MAGNETIC TREATMENT OF FLUIDS --- PREVENTING SCALE

TEXT OF LECTURE AT HDL SYMPOSIA AT THE UNIVERSITIES OF YORK AND ASTON BY PROFESSOR J. D. DONALDSON, PROFESSOR OF INDUSTRIAL CHEMISTRY, THE CITY UNIVERSITY, LONDON

We were introduced to the topic of this symposium when we were asked by HDL to carry out research work on the fundamental processes involved in what was, at the time, described as "Magnetic descaling". The work that we have done over the past three and a half years has, however, shown that the influence of magnetic fields on precipitates and the precipitation process extends beyond simple descaling and hence the title of the lecture is “Magnetic Treatment of Fluids”. All of the work that I shall describe was carried out with HDL Fluid Dynamics magnetic units.

Since our first studies in this field were concerned with descaling, I shall first describe the important features of the scaling process as we see them and then provide details of industrial case studies in which we have been involved.

I will end this presentation by describing some of the new areas of research interest in the magnetic treatment of fluids that are being developed as a direct result of the research work that we have done.

Scale formation is normally associated with the deposition of unwanted solid materials on a surface and typically with precipitates of compounds such as calcium carbonate, calcium sulphate, barium sulphate, magnesium hydroxide, calcium phosphate. zinc phosphate, iron hydroxides and silicates. The evaporation of sea water illustrates the fact that these scale forming precipitates can he deposited together and sequentially from complex systems. In the case of sea water the scale deposited depends upon the temperature of the fluid.

The immediate cause of scale formation in any system is the deposition of a precipitate from a supersaturated solution. The main causes of supersaturation in fluids include concentration of the solution, mixing of incompatible fluid streams, temperature and pressure changes and changes in pH.

These changes are all concerned with the solubility of potentially scale-forming chemicals in the fluids and low solubility is one of the two major effects in scale formation.

The other major effect is nucleation which eventually has to occur to cause the scale precipitate to grow. Nucleation can occur on minute particles of the growing scale or on corrosion products or rough surfaces in pipework and can also be favoured by low fluid rates.

If scale formation is to be controlled or prevented, the treatment must address itself to the control of one or both of these main factors, namely (1) solubility and (2) nucleation and crystal growth. Some methods of scale prevention, such as acid dosing and ion exchange, are designed to control solubility by preventing the formation of supersaturated solutions while others, including chemical inhibitors control nucleation and growth,

Before going on to discuss the work that we have done on the magnetic treatment of fluids, let us first consider both a very simple example of the costs of scaling and the total costs. The simple example concerns direct gas fired storage water heaters which cost about £1,400 new and are covered by a three year warranty.

In hard water areas, if no precautions are taken, scale builds up at the foot of the tank and leads to lower efficiency of heat transfer, lower storage capacity and base-plate overheating. The heater can then fail because the grain structure of the mild steel base plate will grow and the plate will become plastic, sag and then split. This failure can occur within 19 months and the tank replacement cost of about £900 represents a major part of the price of a new heater.

Multiplying up all the costs from all sources it is conservatively estimated that the annual cost of scaling in the UK is £600 million. This large sum

$2HCO_3$ ------Heat-------$CO_2 + CO_3^{2} + H_2O$

$Ca^{2} + CO_3^{2}$--------<50° ----------$CaCO_3$ (CALCITE)

$Ca^{2} + CO_32$ ------->65° ----------$CaCO_3$ (ARAGONITE)

$CO_3^{2} + H_2O$ ------->80° ----------CO_2 + OH

$4Mg^{2} + 3CO_3^{2}$ + 2OH -------------$3MgCO_3.Mg(OH)_2.3H_2O$

$3MgCO_34.Mg(OH)_2.3H_2O$ -------------- $4Mg(OH)_2 + 3CO_2$

$Ca^{2} + SO_4^{2}$ ------> 120° ---------$CaSO_4$

Temperature of fluid and scale deposited. ap

puts into perspective the importance of research studies on scale problems and explains why it is important to find out (a) under what circumstances the magnetic treatment of fluids can be beneficial in scale prevention and (b) the exact scientific basis of the effects involved in the magnetic treatment of fluids.

