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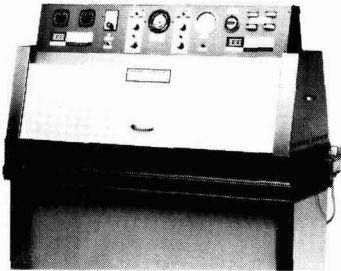
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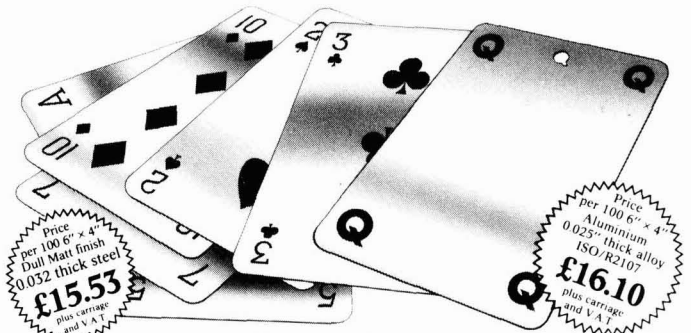
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## Transactions and Communications

# How not to paint bridges\*

By R. R. Bishop and M. A. Winnett

Transport and Road Research Laboratory, Old Wokingham Road, Crowthorne, Berkshire RG11 6AU, England

### Summary

A novel approach to the protection of the structural steelwork of composite bridges is proposed by physically changing the environment to which the steelwork is exposed. Clean steel does not corrode at relative humidities up to 99 per cent if environmental contaminants are absent. It is apparent that the most critical factor affecting corrosion rates in enclosed spaces is pollution by chlorides and sulphur dioxide and not high relative humidity. A small scale experiment has shown that it is possible simply to enclose the already sheltered steelwork of a composite bridge to produce an environment which is contaminant-free

and in which corrosion does not take place. It is very reasonable to assume that blast-cleaned painted steel will have a very long maintenance free life in such environments free from contaminants. There is also interesting preliminary experimental work which indicates that the corrosion rate of pre-corroded specimens reduces rapidly when introduced into a contaminant-free enclosure. This concept of steelwork enclosure is novel but if the observations and experiments carried out to date are proved correct then potential savings in maintenance painting could be considerable.

### Keywords

*Types and classes of structures or surfaces to be coated*

steel

*Processes and methods primarily associated with service or utility*

corrosion

*Properties, characteristics and conditions primarily associated with*

*the environment*

humidity

### Une alternative au repeinturage des ponts en acier

#### Résumé

On propose une nouvelle tentative à la protection des éléments en acier des ponts de construction mixte où l'on change l'environnement physique auquel les charpentes en acier sont exposées. L'acier net n'est pas susceptible à la corrosion, même aux humidités relatives jusqu'à 99 pour cent, pourvu que les contaminants environnementaux soient absents. Il est évident que le facteur qui exerce l'influence la plus critique sur les taux de corrosion dans les endroits clos est la pollution provoquée par les chlorures et par l'anhydride sulfureux, et non par l'humidité relative élevée. Une expérience à petite échelle a démontré qu'il est possible d'entourer la déjà-abritée charpente en acier des ponts mixtes en vue de créer un environnement qui est exempt

de contaminant et où la corrosion n'a pas lieu. Il est très raisonnable de supposer que l'acier nettoyé par sable et ensuite repeint, aura dans de tels environnements une longue vie sans besoin de manutention. Il y a d'ailleurs les travaux expérimentaux préliminaires d'un certain intérêt qui indiquent que le taux de corrosion des éprouvettes où la corrosion a été déjà entamée, se diminue rapidement lors de leur introduction dans un milieu exempt de contaminant. Le concept de renfermer l'acier est nouveau, mais pourvu que les observations et les expériences effectuées jusqu'à présente se montrent justes, les économies potentielles dans le domaine du peinturage de manutention pourraient être considérables.

### Eine Alternative zur Lackierung der Brücken

#### Zusammenfassung

Man schlägt eine neuartige Methode zum Schutz der Stahlteile von gemischtbauweise Brücken vor, wodurch die physikalische Umgebung worin die Stahlbau sich befindet, verändert wird. Reiner Stahl rostet nicht zu relativen Feuchtigkeiten bis auf 99 Prozent, wenn Verschmutzungsmittel abwesend seien. Es ist offenbar dass der kritischste Faktor, der die in eingeschlossenen Räumen vorkommenden Korrosionsziffern beeinflusst, die Verschmutzung von Chloride und von Schwefeldioxyd, und nicht von der höhen relativen Feuchtigkeit ist. Ein Versuch in kleinem Masstab zeigte dass es möglich ist den schon beschützten Stahlbau einer gemischtbauweisen Brücke bloß einzukapseln, um eine Verschmutzungsmittel- und

Korrosionsfreiumgebung zu schaffen. Es ist verständlich anzunehmen dass strahlereinigte und lackierte Stahlbau in solchen Verschmutzungsmittelfreiumgebungen ein sehr langes Wartungsfreileben haben soll. Es gibt auch etliche interessanten Versuche, die zeigen dass die Korrosionsgeschwindigkeit von vorher korrodierten Probestücken bald vermindert wird, wenn sie in eine Verschmutzungsmittelfreistelle eingeführt würden. Diese Vorstellung von Stahlbauinkapseln ist neuartig, wenn jedoch die Beobachtungen und die schon ausgeführten Versuche sich recht erwiesen, würden die potentiellen Wartungslackierungseinsparungen dann wesentlich.

\*Paper presented at the Association's Conference held at Bath, 17-20 June 1981. Reproduced by permission of the director of the Transport and Road Research Laboratory.

## Introduction

Maintenance painting of structural steelwork is labour intensive and costs are increasing at a rate greater than general inflation. Paint itself is still a small proportion of total painting costs but specification writing, scaffolding, surface preparation, paint application and inspection are all very costly items. It is no coincidence that a large number of robots are used by the motor car manufacturing industry for paint application. But no such labour saving devices are applicable to the painting of civil engineering structures. It is now not unknown for maintenance painting costs of a major composite highway bridge or viaduct to exceed £1m.

A novel approach to the protection of structural steelwork of composite bridges is proposed. It is believed that a technique of enclosing the steelwork with plastic or other sheeting material on existing structures could modify the environment to produce a situation in which bridge steelwork would be maintenance-free for several decades. It is assumed that the technique would be applicable only to plate girders, and possibly universal beams, sheltered by a concrete deck. For practical reasons it cannot be envisaged how the technique could be applied to box girder bridges or to other steel structures. Nevertheless there are sufficient composite steel girder bridges in the UK and maintenance painting costs are now so high that the idea merits serious consideration.

## The background

*Refs. 1-6*

With one notable exception there seems to have been little attempt, to date, to search for alternatives to the coating of exposed steel structures. The exception is the use of unpainted weathering steel which has been widely used in highway bridge construction in North America during the last 15 years. It is true, however, that only at the Transport and Road Research Laboratory has a serious effort been made to monitor the corrosion rate of steel in bridgeworks<sup>1</sup>. Following this work the Department of Transport will not allow unpainted weathering steel to be used in motorway overbridges of standard headroom because the steel may be attacked by de-icing salts thrown up by vehicle spray. This still leaves scope for the use of weathering steel in highway bridges elsewhere. The use of unpainted weathering steel in new works, of course, makes no contribution to the problem of maintaining the existing stock of steel bridges. The concept of protecting steelwork by enclosing it with plastic or other sheeting developed through several concurrent observations, literature surveys and research projects undertaken by the authors and their colleagues.

For supposed reasons of corrosion protection humidity control of the interiors of closed boxes of some steel bridges has been practised. The Samlesbury M6 bridge in Lancashire was the first structure in which the use of silica gel desiccant was recorded<sup>2</sup>. In Denmark the Lillebaelt bridge has elaborate air ventilation and dehumidification installed<sup>3</sup>. This obsession with reducing the relative humidity (r.h.) is unsoundly based. In 1935 Vernon showed, in an oft-quoted, but probably seldom read paper, that r.h. as high as 99 per cent does not cause corrosion of clean steel<sup>4</sup>. It is widely quoted, however, that in air the critical r.h. necessary to cause corrosion is about 70 per cent<sup>5</sup> without adding that the 70 per cent critical r.h. relates to an atmosphere containing 0.01 per cent SO<sub>2</sub>.

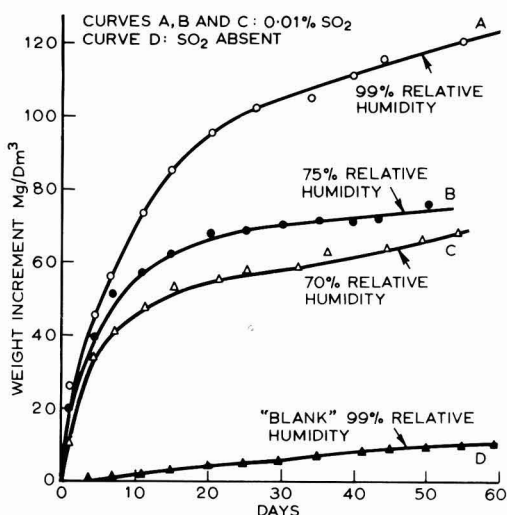


Figure 1. Influence of sulphur dioxide at high relative humidity (after Vernon, *Trans. Far. Soc.* 31, 1935, p. 1680)

Some of Vernon's experimental results are reproduced in Figure 1 and they merit examination. The authors have repeated this type of Vernon experiment in a bridge environment over a long period. Blast-cleaned steel specimens were exposed in an anchorage chamber at the Severn Bridge for two years. The r.h. during the first year of exposure did not fall below 70 per cent and frequently exceeded 90 per cent but there were no significant chloride or sulphur compounds present in the chamber environment. During this exposure period the steel specimens remained bright with only isolated rust spotting.

It is apparent that the critical factor affecting corrosion rates in enclosed boxes is pollution by chlorides and sulphur not r.h. This is supported by a statistical assessment of the effect of environmental factors described by McKenzie<sup>1</sup>.

It is also worth considering the role of paint coatings in the protection of steel. It is generally agreed that Mayne<sup>6</sup> has established that paints are so permeable to oxygen and water that they do not operate by preventing oxygen and water from reaching the metal substrate. There are many instances of coatings which do not contain inhibitive pigments but that have protective properties. By a mechanism, which probably involves ion exchange, corrosive anions are prevented from reaching the metal substrate by paint coatings. It is now suggested that a more efficient long term way of keeping corrosive contaminants away from the steel substrate on certain types of steel girder bridges is to use shuttering to modify the environment.

A way in which some bridge girders could be protected from the environment is indicated in cases where bridges have been provided with metal mesh walkways. This is particularly well illustrated by a walkway provided between girders on the Loudwater Viaduct in Buckinghamshire (Figure 2). It is suggested that if plastic or other sheeting were placed under the mesh the steel girders would be screened from the atmosphere and steelwork would require no further protection for decades.

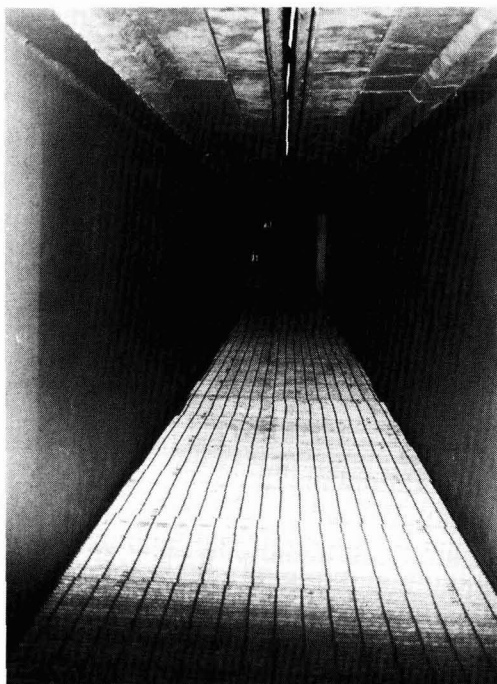


Figure 2. Walkway provided between girders on the Loudwater Viaduct (if sheeting were placed under the mesh the girders would be screened from the atmosphere)

The reasoning so far proposed may be summarised:

- (i) Clean bare steel will not corrode at r.h. up to 99 per cent if environmental contaminants are absent.
- (ii) It is reasonable to assume that blast-cleaned painted steel will have a very long maintenance free life in an enclosed environment-free from contaminants.
- (iii) The interiors of ventilated steel box girder bridges experience such a contaminant free environment. The condition of these supports (ii).
- (iv) It would be practicable to surround the already sheltered steelwork of a composite bridge to produce such an environment.

### Experimental

Refs. 1, 7, 8

For some years observations have been made at the Iden Bridge in Sussex by McKenzie as part of a study of the performance of unpainted Cor-ten weathering steel bridges<sup>1</sup> and by the authors in recording the time of wetness of steelwork sheltered by a bridge deck<sup>7</sup>. This bridge is a single span composite structure with a concrete deck and five universal beams of unpainted weathering steel crossing the River Rother 10 km from the coast (Figure 3). The underside of the concrete deck is lined with plastic coated steel.



Figure 3. The Iden Bridge



Figure 4. The Iden Bridge showing wooden boxed enclosure with plastic window

The following data are already available from this site:

- (i) Corrosion rates of mild steel and Cor-ten steel by weight loss under conditions of bridge sheltering and open exposure.
- (ii) Sulphur compound and chloride levels.
- (iii) Time of wetness of sheltered and open exposed steelwork.

In 1976 a walkway across bottom flanges was constructed to allow access, instrumentation and inspection. For the present programme a section of the bridge was screened in 1979 with wooden flooring, an access door and a perspex inspection window (Figure 4). No attempt was made to make an air-tight enclosure, only simple rubber seals were used. The box is therefore always at atmospheric pressure. The object of the experiment which is now underway is to compare the environment inside the enclosure with conditions outside sheltered by the bridge deck.

The following data are being obtained under these conditions:

- (i) r.h. and temperature
- (ii) sulphur compound and chloride levels
- (iii) time of wetness of surfaces
- (iv) corrosion rates of bare steel by weight loss
- (v) corrosion rates of bare steel using electrical resistance probes (ERP)
- (vi) corrosion rates of pre-corroded bare steel using ERPs.

### Preliminary results

The experimental programme on the Iden Bridge enclosure is in a preliminary phase and will be more fully reported later. But with the limited experimental information already available and the background information (under the heading, The background) there is sufficient evidence that the concept of protecting steelwork by enclosing it is a valid one.

The experimental information so far obtained relates to the period October 1979-April 1980 and can be summarised:

- (i) The r.h. in the enclosure was mostly above 80 per cent and during October 1979-March 1980 was never below 70 per cent.
- (ii) Table 1 shows how atmospheric chlorides and sulphur compounds have been reduced firstly by the sheltering effect of the bridge deck and secondly by the enclosure. In the latter situation corrosive pollutant levels are negligible.
- (iii) Sereda<sup>8</sup> established a direct relationship between times of wetness and corrosion rates of metals. The time of wetness has been recorded at four positions on the Iden Bridge, including the enclosure. The method used and the definition of wetness was given in an earlier report by the authors<sup>7</sup>.

Exposed steel remote from the bridge and sheltered girders was wet for about 25 per cent of the time between October 1979 to March 1980. Despite the high r.h., sensors in the boxed enclosure recorded zero time of wetness for the same period.

- (iv) and (v) The above is compatible with absence of corrosion on blast-cleaned steel specimens exposed in the boxed enclosure over the same 6 month period. Under the sheltered bridge deck rust spotting appeared on specimens within a month and the freely exposed specimens showed uniform rusting of the whole area within a month.

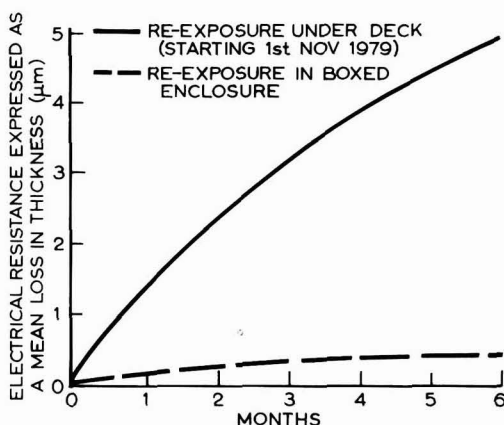


Figure 5. Pre-corroded steel specimens (at a marine site) followed by re-exposure at Iden Bridge

- (vi) The most surprising result comes from the exposure of ERPs pre-corroded at a marine site and re-exposed within the box section at Iden (Figure 5). In a four month period pre-corroded probes re-exposed under the bridge deck lost an average of 4 µm as measured by this method. But re-exposure of similar specimens within the boxed enclosure reduced corrosion to negligible levels. This is an unexpected finding which gives very strong support to the concept of corrosion control by enclosure.

### Conclusions and recommendations

The protection of steelwork by enclosing it with protective sheeting appears to be a possibility. Where paintwork on steel girder bridges is in good condition and was applied over blast-cleaned steel, enclosure that excludes contamination will produce a maintenance-free condition for decades. This is supported by inspection of the ventilated interiors of the boxes of the Erskine Bridge in Scotland.

The technique would also probably extend the maintenance-free life of unpainted weathering steel bridges that have been constructed in unfavourable environments, i.e. in marine locations, or exposed to de-icing salts.

The finding referred to in the section "Experimental", that pre-corroded steel subsequently removed to an enclosed box atmosphere virtually ceases to corrode is very interesting but requires further examination. However, the recommendation to enclose steelwork in good condition does not rest on this experiment. It does mean that if the experiment can be fully substantiated then enclosure of steelwork already corroded would be a valu-

Table 1  
Environmental pollution levels at the Iden Bridge in January 1980

Exposure condition	Average atmospheric sulphur compounds mg SO <sub>2</sub> /100 cm <sup>2</sup> /day	Average atmospheric chlorides mg Cl/100 cm <sup>2</sup> /day
Normal open exposure	0.37	0.11
Bridge sheltering	0.12	0.11
Boxed enclosure	0.005	0.04

able form of corrosion protection. This is an area for further investigation.

If bridge girders are to be successfully enclosed very real problems will have to be overcome. A major difficulty could be the prevention of leakage through the bridge deck into the enclosed area. Nevertheless, in the case of plate girder composite bridges the completion of an enclosure is a perfectly practical procedure.

Plans are in hand to enclose a small unpainted weathering steel bridge which is in a marine environment at Exceat, Sussex and is undergoing excessive corrosion. The procedure will be to blast-clean and then enclose with plastic sheeting. The total cost will be less than painting the structure. This exercise will be regarded as an experiment and corrosion rates and other data will be recorded and evaluated.

The concept described in this report is admittedly controversial but if the observations and experiments carried out to date are accepted then the potential saving in maintenance painting could be considerable.

**Acknowledgements**

The work described in this report forms part of the research programme of the Serviceability and Earthworks Division of the Structures Department of TRRL. The authors wish to thank the East Sussex County Council for permission to carry out work on the Iden Bridge.

*[Received 14 January 1981]*

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**Appendix**

**Description of the electrical resistance probe (ERP) method of measuring corrosion**

The ERP consists of a strip of metal, in this case mild steel. The electrical resistance of the probe, which is measured by a bridge circuit, increases as the probe cross-section decreases with corrosion and this increase in resistance enables total metal loss to be continuously monitored.

The probe must be of sufficiently thin metal for corrosion to cause a significant loss in thickness and hence increase the resistance for significant measurement in a convenient time interval. Probes with thicknesses varying from 0.025 to 2 mm are available or can be made. The thinnest probes are the most sensitive but have the shortest life.

