as is cuprous oxide. The possibility exists of organic compounds being discovered that are fully effective against all the marine plants and animals that settle and grow on ships' bottoms, but they would be used only if (a) they could be incorporated into paints suitable for application under normal shipyard or drydock conditions, (b) they could be handled safely without impracticable precautions against toxic hazards during manufacture and application of the paint, and also during removal from a ship's bottom after a period in service, and (c) they showed some technical or economic advantage over existing antifouling compositions.

Until recent years, antifouling compositions could be classified⁴³ into two broad groups according to the mechanism of releasing poisons into the seawater, as follows:

- (i) **Soluble matrix.** In this type the particles of poisonous pigment are distributed throughout the film of a binder which is slightly soluble in seawater – hence the term "soluble matrix", the word matrix being used in the sense of a cementing material. As the binder dissolves so particles of poison become exposed to the action of seawater, ensuring continued dissolution of poison. The binders of all practical antifouling compositions of this type are based on rosin, which as an acidic material is slowly dissolved by the slightly alkaline seawater (pH 8.0-8.2). Plasticisers are used to modify the physical properties of the rosin and to adjust the

rate of dissolution. The poison release rate ("leaching rate" is the usual term) is determined by the poison content, the amount and type of other pigments and/or extenders, and the resin/plasticiser ratio. Fig. 5 is a diagrammatic representation of the poison release mechanism of this type of antifouling composition.

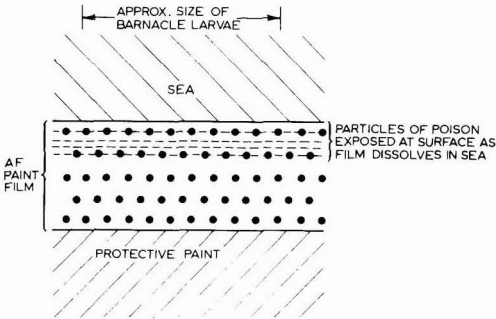


Figure 5. Soluble matrix antifouling – mechanism of poison release

(ii) *Contact*. In this type the poison content is high enough to ensure that particles of poisonous pigment are in contact throughout the dry film. This permits the poison leaching process to continue because as each particle is dissolved so fresh particles are exposed to the seawater. The binder of a contact type antifouling need not be soluble in seawater because the particles of poison dissolve leaving an intact skeleton or honeycomb of insoluble binder through which water penetrates – in fact these compositions have been described as "insoluble matrix" types. In practice, however, all commercial antifouling compositions of this type contain some soluble binder, again generally resin. The "insoluble" portion of the binder is a non-saponifiable or saponification-resistant material such as chlorinated rubber, isomerised rubber, vinyl resin or a tung oil/phenolic medium, with non-saponifiable plasticisers to adjust the physical properties of the film. The poison leaching rate is determined by the poison content, the amount and type of other pigments and extenders (if any) and the insoluble resin/plasticiser/rosin ratio. Fig 6 is a diagrammatic representation of the poison release mechanism of this type of antifouling composition.

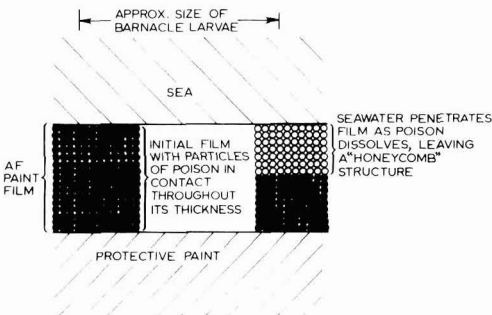


Figure 6. Contact antifouling – mechanism of poison release

It will be realised from the above notes that contact type antifoulings have a higher poison content and, generally, a harder film than the soluble matrix type. Contact types are suitable for fast vessels on which it is important to maintain a smooth hull, the period between drydockings being up to about 15 months. Soluble matrix antifoulings, on the other hand, have a relatively soft film and may have comparatively low poison contents. Many merchant ships, drydocking at intervals up to about 12 months, use the latter type of antifouling composition.

Copper compounds are the most widely used poisons in these two types of compositions and, as already mentioned, they are effective against most fouling organisms. The various plants and animals vary in their sensitivity to poisons; in the case of copper compounds it has been shown that a poison release rate of $1-2\mu\text{g}$ copper/cm²/day is sufficient to prevent settlement of the more sensitive organisms such as mussels, but $10\mu\text{g}/\text{cm}^2/\text{day}$ is required to prevent barnacle settlement. Higher leaching rates of about $20\mu\text{g}/\text{cm}^2/\text{day}$ or more would be required to prevent accumulation of diatom or bacterial slimes, but such rates would not be economic and in practice the critical leaching rate for antifouling compositions based on copper poisons^{39,44} is taken as $10\mu\text{g}/\text{cm}^2/\text{day}$. Higher leaching rates would be wasteful of the poison, leading to rapid depletion of the poison in the film and hence to an unnecessarily short period of effectiveness. The relative sensitivities of the different organisms vary according to the chemical nature of different poisons. Other poisons are frequently used with cuprous oxide and there is some evidence of synergistic effects; mercury compounds and organo-arsenic compounds were formerly used in this way, but cost and health hazards now rule these out and organotin compounds are now the main "booster poisons" used in copper type antifouling compositions.

In the case of very large supertankers and bulk carriers, neither soluble matrix nor contact type antifouling compositions give satisfactory service on the vertical sides. Barnacles are not a problem on these vessels because the larvae require about 48 hours with little water movement to cement themselves firmly to a surface, so any that settled on a supertanker during a normal 20-30 hours stay in port would be washed off when the ship sailed. For this reason supertankers do not require any antifouling composition on their flat bottoms. On the vertical sides of these large vessels, however, plant growths, particularly the green weed *enteromorpha*, are a major problem. The spores of this plant can settle in water moving at up to about 10 knots, become very firmly attached to a surface in only a few hours, and the conditions on the sides of these vessels in service, with exposure to strong sunlight in tropical waters and to damp atmospheric exposure on ballast voyages, encourage vigorous growth. The filaments of *enteromorpha* may grow to a length of 15-25 cm in a few weeks and on the considerable areas involved, say 5000 m² or more on each side, this growth causes a considerable increase in frictional resistance. Speed reductions of $\frac{1}{4}$ to $\frac{3}{4}$ knot have been reported and from the figures given earlier it will be realised that such speed losses are very costly to the shipowner.

There are probably two main reasons for the comparatively poor performance of soluble matrix and contact type antifouling compositions on these large ships:

(1) Cuprous oxide, the principal poison used in traditional antifouling compositions, is not fully effective against

enteromorpha. This is possibly because the spores at the time of settling are only $0.1\mu\text{m}$ long, and may become attached to areas of low toxicity between particles of cuprous oxide which are generally larger than $1\mu\text{m}$. Barnacle larvae at the time of settling are much larger, about $100\mu\text{m}$, so there is no possibility of their settling between particles of cuprous oxide (refer again to Figs 5 and 6).

- (2) Binders containing rosin do not resist intermittent atmospheric exposure, particularly under tropical conditions of strong sunlight, tending to craze and crack.

A different type of antifouling composition has been developed for use on the sides of these large vessels. They are based on acrylic, vinyl or synthetic rubber binders, and the poisons are organometallic compounds that form solid solutions with the binders. Vinyl resin paints containing organotin compounds such as tributyltin oxide, tributyltin fluoride, triphenyltin chloride or triphenyltin fluoride have been introduced in recent years^{38,43,46}. Being in solid solution the poisons diffuse through the binders, maintaining a uniform concentration through the film. Then, as poison is released from the surface of the film, more diffuses from deeper in the film to replace that lost to the sea water. The critical leaching rate of tributyltin oxide is of the order of $1\mu\text{g}/\text{cm}^2/\text{day}$ and the loss of this amount of material does not greatly affect the surface of the film which, therefore, retains its initial smoothness. Since the poisons are in solid solution, i.e. molecularly dispersed, there are no areas of reduced toxicity on which *enteromorpha* spores may settle. Although developed initially for the sides of supertankers, these diffusion type antifouling compositions are also finding application on other vessels. It should also be pointed out that their poison release rate is hardly affected when ships enter the brackish waters of estuaries, unlike soluble matrix and contact types which have a much reduced leaching rate in such waters. Fig 7 is a diagrammatic representation of the poison release mechanism of this type of antifouling composition.

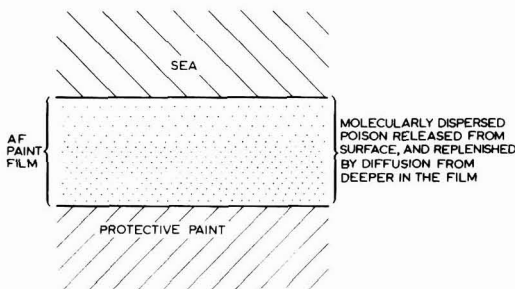


Figure 7. Diffusion antifouling – mechanism of poison release

A new type of antifouling composition has been developed in more recent years^{42,47,48,49}, in which a toxic component is copolymerised with a binder resin. Most work has been concerned with organotin compounds, e.g. tributyltin acrylate (or methacrylate) is polymerised, or copolymerised with other polymerisable unsaturated compounds, leading to the formation of film-forming polymers with a high content of tributyltin groups. When immersed in seawater the polymer is slowly hydrolysed and toxic tributyltin groups released; the residue of the polymer is water soluble. The rate of poison release depends upon the composition of the polymer and may be adjusted by

including water insoluble organic compounds as retarders and water sensitive pigments, such as zinc oxide or cuprous oxide, as accelerators. In this way the surface of the polymer is eroded away and the action is claimed to maintain a smooth finish on ships' bottoms. Experience of the performance of this type of composition on ships in service is still limited and there appear to be uncertainties about fouling settlement that may occur when a ship is stationary for more than a few days, e.g. delayed in port, because erosion of the surface is then diminished.

Yet another new type of antifouling composition consists of a high build coal tar epoxy coating incorporating organotin poisons⁵⁰. This type of coating is applied thickly (say $300\mu\text{m}$) over an epoxy primer, and provides protection against both corrosion and fouling. Part of the organotin poison is crystalline (e.g. tributyltin acetate) and it is released slowly over a long period, claimed to be up to 3 years. The coating has good abrasion resistance and does not become roughened in service.

Antifouling compositions of all types function by releasing poison into the seawater and, hence, can only remain effective for a limited period; the poison content of the film becomes reduced until eventually the leaching rate falls below the critical value and fouling organisms can then settle. Increasing the film thickness, and hence the poison per unit area, lengthens the effective life. Leaching rates, and hence effective lives, are affected by the speed of the vessel and by the temperature, salinity and pH of the seawater. Such factors are determined by the type of vessel and where it sails, and are not subject to control by the paint formulator or applicator. In practice, therefore, it is not possible to predict the effective life of an antifouling composition on a ship with any degree of accuracy, and the owner must select one according to the type of vessel concerned and its intended voyages.

4.3. Interior surfaces – Accommodation spaces

Little need be said about the paints used in these parts of ships because they are the same as would be used in houses, hotels or offices ashore. Gloss finishes based on long-oil alkyds are normally used in public rooms, alleyways, galleys and pantries, being applied over a priming system appropriate to the surface. Semi-gloss or eggshell finishes are used in cabins and on deckheads. Emulsion paints have not been widely used – this is somewhat surprising in view of their quick and easy application properties which would enable cabins to be repainted between voyages to restore a good decorative appearance.

The use of paint in accommodation on ships has decreased considerably during the last 30 years or so. This follows the almost universal adoption of melamine faced decorative laminated plastics as linings for practically all accommodation spaces, the use of paint being minimal.

4.4. Interior surfaces – Cargo holds

These spaces, used for the carriage of dry cargo, present no special problems – the paint systems used being generally similar to those used in factories and warehouses ashore. Thus the steel, after blast cleaning and blast priming before construction of the ship, is coated with one of the standard primers as used for exterior surfaces above the waterline. Lead-based primers are rarely used nowadays because of health hazards. Zinc chromate primers were widely used, but in view of the reported carcinogenic properties of soluble chromates their use is

declining and zinc phosphate based primers are now common. They may be brushed, but airless spraying is more usual. Alkyd finishing paints are generally light coloured to improve the illumination in these spaces, and for the same reason aluminium pigmented finishes are widely used. Such conventional paint systems give good service in holds carrying cased cargo; strong wooden battens are used to prevent damage to the cargo and these also serve to prevent mechanical damage to the interior surfaces of the hold. When bulk cargoes (e.g. grain, coal, ore) are carried there is often considerable abrasion of the interior surfaces and a high performance system is then required; the same applies in the holds of container ships which carry cargo packed in large metal boxes of standard sizes. High build epoxy systems similar to those used on exterior surfaces above the waterline are used, although coal tar epoxies are more general, sometimes being finished with an aluminium pigmented epoxy to improve the level of illumination.

4.5. Interior surfaces – Cargo/ballast tanks

On tankers, the tanks are used for the carriage of various grades of oil cargo, and some tanks must be used for water ballast when no oil is carried, otherwise the ship could become unstable. In addition, the interior surfaces of the tanks must be washed periodically by cold or hot seawater, sometimes with added detergents. The combined effects of oils, fresh or salt water ballast and tank washing are severely corrosive to steel, and the conditions are unlike any met in shore installations. If crude oil ("black oil") is carried, an oily or waxy film may be left on the interior of the tank and this has some limited protective action. The film is never continuous over the entire surface, however, and severe local corrosion may occur at areas of bare steel exposed to the action of the water ballast. (The action may be likened to that on bare areas on an otherwise millscale-covered surface – the wax covered areas function as cathodes and attack is concentrated on the anodic bare areas.) In addition, crude oil from many sources contains appreciable quantities of sulfur compounds, and the residues left in tanks subsequently filled with aerated seawater may react with water and oxygen to produce sulfuric acid, leading to direct chemical attack on bare steel. Accordingly, attack on unprotected steel in crude oil tanks takes the form of pitting; the rate varies with the conditions, but may reach up to about 5 mm/yr. In tanks used for refined oil products ("white oils") the corrosion is more uniform because these cargoes do not leave any significant oily film on the tank interiors – the corrosion is more general, with rates of attack up to about 0.4 mm/yr. Corrosion in unprotected oil tanks was, therefore, a serious problem, extensive and costly steel renewals formerly being common at the second "special survey" of a ship after 8 years in service. During the last 30 or so years various protective measures have been developed, including (a) cathodic protection of tanks carrying seawater, (b) oxygen elimination by injection of inert gases into empty tanks, (c) dehumidification of the air above cargoes or in empty tanks, (d) addition of inhibitors to oil cargoes and/or to ballast water, (e) spraying inhibitors on the interior surfaces of empty tanks, or (f) protective coatings. Methods (a) to (e) are all capable of reducing corrosion but only (f) is capable of providing complete protection. The coatings are required to resist various types of petroleum and other liquid cargoes, ballast water and normal tank cleaning, must not contaminate cargoes and must be capable of application under practical shipyard conditions. It is not easy to meet all these requirements. Vinyls were used to a

limited extent, particularly by the US Navy, but suffered from the practical problems of applying multiple coats of paint in which methyl ethyl ketone was the main solvent – extreme precautions being necessary to counter the fire and explosion hazards when using this low flash solvent in enclosed spaces. The present position is that only zinc silicates, epoxies and, to a limited extent, polyurethanes are used.

Zinc silicate tank coatings⁵¹ were first used on a large scale in the USA, but are now being used to an increasing extent in Europe. They have excellent resistance to refined petroleum cargoes, many organic solvents and some natural oils. Their resistance to acids and alkalis is poor, so they are not suitable for the carriage of acidic natural oils, for chlorinated solvents because contamination with moisture can lead to formation of hydrochloric acid, nor for alkaline cargoes, all of which would attack the zinc. Either solvent or water based types would give satisfactory service, but for use in tanks the aqueous types have the great practical advantage of being safe from explosion or toxic hazards during application. Ventilation is required to remove water vapour from the tank, but the lighting need not be explosion-proof and the painters need only wear a simple filter type face mask to prevent inhalation of spray particles. The zinc silicates already described^{24,25,26} in section 4.1.2. are used, one coat at a dry film thickness of 75-100 μm being applied to a freshly blast-cleaned surface; the tanks are fully coated.

Epoxy paints similar to those used on the exteriors of ships – see section 4.1.2. – are also used on the interior surfaces^{52,53,54} of refined oil tanks. They are resistant to all the common refined petroleum products, and also to alkaline cargoes like caustic soda solution which are occasionally carried to refineries. A typical system, applied over a blast primer in good condition, would consist of an epoxy primer at about 25 μm and two coats high build epoxy each at about 125 μm . The tanks are fully coated. In the case of chemical or solvent tankers which may carry a range of different cargoes it is preferable for the epoxy system to be applied direct to a blast-cleaned surface. This is because the small amounts of some possible cargoes, e.g. benzene, toluene, lower ketones and lower alcohols, that become absorbed into the coating may cause stripping from a weathered blast primer or soften a polyvinyl butyral type. For some liquids, e.g. wine, chlorinated solvents etc., a final coat of oil-free polyurethane enamel is often used because it resists chlorinated solvents better than do epoxies, does not taint wines and is not stained by red wine. Coal tar epoxy coatings would not be suitable for use in tanks carrying refined products, because even small amounts of coal tar leached from the coating would discolour the cargoes. In the case of crude oil, however, the amount of coal tar leached in this way would not make any detectable difference to the cargo. Accordingly the cheaper coal tar epoxies are normally used, a typical system being two coats each about 125 μm applied over a blast primer in good condition. This may be applied to all the interior surfaces, but is more often only applied to the bottom of the tank and about 2 m up the sides, to the top of the tank and about 2 m down the sides, and to other horizontal surfaces where seawater ballast may lie. Partly coated crude oil tanks may be fitted with cathodic protection using sacrificial anodes if the tanks are also to be used for seawater ballast.

The application of tank coatings demands careful attention to surface preparation, ventilation, film thickness, curing times and overcoating intervals at the prevailing

temperature. The work is frequently undertaken by specialist contractors having suitable equipment and experience. When properly applied, coatings prevent corrosion of tanks for up to 8 or 10 years. An additional advantage of coated tanks is that tank cleaning is easier and quicker than with uncoated tanks, since cargo residues are not retained by corrosion products on the interior steel surfaces.

5. Application methods and hazards

Ref. 54-57

Until about 30 years ago ships' paints were applied by brush. In shipbuilding yards staging was erected around the entire outer hull to provide access, whilst in drydocks brushes fastened to bamboos or other lightweight poles up to about 6 m long were used on exterior hull surfaces. Rollers were then introduced and similarly used on long handles. During the 1960's, however, airless spraying was developed and it has now become the most widely used method of painting ships. In fact on the largest vessels the areas involved – see Figs. 8 and 9 – are so large that to paint them by brush or roller would be impracticable. Thus, the area of the outer hull of a 300 000 tonnes tanker exceeds 30 000 m²; high build coatings cannot satisfactorily be applied at 100-125 μm per coat by brush or roller, and to build up the required total film thickness of 300-400 μm by brushing or rolling would require 8 or 10 coats – on such a large area this would take far too long. An airless spray gun, however, is capable under practical conditions of applying about 50-80 l/hr, and this corresponds to a rate of 150-400 m²/hr when applying a typical high build coating at a dry film thickness of 100-125 μm. By using 4 or 6 airless spray guns, therefore, it is possible to apply one coat to the entire area in 2-4 working days, i.e. the outer hull of one of these large vessels can be completely coated in 2 weeks.



Figure 8. Side of a bulk carrier shortly before launching. The cradle used for painting is suspended from the deck
(Photograph: Berger Paints)

Marine paints must be formulated and manufactured so as to be suitable for airless spraying, i.e. they must be capable of application to vertical surfaces at wet film thicknesses of 200-250 μm without sagging or running. Structuring agents such as treated bentonite clays, castor oil derivatives or finely dispersed (fumed) silicas are included in the formulations and the method of manufacture must be such that the effects of these are



Figure 9. Stern of a bulk carrier shortly before launching. Cradles are used for painting at deck level, but staging is required for overhanging areas
(Photograph: Berger Paints)

developed fully, e.g. with castor oil derivatives this may require attaining a minimum, but not exceeding a maximum, temperature during milling. The viscosity of the paint is adjusted to about 6-10 poises at 25°C at a shear rate of 10 000 sec⁻¹, measured on a cone-and-plate rotational viscometer (BS. 3900, Part A7). The paint must also be free from oversize particles that would block the airless spray nozzles – orifice size about 0.3 to 0.8 mm – and this is ensured by sieving the paint as it is filled into drums. Although most ships' paints are applied by airless spray, it is sometimes recommended that plate edges be painted by brush immediately before the surface is coated – this is to ensure that paint penetrates any roughness in the welds and that the thickness in the vicinity is above



Figure 10. Scraping the side of a ship in drydock
(Photograph: Berger Paints)

average. Brush or roller application is also used on small vessels, or on some areas of larger ships where overspray could present problems.

Painting must be inspected regularly to ensure that specifications regarding surface preparation, wet and dry film thicknesses, mixing of two-pack materials, application of two-pack materials within the stated pot-life, drying times, overcoating intervals, quality of workmanship, etc. are met. In the case of large ships an inspector (sometimes more than one) is employed full-time on this work; he may be an employee of the shipowner, the shipyard or the paint supplier, or sometimes of an independent inspection organisation. On smaller jobs a full-time inspector cannot perhaps be justified, but periodic checks are essential.

Ships in service are drydocked at intervals for inspection and maintenance of the underwater hull and its paint coating. Areas where the paint is damaged or failing are cleaned as necessary, preferably by local blast-cleaning although small areas are generally just scraped and wirebrushed – see Fig. 10 – then recoated, generally with the original system. A new coat of antifouling composition is applied to the areas where it is normally used; the surface of the old antifouling may first require sealing with a coat of “anticorrosive” composition.

Techniques have been developed for the underwater cleaning⁵⁵ of ships’ bottoms using rotary nylon or wire brushes; in some ports this is used regularly to remove light fouling and to reactivate the surface of an antifouling composition without drydocking the vessel. It is also possible to blast clean underwater using an open air-blast nozzle with a coarse grade of sand as abrasive. The cleaned areas may then be repainted by brush or roller using paints containing surface active agents that secure adhesion to wet surfaces. Spray application underwater⁵⁶ has also proved possible, water being displaced from the surface by compressed air maintaining an air space within a conical shield through which paint is airless sprayed. So far such methods have only been used for recoating comparatively small damaged areas after underwater repair, but complete repainting of the entire bottom whilst a ship is afloat is technically possible.

As stated earlier, airless spraying is the most widely used method of applying marine paints. This is less hazardous than conventional air-assisted spraying because it produces less overspray, but the risk of inhalation of spray droplets by painters or by other men working in the vicinity is still present. The danger may be overcome by wearing a filter type face mask. Because of the risk, however, lead pigments are now much less used than 20 or 30 years ago and soluble chromate pigments are also being restricted. Antifouling compositions offer special problems because of the poisons they contain – this applies both to the traditional copper compounds and also particularly to the newer compositions containing some organometallic compounds. Suitable protective equipment must be worn by painters and in the UK the Research Organization of Ships’ Compositions Manufacturers has made recommendations⁵⁷ for the precautions to be taken, according to the poisons involved and the method of application to be used. In due course there will be UK Regulations regarding the safety labelling of paints based on EEC Directives; meanwhile drums of marine paints are marked with PPA (Personal Protection Advice) numbers⁵⁸.

