INVESTIGATION OF THE INFLUENCE OF MAGNETIC AND ELECTROMAGNETIC FIELDS ON CaCO₃ PRECIPITATION IN PIPE FLOWS

Ricardo Terra de M. Marques, Giovani Scarpelli, Rogério C. Oliveira, Juliana B. R. Loureiro, Atila P. Silva Freire

ABSTRACT - Scale formation commonly occurs in hard water pipelines and it may result in severe flow assurance problems in the oil industry. The injection of chemical additives on the flow and the use of insulation on the pipe walls are typical methods used for scale control in industry. However, these high cost systems do not provide a consistent and long-term solution for the problem. As an alternative, some attention has been devoted to the influence that magnetic and electromagnetic fields exert on the properties of precipitation and crystallization of calcium carbonate in saline solutions. In this context, the purpose of the present work is to experimentally investigate the effects of magnetic and electromagnetic water treatment in preventing scale formation in long pipes. Data obtained indicate that both magnetic and electromagnetic fields actually change the rate of scale formation and the precipitation pattern along the pipe. In particular, it was shown that the magnetic field might reduce the adhesion of the precipitated calcium carbonate to the pipe walls.

Keywords: scale formation, calcium carbonate, pipe flows.

INTRODUCTION

The precipitation of inorganic compounds in pipes is a problem typically found in many industrial applications, ranging from biomedical to oil engineering applications. Indeed, domestic water supply pipelines may suffer scale formation in places where the hardness of water is high. Most of the precipitation found in nature and technology is due to calcium carbonate. Irrespective of the application, the scale formation on pipe walls always exerts significant influence on the current process. The performance of heat exchangers can be significantly reduced since calcium carbonate deposits reduce the heat transfer coefficient and increases considerably the pressure drop of the equipment. Oil pipelines are also prone to similar problems, since valves and localized accidents impose a pressure drop that favor precipitation, which may result in complete blockage of the flow (Nasser, 2012).

The injection of chemical additives on the flow and the use of insulation on the pipe walls are typical methods used for scale control in the oil industry. However, these high cost systems do not provide a consistent and long-term solution for the problem. As an alternative, some attention has been devoted to the influence that magnetic and electromagnetic fields exert on the properties of precipitation of calcium carbonate in saline solutions. Research on this subject dates back to the sixties and most of the work available in literature is restricted to small scale experiment, mostly conducted in capillaries or small mixing vessels (Farshad, 2002; Donnet, 2009; Nasser, 2010) Despite the number of investigations, e.g. Nasser(2010), Alimi (2006) and Tai (2008), the literature still lacks an extensive and detailed database that allows the comprehension of the influence of external fields on calcium carbonate formation and precipitation. This is a crucial step for advancing knowledge, since a reliable dataset is the only basis to provide information for the correct understanding and modelling of the problem.

In this context, the purpose of the present work is to experimentally investigate the effects of magnetic and electromagnetic water treatment in preventing scale formation in long pipes. A dedicated flow loop...
with three different circuits, temperature and pressure controlled was specifically constructed for that purpose.

Experiments can be performed for pressures up to 420 bar for the 1” diameter pipe circuit, 310 bar and 240 bar for the, respectively, 2” and 3” diameter pipe circuits.

The present experimental investigation has been conducted in a 50m long, 1 inch plexiglass pipe to allow visual inspection of the temporal evolution of the calcium carbonate precipitation. The effects of commercially available magnetic and electromagnetic treatment devices have been evaluated through careful measurements of global properties of the flow and chemical characterization of the water and scale.

Although there is no theoretical framework applicable for the problem, nor an established experimental proof of performance, many industries commercialize magnetic water treatment devices for both domestic and industrial applications since the early seventies. The design of those equipment is totally empirical, and its effective result is always an open question. The present research is conducted with a view to answer three main points: i) to quantify the efficiency of magnetic and electromagnetic devices in preventing or controlling scale formation, ii) to understand which effects are beneficial or detrimental for the water treatment, and iii) to develop a design and predictive tool for field application if the principle of operation is proved to be effective.

**EXPERIMENTAL SET UP**

Once the knowledge available in literature is embrionary, the specific objective of the present work is to investigate the process of precipitation of calcium carbonate in a turbulent pipe flow subjected to a magnetic and an electromagnetic field. An extensive experimental campaign has been performed to produce scales that retain similarity condition to real scale problem.

