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Original Article

Thermal Plant Condenser Tube Advanced Applied Research on Scale Formation with and Without Magnets in the Water Lines

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Abstract - *The current study assessed the application of magnetic water treatment to get rid of scaling salts such as chloride, carbonate, and sulfate salts of Ca2+, Mg2+, Fe2+, and Fe3+ cations from both pipelines well as power heat-exchanger devices. Magnetically assisted water treatment technologies are compared to typical treatment systems in terms of performance. The advantages and restrictions of magnetic field application are investigated to determine the environmental benefits. The important conclusion of the study is that using a magnetic separator reduces the quantity of magnesium, calcium, and chlorine that get accumulated on the surface of the tube; nevertheless, chromium remains in the deposit, increasing the scale deposit weight. The application of superoxide solution is also important in changing biological activity, which causes biological sediments on the walls of the condenser tube and the sticky biofilm coating produced by bacteria upon the tube wall.*

Keywords - *Heat exchanger, Magnetic separator, Performance efficiency, Salts, Scale deposition.*

1. Introduction

There has been a drastic increase in power demand in recent years, owing to the uninterrupted expansion of industries. This situation demands energy creation at an ideal level to meet the demand and power plants to be built to meet a certain energy objective [1]. Any equipment underperforms from its standard outputs and produces losses if it operates continuously [2]. In thermal power plants, steam condenser, the other name for the surface condenser, is used. This is a water-cooled shell and tube heat exchanger applied in the condensation of exhaust steam from the steam turbine. The gaseous stream gets converted into liquid at lower than the atmospheric pressure.

Manufacturers and researchers have improved surface condenser performance based on design features such as changes in material, tube configuration, and flow arrangement [3, 4]. When condenser tubes get fouled with deposits over time, the heat does not get transmitted efficiently while the cooling process fails. Further, the unit production tends to lose. In addition, because the deposition material damages the tube wall, under-deposit corrosion can develop in condenser tubes [5, 6]. Other components in the unit system may be harmed due to a breach or tube leak. Though it is an unwanted event, cooling water enters the condensate, travels across the Boiler, and moves into the turbine. This causes the boiler tube and turbine blades corrosion and erosion and pays the way for major repair and breakdowns of the Boiler and turbine [7,8].

When any material gets deposited upon the heat transfer surface, it inhibits the heat transfer process. This is accounted for in heat transfer calculation as "thermal resistance." Scale formation is common in condensers, evaporators, and chiller heat exchangers used in air-conditioning systems, desalination, power industry, and process industries. It is estimated that about 30% of the additional heat transfer area is required to compensate for scale formation. Scale formation is commonly due to the deposit of calcium carbonate and magnesium sulfate [9,10]. It increases energy consumption, so it is of utmost importance to mitigate the scale formation.

The cooling water tends to possess different types of contaminants based on the source of cooling water and the plant's geographic location. Condenser tubers usually get filled up with carbonate deposits, whereas microbiological particulates tend to populate the interior walls of coastal thermal plant pipes. The water resources vary for thermal plants, i.e., fresh, brackish, or seawater. So, the challenges arise based on the source of cooling water [11]. Particulate fouling is a phenomenon in which the water contaminants accumulate on the surface of the condenser tube. These particulates can be of any type, such as bio-growth or natural sediment. Fouling scenarios tend to reduce water flow inside the condenser [12]. If left untreated at appropriate timing, particulate fouling incurs heavy loss by damaging condenser tubes and nearby components.

Scale deposits are often observed in setups that deal with high-temperature. When scale deposits increase, it severely deteriorates the heat transfer process in condenser tubes. It is possible to eliminate these scale formations found inside condenser tubes through traditional mechanical tube cleaners that use precision cutting blades. These blades break the hard shell-like coating of such scales and ensure the tube wall is safely handled. When cooling water contains heavy volumes of bacterial content, and when the tube experiences a low-velocity flow, it is likely to induce microbiological fouling [13, 14]. Such fouling scenarios tend to exhibit a heavy accumulation of particulates since the fine matter easily sticks with bacterial biofilm present on the tube wall. In worst-case scenarios, the base metal of the condenser tubes is corroded away by corrosive bacterial by-products secreted by the thickening deposits.

In a condenser unit, numerous condenser tubes exist with a common inlet tube sheet of the condenser. When macro fouling and debris occur at this crucial gateway, it tends to diminish the efficiency of the condenser. In line with the plant's water source, debris tends to contain leaves, mud, sticks, seagrass, and sometimes, large particulates too from the cooling tower. The highest contributors of Macro fouling include shellfish and aquatic wildlife when using seawater for cooling purposes. Despite the filters installed at the majority of the plants, debris often ends up in the tube sheet and blocks the passage either partially or fully. This, in turn, diminishes the flow of water through condenser tubes.