The possibility of pollution of the sea by poisons released from antifouling compositions has sometimes

been raised, but a few figures will serve to put this into perspective. Copper is by far the major metal involved, something like 5000 tonnes/year being used in antifouling. The water in the oceans amounts to about 1.4×10^{18} tonnes and the natural concentration of copper in seawater is about $3 \mu\text{g/l}$, the total copper content of the oceans therefore being approx. 5×10^9 tonnes. Accordingly the copper used annually in antifouling compositions is only about one millionth of that occurring naturally – a negligible amount. Similar calculations for other poisons used in antifouling compositions also indicate quantities that are negligible in relation to those already present in the oceans. It is, of course, feasible that concentrations of antifouling poisons in some localities, e.g. land-locked harbours, might reach higher levels, but it is unlikely that they would become dangerous.

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The relationship between glass transition and melting temperatures of natural resins

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Summary

The T_g/T_m ratios of fifteen natural resins have been investigated and have been found to vary between 0.88 and 0.95, with an

average of 0.92. The value of the ratio is found to be somewhat different from that observed by Beaman¹ for other materials.

Keywords

Raw materials for coatings binders

natural resin

Properties, characteristics and conditions primarily associated with material in general

glass transition point
softening point
melting point

Le rapport entre les températures de transition vitreuse et de fusion des résines naturelles

Résumé

Dans le cas de quinze résines naturelles, une étude du rapport T_g/T_m a montré qu'il se varie entre 0.88 et 0.95, avec la valeur

moenne à 0.92. La valeur du rapport est assez différente de celle que Beaman avait noté dans le cas d'autres substances.

Die Beziehungen zwischen Glasübergangs- und Schmelztemperaturen von Naturharzen

Zusammenfassung

Die Beziehungen zwischen T_g und T_m von 15 Naturharzen wurden untersucht, wobei festgestellt wurde, dass sie zwischen 0.88 und 0.95 schwanken – mit einem Durchschnitt von 0.92.

Es wurde gefunden, dass der Wert dieser Beziehung sich etwas von dem von Beaman¹ an anderen Materialien beobachteten unterscheidet.

Refs. 1-9

Beaman¹ in 1952 observed that for certain materials the average ratio between glass-transition (T_g) and melting temperature (T_m), measured on the absolute scale, is 0.658. Recently, Boyer² has shown that the T_g/T_m ratios of 55 per cent of all polymers lie in the band $T_g/T_m = 0.667 \pm 0.05$. In this communication, it is reported that for natural resins the value of T_g/T_m ratio is somewhat different.

All amorphous polymers appear to have a glassy transition, whereas the crystalline polymers possess both a glassy and a melting transition. Natural resins do not show a definite melting point; fusion occurs gradually. They soften with heat and finally melt to a more or less clear liquid. In the author's laboratory the T_g and T_m values of four natural resins have been investigated, namely Manila copal³, mastic, dammar, shellac⁴ and two chief constituents of shellac (hard and soft lac⁵) by dielectric measurements. The average value of the T_g/T_m ratio for these resins has been found to be 0.91, which is somewhat different from the value reported by Beaman¹. For these natural resins, the glass transition temperatures have been observed to be almost identical with their softening temperatures. Softening points, in general, may give high and low values, but a correlation with the glass

transition temperature can be established⁶. It is considered that the softening point provides an approximate value for T_g ^{6,7}. On a molecular scale, the polymer chains are thought to acquire considerable mobility above the softening point⁸ or at the glass transition temperature⁶. As with most polymeric materials, each of the natural resins mentioned above, showed very low (almost constant) values for both dielectric loss and dielectric constant below their glass transition or softening temperatures. Rapid increases in these dielectric parameters have been observed at temperatures greater than their glass transition or softening points^{3,5}.

In Table 1, T_g , T_m and T_g/T_m ratios for the above mentioned natural resins are shown. The softening and melting temperatures of many other natural resins have been collected⁹ and also have been included in the table. Softening or melting of natural resins occur in a range of temperatures. In the table, where the range has not been given, the single value indicates the mean temperature. If it is considered that the softening temperatures of natural resins are identical (approximately) with their glass transition temperatures it can be seen from Table 1 that the T_g/T_m ratios of the natural resins fall between 0.88 and 0.95 with an average of 0.92. Beaman¹ also obtained a range 0.50-0.78 for other materials. The difference in the T_g/T_m ratio obtained for natural resins compared with

those for other materials is difficult to explain, but appears not to be unreasonable, in view of the fact that the natural resins form a different class of materials. A satisfactory interpretation of the observed data is difficult because the chemical structures of the resins are not yet completely

Table 1
Glass transition and melting temperatures of natural resins

| Resins | T_g or Softening point (°K) | T_m (°K) | T_g/T_m |
|---------------------------|-------------------------------|------------|-----------|
| Manila Copal | 343 | 373 | 0.92 |
| Mastic | 345 | 376 | 0.92 |
| Dammar | 373 | 393 | 0.95 |
| Shellac | 313 | 343 | 0.91 |
| Hard Lac | 323 | 353 | 0.92 |
| Soft Lac | 283 | 313 | 0.90 |
| *Pontianak | 360-408 | 408-434 | 0.88-0.94 |
| Sandarac | 373-403 | 408-423 | 0.91-0.95 |
| Kauri | 378 | 403 | 0.94 |
| Congo | 360 | 401 | 0.898 |
| Manila Macassar | 353-361 | 388-401 | 0.91-0.90 |
| Manila Philippine | 359 | 398 | 0.90 |
| Manila Singapore | 367 | 399 | 0.92 |
| Batu East India/scraped | 384-405 | 441-453 | 0.87-0.89 |
| Dust | 404 | 438 | 0.92 |
| Pale East India Macassar | | | |
| Bold-Hiroe | 374-385 | 400-429 | 0.94-0.90 |
| Dust-Hiroe | 389-395 | 413-429 | 0.94-0.92 |
| Pale East India Singapore | | | |
| Bold | 382-401 | 420-429 | 0.91-0.93 |
| Dust | 387 | 423 | 0.91 |
| Accroides | 348-358 | 383-407 | 0.91-0.88 |

$$\text{Average } T_g/T_m = 0.9159 \approx 0.92$$

*The transition temperatures for all these resins were obtained from Barry *et al*⁹.

known even for shellac, one of the most widely studied natural resins. The natural resins consist of various aromatic and aliphatic acids, resinols, resin acids etc. and many contain inert materials called resenes. Very little is known about how these constituents are linked together to form the resins.

There are, of course, two natural resins, *viz.*, red Angola and white Angola for which T_g/T_m ratios of 0.64 and 0.62 respectively have been observed, in agreement with Beaman's limit. These resins are, perhaps, more crystalline compared with other natural resins.

Acknowledgement

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Next month's issue

The Honorary Editor has accepted the following papers for publication, and they are expected to appear in the April issue of the *Journal*:

A study of the natural weathering of sealants by M. J. Welch, P. J. C. Counsell and C. V. Lawton

Evaluation of varnishes by capacitance and resistance measurements by K. S. Rajagopalan, S. Guruviah and C. S. Rajagopalan

Modification of hydrolysed lac with epichlorohydrin and epoxy resin by S. K. M. Tripathi and B. B. Khanna

Study of variables which affect dispersion of antifouling paints in ball mills by C. A. Giudice, J. C. Benítez, V. J. D. Rascio and M. A. Presta

Evaporation and water-dilutable coatings

By L. O. Kornum*

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Summary

The process of evaporation from water-containing coating films in the fluid state has been studied theoretically and experimentally. Measurements made include the evaporation rate of a number of pure volatile materials, including water, at various relative humidities; the drying rates of a few coatings as functions of the relative humidity and air velocity; and the residual volatile composition as drying proceeds, in the case of a mixture of volatiles and a lacquer, both containing water.

The present and previously published data are analysed using established heat and mass transfer theory.

It is demonstrated that the drying rate may be regarded as being controlled by the diffusion of the volatile vapour through a boundary layer above the drying film. It is shown to vary linearly with the square root of the air velocity at velocities exceeding free convection ($\sim 0.05 - 0.1 \text{ ms}^{-1}$). It is also shown that the procedures of estimating solvent balances during drying may be applied to aqueous systems when water is given a rela-

tive evaporation rate varying linearly with the ambient relative humidity. Activity coefficients are not readily available for aqueous systems, but reasonable quantitative agreement is found for the number of volatile mixtures experimentally investigated, if ideal behaviour is assumed. For a neutralised alkyd/melamine system the balance is moved towards a faster relative enrichment of the organic components compared with the estimated values, indicating the presence of an additional phase, with the discontinuous phase having a higher concentration of the organic volatiles than the bulk. The calculation procedure is, however, still capable of reflecting the impact of changes in the physical parameters.

The aqueous systems are found to be somewhat more sensitive to heat transfer than are moderately fast evaporating organic systems. Here the evaporation behaviour may deviate from the above mentioned isothermal descriptions, as do rapidly evaporating organic systems.

Keywords

Types and classes of coatings and allied products

water based paint
emulsion paint

Properties, characteristics and conditions primarily associated with materials in general

evaporation rate

Raw materials for coatings

solvents

water
solvents
ester
ether
alcohol

Le processus d'évaporation à l'égard des revêtements diluables à l'eau

Résumé

On a étudié théoriquement et expérimentalement le processus d'évaporation dans le cas des films à l'état liquide des revêtements contenant de l'eau. Les mesures effectuées comprennent; la vitesse d'évaporation d'une série de substances pures et volatiles, y compris l'eau, à diverses humidités relatives; la vitesse de séchage d'un certain nombre de revêtements en fonction de l'humidité relative et de la vitesse de l'air; la composition des mélanges volatils résiduels au cours du séchage dans le cas d'un mélange de substances volatiles d'une part, et d'un vernis clair d'autre part, où tous les deux contiennent de l'eau.

On fait une appréciation des données actuelles et de celles qui ont été publiées antérieurement, et utilisant la théorie bien établie du transfert de chaleur et de masse.

On démontre que la vitesse de séchage peut être considérée comme étant contrôlée par la diffusion de la vapeur volatile à travers une couche limite située au dessus du film qui sèche, et qu'elle varie de caractère linéaire avec la racine carrée de la vitesse de l'air à des vitesses plus élevées que celle de la convection libre ($\sim 0,05 - 0,1 \text{ ms}^{-1}$). On démontre également que les procédés pur déterminer les proportions relatives de solvants au

cours du séchage peuvent s'appliquer aux systèmes aqueux, pourvu que l'on accorde à l'eau une vitesse d'évaporation relative qui varie de caractère linéaire avec l'humidité relative ambiante. Les coefficients d'activité ne sont pas facile à trouver dans le cas des systèmes aqueux, mais on obtient un accord qualitatif et raisonnable pour une série de mélanges volatils qui a été étudiée par voie expérimentale où l'on suppose un comportement idéal. Dans le cas d'un système alkyde/mélatmine neutralisé, l'équilibre se déplace vers l'augmentation relative des constituants organiques plus rapide que les valeurs prévues, ce qui indique la présence d'une phase supplémentaire, et où la phase discontinue renferme une concentration de matières organiques et volatiles plus élevée que celle de l'ensemble. Toutefois, le procédé de calcul est capable de mettre en évidence l'influence des changements dans le domaine des paramètres physiques.

On trouve que les systèmes aqueux sont un peu plus sensible au transfert de chaleur que les systèmes organiques de volatilité moyenne. Dans ce cas le cours de l'évaporation peut se dévier des conditions isothermiques mentionnées au dessus, comme font les systèmes organiques d'une vitesse d'évaporation rapide.

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Verdampfung und wasserverdünnte Anstriche

Zusammenfassung

Der Vorgang der Verdampfung aus wässrigen Anstrichen im flüssigen Zustand wurde theoretisch und experimentell untersucht. Die Messungen schlossen ein: die Verdampfungsgeschwindigkeiten einer Anzahl von flüchtigen Materialien, mit Einschluss von Wasser, bei verschiedenen relativen Feuchtigkeitsgraden; die Trockengeschwindigkeiten einiger Anstriche unter dem Einfluss der relativen Feuchtigkeit und der Luftgeschwindigkeit; die Zusammensetzung der rückständigen flüchtigen Komponenten von wasserhaltigen gemischten Lösungsmitteln und eines Lackes während des Trocknungsvorganges. Die von den Autoren erhaltenen und auch früher publizierte Daten wurden nach bekannten Methoden der Wärme- und Massentransferierung analysiert.

Es wurde gezeigt, dass die Trocknungsgeschwindigkeit von der Diffusion der Dämpfe durch eine Grenzflächenschichte über dem trocknenden Film abhängig und direkt proportional der Quadratwurzel der Luftgeschwindigkeit ist, wenn die Geschwindigkeiten die unbehinderte Konvektionsgeschwindigkeit (ungefähr $0.05 - 0.1 \text{ ms}^{-1}$) übersteigen. Es wurde ferner gezeigt, dass die Methoden zur Bestimmung des Lösungsmittelgleichgewichtes auf wässrige Systeme angewendet

Introduction

Ref. 1

The drying behaviour of coatings containing water appears to be different from those having only organic volatiles. The physical properties of water are very different from those of the most organic solvents as illustrated in Table 1.

The well-established principles describing the evaporation from coatings containing only organic solvents are, therefore, applicable to aqueous systems only if they do not depend explicitly on the physical properties of the volatiles. In the following the evaporation process for fluid coating films is described. It is compared with measure-

werden können wenn dem Wasser eine relative Verdampfungsgeschwindigkeit zugeteilt wird, die der relativen Feuchtigkeit der Umgebung direkt proportional ist. Aktivitätskoeffizienten für wässrige Systeme sind nicht leicht erhältlich, aber tragbare Übereinstimmung für die untersuchten flüchtigen Mischungen wurde festgestellt wenn man ideales Verhalten annimmt. In neutralisierten Alkyd/Melamin Systemen verschiebt sich das Gleichgewicht schneller gegen eine Anreicherung der organischen Komponenten im Vergleich mit den berechneten Werten. Dies weist auf die Gegenwart einer zusätzlichen Phase hin, wobei die nicht kontinuierliche Phase eine höhere Konzentration an flüchtigen organischen Materialien besitzt als das Gesamtmaterial. Die Berechnungsmethode kann jedoch noch immer den Einfluss der Veränderungen der physikalischen Parameter aufzeigen.

Wässrige Systeme waren mehr empfindlich gegen Wärmeübertragung als mässig flüchtige organische Systeme. In diesem Fall und in schnell verdampfenden organischen Systemen weicht das Verhalten von der oben erwähnten isothermalen Beschreibung ab.

ments on systems containing water to elucidate the validity and limitations of the principles of evaporation from coating films. The influence of ambient conditions and the balance of several volatiles in the coating system are investigated.

Evaporation of pure liquids

Refs. 2-12, 59

Mass transfer through a stagnant air layer

The evaporation from pure liquid films can, in many cases, be regarded as being controlled by the diffusion of their vapours into the surrounding atmosphere.

Table 1
Physical Properties^a—Water vs Solvents (McEvan¹)

| Property | Water | Mineral Spirits ^a | Acetone | Xylene |
|--|--------|------------------------------|---------|------------------|
| B.P. °C | 100 | 214.5 | 56.5 | 144 |
| F.P. °C | 0 | -12 | -95 | -25 |
| (B.P.—F.P.) °C | 100 | 226.5 | 151.5 | 169 |
| Solubility parameter ^b | 23.5 | 6.6 | 10 | 8.8 |
| H-bonding | 39.0 | 0 | 9.7 | 4.5 |
| Dipole moment, Debyes | 1.84 | 0 | 2.88 | 0.4 ^b |
| Latent heat of vap. cal/g at B.P. | 540 | 115 | 135 | 94 |
| B.P. elevation constant | 0.51 | 2.79 | 1.33 | 2.67 |
| Surface tension, dynes/cm | 73 | 18 | 24 | 30 |
| Thermal conductivity $\times 10^3$, W/m ² °C | 5.8 | 1.49 | 1.8 | 1.59 |
| Specific heat | 1.0 | 0.52 | 0.5 | 0.4 |
| Density g/ml | 1.0 | 0.751 | 0.787 | 0.86 |
| Refractive index, Na ^D /20°C | 1.3330 | 1.4216 | 1.362 | 1.50 |
| Dielectric constant | 78 | 1.83 | 21.3 | 2.37 |

(a) Generally, values for dodecane, reference (1c) Schefflan, L. and Jacobs, M. B., *Handbook of solvents*, 1953.

(b) Commercial xylene reference (1b) Crowley *et al.*, *Journal of Paint Technology* 1968 **38** 496 pp. 269.

A first approximation to this process would be to regard it as diffusion of the vapour through a stagnant boundary layer, where the gas is well mixed at the top of the boundary layer, as indicated in Figure 1.

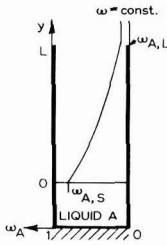


Figure 1. Diffusion of vapour A through a stagnant air layer of thickness L in steady evaporation of liquid A

Assuming ideal gases, a steady, one-dimensional mass balance for this system and Fick's law relating concentration gradients and mass flux for a binary mixture, leads to the Stefan-Maxwell equation² for the evaporation rate. In terms of mass flux, it may be written as:

$$n_A = \frac{\mathcal{D}_{AB}}{L} \ln \frac{1 - \omega_{A,L}}{1 - \omega_{A,S}} \dots \dots \dots (1)$$

when the vapour density is equal to the density of the surrounding gas. For unequal densities the mass flux is given by:

$$n_A = \frac{\rho_{B,L} \mathcal{D}_{AB} (1 + b)}{L} \ln \left[\frac{1 - \omega_{A,L}}{1 - \omega_{A,S}} \cdot \frac{1 + b\omega_{A,S}}{1 + b\omega_{A,L}} \right] \dots (2)$$

where $b = \frac{M_B}{M_A} - 1$

with

- ρ density
- ω mass fraction
- \mathcal{D}_{AB} binary diffusivity of A into B
- L width of diffusion layer
- M molecular weight
- P pressure
- P_A partial pressure of A

and subscripts

- A vapour of evaporating specie
- B surrounding atmosphere
- ,S at the evaporating surface
- ,L at the top of the diffusion layer

and the mass fraction is related to the vapour pressure² by:

$$\omega_A = \frac{M_A}{M_B} \cdot \frac{1}{\frac{P}{P_A} + \frac{M_A}{M_B} - 1} \dots \dots \dots (3)$$

The vapour concentration at the liquid/air interface can be regarded as equal to the partial pressure of the volatile at the surface temperature (ref. 3, p.75-76; ref. 4, p.522) leaving the boundary layer thickness as the only unknown when determining the flux, where the physical data for the liquid are available.

The heat transport towards the evaporating surface, however, may be an additional limiting factor in the evaporation process. The heat of evaporation may originate from the air above the liquid as well as from the liquid and from the material under the liquid.

In addition to the vapour gradient in the boundary layer, there will be temperature gradients in the boundary layer and also in the film and the substrate. This situation is indicated in Figure 2.

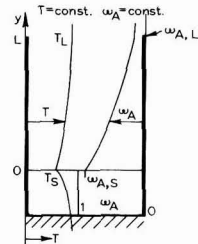


Figure 2. Steady evaporation of liquid A into a stagnant air layer with heat transfer from gas-phase, liquid and substrate

Two limiting cases on the heat transfer are: (1) the case where the substrate is a good conductor and of large extent and the film is either thin or also a good conductor, and (2) the case where the substrate and the liquid are both very poor conductors. In the first case, the surface temperature is equal to ambient temperature and the problem reduces to the isothermal case just described. In the second case, all the evaporative heat must come from the surrounding air and the surface temperature is lower than ambient. This situation of coupled heat and mass transfer in the gas phase is indicated in Figure 3.

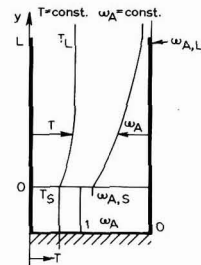


Figure 3. Steady evaporation into stagnant air layer from the isothermal, insulated liquid A

From a heat balance on the boundary layer, the rate of heat transfer can be determined, and equalising the rate of heat transfer to the evaporative heat consumption leads to an expression relating the mass fraction of vapour at the evaporating surface to the surface temperature²:

$$\omega_{A,S} = 1 + (\omega_{A,L} - 1) \left[\frac{c_{pA} (T_L - T_S)}{h_{A,hv}} + 1 \right]^{-1} \frac{k}{\mathcal{D}_{AB} \rho c_{pA}} \dots (4)$$

with the additional nomenclature

- c_{pA} heat capacity at constant pressure of vapour A
- $h_{A,hv}$ heat of evaporation of specie A at temperature T_S
- k thermal conductivity
- T absolute temperature

In this equation, c_p and k are assumed to be constant, since the temperature depression at the surface is relatively small.

Some heat transport will follow with the diffusion, but for the boundary layer thicknesses and mass fluxes considered in the following, this amounts to less than 1 per cent of the heat flux (ref. 4, p.574). Changes in the temperature of the air will, furthermore, influence the diffusion coefficient as quoted from Bird *et al.* (ref. 4, p.505):

For binary gas mixtures at low pressure, \mathcal{D}_{AB} is inversely proportional to the pressure, increases with increasing temperature, and is almost independent of composition for a given gas-pair. The following equation for estimation of \mathcal{D}_{AB} at low pressures has been developed⁵⁹ from a combination of kinetic theory and corresponding states arguments:

$$\frac{P_{Ab} \mathcal{D}}{(P_{cA} P_{cB})^{1/3} (T_{cA} T_{cB})^{5/12} \left(\frac{1}{M_A} + \frac{1}{M_B} \right)^{1/2}} = a \left(\frac{T}{\sqrt{T_{cA} T_{cB}}} \right)^b \quad (5)$$

in which \mathcal{D}_{AB} [=] $\text{cm}^2 \text{sec}^{-1}$, p [=] atm, and T [=] °K. Analysis of experimental data gave the following values of the constants a and b :

For non-polar gas-pairs:

$$a = 2.745 \times 10^{-4}$$

$$b = 1.823$$

For H₂O with a non-polar gas:

$$a = 3.640 \times 10^{-4}$$

$$b = 2.334$$

The temperature sensitivity is obtained from considering all the factors, except \mathcal{D}_{AB} and T , as constants. In temperature changes originating from heat transfer, this influence seems to be a minor one, but it may become important when considering evaporation at elevated temperatures.

At a known surface temperature, the mass fraction of vapour at the surface may be calculated and inserted into the equation for the mass flux under isothermal conditions (eq. 1), giving the mass flux for the film on an isolating substrate.

The vapour pressure and hence the mass fraction above the liquid varies ideally with temperature as⁶:

$$\ln p = - \frac{h_{A,lv}}{RT} + \ln p_{\infty} \quad (6)$$

where p_{∞} is a constant evaluated at the boiling point for the liquid and $h_{A,lv}$ is the molar heat of vapourisation. In

practice the vapour pressure at varying temperatures may be taken from tables, whilst eq. 6 may be used to evaluate the relative behaviour of water and organic volatiles as their heats of evaporation are significantly different.