From equation (1) it can be seen that the resistance (*R*) is inversely proportional to the thickness (*t*) for a metal strip.

$$R = \rho \frac{l}{a} = \rho \frac{l}{w} \times \frac{1}{t} = \frac{K}{t} \dots \dots \dots (1)$$

where:

- $\rho$  is the sensitivity of the metal
- $l$  is the length of the specimen
- $a$  is the cross-sectional area of the specimen
- $w$  is the width of the specimen
- $K$  is a constant

Compensation for the variation of resistance with temperature is achieved by incorporating in the ERP a reference element which effectively maintains the same temperature as the test element. The whole ERP (both test and reference elements) is adhesively mounted on an acrylic sheet and is encapsulated in cured resin with the exception of the exposed test element. This enables the resistance ratio of the probe to be compared with the resistance ratio of the measuring instrument (Figure 6). By application of Equation 1 for both elements of the probe, the resistance ratio of the probe  $R_T/R_R$  can be simply related to the thickness of the test element by Equation 2.

$$\frac{R_T}{R_R} = \frac{K_T/t_T}{K_R/t_R} = \frac{K_T}{K_R} \frac{t_R}{t_T} = \frac{K}{t_T} \dots \dots \dots (2)$$

where:

- $R_T$  is the resistance of the test element
- $R_R$  is the resistance of the reference element
- $t_T$  is the thickness of the test element
- $t_R$  is the thickness of the reference element
- $K_T, K_R$  and  $K$  are constants.

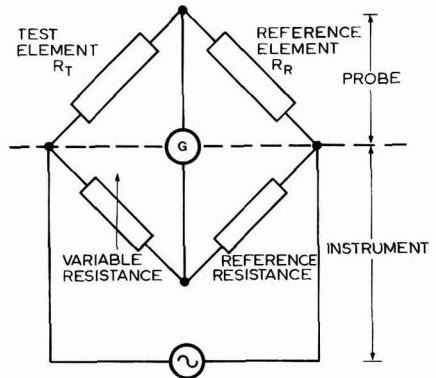


Figure 6. Basic circuit for electrical resistance probe technique

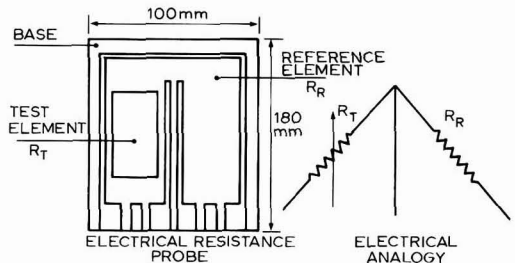


Figure 7. Layout of electrical resistance probe

The measurement of resistance ratio of the probe at intervals over a period of time permits the corrosion rate to be calculated as a mean loss of thickness. There is no limit during the life of the probe to the number of measurements that may be made. Commercially available probes are expensive and for the present work they were fabricated from a single sheet of steel shaped either by cutting or etching into arms of a bridge circuit (Figure

7). The probes were used in conjunction with a commercial measuring instrument (Magnachem K3).

A particular value of this technique of measuring corrosion is that conditions may be changed during the course of an experiment and the change in corrosion rate detected.

### Discussion at Bath Conference

MR G. R. THOMSEN: Dr Bishop, you mentioned at the beginning of your lecture a bridge in Denmark which has air conditioning installed inside it. If we are talking about the same bridge, I have to add that before installing this costly equipment, the inside of the bridge was painted with an anti-corrosion primer and a coal tar paint.

DR R. R. BISHOP: *There shouldn't be too many corrosion problems with that bridge!*

MR E. CARTER: The Tay Bridge, Erskine Bridge and Forth Road Bridge (approach viaducts) are box beam structures and I understand there were corrosion problems when they were sealed. The engineers cured the problem by opening them up and allowing ventilation to take place. This seems to be in contradiction to Dr Bishop's concept. Could he comment on this?

DR R. R. BISHOP: *That is a very interesting point and I don't think we made it clear enough that these enclosures we are producing are not hermetically sealed. They are sealed by rubber gaskets but by no means are they airtight. I was not aware that these bridges you referred to were subsequently opened to solve corrosion problems. I know the Erskine has quite large ventilation apertures as part of the original design, and it was certainly looking at that structure and seeing how good the condition was inside that aided our thinking in going in the direction of enclosure. We have made measurements inside the Erskine bridge using the electrical resistance probes, and just a short distance from the ventilation points no corrosion has taken place at all.*

MR M. A. WINNETT: *As far as I am aware the Erskine bridge has never been fully sealed.*

*I would like to make a point with regard to relative humidity in box sections. If you seal off a box section, as the temperature inside falls, so correspondingly, the RH inside will rise and, in a closed box section, there will be a constant vapour concentration. So, at a particular temperature the RH will reach 100 per cent and moisture will start condensing, and that will be at the dew point temperature. We are proposing some degree of ventilation so that there will be an exchange of air inside the bridge with that outside the bridge. In which case the dew point will often go down as the temperature goes down simply because moisture will be coming out of the air in the evening, it will be deposited on the ground and condense in various ways. Therefore, as the temperature falls often the dew point will fall, but this is not the case in a sealed environment. We are proposing an environment with some ventilation but not enough to allow pollutants to get inside. We are proposing some form of baffling and are looking at ventilation to see what degree of ventilation can be tolerated in box sections. In the Erskine Bridge we noted relative humidities of up to 90 per cent, but no condensation was noted in the two years I was monitoring it. We were monitoring time of wetness near the vents at the top of the structure and on the diaphragm walls.*

MR R. P. HANSON: Dr Bishop, I would like to mention a number of points here as our company STS has been engaged in the protection of steelwork for quite a number of years. We've had a fair amount of experience in our laboratories including some of the work you have carried out.

Considering SO<sub>2</sub> first of all, 30 years ago in Newcastle University we found that we could retain a white metal finish at a 100 per cent RH provided that the steel and the ambient temperatures were in equilibrium, we felt that was the most important facet of all. Dew point and relative humidity, I think, are looked at in the wrong aspect, dew point must be looked upon as the more important factor. If the steel and ambient temperatures are kept in equilibrium, I don't think one is going to have any problems provided SO<sub>2</sub> is absent. We found that even half a ppm of SO<sub>2</sub> on rust free samples which had been exposed for 40 days at a 100 per cent relative humidity became red rust in hours following exposure.

Regarding bridge and also ship structures, we found that the periodicity of the formation of dew point is a direct function of the bulk or mass of steel. A vessel in dry dock, 32,000 tonnes of steel, is a rather massive bulk and we have monitored the steel and ambient temperatures and also the relative humidities over monthly periods. We found that with large bulks of steel, lags of up to eight hours existed between the steel and ambient temperatures. As far as we are concerned, this is the most important period when dew point can be reached, which, together with industrial atmosphere, trace SO<sub>2</sub> etc., leads to the major corrosion problems.

Mentioning this large bulk of steel, there is another point I would like to raise which we have done quite a lot of work on. I would like to draw a comparison between laboratory samples, which are small pieces of steel which have temperatures virtually identical to the ambient, and large bulks of steel which are hours away from the ambient temperature, just the periods when they are being painted. What we are looking for is a monitoring device which will forecast in x hours the rate of change of RH and in which direction. This would give better guidance with regard to painting procedures. Getting back to box section structures and hermetically sealing them, I think this is a rather important point again with respect to temperatures, I would like to hear Dr Bishop's comments on temperature differentials, internal to external. We are probably talking of partial vapour pressures, we have a warm day where the temperature rise is considerable followed by a cold night with a resulting contraction and drop in internal pressure. There would be an intake of exterior pollution gases such as NO<sub>2</sub>, SO<sub>2</sub> etc. Hermetically sealing appears to be very important as with the old car headlamps. When they were switched on they were nice and warm. When they were switched off they cooled down and took in water on contraction, but the water never came out again.

The third point I would like to make concerns the exter-

nal parts of bridges and steel structures in non-rain-washed areas. Here we have a normal evaporation condensation cycle taking place. The dew point is reached and gases are absorbed, the water dries leaving the contaminants behind and this cycle continues. Eventually, it is possible to have quite an acidic film of sulphuric acid left on the paint system. We have been looking at mechanisms in non-rain-washed areas whereby surfactants are put onto the surface. When the dew point is reached the water, instead of forming a uniform film, produces droplets, the droplets fall off taking the soluble contaminants with them.

*DR R. R. BISHOP: The work you did some time ago at Newcastle University on the effect of SO<sub>2</sub> and RH on the corrosion of steel tends to agree with the work we have carried out. As I suggested, we were not producing new information more re-discovering things from the past, except for our discovery that pre-corroded electrical resistance probes cease to corrode.*

*MR M. A. WINNETT: The next point you made Mr Hanson, concerns an eight hour lag between steel and ambient temperatures. Our experiments so far, though not dealing with the same masses of steel you were talking of, have shown that the diurnal temperatures in these boxes vary very little,  $\pm 3-4^{\circ}\text{C}$ , so there is not the same expansion and contraction one would expect. The temperatures in these boxes are very even and, therefore, it is not the same situation as in ships hulls.*

*On the question of size of specimen used, on the Exceat bridge where we did a full scale trial, we sand-blasted the girders and wire brushed some sections. After a year they are still bright metal. So as far as the girder is behaving, it is similar to the small specimens, we thus consider that we are at least working on the right lines. In terms of the predictions of the dew point, I question whether that will be possible for the reason I stated earlier. It is possible to predict the dew point from the relative humidity and ambient temperature if the vapour concentration in the atmosphere remains constant, but it doesn't. So the idea of predicting it is extremely difficult and we have tended to move away from the predictive element altogether and look at the actual effect on the surface. When you mentioned the cooling of air in the evening and the resultant contraction and taking in of moist air, followed by warming and expansion which doesn't allow the moisture, which has by then condensed, to escape, it is not quite the same as small bore pipes such as you might find on crash bars, handrails and things of that nature. We have fairly large vents in our structure and we have not found any condensation at all with respect to diurnal variation in temperature. We are dealing with road bridges with fairly good insulation and from the measurements we have made, the ambient and steel temperatures are very close. There might be two or three occasions a year following a spring frost when the day warms up very quickly resulting in a 2-3° lag, but it is a rare occurrence. I think even if you were to get condensation for 2 or 3 days in a year it would not present great corrosion problems.*

*DR R. R. BISHOP: On the final point you made, Mr Hanson, on sheltered painted areas, this is quite a complicated situation. We have done work on the corrosion rates of Cor-ten weathering steel and it isn't possible to generalise on whether exposure produces a more or less corrosive environment than sheltering. It is also complicated by what happens to bare steel compared to painted steelwork.*

*We find that in rural and industrial atmospheres, steel that is sheltered by a concrete bridge deck is in a less corrosive situation than when it is completely exposed. However, in a marine environment or on a motorway over-bridge which is exposed to chlorides, the sheltered condition for bare steel is more corrosive than free open exposure because, I think, the chlorides remain on the sheltered steel.*

*With painted steel the problems are more specific, an example of particularly bad practice in the past was to include metallic aluminium pigment in micaceous iron oxide formulations. With sheltered painted steel in industrial environments, it was possible to detect aluminium sulphate. It is very bad practice to put something as reactive as aluminium into a top coat, particularly in a paint containing micaceous iron oxide which produces a rough surface. I would like to make the point with regard to paint testing that it is important to evaluate the service conditions required of a paint. For example, the paints that were being recommended for bridges some 20 years ago were paints that had been through accelerated weathering testing, and the two things that paint on the underside of bridges do not get are UV radiation and distilled water squirted at them. So it is very important to consider what the exposure conditions are and not to make deductions from what happens to bare metal. If there is a situation which is corrosive to bare metal, there is no particular reason why it should be related to paint performance. We must test the coatings for the environments in which they are going to be used.*

*MR M. A. WINNETT: I would just like to make one final point on the Exceat bridge which is in a marine environment. I worked for three years on measuring the time of wetness of steel surfaces in sheltered areas. From October through to May the structure was apparently wet all the time. We put this down to chlorides taking up moisture from the atmosphere, on the arrival of very warm weather the area dried out. However, since we have enclosed this structure we have had no chlorides on the surfaces, and using the same techniques for measuring wetness, at an even greater sensitivity, we found no moisture whatsoever. Therefore, we are not getting debris on the surfaces and we are not getting washing either, although the latter is not needed.*

*DR J. E. O. MAYNE: I would like to draw your attention to some further work by Vernon, he not only examined the effects of sulphur dioxide he also exposed two mild steel specimens in the laboratory, one of which was enclosed in a muslin cage. After some years the enclosed specimen was completely unattacked, whereas, the other was very rusty. In a further experiment, a mild steel specimen was placed in a muslin tent suspended over water, and again, in the saturated air with free access to the atmosphere no corrosion occurred. He concluded that corrosion was brought about not only by SO<sub>2</sub>, but also by air-borne particles which carry ammonium salts, or SO<sub>2</sub> by absorption, particles of iron oxide, pieces of carbon which are constantly floating about in the atmosphere etc. These were the things that had to be kept out.*

*DR R. R. BISHOP: Thank you very much for your comments Dr Mayne. What we are proposing is to enclose structures that are already painted and which are in good condition, then instead of repainting the whole structure, to touch-up 5 per cent of the worst areas, the structures then have a good protective coating on them the lifetime of which is extended to 30 or 40 years.*

DR L. VALENTINE: In support of Dr Mayne's comments on particles, the data in Table 1 seem to support the idea that particles are very important. The concentration of sulphur dioxide in the boxed enclosure is reduced a hundred-fold, but the concentration of chlorides only

halved. This seems to support the critical role of  $\text{SO}_2$ , but as the rate of air change should theoretically reduce  $\text{Cl}^-$  and  $\text{SO}_2$  equally, this perhaps supports the idea that the  $\text{SO}_2$  absorbed in particles, which cannot enter the enclosure, is the most damaging form of pollution.



# Plastic pigment: a novel approach to microvoid hiding, effect of composition on latex paint performance\*

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## Summary

Latex paint films containing plastic pigment demonstrate an advantageous balance of properties. This balance allows the design of products of higher hiding power at a given  $TiO_2$  concentration, whilst retaining other properties. The net result is up to a 30 per cent reduction in  $TiO_2$  required to achieve the same opacity as a more conventionally formulated paint. The effects and interactions of plastic pigment concentration,  $TiO_2$  con-

centration, extender concentration and coalescing solvent concentration on performance are described for one set of materials. The experiments were designed to allow analysis of the results by regression methods, and mathematical models are developed. Also included is a discussion of performance optimisation. Comments on the usefulness of this design and analysis methodology are offered.

## Keywords

*Types and classes of coatings and allied products*

latex coating

*Raw materials for coatings*

binders (resins, etc.)

synthetic resin

prime pigments and dyes

titanium dioxide

*Miscellaneous terms*

statistics

*Properties, characteristics and conditions primarily associated with*

raw materials for coatings and allied products

hiding power

bulk coatings and allied products

critical pigment volume concentration  
pigment volume concentration

dried or cured film

sheen

**Le pigment plastique: une nouvelle tentative pour obtenir l'opacité au moyens des microvides, L'effet de la composition sur le rendement**

## Résumé

Les films de peintures-émulsions contenant de pigment plastique démontrent un bilan de caractéristiques avantageux qui permet à chaque concentration de  $TiO_2$  la mise au point des produits de pouvoir opacifiant plus élevé. Par conséquent il est possible de réaliser la même pouvoir opacifiant que possède une peinture dont la composition est plus conventionnelle, et en même temps avec une diminution de jusqu'à 30 pour cent de  $TiO_2$ . Pour un jeu spécifique de constituants, on décrit les effets et les inter-

actions des concentrations de pigment plastique, de  $TiO_2$ , de matière de charge et de solvant coalescent sur le rendement. On a conçu des expériences en vue d'analyser les résultats par les méthodes de rebroussement et on a développé des modèles mathématiques. On ajoute d'ailleurs une discussion sur l'optimisation des rendements rélevants. On offre des observations sur l'utilité de cette méthodologie à l'égard de la mise point des peintures et de l'analyse des résultats.

**Plastisches Pigment: Neue Annäherungsversuch an Hohraumdeckfähigkeit, Die Zusammensetzungswirkung auf Dispersionsfarbenleistung**

## Zusammenfassung

Die plastisches Pigment erhaltenden Dispersionsfarbenfilme zeigen eine günstige Eigenschaftsbilanz, die gestattet die Entwicklung zu einer bestimmten  $TiO_2$ -Konzentration der Produkte, die höhere Deckfähigkeiten gewähren indem sie ihre anderen Eigenschaften bewahren. Deshalb kann dieselbe Opazität wie jene eines konventionelleren Anstrichstoffs mit jedoch einer Verminderung der bis 30 Prozent  $TiO_2$  erreicht werden. Für eine bestimmte Gruppe der Materialien werden die Wirkungen und Wechselwirkungen der Konzentrationen von

plastischem Pigment,  $TiO_2$ , Füllstoff und Zusammenfließendlösungsmittel auf die Leistung beschrieben. Versuche werden ausgeführt um durch Regressionsmethoden die Analyse der resultate zu gestatten und mathematische Modelle werden entwickelt. Eine Besprechung über die Leistungsoptimierung wird auch eingeschlossen. Bemerkungen über die Nützlichkeith dieser Planen- und Analysemethodologie werden angeboten.

\*Paper presented at the Association's Conference held at Bath, 17-20 June 1981

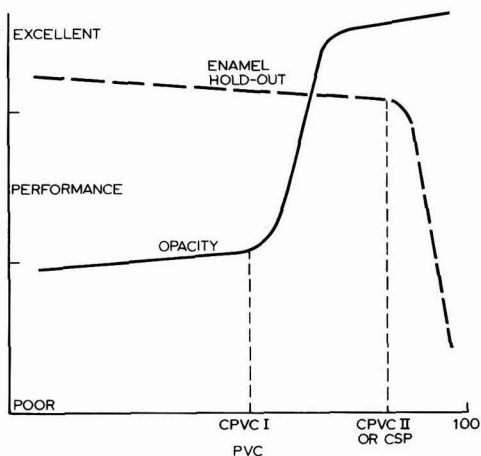


Figure 1. Opacity and hold-out vs. PVC showing noncoincident CPVCs

## Introduction

Refs. 1, 2

Recently the advantages of using plastic pigments in the formulation of latex paints have been described<sup>1,2</sup>. Microvoids are formed in the resulting paint films and are thought to be caused by the regular packing of nonfilm-forming latices, denoted as "plastic pigment". By employing new formulating concepts, the  $\text{TiO}_2$  concentration can be reduced without sacrificing quality. Consequently, an overall improved cost-performance balance can be achieved. However, plastic pigment cannot be used as a simple "plug-in" raw material. Attempts to do so usually result in less than the optimum performance and can result in completely unsatisfactory performance.

This paper will briefly review the basic principles involved and describe the effect of one set of composition variables on paint film performance. In doing so, regression methods were used to derive performance models with prediction capabilities. Also described is a method for identifying cost performance optimised formulations.

## Background

Refs. 1-3

Plastic pigment is prepared by latex polymerization methods such as those described by Pierce and Holsworth<sup>3</sup>. These pigments are easily incorporated into latex paints by simple blending techniques during the manufacturing process. Latex paints formulated with plastic pigment show unexpected results with increasing pigment volume content (PVC) when plastic pigment is used to increase the PVC. Figure 1 shows this novel behaviour. It is noted that the critical pigment volume content (CPVC) for opacity occurs over a small PVC range somewhat lower than the CPVC for hold-out. For convenience the CPVC for holdout has been referred to as the critical surface porosity (CSP)<sup>1,2</sup>. With low lustre plastic pigmented paint, it is vital to identify and formulate at near the CSP to realise the full benefits of this invention. Methods to identify CSP have been previously described<sup>1,2</sup>.

Table 1  
 $\text{TiO}_2$  reduction

Standard	Plastic pigment
$\text{TiO}_2 = 2.5$ lb./gallon	$\text{TiO}_2 = 1.5$ lb./gallon
$\text{CaCO}_3$ extender	Plastic pigment
VA copolymer binder	Same binder
PVC = 48%	PVC = 60%
Enamel hold-out = 80%	Enamel hold-out = 80%
Contrast ratio = 0.97	Contrast ratio = 0.97

When formulating at or near the CSP, it is possible to achieve opacity and holdout properties comparable to conventionally formulated paints that contain significantly higher  $\text{TiO}_2$  concentrations. One such example is shown in Table 1 where two paints are described; one containing plastic pigment and the other containing a calcium carbonate extender pigment. The paint containing plastic pigment has enamel holdout and opacity comparable to conventional paint but contains 1.0 lb./gallon less  $\text{TiO}_2$ .

Paints formulated at or near the CSP contain microvoids. For example, Figure 2 shows the cumulative pore size distribution as measured by mercury penetration for a latex paint formulated near CSP. In this example, the pore volume fraction of the paint film with pore size less than 1.5 microns is 17 per cent. It is believed that the presence of microvoids accounts for most of the observed increase in opacity as the PVC exceeds the CPVC (opacity) and approaches CSP. Previous work<sup>1</sup> using mercury penetration and scanning electron microscopy experiments have confirmed the existence of microvoids in paint films formulated according to the plastic pigment concept.