Partial flow blockages act as a breeding ground for the particulates to accumulate. Further, the local flow around such deposits results in corrosion and erosion. Both debris screens and filters must be inspected at regular intervals and cleaned appropriately to ensure the tube sheets are free from debris and fully functional. In general, the type of condenser tubes, their composition, and their characteristics must be thoroughly studied to understand the complex behavior of fouling. The current research work makes use of a special membrane filter.

The condenser tubes used in the power plant are mostly made up of three materials, namely copper, stainless steel, and titanium [15-17]. Being an antimicrobial material by nature, copper-made condenser tubes prevent some microbes from flourishing, whereas they are likely to get deposited with hair-like oxides. This, in turn, interrupts the transfer of heat in case of non-treatment at the appropriate time. Stainless steel tubes are used across the power plants operating in India since it exhibits high performance. In maintaining these high-performing tubes, slime management and microbiological deposit removal are the key takeaways. Titanium condenser tubes are a recent addition to the production of condenser materials.

1.1. Fouling and its consequences

Fouling brings a series of economic consequences to the power generation plants, which bear the brunt of this phenomenon. When the condenser tube fouls and the tube performance goes south, it economically impacts the power generation plants. It increases turbine back pressure which in turn enhances the unit heat rate. The study at Ennore power station shows that the condenser tubes of the Plant Air conditioning system are very badly affected by scale formation and corrosion. If severe fouling occurs, that can bring down the tubes, and then serious consequences arise since other equipment in the unit gets affected by the induction of contaminants into condensate. It is important to conduct efficient diagnostics to find the type of tube fouling, and its severity since the stakes involved are high. Fouling conditions and their impact can be easily diagnosed with the help of efficient diagnostic approaches such as baroscopic analysis, computer-based performance analysis, deposit sampling, and fouling monitors. Tube cleaning is the next step to recovering from the situation as soon as the analysis yields many insights about the nature and severity of fouling. Four key cleaning approaches are generally followed to clean the fouled tubes: mechanical tube cleaning, hydro lancing, continuous online cleaning system, and chemical dissolution. The usage of chemicals is a complicated process.

1.2. Importance of cleaning

Every fouling scenario demands the development of a novel chemical cleaning strategy. After the cleaning is over, there must be cost-effective ways to dispose of the used chemicals, legal guidelines on the type of chemicals to be used, and the place of treatment to avoid environmental concerns. In case of using chemicals to clean the tubes, gallons of water are to be used for flushing the chemicals out of the tube. The residual deposits can be removed while the tube metal can be saved from getting acid degradation. On the other hand, the usage of water per MW production increases. The hydrolance cleaning process can be made effective based on the deposit and fouling conditions of the tubes, random lance travel speed, and the type of nozzle used. Water is gushed during hydroplaning at a pressure of 20,000 psi or more. The hydrolase method cannot be applied to wall thinning scenarios, tube-to-tube sheet joints, and tube coatings with this high pressure. In the case of places where the water is scarce, it is not wise to spend 2 million gallons of water to clean a unit with 5000 tubes through the hydroplaning method. So, hydro lancing, continuous online cleaning systems, mechanical tube cleaning, and the use of chemicals are complicated processes to be used in cleaning and applied after considering different parameters. Magnetization of water to descale is one of the Idle solutions to this scaling problem in Condenser tubes. The concept of minimizing scale formation was evaluated in this study, which employed a permanent magnet to magnetize the waterline. To test and validate the claim and study the influence of MF Magnetic Force on these water characteristics, an experimental setup was designed and fabricated. Different water sources have been experimented with, and the results are more encouraging with the claim to use a magnetic separator to reduce water consumption and chemical handling. A study of Magnetic Molecular converter reveals that it effectively changes the structure of the scale-forming ions of water, thereby preventing scale formation over heat transfer surfaces. Also Study on Superoxide solution produced from a reactor made by the researcher proves that it destroys scale-forming microbe present in the water, thereby preventing bio scale formation over heat transfer surfaces. A study on the String membrane fine filter is also carried out. It proves that it removes turbidity, dirt, sand, flakes, and coagulated substance of the structurally altered scale-forming ions and sediments deactivated coagulated ions in the circulating water.

