

When a metallic component, either ferrous or non-ferrous, arrives at the end of the production cycle, it is inevitably covered by a noticeable amount of contaminants. These contaminants can be divided into organic contaminants and inorganic contaminants.

Organic contaminants →

- can be transformed into soaps (vegetable and animal oils)
- cannot be transformed into soaps (mineral oils)

Inorganic contaminants →

- metallic particles from mechanical operations, etc...
- atmospheric dust

It is clear that the components cannot progress to the painting operation without removing these contaminants. Even if the absence of inorganic contaminants is assumed, the presence of the organic residues can cause several problems such as physical barrier, incompatibility, side reactions with the binder of the organic coatings with resulting alteration of the binder composition.

Consequently any metallic surface must receive, before the painting processes, a pretreating operation.

From a historical point of view, it can be said that after processes aimed at pretreating the metallic surfaces by means of a simple physical elimination (mainly manual elimination) of contaminants, there followed processes that in addition to the physical cleaning of the substrate, "converted" the metal in order to increase the corrosion resistance of the paint system.

Cleaner Degreasing & Organic Phosphating

by

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The following main industrial processes for the cleaning and/or conversion of metals are today available in the metal finishing market:

1. ALKALINE DEGREASING

These processes eliminate the oily contaminants without producing a conversion of the metal surface.

2. AQUEOUS PHOSPHATING PROCESSES

These processes eliminate the contaminant and convert the metal surface by depositing inorganic salts.

3. SOLVENT DEGREASING & SOLVENT VAPOUR DEGREASING

These processes eliminate the contaminants by dissolving them in organic solvents. Also solvent/water emulsions can be used. They do not convert the metal surface.

4. HOT SOLVENT BASED PHOSPHATING PROCESSES

These processes eliminate the contaminants by means of solvent vapours and convert the substrate by means of an acid attack (after submersion of the components in the hot liquid solvent phase).

5. ORGANIC PHOSPHATING PROCESSES

These processes convert the substrate by depositing an organic phosphate on it. They can be divided into:

- a) Organic Phosphating processes which require previous removal of contaminants.
- b) Organic Phosphating processes which do not require previous removal of contaminants.

Chemical Aspects of Organic Phosphating

The Organic Phosphating process described here differs from the others mentioned in 5 a) since it is capable of degreasing and phosphating metallic surfaces by means of a one-step operation at room temperature.

The agent of this process is a particular organic polyphosphate which, because of its lipophilic nature, simultaneously permits degreasing and phosphating of metallic surfaces contaminated by oils and fats. Steel surfaces are thus covered, at the end of the pretreating operation, by a thin layer of iron phosphates on steel (sometimes other phosphates can also be produced) coated by a polymeric film. Unlike aqueous phosphating processes, this process works in a nearly anhydrous medium, the medium comprising a polyphosphate dissolved in a mixture of organic solvents. Although the process occurs in a single step, it can be described in the following 5 phases:

1. Immersion of the object to be treated in the tank containing the organic polyphosphate.
2. Removal of the oily and fatty contaminants which are present on the surface of the metal by the solvents present.
3. Adsorption of the contaminants by the polyphosphate.
4. Attack of the metal and formation, on the surface of the metal, of a crystalline layer of mixed phosphates.
5. Removal of the object from the tank, solvent flash off and final reaction.

Phases 2 and 3 can be discussed in terms of the hydrogen bonding and solubility parameters of the system (see the information reported in the enclosed Appendix A). For the sake of brevity it should be remembered that:

- (1) From hydrogen bonding and solubility parameters determined both experimentally and by using data published in the literature, it can be concluded that for many oily and fatty contaminants have values as follow:

solubility parameter $\delta \rightarrow$ between 8.8 and 9.1

around 1.5 for mineral contaminants

hydrogen bonding $\gamma \rightarrow$

around 4.0 for vegetable and animal contaminants

- (2) Phase 2 can occur if, and only if, the solvent blend shows a solubility parameter which is near to 9 and a hydrogen bonding parameter near the range 1.5 - 4.