Those studies showed that although a broad distribution of pore sizes exists within the films, the predominant size is less than 1.5 microns. The concentration of microvoids increases with PVC, and close packing of plastic pigment particles at the surface is apparently responsible for good holdout properties at high PVC.

The net practical result for the paint chemist is the possibility of reducing cost without sacrificing performance or quality. For example, a paint with opacity and holdout comparable to a commercial product has been developed at 25 cents per gallon less in raw material cost<sup>2</sup>. Specific formulating techniques are required to maximise

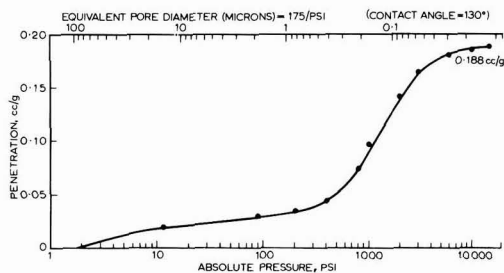


Figure 2. Cumulative pure size distribution showing evidence of microvoids

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the performance of latex paints containing plastic pigment. The basic techniques have been discussed in previous papers<sup>1,2</sup>. Some additional parameters are discussed in this paper and others will be discussed in future papers. Work to date clearly indicates that plastic pigment cannot be used as a plug-in material for other pigments, but rather it must be formulated in a manner that most likely will never be fully disclosed and which will depend on the prevailing market product strategy within organisations using the concept.

## Experimental

### Physical test methods

Test methods for Kubelka-Munk scattering coefficient, K & N ink hold-out and 85° gloss have been described previously<sup>1</sup>.

### Materials

The plastic pigment used in these experiments was a polystyrene latex with an average particle size of 2,400 Å and prepared at 54.2 per cent solids by weight. The binder latex was a copolymer of vinyl acetate and dibutyl maleate with an average particle size of 6,000 Å and prepared at 55 per cent solids by weight. The titanium dioxide was Zopaque® RCL-6 and the calcium carbonate extender pigment was Carbiun®-mm. All paints were stabilised with combinations of Tamol® 731 and Triton® X-100. Drew 913sx was used to control foam and Cellosize® QP4400 was used to adjust consistency to approximately 85 Krebs units. The coalescing solvent used in these studies was butyl carbitol acetate (BCA).

### Sample preparation

All samples were prepared by blending the appropriate quantities of previously prepared TiO<sub>2</sub>, extender, plastic pigment and latex slurries. To these blends the appropriate quantity of coalescing solvent was carefully added and consistency was controlled by a final water thickener adjustment. All paints contained 35 per cent solids by volume.

### Experimental design

The purpose of this work was to define the effect of TiO<sub>2</sub>, extender, plastic pigment, PVC and coalescing solvent on paint film performance by using regression techniques. To this end, 56 paints were evaluated with compositions varying over the following practical design space. Pigment and latex concentrations are presented in volume fraction units within the resulting dry paint films. Coalescing solvent concentration is given as a percentage of the binder latex solids.

TiO<sub>2</sub>: three levels were chosen; 0.0, 0.1, and 0.2.

Plastic pigment: concentrations varied from 0 to 0.6.

Extender: concentrations ranged from 0 to 0.55.

PVC: varied from 20 to 75 per cent.

BCA: three levels were chosen; 5, 18 and 28 per cent.

Volume fraction units were chosen because they were useful in visualising the design for subsequent analysis. For the readers convenience, TiO<sub>2</sub> volume fractions of 0.1 and 0.2 are approximately equivalent to 1.2 lb. of TiO<sub>2</sub> per

gallon and 2.4 lb. of TiO<sub>2</sub> per gallon of wet paint respectively; the actual value varying with pigment volume content. The density of plastic pigment used in these experiments was 1.07 g/cc and the binder latex was 1.1 g/cc. The actual composition of all experimental samples is shown in Table 2.

## Analysis of results

Refs, 4-7

### Models for opacity, K & N ink hold-out and 85° gloss

Let  $Y_1$ ,  $Y_2$  and  $Y_3$  denote the three response variables opacity, K & N ink hold-out and 85° gloss, respectively. TiO<sub>2</sub>, plastic pigment, extender, latex and BCA concentration are represented by  $X_1$ ,  $X_2$ ,  $X_3$ ,  $X_4$  and  $X_5$  respectively. Subsequently, these five variables are referred to as the predictor (or compositional) variables.

Each response,  $Y_i$  is considered to be a function of the predictor variables  $X_1$ ,  $X_2$ ,  $X_3$ ,  $X_4$  and  $X_5$  which are denoted collectively by  $x$ . Thus:

$$Y_i = f_i(x) \quad i = 1, 2, 3.$$

The  $f_i$  represents the functional form of the relationship. The model to be employed however, is a statistical model given by:

$$Y_i = f_i(x) + \epsilon$$

where  $\epsilon$  represents a random error component assumed to have a normal probability distribution with mean 0 and standard deviation  $\sigma_{y/x}$  which is constant over all design points  $x$ . In other words,  $\sigma_{y/x} = \sigma$  for all  $x$ .

Since  $f_i(x)$  has not been derived on a theoretical basis its form will be developed empirically utilising techniques of model building that yield good statistical results, whilst simultaneously achieving results consistent with what is known *a priori* about the behaviour of the paint system.

The functional form of  $f(x)$  is assumed to be polynomial with terms of degree no higher than third order. A full third order model requires estimation of a large number of coefficients, which in this case would not yield useful inferential prediction equations. This holds because  $n = 56$  design points are available as shown in Table 2. Furthermore, model simplicity is desirable for the purpose of practicality.

The following model is used as an example to illustrate the statistical analysis used in this work:

$$Y = \beta_0 + \sum_{i=1}^5 (\beta_i X_i + \beta_{ii} X_i^2) + \sum_{i \neq j} \beta_{ij} X_i X_j + \epsilon$$

The  $\beta$ 's refer to unknown coefficients which are estimated as subsequently described. After estimation of the  $\beta$ 's an equation is determined for estimating (or predicting)  $Y$  for a given  $x$ .

The prediction equation is denoted by:

$$\hat{Y} = b_0 + \sum_{i=1}^5 (b_i X_i + b_{ii} X_i^2) + \sum_{i \neq j} b_{ij} X_i X_j$$

where  $b =$  the estimated  $\beta$ .

To determine the degree of fit of this model, an analysis of variance is performed to obtain the standard error,  $s_{y/x}$

Table 2  
Composition of experimental samples

Sample No.	TiO <sub>2</sub>	Plastic pigment	Extender	Latex	BCA
1	0.10	0.00	0.55	0.35	28.0
2	0.10	0.00	0.35	0.55	18.0
3	0.10	0.00	0.15	0.75	5.0
4	0.10	0.00	0.15	0.75	5.0
5	0.20	0.00	0.25	0.55	18.0
6	0.20	0.00	0.45	0.35	5.0
7	0.20	0.00	0.05	0.75	28.0
8	0.10	0.60	0.00	0.30	28.0
9	0.10	0.35	0.00	0.55	18.0
10	0.10	0.35	0.00	0.55	18.0
11	0.10	0.15	0.00	0.75	5.0
12	0.20	0.45	0.00	0.35	5.0
13	0.20	0.25	0.00	0.55	18.0
14	0.20	0.05	0.00	0.75	5.0
15	0.10	0.30	0.25	0.35	28.0
16	0.10	0.30	0.25	0.35	28.0
17	0.10	0.30	0.05	0.55	18.0
18	0.10	0.15	0.00	0.75	28.0
19	0.20	0.35	0.10	0.35	5.0
20	0.20	0.20	0.05	0.55	18.0
21	0.20	0.05	0.00	0.75	28.0
22	0.20	0.05	0.00	0.75	28.0
23	0.00	0.45	0.00	0.55	5.0
24	0.00	0.25	0.00	0.75	28.0
25	0.20	0.25	0.00	0.55	28.0
26	0.20	0.30	0.15	0.35	5.0
27	0.10	0.40	0.15	0.35	18.0
28	0.10	0.20	0.35	0.35	5.0
29	0.10	0.20	0.15	0.55	18.0
30	0.10	0.20	0.15	0.55	18.0
31	0.10	0.10	0.05	0.75	28.0
32	0.00	0.60	0.05	0.35	28.0
33	0.00	0.50	0.15	0.35	28.0
34	0.00	0.40	0.05	0.55	18.0
35	0.00	0.40	0.40	0.20	5.0
36	0.10	0.00	0.55	0.35	5.0
37	0.10	0.55	0.00	0.35	5.0
38	0.10	0.55	0.00	0.35	5.0
39	0.20	0.05	0.00	0.75	18.0
40	0.20	0.30	0.15	0.35	28.0
41	0.20	0.20	0.00	0.55	5.0
42	0.10	0.10	0.05	0.75	5.0
43	0.10	0.55	0.00	0.35	28.0
44	0.10	0.00	0.55	0.35	18.0
45	0.10	0.30	0.25	0.35	18.0
46	0.10	0.55	0.00	0.35	18.0
47	0.10	0.40	0.15	0.35	5.0
48	0.20	0.00	0.45	0.35	18.0
49	0.20	0.30	0.15	0.35	18.0
50	0.20	0.45	0.00	0.35	18.0
51	0.20	0.00	0.45	0.35	28.0
52	0.20	0.30	0.15	0.35	28.0
53	0.20	0.45	0.00	0.35	28.0
54	0.10	0.20	0.15	0.55	5.0
55	0.10	0.35	0.00	0.55	5.0
56	0.10	0.55	0.00	0.35	5.0

(an estimate of  $\sigma_{y/x}$ ), and  $R^2$  which measures the proportion of the observed variation in  $Y$  that can be explained by the terms of the model.

Least squares regression analysis is performed on various sub-models of  $f_i(x)$  by setting some of the  $\beta$ 's to zero. Variable subset selection procedures, as described by Draper and Smith<sup>4</sup> or Neter and Wasserman<sup>5</sup>, were utilised to aid the search for an "optimal" set of non-zero coefficients capable of describing a large proportion of the variation in  $Y$ , a small number of non-zero coefficients facilitates visualising compositional effects on the

response. To summarise, the goals of the analysis required estimation of a few non-zero coefficients simultaneously yielding a high proportion of explained variation,  $R^2$ , and small standard error,  $s_{y/x}$ .

These analyses were performed using sub-routines from statistical packages SPSS<sup>6</sup> and MINITAB<sup>7</sup> on a Harris/7 computer. Several issues were considered before ultimately selecting a model. Examples are as follows:

1. Analysis of observed residuals to determine adequacy

of model assumptions and detection of possible outliers.

- Trade-off of improved predictability of response via inclusion of additional terms versus the complexity of the model, i.e. statistical significance versus practical significance.

**Optimisation**

The optimisation problem encountered here is that of finding the system  $x$  which simultaneously maximises  $Y_1$  and  $Y_2$ , while minimising cost,  $C$ , a function of  $x$ . One way of formulating the problem is:

$$\text{minimise } C(x)$$

subject to  $Y_1 = f_1(x) \geq a_1$   
 $Y_2 = f_2(x) \geq a_2$

where  $a_1$  and  $a_2$  are variable lower limits of the properties opacity and K&N ink hold-out, respectively. These limits would be determined by the paint formulator, who wants to determine the system  $x$  yielding minimal cost.

The method of optimisation to be used for these multi-level objective functions is a decomposition approach based on evaluating the multiple objective functions over a lattice of points within the space of feasible solutions. The space of feasible solutions is given in Table 2. A lattice is formed over the space by partitioning the range for each  $X$ . The variables  $X_1$ ,  $X_2$  and  $X_3$  were partitioned incrementally by a factor  $\Delta_i$ ,  $i = 1,2,3$ . Since  $X_4 = 1 - X_1 - X_2 - X_3$ , its partition is determined by  $\Delta_i$ . Variable  $X_5$  was partitioned using non-equal increments. Several lattices were reviewed in the attempt to locate an economical but informative one.

The following describes the lattice chosen to study the optimisation problem:

Variable	Concentration range (a,b)	$\Delta$ or incremental partition points
$X_1$ (TiO <sub>2</sub> )	(0.0, 0.20)	.005
$X_2$ (p.pigment)	(0.0, 0.55)	.05
$X_3$ (extender)	(0.0, 0.60)	.05
$X_4$ (latex)	determined by $X_1, X_2, X_3$	
$X_5$ (BCA)	(5,28)	5,10,18,23,28

For the purposes of this paper the following material costs were used:

TiO<sub>2</sub> = 69 cents/lb. (\$23.53/gallon), extender = 8 cents/lb. (\$1.80/gallon), plastic pigment = 50 cents/lb. (\$4.45/gallon), latex = 52 cents/lb. (\$4.73/gallon), BCA = \$4.50/gallon.

The non-linearity of  $f_1(x)$  and  $f_2(x)$  does not yield a simple convenient solution to the stated optimisation problem. However, it is possible to shed some light on cost-performance of various systems.

For example, suppose that cost is restricted to a relatively small interval ( $C_1, C_2$ ), (using an interval of length 20 cents). Consider those points of the above lattice

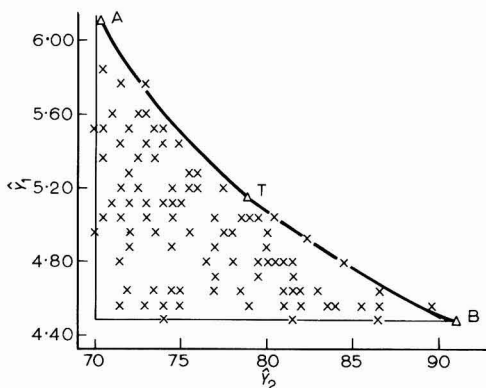


Figure 3.  $\hat{Y}_1$ , vs.  $\hat{Y}_2$  for a cost interval

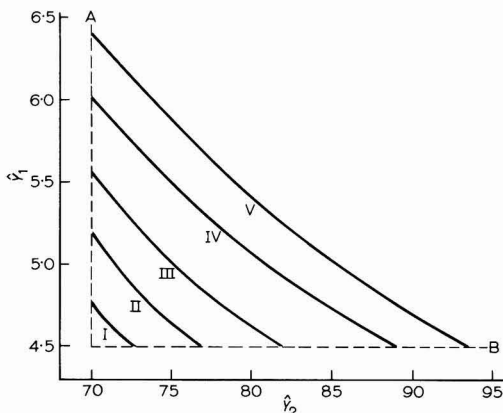


Figure 4. Boundary curves showing performance as a function of cost intervals

that give  $C_1 \leq C \leq C_2$  and  $Y_1 \geq a_1$ ;  $Y_2 \geq a_2$ . When  $\hat{Y}_1$  is plotted versus  $\hat{Y}_2$ , a region like that depicted in Figure 3 results.

For this cost range the boundary connecting points A and B may be said to be the systems of optimal performance for this fixed cost range. Point A corresponds to a system with maximum opacity but poor ink hold-out. Point B, on the other hand, corresponds to a system with maximum ink hold-out but poor opacity. Other points along this boundary would represent trade-off systems such as that labelled T.

Although an algorithm was not developed to obtain the system  $x$  corresponding to a point on the boundary curve, a collection of such boundary curves illustrates achievable gains in performance by increasing system cost. Figure 4 demonstrates five such boundary curves where the cost mid-points range from \$6.50 to \$7.30. Table 3 contains systems (maybe not unique) which yield points, A, B and T.

**Results and discussion**

Refs. 1, 8

Opacity, K&N ink hold-out and 85° gloss results are given in Table 4.

Table 3  
Systems yielding points on fixed cost boundary curves

Systems which optimise opacity – point A.									
Boundary curve	Cost range	TiO <sub>2</sub>	PP	CO	BCA	L	S	INK	Cost
I	\$6.40-6.60	0.105	0.50	0.10	23	0.295	4.83	70.6	\$6.58
II	\$6.60-6.80	0.105	0.55	0.05	23	0.295	5.17	70.2	\$6.71
III	\$6.80-7.00	0.11	0.60	0.00	28	0.29	5.54	71.8	\$7.00
IV	\$7.00-7.20	0.12	0.60	0.00	28	0.28	5.99	71.0	\$7.17
V	\$7.20-7.40	0.13	0.60	0.00	28	0.27	6.44	70.1	\$7.35

Systems which optimise ink hold-out – point B.

Boundary curve	Cost range	TiO <sub>2</sub>	PP	CO	BCA	L	S	INK	Cost
I	\$6.40-6.60	0.095	0.55	0.05	28	0.305	4.55	73.2	\$6.60
II	\$6.60-6.80	0.11	0.35	0.05	10	0.490	4.55	77.5	\$6.77
III	\$6.80-7.00	0.125	0.25	0.10	10	0.525	4.50	82.0	\$6.95
IV	\$7.00-7.20	0.125	0.20	0.00	5	0.675	4.57	89.7	\$7.18
V	\$7.20-7.40	0.13	0.15	0.00	5	0.72	4.51	94.2	\$7.29

Systems which represent a trade-off – point T.

Boundary curve	Cost range	TiO <sub>2</sub>	PP	CO	BCA	L	S	INK	Cost
I	\$6.40-6.60	0.09	0.55	0.00	18	0.36	4.69	71.2	\$6.56
II	\$6.60-6.80	0.095	0.60	0.00	28	0.305	4.87	73.2	\$6.73
III	\$6.80-7.00	0.11	0.50	0.00	18	0.49	5.14	75.0	\$6.97
IV	\$7.00-7.20	0.125	0.45	0.05	23	0.375	5.18	77.6	\$7.20
V	\$7.20-7.40	0.13	0.45	0.00	18	0.42	5.57	78.5	\$7.39

## Opacity

The scattering coefficient varies from 0.09 mil<sup>-1</sup> to 8.45 mil<sup>-1</sup>. As would be expected, low values correspond to paints not containing TiO<sub>2</sub> and high values correspond to samples containing the highest TiO<sub>2</sub> concentration included in these studies.

However, further inspection of the data reveals that high opacity occurs in some samples at TiO<sub>2</sub> concentrations of 0.1. For example, sample 56 has  $S = 6.03$  mil<sup>-1</sup>, which is typical of a high opacity paint. It is well known that opacity is usually enhanced by increasing PVC above the CPVC and that concentration of coalescing solvent can also affect opacity. Additional inspection of the data verifies this prior knowledge and also indicates that plastic pigment concentration has a significant effect. For example, samples 44, 45, 46 and 47 were designed at PVC = 65 (PVC=1-latex) and TiO<sub>2</sub>=0.1. These samples also show that opacity increases as plastic pigment is substituted for the calcium carbonate extender pigment.

As already mentioned, it is believed that plastic pigment enhances opacity by the formation of microvoids and possibly by improving the dispersion of TiO<sub>2</sub> in the resulting paint films. In this work the authors are not as concerned with the mechanism of opacity enhancement as with the effect of paint composition on opacity. Consequently, the following empirical model was developed using regression techniques and *a priori* knowledge as described above.

$$S = 25.24(TiO_2) + 26.15(TiO_2)(PP) - 0.24(PP)(L)(BCA) - 13.44(TiO_2)(CO) + 4.02(PP)^2 + 0.76 \dots (1)$$

Where:

- $S$  = scattering coefficient
- $TiO_2$  = TiO<sub>2</sub> concentration
- $PP$  = plastic pigment concentration
- $L$  = latex concentration = 1-PVC
- $CO$  = calcium carbonate concentration
- $BCA$  = BCA concentration

Analysis of variance gives  $R^2 = 0.972$  and a standard error of 0.365. Both values indicate that the model fits the observed data very well and, therefore, is a good predictor equation.

The model clearly shows that TiO<sub>2</sub> concentration has the largest positive effect on opacity and, of course, this is not at all surprising. Of greater interest is the interaction term involving  $TiO_2$  and plastic pigment, which shows a large positive contribution and has the next greatest positive effect. It suggests that plastic pigment is most effective when some TiO<sub>2</sub> is present. This observation is consistent with spacing and microvoid effects. The model also suggests that the effect of plastic pigment is significantly different from that shown by the mineral extender pigment, as witnessed by the negative interaction term involving  $TiO_2$  and calcium carbonate.