2. Objectives and Methodology

The objective of the work is to study and find a comprehensive solution for the condenser tube descaling. It is proposed to achieve by

- Preventing Biofilm, Algae, and other micro-organism formation by using Superoxide solution generated from a special Reactor.
- Preventing the formation of scale due to salt making chemical elements present in the water and preventing corrosion in the condenser tubes by using Magnetic force generated from a Magnetic molecular separator.
- Preventing debris, solid particles, and coagulated substances from the condenser cooling circulating water by using a special rare earth material coil filter.

2.1. Preventing Biofilm, Algae, and other micro-organism formation in Condenser Tube

In this study, a Superoxide solution is used to avoid microbe scaling. This technology effectively replaces the existing chemical-based chlorination system conventionally being used in thermal plants. Produced on-site by activating water, effectively controls total microorganisms in water media, precipitation of salts and heavy metals, and biofilm formation in the cooling system. With this solution, the cooling water PH can also be adjusted to avoid corrosion in the condenser tube. A powerful mixed oxidizing agent with pH 5-7 and REDOX POTENTIAL + 900mv is produced to control microbe scaling. This superoxide solution killing effectiveness of Bio disinfectant is 99.99%.

Microorganisms need a stable energy supply for survival, like other organisms. The microbes can't survive in an aqueous environment in which the electrical charge is high due to the destabilization of the superoxide solution. For instance, a million E.coli strains can be easily killed by superoxide solution water in 30 seconds since it has an energy of +900 mV, whereas, in normal tap water, it is only +200 mV. Likewise, many other microorganisms are eliminated. A mixed Oxidizing agent is synthesized based on unique electro-chemical conditions utilizing water. A specialized Reactor is made to generate superoxide solution. The Machine Produces a Mixed Oxidizing solution, and it is a reducing agent of the highest quality and efficacy. This is tested in various approved Labs.

Mixed Oxidizing agent /Bio disinfectant (electrically neutral) and (OCl ions which are negatively charged) produce free chlorine in case of bonding with each other. This leads to the killing of microbes present in the condenser cooling water. Being a highly reactive compound, the mixed oxidizing agent is a strong agent that kills microbes compared to hypochlorite. It splits into atom air oxygen (O) and hydrochloric acid (HCl) when hydrolyzed. Between the two, the oxygen atom is an excellent disinfectant. Superoxide solution possesses extraordinary microbial killing characteristics since the free oxygen atoms have high oxidizing power in addition to atoms' chlorine substitution reactions. Pathogens' cell wall is generally negatively charged. So, neutral hypochlorous acid can easily penetrate such negatively-charged cell walls of the pathogens, rather than already negative hypo chloride ions and other such chemicals. The mixed oxidizing agent can pass through cell walls, slime layers, and protective layers of the microbes and efficiently kill the pathogens. Microorganisms tend to die or become impotent to reproduce.

2.2. Preventing the formation of scale due to salt-forming chemical elements present in the water and prevention of corrosion in the condenser tubes

Water is considered a dilute colloidal solution characterized by electrostatic charges of its particles relative to the solvent (H2O). The colloid's stability is decided by electrostatic repulsion versus intermolecular attraction forces. The system behavior is influenced by the external Lorentz forces created by the magnetic field produced by a molecular separator. In physical sciences, when electric and magnetic forces are integrated on a point charge, it produces Lorentz force owing to electromagnetic fields. A particle charged with q travels in an electric field E with v being the velocity and B being the magnetic field, tend to experience force as given below Eqn. (1).

$$F = q\,E + q\,(v \times B) \qquad \ldots\ldots\ldots\ldots(1)$$

As per the formula, electromagnetic force on charge q is nothing but a product of force in the direction of electric field E, the magnitude of the field with the quantity of charge, and a force at right angles to the magnetic field B and the velocity V of the charge, proportional to the magnitude of the field, the charge, and the velocity. This basic formula varies, which details the magnetic force upon the current-carrying element named after Laplace force.

As mentioned earlier, the stability of the colloid present in the cooling water is dependent upon electrostatic repulsion vs. intermolecular attraction forces. When the magnetic force is introduced into water by the molecular converter, the magnetic force influences the electric force of the scale-forming chemical elements present in the water. It deforms it, by which the lattice structure of the scale-forming molecule is changed. This deformation results in the momentary reduction of the repulsion barrier. Accordingly, the coagulation tendency of the dispersed particles gets increases.

