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Prevention of Scale Formation in Heat Exchanger Pipes by Using Magnetic Field

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Abstract

The possibility of using the magnetic field technique in prevention of forming scales in heat exchangers pipes using hard water in heat transfer processes, also the studying the effective and controllable parameters on the mechanism of scale formation.

The new designed heat exchanger experimental system was used after carrying out the basic process designs of the system. This system was used to study the effect of the temperature (40-90 °C) and water flow rate (0.6-1.2 L/min) on the total hardness with time as a function of precipitation of hardness salts from water and scale formation.

Different magnetic field designs in the heat exchanger experimental system were used to study the effect of magnetic field design and strength (200-500 Gauss) on the total hardness with time as a function of precipitation of hardness salts from water and scale formation.

***Keywords*:** scale formation, heat exchanger.

Introduction

In many of the application of heat transfer plants, one or more of the mechanisms of heat transfer (conduction, convection or radiation) may be involved. In the majority of heat exchangers heat passes through a series of different intervening layers before it reach the second fluid. These layers may be of different thickness and different thermal conductivity.

After prolonged usage, solid deposits may form on both the inner and outer walls of the pipes, and these will then contribute as an additional resistance to the transfer of heat. [1]

Generally, water used in commercial application is not pure water but contains a variety of anions, cations, dissolved gases, and particulate matter. When this aqueous raw material is concentrated, blended, pressurized, seeded or pH adjusted, combination as scale forming anions and cations can exceed their solubility limit and deposits can occur.

These water-formed deposits may be reduced or eliminated by the removal of undesirable anions and cations by precipitation or ion exchange reactions soluble or suspended or complex formation. Often the deposition can be controlled by pH adjustment or additives. [2]

Experimental Work

Purpose of investigation

Private companies or some research scientific stations mainly carry out previous investigations on prevention of forming scales process by magnetic field. Detailed information is kept proprietary as (know how). Additional work on the mechanism of scale-Ban is needed since published data on this subject are rather limited.

The purpose of this work is to study the prevention of forming scales on pipes of heat exchangers in a new experimental heat exchanger system and to search for the best design of magnetic field and conditions that can be used. The effect of temperature, time (flow rate of hard water), total hardness, magnetic field strength, surface tension, viscosity, and pH was studied.

Basic process design of system

The components of the systems are shown in the Figure (1), the system consists of:

(a)- Galvanized hard water tank which have 130L volume.
(b)- Magnetic field is used for treatment section of carbon- steel pipe, which have 1inch (2.54cm) diameter and 70 cm length.
(c)- Experimental heat exchanger made of stainless-steel 316L, which used in it an electric heater (3000w) type to heat the hard water, which have 4L volume.
(d)- A.C. Power supply, as variac type (50 BM), which have (0-270) V, (0-25) A, and 7.5KVA from (the Zenith Electric Co. LTD).
(e)- QVF glass condenser used to cool the hard water which has 0.5m length and 2 inch (5 cm) diameter within two sides of coils.
(f)- PVC hard water tank, which have 30L volume.
(g)- Centrifugal pump (Stuart Turner LTD) which has 3-13.7m head, 11.4-54.5L/min and (150-720) GPH.

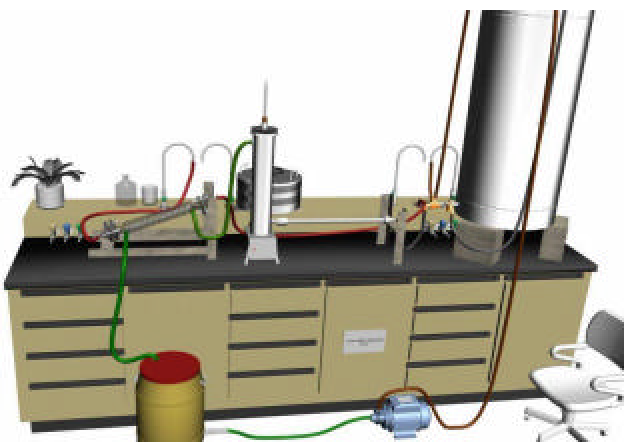

Figure (1) experimental heat exchanger system

Magnetic Field Design

This design is using vertical turn of the coil around the pipe of 30cm length at each of the two parts of the total path show in figure (2) type of coil (SWG30), the magnetic field requirement can be achieved by changing the electrical power from A.C. power supply using the (variances) and. The types of the two variacs is HSN0103 220V plug, 5A and 1.25KVA.An alternative approach is to use electrical current flowing through coils of wire warped around the water pipe to generate the magnetic field .