The negative triple interaction term involving plastic pigment, latex and  $BCA$  is rather more difficult to interpret. Increasing latex (decreasing PVC) has a negative effect as would be expected and increasing  $BCA$  has a negative effect which can be explained by previous work<sup>8</sup>. It is believed that plastic pigment appears in this term because of the strong solvent effect involving  $BCA$ . When  $BCA$  concentration is high, plastic pigment may partially



Table 4  
Opacity, ink hold-out and 85° gloss measurement

Sample No.	Opacity	Ink hold-out	85° gloss
1	2.740	53.1	3.0
2	2.856	70.2	4.0
3	2.777	91.1	22.6
4	2.916	92.5	23.0
5	5.231	62.1	5.4
6	4.953	73.2	11.0
7	5.731	87.7	44.4
8	5.046	74.3	71.4
9	3.672	92.8	56.0
10	3.965	92.2	59.4
11	3.355	99.0	79.8
12	8.425	46.0	71.6
13	6.088	91.1	56.8
14	5.412	97.1	76.8
15	2.981	71.9	9.0
16	3.221	69.2	8.8
17	3.505	92.5	39.4
18	3.580	98.0	68.2
19	7.043	48.5	52.6
20	5.852	87.8	33.4
21	5.999	90.9	60.8
22	6.243	90.4	60.0
23	0.574	86.1	63.4
24	0.092	93.3	72.2
25	6.397	82.7	57.8
26	7.380	48.7	41.4
27	4.367	78.0	36.8
28	3.595	62.6	9.4
29	3.508	90.8	31.8
30	3.179	86.0	16.4
31	3.547	95.7	50.4
32	0.453	83.7	42.2
33	0.570	64.7	24.6
34	0.113	88.4	39.6
35	1.563	32.3	21.6
36	2.756	66.5	4.2
37	5.755	44.7	70.4
38	5.808	50.1	72.4
39	6.120	95.0	69.6
40	6.236	72.1	27.4
41	7.804	77.6	67.6
42	3.198	95.8	56.2
43	4.740	76.2	66.9
44	2.740	72.9	3.4
45	3.600	77.4	11.6
46	5.700	66.6	73.5
47	4.890	47.7	41.6
48	4.450	57.1	3.7
49	7.130	75.9	32.7
50	8.410	70.3	74.9
51	4.380	55.0	3.7
52	6.210	64.0	25.1
53	8.450	67.8	73.8
54	3.450	85.7	16.5
55	4.340	84.0	62.2
56	6.030	44.7	70.5

take on properties of a binder latex. Therefore, this triple interaction term has a negative coefficient.

Previously, the "window effect" resulting from the inclusion of large particle size extender pigments has been discussed<sup>1</sup>. The negative interaction term between  $TiO_2$  and the extender is possibly an empirical expression of this so called "window effect". The plastic pigment squared term is thought to result from the non-linear increase in opacity with increasing plastic pigment when  $TiO_2$  is held constant.

#### K&N ink

Ink hold-out is reported as reflectance over the stained paint films. As can be seen in Table 4, values range from 32.3 to 98.0. As would be expected, the low value corresponds to a high PVC sample and the high value to a low PVC sample. The empirical regression model for ink hold-out is:

$$INK = 87.35(L) + 3.16(PP) (BCA) - 77.19(PP)^2 - 0.05(BCA)^2 + 1.24(BCA) + 25.69 \dots \dots \dots (2)$$

Analysis of variance gives  $R^2 = 0.87$  and a standard error of 6.48. Although the model does not fit the observed data as well as the model for opacity, it remains a valuable predictor equation. The most influential term is latex concentration, which is easily explained using prior knowledge of paint systems. At low PVC (high latex) the films have highest hold-out performance. Consequently, the equation acknowledges strong dependence on PVC.

Of greater interest is the next most influential positive term which involves the interaction of plastic pigment and BCA. As already stated, latex paints formulated with plastic pigment can demonstrate good hold-out properties well above the CPVC for opacity.

Evidently, this can be explained by the partial coalescence of plastic pigment particles which occurs even at high PVC. Hence, it is quite satisfying to observe that the interaction terms involving plastic pigment and BCA appear in the model for hold-out.

The other terms appearing in the model do not lend themselves to obvious explanations. The large negative contribution involving  $(PP)^2$  is probably a result of the rapid deterioration of hold-out at very high PVC, since in these cases the latex concentration is small.

### 85° gloss

For the most part, the samples studied in this work were not high gloss paints. Consequently, sheen (85° gloss) is more interesting. As can be seen in Table 4 sheen varies from a low of 3.0 to 79.8. As expected, the high value corresponds to low PVC and the low value to higher PVC.

However, sheen in paints containing pigment is quite complex. For example, sheen (and 60° gloss, for that matter) is observed to pass through a minimum with increasing PVC when plastic pigment is used to increase PVC.

The regression model for sheen is as follows:

$$G(85) = 181.10(TiO_2)(PP) - 509.47(CO)(L) - 926.23(PP)(L)(CO) - 2.03(TiO_2)(BCA) - 202.60(PP)(L) 221.25(TiO_2)(L) + 109.68 \dots \dots \dots (3)$$

Analysis of variance gives  $R_2 = 0.963$  and a standard error of 5.2. These values suggest good fit and a valuable predictor equation. Since the model consists of a large positive constant, most terms contain negative coefficients. The one positive contribution involves the interaction of  $TiO_2$  and plastic pigment. This result is consistent with our practical experience in that large  $TiO_2$  and plastic pigment concentrations enhance the 85° gloss. Apparently, the interaction of calcium carbonate extender pigment and latex is the major controlling variable.

### Cost optimisation

High quality latex paints usually have good opacity and hold-out properties as well as several other high standard characteristics. Optimising opacity and hold-out simultaneously at the lowest possible raw material cost is a desirable practical goal.

A decomposition approach for cost-performance optimisation is described above in which the predictive

models for opacity and ink hold-out are used to determine performance ranges over small cost intervals. To illustrate this optimisation method, the following boundary conditions were applied: Opacity of 4.5  $mil^{-1}$  or greater and ink hold-out of 70.0 or greater.

Figure 4 shows the opacity and hold-out for five different cost ranges. For example, region I refers to paints with costs ranging from \$6.40 to \$6.60 (note: These costs refer to theoretical paints formulated at 100 per cent solids and do not include the cost of materials other than latex,  $TiO_2$ , plastic pigment, extender and BCA.) Regions II, III, IV and V refer to paints with cost intervals of \$6.60 - \$6.80, \$6.80 - \$7.00, \$7.00 - \$7.20 and \$7.20 - \$7.40 respectively. Figure 4 can also be used to find costs bounded by opacity and hold-out values.

From Figure 4 the data in Table 3 were obtained. Representative paint systems with opacity optimised for the five cost ranges are shown. Likewise, optimum hold-out and trade-off (both opacity and hold-out) systems are shown.

Further analysis indicates that optimum systems contain little or no calcium carbonate extender pigment. Such data could be used by the paint chemist in the following manner. Assume that a raw material cost of \$6.95 - \$7.00/gallon is wanted. Table 3 then shows that paints could be designed with  $S = 5.54$  and hold-out = 71.8;  $S = 4.50$  and hold-out = 82.0 or  $S = 5.14$  and hold-out = 75.0. These values effectively bracket what can be accomplished at this *a priori* determined cost.

### Conclusions

Opacity in latex paints containing plastic pigment,  $TiO_2$  and extender is described by Equation (1). Plastic pigment is most effective when some  $TiO_2$  is present. This observation is consistent with earlier work which established the presence of microvoids in paints containing plastic pigments.

Ink hold-out is PVC dependent but also quite dependent on the solvent effect of BCA with plastic pigment as described by Equation (2). Sheen is described by Equation (3) in which the interaction between the extender pigment and latex concentration is the controlling variable.

Statistical methods of analysis yield prediction models which are useful for determining the effect of composition on latex paint performance. These empirical models are also useful for predicting cost-performance optimised paint systems.

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### Discussion at Bath Conference

MR F. B. REDMAN: Is it true that the increase in gloss at high PVC is due to the degree of coalescence of the BCA?

DR A. RAMIG: *This is speculation, but I think the reason the gloss increases at high PVC is because of the packing of the spheres at the surface. From scanning electron micrographs of the surface a very uniform, hemispherical type of morphology can be seen. It just so happens that the size of the hemispheres are approximately half the wavelength of light, which is very good for reflecting light.*

DR R. BALVERS: Is it true that paints formulated with plastic pigments have poor outdoor durability and that they are only suitable for indoor use?

DR A. RAMIG: *All of the paint samples that I have reported on are for interior use. This particular technology has been commercialised since approximately 1977, again, only for interior latex paints. We have done some studies on the utility of the concept for exterior use but we will proceed very cautiously before we make that jump. The results so far are just not conclusive enough for me to say yes it will work in exterior paints or not it will not.*

DR T. T. BULLETT: Have you examined the significance of the particle size of the plastic pigment, and if so, is the particle size optimised in your formulations?

DR A. RAMIG: *Yes we have done many studies on the effect of particle size and particle size distribution. For example, at one time I believed that a very narrow particle size distribution was important, I later saw that it was not necessarily the case. Particle size, as you well know, can affect many other properties like flow and levelling. So you have to choose what you believe is optimum for opacity, and balance that against what you think is optimum for flow and levelling. However, I do not know what the optimum size for opacity is.*

DR L. VALENTINE: Can Dr Ramig's analysis be extended to cover a wider range of sizes of pigment, plastic pigment and latex particle sizes? Does the optimum size of plastic pigment alter according to the size of TiO<sub>2</sub> latex particles?

On the question of gloss possibly depending on the packing of TiO<sub>2</sub> and plastic pigments, I would definitely support this. Work at the PRA by Cole many years ago showed that high gloss films could be obtained without any binder at all, provided pigment particle sizes could be optimised to get close packing.

DR A. RAMIG: *We have determined that the optimum size is somewhere in the 1000-8000 Å region. If you are working in the range 3000-6000 Å I don't see much preference, empirically, with regard to opacity in using one size over another, the choice is then related primarily to rheology. In a number of cases we have found that smaller particle sized plastic pigments, more around the 2000-4000 Å region, are more beneficial for other reasons. We then worked to develop rheology by other methods.*

*Regarding the point you made on gloss depending on the packing of TiO<sub>2</sub>, I think it also relates to what is observed when a TiO<sub>2</sub> pigment is xyz high sheen.*

MR B. SARGO: A completely coalesced film would flow around a high MFT microvoid plastic pigment, wouldn't this negate possible air entrainment and thus the formation voids?

DR A. RAMIG: *Yes that is true, if the film were completely coalesced there would essentially be annihilation. Therefore, we believe it is important to control the coalescing solvent and to look at partition coefficients in an effort to prevent that happening. This is another reason why I think polystyrene is preferred, because it has such a high glass transition temperature. There is no doubt though that the films contain voids. I think the mercury penetration experiments are sufficient evidence of that.*

MR A. C. JOLLY: I notice the maximum gloss you are talking about is 85, what are the chances of exceeding this?

DR A. RAMIG: *That in fact referred to sheen, I don't think the gloss of those paint systems exceeded much more than 30-35. Of course, when trying to make a flat paint the problem is to reduce the sheen. We have recently done a considerable amount of work on semi-gloss latex paints and have found plastic pigments to be very useful in these types of systems. So plastic pigments do lend themselves to semi-gloss and possibly gloss systems, again for interior use.*

DR B. BALVERS: Can you formulate coloured finishes using microvoids with the same opacity as paints based on TiO<sub>2</sub>?

DR A. RAMIG: *Yes it is possible to formulate coloured finishes in the conventional way and, of course, the microvoids affect tinting strength. The problem is one of adjusting the microvoid and TiO<sub>2</sub> levels, but if you are tied into a tinting system where standards have to be matched, that can be a bit of a problem. It takes a bit of juggling but can and has been done.*

MR S. VOUT: Would it be true to say that the major influence of microvoids in decreasing costs is simply because the PVC is raised, and therefore, wouldn't it be just as easy and far less costly to employ a very fine pigment such as hydrite UF?

DR A. RAMIG: *Those are good questions which get to the crux of the matter. If I can refer you to Figure 1 which shows opacity as a function of PVC, and hold-out as a function of PVC, you will see non-characteristic behaviour. We are more used to seeing opacity increase as a function of dry hiding with a corresponding decrease in holdout, scrubability etc. Therefore, the answer to your question is no, I don't think this is a conventional PVC phenomenon, and no I don't think it can be done with conventional mineral extenders.*

# Flow in coatings and orientation in metallics\*

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## Keywords

*Properties characteristics and conditions primarily associated with*

*coatings during application*

flow

*dried or cured films*

reflectance

*Raw materials for coatings*

*prime pigments and dyes*

metallic flake pigment

## Flow in coatings and orientation in metallics

*Refs. 1, 2*

A wet paint film is subject to various movements not only during the application process but also in the following much longer quiescent period until solidification. The flow processes are connected with the creation as well as the disappearance of surface imperfections but may also have a profound influence through the orientation of constituents of the bulk film.

The following considerations on flow and metallics are mainly of a physical kind forming a description of phenomena and their causes. Some of it may be found in the existing literature<sup>1,2</sup> but most of it has not been reported although it may well coincide with views held by advanced technologists and scientists. Facilities for experimental verification were very limited leaving room for much, hopefully, sensible speculation. The developed mathematics will not be presented here.

### Types and causes of flow

In principle flow processes can and do take place even in a completely dry coating. It never becomes a true solid, but performs as both a solid-like and liquid-like substance, i.e. it is visco-elastic.

This is, however, outside the scope of this article which will deal only with the time span from the formation of a wet coating until the developing elastic properties become predominant.

Due to the presence of the substrate and the thinness of the film, flow takes place predominantly parallel to the substrate, so that changes in film thickness and surface appearance occur only where the velocity of this movement changes; substance must either accumulate or be removed at such a site.

An important cause of flow in vertical films is gravity (Figure 1). At constant viscosity the velocity profile is a parabola but the velocity is higher between A and B than outside this zone. This means removal of material at A and accumulation at B, i.e. downward movement of the disturbance. It can be shown<sup>1</sup> that it moves as a wave

faster than the surface itself by a factor of two or higher (if the material is pseudoplastic) and that high disturbances will catch up on lower ones and thus grow. This is relevant to phenomena such as sagging and curtaining.

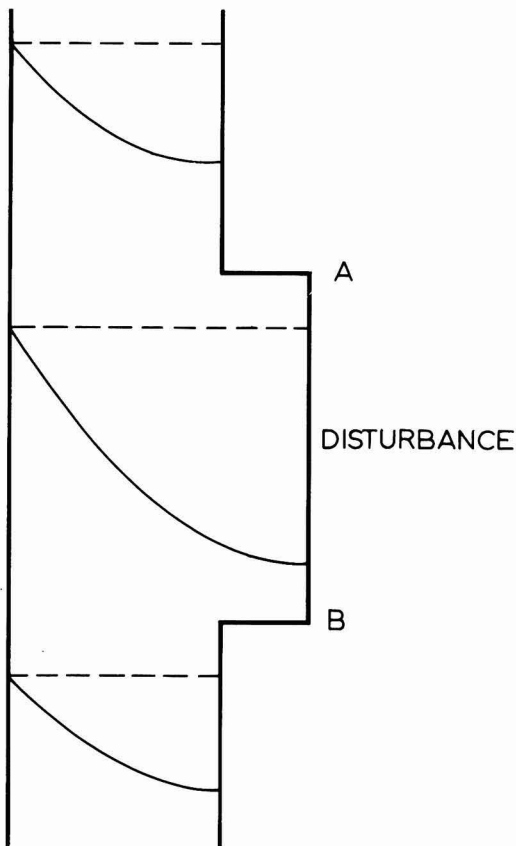


Figure 1. Velocities (parabolas) at a disturbance on a vertical film (schematic)

\*Paper presented at the Association's Conference held at Bath, 17-20 June 1981

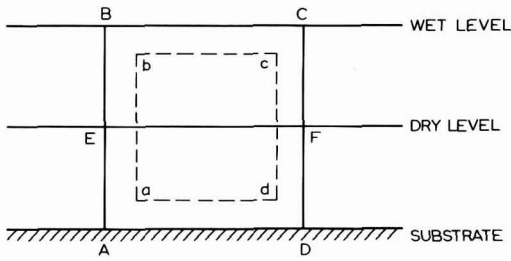


Figure 2. Straining of a volume element ABCD during evaporation and drying to the final shape AEFD

The above is a case of no pressure differences along the film, these can however be created by surface tension if the surface is not a plane. The rate of flow is then proportional to the pressure gradient, i.e. to the gradient of surface curvature along the surface, since the pressure is proportional to the curvature. By these means material flows from high pressure zones to low pressure zones, i.e. from "hills" to "valleys". The surface is levelled at a rate determined by the detailed course of surface tension and rheological properties during drying.

The two causes mentioned may be called first order causes in as far as they depend on intrinsic properties of the material (density, surface tension) plus geometric factors. A second order effect then, would be one caused by differences in properties within the material. The well-known example of this is that a surface tension gradient, produced by variation in temperature or composition, is equivalent to a shear stress on the film making it flow parallel to the substrate. Variations in the surface tension gradient give velocity changes and accompanying surface irregularities. The well-known circulating Bénard cells are produced in this way when self-sustaining composition differences are set up because fresh material coming from the bottom to the surface via the cell centres changes its composition by evaporation when flowing along the surface. The surface tension differences are obviously limited, much smaller than surface tension itself, and thus lose in importance when viscosity increases. Actually, interaction with diffusion causes a complete cessation of movements at fairly low viscosities (of the order of some poises). The creation of mounds along a coating edge may also be ascribed to surface tension differences.

Another second order cause of movements which to the author's knowledge has so far not been described in the literature, is also connected with the evaporation of solvent or dispersion medium and connected concentration differences, but this time effected by differences in a bulk property, i.e. viscosity. Imagine a wet film (level BC in Figure 2) and the corresponding dry film (level EF). If allowed to by its surroundings the element ABCD would gradually contract to the shape abcd but it actually ends up as AEFD. The element is thus continuously being strained during evaporation and viscous stresses are set up. If the same happens to all other elements the forces balance each other, but if for some reason evaporation and viscosity is lower in ABCD stresses become smaller here, BC increases, when AB decreases and a depression is created if similar conditions prevail during the entire course of evaporation.

Although a mathematical model is easily set up, the equation is unwieldy except when concentration and

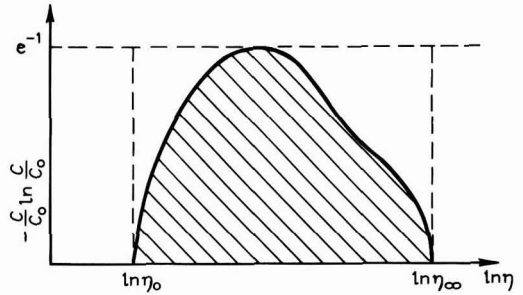


Figure 3. Representation of the factor *N* by an area depending on viscosity development during drying

viscosity can be regarded as constant between surface and substrate and only vary in a direction parallel to the surface.

A further condition is that the solvent volume concentration immediately after application is small enough to allow the layer thickness to be taken as a constant value *h* between the wet and dry thicknesses.

Then the following approximate changes in layer thickness after drying of the film are arrived at:

$$\Delta = \frac{2}{3} c_o h^3 \frac{d}{dx} \left( \frac{d \ln f}{dx} \right) \cdot N \dots \dots \dots (1)$$

where:

- h* = layer thickness
- $\Delta$  = increase in layer thickness due to flow
- c<sub>o</sub>* = original solvent volume concentration
- f* = evaporation rate = relative concentration change per unit of time
- N* = a constant of the applied system

The important factor *N* is calculated from the dependence of viscosity on solvent concentration from the equation:

$$N = - \int_{\eta_0}^{\eta_\infty} \ln \frac{c}{c_0} d \ln \eta$$

where  $\eta_0$  and  $\eta_\infty$  are the initial and final viscosities. *N* is thus equal to the shaded area shown in Figure 3.