The particles get redirected, which in turn enhances the frequency. Based on this frequency, the oppositely charged ions collide and integrate to produce a mineral precipitate or an insoluble compound. As the reaction occurs in a low-temperature region of the heat exchange system, the scale formed remains non-adherent. The Magnet in the Magnetic converter is arranged by considering the type of scale forming element present in the water, the direction of the flow of water, the speed of the water, and the quantum of water flow in the magnetic region such that the magnetic intensity changes the structure of the scale making elements/ions. The converted cations of calcium $Ca2+$ and magnesium can no longer be formed as a hard calcite scale over heat transfer surfaces of the tubes. Still, fall as sediment in the form of a large coagulated lump of amorphous needle-like Aragonite masses.

When the unit works continuously, new calcite crystals do not occur. Under the influence of the unit, the old scale will break and get removed by the water flow. These non-sticky aragonite crystals will flow with water as precipitates and settle down as coagulated masses. Also, a thin oxidized layer is formed in the condenser tube, which prevents the tube from corrosion. The old scale will break and get removed by the water's flow. These non-sticky aragonite crystals will flow with water as precipitates and settle down as coagulated masses. Also, a thin oxidized layer is formed in the condenser tube, which prevents the tube from corrosion.

2.3. Preventing debris, solid particles, and coagulated substances from the condenser cooling circulating water

The water flows through the pores of an ultra-thin string filter which is continuously in hypervibration. This hyper-vibration prevents sedimentation of scale on the filter surface. The pores of the filter element will not plug water flow and allow pure water to pass through, leaving scale-forming ions and other mechanical impurities to sediment in the bottom portion called the bulb. Due to this, filter element life is enhanced compared to conventional filters/membranes. An industrial main-line platinum filter with a direct flow can be used for preliminary treatment of water from mechanical impurities and successive filtration of deactivated ions.

DESIGN: String Membrane Fine Filter consists of a casing with a clutch, a string filter element, a generator, a drain cock, a bulb, and a manometer. The drain cock provides direct flushing of the filter. The platinum filter is easy to maintain and operate and has compact dimensions. The platinum filter element is made of stainless and noble metals high-alloy steel in the form of a string wound on the frame. The body and filter flask is made of stainless medical steel AISI 304; Filtering stringed element of fine cleaning from high-alloy of platinum and stainless steel; NBR seals. The platinum filter has two modes of operation: filtration and washing. Water penetrates through the filter element inward in the filtration mode and comes out already cleaned. All mechanical impurities remain outside the filter element at the bottom of the bulb. The flushing mode is switched on / off by opening the drain cock at the bottom of the flask. During washing, the water stream removes all accumulated debris both from the surface of the filter element and from the bottom of the bulb. The operation of the drain cock can be controlled manually or automatically.

2.4. Preventing debris, solid particles, and coagulated substances from the condenser cooling circulating water

The most common materials used in the condenser are copper-nickel alloys, brass, titanium, stainless steel, and ferritic stainless steel. Generally, most Indian thermal stations use Stainless steel tubes. For the research purpose, the experimental setup is designed and fabricated based on the parameters of the condenser cooling water system of the Alathiyur 2 x 18MW thermal power plant. Like the SS304 condenser tube, the speed of water in the testbed is taken as the Alathiyur Thermal plant condenser tube. The same water taken from Alathiyur is used for testing purposes.

Basic Assumption for the design of Test Bed:

- Sample water taken from the plant quality is not changed during the transportation.
- The heater in the testbed stimulates the same temperature of the cooling water at the thermal plant
- The speed of the water in the testbed is maintained the same as that of the plant by using the flow meter, pump, and flow valve.

2.5. Preventing debris, solid particles, and coagulated substances from the condenser cooling circulating water

Based on the input received from the Thermal Plant. The experimental bed is designed as fallow. Circulation Water used in the testbed is shown in the following Tables:1,2,3.

Table 1. Existing circulating water chemistry 2 x 18mw

S. No	PARAMETER	UoM	Raw water	CT Makeup water after blending	Circulating water
1	pH		7.96	7.96	7.93
2	Conductivity @ 25ºC	micro/cm	1110	1250	4000
3	TDS	ppm	716	750	2400
4	Total Alkalinity	ppm	220	259	148
5	Total Hardness as CaCO3	ppm	250	81	462
6	Ca Hardness as CaCO3	mg/l	150	49	277
7	Mg Hardness as CaCO3	mg/l	100	32	185
8	Chlorides as CaCO3	mg/l	210	326	936
9	Silica as SiO2	mg/l	68	71	181
10	Total Phosphate as PO4	mg/l	- -	--	7.26
11	COC				2.55