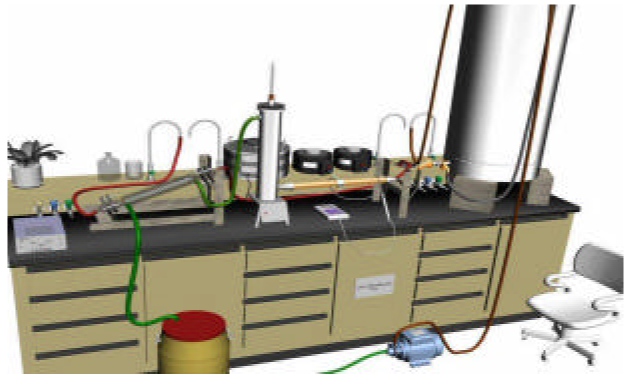

Figure (2) first Design of magnetic field in the system

Measurements

Temperature of water

Temperature of the water was measured by means of mercury in glass thermometer in range (-4 – 250 oC).

Volumetric flow rate of water

Volumetric flow rate was measured manually, using the volumetric flask and stop-watch to measurement the volumetric flow rate of hard water and cooling water in the system or by flow indicators.

A.C./D.C. current

Electric current and voltage measured by means of digital clambmeted type.

pH of water

All pH values were determined by using Metrohm AGCH-9100 Herisau pH meter, and calibrated by standard buffer solution (pH=4,7) depending on the worked zone.

Total hardness of water

The total hardness of water was measured by EDTA titration method; the standard method was used as follows;

(a)- Preparing a standard calcium solution by dissolving accurately weighted 0.5g portion of pure $CaCO_3$ in (40ml) 1M HCl and diluting to (500ml) in a volumetric flask used to calibrated the (Na_2 EDTA) solution, from time to another time.
(b)- Preparing the ammonia buffer solution by dissolving (16.9 g) of NH_4Cl in (143 ml) of concentrated NH_4OH, that first solution, and the following second

solution prepared from dissolving (1.179 g) Na2EDTA and (0.644 g) MgCl2.6H2O in (50 ml) of distillated water, and by adding first solution to second solution, and diluting to (250 ml) with mixing and placing in a closed volumetric flask.

(c)- Preparing Eriochrome black-T indicator by mixing (0.8 g) of eriochrome black-T with (100 g) of NaCl using milling for solid materials.

(d)- Preparing the (0.01M) Na2EDTA by dissolving (3.723 g) dehydrate in distillate water and complete the volume to (1L) in volumetric flask.

The procedure of measuring the hardness of water consists of (10 ml) of hard (tap) water and diluting to (50 ml) by distillated water in a conical flask with adding (1 ml) of ammonia buffer solution to obtain the (pH=10) solution. After that added (0.1 g) of indicator to obtain the red (purple) color, and then titrate with the (0.01 M) Na2EDTA solution. The end point was color changes from win red (purple) calculate the total hardness as CaCO3 is done by using equation (3.1).

$$\text{mg/l Hardness as } CaCO_3 = \frac{AxBx1000}{mlsample} \quad (1)$$

After calibrated (Na2 EDTA) solution with standard calcium solution, then (1 mg) of CaCO3 equivalent to (100 ml) of Na2EDTA solution. If the concentration of Na2EDTA is (0.01M) then (B=1), and A is milliliters of Na2EDTA solution for titration.

Magnetic Field Strength

Magnetic flux density or magnetic field strength was measured by using the Hirst GMO4 Handhels Gaussmeter,

Surface tension of water .

Surface tension of water was measured by means of the surface tension meter type (KRUSS GmbH Hamburg 90324, Germany).

To determine the value of surface tension equation (3.2) was used.

$$s = P \times F \quad (2)$$

Where P is the tensiometer reading, and F is the correction factor, practical was equal to (1.39).

Viscosity of water.

Viscosity of water was measured by means of the viscometer glass tube, type (Volac B5.IP.CF71) size 50. To determine the value of kinematics viscosity equation (3.3) was used. The unit of kinematics viscosity in the relation is (C. Stock or mm2/S).

$$h = \text{time} \times 0.004 \quad (3)$$

X-ray diffraction.

The X-ray diffraction used to determine the type of scale crystals and estimated relative line intensities. This test was carried out in (S.C. of Geological survey and mining).

Water analysis

The analysis of the tap (hard) water which used in the experimental was carried out in (S.C. of Geological Survey and mining) to determined the water content.

Scale crystals photography.

The scale crystals photographed was carried out by using the photomicrograph in (Al-Nahrain University) to obtain the type and shape of scale crystals. By using the light microscope with digital camera type (Olympus, CH40).

