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Alternating magnetic field influence on scaling in pump diffusers

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ABSTRACT

This paper examines the influence of alternating magnetic fields on water scale precipitation on diffusers in vertical multistage pumps in real drinking water systems. The exact conditions in pumping stations were simulated in the laboratory using in-house techniques. The testing device consists of two lines, the first a control line and the other for testing, where a permanent magnet was installed. The influence of magnetic fields intensity, post-magnetisation time, temperature and saturation index on calcium carbonate nucleation and crystallisation was studied. The precipitate was analysed using X-ray powder diffraction (XRD) and a scanning electron microscope (SEM). It was found that the precipitate in water from the control line was in the form of calcite, while after the magnet treatment it was in the form of a non-adhesive aragonite powder that could be easily removed with the turbulent flow through the pump diffuser. The results suggest that the magnetic field has a noticeable effect on the transforming process of clusters in the solutions.

1. Introduction

The build-up of scale deposits is a common problem in water systems (Dobersek and Goricanec, 2014). Calcium carbonate is a dominant component in scale, because natural waters are rich with Ca^{2+} ions and carbonic species. The super-saturation to calcium carbonate scale may occur. Chemical additives are the most-often used scale inhibitors for drinking water. Much effort has been expended recently to generate green inhibitors, either from plant extraction or by using natural organic molecules (Chaussemier et al., 2015). The effect of maleic acid on mass and morphology of scale has been studied (Muryanto et al., 2014). The reduction in scale mass suggests that malic acid could be an effective anti-scalant for calcium carbonate.

Many factors, such as temperature, pressure, ionic strength, pH, water flow and impurity ions, affect scale inhibition. Magnesium, for example, is readily incorporated into growing calcite crystals at low concentrations but inhibits calcite growth at higher concentrations. A model has been developed to describe crystal growth kinetics. Magnesium may attach to active growth sites and impede crystal growth (Nielsen et al., 2013).

A calcium carbonate crystallisation fouling model on a heat exchanger surface was developed (Pääkkönen et al., 2015). The best fit was achieved when the model included scaling time and flow velocity factors. In another study, a model was developed where deposition of calcium carbonate mainly depended on temperature and total ionic strength (Kamari et al., 2014). In our previous study, the effect of Zn released from an electro galvanic device onto the calcium carbonate crystal morphology was studied (Simonič and Ban, 2013). It was confirmed that trace amounts of Zn substantially inhibit the nucleation rate of calcium carbonate. The kinetics of scale formation was studied (Zhang et al., 2001) and it was found that as pressure decreases, CO_2 solubility in the water phase decrease and raise the pH and increase the saturation index. A similar effect is observed in the turbulent water flow regime.

The use of chemical inhibitors to prevent calcium carbonate scale is not desirable. The influence of weak magnetic fields on the crystallisation and colloidal stability in aqueous systems, which mostly contain non-ferromagnetic compounds, has been investigated over the last few decades. The lowest intensity of the magnetic field that affected the calcite growth rate reported in the literature was 1800 Gauss (0.18 T) (Sohaili et al., 2016) where the solution was subjected to magnetisation and calcite growth rate stopped. The recirculation of water over the permanent magnets with alternating magnetic fields has already been studied (Gabrielli et al., 2001). The effectiveness of this procedure increases with flow velocity up to 1.8 m/s and the number of circulations through the magnetic field. Scaling still occurred, but the scales were less compact and easier to remove. It seems that the nature of the

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precipitation from magnetically treated water may be explained by a modification of crystal seeds (Gabrielli et al., 2001). Calcite growth rates in the presence of the magnetic field have been found to be lower than those in the absence of a magnetic field (Tai et al., 2008). Higher magnetic intensities yield a lower calcite growth rate. The total amount of precipitate depends on the solution pH, the flow rate and the duration of the treatment (Knez and Pohar, 2005). The results suggest that magnetic fields influence calcium carbonate polymorph phase equilibrium either by influencing the CO_2/water interface or through the hydration of carbonate ions prior to the formation of stable crystal nuclei in the solution.