Table 2. Power plant specification concerning cooling water system

S. No	Parameter	Specification
1	The capacity of the power plant	18 MW x 2 + 6MW x 1
2	Schematic diagram of cooling water circuit mentioning the flowrate	2200 m^3/hr per Cell
3	OD, Thickness, and material of the CW pipe circuit after CW pump.	800 mm, 8 mm, MS
4	The total volume of cooling water	8800 m^3
5	Schematic diagram of makeup water pipe circuit mentioning the flowrate	110 m^3/hr
6	OD, Thickness, and material of makeup water pipe	150 nb,10 mm, UPVC
7	Source of cooling water	Raw water from the Softener plant
8	Complete water chemistry of a. Makeup water b. Circulating water	Water report Sheet
9	Total microbial count in makeup water and circulating water	N/A
10	Is an automated ball cleaning system installed	No
11	Bay dimension and CT basin dimensions	Bay-44.28 m X 4.0 m X 2.65 m, CT-44.28 m X 11.07 m X 2.65 m
12	Present Circulating water temperature at the inlet of condenser and outlet of the condenser as well as design inlet and outlet temperature	Present- Inlet-35ºC, Outlet-45 ºC, Design- Inlet-33 ºC, Outlet -42 ºC

Table 3. Power Cooling Tower Water Analysis Report

Parameter	Units	CT make up	CT circulation
pH	..	7.96	7.93
Cond	µs/cm	1250	4000
TDS	ppm	750	2400
Silica	ppm	71	181
Total Hardness	ppm	81	462
Ca. Hardness	ppm	49	277
Mg. Hardness	ppm	32	185
Chloride	ppm	326	936
Total Alkalinity	ppm	259	148
COC	ppm	…	2.55
PO4	ppm	…	7.26

3. Experimental Setup Design and working Procedure

Based on the above data Experimental bed was designed into two different flow configurations to evaluate the effect of the magnetic field by introducing a magnetic molecular separator in the pipeline flow. One pipeline is fixed with a magnetic molecular separator, whereas the other pipeline is not fixed with any magnetic molecular separator. Fig. 1 shows the Photograph of the experimental setup. Fig. 2 represents the schematic representation of the setup in addition to a magnetic separator. Fig. 3 portrays the flow arrangement without a magnetic separator.