(3) Phase 3 can occur if, and only if, the phosphate polymer shows a solubility parameter which is near to 9 and a hydrogen bonding parameter near the range 1.5 - 4. In this case the oily or fatty contaminants physically combine with the phosphate polymer by mixing with it, roughly as a plasticiser mixes with a linear polymer.

(4) As far as Phase 4) is concerned, there is not a great deal of difference between phase 4 of this process and the first step of the phosphating reaction which occurs with the conventional hot aqueous-based phosphating system. It would be sufficient to mention that with organic phosphating, the starting attack relies on the presence of phosphoric acid and phosphate ions derived from the dissociation of acid phosphates which are in equilibrium with the polyphosphate polymer. (For more detailed information consult the enclosed Appendix B)

The phosphating reactions, on the other hand, terminate during phase 5. In fact, during solvents flash off the free acid groups present in the polymeric phosphate react with the substrate, giving rise in a very short time to a three-dimensional structure. These strongly three-dimensional macromolecules trap the oily and fatty contaminants preventing their migration. The final structure of the organic polyphosphate is therefore constituted by a very thin layer of mainly amorphous inorganic phosphates covered by a film of organic polyphosphate polymer.

Stability of the phosphating solution in the presence of oily contaminants.

The stability limits of the process can be demonstrated by using a purpose-designed mathematical model of the reactions involved (see the enclosed Appendix C). With this mathematical model it is possible to demonstrate that the phosphating solution is capable of absorbing a given percentage of oily contaminants without giving rise to poor film adhesion (polyphosphate film alone or in combination with the final paint). This percentage has been determined experimentally and it corresponds to 6 per cent by weight on the ready to use organic polyphosphate solution. Consequently, it can be stated that the process is capable of treating without time limitation, contaminated components with a quantity of oil not exceeding 1.5 g/m². Moreover, as the oil contamination normally present on 1 sqm of cold rolled steel is generally equal to 0.3-0.4 g, it can be concluded that the process is capable of treating components showing a contamination level four/five times higher than normal irrespective of the time factor.

Corrosion Resistance and Mechanical Properties

The organic polyphosphate film obtained with this process shows good corrosion resistance properties. It is interesting to note that the corrosion resistance of the cycle: "organic phosphating/final paint coating" is not influenced negatively (within very wide limits) by the presence in the phosphating solution of oily and fatty contaminants. It can be demonstrated that the maximum corrosion resistance was obtained with an oil contamination level of 1 - 2 per cent, while an oil contamination level of 3 - 4 per cent does not lead to decreases in corrosion resistance in comparison with the fresh non contaminated organic phosphating solution.

As far as corrosion resistance and mechanical properties is concerned, the following conclusions can be drawn:

- the corrosion resistance produced by the Organic Phosphating is superior to that produced by vapour degreasing or alkaline degreasing.
- the corrosion resistance produced by the Organic Phosphating is superior to that produced by conventional aqueous inorganic iron phosphate processes.
- the corrosion resistance produced by the Organic Phosphating is inferior to that produced by the aqueous zinc phosphate process.
- the mechanical properties of the organic polymeric film produced by the Organic Phosphating are superior to those of the layers produced by the aqueous iron phosphate processes.

Another interesting feature of the Organic Phosphating is the corrosion resistance shown by pieces PRETREATED BUT NOT PAINTED. This is connected with the non-porosity of the organic polyphosphate when compared with conventional aqueous inorganic phosphates, which are essentially microporous. The excellent temporary protection of the process allows the storage of pretreated pieces for weeks and even months without corrosion attack, as long as, the pieces are stored in premises with normal relative humidity.

Organic Phosphating & Environment Protection

The Organic Phosphating Technology was developed with the objective of providing an economical and safe method of degreasing and phosphating both from the point of view of environmental and operator safety.

