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Lifting the scales from our pipes

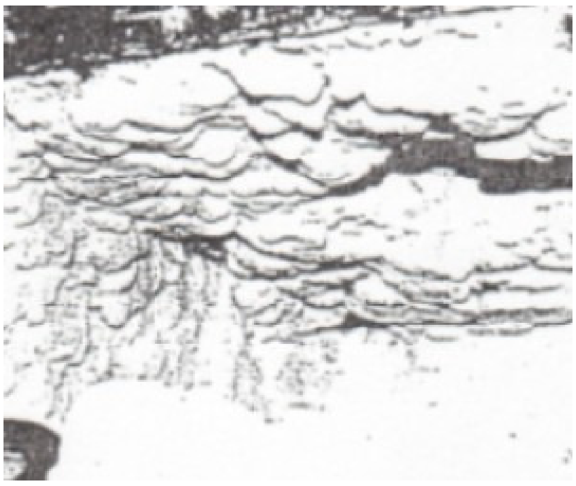
Magnetic fields change the way crystals form in fluids. This could prevent the formation of scale in pipes and boilers

John Donaldson and Sue Grimes

INDUSTRIALISTS don't usually call in scientists to convince their customers that a process works but HDL Fluid Dynamics based in Amersham, was in great difficulty. Engineers would not believe that scale deposited in pipes by hard water would disappear or reduce if the water flowed through a magnetic field. The company asked us to investigate the fundamental processes of what was described as magnetic descaling. At this stage, we said: "We don't believe you either!" But then we visited industrial sites where HDL had installed magnetic units and found that they did indeed remove scale from pipes. At the time, we could not explain why the magnetic treatment worked.

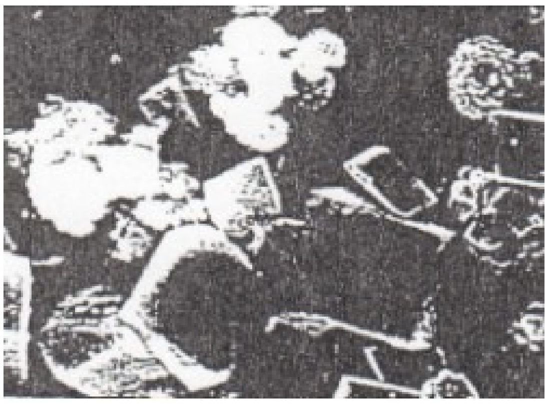
Scale is one of the banes of industry. It narrows pipes, blocks jets and is expensive to cleanup. Mineral compounds in the water, such as calcium or magnesium carbonate, sulphate or chloride, form these deposits when they precipitate out of the water, lining pipes with the furry deposits you can see in any kettle.

Researchers first discovered in the 1930s that magnetic treatment could remove scale from pipes, but no one could explain why or how this happened. Then charlatans began selling toy magnets as a quick cure for blocked pipes and furred kettles. These weak magnets did not work, and the technique fell into disrepute. Now, Britain spends around £600 million each year to clean or to repair pipes and boilers damaged by scale, so it is worth following up any technique that could alleviate the problem.



Calcite is one of the main culprits of scale. It is the commonest form of calcium carbonate occurring naturally as an essential ingredient of limestone, marble and chalk. Water passing over such rocks dissolves calcite, which may then form a stony scale inside pipes and tanks. Rock-like deposits appear on boiler walls and tubes when water heats up or evaporates. The problem increases as water gets hotter. Water with 145 parts per million of calcite flowing at 5000 litres a day, can produce 4.8 kilograms of scale each year at 60^{O}C. At 80^{O}C, it produces 29.9 kilograms. In a hot water tank at McMullens, the brewers, so much calcite scale built up on the 69 000-litre vessel that it needed a regular shutdown for descaling. The firm had to build scaffolding inside the tank to support people while they chipped away the scale, which was about 2 centimetres thick. This took around ten davs--and a large amount of descaling chemical. After installing a magnetic unit, the scale at the next shutdown was soft and thin. There cleaners could brush it off in only two to three days. They needed far less descaling fluid.