Results and Discussion

Scale Formation Stage

Before the treatment by magnetic field, the formation of scales conditions and the behavior of hardness salts in the water were studied. From the water analysis results, the water contents (cation ions, anion ions, impurities, T.D.S.….etc) can be determined the type of scales. The formations of scales depend on the temperature and volumetric flow rate of hard water (tap water) in the system. The scale formation is also a function of the precipitation of hardness salts in the water as found in the total hardness of hard water testing.

The viscosity, surface tension, and pH of hard water also depend on the temperature and water contents. The influences of these properties were tested. After the system reached to steady-state (closed system), these testes were carried out as a series of (6 hours) cycles for one day. After the formation of scales, the shape and type of scales were determined by using X-ray diffraction and photomicrograph at the same temperature.

The Best Process conditions

When studying the influence of temperature and flow rate of hard water in the system on the total hardness and physical properties of hard water, the best process conditions can be determined by the following factors:

a-The explanatory effect on the total hardness of water.

b-The controllability on the condition system.

c-The suitable design of magnetic field.

The best process conditions (temperature) were processes at (70) o C, figure (3)due to the best process and best volumetric flow rate of hard water in the system.

After long time (50-60 day) the scale were form on the hot surface of the system, samples were taken and analysis using x-ray diffraction test and photomicrograph to determine the type of scales, intensity, structure of scale crystals, and shape of crystals, figures (4 and 5).

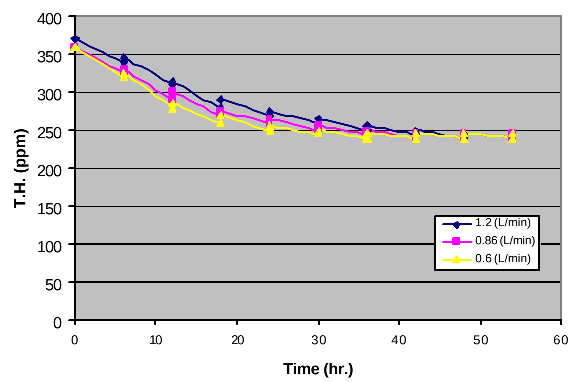

Figure (3) Total Hardness (T.H.) VS. Time at 70 c

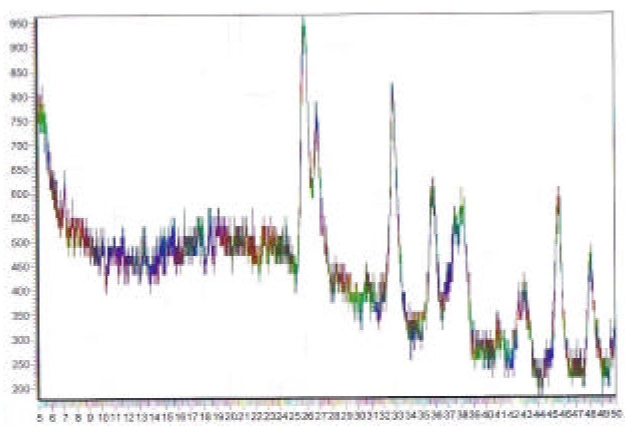

Figure (4) X-Ray diffraction for scale samples at heater surface of heat exchanger without magnetic field

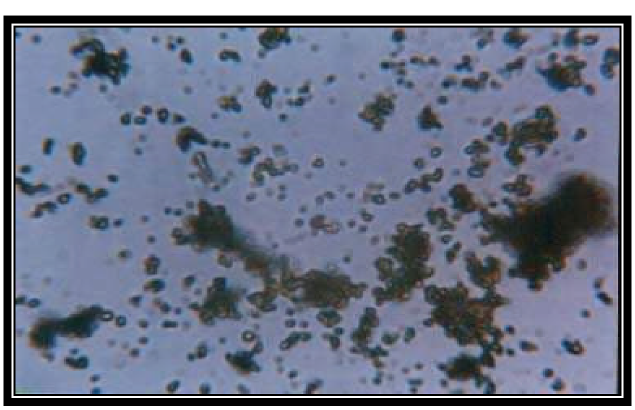

Figure (5) Photomicrograph of scales from heater surface without magnetic field

Effect Of Magnetic Field Strength

The magnetic field strength was found to affect the precipitation of hardness salts, crystallization stages crystal structure and corrosion of metals.