The target was achieved by creating a more systematic approach to the problem of environment protection and by launching a Pollution Prevention Program.

The three main elements of the Pollution Prevention Programme include:

1. MATERIAL SUBSTITUTION
2. RESOURCE RECOVERY
3. GOOD HOUSEKEEPING

1. Material Substitution

" Substituting one material for another offers prospect of completely eliminating a given pollution problem"

Degreasing & Phosphating is an unwanted but necessary treatment used to remove organic and inorganic contaminants from metal surfaces before additional surface treatment can be done (in case of phosphating a deposition of phosphate layer is expected after the treatment).

A common and efficient method is degreasing by chlorinated solvents but the use of these solvents has been criticized because of their negative impact on the environment. The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer brought to the attention of the world that the destruction of the stratospheric ozone layer can be attributed to emissions of CFCs and HHCs. Said Protocol and its subsequent amendments proposed eliminating the use of CFCs and HHCs by the end of this decade. Since the Protocol was signed, looking for alternative substances or processes has been the heart of many company's managements. The industry is changing its degreasing & phosphating processes to meet new environmental requirements.

At this stage the question is:

**are water based degreasing & phosphating processes
the only real alternative to chlorinated solvents ?**

Changing the degreasing & phosphating process from solvents to water results in moving the environmental problems from air to water.

Atmospheric emission control is not the only problem facing the metal finishing industry. The most immediate impact on the metal finishing industry was tighter controls on its atmospheric emissions but today, more and more, industry's methods of disposing of solids and effluent waste are coming under greater scrutiny.

In water based degreasing and phosphating processes impurities such as oils, greases, metals and additives continuously accumulate in the degreasing bath during operation. Because it is not practical to mix metal-containing waste waters with degreasing bath liquors and environmental impurities, the use of separate treatment techniques for spent degreasing bath liquor is necessary. Said techniques (for example membrane filtration and evaporation, or combinations of both) are often expensive and means extra use of energy. Furthermore, even though good results can be achieved with the right technology for effluent treatment, end-of-pipe solutions are only of interest at the end of a water based degreasing bath's lifetime. A prolonged life for the solution is very important to limit the volumes that have to be finally treated.

And what about the Organic Phosphating ?

**What is the Environmental Impact associated to
the use of this metal pretreatment technology ?**

"Water "

The Organic Phosphating works in a nearly anhydrous medium, no water is involved in the process , NO RINSING stages are necessary so that no water effluent are generated. That means that an Organic Phosphating plant does not require the installation of costly water purification equipments and no extra costs are needed to dispose of contaminated water.

"Soil"

Unlike conventional Aqueous phosphating processes, which require the metal parts to pass through a number of tanks and chemicals to be heated in order to complete the treatment, the Organic Phosphating reaction takes place in ONE SINGLE TANK AT ROOM TEMPERATURE and does not generate undesirable "by-products" such as metal sludge and muds, which have to be disposed of in landfills.

"Atmosphere"

For the Organic Phosphating Technology, the biggest issue is how to deal with emissions of compounds which are linked to two of the industrial world's major air pollution problems: ozone depletion and global warming.

It is recognized that certain solvents may be hazardous to human health or to the environment, when emitted to air, disposed either in drains or landfill sites.

IT IS ALSO RECOGNIZED, AND THIS CONCEPT IS NOT NEW BUT IS AS OLD AS NATURE, THAT IN NATURE EVERYTHING IS USED AND RE-USED BY FOLLOWING CYCLES.

"By the end of the 1960 there was increasing concern about the impact that phosphates used in water based detergents were having on waterways. Mounting scientific evidence linking phosphates with eutrophication caused understandable concern in the detergent industry and the major worldwide detergents producers decided to invest in the search for effective substitute. The strategy worked, and nowadays phosphate-free" biodegradable detergents have 100 percent market share in many countries. This goal was achieved after more than a decade of intensive research and development oriented to introduce the concept of BIODEGRADABILITY".