Since

$$- \frac{c}{c_0} \ln \frac{c}{c_0}$$

always attains a maximum value of 1/e, the highest possible value of *N* is:

$$N = \frac{1}{e} \ln \frac{\eta_\infty}{\eta_0}$$

Since  $\eta_\infty$  could easily become  $10^9 - 10^{10}$  poise *N* could become of the order of 8. Further, since *N* will not change by increasing all  $\eta$  values by a common factor, it does not depend on viscosity as such but entirely on the shape of the viscosity/concentration relationship. Actually, if viscosity could be taken as inversely proportional to a power of concentration, *N* would equal that power.

$N$  would become zero if viscosity did not change at all until nearly all the solvent was gone. Crudely it would be said that  $N$  becomes relatively large when  $\eta_{\infty}$  is large and a major part (logarithmically) of the viscosity change takes place around the concentration of  $1/e$  of the initial value.

To make all this somewhat more tangible Equation 1 has been applied to the case of a level film on a substrate with depressions (for example scratches). The evaporation rate may then, without new assumptions, be taken to be inversely proportional to layer thickness and the change in thickness becomes:

$$\frac{\Delta}{h} = \frac{2}{3} C_0 \cdot \frac{h}{r} \cdot N \dots \dots \dots (2)$$

if the depressions are less than  $ca. h/2$ .  $r$  is the radius of curvature of the substrate at the position considered (taken as negative if the centre of curvature is outside the substrate). Since a scratch must show positive as well as negative curvatures both increases and decreases of  $h$  will occur, especially when  $r$  is small, i.e. with abrupt changes.

As a numerical example we could take a cylindrical depression in the substrate of width  $3h$  and depth  $h/4$ . With  $C_0 \approx 1/3$  and  $N \approx 4$ , then  $\Delta/h = 0.2$  which is quite impressive. With greater width the effect soon becomes insignificant and it must gradually disappear when the width becomes less than the layer thickness. Thus with scratches that are neither too broad nor too narrow major effects are obtained. The material removed from the depression is to be found as mounds outside it.

Equation 2 shows that the effect is independent of whether evaporation is fast or slow. This is true as long as surface tension does not interfere to cause levelling, but obviously the slower the evaporation, the more time is available for the surface imperfections created to level. It then becomes important that levelling is inversely proportional to viscosity and therefore almost disappears at an instant when the discussed rheological mechanism may still be in operation and when viscosity has become very high, for example  $10^4$  poise.

The above considerations are meant to show that the mechanism may well explain a good deal of the build property or lack of it. It certainly cannot be explained by solvent content, yield value, surface tension or evaporation rate.

It is an open question as to whether the explanation given is valid. There is no experimental evidence to prove or disprove it for the time being.

**Metallics**

Metallic finishes are becoming more and more popular, in particular for cars. They contain aluminium flakes acting as minute mirrors which through their preferred orientation parallel to the surface create a coating which in directional illumination reflects directionally as an imperfect mirror contrary to the usual solid colours. Thus for example with perpendicular illumination the brightness is, irrespective of colour, much higher with  $30^\circ$  viewing than with  $60^\circ$ , for example by a factor of 3, being of course, even higher close to  $0^\circ$  (e.g. by a factor of 6). Due to internal reflection from the plane coatings surface, light from below only penetrates the surface at angles of incidence below  $42^\circ$ ; therefore only flakes with angles of less than  $21^\circ$  to the surface are active. Similarly, since

most of the measured light is to be found at viewing angles below  $30^\circ$  it must have been reflected by particles of less than  $10^\circ$  deviation from horizontal. Obviously a very high degree of orientation is necessary to obtain the right appearance and also to utilise the reflecting power of all or nearly all flakes.

Another characteristic is the sparkling appearance of the finish due to an independence of orientation in small neighbouring areas. The sparkling and also brightness must be uniform over the coating surface, i.e. the statistical spread and mean of orientation of the particles must not vary along the surface. The size of the flakes determines whether the sparkling becomes more or less eye catching.

**Orientation**

The following considerations are some results of efforts to pave the road to instrumental matching of metallics, a problem which is not easily solved, not least because of the well-known extreme sensitivity to spray conditions and lack of possibilities to control these efficiently. The property that varies is the orientation of the metallic flakes. It is therefore relevant to ask in which way orientation is actually accomplished. The answers given below are obviously simplified but probably constitute a sensible and logical approach to the important features.

A commonly held opinion that orientation is due to particular surface properties of the particles or mechanical interactions between them (as in a deck of cards) is easily ruled out because orientation is observed in very dilute flake suspensions and far away from the coatings surface. The explanation can only be that certain flow conditions have been in operation. It is easily observed on stirring the paint with a spatula that poorly and well oriented stripes are created along the track and a drop from the spatula on the paint surface creates a shining mirror-like circular area with a dark rim. In both of these cases flow in the paint is the obvious reason.

Movements in a viscous liquid are of three kinds: translation, rotation and deformation of its volume elements. As translation does not affect orientation it is irrelevant here, whilst a rotation of the element clearly is significant. Deformation means a stretching of a cube element in the direction of one of its edges. This does not change the orientation of the faces of the element, but it does change orientation of any plane in the element not parallel to the faces. Thus an infinitely thin flake will be turned and approach parallelism with the direction of stretch, or conversely approach parallelism with a plane perpendicular to the direction of compression. In the case of rotation the detailed shape of the particle is not important because it does not move relative to its surrounding medium. With deformation it is different however. As the liquid plane in which the flake is placed changes its dimensions while the solid particle can't, there must be a flow of liquid relative to the particle and then its shape becomes important. In the extreme case of a sphere the symmetry makes it easy to see that there can be no turning at all.

As stated earlier movements in paint films are predominantly parallel to the substrate and four causes have been mentioned. To these of course, should be added the effect of possible external mechanical forces imposed upon the film.

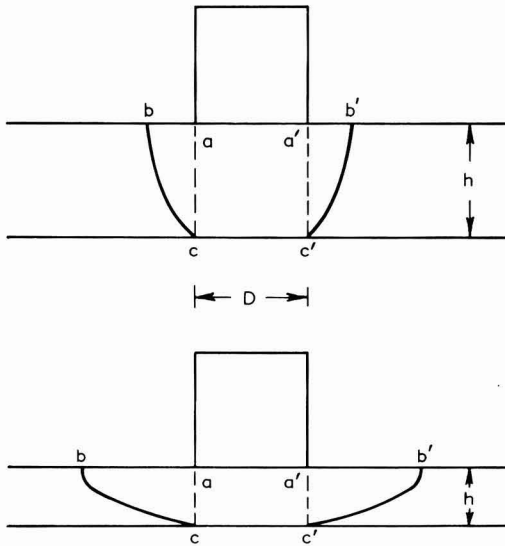


Figure 4. Dependence on film thickness of material movements connected with the flowout of a drop on a liquid film

#### Movements connected with spraying

As orientation is closely connected to application, and ideally is uniform, the causes depending on gravity or the secondary mechanisms are ruled out leaving surface tension and mechanical forces as causes. When leaving the gun the paint receives kinetic energy and surface energy residing in the surfaces of the drops and this total energy is transferred to the wet film. Regarding a droplet with a diameter of, for example, 50 microns with a surface tension of 30 dynes/cm and a velocity of a few meters per second it is easily calculated that the two kinds of energy are of about the same order. Yet the deformation and flow created by the kinetic energy is small compared to the effect of the surface energy for the simple reason that the kinetic energy gets lost in a small fraction of a second (e.g.  $10^{-4}$  s) on impact and that a fast viscous deformation is much more costly energy-wise than a comparatively slow one (in fact energy consumption is inversely proportional to the available time). The dominating flow effect is therefore bound to be the one caused by surface tension.

Consider then Figure 4, a droplet of diameter  $D$ , has just arrived at the surface of a wet paint layer of the same viscosity and of thickness  $h$ . When its gradual levelling is completed layer thickness has only increased infinitesimally while the paint at "a" has moved to "b"; similarly the line ac has been transferred into the approximately parabolic curve bc. It is to be noted that the material transport is limited in extent although the surface disturbance has broadened infinitely because the volumes of the droplet and the annular body connected with abc must be equal. The volume caa'c' plus the drop has thus been compressed vertically into the body cbb'c'. If both volumes are taken to be cylindrical it is easily calculated that the ratio of diameter to height has been increased by a factor of:

$$K = \left(1 + \frac{D}{h}\right)^{\frac{1}{2}}$$

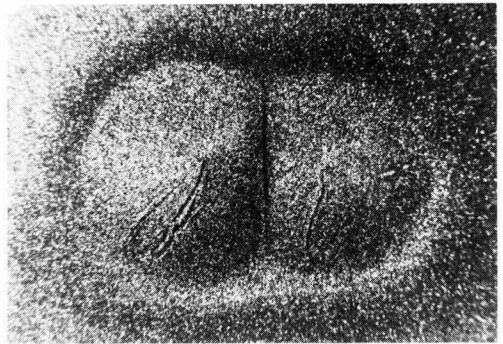


Figure 5. Negative orientation showing up as rings around a central area and in the dividing line of the coalescing drops

(a further increase will occur as the film dries, since removal of solvent with accompanying decrease of layer thickness is also a vertical compression). To obtain high compression the thickness of the fluid film should obviously be as small as possible.

Outside b material has also been moved providing room for the total volume of the drop but this movement becomes less and less with increasing distance from the drop centre. That means a compression radially and an extension circularly, i.e. a decrease in orientation parallel to the surface. Thus a positively oriented and light disc will be surrounded by a negatively oriented and usually dark ring. Under certain illumination conditions it may, however, look bright. This can be seen in Figure 5 where two drops on a liquid film unite. The negatively oriented areas are dark on one side of the drops and bright on the other side. Negative orientation also occurs at the line of division due to horizontal compression by the outflowing drops. The phenomenon can also be observed by microscopic examination of a dry film which has been suitably sprayed as a crisscross of uniformly sized dark circles on a glittering background.

The mechanisms of flow mentioned earlier have easily verifiable deterring effects on the regular orientation pattern and do not contribute to the main effects.

In the above it has been neglected that in the lowest part of the film there is only little horizontal extension, this being substituted by a simple shear. This supplies a turning of the flakes which also tends towards positive orientation. However the shear contributes comparatively little because flakes that are parallel or nearly so to the direction of shear are very sluggish in changing their orientation compared to the rest. Thus only those with a suitable pre-orientation can readily attain an angle smaller than the critical value of  $21^\circ$ .

A pure simple shear is hardly ever met with in coatings and would be inefficient with regard to orientation. Yet it deserves some attention because some characteristics of the flakes become manifest with it. Simple shear is easily created by a relative motion of two glass plates with paint between.

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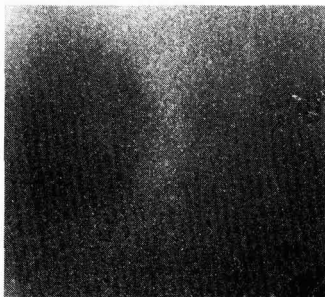


Figure 6. "Record" effect with rotational shearing of liquid metallic film

between. As flakes parallel to the direction only slowly change their orientation and the others quickly obtain such a position (although also parallel to the plates) a kind of cylindrical geometry develops causing reflection properties somewhat like a stack of parallel, reflecting rods. If the plates are rotated relative to each other these rods are bent into circles, the result being reflection properties similar to a gramophone record; see Figure 6. This corresponds fully to what is expected with ideal flakes.

That the situation is not at all ideal is immediately obvious when the sliding is performed under a microscope with a low magnification. The movement of the flakes does not turn out to be just a slow approach to a final orientation, they rotate, some very slowly some faster, around an axis parallel to the plates and at right angles to the direction of sliding. Each particle exhibits a light flash, its origin being similar to that of a beam from a lighthouse. The lack of ideality is inherent in the particles.

The simple shear is to be regarded, rheologically, as two overlapping phenomena, a compression under  $45^\circ$  to the direction of shear and a rotation of each volume element. The rotation is transferred to all particles irrespective of their shape but in the ideal case is exactly cancelled out by the orientation phenomena due to compression when the flakes are parallel to the direction of shear. The period of rotation thus becomes infinite. Particles that do not show good orientation properties during the compression connected with the flow of spray drops will therefore rotate under simple shear and rotate the faster the less perfect the ability to orientate. For circular flakes the rotation period is directly a function of the ratio of thickness to diameter. The finer fractions of a pigment usually have a higher dimensional ratio than the rest and thus have inferior orientation properties along with short rotation periods. Practical pigment flakes are often rippled, buckled or bent arising from their production or the manufacture of the paint. This adds a thickness which may be much more important than the thickness of the flattened flake. It goes without saying that reflection from the sheared layer will also depend on the orientation property but this can hardly provide a sensitive method of testing as opposed to one based on the period of rotation.

### Effects of spray conditions

The following section is an effort to bridge the gap between theory and practical experience. Common difficulties and defects are explainable in terms of the discussion above which may prove helpful in as far as understanding has a merit of its own, even if little help can be put forward to remedy or remove the difficulties.

It has already been stated that good orientation demands that drop size should not be too small compared to layer thickness. This is in agreement with the practical observation that thick wet metallic layers cannot usually be sprayed satisfactorily. Optical measurements indicate a compression ratio  $K$  of about 5 or more to be usual, which according to the tentative equation would demand the layer thickness to be at most half of the drop diameter  $D$ . Drop diameters are usually not known, but assuming  $D \approx 50 \mu\text{m}$ ,  $25 \mu\text{m}$  would be the upper limit for  $h$ . In a known case, good orientation was obtained by spraying a  $12 \mu\text{m}$  dry film (roughly  $20 \mu\text{m}$  wet) on an insoluble substrate such as a metal panel or an oven-dried metallic film, orientation was very inferior if this base coat was only air-dried for some minutes apparently because it dissolved creating one thick layer.

It has been presumed so far that the impinging drops and the wet film are fluid enough and the layer thickness large enough to allow a quick levelling of the drops, quick levelling meaning that it should be fairly complete before new drops arrive within the area. If this fails to be the case droplets unite forming large drops. Potentially this could lead to good orientation but actually flowout is further slowed down and "orange peel" created. When it flows out during spraying or after, the mounds cause positive orientation and brightness while the valleys confer negative orientation and darkness. The pattern, notably its coarseness, is representative of later movements before drying which may easily be observed on panels that have a very flat and coarse almost invisible "orange peel" remaining. The pattern thus created may vary from almost invisibility to the well-known cloudy appearance with patches in the centimeter range.

This may be avoided by thinning and reducing the drop arrivals per second, i.e. slower spraying. Over-thinning is deleterious because the earlier mentioned flow mechanisms come into play to create unevenness, anisotropic reflection (sagging) or decreased orientation (Bénard cells). Often the effects are pronounced at edges.

The detailed scheme of spraying, number of passes and intervals between them influences the viscosity of the lower layers, an increase of which in effect simulates a decreased fluid layer thickness. Likewise solubility or swellability of the substrate in question (possibly the metallic itself) will influence viscosity or fluid layer thickness which emphasises the properties of the polymers and solvents used.

The factors mentioned may be difficult to control but this applies also to the viscosity of the impinging droplets as depending on spray rate, volatility, drop size, temperature, shape of spray cone and probably other factors. No wonder that metallic coatings are difficult to reproduce. Some experienced painters know how to do it in their practical way but it is hardly possible from this to specify the important variables quantitatively with sufficient accuracy let alone to control them.

Also to the manufacturers of pigments and paints this presents a difficult problem because they, irrespective of the variability, should supply a product which is as insensitive as possible to the conditions of use. They should match a certain sample when applied under "average conditions", average conditions that they cannot reproduce with higher accuracy than their customers and often not as well. Today the trial and error procedure is used, but it is costly and slow. An instrumental method as



used with solid colours is highly desirable, the methods offered today are at most good for production correction. The first problem is one of characterisation of a sample when colour is different at different illumination levels and viewing angles. When that is solved progress towards a matching procedure can begin.

### Characterisation of metallics

Ref. 3

The number of possible combinations of illumination and viewing conditions is infinite and a selection has to be made. In colour measurement it is usual to select one direction of illumination combined with either one viewing angle in the plane of incidence or diffuse viewing i.e. integration over all possible viewing angles. With solid colours, which apart from the specular reflection from the sample surface usually can be regarded as almost ideally diffusing bodies, the choice is not of great importance. A good estimate of reflection under any condition can be derived. With metallics it is different because the distribution of reflected light is, at least to a large extent, determined by the orientation of a great number of small orientated mirrors.

Considering in the first place illumination in one particular direction ( $i$ ) and viewing in some direction in the plane of incidence ( $u$ ) it is obvious that only flakes with a particular orientation contribute actively to the observed reflection. If the angle of illumination is changed the same flakes will still reflect but light will emerge in a different direction. Let it be assumed that the amount of reflected light is determined mainly by the number and size of the active flakes and that absorption by colouring pigments is constant. It is then possible to calculate the combinations of  $i$  and  $u$  that should give the same reflectance. The result is shown in Figure 7 where such iso-reflection-lines are depicted in an  $i$ - $u$  diagram.  $i = u$  corresponds to viewing in the gloss angle and should correspond to maximum reflection from the flakes because they generally have approached parallelism with the outer surface. The diagram was put to a test with a medium blue panel. Unfortunately no instrument was available that could deal with all parts of the diagram but in the accessible part the agreement was surprisingly good as shown by the measured  $Z$  values indicated (they have been slightly corrected to take into account the aperture of viewing). The same applied to  $X$ ,  $Y$ ,  $x$ ,  $y$  and spectral reflectance at all wavelengths. While constant along the lines their values change from line to line, the shade becoming lighter and paler when specular conditions are approached. This last effect, which is easily recognised visually, was also reported by Billmeyer and Davidson<sup>3</sup> in their different approach to the same problem. Near grazing angles the diagram is expected to fail unless some easy corrections are used to compensate for the increased reflection and other effects at the interface between air and film.

If the results of Figure 7 can be confirmed on a larger scale it will allow some important conclusions to be made. Firstly that the reflectance or chromaticity at any  $i$ - $u$  combination can be derived if their values are measured along a curve or line crossing the iso-reflection lines. Secondly that the chromatic values for angles of incidence and reflection that are not in the same plane can be derived from the measurements. In other words, the colour

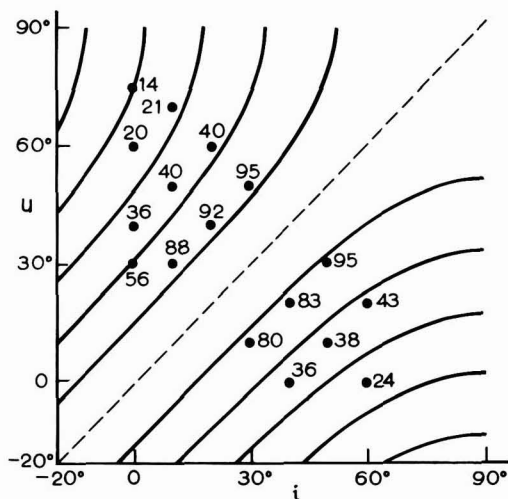


Figure 7. Calculated iso-reflection lines and measured  $Z$  values

of the metallic film will be well characterised by the variation along the arbitrary curve or line just mentioned. Thirdly, measurements with a constant angle between the incident and the detached beam at various angles of incidence (a straight line perpendicular to the  $i = u$  iso-line) is, instrument-wise, very convenient since measurements can be performed without the necessity of changes to the instrument but by mere rotation of the sample.

The next question would be this: How many measurements are needed to fully characterise, just for a single wavelength, the variation along the line of measurement, this being most pertinent to the problem of instrumental matching? It seems to be usual to measure at two positions, probably to avoid too much complication, implying that the curve of variation can be described by two parameters.

This is hardly sufficient to account for the influences of flake type and concentration, absorption by colouring pigments and orientation. Even a very simple model has three parameters necessitating measurements at three points.

The details of this and its possible utilisation may become the theme of a subsequent paper.

### Acknowledgements

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**Discussion at Bath Conference**

MR M. SYMES: Are there any suitable instruments available today for measuring metallics?

*MR P. FINK-JENSEN: I don't think so, although it is possible that there is a German instrument and an American instrument. The points on the graph were measured with a Leres-Trilac spectrophotometer which is probably no longer available. For research purposes the following facilities are required: continuously variable angles, low levels of illumination, small viewing apertures and narrow spectral bands. For my own work I use an old photometer, although it lacks precision it meets my requirements to a reasonable degree.*

MR T. R. BULLETT: Many car finishes today have a clear coat applied over the metallic one. This appears to aid the reproducibility and uniformity of appearance. Does Dr Fink-Jensen agree and has he an optical explanation?