Figure 1 presents an overview of the Multipurpose Flow Loop located at the Laboratory of Well Technology (NIDF/COPPE) and its main characteristics are summarized in Table 1.

**Table 1 – General characteristics of the Multipurpose Flow Loop.**

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Length (m)</th>
<th>P (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1” plexiglass pipe</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>1” steel pipe</td>
<td>100</td>
<td>420</td>
</tr>
<tr>
<td>2” steel pipe</td>
<td>100</td>
<td>310</td>
</tr>
<tr>
<td>3” steel pipe</td>
<td>300</td>
<td>260</td>
</tr>
<tr>
<td>Reservoirs</td>
<td>Quantity</td>
<td>Volume (m³)</td>
</tr>
<tr>
<td>Supply/discharge</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Supply/discharge</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Salt injection</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 1 – Overview of the Multipurpose Flow Loop (LTEP/NIDF/COPPE).

Present experiments have been conducted on the plexiglass circuit where calcium carbonate was formed by the mixture of two feeding lines with solutions of calcium chloride and sodium bicarbonate, respectively. The flow rate of each supply pipeline was measured by sonic flowmeters (Endress Hauser) and controlled by the rotation of two progressive cavity pumps. This initial experimental campaign was developed at the low pressure flow loop to furnish visual inspection of the scale formation process and to develop optimized experimental procedure. In fact, the amount of salts required for each experiment, besides the acids necessary to clean the pipes, involve considerable cost and must be used according to optimized procedures.

Ambient temperature and humidity was monitored along every experiment. Flow temperature can be controlled by a 50kW heating system. Temperature measurement in made by a Pt-100 probe. Absolute and differential pressure transducers (Endress Hauser) were used to monitor the scale formation along the time and length of the pipe.

The flow loop is equipped with six pressure taps for differential pressure reading and six removable test sections, which allow measurement of the weight of deposited mass. Fluid samples can also be extracted in six points along the pipe length, as illustrated in Fig. 2, to provide temporal and spatial information about the evolution of the precipitation phenomenon inside the pipe. Chemical characterization of the saline solution is performed by pH and conductivity measurements. Particles in
Figure 2 – Illustration of the experimental set-up.
suspension are analyzed in Malvern Mastersizer, that that provides its diameter distribution by laser diffraction. The crystal structure of precipitated calcium carbonate is analyzed through x-ray diffraction (Bruker) and by an electron scanning microscope (TM3030 Hitachi).

The roughness of the pipe is also a relevant parameter for the experiment, since it may result in potential nucleation sites for crystal growth. As so, a crucial part of the experimental procedure is to assure that the pipe is perfectly clean, i.e. with a smooth wall, prior to the next experiment. The cleaning procedure is performed by recirculating acetic acid 1% v/v during one hour after each experiment.

Three experimental tests were developed: i) flow of saline solution with no treatment, ii) saline solution with magnetic treatment and iii) saline solution with electromagnetic treatment. Given the time involved in preparing and performing each test, statistics are based only on a replication of each run.

Regarding the experimental procedure, questions are raised whether the experiment should be conducted in open or closed circuit. Many articles in the literature, Nielsen (1959) and Wiechers (1974), explored the formation of calcium carbonate in closed systems, i.e. systems where there is recirculation streams containing precursors of the salts besides calcium carbonate itself.

The main disadvantage of this approach is the loss of control over the concentration of species, once the recirculating system keeps concentrations of reactants and products simultaneously. Moreover, crystallization rates and particle growth are also affected. Bearing this fact in mind, the present experiment is operated in an open circuit, where the precursor salts of calcium carbonate were injected into a common mixture point in the circuit to generate a flow with chemical reaction. The saline solution flows through the test pipe and then follows to the discharge tank.

\[
\text{CaCl}_2(\text{aq}) + 2\text{NaHCO}_3(\text{aq}) \rightarrow \text{CaCO}_3(s) + \\
+2\text{NaCl}(\text{aq}) + \text{CO}_2(g) + \text{H}_2\text{O}(l) \quad \text{Eq. (1)}
\]

Eq. (1) shows the chemical equilibrium of the reaction of CaCl_2 and NaHCO_3, used in the present work.

For each experimental run 700.0 l of saline solution of calcium chloride (VETEC™) of concentration 7.350 g/l plus 700.0 l of saline solution of sodium bicarbonate (VETEC™) of concentration 12.60 g/l were used. Each solution was stored in a 1.0 m³ tank and pumped at a flow rate of 150.0 l/h, resulting in a global flow rate of 300.0 l/h. Each experimental run lasted four hours.