Quantitative evaluation

The isothermal description has been shown to be sufficient to describe the evaporation of most organic solvents under real conditions. Assuming that the mass fraction of vapour outside the diffusion layer is small compared to the mass fraction at the evaporating surface, eq. 2 reduces to a proportionality with the product of diffusion coefficient, density and mass fraction of vapour at the surface, or by conversion, with the product of diffusion coefficient, molecular mass and partial pressure of the liquid. Using a theoretical estimation of diffusion coefficients Gardner⁵ has verified this relationship for a wide range of solvents by comparing the calculated product for a number of solvents to the measured evaporation rate for the solvents under identical conditions, as shown in Figure 4.

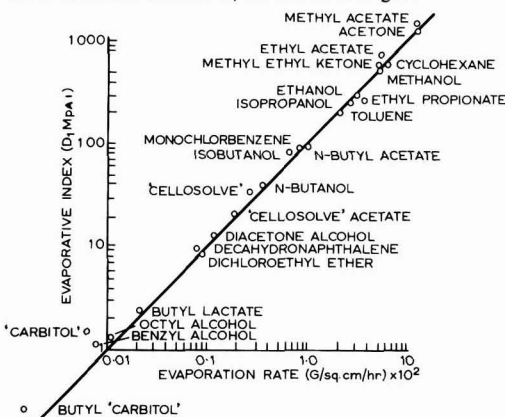


Figure 4. Experimental evaporation rate versus evaporative index (from Ref. 5)

To evaluate the isothermal description of the evaporation of water, the product of mass flux and diffusion layer thickness may be calculated from eq. 2 using the following physical data on water and air.

The molecular mass of water² is 18.02 kg/kmol and of air 28.96 kg/kmol. Applying this to the vapour pressure of water in eq. 4 gives the mass fraction of water vapour at the surface at different temperatures as shown in Table 2.

For calculation, the vapour pressure of water may be represented⁷ by:

$$P_A = 6.131 + 0.467T + 0.00898T^2 + 0.000527T^3 \quad (7)$$

with P_A in mbar and T in degrees centigrade.

Table 2
Vapour pressure and mass fraction of water in air at atmospheric pressure at different temperatures

| Temperature, °C | 20 | 21 | 22 | 23 |
|--------------------------------|--------|--------|--------|---------------------------|
| P_A , vapour pressure, mm Hg | 17.535 | 18.650 | 19.827 | 21.068 (data from ref. 8) |
| $\omega_{A,S}$, mass fraction | 0.0145 | 0.0154 | 0.0164 | 0.0174 |

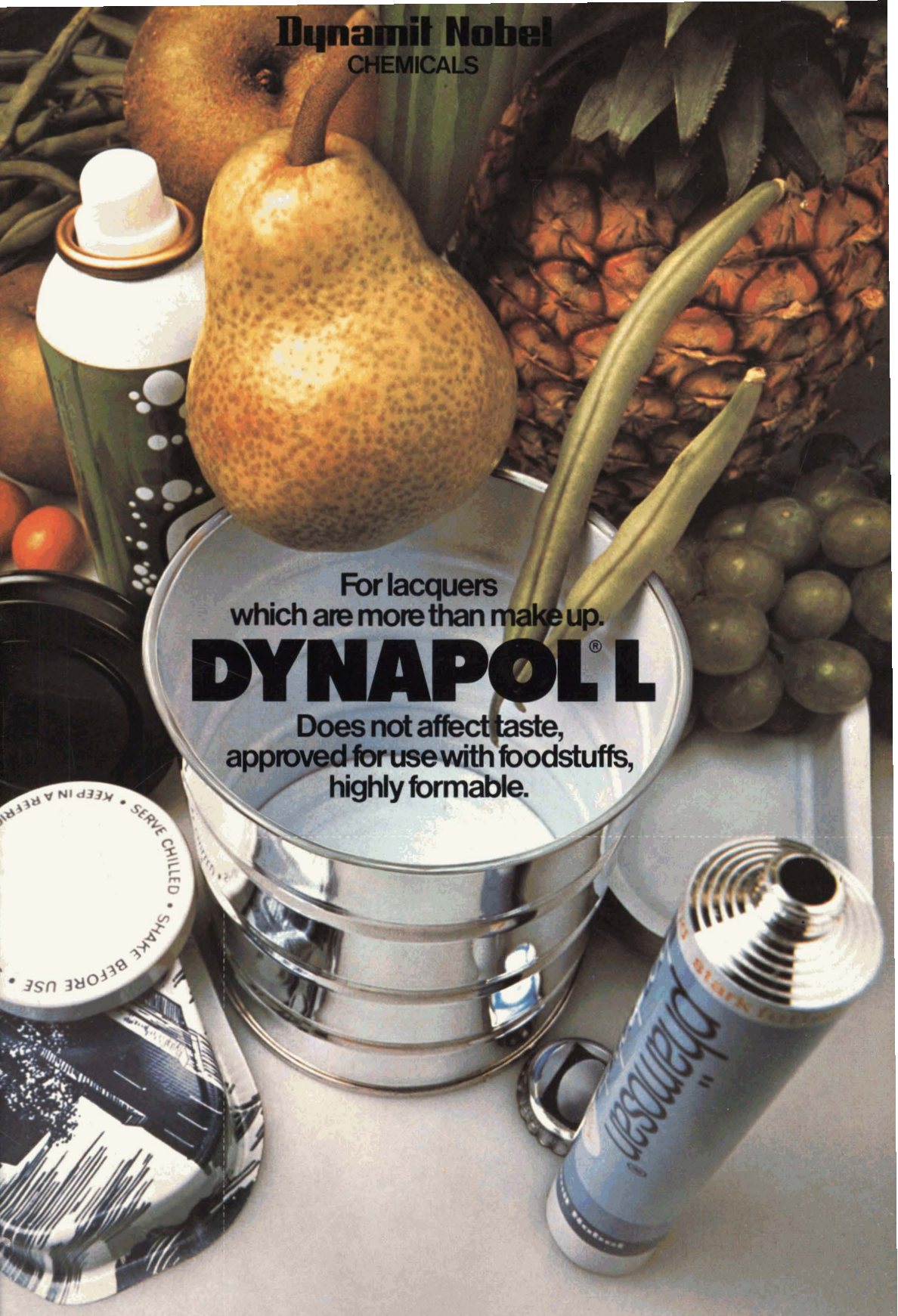
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The diffusion coefficient of water vapour in atmospheric air is of the order $0.254 \text{ cm}^2 \text{ s}^{-1}$ at 23°C (according to data from refs. 8, 9 and 10 when reduced to 23°C (eq. 5)), and the density of dry air⁹ is 1.193 kg m^{-3} at 23°C and 760 mm Hg (101.325 kPa). This is a good approximation also for humid air, since the mass fraction of water is rather small. At 23°C , eq. 2 thus becomes:

$$n_A L = 0.0487 \ln \left[\frac{1.029 \frac{1 - \omega_{A,L}}{1 + 0.6071 \omega_{A,L}}}{\dots} \right] \text{ kg m}^{-1} \text{ s}^{-1} \quad (8)$$

Eq. 8 evaluated at different levels of the relative humidity in the surrounding air, given the mass fraction of water, $\omega_{A,L}$, present in the surroundings, is listed in Table 3.

Table 3
Mass flux times boundary layer thickness for water at 1 atm. and 23°C and different relative humidities

| Relative humidity | Mass fraction of water in atm. | $n_A L$ | |
|-------------------|--------------------------------|---|----------|
| 0 | 0 | 1.3690 | — |
| 10 | 1.727 | 1.2339 | — 0.1352 |
| 20 | 3.457 | 1.0983 | — 0.1356 |
| 30 | 5.191 | 0.9623 | — 0.1359 |
| 40 | 6.929 | 0.8260 | — 0.1363 |
| 50 | 8.670 | 0.6893 | — 0.1367 |
| 60 | 10.415 | 0.5522 | — 0.1371 |
| 70 | 12.164 | 0.4147 | — 0.1375 |
| 80 | 13.916 | 0.2769 | — 0.1379 |
| 90 | 15.672 | 0.1386 | — 0.1383 |
| 100 | 17.432 | 0 | — 0.1386 |
| % RH | 10^{-3} | $10^{-3} \text{ g m}^{-2} \text{ s}^{-1} \text{ m}$ | |

Examination of Table 3 shows that the influence of the relative humidity in the isothermal case can be regarded as linear, a fact that could be deduced from eq. 1 which for $\omega_{A,S} - \omega_{A,L} \ll 1 - \omega_{A,S}$ becomes²:

$$n_A = \frac{\rho \mathcal{J}_{AB}}{L} \cdot \frac{\omega_{A,S} - \omega_{A,L}}{1 - \omega_{A,S}} \quad (9)$$

Comparing these results with the evaporation from a free surface (Petri dish 90 mm ϕ , height 20 mm, filled to the edge) in a room at 23°C and the relative humidity controlled in the range 20 to 50 per cent RH and no sig-

nificant convection (see Figure 5A) agreement is found with the calculated values for a diffusion layer thickness of approximately 35 mm, which seems to be exceptionally high.

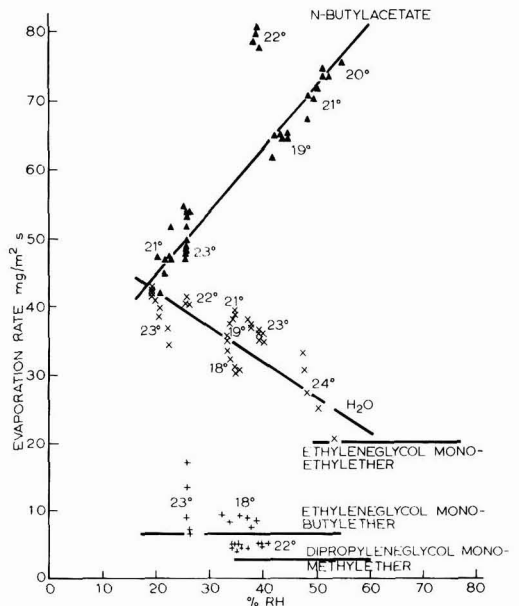


Figure 5A. Absolute evaporation rate for different volatiles as a function of relative humidity. The measurements are made in a closed room without forced convection from a 20 mm deep, 90 mm diameter petri dish. The numbers in the figure indicate the room temperature during measurement

Applying the same reasoning to the measured evaporation rates of n-butylacetate and ethylene glycol monoethyl ether (EGMEE), also shown in Figure 5A, indicates a boundary layer thickness of 0.5 mm for n-butylacetate at 50 per cent RH and 0.9 mm for EGMEE for the following parameters given in Table 4 where \mathcal{J}_{AB} is calculated values of Gardner⁵ relating to atmospheric conditions¹¹.

A stagnant air layer in the millimeter range seems realistic from the viewpoint of fluid mechanics, whereas an air layer of 35 mm seems extremely large, indicating that heat transfer is also rate-determining. Actually, a temperature depression was measured roughly to 2°C by thermocouples. The calculation is, therefore, repeated for the case of water taking this temperature difference into account through eq. 4. Applying the material constants indicated in Table 5, the values for mass flux times

Table 4
Parameters for the calculation of mass flux times boundary layer thickness for n-butylacetate and EGMEE⁵

| | vapour pres. P_A | mol. weight M | mass fraction | | diffusion coefficient \mathcal{J}_{AB} | $n_A L$ (eq. 2) |
|----------------|--------------------|-----------------|---------------|---------------|--|---|
| | | | at surface | at atmosphere | | |
| n-butylacetate | 11.6 | 116.1 | 0.0585 | 0 | 0.065 | 3.0 |
| EGMEE | 5.3 | 90.1 | 0.0214 | 0 | 0.066 | 1.8 |
| | mm Hg | | | | $\text{cm}^2 \text{ s}^{-1}$ | $10^{-5} \text{ g m}^{-1} \text{ s}^{-1}$ |

Table 5
Properties of air and water

| | | |
|--|---|----------|
| heat capacity of water vapour at 25°C, C_{pA} | 1.87 kJ kg ⁻¹ C° ⁻¹ | (ref. 2) |
| thermal conductivity of air at 23°C, k | 0.025782 W m ⁻¹ C° ⁻¹ | (ref. 9) |
| heat of evaporation of water at 21°C, $h_{A,lv}$ | 2602 kJ kg ⁻¹ | (ref. 9) |

Table 6
Mass flux times boundary layer thickness of water assuming a surface temperature 2°C below ambient and boundary layer thicknesses applying the mass flux indicated in Figure 5A

| Relative humidity | Mass fraction of water in atm. $\omega_{A,L}$ | Mass fraction at surface $\omega_{A,S}$ | $n_A L$ | L |
|-------------------|--|--|--|--------|
| 0 | 0 | 0.654 | 0.05114 | 0.9649 |
| 10 | 1.727 | 2.379 | 0.05105 | 1.0862 |
| 20 | 3.457 | 4.108 | 0.05100 | 1.2143 |
| 30 | 5.191 | 5.841 | 0.05096 | 1.3773 |
| 40 | 6.929 | 7.558 | 0.05092 | 1.5913 |
| 50 | 8.670 | 9.318 | 0.05088 | 1.8844 |
| 60 | 10.415 | 11.062 | 0.05083 | 2.3105 |
| 70 | 12.164 | 12.810 | 0.05079 | 3.1744 |
| 80 | 13.916 | 14.560 | 0.05067 | 5.0670 |
| 90 | 15.672 | 16.315 | 0.05063 | 8.4383 |
| 100 | 17.432 | 18.079 | 0.05059 | ∞ |
| % | × 10 ⁻³ | × 10 ⁻³ | × 10 ⁻³ g m ⁻¹ s ⁻¹ | mm |

boundary layer thickness and the thickness resulting from the measurements in Figure 5A are both indicated in Table 6.

Including the heat transfer effect thus leads to a realistic value for the boundary layer thickness. The variation in the calculated thickness at varying relative humidities is probably due mainly to the assumption of the same temperature difference irrespective of evaporation rate.

The measured evaporation rate for n-butylacetate shown in Figure 5A increases markedly with increasing relative humidity. This behaviour was unexpected, but it was reproducible in a second series of measurements. It may be explained by vapour pressure considerations for an n-butylacetate/water mixture as the liquid in all cases will contain water in an equilibrium with the humidity in the atmosphere. The evaporation of mixtures of volatiles will be discussed in detail below. The phenomenon may also be due to heat transfer involved in the evaporation process, since the liquid was placed in a glass Petri dish with a thickness of 20 mm and n-butylacetate was the fastest evaporating of the liquids investigated. The heat capacity of water vapour at 23°C is 1.83 kJ kg⁻¹C°⁻¹ compared to 1.005 kJ kg⁻¹C°⁻¹ for dry air and the thermal conductivities are 0.0177 W m⁻¹C°⁻¹ and 0.0258 W m⁻¹C°⁻¹, respectively. Since the measurements are made with continuous registration of weight over long periods, steady state should be ensured and the water content in the air amounts to less than 1.7 per cent (Table 3). Only a very slight influence due to the differences in heat transfer properties would be expected. The boundary layer thickness, assuming isothermal conditions, is estimated to be of the order 0.5 mm, supporting this conclusion.

If the phenomenon is due to interaction in the liquid mixture, it should be apparent irrespective of the evaporation situation.

The measurement series was repeated with n-

butylacetate, water and propanol-2 which has a higher evaporation rate than n-butylacetate (Fig. 5B). The measurements were made with evaporation from a 150 × 70 × 2 mm film in a 1 kg steel block. No increasing evaporation was measured for n-butylacetate in this situation. In similar measurements with small amounts of fluid in a metallic dish under air flow, Rudd and Tysall¹² also found the evaporation rate of n-butylacetate to be independent of the humidity.

For propanol-2 with an even higher evaporation rate, it was not possible to measure whether the evaporation rate was humidity sensitive or not, since the decreasing film thickness with the evaporation gave a significant decrease in the evaporation rate. The decreasing evaporation rate with a decreasing film thickness compared to the edge of the container was significant for all the volatiles.

With the evaporation rate for n-butylacetate independent of the humidity as indicated in Figure 5B, it is possible to give a relative evaporation rate of water relative to n-butylacetate:

$$RER = 80 \left(1 - \frac{RH}{100} \right)$$

The absolute evaporation rate of water in Figures 5A and 5B is evaluated from the first few grams evaporated where the decreasing film thickness has not started to delay the evaporation, and assuming no evaporation at 100 per cent RH.

Mass transfer and convection

Refs. 4, 8, 9, 12-22, 60

The extent of the boundary layer through which the evaporating vapour has to diffuse and the extent of the layer in which the heat is transported by conduction, is determined by the motion of the surrounding gas, giving rise to mass and heat transfer by convection.

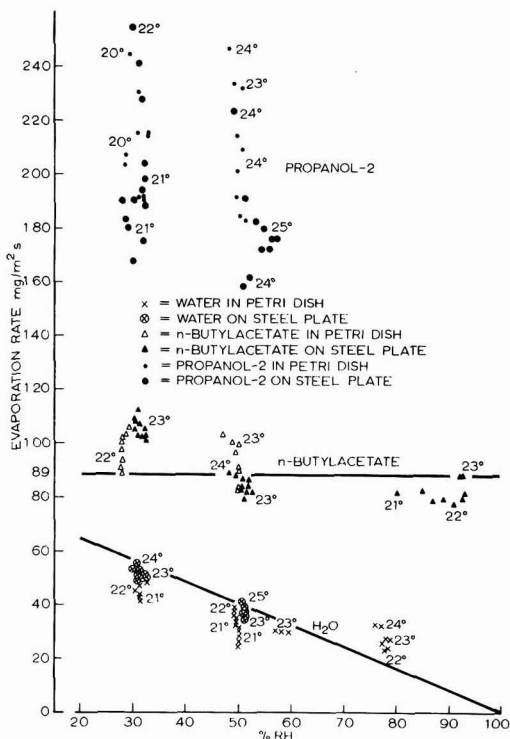


Figure 5B. Absolute evaporation rate for different volatiles as a function of relative humidity. The measurements are made in a closed room without forced convection from a 150 × 70 mm liquid film in a 1 kg steel block and a 20 mm deep, 90 mm diameter petri dish. The numbers in the figure indicate the room temperature during measurement

Instead of defining a stagnant air layer of a certain thickness over which the gradients abruptly disappear, the heat and mass transfer may be regarded in connection with the air flow.

Considering the liquid film with an air flow parallel to the film surface, three boundary layers may be ascribed to the film in which vapour concentration, temperature and air velocity, respectively, differ from their values in the ambient atmosphere. This is indicated in Figure 7 for the simple case of the isothermal flat plate.

Balances of mass, energy and momentum in the boundary layers, each lead to the same type of equation and boundary conditions (ref. 4, § 19.3), when the material properties density ρ , viscosity μ , heat capacity c_p , heat conductivity k , and diffusion coefficient \mathcal{D}_{AB} are regarded as constant through the boundary layer.

This assumption implies that $M_A = M_B$ and $c_{pA} = c_{pB}$ since ω_A is a function of position. From equations 1 and 2 this assumption is seen to be reasonable in most situations.

Describing air velocity, temperature and mass fraction of vapour by the following dimensionless quantities:

$$\Pi_v = \frac{v_x - v_{xS}}{v_{x\infty} - v_{xS}} = \frac{v_x}{v_{\infty}}; \quad \Pi_T = \frac{T - T_s}{T_{\infty} - T_s}; \quad \Pi_{AB} = \frac{\omega_A - \omega_{A,S}}{\omega_{A,\infty} - \omega_{A,S}}$$

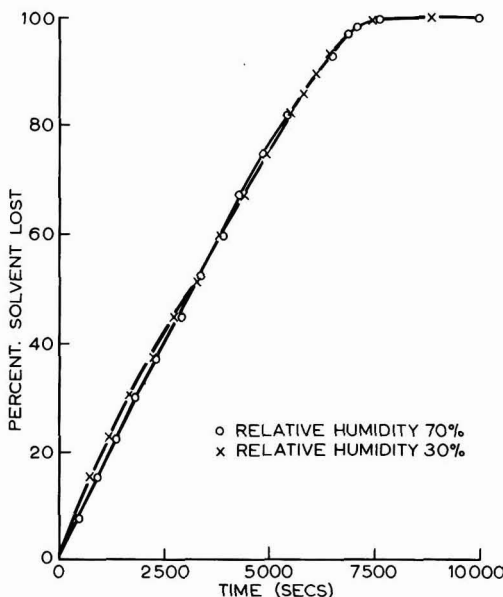


Figure 6. Effect of relative humidity on the evaporation behaviour of n-butyl acetate (from Ref. 12)

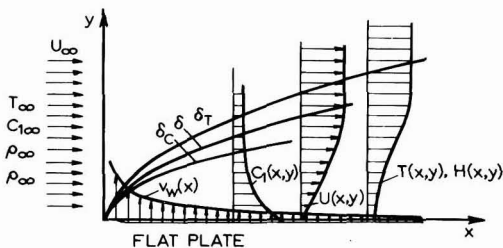


Figure 7. Boundary layers along a flat liquid film in parallel flow (from Ref. 13)

and defining the dimensionless physical properties:

$$\Lambda_v = \frac{\nu}{\nu'} = 1; \quad \Lambda_T = \frac{\nu}{\alpha} = Pr; \quad \Lambda_{AB} = \frac{\nu}{\mathcal{D}_{AB}} = Sc$$

the equations for the profiles of velocity, heat and vapour concentration take the common form:

$$\Lambda \left[K - \int_0^\eta 2\Pi_v d\eta \right] \Pi' = \Pi''$$

$$K = \frac{1}{\Lambda_{AB}} \left(\frac{\omega_{A,S} - \omega_{A,\infty}}{1 - \omega_{A,S}} \right) \Pi'_{AB}(0)$$

with boundary conditions:

$$\text{at } \eta = 0, \quad \Pi = 0$$

$$\text{at } \eta = \infty, \quad \Pi = 1$$

where η is the dimensionless distance from the surface:

$$\eta = \frac{y}{2} \sqrt{\frac{v_{\infty}}{\nu_x}}$$

In the equations, ν is the kinematic viscosity, μ/ρ , α is the thermal diffusivity, $k/\rho c_p$, and x the distance from the starting point of the boundary layer. The Prandtl and Schmidt numbers, Pr and Sc , are defined by the equations shown above.

The K in the equation for the profiles implies that the rate of mass transfer at the wall in terms of $\Pi'_{AB}(0)$ directly affects the three profiles Π_v , Π_T and Π_{AB} as is also obvious from the numerical solutions of the profiles shown in Figure 8 (ref. 4, p.613). At the rates of mass transfer occurring in the drying of coating films, the flow and heat transfer normally can be regarded as independent of the mass transfer rate as discussed in the preceding section.