*MR P. FINK-JENSEN: That is probably correct because, for example, a glossy surface is created which levels out*

*extensive or local differences in external and internal surface reflection.*

MR H. FOSTER: Is the orientation of metallic flakes near the surface of a sprayed film affected more by the evaporation rate or by the type of solvent used in the spraying operation?

Generally speaking, hydrocarbon solvents such as xylene and toluene give a more acceptable metallic pattern compared with certain polar solvents such as n-butanol and iso-butanol. Is this simply a question of evaporation rate or do the polar properties of the butanol contribute in some way, for example, by affecting the surface tension?

*MR P. FINK-JENSEN: Differences in surface tension is probably not the explanation. The effect is more likely to be due to the rheological properties of the impinging drops. Such properties may be due either to different evaporation rates, or to intrinsically different flow properties with solvents of different polarity (pseudoplasticity, yield value etc.). Depending on spray conditions each of the two causes may become predominant. Furthermore, the solvent sometimes induces a tendency in the flakes to flocculate.*

# Prospects for automation in the paint industry\*

By M. Camina

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## Summary

The present state and future prospects concerning automatic operation in paint and resin production is discussed. Some processes could, at this stage, be controlled by microprocessors by adapting equipment already available. However, for some operations, which in theory could be so controlled, no suitable equipment has yet been developed.

Some aspects of the processes involved in paint and resin manufacture require a better understanding before entirely automatic methods can be adopted.

## Keywords

*Processes and methods primarily associated with manufacturing or synthesis*

paint manufacture  
resin manufacture

*Equipment primarily associated with manufacturing or synthesis*

computer

## Perspectives pour l'automatisation dans le domaine de l'industrie de peintures

### Résumé

On discute la situation actuelle et les perspectives d'avenir à l'égard des procédés automatiques pour la production de peintures et de résines. Certains procédés peuvent être contrôlés par microprocesseurs à l'heure actuelle, où l'on modifie le matériel déjà disponible. Cependant dans le cas de certaines

opérations, qui en théorie peuvent être contrôlées par ce moyen, aucun matériel convenable n'a été mis au point. Certains aspects de la fabrication de peintures et de résines exigent une meilleure compréhension des processus intéressés, avant que des méthodes entièrement automatiques puissent être adoptés.

## Die Automationsaussichte in der Lackindustrie

### Zusammenfassung

Die gegenwärtige Lage und die künftigen Aussichte werden hinsichtlich der Regeltechnik von Anstrichst- und Harzherstellung diskutiert. Einige Prozesse könnten zum gegenwärtigen Zeitpunkt von Mikroprozessoren kontrolliert werden, wenn die jetzige Anstrüstung modifiziert werde. Im Falle jedoch gewisser Verfahren, die theoretisch solcherweise

kontrolliert werden könnten, wird keine geeignete Ausrüstung schon entwickelt.

Gewisse Aspekte des Anstrichstoff- und Harzherstellung erfordern ein besseres Verständnis der betreffenden Verfahren, ehe ganzautomatische Methoden angenommen werden könnten.

## Introduction

Many companies have now installed computers for management and accounting purposes. In the next decade many manufacturing businesses will be considering, and probably installing, microprocessors to assist in the running of their plants. Computer controlled resin manufacture with partial manual operations are now in existence. Car body plants and automatic painting controlled by microprocessors are a reality. Micro electronics has opened new vistas for industry, and their potential use for paint and resin manufacture requires examination.

ing thousands of electronic components which forms the controlling and calculating circuits of a computer. To this is added further electronic circuits for holding data and programs, and also for operating electromechanical devices. Some of the characteristics which make the systems so useful are:

- (a) It can retain and operate a sequence of given instructions, i.e. it can be programmed.
- (b) It can receive and manipulate data from sensors such as load cells, thermometers etc., and act on the data.
- (c) It can time events and control several different operations.

## Application of microprocessors

A microprocessor consists of an integrated circuit contain-

A microprocessor is a dedicated tool which assists in

\*Paper presented at the Association's Conference held at Bath, 17-20 June 1981

the partial or full automation of a manufacturing process. Although in itself inexpensive, skilled personnel are required to construct programs for a particular plant process, and peripheral equipment and sensors can be quite expensive. Industrial machines and processes, now manually operated, need to be redesigned for microprocessor control, and full automation in resin and paint making is unlikely until such machinery is available. There are a number of levels at which microprocessors can be employed in monitoring and controlling production, three will be considered:

1. A level of control where there is no feedback from the microprocessor to the plant and all operations are carried out manually through a visual display unit (VDU). An appropriate process stage will be displayed on the VDU but the next stage will not be displayed until specified manual operations have been carried out. The microprocessor and VDU act as a prompting aid.
2. A level of control where the microprocessor takes over many of the manual operations, in particular the charging of materials, filling plant, following temperature/time profiles and responding to information received from the plant. Overall control of the process however, resides with the operative.
3. A level where the plant is controlled completely by microprocessors and a computer, without any operator involvement.

#### **Charging and raw material handling**

Automatic charging of raw materials into a premixing tank for both paint and resin manufacture using load cells or metering pumps is available. Solids present more difficulties than liquids but weigh-hoppers can be used with flake, dried or pelleted resins. Pigment slurries may be used for paint making and molten raw materials for resin manufacture. It is unlikely that microprocessor controlled automatic charging will be used for making industrial paints because of the diversity of their formulations but whites made in bulk and pale tints could be so controlled. With all raw material charging, the amount charged would be available as a print out and the microprocessor could calculate the tare and weight charged and modify the quantities of other components to be added if necessary. Depending upon the complexity of the system and the type of variation in the products made, a complete microprocessor controlled program could be introduced to control stock levels.

Valves, metering and measuring equipment must be able to transmit and receive data in either analogue or digital form.

The benefits of microprocessor controlled charging and handling are difficult to assess because first generation automatic techniques are only now being used in the paint industry.

#### **Paint manufacture**

The process of paint manufacture can be divided into a number of stages: stock control, delivery of liquids, addition of solids, premixing, dispersion, delivery to blending tank, further addition of materials, colour correction, viscosity adjustment, straining and finally filling.

Premixing and dispersion processes could be monitored

by microprocessors measuring energy usage. This should give better control of these processes and, therefore, give a more consistent and economical product. The end of the dispersion operation is not, however, capable of being measured on-line, so samples would have to be taken periodically. A continuous or recirculatory dispersion process would be easier to control than a batch process but until more is known about dispersion, its energy requirements, and a method of measuring the degree of dispersion, little benefit can be achieved by microprocessor control. Research is needed to determine the end point of both the premixing and dispersion stages, and the relevant operating parameters to achieve maximum colour strength and the optimum paint properties.

The use of microprocessors to control paint tinting depends either on the method now employed or on the development of a new technique. Three procedures are used in the paint industry, co-grinding of pigment to achieve the closest match, "in-plant" tinting of base paints and "in-can" tinting of base paints. For co-ground base paints only small additions of stainers are required, whereas with in-plant tinting large amounts are initially required. In the final tinting operation however, only small amounts of stainer are added. Two levels of quantities of stainers must therefore be considered for microprocessor control, and adequate volumetric metering pumps to deal with both these levels would be required.

One possible solution is to use one tinting process for all depths of shades by using highly concentrated stainers. Such dispersions have been available for water thinned paints for many years. The basis of manufacture could then be an automatic liquid blending operation, similar to in-can tinting but on a much larger scale. Microprocessors would control the metering pumps controlling the flow of colourants; a mini computer would carry out the necessary colour calculations and operate the microprocessor.

Colour measurement on a co-grind is necessary to assess the accuracy of matching, whilst in-plant tinting would also require a measurement after the first addition of the prescribed quantities of stainers. Ideally, this should be a measurement on a wet sample of paint to avoid delay. The Paint Research Association's Fibre Optics Colorimeter could be used as the colour sensor, once the relation and the reliability of wet to dry colour matching has been established. This method would need accurate data on all pigment dispersions used in the tinting process.

An alternative to batch tinting would be a continuous process in which the base paint and stainers are fed continuously into a mixer. On the outlet side, a colour sensor would initiate signals to control the pumping rate of individual ingredients. An on-line viscometer could be incorporated to initiate and regulate solvent addition.

Certain benefits can be envisaged by automatic colour matching and paint making; improved productivity, reduction in factory space, improved quality and reproducibility of product.

Automatic can filling is now available and some parts of the process could be adapted for microprocessor control. A typical filling plant would include the following facilities: removal from pallets, feeding onto line, filling tins including check weighing, lidding, placing into cartons and loading onto pallets, application of labels and batch

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coding. It is unlikely that removal from pallets, feeding onto line, and lidding could be satisfactorily controlled by a microprocessor. The ability to weigh accurately and analyse, statistically, the information provided becomes important in the filling operation; the prevention of over-filling tins and keeping within tolerance limits. Average weight rules could provide substantial saving in final paint costs. In addition, the facility to record this information should be included and a microprocessor would be needed, firstly to compute the statistics and, secondly, to control the process by changing both the rate of filling and quantity per tin. Packing into cartons could be controlled by a microprocessor where a large number of can sizes are used, but the machinery to do this appears unavailable.

Loading onto pallets is a process where a microprocessor could be readily applied by storing programs for stacking arrangements of a wide range of can sizes. The benefits of a microprocessor controlled automatic filling line would be a saving in manpower and improved accuracy of filling.

Automatic plant for mechanical charging and raw material handling and for tin filling is available, although only some stages can be microprocessor controlled. Research and development work is required to adapt dispersion and colour matching to automatic running and eventually to microprocessor control.

### Resin manufacture

Two types of resin reactions can be considered, condensation and addition. An alkyd resin, a typical product of a condensation reaction, can be taken through a sequence of time-temperature stages by a microprocessor which might be able to monitor the process by determination of the water formed by measurement of the reflux rate. A predetermined rate of heating would be controlled by a microprocessor by using the flow of hot oil. Some of the specified functions for plant operation would be, heat input, temperature zones and times, flow rate of cooling water and emergency flow rates, stirrer speeds, reflux rates and inert gas flow, vacuum, pressure and foam control.

There are no instruments available that can be used for on-line analyses to measure the progress and determine the end of the reaction, so conventional sampling and testing would still be required. With azeotropic removal of water during the process, however, the volume of water removed could be measured and perhaps related to the degree of reaction and acid value.

Research and development work is needed to examine the potentialities of on-line viscometry, refractive index, pH and conductivity measurements in order to evaluate the progress and indicate the termination of the reaction.

Addition polymers, which are formed by an exothermic reaction, are typified by vinyl and acrylic emulsions and acrylic solution polymers. The manufacturing process consists essentially of charging the ingredients, processing, including further additions, and final adjustments. Heat is

needed to start the reaction, then once the reaction begins, heating must cease and possibly cooling applied. The advantage of microprocessor control would be monitoring the heat balance resulting from the heating and cooling stages. Both the rate of feed of monomer or catalyst could be controlled by the microprocessor via the heat balance calculations.

Termination of the reaction would be determined by disappearance of volatile monomer, increase in non-volatile content or the terminal viscosity and could be automatically measured.

Benefits claimed for automatic resin production are more reproducible batches, increased throughput, safer plant operation, and savings in labour and fuel. Constant monitoring of the reaction process allows greater control over the cycle time and the yield, so that savings in both can be achieved.

Research and development work is needed to obtain a useful method for on-line measurement of the end of the reaction for both addition and condensation polymerisation. Foam detection and control would be another useful topic for research.

### Conclusions

There are four operations in paint manufacture that would be worthwhile controlling by microprocessors; filling and charging and raw material handling could be adopted using available equipment; dispersion and colour adjustment however, would need research and development work. It is likely that completely new resin plants will be designed with computer and microprocessor control requiring only minimal human supervision, although conventional sampling will still be needed.

Total computer control of paint and resin making is unlikely until interface and sensor problems have been overcome by research and development work.

The main benefits appear to be a saving of space, energy and more importantly raw materials, greater reproducibility of batches, flexibility of production and, once the software has been developed, reduced labour costs.

The results of computer control of production will lead to a change in management style with higher plant utilisation becoming important. The skills of the labour force will have to change by retraining. It is hoped that society can cope with the changes about to occur without upheaval.

### Acknowledgements

The author wishes to thank the Paint Research Association working parties on microprocessors in the control of paint and resin manufacture.

*[Received 2 February 1981]*

### Discussion at Bath Conference

MR F. B. REDMAN: Can you visualise the application of microprocessor techniques to quality control and testing procedures, as well as to the production processes?

MR M. CAMINA: *Yes, it would certainly be possible for some parts of the testing procedure to be microprocessor controlled, but it would be very difficult to put a wet panel onto a line to measure the touch-dry time and then the gloss. The cost of development for such a system would, I think, be prohibitive.*

MR F. B. REDMAN: The testing procedures, though, are very labour intensive and it did strike me that we could utilise modern technologies.

MR M. CAMINA: *Again, I think it would be possible if the development costs for such a process were found, but I think that the difficulties would be quite considerable and the saving in manpower quite small.*

MR T. R. BULLETT: It is to be hoped that the introduction of automation such as this will reduce the variability of the product, this would in turn reduce the amount of quality control testing necessary.

MR A. C. JOLLY: Presumably we are going to see large changes in the staffing of factories because highly qualified experts in electronics will now have to be included, especially on the maintenance side.

MR M. CAMINA: *Yes that is quite correct. A much more highly qualified maintenance staff will be required than is the case at present. I think Mr Bullett's point on the increased reproducibility of product is a very important one. This is particularly so in resin manufacture, where it is possible to control the rate of heating more critically, and so produce resins closer to required profiles.*

DR K. BORER: I agree in trying to introduce automation into resin manufacture. We have the problem of trying to get nearer and nearer critical viscosities, which could result in much cheaper products. However, I disagree strongly with doing so in paint manufacture because paint manufacture is relatively cheap and relatively untricky. What I am more interested in is paint application.

MR M. CAMINA: *Our working parties on the use of microprocessors did not look at paint application or testing. There are, of course, robots which are capable of spraying almost any design and the more recent machines do not require a man to go over the spraying geometry, they can simply be programmed for whatever pattern is required.*

DR G. DE W. ANDERSON: Perhaps I could try and answer Dr Borer's question. This is something that has been looked at very closely by the PRA Working Party on Microprocessor Manufacture chaired by the President of the PRA. Colour control was one of the areas in paint making where they thought we could benefit from developments in automation for reasons mentioned in Mr Camina's paper. Firstly, higher productivity, which is good in itself. Secondly, lower labour charges, although I agree with you that for paint manufacture the gains would be rather small. Thirdly, for greater reproducibility of paint batches, again a good thing. Lastly, for general plant occupancy because of the greater speed - colour matching

is the time determining step in most paint manufacture. These are the reasons we looked at automatic colour matching as long ago as 1971, and why we devised the fibre optics colorimeter. The aim was to get automatic on-line control of colour, so that when microprocessors became cheap enough we could add a feed-back control mechanism. So I think there are, arguably, very great advantages for automation of the colour tinting step.

MR M. CAMINA: *Automation would also be valuable in the filling process where most of the labour in a paint factory is used.*

DR F. M. SMITH: Is it not correct that the robotics of paint application have been worked out, that it is easy to make paint and that microprocessor techniques and paint processing techniques are well known, but that the methods of instrumental measurement of critical parameters still have to be worked out and justified economically?

MR M. CAMINA: *Yes I agree, the microprocessors are there but the interfaces are not. There is still a lot of equipment needed. For example, you cannot get a pH meter to work at high temperatures.*

DR K. BORER: May I return to my earlier point and quote some approximate figures. To make a litre of paint costs 6-23p per litre, depending upon the complexity and the size of the batch. The cost of inspection is 1-2p per litre, again depending upon the size of the batch. What I am interested in is the 30-50 per cent of the paint that we sell that is wasted by failing to get it on to the right surface, and the fact that having put it on the right surface, the chances of the right film thickness being achieved is very small. Even in the laboratory with trained spray hands I could not get film thicknesses of better than  $\pm 50$  per cent of what I wanted. It is this type of wastage, the fact that paint is nearly always over atomised which is what I thought we should be looking at.

MR M. CAMINA: *I am afraid it is a little out of my field but I see no reason why paint application cannot be microprocessor controlled, however, it is something that must be discussed with contractors, equipment manufacturers and so on.*

MR S. T. HARRIS: One of the aspects of microprocessor control in synthetic resin manufacture (particularly polyesters) that I have come across that has been very effective, is in the control of the reflux in the partial condenser. I know one company where they have cut 2 hours from a 15 hour process cycle on a repetitive batch. One aspect of microprocessor control is that it not only replaces manual control but it does it so very much better, and I feel that it is this aspect that ought to be considered: it can carry out these operations much better, it is not just a replacement.



## Short Communication

# If you must paint – coil coat\*

By N. S. Makins – European Coil Coating Association

Constrado, 12 Addiscombe Road, Croydon CR9 3JH, England

The proposition made in the title of this paper is obviously not generally true, as coil coating means the application of organic coatings to strip metal in a continuous process, and is only used for products made from flat metal strip up to about 2.0 mm thick in Europe and 3.00 mm thick in the USA.

Coil coated strip has to have a high quality finish which can be formed and perform satisfactorily in service. These requirements are dependent on a suitable substrate material, effective cleaning and pretreatment, an organic coating often specially formulated for the intended application and a coating operation which can satisfy all these requirements at high speed. The more modern lines operate at speeds of up to 100 m/min and the most recent lines are capable of running at 200 m/min.

The success of the operation is a result of close technical collaboration between the suppliers of the strip metal pretreatment processes and the organic coatings.

The production process, the product and applications are outlined below.

In a typical modern coating line the initial mechanical section contains two decoilers, strip joiner, roller or tension levellers and an entry accumulator. This is followed by the main processing units i.e. the pretreatment section and two coating stations with associated curing ovens. The final mechanical section contains the exit accumulator and recoilers.

The importance of pretreatment will be appreciated and that it has a significant influence on the formability and corrosion resistance of finished coated strip.

The use of organic coated strip entails carrying out forming and drawing operations after pretreatment and coating, thus increasing the demands on the conversion coating compared with products which are conversion coated and painted after being formed. Because of the high coil coating line speeds, the pretreatment times have to be considerably shorter than those used in post painting operations placing even further demands on the pretreatment processes.

Conventional pretreatment conversion coatings are iron phosphate, zinc phosphate, chromates and complex metal oxide coatings.

Significant developments have taken place in the past few years – particularly in the USA, Germany and the UK – in conversion coatings applied by roller coating which are independent of line speed, do not require finish rinsing and reduce effluent problems.

The organic coatings are applied either as liquids or films. Liquid or paint coatings are normally two-coat systems applied by roller coater. Films are laminated to the strip which has been coated with an adhesive, again applied by roller coating. Continuous thickness measurement is made using infrared gauges which measure dry film thickness.

After coating, the strip passes through the curing ovens, most of which are of a conventional catenary type, but in some of the more high-speed lines a flotation type oven is used. In this type of oven the strip is supported on high velocity hot air. The main advantage is that much shorter ovens can be used because of the higher heat transfer. Infrared temperature measuring pyrometers are used to measure the temperature of the paint/polymer coating which virtually eliminates under or over curing.

The most common substrate materials are steel and aluminium, although some use is made of brass and stainless steel. Steel substrates can be uncoated cold reduced, electro zinc coated, hot dip zinc coated, hot dip aluminium coated, tin plate/black plate or the tin free coatings.

All these substrates can be provided in a range of qualities to meet the forming operations required or with specific tensile strengths for structural applications.

The aluminium substrate is available in a range of qualities and tempers to meet various formability and strength requirements.

The organic coatings can be categorised as thermosetting liquids, thermoplastic liquids, thermoplastic films, zinc powder and heat resistant/non-stick. Waterborne paint systems have been developed with the intention of reducing air pollution and dependence on petrochemical solvents.

This is a brief outline of the process and the product for which, by the way, there is no British Standard although a Euronorm for steel based products is being prepared.

Applications are numerous and in many cases the organic coatings are specially formulated to meet specific requirements – particularly corrosion resistance and formability.

Coil coating offers many advantages over post painting as follows:

1. Production cost savings – since the metal strip is prefinished, there is no need for a paint line resulting in savings in plant space and production bottlenecks.

