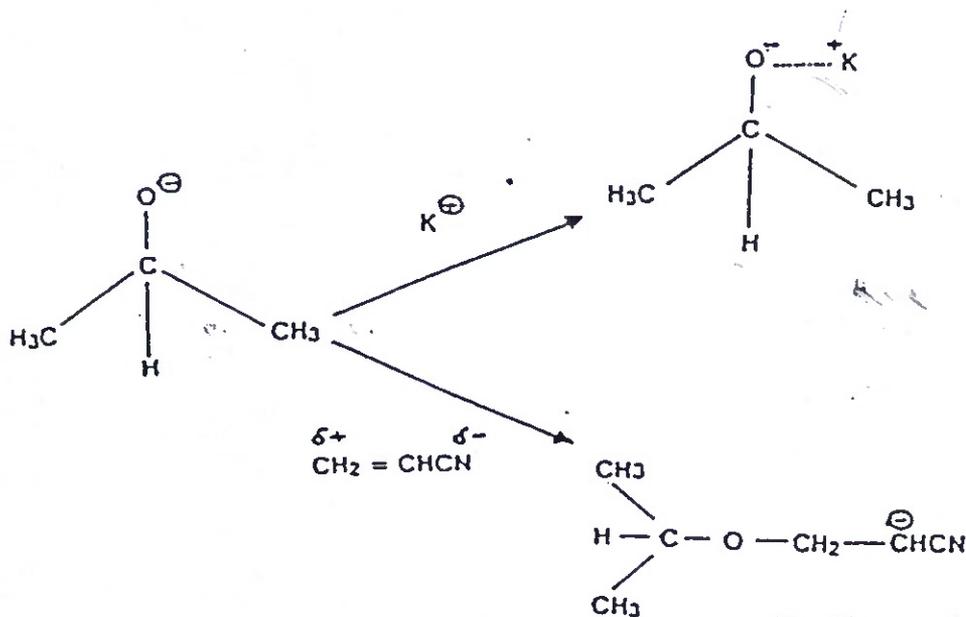


FIGURE 2

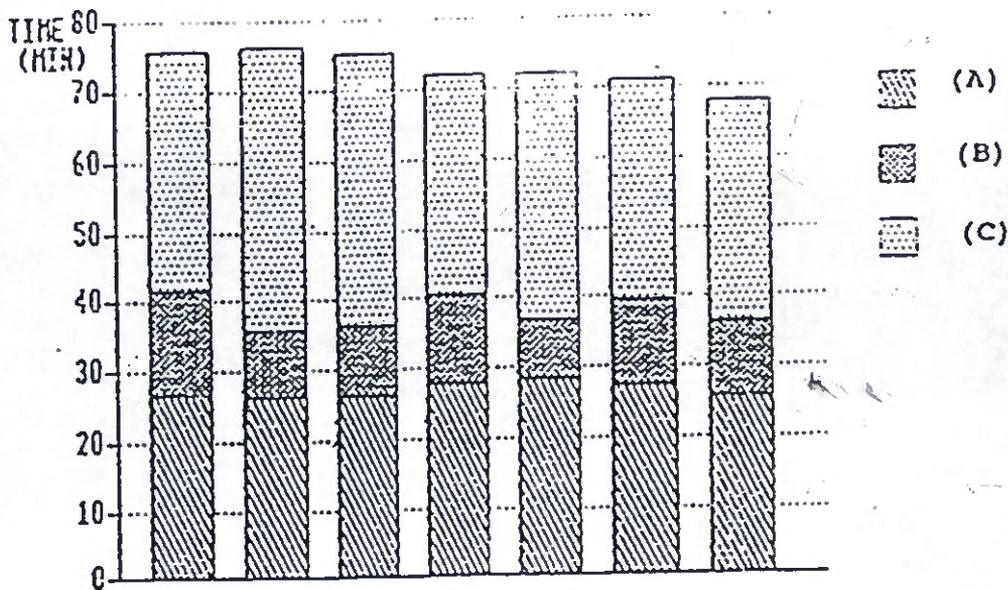
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ALTERNATIVE REACTIONS OF THE PROPAN-2-OXIDE ION -
ION PAIR FORMATION AND POLYMERISATION

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FIGURE 1



RELATIVE TIME TAKEN TO FORM CALCIUM CARBONATE SCALE AT 70°C FOR REPLICATE EXPERIMENTS WITH (A) NO MAGNETIC UNIT (CONTROL), AND (B) A DUMMY UNIT OF THE SAME GEOMETRY AS (C) A MAGNET UNIT. THE DATA SHOW AN AVERAGE REDUCTION IN PROPENSITY TO SCALE OF 60% FOR MAGNETIC TREATMENT OVER THE CONTROL