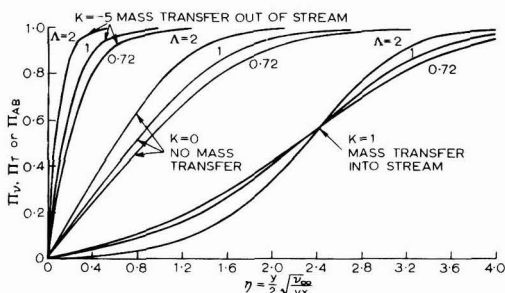


Figure 8. Theoretical velocity, temperature and composition profiles in the laminar boundary layer on a flat plate with mass transfer at the wall (Refs. 4, 60)

Since the temperature and mass concentration profiles are described by the same equations when expressed in dimensionless terms, and since also the equations relating the gradients to the resulting fluxes, the Fourier and Fick equations, are similar in structure, the large number of solutions to heat transfer problems may be applied to mass transfer situations by exchange of the various dimensionless properties and parameters involved in the problem¹⁴. The analogy between heat and mass transfer is limited by the assumption of moderate rates of mass transfer and of constant properties in the boundary layer. Spalding¹⁵ has evaluated the validity of the analogy from experimental work, and the deviations seem to be of minor importance in the range in which the drying of coatings is situated since the rates of mass transfer are low.

Quantitative evaluation

Applying this boundary layer description to the evaporation of volatiles indicates, as seen from eq. 10 and Figure 8, that the vapour concentration profile is related to the air velocity only by the dimensionless distance, which means that the mass boundary layer thickness is inversely proportional to $\sqrt{V_\infty}$. Since the mass flux in the preceding was found to be inversely proportional to an effective thickness of the boundary layer, the mass flux should be proportional to the square root of the air velocity.

Measurements on some, not too rapidly evaporating, organic volatiles¹⁶ indicate, however, that the mass flux is proportional to the air velocity rather than to its square root, as shown in Figure 9.

The measurements were made on a relatively deep pan (10 mm) in parallel flow and the stronger influence of air flow than expected may be ascribed to non-laminar or possibly separated and recirculating flow in the volume of

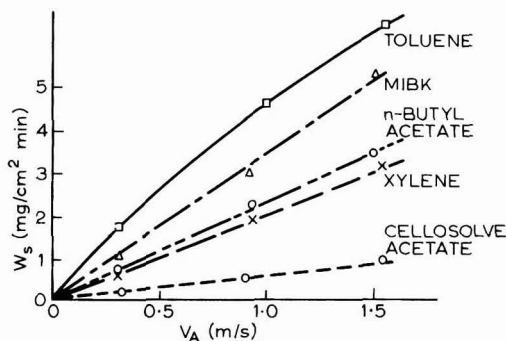


Figure 9. Relation of evaporation rate of solvent (W_s) and flow rate of air (V_A) at 30°C, 55 per cent RH (from Ref. 16)

gas below the edges of the pan. Unfortunately no detailed description of the measurements is readily available. The heat transport cannot account for this discrepancy, since it is related to the air velocity in the same way as is the mass transfer, provided the evaporative heat is coming from the atmosphere alone.

Where the evaporative heat is taken mainly from the substrate or is due to radiation, the air flow will promote the mass transfer, but not the heat transport. This leads to a lower surface temperature and thus a lower vapour concentration at the surface. In such cases, the increase in evaporation rate will not increase with the air flow as fast as described. The effect is not significant for not too rapidly evaporating volatiles at low air velocities. Yoshida¹⁶ relates the deviation from linearity between air velocity and evaporation rate for the fastest evaporating volatiles at the largest speeds shown in Figure 9 to this effect.

Measurements of the evaporation rate of water are found to be in excellent agreement with the boundary layer description by Pramojaney¹⁷. The measurements were made on 0.1 mm thick films in a wind tunnel with very well-defined flow, temperature and humidity conditions and covered the ranges of 0.84–3.50 m s⁻¹, 18–72 per cent RH and 25–45°C. The measured evaporation rates were compared to a solution of the thermal boundary layer problem (ref 18, § XII g) expressed in terms of the mass transfer coefficient¹⁷:

$$K_{xL} = 0.664 \left(\frac{\rho V}{\mu} \right)^{1/3} Sc^{1/3} \left[\frac{\rho V}{\mu} \right]^{1/3} (L^3 - x^3)^{2/3} / (L - x) \dots (11)$$

which is an integration over the length of the liquid film located in the region x to L from the starting edge of the boundary layer.

From the definition of the mass transfer coefficient $K_A = n_A / (\omega_{A,S} - \omega_{A,L})$ the evaporation rate may be determined when the surface concentration is known. This is found from eq. 4 assuming the surface temperature to equal the wet-bulb temperature in psychrometer measurements (ref. 4, p.649, ref. 8 sect. 15; ref. 19, p.261).

Heat analogies to more complex mass transfer situations

The boundary layer considerations presented here show the basic relationships between air velocity, heat and mass transfer. The considerations have, however, been restricted to laminar flow which means $Re = UL/\nu < 10^5$. This will nearly always be the case in the drying of coatings.

Table 7
Analogies between heat and mass transfer

| | Heat Transfer | Mass Transfer |
|--|---|---|
| Profiles | T | ω_A |
| Diffusivity | $\alpha = \frac{k}{\rho c_p}$ | \mathcal{D}_{AB} |
| Transfer coefficient | $h = \frac{Q}{A\Delta T}$ | $k_A = \frac{n_A}{\Delta\omega_A}$ |
| with transfer rate | Q | $n_A A$ |
| Dimensionless velocity Reynolds number | $Re = \frac{V_\infty L \rho}{\nu}$ | |
| Dimensionless coefficient of heat/mass transfer, Nusselt/Sherwood number | $Nu = \frac{hL}{k}$ | $Sh_{AB} = \frac{k_A L}{\rho \mathcal{D}_{AB}}$ |
| Dimensionless diffusivity Prandtl/Schmidt number | $Pr = \frac{\nu}{\alpha}$ | $Sc = \frac{\nu}{\mathcal{D}_{AB}}$ |
| Dimensionless buoyancy Grashof number | $Gr = \frac{g \rho^2 \beta L^3 \Delta T}{\nu^2}$ | $Gr_{AB} = \frac{g \rho^2 \zeta L^3 \Delta \omega_A}{\nu^2}$ |
| with the effect of the profiles on density | $\beta = -\frac{1}{\rho} \left(\frac{\delta \rho}{\delta T} \right) P, \omega_A$ | $\zeta = -\frac{1}{\rho} \left(\frac{\delta \rho}{\delta \omega_A} \right) P, T$ |

Furthermore, only steady state evaporation has been considered, since the deviations in practice are regarded as fluctuations rather than an unsteady period. Situations where the vapour accumulates in the surroundings could be included if they are slow in a quasi-steady manner. Finally, the boundary layer considerations have been based on air flow parallel to the liquid surface. This will seldom be the case in practice. Yet, the boundary layer concept, as such, does apply and so does the similarity between heat and mass transfer. Table 7 summarises corresponding quantities in the analogy between heat and mass transfer at atmospheric pressure and low rates of mass transfer of one species (ref. 4, p.646).

In this table, A is the area considered, L a characteristic length and the subscript ∞ denotes conditions in the bulk (as did L for the stagnant layer situation).

As the boundary layers become more complicated in the more applied situations, it is more convenient to express the transfer in terms of a mass transfer coefficient for the actual situation.

Evaporation rate measurements are often made by air flow around a tray in which the liquid is placed. Such a flow field may be approximated by flow around a sphere rather than parallel flow. The heat transfer and hence the mass transfer for the flow around a sphere is described by (ref. 4, p.409)

$$\frac{h D}{k} = 2.0 + 0.60 \left(\frac{Dv}{\mu} \rho \right)^{\dagger} \left(\frac{C_p \mu}{k} \right)^{\dagger}$$

or $Nu = 2.0 + 0.6 Re^{1/2} Pr^{1/3}$ (12)

Figure 10 shows some measurements of this type. The influence of air velocity on the evaporation rate in this measurement may be described by a linear relationship to the square root of the air velocity as the solution for a sphere indicates.

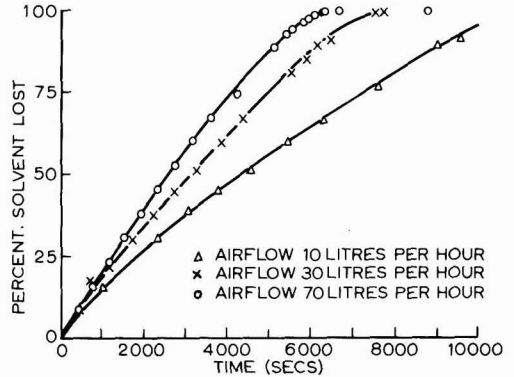


Figure 10. Effect of variations in rate of air flow on the evaporation behaviour of n-butyl acetate (from Ref. 12)

The minimum flow involved in any evaporation process will be the flow caused by the buoyancy variation due to density variation with temperature and composition of the gas layer on top of the film. The heat transfer due to this free convection on a cooled horizontal plate can be described^{20,21} by:

$$Nu = 0.27 (GrPr)^{1/4} \quad 2.10^7 < GrPr < 3.10^{10} \quad \dots (13)$$

where the parameters are as defined in Table 7.

The range of validity seems appropriate to evaporation from coatings on extended surfaces.

In an evaporation process, the free convection will be due to the density variation with temperature, as taken

into account by eq. 13, as well as to the density variation with the variation in concentration of volatiles in the boundary layer, the influence of which will be given by the similar expression in mass terms.

The free convection will always be superimposed on a forced flow, but as Re^2 becomes of the same order as Gr , the free convection will cease to be significant (ref. 18, p.265). In the interval $0.3 < Gr/Re^2 < 16$ the flow is a mixture of free and forced convection²² on a horizontal plate.

In the case of an object 25 cm long and a temperature difference of 2°C, the square of Reynolds number and the Grashof number become equal at an air velocity of the order 0.09 m s⁻¹ evaluated from data⁹ at 23°C. Assuming 50 per cent R.H., the square of Reynolds number equals the Grashof number based on mass transfer at 0.02 m s⁻¹. Even though those two mechanisms may support each other, the forced convection will be the sole significant flow in the case considered at air velocities above 0.1 m s⁻¹.

Evaporation of mixtures of volatiles

Refs. 1, 4, 12, 27-37

When the evaporating liquid is a mixture of several volatile species, the diffusion of each species will be through a boundary layer consisting of air as well as the other volatile species from the liquid. For an ideal mixture, the diffusion through the boundary layer for the single volatile is given by (ref. 4, p.569):

$$n_i = \frac{\rho}{1-\omega_i} \sum_{j=1}^n D_{ij} \frac{\partial \omega_j}{\partial y} \quad i = 1, 2, \dots, n \quad \dots \dots (14)$$

D_{ij} is the diffusion coefficient for species i with respect to species j in the multicomponent mixture. D_{ij} can be related to the similar diffusion coefficient in the binary mixture of components i and j (ref. 4, p.570) and nearly equals this when the concentration of other species is small. The diffusion coefficient in eq. 14 will, therefore, be determined mainly by the binary diffusion coefficient of each volatile with respect to air.

The composition of the vapour mixture at the film surface to diffuse through the boundary layer is determined by the equilibrium with the liquid mixture at the interface. The vapour mixture may, therefore, be determined from the mixture of the liquid at the surface, the vapour pressures of the pure volatile components and possibly the activity coefficients, taking the non-ideal interaction between the molecules in the liquid into account.

The evaporation process may thus be calculated according to the principles outlined in the preceding sections, describing the evaporation rate for each of the volatiles as the evaporation proceeds and the mixture changes composition.

In order to carry out such calculations, the diffusion coefficients for the volatiles and the physical conditions of the evaporation situation must be known. In practice, interest is limited to determining the change in composition of the mixture as the evaporation proceeds i.e. the evaporation of the volatiles relative to each other. The ratio of the diffusion coefficients is equal to the ratio of the evaporation rates of the volatiles (eq. 1), provided that the

evaporation may be regarded as isothermal and that the concentration in the atmosphere is constant. Furthermore, by expressing the evaporation rates relative to each other or to one reference material (n-butylacetate or ether), the evaporation rates become largely independent of the physical conditions under which the rates have been determined. A number of studies have been made to evaluate this description^{12, 23-26}.

Under those conditions the total evaporation rate at a given instant is given by:

$$R_{total} = C_1 \gamma_1 R_1 + C_2 \gamma_2 R_2 + \dots + C_n \gamma_n R_n \quad \dots (15)$$

where C_1 is the volume concentration of species 1 at the surface, γ_1 the activity coefficient of species 1 in the actual mixture, and R_1 is the evaporation rate of pure species 1.

As the drying proceeds the relative concentrations change and thus also the activity coefficients. Applying evaporation rates relative to a reference volatile (n-butylacetate or ether) instead of absolute evaporation rates, eq. 15 may be used to describe the change in composition as the drying proceeds, expressing the drying in relative amounts evaporated instead of time. The relative concentrations at the surface are usually expressed by the relative concentrations of the bulk film, thus assuming that the liquid/liquid diffusion is fast compared to the evaporation.

The mathematical procedures to calculate this change in composition with evaporation have been developed by Derr and Deal²⁷ and by Sletmoe²⁸. The latter regarded the activity coefficients as constant throughout the evaporation. A procedure similar to that of Derr and Deal using absolute evaporation rates for the volatiles and thus giving absolute evaporation times has been presented by Walsham and Edwards²⁹.

The relative evaporation rates of most organic volatiles used in coatings can be found in tables³⁰ and the thermodynamic activity coefficients have been averaged in graphs for chemically similar types of solvents, i.e. hydrocarbons, alcohols/ether alcohols and esters/ketones, by Deal and Derr³¹.

The procedure of Sletmoe is widely used for a technological evaluation of the solvent balance in organic systems containing more than one volatile component. When water is one of the volatiles in the mixture, the assumption of constant (in practice zero) content of each of the volatiles in the surroundings is no longer acceptable. For a given relative humidity, the evaporation rate of water can be approximated by the linear relation suggested in the preceding sections.

The activity coefficients in systems of organic volatiles also containing water are not readily available, but may be calculated from the principles indicated by Deal and Derr²⁷ and by Fredenslund *et al.*^{32,33}, and might be fitted into a practicable system similar to that for purely organic volatiles.

Measurements on aqueous volatile mixtures

C. M. Hansen³⁴ has applied Sletmoe's procedure to binary mixtures of water with diethyleneglycol monobutylether, ethyleneglycol monobutylether, ethyleneglycol monoethylether, ethyleneglycol monoethylether, diacetone alcohol and t-butanol setting the activity coefficients at

unity and with the evaporation rate of 45 for water relative to n-butyl acetate. He finds a reasonable agreement with measurement in all cases for the number of initial concentrations considered. Jørgensen and Nielsen³⁵ (See Appendix Figures 1-2) have compared measurement and calculation for binary aqueous mixtures of 25 per cent ethyleneglycol monobutylether and dipropyleneglycol monomethylether and find an excellent agreement in both cases, ignoring activity coefficients.

Measurements by Shell Chemicals³⁶ of the evaporation of binary aqueous mixtures with t-butanol, propanol-2, ethyleneglycol monoethylether, diethyleneglycol monobutylether in different initial concentrations have been reported. Applying the Sletmoe procedure to these measurements with the relative evaporation rate of water as 45 gives a reasonable qualitative agreement (See Appendix Figures 3-6).

At the Scandinavian Institute, the volatile balance of a ternary mixture of initially 10.2 vol. per cent propanol-2, 24.15 vol. per cent ethyleneglycol monobutylether and 65.65 vol. per cent water has been followed during evaporation from cups at 20, 35 and 50 per cent RH at 23°C, using gas chromatography. These results are compared to calculations of the balance applying relative evaporation rates deduced from Figure 5. As shown in Figures 11, 12 and 13, excellent quantitative agreement is found.

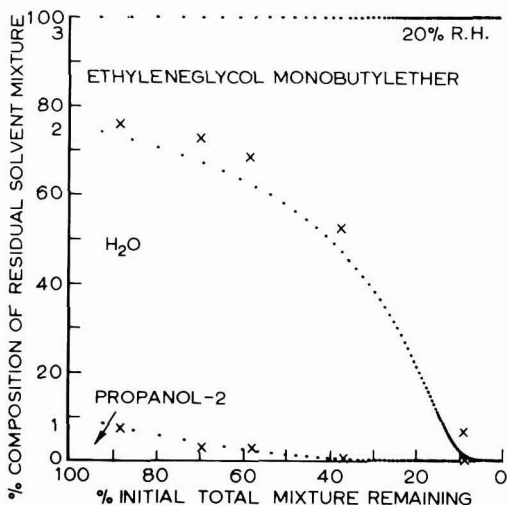


Figure 11. Volatile balance of ternary mixture of propanol-2, ethyleneglycol monobutylether and water as the evaporation proceeds at 23°C and 20 per cent RH. The calculated curve is determined from relative evaporation rates as indicated in Figure 5

When comparing the differences in balance at the different relative humidities, the expected differences are within the uncertainty of the measured values.

McEwan¹ has measured the total evaporation rate for a number of binary mixtures of water and organic volatiles. These results are found to be different from the mole averaged evaporation rate of the mixtures, but this fact does not give any information about deviations from ideality without information on the evaporation rates of each of the volatiles. In the case of water with smaller con-

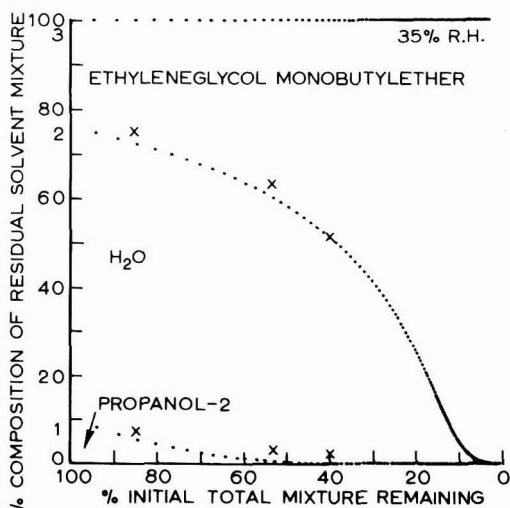


Figure 12. Volatile balance of ternary mixture of propanol-2, ethyleneglycol monobutylether and water as the evaporation proceeds at 23°C and 35 per cent RH. The calculated curve is determined from relative evaporation rates as indicated in Figure 5

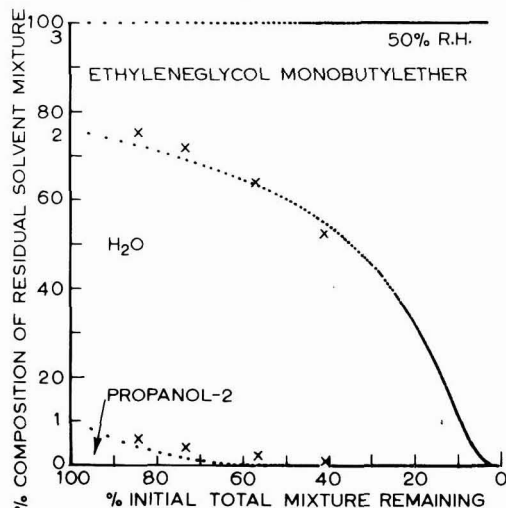


Figure 13. Volatile balance of ternary mixture of propanol-2, ethyleneglycol monobutylether and water as the evaporation proceeds at 23°C and 50 per cent RH. The calculated curve is determined from relative evaporation rates as indicated in Figure 5

tents of ethyleneglycol monobutylether an evaporation rate exceeding the rate of both of the pure volatiles is obtained. This result may be related to the observation for n-butyl acetate in humid air (Fig. 5A) indicating that such behaviour could be caused by liquid/liquid interaction. It should, however, be noted that the evaporation measurements of McEwan were made on porous sintered glass dishes where capillary phenomena might have been involved.

Dillon³⁷ has analysed the evaporation from binary

aqueous mixtures of butanol-1, propanol-1, propanol-2, butanone, ethyleneglycol monoethylether, diethyleneglycol monoethylether, propyleneglycol mono-propylether, ethyleneglycol monoethylether, ethyleneglycol monobutylether, and ethylene-glycol monobutylether-acetate in terms of the relative humidity where the mixtures retain the same composition throughout the evaporation (the critical relative humidity). This situation implies that the corrected evaporation rate times the concentration is the same for each of the volatiles (eq. 15). For ideal systems, where the activity coefficients are unity, the critical humidity will vary linearly with the content of organic component, since the evaporation rate varies linearly with the relative humidity.

Dillon's results are shown as curves for the critical relative humidity as the volume per cent of organic component is varied. Those curves may in most cases be approximated by straight lines, dependent on how well the curves actually reflect measured values. The theoretical linearity does not include the extremes, where only one of the volatiles is present. Actual deviation from a straight line is an indication of a significant activity coefficient.

When the temperature is raised, the vapour pressure will increase as discussed above (eq. 6). Since the heat of evaporation of most organic volatiles is of the same order, the relative behaviour will be mainly independent of the temperature. For water, however, the heat of evaporation is significantly larger (Table 1) and the evaporation rate will not change significantly with temperature for a given relative humidity, since the vapour pressure in the surroundings increases with temperature as does the vapour pressure at the evaporating surface, resulting in a constant gradient. The relative evaporation rate will thus diminish with increasing temperature, explaining the decreasing critical humidity with increasing temperature as found by Dillon. Dillon, however, concludes that this influence is only moderate to small.

The temperature characteristics of water may also explain why Dillon finds a decreasing rate of evaporation for water relative to the organic volatile at increasing air speeds. An increased air velocity should not change the diffusion conditions for the volatiles relative to each other, but the increased evaporation rate may lower the surface temperature. Since the heat of evaporation for water is significantly larger than for that of the organic volatiles (Table 1), the water vapour concentration at the surface will diminish faster than will the concentration of organic volatiles (eq. 6), thus leading to the relatively slower evaporation of water.

Evaporation from solutions and dispersions

Refs. 16, 38-50

When the fluid under consideration contains non-volatile components the transport of volatiles through the fluid to the free surface is part of the evaporation process. Actually, the diffusion through the film often determines the evaporation rate. A surface layer of a composition different from the bulk of the film may build up, also offering a potential third factor which could control the evaporation process. This situation of three diffusion layers (liquid, surface, gas) indicated in Figure 14 has been discussed by Sletmo³⁸.

The drying of paint films has been found to consist of

mainly two periods. The first period where the vapour diffusion is the controlling factor and the second period where the diffusion of volatiles through the film towards the surface is controlling^{16,39-41}. In an intermediate period both these factors may be significant. In the following only the first phase will be considered, since the film is no longer a fluid when the second stage is reached.

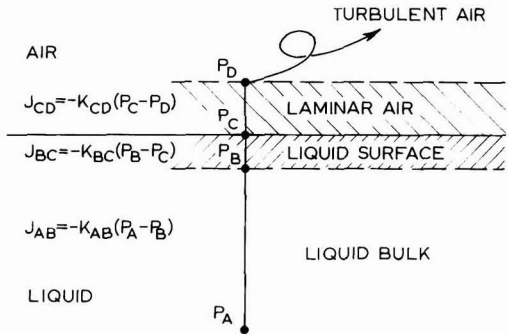


Figure 14. Solution evaporation diagram (from Ref. 38)

The presence of non-volatile components in the fluid leads to a lower vapour pressure or a lower concentration of vapour over the film ($\omega_{1,s}$), because of the diminished probability of having a molecule of the volatile leaving a certain surface area. The evaporation rate will thus be lower in the system containing non-volatile than for the similar system containing only volatile matter.