Crystals of calcium carbonate from hard water form a stony scale in a water heater. A magnetic. field alters the size of crystals. They stay small (right) and do not precipitate. Larger crystals in untreated water jar right) appear as scale



HDLs magnetic units contain four bar magnets mounted inside a stainless steel tube with flanges to attach it to other pipes. They can fit in a system vertically or horizontally and as the magnets are permanent, they do not need power connections. Magnets in the unit consist of 24 per cent cobalt, 14 per cent nickel, 8 per cent aluminium and 3 per cent copper. The balance is iron. The manufacturer of the magnets, Magnetic Developments, melts the raw materials in a high frequency furnace at 1100^{O}C, then casts them in sand. It "fast cools" the bars to prevent polymorphic iron forming. The irregular crystals of this kind of iron lower the performance of magnets. Heating the rough castings to 930^{O}C cleans and tempers them. Cooling them at a controlled rate in a magnetic field produces permanent magnets. The manufacturer coats the magnets with polytetrafluroethylene, which is highly resistant to oxidation and the action of chemicals. It also strengthens the magnets. A coating of PTFE prevents corrosion in, for example, abrasive phosphate systems in the pretreatment of steel.

Magnetic units can be from 2 centimetres to 35 centimetres in diameter, and from 2 centimetres to 45 centimetres long. They can cope with flow rates of up to 9000 litres per minute. Fluids pass the horizontal poles of the magnets, and constrictions in the tubes-venturis-vary the rate at which fluids flow through the units. Varying the strength of the magnets in a unit affects the size of particles precipitating out of a fluid. Increasing the strength of a field through which water containing dissolved calcium carbonate flows, for example, produces larger crystals. But there appears to be a limit to this effect. A typical unit has a field strength of between 2.5 gauss to 2500 gauss, depending on its function. Increasing a field to 25 000 gauss did not increase the size of particles by a factor of ten.

Over the past three and a half years, we have investigated the effect of magnetic fields on fluids at City University, and have monitored industrial trials. We can now show that the influence of magnetic fields on precipitation extends beyond simple descaling: it can prevent scale from forming. We examined its action on other fluids, not just water, and found beneficial effects in metal pretreatment (see Box).

We monitored industrial studies on the magnetic treatment of fluids to prevent scale forming in systems ranging from plate heat exchangers to the humidifier in a chicken hatchery. In all cases, the magnetic field lessened the build-up of scale significantly. We collected data on energy savings, as well as on the removal of scale by measuring, for example, pumping energies and the increase in efficiency in heat transfer.

At a GKN plant, photographic monitoring of a cooling system showed that a magnetic unit was removing existing calcite scale, and that further hard scale was not forming. Another study involved fitting a magnetic unit to a hard-water supply feeding the boilers of humidifiers at a computer centre. Although the typical life of a boiler unit in the untreated system was 1000 to 1500 hours, five of these boilers supplied with water passed through a magnetic unit still functioned after an average of 2400 hours.

Similar results came from tests at the Sovereign Hatchery, Suffolk. Hard-water blocked spray jets every 21 days in the humidifier system and caused a gradual build-up of calcite on the walls of the chicken hatchery where it had splashed. Within three weeks of the installation of a magnetic unit, the problems with blocked jets stopped. HDL continued treatment. It found that scale on the hatchery walls decreased, making them easier to keep clean.

In our preliminary laboratory studies we found that over a period we could remove scale from a pipe lined with calcite deposit if we ran along it hard water that had passed through a magnetic field. We concentrated on how the deposits form, rather than on how they dissolve, by investigating the process of precipitation that leads to scale. We carried out experiments in duplicate with magnetic and dummy units of the same geometry to eliminate changes unrelated to magnetic fields. We pumped the fluid from a reservoir through a unit into a test zone where precipitates were formed. Collecting samples from this zone, we analysed the precipitates with a variety of techniques, including analysis of the size of particles, electron or optical microscopy, X-ray diffraction and chemical analysis.

Our results showed that the magnetic field affected precipitation. It could change the size of particles of precipitated compounds, the ability of crystals to form, their shape and altered the solubility of compounds. In the case of calcium carbonate, we can show that particles precipitated from hard water decrease in size when the water passes through a magnetic field.

An increase in the size of particles can have two beneficial effects. First, the larger crystals will not coagulate to form a scale in the same way that smaller crystals would. This is the purpose of the magnetic units. Secondly, the presence of the larger crystals disrupts the equilibrium between the fluid and any existing scale. Smaller particles, in general, dissolve more easily so larger particles will reduce the local concentration of calcite in solution - and remove the existing scale.

Expanding the crystal world

Electron micrographs of calcium carbonate scale produced by evaporation show that crystal size decreases when the fluid is treated magnetically. Associated with these differences in size are changes in the crystallinity - or the ability of precipitates to form crystals - that you can observe after magnetic treatment. The magnetic field affects the growing crystals. Under an electron or optical microscope, you can see, for example, that in a solution of calcium sulphate dihydrate, large single crystals form in the absence of a magnetic field. Within a magnetic field, groups of smaller crystals precipitate.