Results of a descaling experiment carried out in our laboratories depicted on the three photographs show (a) a calcite scaled pipe from a cooling system (b) the same pipe six months after installation of a magnetic unit in the water circulation system and (c) the final state of the pipe after prolonged treatment. Although these photographs were obtained from a laboratory experiment, collaboration with industry in monitored trials of units in real situations has formed an important part of our programme.

In the steel pretreatment industry the phosphating systems used involve solutions of zinc, manganese, iron or chromiurn phosphates that are on the edge of supersaturation. Use of these materials in spray or dip operations leads to the production of sludge and then scale that can result in jet blockage, pipework blockage and scaling of heat exchangers and tank wall surfaces. The use of hard water to rinse the treated steel can also give rise to scale formation because of the precipitation of calcium phosphate.

An example of the latter type of problem comes from a monitored study, of the magnetic treatment of rinse water in the Bedford van body steel pretreatment plant. The details of this study will be published elsewhere but, in summary, the installation of a magnetic unit in the hard water rinse system following an alkali rinse bath resulted in the removal of the calcium phosphate scale that had formed on the dip tank walls and on the tank housing walls. The original scale was 6-8mm thick on the walls of a tank of $1.63m^3$ capacity.

Installation of a magnetic unit resulted in removal of this scale with estimated annual savings of £22,000 in acid cleaning. In the Bedford plant a magnetic unit has also been used to reduce the scale problems arising from hard water in a plate heat exchanger. The installation of a unit in the circuit prior to the heat exchanger resulted in the deposition of soft scale on the exchanger plates. This scale was easily removed by brushing, in contrast to the hard scale formed in the absence of the unit.

In two examples where units were installed in spray zinc phosphate systems evidence was found for (1) a reduction in the amount of sludge formed and in the chemicals required, suggesting that more of the zinc phosphate was being held in solution and that less was being converted to unwanted sludge (in one case a 20% reduction in phosphate consumption was found) and (2) for the reduction in jet blockage and the financial savings described in Table 1.

A monitored case study was also carried out on a wash system in a steel phosphating process in which jet blockage occurred because of calcite formation resulting from the use of hard water. Again in this

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(Continued from page 22) case reduction in jet blockage was achieved which resulted in an extension of the working period to close down for cleaning from a few weeks to, at the time of this lecture, more than one year.

Moving away from the steel pretreatment industry to monitored studies of scale prevention in water usage, I should like to describe. in addition to the plate heat exchanger in the Bedford plant discussed above, results from different applications. In one water usage study involving photographic monitoring at a GKN plant, installation of a unit in a cooler system was shown to result in the removal of existing calcite scale, to the prevention of further hard scale formation and to the prevention of seizing of the inspection ports with scale.

A second study involved the fitting of a magnetic unit to a hard water supply feeding the boilers of humidifiers. Although the normal life of a boiler unit in the untreated system was 1,000-1,500 hours, five of these boilers supplied with water passed through a magnetic unit were, some months ago, still functioning after an average of 2,200 hours.

The third study was concerned with a large hot water tank in a brewery. The build up of calcite scale on the tank required a regular descaling shut-down in which scaffolding had to he built inside the tank to allow a team of men to chip away the approximately 1 inch thick scale. The task took more than one week and a considerable amount of chemical was used in the process. After the installation of a magnetic unit. the scale present at the next shutdown was very thin and soft and could be removed by brushing. The time required to remove this soft scale was 2-3 days and very much smaller quantity of descaling chemical was used.

Results of a six month trial of an HDL magnetic unit in the cooling water circuit chillers at Gatwick Airport provided interesting data on both the removal of scale and energy, savings. Installation of the unit in the heavily scaled system resulted in an increase in suspended solids in the water circuit from about 2,200ppm to about 7,000ppm as a magnetic unit caused descaling of the circuit and a subsequent drop to a value of about 1,200 ppm when all of the old scale had been removed. The fact that this low level of suspended solids was maintained on subsequent operation of the chillers showed that, after the descaling process. the unit acted as a scale preventor.