As the drying of a film proceeds, the vapour concentration over the film will thus diminish as the relative amount of volatiles in the film diminishes and the evaporation rate will diminish further as the drying proceeds, even when the gaseous boundary layer is the only controlling factor.

This situation is included in Hansen's⁴² quasi-steady mathematical model, where the evaporation rate is expressed by a mass transfer coefficient (see Table 7) proportional to the volatile concentration in the film. The decrease in concentration as the drying proceeds is seen to be proportional to the thickness of the film, since the amount of solvent evaporated to reach a given solids content is proportional to the film thickness. Hansen finds good agreement between calculated and measured evaporation for chlorobenzene in polyvinyl acetate applied in different film thicknesses.

Hansen actually considers the situation of both mass transfer over the film and diffusion of volatiles in the film. The mathematical description, therefore, is rather complicated, but in the first phase of drying, the diffusion in the film is found to be so fast (large diffusion coefficient) that it does not influence the mass transfer.

In experiments the evaporation rate is practically constant in a considerable period of the drying^{16,40,41,43-47}. The decrease in solvent concentration at the interface is, therefore, slow compared to the decrease of the mass of the film. In a first approach the decrease in concentration may, therefore, be disregarded.

The presence of an especially dense surface layer (a skin on top of the film) will not alter the evaporation behaviour, since a surface layer will act as a barrier with a quasi-steady mass transfer from a reservoir of volatile to the

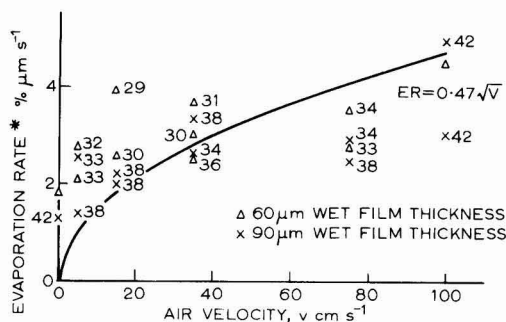


Figure 16. Evaporation rate for red latex/alkyd paint as a function of air velocity in parallel flow. The curve indicates the expected proportionality between evaporation rate and square root of air velocity when forced convection dominates air flow. The number at the measured values indicates the relative humidity during measurement

$$* (\text{remaining solvent} \times \text{film thickness}) / (\text{solid content} \times \text{time})$$

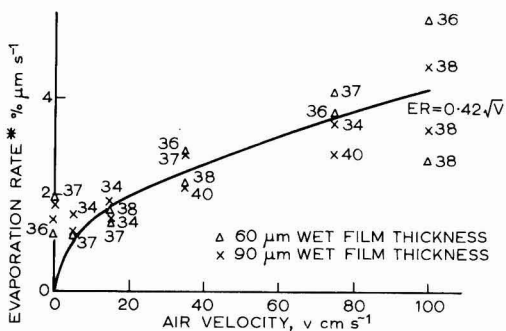


Figure 17. Evaporation rate for a green latex/alkyd paint as a function of air velocity in parallel flow. The curve indicates the expected proportionality between evaporation rate and square root of air velocity when forced convection dominates air flow. The number at the measured values indicates the relative humidity during measurements

$$* (\text{remaining solvent} \times \text{film thickness}) / (\text{solid content} \times \text{time})$$

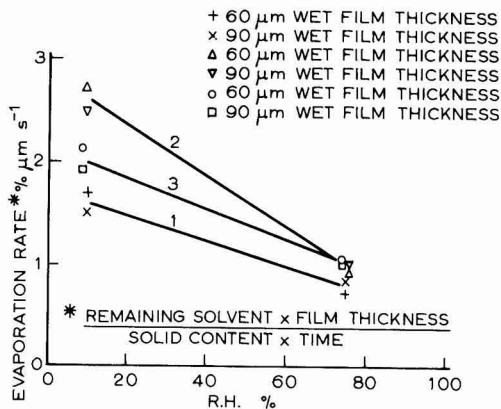


Figure 18. Evaporation rates for the white latex paint (1), the red (2) and the green (3) latex/alkyd paints at 10 and 75 per cent RH and 0.1 m s⁻¹

The theoretical relationships are also found to be applicable directly to drying times instead of the evaporation rate⁴⁵. This is mainly because the single paint is found to be dry (the drying has reached the second phase) at approximately the same solid content irrespective of the ambient conditions.

Measurements of volatile balance

Refs. 11, 37, 53-57

Returning to the balance between the different volatile species in the fluid as drying proceeds, only the molecular interaction in the fluid should be altered by the presence of non-volatiles in the mixture. The calculation procedure of Sletmoe has been used extensively on coating systems with organic volatiles and the presence of particles and material in solution does not seem to change the evaporation balance. Doolittle¹¹ states, however, that in the last half of the evaporation cycle for conventional products, i.e. at

Table 8
(Stromberg and Wind⁵³)

| No. | % Total Volatiles* | % H ₂ O | Solvent | Boiling Point Solvent (°C) | Evaporation Rate | Boiling Point Category | H-Bonding Category |
|-----|--------------------|--------------------|-------------------------------|----------------------------|------------------|------------------------|--------------------|
| 1 | 70 | 50 | 20 n-Hexane | 68.7 | 320 | Low | Weak |
| 2 | 70 | 50 | 20 o-Dichlorobenzene | 178 | 12 | Medium | Weak |
| 3 | 70 | 50 | 20 Nitrobenzene | 211 | <1 | High | Weak |
| 4 | 70 | 50 | 20 Acetone | 56.1 | 320 | Low | Moderate |
| 5 | 70 | 50 | 20 n-Butoxy ethanol | 171 | 6 | Medium | Moderate |
| 6 | 70 | 50 | 20 n-Butoxy diethylene glycol | 230.6 | <0.01 | High | Moderate |
| 7 | 70 | 50 | 20 Methyl alcohol | 64.6 | 151 | Low | Strong |
| 8 | 70 | 50 | 20 Propylene glycol | 189 | <1 | Medium | Strong |
| 9 | 70 | 50 | 20 Diethylene glycol | 245.5 | <0.01 | High | Strong |
| 10 | 70 | 50 | 10 Methyl alcohol | 64.6 | 151 | Low | Strong |
| | | | 10 n-Butoxy diethylene glycol | 230.6 | <0.01 | High | Moderate |
| 11 | 70 | 50 | 10 n-Butoxy ethanol | 171 | 6 | Medium | Moderate |
| | | | 10 Propylene glycol | 189 | <1 | Medium | Strong |
| 12 | 70 | 50 | 10 Methyl alcohol | 64.6 | 151 | Low | Strong |
| | | | 10 n-Butoxy ethanol | 171 | 6 | Medium | Moderate |
| 13 | 70 | 50 | 10 Propylene glycol | 189 | <1 | Medium | Strong |
| | | | 10 n-Butoxy diethylene glycol | 230.6 | <0.01 | High | Moderate |

*Total Volatile: 71.4% H₂O and 28.6% Coupler solvent

Table 9
(Stromberg and Wind⁵³)

| No. | % Total Volatiles | % H ₂ O | % Solvent | Polymers |
|-----|-------------------|--------------------|--|-------------------|
| 14 | 70* | 50 | 10 Methyl alcohol 10 n-Butoxy ethanol | Alkyd type - TMA |
| 15 | 70* | 50 | 10 Methyl alcohol 10 n-Butoxy ethanol | Alkyd type - DMPA |
| 16 | 70† | 30 | 25 Methyl alcohol 15 n-Butoxy ethanol | Linseed oil - MA |
| 12 | 70* | 50 | 10 Methyl alcohol 10 n-Butoxy ethanol | Linseed oil - MA |

*Total Volatiles: 71.4% Water and 28.6% Solvent

†Total Volatiles: 42.9% Water, 35.7% Methyl alcohol and 21.4% Butoxy ethanol

higher solid contents, the balance is influenced in a manner depending on the volatiles involved. This is noteworthy when high-solids coatings are considered. The presence of a surface layer may change the balance of the volatiles at the surface arbitrarily from the mixture in the bulk of the film, depending on the diffusion characteristics of the single volatile material through the surface layer.

Stromberg and Wind⁵³ have measured the volatile balance (by gas-chromatography and the Karl Fischer test) for a number of water/organic volatile mixtures in a maleinised linseed oil (15 per cent maleic anhydride), neutralised with potassium hydroxide, in 7-12 mm thick films at atmospheric conditions. The mixtures investigated are shown in Table 8.

The balance was, furthermore, measured for one system with other resins (water soluble condensation polymers based on trimellitic anhydride and dimethylolpropionic acid, respectively) and one system with another initial water/organic volatile balance. Those systems are listed in Table 9.

The solvent balance during evaporation for all these systems is calculated according to Sletmoe using the relative evaporation rates given by Stromberg and Wind in the same paper (Table 8, the relative evaporation rate for water was 16). These calculations are in excellent agreement with the measured values of Stromberg and Wind (see Appendix Figures 7-21). The calculations yield too low values for the fastest evaporating volatiles (hexane, acetone and methanol) in the last half of the evaporation, however. There does not seem any straightforward reason for these findings, but they do not appear to be related to the hydrogen bonding strength for the volatiles (see Table 8), contrary to the conclusion of the authors.

An alkyd/melamine lacquer (3:1, oil-free polyester based on adipic acid, isophthalic acid neopentylglycol and trimethylolpropane, acid value 35 mg KOH/g, hydroxyl value 145 mg KOH/g (Berol) and a methylated melamine containing monomer : dimer, 2:1 (Monsanto) neutralised to pH 8 with dimethylaminoethanol with ethylene glycol monobutylether and propanol-2 as cosolvents investigated at the Scandinavian Institute showed the same divergence for the fast volatile as shown in Figure 19. The values were measured for 35 and 50 per cent RH at 23°C. The relative evaporation rate for water was determined from Figure 5.

The calculated balances for this system indicate, furthermore, a much slower decrease in the relative water content than actually measured. The quantitative

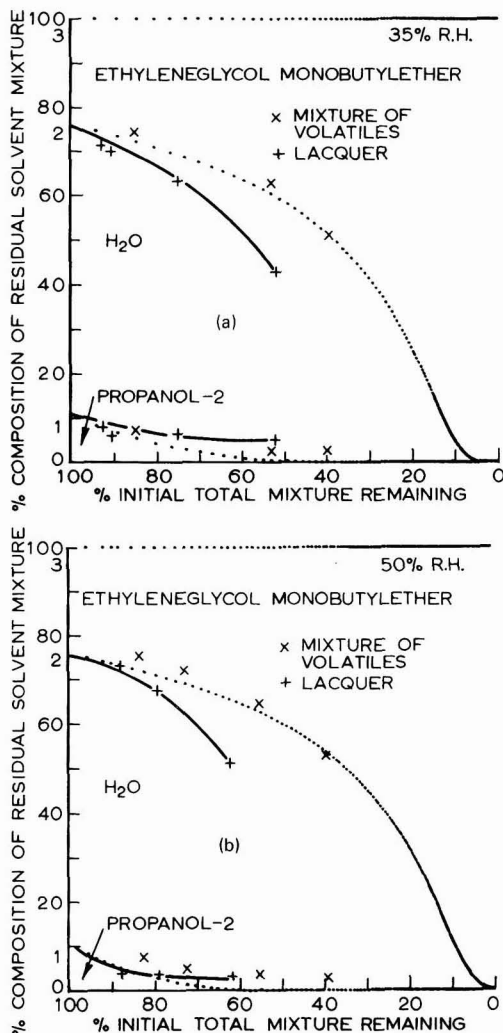


Figure 19. Predicted and measured volatile balance for the mixture of volatiles considered compared to the balance of the alkyd/melamine lacquer with the same initial volatile composition. (a) Evaporation at 23°C, 35 per cent RH (b) Evaporation at 23°C, 50 per cent RH

difference between the balances at 35 and 50 per cent RH is, however, still predicted closely by the calculations.

These deviations raise the question of non-ideal interaction between the molecules and thus of activity coefficients. Figure 20 shows the solubility parameters for the volatiles that have been considered in this paper. The volatiles with the largest deviations from the predictions in the work of Dillon³⁷, Stromberg and Wind⁵³ and for the present lacquer (acetone, methanol, butanol-1, ethyleneglycol monoethylether, ethyleneglycol monobutylether acetate, and hexane) do not show any similarity either with respect to polarity nor to hydrogen bonding strength. When the alkyd/melamine lacquer is observed visually, it is found to be slightly hazy until approximately 25 per cent of the volatiles have evaporated. This is because of the presence of different phases in the lacquer. The predictions assume the volatiles to be in one phase only, however. In a two-phase system, the solvent concentrations in the continuous phase may differ from the total if the individual volatile components have different affinities to the discontinuous phase. This has been shown to be true^{54,55} with organic solvent tending to concentrate in the organic (polymer) phase in emulsion systems. This fact seems to explain the relatively faster evaporation of water than expected, when the resins are present. This is not the case when the same volatile mixture is regarded alone (Figures 12 and 13). It indicates that the polymers should be included in the evaluation of non-ideal molecular interaction in water dilutable coatings. This is possible in the theories of Prausnitz and Fredenslund *et al.*^{56,57}.

Conclusions

Refs. 28, 31, 32, 56-58

Comparison of the experimental observations of the evaporative behaviour of water, water/organic volatile mixtures, and water dilutable coatings in the fluid state to the mass- and heat transfer theories demonstrates a general agreement. On some points, however, only qualitative agreement is found, since the analytical models are idealised and the exact details of the single observations are rather limited on some crucial points. The different relationships emerging from the mass- and heat transfer theories are, however, still capable of indicating the impact on the evaporative behaviour from changes in physical parameters. This is true for systems containing water as well as for purely organic systems.

The evaporation of water is found both theoretically (eq. 9) and experimentally to vary linearly with the ambient relative humidity. Evaporation of water is more sensitive to the heat transfer situation retarding the evaporation rate, compared with organic systems with moderately fast evaporating volatiles.

In forced convection the evaporation rate is found to vary linearly with the square root of air velocity. The transition to free convection was found to occur at about 0.1 m s^{-1} in parallel flow. The main influence of room ventilation, especially where this is suction³⁸, is the maintenance of a low humidity. Strong forced convection facilitates fast evaporation, which may in turn lead to a lower surface temperature if the heat transfer from the interior becomes insufficient, as observed with water. This will limit the influence of the air velocity on the evaporation rate.

Variations in air velocity and temperature are not

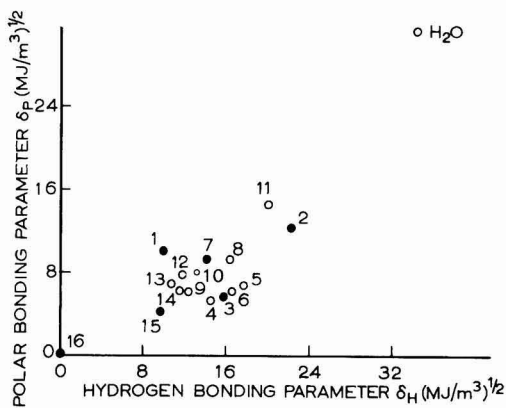


Figure 20. The solubility parameters of the volatiles being considered in the referred articles and this paper

- 1) Acetone
- 2) Methanol
- 3) Butanol-1
- 4) Tertiary butanol
- 5) Propanol-1
- 6) Propanol-2
- 7) Ethyleneglycol monoethylether
- 8) Ethyleneglycol monomethylether
- 9) Ethyleneglycol monobutylether
- 10) Ethyleneglycol monopropylether
- 11) Diethyleneglycol
- 12) Diethyleneglycol monoethylether
- 13) Diethyleneglycol monobutylether
- 14) Dipropyleneglycol monomethylether
- 15) Ethyleneglycol monobutyletheracetate
- 16) Hexane

expected to change the volatile balance when purely organic systems are considered. The concentration gradient driving the evaporation of water is, in contrast to the organic volatiles, directly influenced by the water content in the ambient atmosphere. Assuming the same relative humidity, the concentration gradient for water remains unchanged at increasing temperatures, whereas it increases for the organic volatiles. The vapour pressure variation with surface temperature is related to the latent heat of the volatile material. The temperature dependence of the evaporation rate for water is thus greater than it is for organic volatiles (assuming otherwise constant conditions). The air velocity may, therefore, change the balance towards slower relative evaporation of water, if increased air flow leads to a decreased surface temperature. In practice this effect is, however, of minor importance.

The potential presence of special surface layers retarding the evaporation is not found to be significant in the experimental observations on aqueous systems.

The established procedures for estimating the balance of mixtures of volatiles during evaporation²⁸ are shown to be applicable to mixtures of volatiles containing water by applying a relative evaporation rate for water varying proportionally with the relative humidity. For volatile mixtures containing water, non-unity activity coefficients are not readily available to take non-ideal interactions into account, as is the case for solely organic mixtures³¹. Reasonable quantitative agreement is, however, found in all the observations assuming only ideal behaviour.

The theoretical basis and calculation procedures are

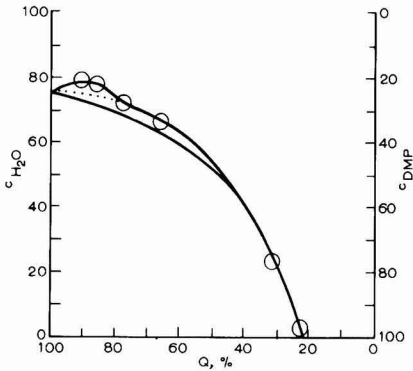
available to calculate activity coefficients^{32,57}. The volatile/polymer interaction seems more non-ideal in "water soluble" coatings than in conventional organic systems, resulting in phase shifts during drying and, thereby, causing also unexpected viscosity changes. This might also be treated systematically in the above mentioned framework of activity coefficients^{56,57}. This framework may offer practicable solutions to deal with aqueous and high-solid coating systems more systematically. The experimental observations on aqueous coating systems show, at any rate, that the predictions assuming ideal behaviour can reflect the changes in the mixture as the evaporation proceeds, at least to the extent of showing the correct direction of change.

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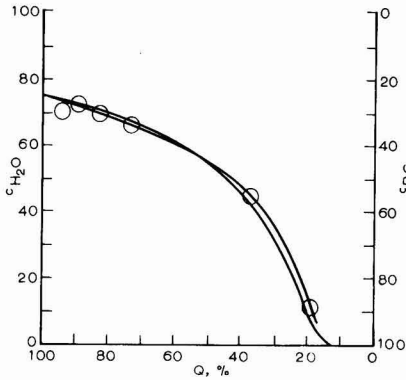
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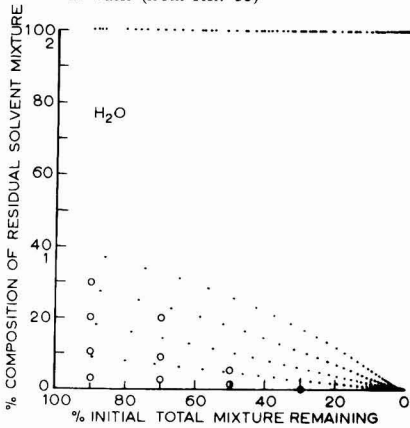
Appendix



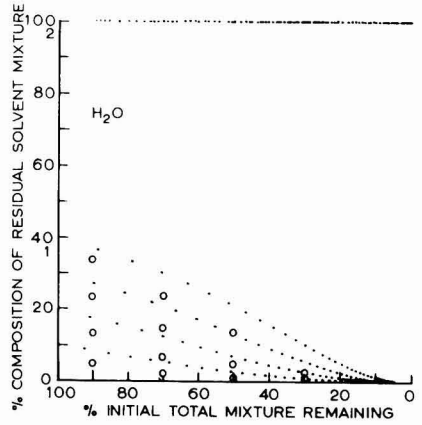
App.Fig.1. Measured and calculated volatile balance during evaporation of 25% dipropylene glycol mono-butylether in water (from Ref. 35).



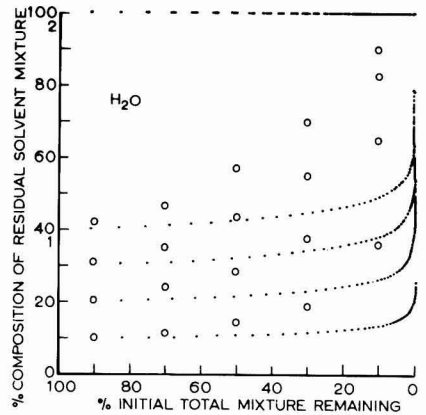
App.Fig.2. Measured and calculated volatile balance during evaporation of 25% ethyleneglycol mono-butylether in water (from Ref. 35).