Studying the solubility of calcium phosphate, we found that magnetic fields alter the solubility or levels of supersaturation of solutions used in the phosphating industry. We found that, comparing the results of using dummy or real magnetic units, more calcium phosphate stays in solution in magnetically treated fluids.

On a crystal, the external faces are the slowest to grow as the crystal develops. Adding chemicals to a saturated solution can change the growth on one set of crystal planes relative to other planes, altering the shape of the crystals. There is considerable evidence that applying a magnetic field to growing crystals also changes the relative rate of growth of their external faces. These changes in crystallinity and in crystal structure must arise because of interaction

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How to increase efficiency in steel pretreatment

IF YOU DON'T protect it, steel will form oxides on its surface. For cars and vans, this quickly leads to corrosion. Car manufacturers treat steel by adding a layer to which paint will adhere to protect it.

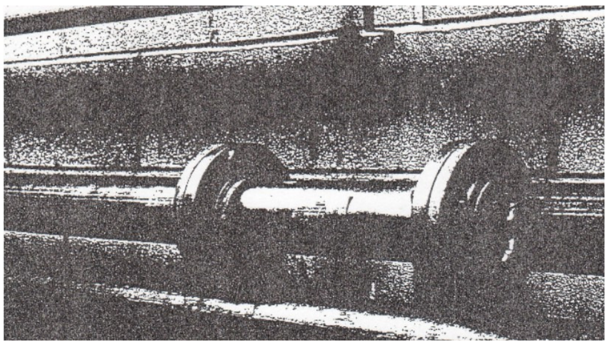
To "pretreat" steel, you bathe it in solutions of zinc, manganese, iron or chromium phosphates that are on the edge of supersaturation. After spraying and dipping the metal a thin layer of phosphate coats the surface of the steel. A sludge also forms as a result of chemical action between the pretreatment solution and the steel. As it dries, this sludge can convert into phosphate scale.

Scale blocks jets and pipes, forming layers on the surfaces of heat exchangers and tanks. A final rinse of the treated steel with hard water can also deposit scale on its surface when the calcite in the water precipitates out as calcium phosphate or mixtures of calcium carbonate and calcium phosphate. Bedford had this problem at its steel pretreatment plant for van bodies at Luton. Usually, scales of phosphates rather than hard-water scale are the main problem.

We monitored the results of installing a magnetic unit in the Bedford plant in the pipes that carried water for rinsing. The manufacturer washed the steel with water after dipping it in a bath of alkali. After the unit arrived, the calcium phosphate scale on the walls of the dip tank and on the housing walls of the tank disappeared. Originally the scale had been 6 to 8 millimetres thick in a tank with a capacity of 1.63 cubic metres. Bedford saved an estimated £22 000 a year on cleaning its tanks with acid after installing its magnetic unit.

We also monitored the effects of magnetic units in spray systems that used zinc phosphate. We found that less sludge formed and that consumption of pretreatment fluid was cut. This suggests that more zinc phosphate remained in solution and less converted to unwanted sludge Brush Switchgear, for example, reduced its use of phosphate by 20 per cent. It also found that spray jets did not get blocked quite so quickly. At the Servis Group, the benefits of installing a magnetic unit included a reduction of 80 per cent in blocked jets. In addition, Servis also improved its heating efficiency because only a slight amount of scale built up on the heating coils. It had less sludge to get rid of. The firm also saved 30 man/hours a week on cleaning jets and pipes and 40 to 50 man/hours every six weeks on a cleanup of the whole plant. When the factory had to shut, the downtime was cut by a day.

Another case study of a wash system for a phosphating process for steel treatment confirmed these findings. In this plant, scale from hard water blocked up jets every few weeks. After putting a magnetic unit in the water pipe, the plant did not close to clean the jets for more than a year.



A magnetic unit installed at GKN's technology centre treats water to prevent scale. It contains four permanent bar magnets and constrictions in the pipe make the flow of water or other fluids through it turbulent. This, however, has a secondary effect when it comes to preventing scale. The unit alters the way in which crystals form, changing their size and ability to form scale

between the field and the nucleating and growing crystals.