\*Paper presented at the Association's Conference held at Bath, 17-20 June 1981

2. Quality control – on-line quality control means that adhesion and film thickness are precisely controlled.
3. Pollution control – air and water pollution are taken care of by the coil coater.
4. Corrosion protection – there is complete coating of the product on both sides if required and in crevices.
5. Energy conservation – with coil coated strip no costly paint curing ovens are required and there is an overall national saving in energy. A study carried out in America by the NCCA states that the consumption of

gas used on a coil coating line is one-quarter to one-sixth of that used to post paint the same area.

The use of coil coated products in Europe has grown at an average rate of 15 per cent per year over the past 15 years. Last year, based on returns made by members of the ECCA, a total of 284 million m<sup>2</sup> were produced which was 8.5 per cent up on 1979. In tonnage terms this was 1.2 million tonnes which is 6.6 per cent up on 1979. This is very impressive bearing in mind the general economic position in Europe as a whole, and shows that many users believe that if you must paint – and the product can be made from metal strip – don't paint, use coil coated strip.

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## Next month's issue

The Honorary Editor has accepted the following papers for publication. They are expected to appear in the December issue of the *Journal*:

**Veova 10 based mass polymers as binders for solvent-borne industrial coatings** by *W. C. Aten*

**An interpretation of viscosity measurements on suspensions of powdered solids, in terms of the physical state of the suspended particles** by *N. Casson*

**Yellowing of alkyd paint films** by *L. A. Simpson*

**Problems involved in determining the solids content of amino resins, taking melamine resins as an example** by *R. Stange, L. Klug and H. Klug*

**Preparation of steel substrates before application of paint and related products** (*Short Communication*) by *A. N. McKelvie*

Further information on any of the publications reviewed 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 publisher.

# reviews

## Developments in Polymer Photochemistry – 2

Edited by N. S. Allen

Applied Science Publishers Ltd

x + 278 pp.

This second volume in the series on polymer photochemistry contains seven chapters written by individual experts. Some of these contributions are on subjects which will become increasingly important in the coatings field. For example, the first chapter is on photoinitiated cationic polymerisation by sulphonium salts. Whilst radiation curing processes used in the coatings and printing fields are currently based on free radical polymerisation, it is not unlikely that cationic photopolymerisation of epoxy and other resins may

become industrially more important. Use of graft polymers in the coatings field is growing, and the second chapter considers photografting of monomers onto synthetic polymer substrates. Phenolic antioxidants are not extensively used in the coatings field, but the third chapter examines their photo-oxidation reactions. Photo-oxidation of polypropylenes, polyundecanoamides and of cellulose are the subjects of the next two chapters. Finally, the general mechanisms of polymer photostabilisation and the use of hindered piperidine compounds in commercial polymers for this purpose are considered. All chapters quote original references, and there is a short subject index.

*Reader Enquiry Service No. 21*

*L. A. O'Neill*

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

# occa meetings

## West Riding

### The Principles of Emulsion Polymerisation

The 1981/82 session of the West Riding Section was opened on 1 September, 1981 at the Mansion Hotel, Leeds with a lecture on emulsion polymerisation.

Although the Lecture, given by Mr D. S. W. Dargan of Kirkless Chemicals Ltd, was primarily intended for junior Members, the topic also attracted a high attendance of senior Members.

Mr Dargan introduced emulsion polymerisation as being an addition free radical polymerisation, producing a stable dispersion of finely divided polymer particles in an aqueous medium.

The mechanism of the polymerisation process was outlined. Also, the theories of Harkins and Smith, Smith-Ewart, and Medvedev were explained. Mr Dargan suggested that one theory only would not fit every polymer/monomer system.

Mr Dargan then went on to discuss the individual components present in industrial emulsion polymers. The list included, monomers, water, stabilisers, initiators, pH buffers, electrolytes, defoamers, biocides and modifiers/chain transfer agents.

Monomers commonly used for commercial polymers were said to include vinyl acetate, veova, styrene, methyl methacrylate and vinyl alcohol. Mr Dargan explained the effects of monomer reactivity ratios on the type of polymer produced, i.e. random, block and alternating copolymers. It was suggested that by a suitable combination of "hard" and "soft" monomers, and by allowing for differences in reactivity, the polymers in commercial production could be achieved.

Mr Dargan then outlined in some detail the process variables involved in emulsion polymerisation and their effects on polymer properties. These included, temperature, iniator type, agitation, pressure and distribution of stabilisers, initiators and monomers.

Finally, Mr Dargan illustrated the many formulations and manufacturing techniques, both old and new, that are used in industry.

After a very stimulating question period, the vote of thanks was given by Mr D. V. Maltman.

*D. V. Maltman*

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.

## BAA chooses Coates

The British Airports Authority has awarded Coates Brothers (Industrial Finishes) Ltd an £80,000 contract for the supply of Marathon chlorinated rubber based airfield marking paint.

This is the third time that Coates has been awarded such a contract and on this occasion the paint will be used principally at Heathrow, Gatwick and Stansted Airports.

*Reader Enquiry Service No. 31*

# news

# news

## DIY market in EEC

A study by Frost & Sullivan, "Do-it-yourself materials in the EEC", predicts retail sales of do-it-yourself products in the European Economic Community will increase by 89 per cent during the 1980s.

Measured in dollars at the 1979 value (in American billions), volume is seen building from \$15.3 billion in 1980 to \$28.9 billion by 1990. The study points out however, that the overall growth rate will be somewhat less than in the past, due primarily to slower expansion in the important paint and wallpaper categories. Indeed, paint sales are projected to advance 67 per cent from \$1.97 billion in 1980 to \$3.29 billion in 1990, with wallpaper rising 35 per cent from \$1.85 billion to \$2.51 billion, in both cases falling short of the 89 per cent overall mark.

Slower growth in paints is attributable to expectations of increases in the useful life of water-based products. At the same time, longer-lasting plastic-based wallpaper has been cutting into sales of paper-backed coverings. Other product categories seen expanding at less than average rates are tiles (up 64 per cent from \$588 million to \$967 million), laminates (up 23 per cent from \$597 million to \$734 million), adhesives (up 60 per cent from \$384 million to \$615 million), and furniture and other DIY kits (up 75 per cent from \$1.9 billion to \$3.33 billion). Categories expected to attain better than average growth include insulating materials (up 158 per cent from \$191 million to \$492 million), hardware (up 97 per cent from \$318 million to \$628 million), lumber (up 93 per cent from \$815 million to \$1.57 billion) and other products (up 123 per cent from \$6.65 billion to \$14.8 billion).

Significantly, the study suggests that the 1980s will bring some major shifts in retail distribution patterns for these products. In developed markets during the first half of the decade, supermarkets and hypermarkets are forecast to grab a greater share of sales putting pressure on small DIY outlets. With that, the smaller stores are expected to re-define their roles during the latter portion of the decade, tending towards specialisation. "Opportunities for smaller outlets are likely to arise because purchasers will find it less worthwhile to travel a number of miles to a hypermarket", Frost & Sullivan observes. While this increased competition is expected to reduce margins in such categories as paints and insulating material, "healthy markups will be maintained in most product lines", the study continues.

*Reader Enquiry Service No. 32*

## Laporte expands TiO<sub>2</sub> plant

Laporte has announced a significant expansion of its titanium dioxide pigment plant which uses the Laporte-developed chloride process. The expansion will provide additional capacity by mid-1982.

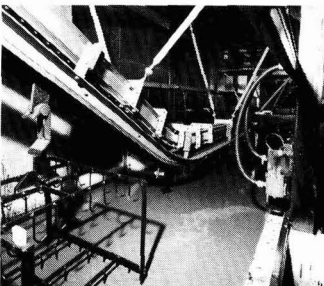
Earlier this year, Laporte announced the closure of old plants using the traditional sulphate process, in order to concentrate on producing titanium dioxide pigments in the UK by the chloride route. The company believes the chloride process to be the most efficient, energy-saving and environmentally desirable base for its European production of pigments in the 1980s.

*Reader Enquiry Service No. 33*

## BP modernises phenol plant

BP Chemicals has completed a £2.5m investment in heat recovery equipment on its phenol production facilities at Grangemouth, which will result in a substantial reduction in overall energy consumption. A further investment of £1m to improve the chemical efficiency of phenol production has recently been authorised and is currently being carried out.

*Reader Enquiry Service No. 34*



The electrocoat tank at Automotive Products Ltd

## Finishing line commissioned at Automotive Products

An investment representing £1.4m has been made by Automotive Products Ltd, the international manufacturers of vehicle components, at its group headquarters in Leamington Spa. The expenditure has taken place on a dual purpose finishing complex, designed and commissioned over two years from a leading plant supplier of this type of equipment: Electropaint Ltd.

The complex covers two lines of operation, phosphate/oil treatment systems and cathodic electrocoat finishing. As the pretreatment is similar for both lines, Electropaint has ingeniously incorporated them at the start for each process.

Even with an output in excess of 10,000 parts per hour for brake, clutch, steering and suspension equipment, Automotive Products can programme the finish required on each component batch.

*Reader Enquiry Service No. 35*



Metal Box's polypropylene tub for the Berger/Black & Decker Paintmate, the tubs possess a number of new features

## Metal Box to provide tub for Paintmate

Paintmate is a new idea in DIY painting developed by Berger and Black & Decker. Paint, stored in a plastic tub, is forced by the pressure from a soda syphon bulb via plastic tubing to a painting head: a brush, pad or roller.

Metal Box will provide the tubs containing the paint which will be injection moulded at its Swindon factory using polypropylene.

An interesting innovative feature of the new tub is a patented anti-slop lip, it prevents paint from spilling before the tub is closed.

The paint is forced up from the bottom of the tub via a dip tube, and a gland incorporated in the centre hole of the tub's lid wipes the tube clean as it is removed.

*Reader Enquiry Service No. 36*

## ITI Anti-Corrosion Ltd in Aberdeen

ITI Anti-Corrosion Ltd of Watford, the new specialised coatings inspection company formed earlier this year, has now opened an office in Aberdeen.

Managing director, David H. Deacon, says: "This is for the simple reason that we need to have a presence where the business is. We have already opened an office in Houston. This new office in Aberdeen is a logical move, as more and more of the operators have established their centre for North Sea operations in Scotland".

Manager of the new office is Jim Howes, who was a highly experienced chief inspector before being appointed to this position. He therefore has extensive experience in all aspects of the control of surface preparation and painting.

*Reader Enquiry Service No. 37*

## Change of address

Estochem has recently changed its address to: 6 Knotts Place, Sevenoaks, Kent.

*Reader Enquiry Service No. 38*

## Donald Macpherson acquires Drynamels

The Donald Macpherson Group Ltd has acquired the whole of the issued share capital of TI Drynamels Ltd (Drynamels) from Tube Investments Ltd (TI) for a total cash consideration of £2.7 million, subject to minor adjustment. TI has agreed to dispose of its interest in Drynamels because the activities of this company are outside the main stream operations of the group.

Drynamels is a supplier of surface coatings, both powders and more conventional solvent-based materials, to manufacturing industry for use in product finishing. On the powder side, Drynamels is one of the largest manufacturers in the UK. Its capabilities in this field will complement Donald Macpherson's established interest in the growing market for powder coatings. In general, the acquisition of Drynamels will further strengthen Macpherson's position as the second largest supplier of industrial coatings in the UK.

*Reader Enquiry Service No. 39*

## Elcometer relinquishes UK Agency for Erichsen

Elcometer Instruments Ltd has by mutual agreement, ceased to act as UK distributor for Erichsen products.

The decision has been taken to avoid any possible conflict of interest in the field of colour and gloss measurement, where Elcometer already represents the Gardner Laboratory Division of Pacific Scientific. Since Erichsen intends to introduce colour measurement equipment and already offers gloss instruments in its product range, Elcometer felt that its responsibilities lay in continuing to promote the Gardner range and have, therefore, agreed with Erichsen to relinquish the UK distributorship. The new distributor for Erichsen in the UK will be Messrs Pearson Panke Ltd.

Elcometer will continue to offer a comprehensive range of paint testing instruments.

*Reader Enquiry Service No. 40*

## Morris Ashby ceases ZnO and Zn dust production

Morris Ashby Ltd, who for a number of years have marketed zinc oxide and zinc dust manufactured by their subsidiary company Amalgamated Oxides (1939) Ltd at Dartford, Kent, have announced that they are withdrawing from this market. This decision has been taken in the light of the sharp decline in demand for zinc oxide in particular and after careful consideration of the future potential for these products. Production operations at Amalgamated Oxides, Dartford, will cease early in December this year.

*Reader Enquiry Service No. 41*

## Silexine expands service

Silexine Paints Ltd has announced a major development in their services to the West Midlands and East Midlands areas. Following negotiations with Madeley Paints of Aston, Birmingham, and Greenway Reeve of Stapleford, Nottingham, Silexine Paints have set up two regional depots to service West Midlands and East Midlands customers.

Silexine is opening its western depot in Bristol to service Avon and Somerset, and for certain minimum loads, as far as Dorset and South Wales.

Silexine Scotland has also given notice that it will be shortly setting up a Silexine depot at Glengarnock, Reith.

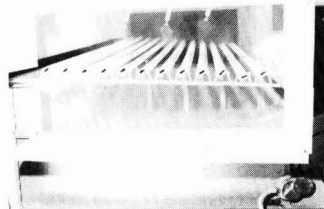
*Reader Enquiry Service No. 42*

## Power Adhesives and Dexter Corp. sign agreement

An agreement signed between Power Adhesives Ltd and the Hysol Division of the Dexter Corporation of the United States, has resulted in the British company taking over the exclusive distribution rights for the Dexter Hysol range of industrial glue guns and adhesives in the UK.

Power Adhesives has been marketing the American company's hot melt adhesives and hand gun applicators for several years. Originally manufactured by the Adhesive Machinery Corporation, the guns include the well-known Hipermatic, Minimatic and Supermatic ranges, together with Polyshot, Polystick and Ministick hot melt adhesives.

*Reader Enquiry Service No. 43*



**Volstatic's low voltage air ionising electrostatic powder coating guns**

## New powder coating technology from Volstatic

The scope for electrostatic powder coating is claimed to have been significantly enlarged by the development of a new, low voltage technology announced by Volstatic Coatings Ltd.

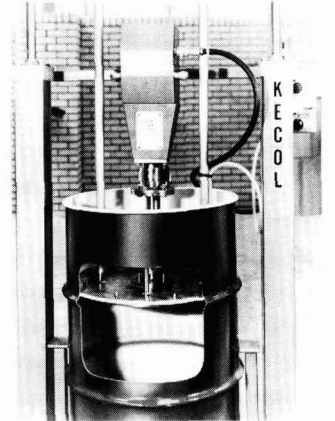
It makes it possible for the first time to powder-coat an electrophoretically primed workpiece successfully, and to obtain a full powder coating even in deep recesses.

It also contributes to a smoother finish generally, and to a more even film thickness over the entire workpiece.

*Reader Enquiry Service No. 44*

# news

## new products



**The new Series 160 from Kecol**

## Kecol develop pump range

Following the successful introduction of the Kecol Series 100 pumps, a further development in the form of a Series 160 has been made available.

The air motor which gives Series 100 pumps their outstanding reliability has been incorporated into the new pumps. They are intended for pumping low to medium viscosity substances.

The Kecol Series 160 feature double action pumps with cushioned stroke, corrosion-proofed standard steel tubes, with a choice of drum or stubby length pump tube in carbon steel or 316 stainless steel.

*Reader Enquiry Service No. 45*

## Road marking reflectometer

Erichsen recently introduced an instrument for the determination of the "night visibility" of road marking paint. The efficiency of road marking paint is determined by the amount of light coming from the headlamps of a car that is reflected into the eyes of the car driver, after striking the paint at narrow angles. The instrument uses a 24 volt halide lamp that can be operated either from the mains or a car battery. It can thus be used in a Laboratory as well as in the open.

*Reader Enquiry Service No. 46*

# news

## Mixing by micro

A microcomputer version of a well known software package that is claimed to reduce costs in many industrial processes, has been announced by GMS Computing Ltd.

The package, called MOP (mix optimisation), computes the most economical combination of multi-element ingredients in a blending process, to produce an end-product with a given specification. It can be used to reduce costs in the processing of a wide variety of products, for example, steels, chemicals, foodstuffs, paints and laboratories.

Written in FORTRAN, the new version of MOP can be run on low-cost microcomputers that operate under the CP/M operating system. This makes MOP interesting to smaller companies, and GMS is offering the system either as software or as a hardware/software turnkey deal, which also includes training and implementation.

GMS reports that the first two orders have been received from steel foundries in Manchester and Sheffield. An indication of the speed with which GMS is able to implement the system, is given by the fact that both initial users have been able to achieve cost savings on steel-making within a week of taking delivery of the microcomputers. In one case, the entire ordering cycle took less than five weeks, from the initial placement of the order to full implementation of the system, including program customising and staff training.

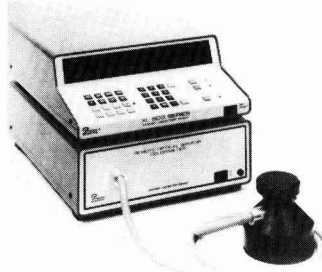
*Reader Enquiry Service No. 47*

## Computer colour system with infrared capability

Applied Color Systems has announced a new model Spectro-Sensor spectrophotometer, which is designed for use with ACS computer colour control systems. It provides reflectance and transmission measurements in the infrared wavelength region 680 - 1100 nanometers, as well as visible measurements from 400 - 700 nanometers.

The infrared measurement capability is provided primarily for manufacturers of products with military camouflage paint and apparel applications, which may have to meet government specifications on infrared reflectance.

*Reader Enquiry Service No. 48*



The XL-825 Gardner Colorimeter

## Colorimeter system for large objects

The new XL-825 Colorimeter quality control instrument from Gardner Laboratory Division, has the ability to measure extremely large and bulky objects that cannot be readily presented to a conventional colorimeter.

The lightweight optical sensor has a 2 beam, 45°/0° geometry conforming to ASTM E-97. The sensor head features a five foot fibre optic cable that enables remote measurement and flexibility of movement. For added convenience, a switch on the sensor head activates the measurement sequence within the control console. The XL-825 Colorimeter system can be used for in-plant quality control or adapted for monitoring a production process. Since there are no sensitive components in the sensor head, this rugged system can be readily used in industrial environments.

*Reader Enquiry Service No. 49*

## Industrial surface conditioners

Surface conditioning materials and cleaners for a wide range of industries and applications have been made available by Magnaflux Ltd.

Introduced as a logical extension to the existing range of dye penetrants and magnetic inks, already produced for non-destructive testing, the new range of surface conditioning materials includes acid, alkali, and neutral cleaners, solvent cleaners, paint and organic-coating strippers; and special purpose cleaners for the transport industry and maintenance, and for manufacturing and process engineering.

*Reader Enquiry Service No. 50*

## literature

### BSI publication

The British Standards Institution has recently published BS 5598 :Pt 9: 1981 "Methods of sampling and test for halogenated hydrocarbons. Part 9. Determination of boiling range of chlorofluorinated hydrocarbons".

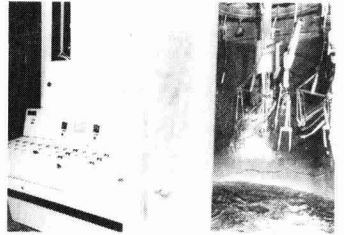
*Reader Enquiry Service No. 51*

## High solids paints

Earlier in the year, a symposium was held in Nottingham organised by TI Drynamels and TI Raleigh. The aim of the symposium was to bring together experts to review progress and developments in the field of high solids paints and high speed discs and bells.

In view of the interest shown in developments in this field, TI Drynamels has produced specification sheets for its products S40 and HS40, copies of which are available free on request. These products (both stoving acrylic paints) are suitable for high speed electrostatic disc and bell application without the addition of thinners, thus giving valuable cost savings when compared with conventional paints.

*Reader Enquiry Service No. 52*



High speed disc applications of high-solids paint to bicycle frames at TI Raleigh

## meetings, etc.

### 8th International Conference

The Eighth International Conference on Organic Coatings Science and Technology has been scheduled for 12-16 July 1982.

It is to be held in Athens, Greece, and the organisers have announced a call for papers. Anyone who is interested in presenting a paper or wishing to attend the conference should contact: Dr Angelos V. Patsis, Director, Institute In Science and Technology, State University of New York, New Paltz, New York 12561, USA.