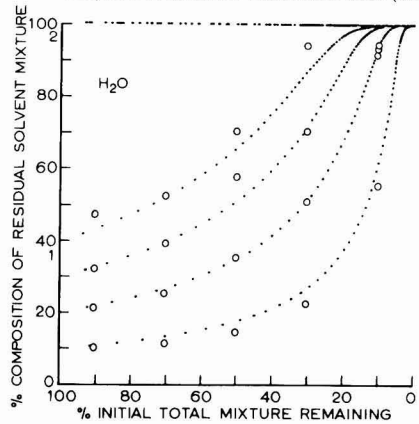
App.Fig.3. Calculated volatile balances of different concentrations of t-butanol in water compared to measured values from Shell (Ref. 36)



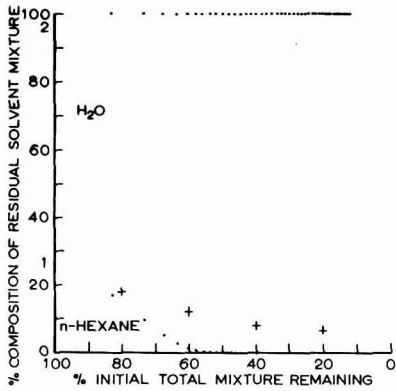
App.Fig.4. Calculated volatile balances of different concentrations of propanol-2 in water compared to measured values from Shell (Ref. 36)



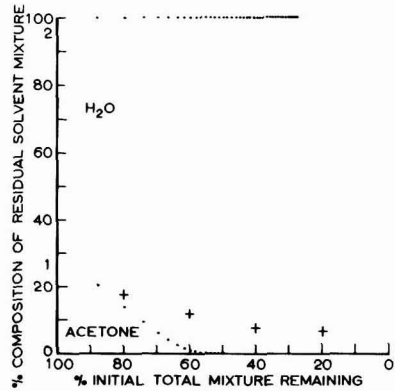
App.Fig.5. Calculated volatile balances of different concentrations of ethyleneglycol monoethyl ether in water compared to measured values from Shell (Ref. 36)



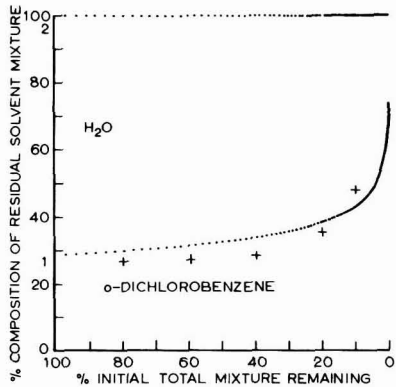
App.Fig.6. Calculated volatile balances of different concentrations of diethyleneglycol mono-butylether in water compared to measured values from Shell (Ref. 36)



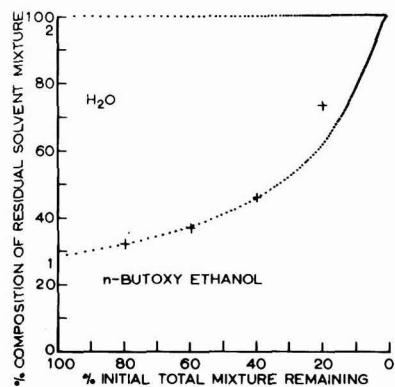
App. Fig. 7. Calculated volatile balance for 28.6% n-hexane in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



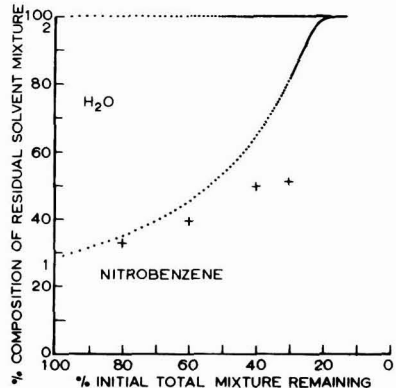
App. Fig. 10. Calculated volatile balance for 28.6% acetone in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



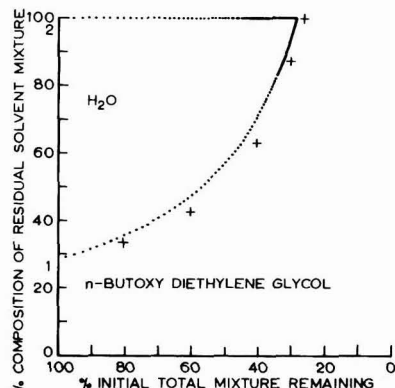
App. Fig. 8. Calculated volatile balance for 28.6% o-dichlorobenzene in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



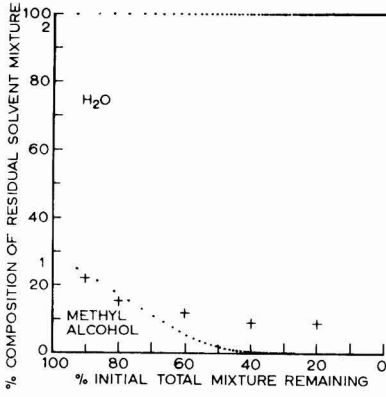
App. Fig. 11. Calculated volatile balance for 28.6% n-butoxy ethanol in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



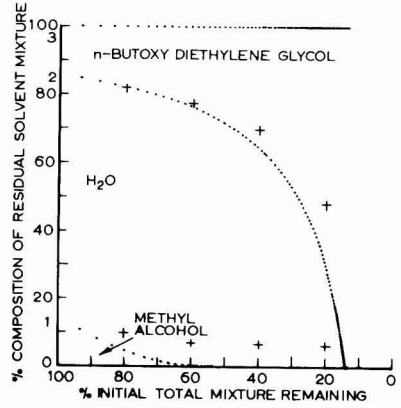
App. Fig. 9. Calculated volatile balance for 28.6% nitrobenzene in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



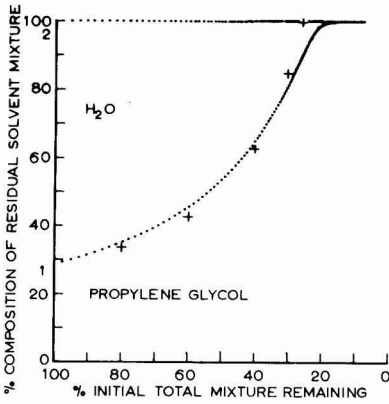
App. Fig. 12. Calculated volatile balance for 28.6% n-butoxy diethylene glycol in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



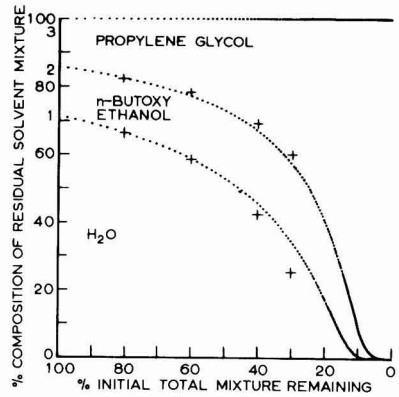
App.Fig.13. Calculated volatile balance for 28.6% methyl alcohol in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



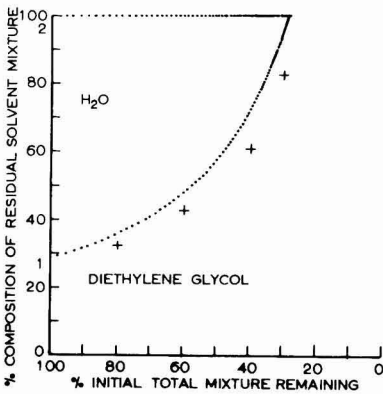
App.Fig.16. Calculated volatile balance for 14.3% methyl alcohol and 14.3% n-butoxy diethylene glycol in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



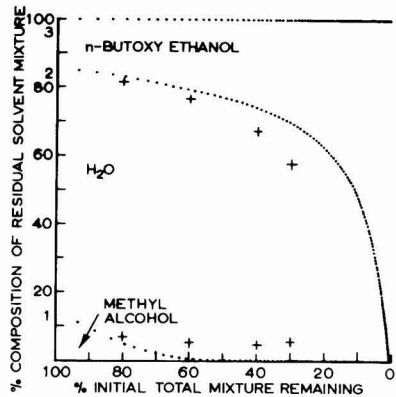
App.Fig.14. Calculated volatile balance for 28.6% propylene glycol in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



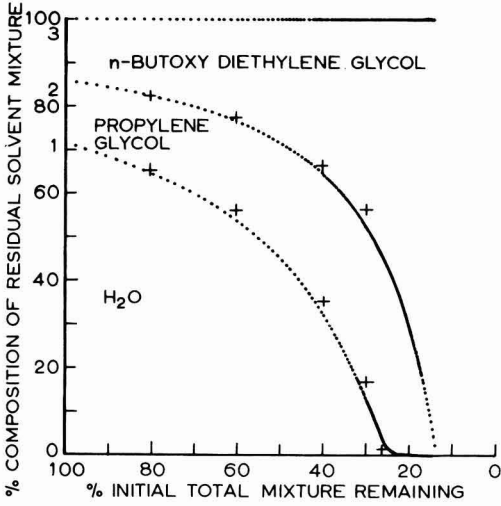
App.Fig.17. Calculated volatile balance for 14.3% n-butoxy ethanol and 14.3% propylene glycol in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



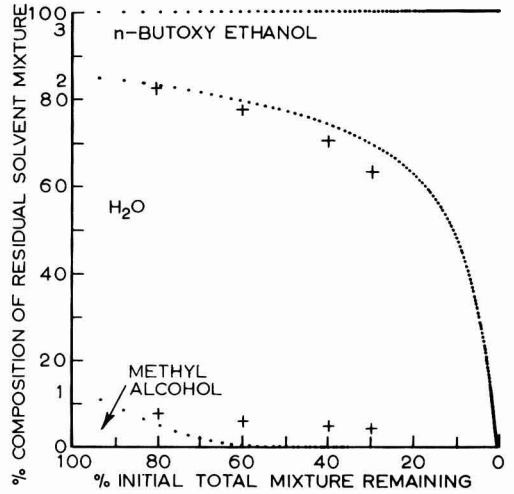
App.Fig.15. Calculated volatile balance for 28.6% diethylene glycol in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



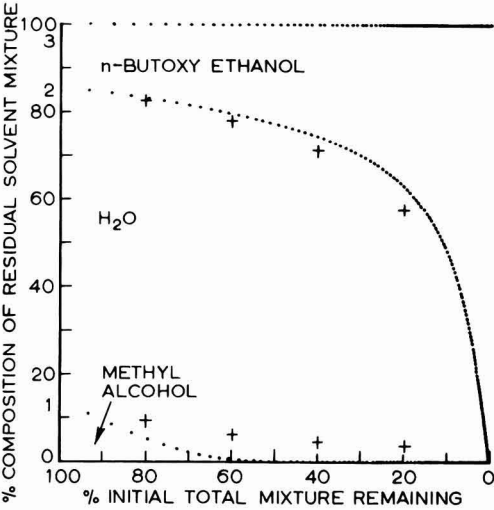
App.Fig.18. Calculated volatile balance for 14.3% methyl alcohol and 14.3% n-butoxy ethanol in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



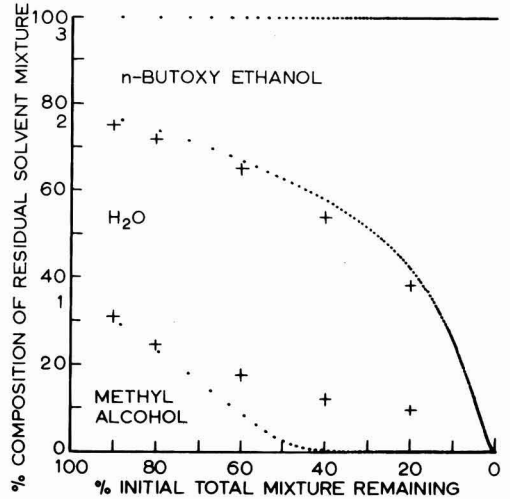
App.Fig.19. Calculated volatile balance for 14.3% propylene glycol and 14.3% n-butoxy diethylene glycol in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)



App.Fig.21. Calculated volatile balance for 14.3% methyl alcohol and 14.3% n-butoxy ethanol in water compared to measured values for this volatile mixture 70% in alkyd type DMPA (from Ref. 53)



App.Fig.20. Calculated volatile balance for 14.3% methyl alcohol and 14.3% n-butoxy ethanol in water compared to measured values for this volatile mixture 70% in alkyd type TMA (from Ref. 53)



App.Fig.22. Calculated volatile balance for 35.7% methyl alcohol and 21.4% n-butoxy ethanol in water compared to measured values for this volatile mixture 70% in maleinised linseed oil (from Ref. 53)

letters

Spontaneous combustion of paint waste from spray booths

Sir – Recently a couple of fires in Sweden were traced to spontaneous combustion (autoignition) of paint waste (overspray) from spray booths. The Scandinavian Paint and Printing Ink Research Institute has been asked to investigate the causes and the mechanisms of such autoignition processes, especially in the overspray from spray booths (in powder form) and in catalysed unsaturated polyesters.

A limited literature search produced some literature

Most Secret War

Sir – I have been reading *Most Secret War*, Dr R. V. Jones's absorbing account of the operations of British Scientific Intelligence 1939-1945 and as I read it, it dawned on me that an important figure in the Intelligence Service, Eric Welsh, a paint chemist, was my senior at International Paint Co., Felling on Tyne. This was in 1915 when I was serving a Paint Apprenticeship (the first ever!). Eric was transferred to International Paint Co. Norway and I joined the Army. In the Second World War Eric turns up again, this time as one of the heroes whose valour led to the destruction by our Commandos of the heavy water plant at Rjukan in Norway, putting Germany out of the race for the atomic bomb.

Another paint chemist – this time from British Paints – one Albert Bartroli, working in our Madrid factory when World War II broke out, joined the RAF and later the Intelligence Service. He and his sister, Eliane, were

about spontaneous combustion in general, and about autoignition of drying oils and alkyds based on these oils. Very little seems to have been published about spontaneous combustion of paint waste from spray booths and of catalysed unsaturated polyesters. Before extending the scope of our effort, we would like to be sure we have uncovered what is already known in this area. Therefore, we would be extremely thankful to receive additional information about fires caused by spontaneous combustion of overspray from spray booths and by unsaturated polyesters or to obtain references to scientific investigations to such.

All contributors to this pool of knowledge will of course receive a complimentary copy of the finished report. We expect this will be finished in the Fall of 1980.

Yours faithfully,

AGO SAARNAK

*Scandinavian Paint and Printing Ink Research Institute,
Agern Alle 3,
DK-2970 Horsholm,
Denmark*

30 January 1980

dropped into France. Eliane was captured and shot, but Albert became Commander of a formidable Resistance Army and harassed the Germans during their retreat. He was awarded the DSO, the Croix de Guerre and the Freedom of the City of Cluny. He reverted to his RAF rank of Sqn. Leader and finished the war fighting the Japanese in Burma.

I thought this little saga might interest our paint chemists of today.

Yours faithfully,

HARRY KEENAN
(President 1944-47)

*Claremont,
Stonnards Brow,
Shamley Green,
Surrey*

6 February 1980

occa meetings

Auckland

The effective use of solvents

On 15 November 1979 the Auckland Section organised a workshop on the important and topical subject of "The effective use of solvents – Cost and conservation". Eighty-five delegates from the paint, printing ink, automotive, metal containers, and white goods industries attended, and also members of the Department of Scientific and Industrial Research.

Further information on any items mentioned below may be obtained by circling the appropriate *Reader Enquiry Service* number on the form at the back of the *Journal*. Enquiries will be forwarded to the Section concerned or may be forwarded to the lecturer.

In the absence of the Minister of Energy, Mr W. Birch, at a parliamentary meeting making decisions regarding the use of New Zealand's gas resource, the Auckland Section Chairman, Mr W. Paul, introduced Dr I. J. Shearer MP who gave the opening address and set the scene as it is currently in New Zealand.

Mr G. L. Willis of Shell Chemical NZ Ltd, gave his paper on "Energy and petrochemicals" and detailed the world and local situations. Oil feedstock is imported into New Zealand and is refined to produce petrol, but most petroleum derived chemicals are imported.

"Solvent system design" was the subject for Mr R. Turner of Shell Chemicals NZ Ltd, who showed how, by using solvent parameters and solvent activity coefficients, it was possible to substitute solvents when those desired were not available or were too expensive. The flashpoints

of mixtures could also be predicted. This talk had particular relevance to industrial coatings.

Following luncheon, Mr W. Booth of Dominion Oil Refining Co. Ltd, spoke of the "Viability of used solvents recovery", and stated that little recycling was being carried out in New Zealand, but that his company was entering this field. With co-operation from companies holding contaminated solvent it was anticipated that positive results could be obtained.

The final session was chaired by Mr G. Crier of Flinders Cook Technical Services Ltd and was an open forum for general discussion and comment by the panel of the three speakers and the audience. This generated considerable comment with a majority of the questions being concerned with recycling and disposal of used solvent.

Mr C. Gooch, Wellington Section Chairman, gave the closing address and summarised the day's discussion. Much food for thought was provided and the changing situation would tax both resources and capabilities. New Zealand is poor in oil resources, but now has a gas supply which will last for about 30 years, large deposits of coal, and an abundant capacity for electricity generation.

Reader Enquiry Service No. 21

A. M.

Manchester

Matting silicas in UV cured systems

Mr S. E. Maskery of Joseph Crosfield & Sons Ltd, Warrington, gave the above lecture to an audience of 30 members and visitors on 14 December 1979 at the New Administration Building, Manchester Polytechnic, All Saints, Manchester.

The lecture began with an explanation that in his role as Technical Service Manager – Surface Coatings Industry, Mr Maskery was involved with the paint, paper and plastics industries. The matting silicas to be discussed in the lecture are pure, synthetic, porous sands having an amorphous rather than crystalline structure and whose matting efficiency depended mainly on their ability to reduce gloss by a light scattering effect. Crosfield's, who are part of the Unilever group, produce an extensive range of matting silicas by a "wet process" rather than by the alternative pyrogenic methods.

Systems cured by UV light are essentially free from solvents and this, it is claimed, has the advantage of rapid curing coupled with freedom from damage when used in conjunction with temperature sensitive substrates. One disadvantage is the possible toxicity of some of the monomers used. Various applications described involve use with the following materials:

| | |
|---------------|-------------------|
| Tinplate | PVC1 flooring |
| Wallcoverings | Woodfinishing |
| Printed card | PVC1/paper veneer |
| Coated fabric | finishes |

The curing is due to the action of UV on the photoinitiator to form "free radicals", which then start the polymerisation of the multi-functional monomers and pre-polymers to form the final polymer. The work carried out by Crosfield's involved the comparison of various polyester and acrylic resins. The acrylics used were of several types and included polyester, epoxy and urethane modifications. The diluents used were acrylic monomers.

occa meetings

The extent to which matting occurs is believed to be related to the ease with which the gloss, in solvent based systems, is reduced by shrinkage at the surface during drying. The difficulty in matting some finishes, particularly acrylics, is due to their lack of shrinkage during curing. Five grades of silicas were evaluated in comparison with similar coatings to which no silica was added. Tests were carried out at 10 μ and 100 μ film thicknesses and on both wood and glass substrates. Other factors which may affect the extent of matting are the similarity of the reflective indices of the silica and the resins, the level of silica addition and the effect of the clarity of the film formed.

The lecture was followed by numerous questions from the audience which referred to the types of polyesters used; the determination of the surface area of the silicas (BET method); wood finishes; scratch and boiling water tests; types of dispersing equipment and flocculation; marketing needs; transparency to UV and the lower cost of UV in comparison to electron beam curing.

The vote of thanks was proposed by David Wilson on behalf of the Section and was warmly supported.

Reader Enquiry Service No. 22

F. B. W.

Midlands

The role of the technologist in marketing

The annual dinner lecture of the Midland Section was held at the Birmingham Chamber of Commerce and Industry on Friday, 18 January 1980. This was a joint meeting with the Trent Valley Branch.

Members and guests heard Mr R. A. Fidler of International Paints give a talk entitled "The role of the technologist in marketing".

Mr Fidler opened his talk by saying that marketing could be defined as "to earn a profit by adding the maximum value at minimum cost". The industrial section of the paint market currently has a sales value of £210 m and it was about this section that the speaker concentrated his talk, although some comments were also applicable to the other sections.

The modern technologist needs to be a man with specialised knowledge and aptitude. He will need to know what raw materials are available and how to put them together. He will also need to know his customer, how the products are to be used, what substrates are involved and what performance can be expected. He will also have to consider his company's resources, ensure the profitability of the product and also ensure that it is easily serviceable. With today's ever changing legislation he will have to make sure that the product conforms to the latest solvent regulations and that it satisfies all health and safety requirements.

OCCA meetings

Mr Fidler concluded his talk by outlining some of the precautions that can be taken to avoid product failure and what can be done to reduce the risks.

The interest shown by the members in the talk was reflected by the numerous questions that were asked. The meeting was brought to a close with a vote of thanks proposed by Mr R. L. Devenish and warmly endorsed by the audience.

Reader Enquiry Service No. 23

B. E. M.

Thames Valley

Works visit to Rondec

The first meeting of the Section in the new decade was a

very interesting works visit to Rondec, silk-screen/equipment manufacturers.

The first part of the visit was to participate in the generous hospitality and refreshment provided, which was very pleasant. The party was then given a very informative, although informal, talk by the Managing Director, Mr Gordon Taylor, which showed the frequency with which silk-screen printing is used. Many articles in the home are decorated or printed using the silk-screen technique. Similarly, at work many other screen printed articles are also encountered, typical examples being bottles, jars, plastic cigarette lighters, plant pots, tins etc.

After this interesting talk the party was given a very interesting tour of the factory and laboratory areas, being shown various screen-printing machines which ranged from printing cigarette lighters to 205 litre barrels. The process of screen manufacture was clearly shown and explained, including a very interesting photographic department.

A vote of thanks was proposed by Mr Prigmore and the party left after being given useful examples of silk-screened articles.

Reader Enquiry Service No. 24

A. W. F.

news

Equipment agency

The Sorbini range of curtain coaters and roller coaters for the application of paints and lacquers is now being marketed in the UK by the machinery division of McPherson Components Limited. Also included in this extensive range are debribing and brushing machines.

MacPherson Components are now able to offer a complete design service for lacquer line installations to meet customer requirements. These are based on Sorbini equipment and the Comil range of drying ovens for which MacPherson Components also hold the UK agency.

Reader Enquiry Service No. 31

Thermal oxidation system

Hygrotherm Engineering Limited have announced the award of a contract by Glaxo Operations (UK) Limited for a new thermal oxidation system for Glaxo's Montrose site. The system will be used to destroy process effluent generated in the production of pharmaceutical products. Continuity of disposal is all important and two hydrotherm thermal oxidisers will be installed, one on main stream and the other on standby, with automatic changeover facilities.

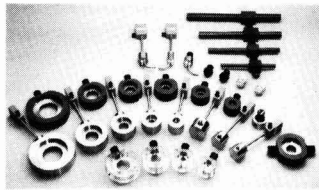
Reader Enquiry Service No. 32

Further information on any items mentioned below may be obtained by circling the appropriate Reader Enquiry Service number on the form at the back of the Journal. Enquiries will be forwarded to the organisation concerned.

New factory

Litre Metre, an Aylesbury flowmeter company specialising in the design, manufacture and sale of cost-effective flowmetering devices, are moving into a large new factory near to the premises in which the products were first conceived 3½ years ago. This company and its associate, Agmet Instrumentation have grown at such an impressive rate that this move has become necessary.

Reader Enquiry Service No. 33



The range of transmitters available from Litre Meter Ltd

Plant closure

Laporte Industries Limited is proposing to close its chemical works at Ilford, Essex, and transfer the manufacture and supply of products from Ilford to other more suitable sites within the Company. The transfer of activities will be carried out in stages, between March and September 1980, and will involve the loss of some 94 jobs.

The capital investment needed to maintain the present small range of

products made at Ilford, coupled with the impracticality of any future growth on this site in a residential area, have necessitated the review.

Reader Enquiry Service No. 34

French choose International Paint

International Paint has beaten off fierce American competition to secure a £200,000 export order to France, expected to lead to business exceeding £1 m a year.

The order from Elf Aquitaine is for Interpon pipe coating powder to cover a 110 kilometre oil pipeline in Oman.

Interpon, developed and manufactured at the International Paint research and production complex at Felling on Tyne, is backed by one of the largest research units of its kind. Interpon coating is sprayed as a dry powder, charged at 75,000 volts, on to 40 feet long steel pipes which have previously been heated to a temperature of 250°C. Within two minutes of application, the powder melts, flows out and hardens to a smooth and glossy coating which is superior to other protective coatings for pipes.

Reader Enquiry Service No. 35

Change of name

The manufacturers of the "Thermindex" range of reversible and irreversible temperature-sensitive paints and self-adhesive temperature indicators have announced a change in their company name. These products are now manufactured at their new premises by

Therminex Chemicals and Coatings Limited. The former company name, Synthetic and Industrial Finishes Limited has been transferred to another, unconnected company.

Reader Enquiry Service No. 36

Spray equipment group

Five spray equipment manufacturers have formed a spray equipment manufacturers group within the Paint Research Association, Teddington. Membership, at present comprising Aerostyle, Atlas Capco, Graco of England, Kremlin and Volstatic, is expected to grow rapidly.

The Group feels that there is an urgent need for representation of its interests in view of increasing legislation and growing technical complexities.

Through SEMG, the knowledge, experience and policies of its member companies will be coordinated to present a unified and strengthened attitude in negotiations with Government and with industry in general.

Reader Enquiry Service No. 37

"Tedlar" distributor

Du Pont de Nemours International SA has appointed Richard Klinger Limited of Sidcup, Kent, a distributor of "Tedlar" polyvinyl fluoride film for solar energy collectors.