Evidence from the precipitation of calcium carbonate and zinc phosphate suggests that. under certain conditions, you can alter the chemical phase of these precipitates if you treat the fluids containing them with magnets. This could result only from changes in the equilibrium between the fluid and the precipitate altering the relative stabilities of two phases with closely matching lattice energies. When we evaporated hard water, for example, we found that before treatment the precipitate of calcium carbonate contained calcite and aragonite-in a ratio of about 4: 1. After treatment. the ratio of these phases was about 1:4. Electron micrographs and X-ray diffraction patterns show these changes clearly.

There are three possible explanations of why the magnetic devices prevent scale from forming, and encourage scale to dissolve. First. turbulence. In a system where a fluid passes through a slit in a pipe of a larger diameter. turbulence occurs. There is no doubt that the flow of liquid through the magnetic units is very turbulent: the geometry of the unit narrows the pipe. However, we found no evidence that you could produce the same effects on crystal growth, precipitation and solubility with nonmagnetic dummy units of the same geometry, as table real units. Turbulence helps to prevent small imperfectlv formed crystallites from aggregating to form scale, and in the descaling process, but these effects are essentially secondary to the effects of a magnetic field on a fluid.

The second explanation could be the Lorentz effect. that is, the combined effects of an applied magnetic field, a charged

Scale narrows and eventually blocks pipes (above). It decreases efficiency in heating systems, for example, because it is a poor conductor of heat. You need more energy to heat a badly furred kettle or water tank than you do a clean vessel. Cleaning pipes, boilers and tanks is expensive It also disrupts production .to close a system down for several days to scrape off accumulated scale Putting a magnetic unit into the water supply system softens scale, so it is easier to remove (above right). It also prevents scale forming (right) in pipes

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species, the induced magnetic field on the charged species and rate of flow of the fluid, could together produce energy that, by normal collision processes between molecules, could act downstream in the system, removing or preventing scale. The amount of energy produced in this process in typical scale forming systems is likely to be small. Although it may contribute to the overall process, it seems unlikely that it explains the observed phenomena fully. The energy available to single ions from this process might perhaps alter the way in which these ions interact with the growing crystals in the fluid. This energy might be important in modifying the way in which crystals form around a nucleus.

Changes in nuclei

The third explanation covers everything we have seen so far: the magnetic field is modifying crystal nuclei. The nuclei on which the crystals start growing - and the growing crystallites - are very small and will have charged surfaces. As they pass through the magnetic field, these charged particles encounter considerable forces as the magnetic field interacts with them. This distinguishes fluids treated magnetically from untreated fluids. The magnetic field acts at the surface of the crystallites, modifying the nature of the charges at the surface. This alters the growth of the crystals in general and on specific planes. Such a modification of the way nuclei form around which crystals grow explains everything we have seen. The size of the crystal will change as the pattern of growth in the field alters. The ability to form crystals alters as the relative rate of growth of specific planes of the crystals responds to the magnetic field. This also changes the crystal's shape. As the relative energies available to the growing crystals vary with and without a magnetic field, so will the crystal phase. in turn, as crystals grow differently, their solubility or levels of supersaturation in fluids alters. This explains why scale starts to dissolve; the equilibrium between the fluid and the precipitate changes because crystals are growing in a different way. The rate at which crystals form changes as well.

At the interface between solids 'and fluids, diffusion layers arise between the solution and the faces of the growing crystal. The growing faces each carry a distinctive charge. How the magnetic field affects the surface of the crystal and the diffusion layer is critical. These phenomena govern the effect that the field will have on crystal growth. In a simple precipitating solution, the field will affect the charged surface of the growth nuclei, the anions and the cations. It is in the region where the fluid meets the solid that we must look for explanations of the effects of magnets on fluids. Currently, we are investigating ways in which a magnetic field can alter crystal nucleation and how the field affects the transport of ions through the barrier layer towards the charged surface of growing crystals.

We now believe that the main effect of the field is its interaction with crystallisation nuclei. This opens up the removal and prevention of scale to a wide range of studies. Magnetic effects on fluids could affect processes throughout the chemical industry from hydrometallurgy to filtration.

A magnetic field will interact with any substance that carries a charge, however small, in any fluid. This has lead us to new areas of research. Some have produced interesting results, leading to commercial exploitation. We found, for example, that magnetic treatment of cement and ceramic slurries can improve their strength. The oil industry now funds research to reduce scale in North Sea rigs. Pumping solvents into the bedrock can damage pipes and pumps. Reducing or eliminating scale would save the oil industry a barrel of money.

Professor John Donaldson and Dr Sue Grimes research the effects of magnetic fields on fluids in the chemistry department of City University, London.