Table 1: Spray Phosphate Steel Pretreatment
(Private Communication Servis Group, Wednesbury)

Effects of Magnetic Unit
A. 80% reduction in blocked jets
B. Only slight build-up of scale on heating coils
C. Improved heating efficiency
D. Less sludge to dispose of
E. Reduced plant downtime

Savings
1. 30 man hours/week on jet and pipe cleaning
2. 40-50 man hours/six week period on full plant cleandown
ANNUAL SAVINGS £9,500

The effectiveness of the descaling and subsequent scale prevention was also followed by monitoring the energy consumption of the pumps over a six month period using new carefully zeroed measuring equipment. Both pumps showed a reduction in energy consumption as a result of the effects of the magnetic unit. The data for one of the pumps being 17.5, 16.5, 16.0 and 15.25 amp per phase after 0, 4, 8 and 24 weeks respectively. Similar results have been obtained in tests on boiler efficiencies.

The industrial case studies that I have described show that the magnetic treatment of fluids can have a profound effect on scale prevention in both single-pass and circulating systems and I would like to turn my attention to the concept of the magnetic treatment of fluids.

In all of the systems investigated in our laboratories and in the case studies, we have a situation in which a fluid containing dissolved or suspended solids is passed through a magnetic field.

All of the experiments carried out by us have been conducted with HDL magnetic units and the results that we have are appropriate to the magnetic field, flow rates, and design of these units. We have to consider (a) the effects of the magnetic field on the precipitates obtained from the fluids: (h) the effects of the magnetic field on the fluid-precipitate equilibria and (c) the possible scientific basis for the observed effects. Our results have so far shown that the magnetic treatment of fluids can result in:

1. Changes in particle size
2. Changes in crystallinity
3. Changes in crystal morphology
4. Changes in crystal phase
5. Changes in solubility
6..Changes in rate of precipitation

Let us consider these changes in turn.

Changes in particle size - In the case of calcium carbonate scale, we have been able to show 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 larger crystals will not adhere together to form a scale in the same way as smaller crystals would;

(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 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.

Electron micrographs of calcium carbonate scale produced by evaporation show the increase in crystal size achieved in this situation when the fluid is treated magnetically.

Changes in crystallinity

Associated with changes in crystal size, changes in the crystallinity of precipitates can also be observed in some systems subjected to magnetic treatment. These changes result from the effect of the magnetic field on the growing crystals and show up in electron or optical microscopic examinations which distinguish among other features, between single-crystal and aggregate particles in the precipitates.

Changes in 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 chemicals can change the growth on one set of crystal planes relative to other planes and hence change the morphology.

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 of the possible external faces of the crystals precipitated.

Both the changes in crystallinity and morphology must arise because of the interaction between the field and the nucleating and growing crystals in the system.

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 changed if the fluids containing them are subjected to magnetic treatment. These changes could only result from 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 we 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.

Changes in solubility--- There is a considerable amount of evidence from the zinc phosphate experiments both in industry and in the 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 areas such as removal of scale, chemical synthesis and hydrometallurgy.

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 (Table 2) show that more calcium phosphate is retained in solution in the magnetically treated fluids.

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One additional piece of information that we must take account of before considering the scientific basis of the phenomena observed in the magnetic treatment of fluids is that resulting from evidence presented by me at the first HDL symposium.

In an experiment such as that described elsewhere in which water from a single reservoir is split and passed through two scaled pipes with one stream passing through a magnetic unit and the other stream passing through a dummy unit,

Table 2

$Ca_3(PO_4)_2$ Solubility Ratios
Value at start of experiment = 100

Time (hours)	Dummy	Magnet
0	100	100
24	118	128
120	122	215

both scaled pipes are eventually descaled

Of course, the pipe irnmediately following the magnetic unit is descaled first but the pipe not immediately followed by a unit does become descaled in time because it is being supplied with water from a common reservoir and which has, therefore, passed through magnetic unit in some of its cycles.

Possible explanations

Let us now consider the possible explanations of the observations made above and which are relevant to the descaling and scale preventing properties of the magnetic devices. There are three possible explanations that we should consider:

(1) turbulence
(2) the Lorentz effect and
(3)crystal nucleation modification.

Turbulence - In a system where a fluid is being passed through a slit in a pipe of a larger diameter. turbulence must be produced and there is no doubt that the liquid flow through the magnetic units is very turbulent. We have, however, found no evidence that the effects on crystal growth, precipitation and solubility described earlier in this lecture can be produced using non-magnetic dummy units with the same geometry as the magnetic units.