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Summary

The research we have carried out shows that magnetic fields do interact directly with charged species in fluids and that these interactions change the subsequent behaviour of the charged species. The use of applied magnetic fields to control crystal growth, including the hard water scale prevention processes, is part of the general phenomenon - the magnetic treatment of fluids. A good deal of work remains to be done to explain all of the detailed interactions between magnetic fields and the growing calcium carbonate scale-forming crystals, but enough has been done already to show that general explanations exist (as they must). The importance of continuing the research work is well illustrated by the fact that the annual cost to the UK of hard water scale is estimated at £850 million. The lack of a scientific rationale has in the past caused problems in marketing magnetic units. Some of the marketing has been totally unscientific and has brought the use of magnetic units into disrepute. It is, therefore, important that the current marketing of water conditioners takes account of present knowledge and does not resort to the concepts of 'magic' or make unwarranted claims which will only destroy the good scientific work that has been done.

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Calcium Phosphate Solubility Ratios

Value at start of experiment = 100

Time (hours)	Zero field	Magnetic Field
0	100	100
24	118	128
120	122	215

Changes in rate of precipitation - we have had evidence in laboratory studies for changes in rates of precipitation carried out in an applied field in comparison with the rates for the zero field situation. The precipitation of aluminium hydroxide and calcium oxalate are, for example, delayed by magnetic treatment.

Interpretation of Available Data

Three components of a simple precipitation solution will be affected by the field: (a) the charged surface of the growth nuclei, (b) the anions and (c) the cations. The individual anions and cations may increase their available energy by the Lorentz effect as they pass through the field, this extra energy will only be of value if it is dissipated by collision with a growing crystal and this must be a rare occurrence in comparison with normal inter-ionic collisions and collisions between ions and water molecules. It is, therefore, in the solid/fluid interface region that explanations of the effects of the magnetic treatment of fluids must be sought. In more general terms there are other possible charged species in solutions that could be affected by magnetic fields. These include the water molecules which have a permanent dipole and clusters made up of aggregates of hydrated anions and cations that might have a sufficiently long lifetime to retain the influence of the magnetic field for long enough to have a significant downstream effect.

Current research is geared towards considering the ways in which a magnetic field can alter crystal nucleation and the ways in which the field affects transport of ions through the barrier layer towards the charged surface of growing crystals. (2)

It is because we now believe that the major effect of the field is its interaction with crystallisation nuclei, that magnetic treatment of fluids as a description of the phenomena observed rather than magnetic descaling is preferred. If it is accepted that nucleation modification is the major effect, a wide range of research projects is opened up with possible commercial implications both in energy saving and control of crystal growth.

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of the possible external faces of the crystals precipitated. The examples chosen here to illustrate changes in morphology on magnetic treatment are the crystallisations of calcium sulphate dihydrate and anthranilic acid. Changes in the relative intensities of the two strongest lines in the X-ray diffraction powder pattern for calcium sulphate dihydrate on magnetic treatment are consistent with a change in morphology of the crystals. In the case of anthranilic acid, the crystals obtained in a zero field are very large, thin, acicular plates, which contrast markedly with the small, well formed, three-dimensional rhombic crystals deposited on magnetic treatment.

Changes in crystal phase - there is evidence in the precipitation of both calcium carbonate and zinc phosphate scales that the chemical phase of the precipitates obtained can be changed if the fluids containing them are subjected to magnetic treatment. These changes could only result from the changes in the fluid-precipitate equilibria that alter the relative stabilities of two phases with relatively similar lattice energies.

In an evaporation experiment with hard water it was found that before treatment the calcium carbonate precipitated contained calcite and aragonite in the ratio 80:20, but after treatment the ratio of these phases was 20:80. The electron micrographs of the magnetically treated sample show that the predominant phase present consists of acicular aragonite crystals while the predominant phase in the zero field sample consists of cubic calcite crystals. The X-ray diffraction data are consistent with this observation. It should be stressed here, however, that the change from calcite to aragonite induced by magnetic treatment is rare and occurs only under specific circumstances. This phase change is not responsible for the scale prevention properties normally observed on magnetic treatment.