Virtually the same goes for the usage of "Solvents".

Scientific researches have found that not only CFCs and HHCs but also other apparently benign materials have undesirable environmental side effects when released to atmosphere and there is increasing concern about the impact that some materials are having on atmosphere.

At the same time, scientific researches have proved that, in between the class of Volatile Organic Compounds (VOCs), some important clear distinctions have to be made and that the hazardous potential may vary enormously over the vast range of VOCs.

A recent study conducted by the Organization for Economic Co-operation and Development (OECD), demonstrates that a first important distinction in between the class of VOCs can be made by taking into consideration the "rate of photochemical transformation" of VOCs in air under tropospheric conditions.

In other words, it can be said that the new concept of **PHOTODEGRADABILITY / AIRDEGRADABILITY** have been introduced to estimate the hazardous potential of VOCs. Today, it is recognized that the VOCs which enter the troposphere due to manufacturing processes, use patterns and their physico-chemical properties may undergo various photochemical reactions and subsequent breakdown.

The following photochemical processes may contribute to a chemical's reaction and breakdown or degradation in the troposphere:

Direct phototransformation, i.e. excitation of a molecule through absorption of a photon followed by chemical reaction, usually oxidation through reaction with oxygen;

Indirect phototransformation processes:

- reaction with OH-Radicals
- reaction with ozone
- reaction with other photochemically generated species.

Of the direct and indirect phototransformation processes possible in the troposphere, reaction with OH-Radicals is generally the most important. This is because reaction with OH-Radicals is the most rapid phototransformation process for the majority of organic chemicals. Organic chemicals that do not or only very slow react with OH-Radicals do not react with any other photochemically formed reactive species.

Reaction with ozone is generally of secondary importance and only unsaturated aliphatic compounds, sulphur(II) compounds, amines, polycyclic aromatic hydrocarbons and phenolic compounds undergo ozonolysis easily.

The theory of Photodegradability plays an important role in the explanation of many important phenomenon such as the depletion of the ozone layer and the creation of acid rains and photochemical smog:

"Due to their great stability, CFCs and Halons migrate to the stratosphere, where they decompose when exposed to ultraviolet radiation, releasing chlorine and bromine. These chemicals interact in the ozone layer and each atom of them can destroy anywhere from 10,000 to 1 million ozone molecules".

"Due to the presence of Sulphur and Nitrogen some VOCs, when emitted into atmosphere, may breakdown releasing SOx and NOx which give an important contribution to the formation of acid rains and photochemical smog"

On the other hand, the theory of Photodegradability demonstrates that NOT ALL VOCs produce the same effects when released into atmosphere; many VOCs when emitted to atmosphere, breakdown with a "relative short-time" forming natural molecules that enter into the natural ecosystem without giving rise to the formation of pollutants.

"Air Pollution Prevention" DOES NOT necessarily mean ELIMINATING the use of solvents. "Air Pollution Prevention" means look for environmentally safe substitute products operating a RESPONSIBLE SELECTION OF MATERIALS and above all looking for CLEANER PRODUCTIONS that involve "LIFE CYCLE ANALYSIS" to try and duplicate nature and make the maximum use of resources with minimum waste.

2. Resource Recovery

"Pollution Prevention" can also be made by keeping the potential pollutants within the production system and re-using them in the same or other processes.

The ECOPHOR SYSTEM, the latest Organic Phosphating technology now available, was developed by following the Resource Recovery concept. In this process a sort of "Industrial ecosystem" has been created so that a simple low-cost Recycling Unit permits to Recover most of the "solvents" and to re-use them in the plant, directly.