The magnetic device tested consists of a series of static magnets provided by HIDROMAG company. The magnets are installed around the pipe and fastened with cable ties so that the field is formed in transverse position to the flow.

Figure 3 shows the installation of the devices in a pipe section at the beginning of the circuit, just after the point of mixing, denoted as point D of the previously disclosed process diagram. These devices when aligned form a repulsive field, unlike many other commercially equipment.

![Figure 3 – Magnetic device mounted on the flow loop.](image)

![Figure 4 – Electromagnetic device installed on the flow loop.](image)

The electromagnetic device consists of a main controller with a long flexible cable. The cable must be wound on the pipe according to some standards the manufacturer provided (Scalewatcher company). Its system is composed by just a frame display, that does not allow any adjustments. The manufacturer states that the field strength generated in the equipment is self-regulating, varying according to the current dynamic response induction of the magnetic flow-field system.

**RESULTS AND DISCUSSIONS**

The temperature along the experiments remained between 27.0-29.0°C. Temperature control benefits from the fact that plexiglass is an insulating material and the chemical reaction that forms the calcium carbonate does not release or absorb significant heat, so as to influence the experiment.

Figure 5 shows the temperature fluctuation along the apparatus length. These results indicate
that the temperature fluctuations were of the same order of magnitude, so that the solubility of the species did not vary between experiments.

The currents of calcium chloride and sodium bicarbonate reach the mixing point at maximum concentration, so that near to this point of the circuit a more intense precipitation occurs.

Moreover, as the saline currents mixes along the length of the apparatus, dilution of the species in solution and formation of aggregates occur. These aggregates are entrained by the flow, a fact that results in lower scale deposition on the surface.

Regarding the effects of devices, it is clear that the embedded mass was slightly higher than the condition without the device, but still very close. This shows that the devices do not work in the prevention of deposits, but perhaps in the crystal structure and in its adhesion to the surface.

The results for the differential pressure measurements were made over space and time, revealing a pressure drop profile quite linear, as can be seen in Figure 7.

The pressure drop is related to two key factors: modified roughness and reduction of the useful diameter, as seen in Figures 8 and 9. These effects occur simultaneously because the deposition alters the pipe surface, i.e. the roughness, and the continuous deposition process tends to reduce the useful diameter of the pipe. None of the two devices exerted any significant effect in reducing these effects, so the experiments showed equivalent results in this aspect.

Absolute pressure is a local measure, therefore, has only variation in time as shown in Figure 10. The results show that the absolute pressure increased in all tests, but reached higher values for electromagnetic experiment. The origin of this discrepancy should be credited more to the uncertainty of measurement than to the physical effects that may provoke this increase.
To the experimental run tested without the devices, it is expected that the conductivity varies in a higher range, as in the beginning of the chemical reaction solids crystallize from the solution core and thus increase the amount of total solids in the system.

However, we see a drop in conductivity in the experiments with the devices, showing that the devices had significant effects in modifying the rates of formation and aggregation of crystals in the core of the solution.

The results of X-ray diffractometer show that the crystalline structure of the deposited calcium carbonate did not change due to exposure to magnetic and electromagnetic devices, such as occurred in previous experiments. Therefore, the calcite has been the most common form found when analyzing solid samples withdrawn from all experiments.

Figures 12, 13, 14 show the XRD patterns obtained from the analysis of samples from free different runs: without devices, magnetic device and electromagnetic device, respectively. The D2PHASER post-processing software indicated the peaks corresponding to calcite.

This result is important because it proves that the conversion between calcite crystal structures and vaterita occurs under certain operating conditions, depending on the extent and intensity of the magnetic or electromagnetic field applied.

Besides, it may be useful to manipulate the crystal structure of carbonate as a means to assure a lower fouling rate, whether due to a gain of solubility or even forming a layer that is soft and can easily be removed.
FINAL REMARKS

This work was successful in its objectives, so that the findings support an important study that may ultimately contribute to the flow assurance area and preventing fouling.

The experimental apparatus is successfully constructed in the form of a plexiglass circuit on a pilot scale, in order to ensure a greater likelihood with the industrial flows.

At this stage, it is not possible to affirm the effectiveness of prevention devices, but the study provides evidence that rather than inhibit precipitation such devices act by modifying the structure of deposits, resulting in an inlay with less intensity accession and easier removal.

REFERENCES