"Tedlar" PVF film was introduced commercially in the early 1960s. With its outstanding combination of weather resistance, toughness and inertness to many chemicals and to temperature extremes, it is an excellent outer glazing material for solar collectors. The film transmits about 90 per cent of total incident solar energy, with principal losses being caused by surface reflection.

"Tedlar" PVF film is also widely used as a protective surface on metal, reinforced plastic panels and substrates used as siding for residential, commercial and industrial buildings.

Reader Enquiry Service No. 38

Crown Paints modernisation

Crown Paints have announced a multi-million pound scheme to modernise their factory in Lancashire. The first stage of a three year plan will make the company's oil-paint production plant in Darwin the most modern in Europe. Three million pounds is to be spent on changing the present three separate departments into a single modern manufacturing unit.

The new facility will enable the company to increase its present annual output by 28 per cent. Work is due to start on the new buildings towards the end of this year with new processing equipment scheduled for installation next year. The plant should be fully on stream by 1982.

Reader Enquiry Service No. 39

New distributor

Cabot Carbon Limited, a subsidiary of Cabot Corporation, manufacturer of carbon blacks and fumed silicas, has announced the appointment of Blagden Campbell Chemicals Limited as distributor of their Cab-o-sil range of fumed silicas for UK and Eire.

Reader Enquiry Service No. 40

Solvent recovery

Solrec Limited is a new company which has been set up specifically to recover waste solvents and formulate special solvent products. The increasingly high cost of waste disposal and the rapidly escalating cost of oil-based products now makes recovery of waste or contaminated solvents an economic necessity in the paints industry.

Solrec have developed a unique distillation plant which they claim makes solvent recovery a safe, reliable and economically viable proposition for many companies. This new plant is based on a "dry" process, which eliminates the water contamination so often associated with the more conventional steam distillation processes. Distillation is carried out under vacuum with continuous cleaning of heat transfer surfaces to ensure a high level of purity.

Reader Enquiry Service No. 41

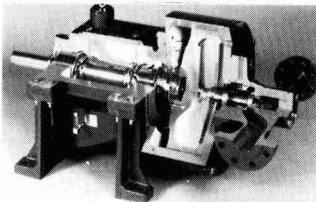
new products

New pitot tube

Haskel Energy Systems Limited have recently introduced a new model RO Roto-Jet pump into Europe. The manufacturer claims that the pump is 9 per cent more efficient than its nearest single stage API 610 competitor at 250 gpm, and 12 per cent more so at 50 gpm.

Built-in S-4 and A-8 class materials to meet the rigorous API 610 standards of the chemical, hydrocarbon processing and refining industries, this single stage centrifugal pitot tube design requires only 192 hp at 250 gpm and works at only 3550-4380 rpm, less than a third the speed of its nearest single stage competitor. Despite its slow working speed, the RO pump still generates pressures up to 1100 psi and flows up to 350 gpm.

Reader Enquiry Service No. 42

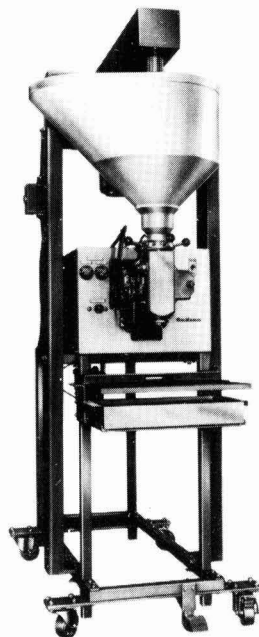


The single stage centrifugal pitot tube from Haskel Energy Systems

news

Faster filling machine

One of the problems encountered by the manufacturers of semi-liquid and paste products occurs at the packing stage. When cans are filled the high viscosity of these types of products means that considerable delay occurs before the lidding operation can be completed to allow the contents to settle.



The De Vree 188 pneumatic filling and dosing machine

De Vree, a specialist can filling machine manufacturer, has now introduced the 188 filling machine which overcomes this problem. The 188 incorporates a vibratory system which oscillates the can during the filling process, thereby causing rapid settlement of the product and minimising the delay before the lidding operation.

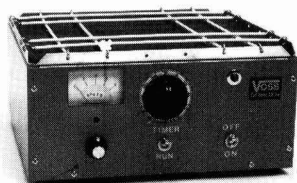
The De Vree 188 is a volumetric, pneumatic filling and dosing machine, and is suitable for liquid products as the agitator can be easily uncoupled. The dosing cylinder and piston can be easily adjusted to deliver quantities from 50 to 1,500 cc or from 100 to 5000 cc.

Reader Enquiry Service No. 43

Orbital shakers

Voss Instruments Limited has introduced a new rotary shaker. The instrument has a robust case in a blue hammer finish and rotates at 350 orbits per minute with a described orbit of $\frac{3}{4}$ inch (20 mm). The top tray is rubber lined and provided with adjustable plastic coated retaining springs suitable for holding the shaker flask or beaker. The unit is fitted with heavy duty rubber feet and ballast weight for bench stability.

Reader Enquiry Service No. 44



The new orbital shaker from Voss Instruments

Aqueous GPC columns

Perkin-Elmer are offering a new range of GPC columns suitable for the analysis of water soluble polymers using aqueous eluents. The Shodex S800 series is able to cope with water soluble polymers and organics in materials such as biochemicals, foods, drugs and industrial wastes etc. which have very complex constitutions.

Reader Enquiry Service No. 45

New colour measurer

A new colour measuring instrument which incorporates a microcomputer to provide a range of highly accurate and versatile colour control operations is to be marketed in the UK by the special products division of Henry Simon Limited.

Manufactured by Neotec Instruments Inc. of Maryland, USA, the system is called Digi-Color and is suitable for colour analysis in a wide range of industries.

Digi-Color incorporates automatic self-standardisation and is easy to operate. It is supplied suitably programmed for various colour measurement systems including RGB, CIE and Lab, and evaluates differences from reference colours. A TV monitor presents these results together with other information such as yellowness and whiteness indices.

Reader Enquiry Service No. 46



The new Micro Match spectrophotometer from Instrumental Colour Systems

New spectrophotometer

A new spectrophotometer, the Micro Match, has been introduced by Instrumental Colour Systems.

In keeping with the ICS approach to colour control the keynote of the Micro Match is its flexibility of output, coupled with ease of operator use.

The three main components of the system are the spectrophotometer measuring head, a microprocessor and video unit, but graph plotter, graphical video display unit and line printer are available to augment the basic system. The spectrophotometer's diffraction grating and 16 channel silicon detector array give a high wavelength accuracy and long term stability.

Reader Enquiry Service No. 47

Vortex flowmeter

A new high-performance Vortex flowmeter which ultrasonically measures liquid flowrate and uses no moving parts is the latest development from Brooks Instrument.

The new Brooks Vortex Flowmeter is designed for accurate, reliable and trouble-free operation with process liquids such as condensate, caustics, acids, hydrocarbons, liquified gases and beer, and ultrasonically measures the turbulence created by a "vortex street" in the pipeline to determine the rate of flow.

This simple and durable design is particularly effective with particle-laden and dry process liquids, and meter accuracy is ± 1 per cent of flowrate.

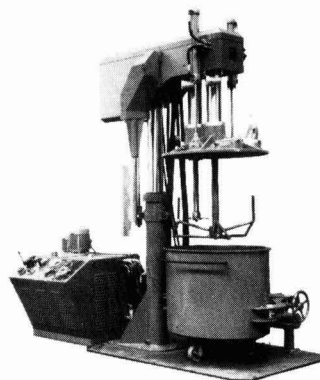
Reader Enquiry Service No. 48

New disperser/mixer

OBS Machines Limited has available a new hydrosolver/dual disperser and mixer, a machine which is claimed to offer ultimate versatility and reliability in high-speed dispersion techniques.

The unit is superbly engineered, and features a variable speed, hydraulically driven high speed and low speed twin shaft disperser. The fact that the speed ranges, namely 0-1400 rpm for the dispersion saw tooth blade, and 0-180 rpm for the trifoil are regulated independently, offers a wide range of applications for mixing and dispersing products from low to high viscosities, in batch capacities of up to one ton.

Reader Enquiry Service No. 49



The Hydrosolver/Dual disperser/mixer from OBS Machines

**OIL & COLOUR
CHEMISTS' ASSOCIATION**

Newcastle Section Symposium



**ULTRAVIOLET POLYMERISATION
AND THE
SURFACE COATING
INDUSTRIES**

UV2

UV2

The eleven papers in this volume were originally published in *JOCCA* during 1978 and are based on lectures presented at the Second International Symposium of the Newcastle Section of the Association. Titles and authors are given below:

Exciplex interactions in photoinitiation of polymerisation by fluorenone amine systems by *A. Ledwith, J. A. Bosley and M. D. Purbrick*

Recent developments in photoinitiators by *G. Berner, R. Kirchmayr and G. Rist*

Present status of ultraviolet curable coatings technology in the United States by *J. Pelgrims*

The design and construction of ultraviolet lamp systems for the curing of coatings and inks by *R. E. Knight*

New developments in ultraviolet curable coatings technology by *C. B. Rybny and J. A. Vona*

Cure behaviour of photopolymer coatings by *R. Holman and H. Rubin*

Photoinitiator problems in clear coatings by *M. de Poortere, A. Ducarme, P. Dufour and Y. Merck*

The UV curing of acrylate materials with high intensity flash by *R. Phillips*

Parameters in UV curable materials which influence cure speed by *A. van Neerbos*

The use of differential scanning calorimetry in photocuring studies by *A. C. Evans, C. Armstrong and R. J. Tolman*

The UV curing behaviour of some photoinitiators and photoactivators by *M. J. Davis, J. Doherty, A. A. Godfrey, P. N. Green, J. R. A. Young and M. A. Parrish*

Copies of **UV Polymerisation**, the first volume published by the Association on this subject, are available and may be purchased separately or at the specially reduced price if purchased together with a copy of *UV2*.

The two volumes together form the authoritative work on the rapidly developing subject of ultraviolet polymerisation in the surface coatings industries. It is a work that no company in the field can afford to be without.

ORDER FORM

(Prepayment only)

To: **Oil & Colour Chemists' Association**,
Priory House, 967 Harrow Road,
Wembley, Middlesex HA0 2SF, England.

Please send me copies of Ultraviolet polymerisation 2 (*UV2*)

Please send me copies of Ultraviolet polymerisation 1 (*UV1*)

I enclose remittance of £(US\$) to cover the cost.

Name: _____

Address to which books should be sent:

Price: Ultraviolet polymerisation 2 (*UV2*) £7.50 (US \$18.00) each

Ultraviolet polymerisation 1 (*UV1*) £5.00 (US \$12.00) each

UV1 and *UV2* purchased together £10.00 (US \$24.00)

Prices include postage/packing (surface mail)



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Reader Enquiry Service No. 112

Hazardous dust suit

Multifabs Limited have produced a one piece coverall suit designed to provide protection from nuisance dust. Called the Gordon, the suit is manufactured from ceramic terylene, a fabric specially produced to provide protection in the pottery industry.

The suit incorporates the recommendations issued by the Asbestos Research Council for clothing suitable for protection from asbestos dust. It has also been successful in trials against epoxy resin, particularly as used in the manufacture of paint. For this particular application, a disposable suit is worn over the Gordon suit, thus providing relatively cheap throw-away clothing which at the same time, protects the ceramic terylene suit from the worst paint contamination.

Reader Enquiry Service No. 50

Matting agent

Crosfield HP37 Silica, a new addition to the Crosfield range of high performance matting agents is claimed to give superior matting efficiency compared with that of a conventional product. It has been designed for use in the gloss control of coil coating systems such as organosols, oil free polyesters and thermosetting acrylics where its superior technical performance makes it highly cost effective.

HP37 Silica is also recommended for the matting of high solid systems including those which are radiation cured.

Reader Enquiry Service No. 51

literature

LC system catalogue

A new 44-page liquid chromatography recommended systems catalogue available from Perkin-Elmer introduces a wide range of liquid chromatography instrumentation available from them. The catalogue is presented in three major sections and illustrated with line drawings.

The first section describes important specifications and technical features of the major modules. This is followed by a clear and concise presentation of the recommended systems, highlighting the problem solving capability provided by each combination of modules. The last section briefly summaries the major accessories, and applications support opportunities offered by Perkin-Elmer to their customers.

Reader Enquiry Service No. 52

Flow analysis equipment catalogue

ChemLab Instruments Limited have published a new catalogue for their complete range of automatic continuous flow analysis equipment. It contains detailed information on the equipment available, including the latest designs of high



The new hazardous dust suit manufactured by Multifabs Ltd

temperature and dialysis baths. CAAL type analytical cartridges and peristaltic pumps with "stand-by" facility.

Reader Enquiry Service No. 53

Heat transfer leaflet

Hygrotherm Engineering Limited have produced a new leaflet outlining their well-established range of process heat transfer systems. Entitled "New heaters and heating systems", the leaflet briefly describes the complete range of Hygrotherm vertically and horizontally fired heaters. Details include applications, temperature ranges, fluids, and examples of relative installations.

Reader Enquiry Service No. 54

Hydrated alumina brochure

A new 16-page brochure on hydrated alumina, produced by Aluminium Company of America, the parent company of Alcoa of Great Britain, is now available in Europe. Hydrated alumina is used extensively in the production of industrial chemicals and acts as a flame retardant by absorbing the heat of fire.

Reader Enquiry Service No. 55

Chemistry of carbon compound

Elsevier Scientific Publishing Company has recently published Volume IV L of Rodd's Chemistry of Carbon Compounds which covers fused-ring heterocycles with three or more nitrogen atoms; purines, nucleotides and nucleic acids; pteridines and related compounds; biosynthesis of plant alkaloids and nitrogenous microbial metabolites.

Reader Enquiry Service No. 56

Coating of steel structures

Steel Structures Painting Council of Pittsburgh, USA, has available a new book entitled *Corrosion in civil engineering*

news

which summarises current standard methods of protecting structural steel by the use of protective coatings. The book is based upon the papers and ensuing discussions presented at the conference on corrosion in civil engineering held in London during February 1979.

Reader Enquiry Service No. 57

PPC year book

The 1980 edition of the *Polymers, Paint and Colour Year Book*, an up-to-date guide to suppliers of raw materials, plant and equipment used in the paint, ink and polymer processing industries is now available from Fuel and Metallurgical Journals Limited. The year book also contains much ancillary information, including lists of UK and overseas paint manufacturers, trade and technical associations, consultants etc.

Reader Enquiry Service No. 58

Continuous mixing

E. T. Oakes Limited, a member of the Mono Group of companies, has produced a new brochure describing its range of continuous mixing equipment. Oakes offers a range of highly versatile equipment for many industrial mixing duties, ranging from gas blending and slurry mixing, to foaming and the blending of high viscosity pastes or suspensions.

Reader Enquiry Service No. 59

British Standards

British Standards Institution has available the following publications:

BS 5627: Insulating varnishes containing solvent. Part 3: Methods for specifying requirements for individual materials.

BS 5711: Parts 0-22:1979, Methods of sampling and test for glycerol.

Reader Enquiry Service No. 60

meetings, etc.

Paints and buildings

The Paint Research Association is organising its fourth international conference on paints and buildings in the 80s and 90s to be held at the Excelsior Hotel, London Heathrow Airport on 11-13 November 1980. The conference will cover the main influences on changes in building practice, the different building materials and demands that these will make on the paint systems.

Reader Enquiry Service No. 61

news

Emulsion polymerisation

The Emulsion Polymers Institute of Lehigh University, Pennsylvania, is organising its 11th annual one-week short course on advances in emulsion polymerisation and latex technology to be held at the university during the week 9-13 June 1980.

Reader Enquiry Service No. 62

Pigment dispersion equipment

The Cleveland Society for Coatings Technology, a member of the FSCT, is organising a symposium entitled "Formulation for and utilisation of pigment dispersion equipment" to be held on 7 October 1980 at the Cleveland Engineering and Scientific Center, Cleveland, Ohio, USA.

Reader Enquiry Service No. 63

Electroplating

The Scientific Society of Mechanical Engineers, Budapest, is organising its sixth colloquium on electroplating, to be held from 27-29 August 1980 in Budapest.

Reader Enquiry Service No. 64

OCCA news

Scottish Section

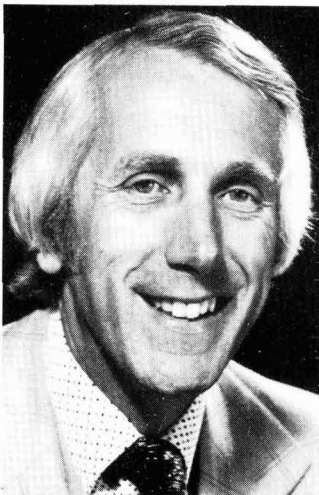
Morris Ashby Golf Trophy

Morris Ashby Limited have presented a "Quaich" to the Scottish Section of the Oil & Colour Chemists' Association, and keen golfers will compete for this at the Section Annual Golf Outing held each year in May. The quaich, to be known as the "Morris Ashby Trophy" will be awarded to the OCCA member with the best Scratch Score.

A "Quaich" is a two handled Scottish drinking cup. In the old days, every highlander carried his own quaich - usually made of wood - and he used it as an eating and drinking utensil. The story goes that the two handles were essential,

appointments

Mr Graham G. Anthony has been appointed commercial director of Ciba-Geigy Plastics and Additives Company. Mr Anthony took up his new appointment on 1 January 1980. Mr Anthony succeeds **Mr Hans R. Durr** who has taken up a senior position in the Central Regional Services Department of the parent company in Basle, Switzerland.



G. G. Anthony

Mr R. C. Hampel, ICI's General Manager, Commercial, has been

appointed Chairman of ICI Paints Division with effect from 1 March 1980. He succeeds **Mr D. H. Henderson** whose appointment as an ICI Director, with effect from the same date, was announced recently.

Mr M. F. T. Barrett, at present UK and Irish Sales Manager, has been appointed Commercial Manager of Ward Blenkinsop & Company Limited. **Mr P. N. Croft**, Export Director, will also be responsible for sales in the UK and Ireland, and becomes Sales Director. **Mr D. C. J. Ward** has been appointed General Sales Manager. **Mr A. M. Blenkinsop** has been appointed Deputy General Manager, in addition to **Mr D. D. Steele**, of the company's factory near Widnes, and will be responsible for factory operations.

Mr Alfred Levy has been appointed Group Managing Director of Carless, Capel & Leonard Limited. **Mr John Leonard** continues as Executive Chairman of the Company. **Mr Roy Emerson**, **Mr Ken Wiseman** and **Mr Ken McDonald** have been appointed Directors of Carless Solvents Limited and **Mr Lou Stroud** a Director of Carless Petroleum Limited.

Mr Norman Gray, a member of the Board of Tioxide Group Limited will retire shortly after 34 years service with the company. As a result, the following appointments are announced. **Dr Keith Sugars** becomes Chairman, with effect from 1 February 1980, retaining his present appointment as Managing Director. **Mr Jacques Gateaux** has been elected Président-Directeur-Général of Tioxide SA.

Further information on any items below may be obtained by circling the appropriate Reader Enquiry Service number on the form at the back of the Journal.

because if you were invited into another clan's tent for a "friendly" drink, neither visitor nor host had any hands free to draw his sword.

Morris Ashby have not said the quaich will be filled with scotch... but rumour has it that there will be no lack of the "Spirit of Scotland" in evidence.



The Morris Ashby Golf Trophy



OCCA-32 Exhibition

13-15 May 1980

Cunard International Hotel
Hammersmith, London W6

OCCA news

The international focal point

Allocation of Space

The first allocation of space for the OCCA 32 Exhibition took place in December and a list of exhibitors was published in the January 1980 issue of the *Journal*.

The list of companies participating at the Exhibition included several organisations returning to the exhibition after an absence of several years as well as more regular exhibitors and those completely new to the Exhibition.

Since the list was published in the January issue and added to in the February issue, several other companies have booked space and are listed below (marked with asterisks) together with the names of organisations whose products will be shown on the stands of other exhibitors.

- Willy A. Bachofen AG
- Cornelius Chemicals
- Ecomax
- Engelhard Minerals & Chemicals Inc.
- *Engelmann & Buckham Ancillaries Ltd
- Ernstrom International
- *FMK International
- Gardner Laboratory
- Gleefield Ltd
- *Grilon (UK) Ltd/Emser-Werke
- Hilton-Davis
- *Italintto Industria Vernici
- S. C. Johnson & Son Inc.
- Leneta
- Micro Powders Inc.
- Micro Products Co.
- *Paragon Chemicals Ltd
- Peerless Pump Ltd
- *Scale Services
- *Schering Chemicals
- Taber
- Tiszamenti Vegyiművek
- Westerlins

The OCCA Exhibition, which is known as the international focal point for the surface coatings industries, is the most important annual event of its kind in the industries, and it offers an unparalleled opportunity for personnel in the manufacturing industries to meet and discuss their requirements with their counterparts in the supplying industries.

In recent years, the OCCA Exhibition has regularly attracted thousands of visitors from 50 countries, who travel to London each year to view the latest



The Cunard International Hotel

developments affecting the industry and to contact leading companies for their needs.

Theme for the Exhibition

Motif: The motif, designed by Robert Hamblin, uses the compass to symbolize the unique attraction of the OCCA exhibitions which annually draw exhibitors and visitors from numerous countries.

The aim of the Exhibition is the presentation of technical and commercial information relating to raw materials, plant and equipment used in the paint, polymer, printing ink, colour, adhesive and allied industries, both in manufacture, processing and application.

Dates and times

The thirty-second annual OCCA Exhibition, a three day event, will be open as follows:

Tuesday 13 May 1980 09.30 to 17.30
 Wednesday 14 May 1980. 09.30 to 17.30
 Thursday 15 May 1980..... 09.30 to 17.30

The Cunard International Hotel

The new venue for the 1980 Exhibition will be the Cunard International Hotel, Hammersmith, London W6, and the main part of the Exhibition will be in two sections; on the ground floor, forming the entrance to the Exhibition, traditional style stands will be accommodated in the New Exhibition Hall where exhibitors of heavy machinery, plant and equipment will be located; on the first floor of the hotel, in the Queen Mary Suite, the stands will be of a simplified nature with the objective of allowing exhibitors to use modular display systems. These stands will have no platform, being erected directly on to the carpeted Suite floor, and so it will not be possible for heavy equipment to be displayed in this section.

Access between these two areas will be through the intermediate Mezzanine floor, where there are a number of rooms in the Armada Suite for companies to display free standing exhibits together with an Exhibitors' lounge.

In addition there will be several suites and syndicate rooms on the third floor of



the hotel, either for companies who wish to use this type of facility to exhibit, or for those who wish to have somewhere convenient to entertain their visitors in addition to their main stands elsewhere in the Exhibition. Already, several organisations have taken advantage of this opportunity to have a main stand for general enquiries, and the more private room for detailed discussions.

Travel arrangements

The Exhibition Committee has decided to move the venue of the 1980 Exhibition to the Cunard International Hotel, as it is felt that the more central site and greater range of types of exhibiting facilities it offers will be welcomed both by exhibitors and visitors to the Exhibition.