This new system is a valid combination of MATERIAL SUBSTITUTION + RESOURCE RECOVERY. New "airdegradable" compounds are used so that the process does not give rise to hazardous emission at all. Furthermore, we use compounds having a very low vapour pressure (more than 1500 times lower than water) in a process that takes place at ROOM TEMPERATURE so that a dramatic reduction of natural evaporative losses can be achieved easily. Last but not least, the careful selection of the materials used not only ensures a limited emission of "airdegradable" compounds but also made it possible to realize an extremely simple low-cost equipment which permits to Recover, from the air stream leaving the plant, most of the solvents contained in it.

The result: materials previously lost are Recovered and Re-used, Yields are increased, there are Savings in Transportation, Emissions have been significantly reduced in quantity and improved in quality and we continue to provide the metal finishing market with the Best available Technique Not Entailing Excessive Costs (BATNEEC).

3. Good Housekeeping

"The aim of Good Housekeeping is to operate machinery and production system in the most efficient manner".

Improvements in Housekeeping practices can often reduce pollution by between a quarter and a third. For example the proper operation and regular maintenance of equipment can often reduce Leakage and Overuse of material.

Thus environmental improvements can be achieved through relatively simple good housekeeping practices and usually this does not require large capital expenditures. Good Housekeeping is a basic task of companies managements and requires attention to detail and constant monitoring of raw material flows and impacts.

Conclusions

The aim of this paper was not to present the Organic Phosphating as a miracle technology capable to substitute every other metal pretreatment process but that to demonstrate that there are ways to produce simultaneously both economic development and a cleaner, safer environment.

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APPENDICES

The Organic Phosphating process described here differs from the others mentioned in 5 a) since it is capable of degreasing and phosphating metallic surfaces by means of a one-step operation at room temperature.

The agent of this process is a particular organic polyphosphate which, because of its lipophilic nature, simultaneously permits degreasing and phosphating of metallic surfaces contaminated by oils and fats. Metallic surfaces are thus covered, at the end of the pretreating operation, by a thin layer of mixed zinc and iron phosphates coated by a polymeric film. Unlike aqueous phosphating processes, this process works in an anhydrous medium, the medium comprising a polyphosphate dissolved in a mixture of organic solvents. Although the process occurs in a single step, it can be described in the following 5 phases:

1. Immersion of the object to be treated in the tank containing the organic polyphosphate.
2. Removal of the oily and fatty contaminants which are present on the surface of the metal by the solvents present.
3. Adsorption of the contaminants by the polyphosphate.
4. Attack of the metal and formation, on the surface of the metal, of a crystalline layer of mixed phosphates.
5. Removal of the object from the tank, solvent flash off and final reaction.

Phases 2, 3 and 4 can be discussed in terms of the hydrogen bonding and solubility parameters of the system. The existing literature on these subjects is, nowadays, very well known and consequently the basic thermodynamic theories need not be discussed. However, it should be mentioned that, in the course of this discussion, use will be made of these concepts as they are described in a technical article published by Huls, which ought to be consulted for a deeper knowledge of this matter.

It should be remembered that:

- (a) The solubility parameter δ_m of a solvent blend is a linear function of the solubility parameters of the single solvents.

Therefore, by using the linear algebraic form, it can be shown that:

$$\delta_m = \delta x$$

where δ is the vector $\delta_1, \delta_2, \dots, \delta_n$ of the solubility parameters of single solvents and x is the vector x_1, x_2, \dots, x_n of the volume fraction of the single solvents.

- (b) The hydrogen bonding parameter of a solvent blend is a linear function of the hydrogen bonding parameters of the single solvents.

Therefore, by using the linear algebraic form it can be shown that:

$$\gamma_m = Hx$$

where H is the vector: $\gamma_1, \Psi_1, \gamma_2, \Psi_2, \dots, \gamma_n, \Psi_n$

and where $\gamma_1, \gamma_2, \dots, \gamma_n$ are the hydrogen bonding parameters of the single solvents and $\Psi_1, \Psi_2, \dots, \Psi_n$ are correcting coefficients which can assume the value -1, 0, +1, and x is the vector of the volume fractions of the single solvents.