Turbulence must have a beneficial effect both in and prevention of aggregation of crystallites to form scale and in the descaling process but these effects must essentially be secondary to the major effects of the magnetic field on the treated fluid

The Lorentz effect - The Lorentz effect, that is the combined effects of an applied magnetic field, a charged species, the induced magnetic field on the charges species and rate of flow of the fluid, could result in the production of energy that by normal collision processes could be used to do work downstream in the system i.e. to remove or prevent scale formation. The amount of energy produced in this process in typical scale forming systems is likely to be small and, although it may contribute to the overall process, it seems unlikely that it would be the major effect responsible for the observed phenomena.

It is possible, however, that the energy available to single ions from this process may result in changes in the way in which these ions interact with the growing crystals in the fluid and this energy may be important in determining the crystal nucleation modification process described below.

Crystal nucleation modification -- All of the data observed so far can be explained in terms of the modification of crystal nucleation by the magnetic field. The nuclei on which the crystals start growing and the growing crystallites themselves are very small and will have charged surfaces. It seems reasonable to suppose that these charged particles would be subjected to considerable forces as they pass through the magnetic field.

Energy available

In terms of energy available, the interaction between the magnetic field and the charged particles seems to be the major difference between fluids treated magnetically and those not treated. The magnetic field will act at the surface of the crystallites and can modify the nature of the charges at the surface and as a consequence, can also modify, the growth of the crystals both in general and on specific planes.

Such a modification of the nucleation process can be used to explain all of the observed data. Changes in crystal size will result from changes in the general overall growth pattern in the field. Changes in crysallininty and morphology will result from changes in the relative rate of growth of specific planes of the crystals in the field.

Changes in crystal phase will result from changes in the relative energies available to the growing crystals with and without a magnetic field. Changes in the solubility of precipitates in fluids, including the dissolution of existing scale, will arise from changes in the fluid-precipitate equilibrium as a direct consequence of changes in crystal growth in the systems.

Changes in the rate of precipitation would result again from changes in the rate of growth of crystals subjected to a magnetic field in comparison with that for a normal precipitation experiment.

At the solid-fluid interface, diffusion layers are set up between the solution and the faces of the growing crystal. The growing faces will all carry a charge which will differ from face to face, and the effect of the magnetic field on the surface of the crystal and on the diffusion layer will be critical in determining the effect that the field will have on crystal growth.

Three components of a simple precipitating solution will be affected by the field (a) the charged surface of the growth nuclei (b) the anions and (c) the cations. It is in solid-fluid interface region that we must look for explanations of the effects of the magnetic treatment of fluids.

Current field

Our current research 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.

It is because we now believe that the major effect of the field is its interaction with crystallisation nuclei that we prefer magnetic treatment of fluids as a description of the phenomena observed rather than magnetic descaling.

If we accept that nucleation modification is the major effect, we have opened up a wide range of research projects with possible commercial implications both in energy saving and control of crystal growth. The types of project that we shall be considering in the future range from continued studies of scale removal and prevention. through studies on the effects of rnagnetic fields on crystallisation processes in the chemical industry, studies on the improvement in the filtration characteristics of precipitates in the chemical hydrometallurgical and food industries, and studies on the solubility on clarification processes in systems such as clay suspensions.

In fact, the application of a magnetic field may have beneficial effect in any system that contains charged species or radicals and it is towards investigations of suitable systems that our research shall move.

Recent water usage case studies, in which we have been involved, include studies on the use of magnetic units to prevent scaling in feed-water supply systems to battery reared poultry in the humidification system in hatcheries and in tea and coffee making machines.

New research areas

Our conclusion that the beneficial effects of magnetic treatment of fluids results from the interaction of the magnetic field with any species in the fluid that carries a charge, however small. has led us to new areas of research. Some of these new areas have produced interesting results and have led to some commercial exploitation.

We have for example found (a) that magnetic treatment of cement and ceramic slurries can lead to improved strength in the final products and (b) that magnetic treatment of organic dyestuff and fabrictreating solutions can produce improved quality products.

We are only at the beginning of our research work in terms of the number of systems that we consider would benefit from studies involving the magnetic treatment of fluids. Magnetic descaling. as you know. has been with us for fifty years and has been variously described as a myth and as black magic.

I find it surprising that research scientists in the past have not taken the trouble to check the claims made for these units particularly in view of the fact that we have been able to show that magnetic descaling is neither a myth nor black magic but is in fact part of a wider and obviously important topic - The Magnetic Treatment of Fluids.

Finishing