## appointments

Mr Hugh Murray has been appointed sales manager of Silexine, Scotland. Mr Murray has had a long career in sales, technical service, works management and plant design. In addition, he also owns a shot-blasting and metal spraying company. Mr Murray will be responsible for all Silexine sales and technical service activities in Scotland. Silexine will be shortly setting up a Silexine Scotland depot at Caledonian Road, Glengarnock Industrial Estate, Glengarnock, Reith KA14 3BB, Tel: Kilbirnie 5297.



Motif designed by Robert Hamblin

# OCCA-34 Exhibition

27-29 April 1982

Cunard International Hotel  
Hammersmith, London W6

## OCCA news

## INNOVATIONS AT OCCA-34

### Innovations at OCCA-34 welcomed

The Annual Exhibition of the Oil & Colour Chemists' Association has long been known as the international forum for display and discussion for the surface coatings industries and – in pursuance of this theme – the Exhibition Committee has made innovations in the arrangements for OCCA-34 which have already been welcomed. These are set out below and intending exhibitors are asked to send in their applications as soon as possible so that adequate time is available for making all arrangements and publicity.

#### 1. Discourse Sessions

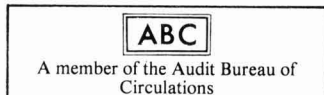
The opportunity is offered without charge to exhibitors to present short discourses on commercial or technical developments. These sessions will take place in separate rooms; full publicity will be given in *JOCCA* and in the *Official Guide* to the Exhibition.

#### 2. Demonstrations/competitions

The Association wishes to extend the scope of the exhibition, particularly in the application field, and encourages exhibitors to arrange demonstrations, to hold competitions and to take advantage of presenting their company image and products before visitors who, in recent years, have been drawn from between 40-50 countries as shown on the



Several exhibitors featured competitions on their stands at OCCA-33. The winner of the competition shown on the above stand (Victor Wolf Ltd) was Mr R. K. Dobell of NL Chemicals whose guess of 7213 was closest to the number of beans in the jar, the actual number was 7209. He won the prize of a dozen bottles of wine



Members of the Association's staff at the Information Centre at OCCA-33, on which was displayed the Reed International Award won by the Association's Journal in November 1980

Associations' Audit Bureau of Circulations Exhibition Data Form.

#### 3. Dinner Dance

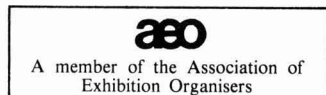
As the social highlight of the Exhibition, the Association has arranged for its prestigious Dinner Dance at the Savoy Hotel, London, WC2 to be held on the middle day of the Exhibition (Wednesday 28 April) thus affording exhibitors an excellent chance to entertain their customers. Exhibitors who usually hold social functions during OCCA Exhibitions are asked not to hold them on this evening.

#### 4. Stands and rooms

Exhibitors can exhibit on stands of the shell scheme pattern or in special individual rooms of varying sizes. Exhibitors are permitted to serve alcoholic refreshments on stands but some may feel that they wish to have private talks in separate rooms and for exhibitors taking both a stand and a room the Association offers substantial reductions of 25 or 50 per cent on the room charges only.

#### 5. Special advertising rates

The OCCA Exhibition is a first class medium to project your spring sales



campaign and to help exhibitors who wish to reinforce this by advertising in *JOCCA*, the Association has recently introduced a special 3 insertion rate which can, if so desired, cover the *Official Guide* as well as the *Preview* and *Review* issues of the *Journal*. *JOCCA* won the 1980 ABC Reed International Award for its Media Data Form and this shows that advertisements reach over 22,000 readers in 80 countries at a cost of less than 1p each!

#### Aim of Exhibition

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

The Exhibition Committee will be particularly pleased to welcome exhibits from companies relating to the new energy efficient, low-polluting technologies, including powder coatings, high solids coatings, radiation curing, water-based coatings and other developments.

OCCA-34 will take place at the Cunard International Hotel, Hammersmith, London, W6 on 27, 28 and 29 April 1982 from 9.30 a.m. to 5.30 p.m. The closing date for applications to exhibit will be 1 December 1981 but those organisations intending to exhibit are urged to submit their applications as quickly as possible.

#### International forum

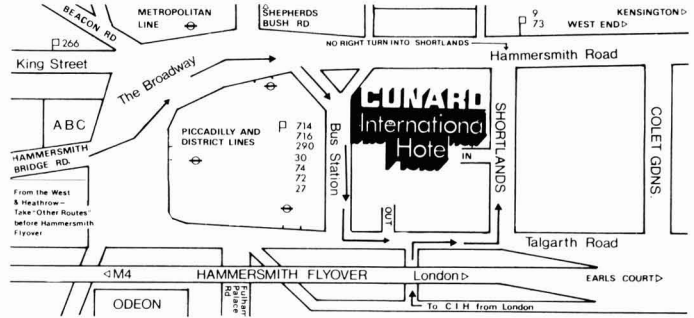
OCCA-33 in April 1981 drew exhibitors from ten overseas countries. Many exhibitors were surprised at the number of worthwhile enquiries which they obtained and figures given below show the very high level of the attendance attracted to this annual forum for the surface coatings industries which can claim to be the leading exhibition of its kind in these industries.



A delegation of Japanese scientists being greeted at the entrance to the Information Centre by the Director & Secretary (Mr R. H. Hamblin) on the right

An analysis of the registration cards completed at the entrance to the 1981 Exhibition showed that visitors to the Exhibition were drawn from the followings 37 countries.

- Argentina, Australia, Austria, Belgium, Canada, Cyprus, Denmark, Egypt, Eire, Finland, France, East and West Germany, Hungary, Iceland, India, Israel, Italy, Japan, Kenya, Libya, Netherlands, New Zealand, Nigeria, Norway, Poland, Portugal, South Africa, Spain, Saudi-Arabia, Sweden, Switzerland, Turkey, UAE, Uruguay, USA and Zimbabwe.



Location of the Cunard International Hotel

Over 16 per cent of visitors completing cards came from overseas and an analysis of cards (both from the UK and overseas) by job function confirmed that the OCCA Exhibition has not only a wide appeal but is also able to attract the top level of the industries, as follows:

Description	Percentage
Director/Owner	15.11
Management	21.90
Section Head	
Group Leader	3.87
Chemist/Physicist/Technologist	18.48
Lab Assistant/Technician	11.75
Sales & Marketing	18.73
Buyers	2.41
Administration/Secretarial	2.10
Lecturer/Student	0.63
Other	1.08
Cards not completed	3.94

The products manufactured by visitors were:

	Percentage
Paints	21.98
Coverings and Coatings	5.14
Resins	6.79
Pigments and Dyes	8.76
Dispersants and Solvents	1.46
Inks and Graphic materials	8.19
Plastics	1.33
General chemicals	9.84
Other	25.65
Cards not completed	10.86

Full details of exhibiting and advertising are obtainable from the Association. Requests for information and forms can be made by telex (922670), telephone (01 908 1086) or by writing to The Director & Secretary, Priory House, 967 Harrow Road, Wembley, Middlesex HA0 2SF, England.



The Cunard International Hotel, Hammersmith, London, venue for OCCA 34, 27-29 April 1982



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

# new members

## Ordinary members

BUTT, MICHAEL GEORGE, 6 Hay Hill, 43 Hartley Road, Durban 4001, Republic of South Africa (*Natal*)

COSTA, MARIA JULIA LIMA, PO Box 65, New Germany 3620, Republic of South Africa (*Natal*)

COUCHMAN, GERALD NEIL, 33 Vergelegen Avenue, Natures Valley, Somerset West, Republic of South Africa (*Cape*)

GARVIE, KENNETH RHODES, c/o AECI Paints (Pty) Ltd, PO Box 3704, Alrode 1451, Republic of South Africa (*Transvaal*)

GREEFF, MATTHEW PHILIP, BSc, c/o AECI Paints (Pty) Ltd, PO Box 3704, Alrode 1451, Republic of South Africa (*Transvaal*)

HONOUR, PAUL RICHARD, BSc, 47 North Street, Plaistow (*London*)

HOPPER, DONALD, GRAD.PRI, 26 Carrwood, Knutsford, Cheshire (*Manchester*)

JONES, DENISE, BSc, Box 75026, Henkel, Gardenview 2047, Republic of South Africa (*Transvaal*)

KORN, ALAN JOSEPH, BSc, 37 Watton Road, Colney, Norwich, NR4 7TY (*London*)

LOVELL, ANTHONY CHANEL, NZCS, 271 Richardson Road, Mt. Roskill, Auckland, New Zealand (*Auckland*)

MCDONALD, JOHN JOSEPH, LRIC, 50 Clavell Road, Allerton, Liverpool L19 4TS (*Manchester*)

MORGAN, DAVID L., BSc, 56 Rakau Road, Hataitai, Wellington, New Zealand (*Wellington*)

POPPING, ANDRIES JOHAN, BSc, 1 Louvain Avenue, Mt. Roskill, Auckland 4, New Zealand (*Auckland*)

RONSON, DAVID JAMES, Titan Chemicals Ltd, Box 13-222, Onehunga, Auckland 6, New Zealand (*Auckland*)

TONER, WAYNE FRANCIS, BSc, MSc, 3 Whites Way, Ellerslie, Auckland, New Zealand (*Auckland*)

TWEEDDALE, GORDON CHARLES, 252 Cockayne Road, Ngaio, Wellington, New Zealand (*Wellington*)

WARRINGTON, SUSAN ANNE, BSc, 28 Catkin Crescent, Papatoetoe, Auckland, New Zealand (*Auckland*)

ZACHARIAS, MICHAEL GERD, Engineering Inspection Co. (Pty) Ltd, Box 6527, Roggebaai 8012, Republic of South Africa (*Cape*)

## Associate Members

HEESCH, KLAUS, PO Box 8692, Johannesburg 2000, Republic of South Africa (*Transvaal*)

PARKER, MAXWELL RALPH, Watty! NZ Ltd, PO Box 1545, Auckland, New Zealand (*Auckland*)

PATEL, SUSHILA M., 8A Felix Street, Te Papapa, Auckland, New Zealand (*Auckland*)

THOMPSON, RONALD HECTOR, Marine Oil Refiners of Africa (Pty) Ltd, Diamond Shamrock, PO Box 361, Bergvlei 2016, Republic of South Africa (*Transvaal*)

TOMBLESON, MAX BRIAN, 34 Himalaya Drive, Bucklands Beach, Auckland, New Zealand (*Auckland*)

WHEELER, MARK GEOFFREY, 21 Muritai Road, Milford, Auckland, New Zealand (*Auckland*)

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

## November

### Monday 2 November

*Hull:* First Ordinary Meeting. F. Dunstan of Perkin Elmer Ltd will be discussing "The application of modern analytical techniques to the surface coatings industry", at the Grange Park Hotel, Willerby, Hull, commencing 6.45 p.m.

### Tuesday 3 November

*West Riding:* "Toxicology with particular reference to proposed draught EEC regulations dealing with labelling and packaging for paint products" by P. Bourne of Shell Chemicals (UK) Ltd, at the Mansion Hotel, Roundhay Park, Leeds 8, commencing 7.30 p.m.

### Thursday 5 November

*Newcastle:* "Cost effective alkyd

resins" by A. F. Everard, Berger Resinous Chemicals, at the Students' Common Room, St Mary's College, Elvet Hill Road, Durham, commencing 6.30 p.m.

### Friday 6 November

*Irish:* Annual Dinner Dance, at the Clarence Hotel, Wellington Quay, Dublin 2, commencing 8.00 p.m.

*London:* Ladies Night at the Hamilton Hall, Great Eastern Hotel, Liverpool Street, EC2, commencing 6.30 p.m.

### Monday 9 November

*Manchester:* Lecture "The dispersion of pigments - theory and practical experience" by L. Gall, BASF, at the Crest Motel, Bolton, commencing 6.30 p.m.

### Wednesday 11 November

*Manchester:* Student Lecture "Alkyd

# occa diary

resins and their use in surface coatings" by A. G. Robinson, Synthetic Resins Ltd, at the Manchester Polytechnic, New Administration Building, All Saints, commencing at 4.30 p.m.

### Thursday 12 November

*Midlands Section - Trent Valley Branch:* "The painting inspector" by J. Fowles-Smith, at the Sutton Centre, High Pavement, Sutton-in-Ashfield, Notts, commencing 7.15 p.m.

# OCCA news

## Thursday 12 November

*Scottish:* Joint meeting with SDC "Energy resources – conservation and utilisation" by M. Slessor of the University of Strathclyde, at the Albany Hotel, Glasgow, commencing 7.30 p.m.

## Wednesday 14 November

*Scottish Section – Eastern Branch:* "Resins for water dilutable flexographic and gravure printing inks" by George Brown of Harlow Chemicals who are sponsoring this lecture, to be held in the Murrayfield Hotel, commencing 7.30 p.m.

## Wednesday 18 November

*London:* One day symposium at Thames Polytechnic, Woolwich, SE18. "Ink technology – a survey of current practices".

*Midlands:* A one day symposium will be held at the Birmingham Metropole, National Exhibition Centre, Birmingham B40 1PP, commencing 9.45 a.m.

## Thursday 19 November

*Thames Valley:* "Electrostatic methods" by Volstatic Ltd, at the Beaconsfield Crest Motel (White Hart), Aylesbury End, Beaconsfield, Bucks, commencing 6.30 p.m. for 7 p.m.

*Midlands:* "Driers for paint" by D. J. Love, Manchem Limited, at the Calthorpe Suite, County Cricket Ground, Edgbaston, Birmingham, commencing 6.30 p.m.

## Friday 27 November

*Bristol:* Ladies' Evening, "Natural pigments – from flowers to red wines" by C. F. Timberlake from the Long Ashton Research Station, at the George and Dragon, High Street, Winterbourne, Nr. Bristol, North Avon, commencing 7.15 p.m.

## December

### Tuesday 1 December

*West Riding:* "The storage and uses of flammable materials in industry" by D. Gill, assistant chief officer, Fire Service Dept., Birkenshaw. To be held at the

Mansion Hotel, Roundhay Park, Leeds 8, commencing 7.30 p.m.

### Thursday 3 December

*Bristol:* "Solubility parameters" by P. Kershaw of Shell Chemicals (UK) Ltd, a joint meeting with the Birmingham Paint, Varnish and Lacquer Club in Birmingham.

*Newcastle:* "Durability of decorative gloss paints" by E. A. Oakley of BTP Tioxide Ltd at the Students' Common Room, St. Mary's College, Elvet Hill Road, Durham, commencing 6.30 p.m.

### Friday 4 December

*Irish:* "Purchasing and quality control" by D. Donnelly Irish Institute of Purchasing and Materials Management at the Clarence Hotel, Wellington Quay, Dublin 2, commencing 8.00 p.m.

### Monday 7 December

*Hull:* Second Ordinary Meeting. D. Wilson of Vinyl products Ltd will be discussing "Some recent developments in pressure polymer emulsions" at the Grange Park Hotel, Willerby, Hull, commencing 6.45 p.m.

### Thursday 10 December

*Scottish:* "Pigment dispersion", to be given by a lecturer from Ciba-Geigy at the Albany Hotel, Glasgow, commencing 6 p.m.

### Friday 11 December

*Manchester:* Whips meeting at ICI Ltd. Piccadilly Plaza.

*Manchester:* Lecture "Identifying vehicles for paint transfer" by Dr Wright, NW Forensic Science Laboratories at Manchester Polytechnic, New Administration Building, All Saints commencing 6.30 p.m.

## January 1982

### January

*Midlands – Trent Valley Branch:* Joint dinner lecture with Midlands Section. Details to be announced.

### Thursday 7 January

*Newcastle:* "Occupational health & safety – corporate and personal commitment and accountability" by F. Riddell of Crown Decorative Products Ltd, to be held at the Students' Common Room, St Mary's College, Elvet Hill Road, Durham, commencing 6.30 p.m.

### Monday 11 January

*Hull:* Third Ordinary Meeting. F. J. Morpeth of Foscolour Ltd will be

talking on the subject of "The manufacture and uses of pigment chips", to be held at the Grange Park Hotel, Willerby, Hull, commencing 6.45 p.m.

*Manchester:* Lecture "Radiation curing of polymers" by K. O'Hara or M. Holder, Cray Valley Products Ltd, to be held at the Lord Daresbury, Warrington, commencing 6.30 p.m.

### Thursday 14 January

*Scottish Section – Eastern Branch:* Joint Scottish Section/Eastern Branch meeting in the Maybury Roadhouse, Edinburgh, "Mossmorran in relation to the North Sea" by J.R. Alywin of Esso Chemical Ltd, commencing 7.30 p.m.

*London:* "Optimised TGIC levels in polyester powder" by D. Lawlor, Grilon (UK) Ltd, at the Great Eastern Hotel, Liverpool Street, EC2, commencing 6.30 p.m. Refreshments will be available from 6.00 p.m.

### Friday 15 January

*Scottish:* Annual Dinner Dance, to be held at the St. Andrew Suite, Albany Hotel, Glasgow, commencing 6.45 p.m.

*West Riding:* Annual Dinner Dance to be held at the Crown Hotel, Harrogate.

*Midlands:* One day symposium to be held at the Birmingham Metropole, National Exhibition Centre, Birmingham, commencing 9.45 a.m.

### Tuesday 19 January

*Bristol:* "Colour instrumentation" by D. A. Plant, supported by BOC (Software Science) Ltd, to be held at the George and Dragon, High Street, Winterbourne, Nr. Bristol, North Avon, commencing 7.15 p.m.

### Wednesday 20 January

*Manchester:* Student lecture "Cellulose esters for liquid inks" by K. Walker, Eastman Chemicals Ltd, to be held at the Manchester Polytechnic, New Administration Building, All Saints, commencing 4.30 p.m.

### Thursday 21 January

*Midlands:* M. Levete, Paintmakers Association. Details to be announced.

*Irish:* Technical and commercial business forum to be held at the Clarence Hotel, Wellington Quay, Dublin 2, commencing 8.00 p.m.

*Thames Valley:* "Electron beam curing in the 80s" by P. Cahill of Otto Durr Ltd to be held at the Beaconsfield Crest Motel (White Hart), Aylesbury End, Beaconsfield, Bucks, commencing 6.30 p.m. for 7 p.m.

# Dynamit Nobel

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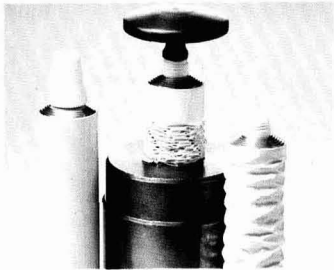
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## DYNAPOL polyesters at a glance:

DYNAPOL	L 205	L 206	L 411	L 850	LH 818	LH 812
Form supplied	Granules	Granules	Granules	Granules	Solution	Solution
Hydroxyl No.	10	5-10	5-10	5-10	15	35
Molecular weight	15000	18000	16000	14000	7000	3000
Glass temperature	70°C	70°C	50°C	40°C	40°C	30°C

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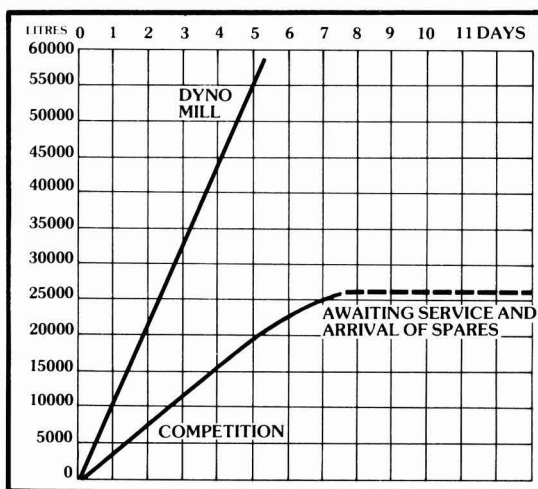
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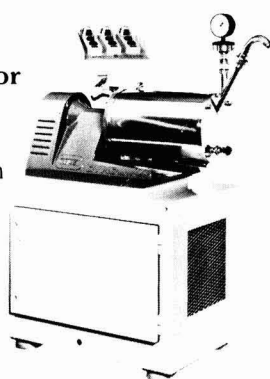


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