- (c) If δ_1 and γ_1 denote the solubility parameter and the hydrogen bonding parameter of a certain substance and δ_2 and γ_2 , the solubility parameter and the hydrogen bonding parameter of a second substance, the solubility and compatibility between the two substances is:

$$\begin{aligned} \delta_1 &= \delta_2, \\ \gamma_1 &= \gamma_2. \end{aligned}$$

From hydrogen bonding and solubility parameters determined both experimentally and by using data published in the literature, it can be concluded that for many oily and fatty contaminants have values as follow:

solubility parameter $\delta \rightarrow$ between 8.8 and 9.1

around 1.5 for mineral contaminants

hydrogen bonding $\gamma \rightarrow$

around 4.0 for vegetable and animal contaminants

The almost invariable δ values may appear rather strange considering the great variety of oils and fats which are industrially available.

Nevertheless, a quick examination of Small's formula:

$$\delta = \rho \frac{\Sigma G}{(PM)}$$

and the consideration that these substances are essentially made up of long chains of carbon atoms with many $-\text{CH}_2-$ groups, leads to the conclusion that the possible presence of side chains, unsaturation, functional groups, etc. involves small variations of the terms ΣG and consequently of δ .

In view of the above, it can be stated that:

- (a) Phase 2 can occur if, and only if, the solvent blend shows a solubility parameter which is near to 9 and a hydrogen bonding parameter near the range 1.5 - 4.

- (b) Phase 3 can occur if, and only if, the phosphate polymer shows a solubility parameter which is near to 9 and a hydrogen bonding parameter near the range 1.5 - 4. In this case the oily or fatty contaminants physically combine with the phosphate polymer by mixing with it, roughly as a plasticiser mixes with a linear polymer.

It is worthwhile mentioning that as δ and γ of the polymer differ from 9 and from 1.5 - 4, so a proportionate incompatibility will be achieved with consequent oil separation, precipitation, etc.

This fact explains why the organic phosphating processes described in 5(a) require a degreasing operation before phosphating can be carried out.

Chemical Aspects of Organic Phosphating
Appendix "B"

Attack of the Metal Surface

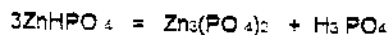
With organic phosphating, the starting attack relies on the presence of phosphoric acid and phosphate ions derived from the dissociation of zinc acid phosphates which are in equilibrium with the polyphosphate polymer.

The metal attack reactions correspond to the presence of polarised areas on the substrate: anodic areas, where metal dissolution occurs and cathodic areas where hydrogen gas is evolved.

In theory these areas arise permanently, but in practice, as metallic surfaces are heterogeneous, there are differential polarities which hinder a homogenous attack. Subsequently there is the deposition of a salt layer on the metal surface.

To explain this phenomenon two theories are generally accepted.

The first explains the deposition in terms of a cathodic process connected with a local loss of acidity and precipitation of phosphates because of hydrolysis equilibrium reactions. For instance, in the case of zinc phosphate there are the following reactions:



The second theory explains the deposition in terms of an anodic process. In the anodic areas there is a high concentration of cations created by the attack of the metal. Because of this high cation concentration, the value of the solubility product $[M^{2+}]_3 [PO_4^{3-}]_2$ can be overcome, with a consequent precipitation of salts.

It is important to note that according to this theory, the cation M^{2+} can be either created by the dissolution of the substrate being treated or can be present in the phosphating solution.

Moreover, according to some authors the two precipitation processes occur at the same time, and therefore it is believed that in the case of organic phosphating, the inorganic phosphate deposition can be explained by using both theories, i.e. formation of hydrated $\text{Zn}_3(\text{PO}_4)_2$ (on the microcathodic areas), formation of a layer of zinc/iron phosphate (on the microcathodic areas in the case of the pretreatment of steel).