Changes in solubility - there is a considerable amount of evidence from the zinc phosphate experiments carried out both in industry and in our laboratories to suggest that treatment of fluids containing zinc phosphate leads to an increase in the solubility or the level of supersaturation of the zinc phosphate in the fluid. This is one aspect of the magnetic treatment of fluids which could clearly have important implications in scale prevention and removal.

Support for the suggestion that the solubility, or level of supersaturation of phosphates can be altered by magnetic treatment of the fluids comes from a laboratory study on calcium phosphate. The solubility data obtained from duplicate experiments with dummy and magnetic units, shown below, show that more calcium phosphate is retained in solution in the magnetically treated fluids.

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Changes in particle size - in the case of calcium carbonate scale, it has been shown that the particle size of the precipitates obtained from hard water increases when the water is passed through a magnetic field. An increase in particle size in this case can have two beneficial effects:

- (1) The large crystals will not adhere together to form a scale in the same way as smaller crystals which have higher surface charges,
- (2) The presence of the larger crystals will upset the equilibrium between the fluid and any existing scale because, in general, smaller particles have higher solubility and hence for larger particles local concentration in solution will be lower.

The function of the magnetic units is to alter the nature of the precipitation of calcium carbonate from the solution in such a way that scale formation is prevented. The descaling action, therefore, arises as a consequence of this effect and of the resulting changes in scale/fluid equilibria. The increase in particle size of calcium carbonate precipitates on magnetic treatment has been confirmed by both electron microscopy and laser-scattering particle size measurement.

Changes in crystallinity - associated with changes in crystal size, in some systems, are changes in the crystallinity of the precipitates obtained. The precipitation of the amino acid, DL-valine, for example, shows how the magnetic field can alter the crystallinity. In the presence of an applied magnetic field the DL-valine crystals are large and well formed hexagonal platelets while the crystals obtained under the same conditions but in a zero field are much smaller and less well formed.

Changes in crystal morphology - the external faces seen on a crystal are those of the slowest growing faces in the development of the crystal. It is well known that the addition of a chemical can change the growth on one set of crystal planes relative to other planes and hence change the morphology (habit).

Any factor that affects the relative rates of growth of crystals on the various planes of the planes of the crystal could alter the crystal habit. An ability to change the crystal habit can be important in determining the nature of precipitation, scale formation and scale prevention. Among the factors that are known to change the morphology of growing crystals under specific circumstances are rate of cooling, nature of solvent, pH, impurities present and degree of supersaturation. There is considerable evidence that the effect of the magnetic field on the growing crystals in magnetically treated fluids also changes the relative rates of growth

propan-2-oxide ions. In the reaction there must be competition between the formation of ion-pairs with propan-2-oxide ions and their catalytic use as shown in Figure 2. The magnetic field on acting to prevent the formation of $RO^-...K^+$ ion pairs thus releases the active catalytic species and favours the polymerisation reaction.

The example of the effects of an applied magnetic field on acrylonitrile polymerisation is only one of many types of field-charge interactions that could be used to demonstrate that the magnetic treatment of fluids is a general phenomenon involving interactions between the fields and charged species.

Crystallisation and Magnetic Field Effects

The formation of chemical scale, including the deposition of calcium carbonate from hard water, is, in chemical terms, simply an example of precipitation and crystallisation. We have shown that magnetic fields will interact with the surface charges on fine particles of clay and other dispersed phases. The nuclei on which precipitation and crystallisation processes occur in fluids must carry large surface charges and should be affected by applied magnetic fields. There are only two major factors in the growth of precipitates and crystals, and, therefore, in the deposition of chemical scales, namely:

- The solubility of materials in the fluid
- The crystal nucleation process.

If we are to explain the effects of magnetic fields in scale prevention, we have to consider how the fields will affect these two major factors.

In our laboratory work on the crystallisation process we have shown that the magnetic treatment of fluids can result in:

- changes in particle size
- changes in crystallinity
- changes in crystal morphology
- changes in crystal phase
- changes in solubility
- changes in rate of precipitation

These changes are now considered in turn.

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and hence reduces the propensity to form scale. In a similar experiment on calcium sulphate solutions, application of a magnetic field was found to double the time required to deposit gypsum scale.

In view of the wealth of evidence from both laboratory and industrial trials, it is clear that the magnetic treatment of fluids does have a scale preventing effect on many solutions and in particular on hard water. The general acceptability of the technique, however, does depend on the development of an acceptable scientific explanation for the observed effects. In this lecture, I shall first describe experiments to show that the interactions between magnetic fields and charged species in fluids can have a profound effect on the subsequent behaviour of these species and that the magnetic treatment of fluids is a general scientific phenomenon. I shall then consider the interactions between magnetic fields and the nuclei of growing crystals which are the basis of the scale prevention properties of magnetic units.