Because of calcium carbonate scale formation, pumps must be frequently stopped and mechanically cleaned. The idea of the present study was to apply permanent magnets to disable calcium carbonate scaling in pump diffusers. Two experimental lines were installed to compare the amounts of scale precipitated in a pump diffuser. The experiment was carried out in a flow system using in-house techniques, simulating a real pump diffuser; in one-line drinking water was magnetically treated and in the other not. The influence of magnetic fields, post-magnetisation time after water recirculation through the magnetic field, temperature and saturation index on calcium carbonate nucleation and crystallisation was studied. Physico-chemical and microbiological analyses were performed. The precipitate morphology was examined using X-ray powder diffraction and Scanning Electron Microscopy (SEM).

2. Methods

2.1. Sampling and experimental procedure

The pumping station is the last one of a total of five pumping stations on a more than 1500 km water pipeline system. Water samples were taken from a pumping station (Fig. 1a), which is a part of the city water system. The amount of water consumption is 240–280 m^3 monthly. This pumping station supplies only 22 households. The scaling problem occurs in a vertical multistage pump (Fig. 1b), which operates only occasionally because of very low water consumption; water scale builds up on the diffusers and block the pump.

The magnetic water treatment method was tested for effectiveness in experimental lines, in which the problem in the pumping station was simulated.

Two experimental lines were installed to compare the amount of scale precipitated in two identical pipes from magnetically treated (MT) and untreated water (Fig. 2). Both lines were supplied continuously with water from the city water system as it flows through the vertical multistage pump. The water recirculated through the magnet and the water solution was then allowed to precipitate for 1, 2, 3 and 4 h and afterwards analysed with X-ray powder diffraction.

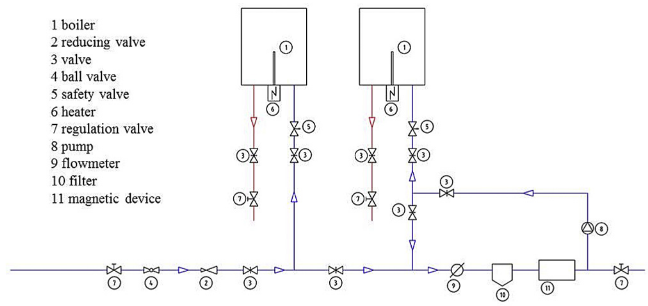

Fig. 2. The experimental lines for permanent magnet scale control test.

2.2. Methods for precipitate characterisation

The precipitate obtained was washed using milli-Q water and dried under vacuum conditions. X-ray powder diffraction data were collected with an AXS Bruker/Siemens/D5005 diffractometer using Cu-Kα radiation at 293 K. The samples were scanned with a position sensitive detector (PSD) and measured in the range of $10° <$ 2-Theta-Scale $<80°$, with a step of 0.014 and a scanning speed of 2 s per step. Determination of phases present in the sample was done with the Search/Match program (Kristl et al., 2013).

SEM combined with Energy Dispersive X-ray Spectroscopy (EDS) analysis was used to identify the surface morphologies of carbonate crystals. The precipitate was dried in order to remove the excess surface water. The specimens were attached to a stainless steel carrier and coated with a thin layer of gold under vacuum to increase the electrical conductivity of each sample and to protect the sample's structure from electron beam damage and dehydration within a vacuum. The specimens were observed using a Quanto 2003D FEI scanning electron microscope, equipped with a Sirion 400 FEI energy dispersive microanalysis system (Oxford Instruments, UK) at 15 kV.

2.3. Selected influential factors

Two alternately arranged permanent Neodymium magnets yielding a magnetic field density of 0.6 T and 1.44 T were available to study the effect of magnetic fields.

Five experiments were performed to study the effect of post-magnetisation time on crystal morphology, starting without recirculation, then with 30 min recirculation; the morphology was determined after 1 h, 2 h, 3 h and 4 h with water recirculation. In the MT line, water was recirculated through the magnetic device (Fig. 3). The water was recirculated through the magnetic device to intensify its effectiveness. In our experiment, velocity was set to

(a) (b)

Fig. 1. Pumping station (a) and the vertical multistage pump (b).