Effect on the Precipitation

The magnetic field strength influences the precipitation of hardness salts in water. The magnetic field strength effectiveness due to the decreasing the precipitation of hardness salts. It can be seen that an increasing in the total hardness of water as in Figure (6). The magnetic field strength which was (400-500) Gauss. This phenomenal appears at the same case for the effect of flow rate of hard water, when decreasing the volumetric flow rate of hard water leads to increasing the effect of the magnetic field system. Shows plotting the (T.H) with temperature.

The precipitation of hardness salts using magnetic field will lead the magnetic field to affect the physical properties of water such as decreasing the surface tension and increasing the viscosity of water .

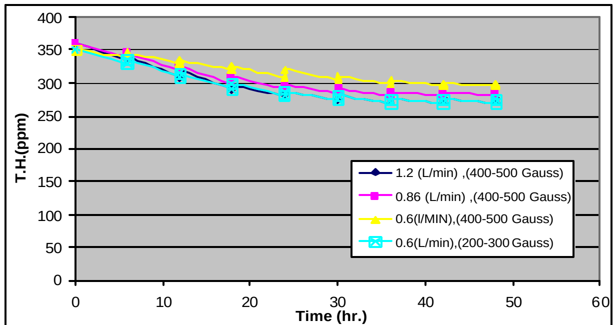

Figure (6) Total Hardness (T.H.) VS. Time at 70 c

Effect On The Crystallization

The magnetic field strength influences the crystallization stage. When increasing the strength and contact area of magnetic field will effect on the crystallization stage and cause it to be more unstable and decreasing the intensity of crystals as (aragonite) shown in x-ray diffraction figure (7). It was found that at high magnetic field strength and large contact areas between the magnetic field and the hard water will cause bounded the crystallization stage at least level and prevention it.

Effect Of The Crystal Structure

Using the magnetic field will affect the crystallization behavior and converted it from calcite to aragonite, which has a minor stability and un charges crystal germs. At greater quantity of germs the more fine amorphous crystal mud was formed as shown in photomicrograph figure (8).

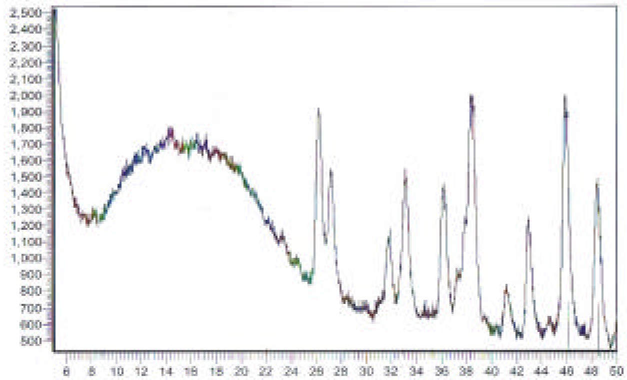

Figure (7) X-Ray diffraction for scale from the heater surface with magnetic field

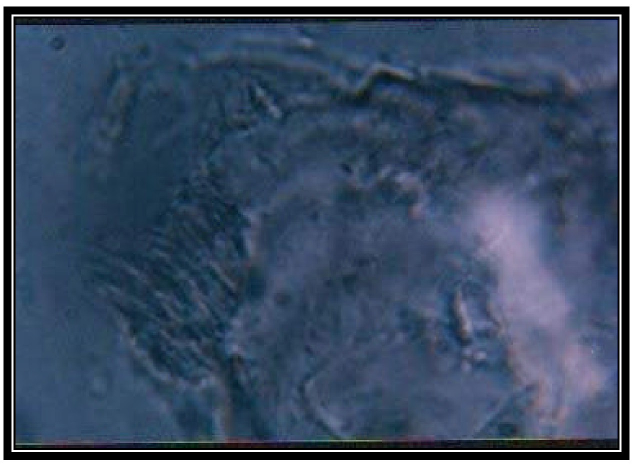

Figure (8) Crystal mud photomicrograph

Effect On The Corrosion

The magnetic field used on the system was influenced the rate of corrosion and decreased it to a minimum rate (prevented it).

Conclusions

1-The new heat exchanger experiments system design was very suitable system to study the scale formation.

2- Scale formation at inverse solubility region is not dependent on the water content and temperature but influenced by water flow rate and time.

3-The amount of scale formation increased with increasing the hardness of water and time of heating.

4-The effects of magnetic field strength and design on the scale formation at all stages showed that a suitable strong magnetic field cans prevent the formation of scales.

5-The prevention of forming scales depends on the water flow rate and magnetic field strength and design.

6-The strong permanent magnetic field was found to be magnetic field design in order to prevent the scale formation.

7-Using a suitable strong magnetic field will reduce the rate of corrosion of the metal and prevent it.

8-The magnetic field strength depends on the water flow rate in the system.

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