Magnetic Field - Charged Species Interactions

The interactions between applied magnetic fields and many types of charged species in fluids can be shown to change the behaviour of the charged species. Examples of charged species that can be affected by applied magnetic fields include ions, crystal nuclei, polar molecules (dipole charges), ion-pairs, fine suspensions (surface charges) and free radicals. The interaction between a charged particle and a magnetic field can be of two types, *viz* (a) direct field charge interactions that affect the entire charged particle and (b) magnetokinetic energy level modification in which the observed effects arise because of interactions between the magnetic field and specific energy levels. Magnetokinetic energy level modification is important in free radical reactions and involves the use of weak magnetic fields (strength 10-100G). Direct interactions require somewhat stronger fields (greater than 500G) and depend upon the nature of the charged species and the strength of the applied fields. An example taken from our own work at the City University shows that the rate of polymerisation of acrylonitrile can be increased by magnetic techniques. It is an example of a direct field-charge interaction in which ion-pairs in the fluid are affected by a field of about 1,000G. In the process the magnetic field weakens the interaction between the positive and negative parts of the ion-pairs by attempting to set them in helical motion in opposite directions. This, in turn, makes the active catalyst species more available, as described in the following paragraph, and speeds up the action. The polymerisation of acrylonitrile to polyacrylonitrile is an exothermic reaction providing a means of studying the rate of reaction by thermometric titimetry. Application of a magnetic field results in an increase in the rate of polymerisation as indicated by an increase in heat output. The active catalyst species in the polymerisation is the propan-2-oxide ion (OR^-) which is added to the monomer solution as a solution of potassium hydroxide in isopropan-2-ol. A disadvantage of adding the catalyst in this way is that the activity of the propan-2-oxide ion as a catalyst is reduced by the formation of an ion-pair with potassium ions (Figure 2). We have interpreted the increase in the rate of polymerisation measured by heat output, on magnetic treatment of the polymerising reaction, in terms of a breaking or a weakening of the ion-pair interaction between potassium and

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Magnetic Treatment of Fluids

Introduction

The purpose of this lecture is to show (1) that applied magnetic fields can have a profound effect on the behaviour of charged species in fluids and (2) that the scale prevention results achieved with magnetic devices are part of this general phenomenon - the magnetic treatment of fluids.

There has been a great deal of controversy over the use of magnetic fields in chemical scale prevention, mainly because of a perception that the units work by "magic" and that there is no generally accepted scientific explanation of the phenomenon. It is easy, however, to show that applied magnetic fields do act as scale preventors. Two examples from industrially monitored trials carried out as part of my research work are quoted here:

(1) In duplicate trials with pot heat exchangers [an inner service water stream and an outer hot water circuit], the amount of calcium carbonate deposited was measured after use for the same period of time in a situation where the water supply was hard. Over the period of study the amount of calcium carbonate leached from the heat exchanger when no magnetic unit was used was 40g. in comparison with less than 0.1g. leached when the water was subjected to an applied magnetic field.

(2) In a series of experiments with five boiler units of a humidifier system in a hard water area, the life of the boilers was extended from the normal value of 1,000-1,500 hours to well over 2,200 hours when the monitored trial was stopped with all five boilers still functioning.

In our laboratories we have developed a method of testing the ability of a solution to form a chemical scale. In addition to tests on hard water we have carried out studies on the propensity of many solutions to form scale, these include calcium phosphate, calcium sulphate, barium sulphate, zinc phosphate and calcium oxalate. The method involves the deliberate deposition of scale in a small bore tube and the measurement of back-pressure as the scale deposit builds up in the tube. The back-pressure thus gives a determination of the rate and extent of scale formation which can conveniently be measured in terms of the time required to build up to a given back-pressure. Figure 1 shows the reproducibility of the method in a series of replicate measurements of calcium carbonate scale formation in three situations, *viz* (i) a control experiment with no unit, (ii) a dummy experiment in which the water passed through a non-magnetic unit with exactly the same geometry as the magnetic unit and (iii) a magnetic experiment in which the water was passed through a magnetic unit. The results show firstly that consistent data can be obtained from replicate experiments and secondly that, although turbulence in the dummy unit does reduce the time to scale, the application of a magnetic field considerably increases the time required to build up a scale

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"MYSTICURE"

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