It is interesting to note that according to these authors, the zinc/iron phosphate shows excellent adhesion as it is the metal itself of the substrate which participates in the formation of the layer. Nevertheless, the presence in the phosphating solution of an organic phosphate polymer showing strong steric hindrance and poor ion dissociation limits the development of the above-mentioned deposition processes. Therefore, there is in the case of organic phosphating, during normal treatment times, only a very thin inorganic crystalline or amorphous phosphate layer.

The phosphating reactions, on the other hand, terminate during phase 5. In fact, during solvents flash off the free acid groups present in the polymeric zinc phosphate react with the substrate, giving rise in a very short time to a three-dimensional structure.

These strongly three-dimensional macromolecules trap the oily and fatty contaminants preventing their migration.

The final structure of the organic polyphosphate is therefore constituted by a very thin layer of mainly amorphous inorganic phosphates covered by a film of organic polyphosphate polymer.

Stability of the phosphating solution
in the presence of oily contaminants.
Appendix "C"

The stability limits of the process can be demonstrated by using a mathematical model of the reactions involved. It is possible to demonstrate that the percentage of oil $P(t)$ present in the tank after the treatment of t m of metallic surface is:

$$P(t) = \frac{-\alpha \times 100}{W} \left(\frac{W-25}{25} \right)^t + \frac{\alpha \times 100}{W} \left(\frac{W-25}{25} \right)$$

Where: α = quantity of oil in grams introduced into the tank by 1 square meter of metal surface.

W = total weight in grams of the organic phosphating solution

25 = assuming a consumption of chemicals equal to 25 grms/sqm.

It is clear from Figure (1) that when t is very high the curves show a horizontal asymptote.

Moreover, it is possible to demonstrate that the oil percentage $P(t)$ at the asymptote point is:

$$P(t) = 4 \cdot \alpha$$

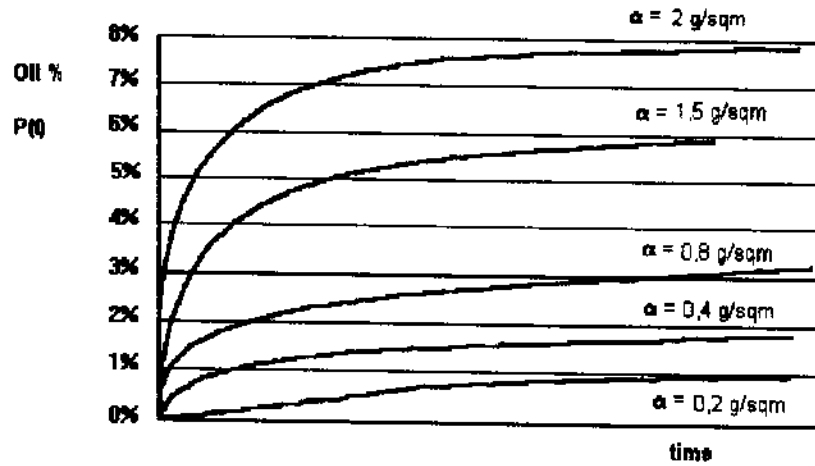
considering α in this case to be a dimensional value. The straight line indicates the oil percentage that the phosphating solution is capable of absorbing without giving rise to poor film adhesion (polyphosphate film alone or in combination with the final paint).

This percentage has been determined experimentally and it corresponds to 6 per cent by weight on the ready to use organic polyphosphate solution. Consequently, it can be stated that the process is capable of treating without time limitation, contaminated components with a quantity of oil not exceeding 1.5 g/m.

Moreover, as the oil contamination normally present on 1 sqm of cold rolled steel is generally equal to 0.3-0.4 g, it can be concluded that the process is capable of treating components showing a contamination level five times higher than normal irrespective of the time factor.

Pai-Kor Organic Phosphating

Percentage of oily contaminants present in the organic phosphating bath $P(t)$ versus time (t)



Balance of the Pai-Kor Organic Phosphating