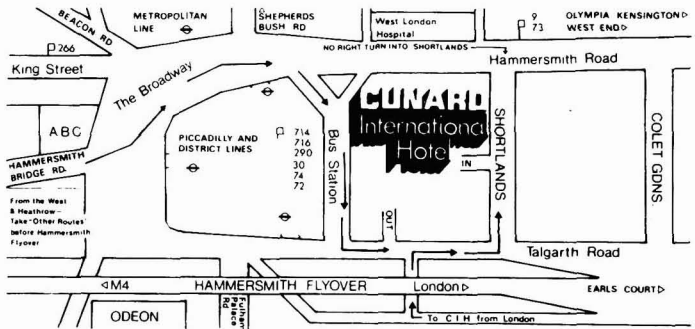
The Hotel is situated near Hammersmith Station on the Piccadilly Underground Line between Heathrow Airport and the centre of London. Visitors from overseas may board the Piccadilly Line in the Airport complex, which will take them direct to Hammersmith Station or to central London where they may be staying. Hammersmith Station is also served by the Metropolitan and District Underground Lines (the latter of which connects to Victoria Station for those arriving at Gatwick Airport). The Hotel is adjacent to the Hammersmith flyover on the M4 Motorway which links Heathrow Airport by road. Car parking at the Hotel is limited, but there is a large NCP car park close by in King's Mall off King Street.

Admission

Admission to the Exhibition will be free, and visitors will be asked to complete registration cards which will be available from the Association with copies of the *Official Guide* in advance. Copies of the *Official Guide* will be charged at £1.50 each, and both registration cards and copies of the *Official Guide* will also be available at the entrance to the Exhibition.

Official Guide

It is intended, as in previous years, to publish the *Official Guide* to the Exhibition several weeks in advance so that it may be sent to visitors to enable them to plan the itinerary for their visits. The *Official Guide* will contain descriptions of all the exhibits together with much other useful information for visitors, such as maps of the exhibition areas, details of facilities, travel information and an analysis of the exhibits.



News of Exhibitors at OCCA-32

Stand 202

Blagden Campbell Chemicals Ltd

This is a new name at the OCCA Exhibition but there is behind it more than 100 years experience in supplying bulk and speciality chemical products.

The Company amalgamates the former Victor Blagden & Co. Ltd, Rex Campbell & Co. Ltd, and the solvents and plasticisers department of the Chemical Supply Company Ltd.

The extensive bulk storage and warehousing facilities at Haverhill, Suffolk handle the products of more than 30 important overseas and UK chemical manufacturers represented by BCCL. From this extensive range the following will be featured;

Solvents and Plasticisers

The range of solvents includes alcohols, ester, ketones, glycol ethers, aromatics,

chlorinated solvents and special types such as dimethyl formamide and tetrahydrofuran. Expert advice is available on solvent selection. The plasticisers include acetates, maleates, phthalates, phosphates, and synthetic camphor.

Hydrocarbon Resins/Neville-Cindu Chemie B.V.

A range of resins with good solubility in ink oils, resistance to emulsification and fast solvent release for heat-set offset, web offset news, and letterpress heat-set inks.

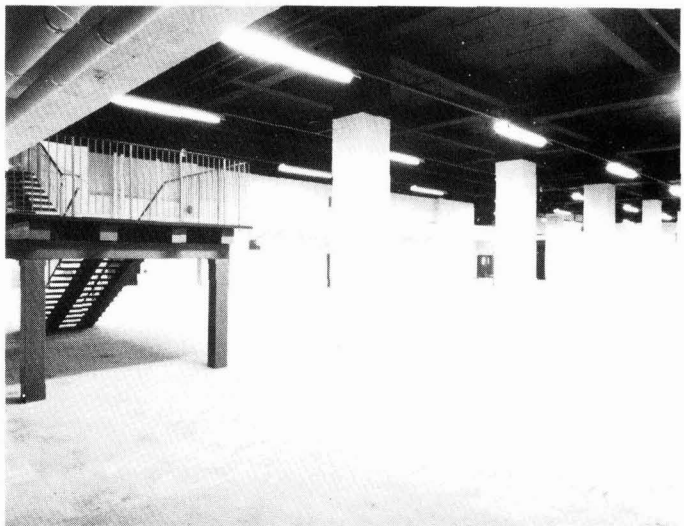
Necires – unmodified heat reactive resins for combination with drying oils are neutral, non-toxic and water-repellent.

Nevroz – modified hydrocarbon resins have good pigment wetting properties and will cross-link under heat to give gelled vehicles.

Nevchem – alkyl aromatic resins are non-toxic, pale colour, non-polar and non-heat reactive.

Products for Printing Inks

Magiesol – low odour printing ink



A view of part of the New Exhibition Hall at the Cunard

distillates for heat set inks. Shamrock micronised waxes (Fischer-Tropsch, polyethylene and PTFE) and ink additives.

SPCM Organic pigments and UV curing agents.

Thixotropic additives.

Barium Metaborate/Buckman Laboratories Inc.

Busan 11-M1 is an anticorrosive pigment for both solvent and water-based primer paints, preventing flash-resting in the latter. Additionally it has fire-retardant properties and may be used as an extender for antimony oxide and other expensive agents.

Stand 212

Foscolor Ltd

Foscolor Limited, are specialist manufacturers of pigment dispersions, producing tailor-made formulations for the printing ink, paint and allied surface coating industries.

They will be exhibiting examples of their extensive range of pigment chips including high quality dispersions in polyamides, acrylics, cellulose esters, vinyls, chlorinated rubbers, maleics, phenolics etc., and will be highlighting particularly two new product ranges.

Powder Coating Masterbatches

Foscolor now offer dilute and concentrated dispersions of individual pigments in epoxy, polyester and acrylic for the direct colouration of powder coatings. They are fully dispersed to a standard not generally achievable by extrusion, in many cases giving sufficient extra strength development to show economic as well as technical advantages over the addition of raw pigment.

They are sold in a physical form which greatly facilitates uniform blending and their complete colour development eliminates problems of colour variation on the run.

Dry Tinters for Gloss Emulsion Paints

This range consists of chip-quality dispersions of individual paint pigments in a specially selected, alkali-soluble acrylic resin which can be dissolved or stirred directly into emulsion paint.

In physical form they are clean-to-handle powders with a long shelf-life. Pigmentation levels are almost double those of aqueous pastes so that much less storage space required and no water is added to them giving much greater flexibility in formulation.

In addition to these commercial advantages, technical improvements are also achievable in the form of better tinting strength pigment for pigment, greater resistance to flotation, much better gloss and the ability to produce full shades.

Vinyl Dispersions for Wallpaper and Calendered Sheet

As well as the new products mentioned above, Foscolor will be showing their recently completed range of vinyl chips for wallpaper and PVC printing and the mass colouration of calendered sheet. The newly published brochure on these products will be available on request.

Technical representations will be available for discussions throughout the exhibition.

News of Members

Dr David Norman has been appointed Chairman of Council of the Institution of Corrosion Science and Technology. Mr Norman is an Ordinary Member of the Association attached to the Midlands Section, and at present is the Chief Corrosion Engineer for the Production and Supply Division of the British Gas Corporation (Pipelines Department), having previously worked within the Scientific Services of the Central Electricity Generating Board and the Paints Division of ICI Ltd.

Mr Derek Bayliss, a former Chairman of the London Section and a Fellow in the professional grade, is to deliver a paper in March to the technical meeting of the NACE Corrosion 80 conference in Chicago. The paper concerns the development of painting inspection in the UK. Later in the month he is to give a talk at a one-day seminar in London on "Responsibilities and financial obligations of the owner, contractor, inspector and consultant".

One month later, Mr Bayliss will be in Tel Aviv attending the International Standards Meeting TC/35 SC12 as nominated expert to Working Group 2, dealing with surface contamination of steel before application of paint. In June



he is the UK delegate to the European Federation of Corrosion Working Group 2, dealing with the protection of structural steelwork, to be held in Sweden.

From 22 June to 7 July he is a keynote speaker at a University of Queensland, Australia, symposium on "Paint coatings for the protection of metal structures", and he is also to deliver papers to the Australian Corrosion Association at Melbourne and Sydney.

Derek Bayliss is the Technical Director of BIE Anti-Corrosion Ltd, of Watford, Herts, and is responsible for technical back-up and training of the company's field staff and acts as an independent consultant to a number of major engineering consultancy firms.

SDC Visit

The photograph shows the President, Dr F. M. Smith (right), on a visit to Perkin House, the headquarters of the Society of Dyers and Colourists, being greeted by the President of the Society, Dr J. K. Skelley, in front of the portrait of Sir William Perkin, who at the age of eighteen in 1856 discovered the first synthetic dye.

A short article on the "Perkin Connection", tracing some links between the SDC and OCCA, appeared on page 210 of the June 1978 issue of *JOCCA*.



Dr Smith being greeted by Dr J. K. Skelley in front of a portrait of Sir William Perkin

OCCA CONFERENCE 1981



Alternative technologies in coatings

CALL FOR PAPERS

The next OCCA Biennial Conference will be held at the Beaufort Hotel, Bath from 17 – 20 June 1981 with the theme "Alternative technologies in coatings".

The future holds both opportunity and challenge for alternative technologies and topics covered by the Conference should include, EEC regulations covering the introduction of new chemicals, alternative means of obtaining opacity, the impact of microprocessors and computers on processing and application methods, high solids coatings, aqueous systems, radiation curing and powder coatings.

A departure from the usual conference format will be the inclusion of a "Discourse" session with the sub-title "Alternatives to coatings", where the use of techniques such as cathodic protection and substitution of coated items by plastics could be discussed.

The Hon. Research & Development Officer now invites offers of papers for presentation at this Conference. Anyone wishing to submit a paper for consideration should notify his intention as soon as possible to: **The Director & Secretary, Oil & Colour Chemists' Association, Priory House, 967 Harrow Road, Wembley, Middlesex HA0 2SF, England (Tel: 01-908 1086; Telex: 922670 OCCA G).**

Annual General Meeting

The Eighteenth Annual General Meeting of the Incorporated Association is to be held in London on 26 June 1980 at the Piccadilly Hotel, London W1, following a Luncheon and Lecture. The Speaker will be Professor, Sir Herman Bondi, KCB, FRS, Chief Scientist of the Department of Energy.

After presenting the West Riding Golf Trophy to Mr J. Wood, the Chairman invited members of the section to toast their guests and ladies. The President replied on behalf of the guests.

Following the dinner, the party rapidly got underway, with dancing to the Peter Edwards Sextet.

D. V. M.

**occa
news**

West Riding Section

Ladies' Evening

The annual dinner dance of the West Riding Section, was held on Friday, 30 November, at the Crown Hotel, Harrogate.

To start the evening on a very pleasant note, each lady received a gift of an orchid.

A party of 234 sat down to a most enjoyable meal, after which the Chairman, Mr M. G. Bentley, welcomed his top table guests. They were the President and his wife, Dr and Mrs T. A. Banfield (London), Mr and Mrs G. V. G. Hill (Thames Valley), Mr and Mrs J. A. Burns (Midland), Mr and Mrs A. C. Jolly (Manchester) and Mr R. H. Hamblin (Director and Secretary).



Shown at the Annual Dinner Dance of the West Riding Section are (left to right): Mr G. V. G. Hill (Chairman, Thames Valley), Mrs Hill, Dr F. M. Smith (President), Mrs Smith, Mr M. G. Bentley (Chairman, West Riding), Mrs Bentley, Dr T. A. Banfield (Chairman, London), Mrs Banfield, Mr J. A. Burns (Chairman, Midlands), Mrs Burns, Mrs Jolly, Mr A. C. Jolly (Chairman, Manchester) and Mr R. H. Hamblin (Director and Secretary).

The following elections to membership have been approved by Council. The Section to which each new Member is attached is given in italics.

Ordinary Members

ASHBOLT, ROGER HENRY, 6 Champion Road, Upminster, Essex. *(London)*

FLYNN, ROY, MERIC, Silver Paint & Lacquer Co. Ltd, 513 Bradford Road, Batley, W. Yorks *(West Riding)*

GREGORY, BRIAN JAMES, BA, MSc, 1 Austin Court, Milden Close, Austin Drive, Didsbury, Manchester M20. *(Manchester)*

GRUAR, WILLIAM DONALD, BSc, 124 School Lane, Woolton, Liverpool L25 7UD. *(Manchester)*

HURRY, DAVID, 8 Academy Gardens, Gainford, Darlington, Co. Durham. *(Newcastle)*

KENNEDY, SAMUEL, 18 Bushey Close, Linden Village, Buckingham. *(Thames Valley)*

LEADBETTER, JOHN GRAHAM, BSc, 12 Upton Park, Upton By Chester, Cheshire CH2 1DG. *(Manchester)*

LORD, KENNETH GRAHAM, D. MacPherson & Co. Ltd, Warth Mills, Radcliffe Road, Bury, Lancs. *(Manchester)*

MAZZANTINI, MARIO, Centenera 2750, 1437 Buenos Aires, Argentina. *(General Overseas)*

RICHARDSON, NORMAN, 17 De Montfort Court, Blackley, Northants. *(Thames Valley)*

**new
members**

TORTORICI, FRANK J., 144 Skyway Avenue, Rexdale, Ontario, Canada M9W 4Y9. *(Ontario)*

WILKES, DAVID GRAHAM, BSc, LRIC, 3 Helenny Close, Wednesfield, Wolverhampton, West Midlands. *(Midlands)*

Associate Member

GASKELL, PETER, 17 Lambtons Way, Winslow, Bucks MK18 3ET. *(Thames Valley)*

Registered Students

BROWN, ELAINE KATHRYN, 5 Allerton Terrace, Chorley Road, Whitnell Chorley, Lancs PR6 8BQ. *(Manchester)*

LEONARD, MICHAEL JOHN, 4 Hampshire Close, Wilpshire, Blackburn, Lancs. *(Manchester)*

STREETS, PAUL, 15 Darras Road, Ponteland, Newcastle upon Tyne. *(Newcastle)*

ZAKARIA, ANIS, Crown Decorative Products, Ind. Research, Hollins Road, Darwen, Lancs. *(Manchester)*

OCCA diary

Details are given of Association meetings in the United Kingdom and Ireland up to the end of the second month following publication and in other parts of the world up to the end of the third following publication.

End. Beaconsfield, Bucks commencing at 6.30 p.m. for 7.00 p.m.

Thursday 17 April

Thames Valley Section: Annual General Meeting. "Unusual experiences of a paint supplier" by R. Peacop of Technical Paint Services, at the Beaconsfield Crest Motel (White Hart), Aylesbury End, Beaconsfield, Bucks commencing at 6.30 p.m. for 7.00 p.m.

Friday 18 April

Irish Section: Annual General Meeting, at the Clarence Hotel, Dublin, commencing at 8.00 p.m. *Details to be announced.*

Manchester Section: Annual General Meeting, at the Lancashire Cricket Club, Old Trafford, Manchester. *Details to be announced.*

Wednesday 23 April

Scottish Section - Eastern Branch: Annual General Meeting, followed by "Pencil manufacture" by D. W. Tee of the Cumberland Pencil Co., at the Murrayfield Hotel, 18 Corstorphine Road, Edinburgh commencing at 7.30 p.m.

Thursday 24 April

London Section: Annual General Meeting, at the Rubens Hotel, Buckingham Palace Road, SW1 commencing at 6.30 p.m., followed by a lecture of general interest (*speaker and subject to be announced*). *Ladies' Evening.*

Friday 25 April

Midlands Section: Annual General Meeting, at the Belfry Hotel, Lichfield Road, Wishaw, commencing at 7.30 p.m. There will be a golf tournament in the afternoon at the adjoining golf course.

Bristol Section: Annual General Meeting at the Royal Hotel, College Green, Bristol, commencing at 7.15 p.m. A film will be shown at the end of the proceedings.

May

Friday 9 May

Bristol Section: Skittles Match, at BP Chemicals, Stroud. *Details to be announced.*

13 - 15 May

OCCA-32 Exhibition, at the Cunard International Hotel, Hammersmith, London W6. 09.30 to 17.30 hrs.

Friday 21 March

Bristol Section: Dinner Dance, to be held in the Mayfair Suite, New Bristol Centre, at 7.30 p.m. for 8.00 p.m.

Irish Section: "Paint lecture", at the Clarence Hotel, Dublin commencing at 8.00 p.m. *Details to be announced.*

Midlands Section: *Newton Friend Ladies' Invitation Lecture:* "Greeting cards through the ages" by A. Gemmes of Webb Ivory Ltd, at the Birmingham Chamber of Commerce and Industry.

Wednesday 26 March

London Section: "Resins". Day meeting at Thames Polytechnic, Woolwich SE18, commencing at 10.00 a.m.

Scottish Section - Eastern Branch: Works visit to Lorimers Brewery, St. Leonards Street, Edinburgh at 7.15 p.m. for 7.30 p.m.

Friday 28 March

Bristol Section: "Low odour solvents" by A. Cumbers of Carless Solvents Ltd, at the Royal Hotel, Bristol commencing at 7.15 p.m.

Monday 31 March

Hull Section: Annual General Meeting. *Details to be announced.*

April

Midlands Section - Trent Valley Branch: Annual General Meeting, to be followed by a Buffet Dance at the Cross Keys Inn, Turnditch. *Details to be announced.*

Tuesday 1 April

West Riding Section: Annual General Meeting, at the Mansion Hotel, Roundhay Park, Leeds 8, commencing at 7.30 p.m. *Details to be announced.*

Thursday 10 April

Newcastle Section: Annual General Meeting, at the Students Common Room, St. Mary's College, Elvet Hill Road, Durham, commencing at 6.30 p.m. *Details to be announced.*

Friday 11 April

Association Dinner Dance, at the Savoy Hotel, London WC2.

March

March

Manchester Section: Student Works visit. *details to be announced.*

Manchester Section: Informal Buffet Dance. *details to be announced.*

Monday 3 March

Hull Section: Ladies' Evening. *details to be announced.*

Tuesday 4 March

West Riding Section: "Industrial nitrocellulose - Manufacture and use" by A. W. E. Staddon of ICI Ltd, Organics Division, at the Mansion Hotel, Roundhay Park, Leeds 8 commencing at 7.30 p.m.

Thursday 6 March

Newcastle Section: "The manufacture and uses of pigment chips for the printing ink and paint industry" by F. Morpeth of Foscolor Ltd, at the Students Common Room, St. Mary's College, Elvet Hill Road, Durham commencing at 6.30 p.m.

Monday 10 March

Manchester Section: "Electrodeposition - Anodic versus cathodic" by H. V. Schenk of BASF Ludwigshafen, at the Woodcourt Hotel, Sale commencing at 6.30 p.m.

Thursday 13 March

Midlands Section - Trent Valley Branch: "Fire precautions" by an officer of the Derbyshire Fire Service, at the Derby Crest Motel, Pastures Hill, Littleover, Derby commencing at 7.15 p.m.

Scottish Section: Student Invitation Lectures: "The practical aspects of colour in surface coatings" by T. Grieve of Isaac Spencer Ltd, and "The practical aspects of colour in printing inks" by G. Hutchinson of Croda Inks Ltd, at the Albany Hotel, Glasgow commencing at 6.15 p.m.

Thursday 20 March

Thames Valley Section: "Cathodic electrodeposition" by R. L. Bayliss of ICI (Paints) Ltd, at the Beaconsfield Crest Motel (White Hart), Aylesbury

CLASSIFIED ADVERTISEMENTS

Classified Advertisements are charged at the rate of £4.00 per cm. Advertisements for Situations Wanted are charged at £1.00 per line. A box number is charged at 50p. They should be sent to D. M. Sanders, Assistant Editor, Oil & Colour Chemists' Association, Priory House, 967 Harrow Road, Wembley, Middlesex HA0 2SF. JOCCA is published EVERY month and Classified Advertisements can be accepted up to at least the 12th, and in exceptional circumstances the 20th of the month preceding publication. Advertisers who wish to arrange for an extension of the copy deadline should contact the Assistant Editor, D. M. Sanders, at the address given above (telephone 01-908 1086, telex 922670 OCCA G).

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| TUESDAY | 13 MAY | 09.30 | 17.30 |
| WEDNESDAY | 14 MAY | 09.30 | 17.30 |
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ADMISSION FREE

Copies of the "Official Guide" including registration cards, at £1.50 each are obtainable in advance from the address below or at the entrance to the Exhibition.

Oil & Colour Chemists' Association,
Priory House, 967 Harrow Road, Wembley, Middlesex,
England, HA0 2SF
Telephone: (01) 908 1086 Telex: 922670 (OCCA Wembley)

CLASSIFIED ADVERTISEMENTS

SITUATIONS VACANT

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The Paint and Sealants Division of the SABS has a vacancy for an experienced paint chemist. Applicants should preferably have a university or equivalent qualification plus a substantial number of years experience in the paint field. Professional grading in OCCA will be a strong recommendation.

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**South African
Bureau of Standards**



Birmingham Paint, Varnish and Lacquer Club

50th Anniversary Year Symposium

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The symposium will be held at the Birmingham Metropole Hotel on 15 May 1980.

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London Section OCCA Golf Trophy Tournament

The 1980 Golf Tournament for the OCCA Golf Trophy being organised by the London Section will be held on Wednesday, 11th June at the Canons Brook Golf Club in Harlow, Essex.

Intending participants should contact Mr B. F. Gilliam, 25 Regency Close, Chigwell, Essex IG7 5NY.

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- 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
- 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
- 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100
- 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120
- 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140
- 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160
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INDEX TO ADVERTISERS

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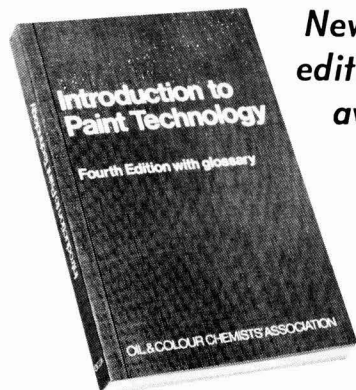
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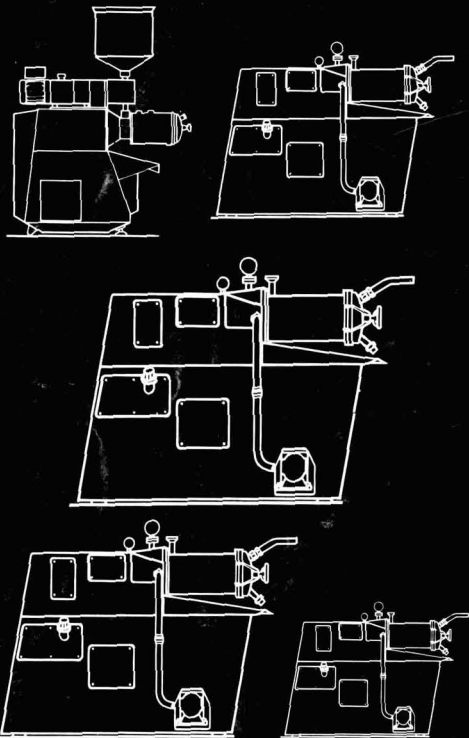
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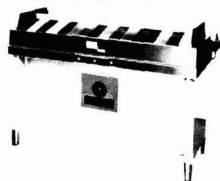
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