Fig. 1 Photograph of the experimental setup

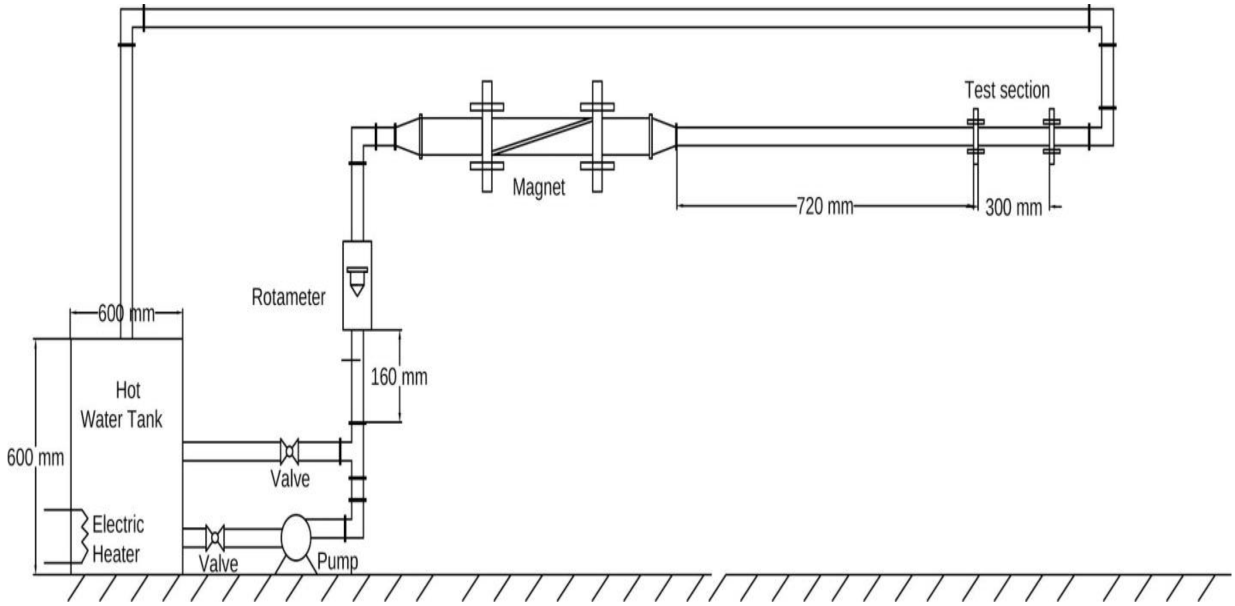

Fig. 2 Schematic representation of the setup in addition to a magnetic separator

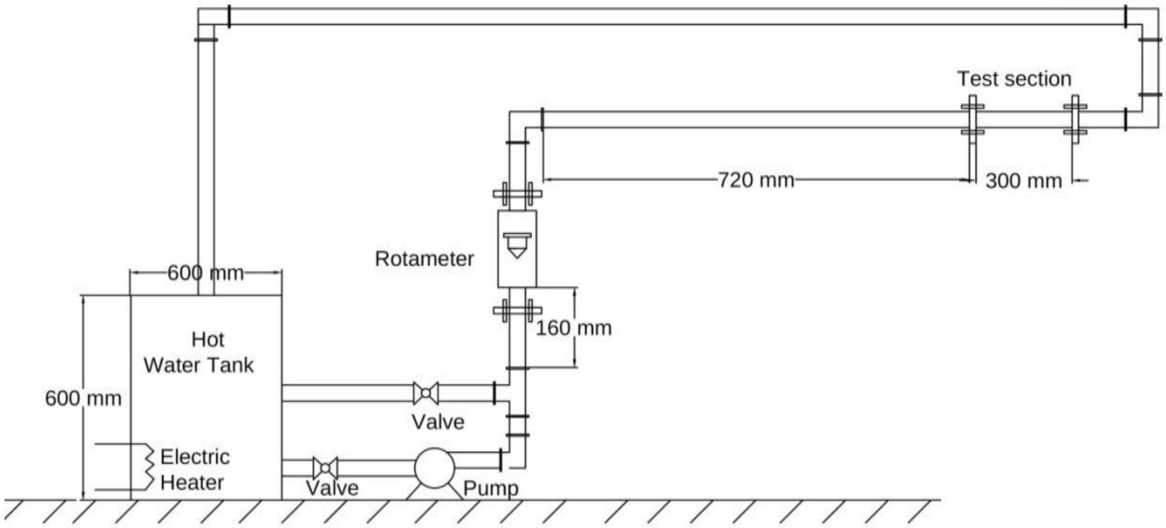

Fig. 3 Flow arrangement without a magnetic separator

Clamps were used to secure the180 mm test section pipe to the flow arrangement for simple removal and re-fixing of the test pipe. The test part is placed so that the flow has completely evolved before arriving at the test section. Immersion electrical heaters with a relay and a temperature sensor keep the water temperature constant at any specified magnitude. A rotameter monitors the water flow rate, and valves are used to regulate it. The design parameter specification of the Magnetic separator is given in Table 4. The technical specification of the experimental setup is given in Table 5.

Table 4. Design specification of the Magnetic separator

Design Parameters	Values	Units
The inner diameter of the magnetic separator	0.039	m
Area of a cross-section of magnet separator, A_{ms}	1.194×10^{-3}	m^2
Magnet diameter	0.013	m
Area of a cross-section of the magnet, A_{mag}	1.327×10^{-4}	m^2
Net area of the cross-section for flow = A_{ms} - 2×A_{mag}	9.29×10^{-4}	m^2
Permissible velocity inside the magnetic separator	0.7 – 4	m/s
Tube ID	0.02397	m
Velocity inside the tube (from condenser datasheet)	2	m/s
Flow rate, Q = AV	9.025×10^{-4}	m^3/s
Velocity inside the magnetic separator, V_{ms}= Q/A_{ms}	0.97	m/s

A weighing balance with a precision of 0.001 g is used to determine the test sections' deadweight (before starting the run). The system is set to run for 40 hours at an interval of 8 hours per day at a constant flow rate of 60 LPM and a water temperature of 42.5oC. The setup is dismantled, and the test sections are allowed to dry. The weight of the test section is taken, and the difference from the dead weight is noted. The method is continued until a total operation time of 140 hours per session is reached. On the inner tube surface of both test tubes, a scale deposit is collected. The researcher removed the sediments from the bottom of the hot water tank for which Funnel and filter paper arrangement were used. The water gathered from the hot water tank, the water after filtration, and the sediments collected on the filter paper in pictures are used for the structural analysis. Scanning Electron Microscope (SEM) images are used to investigate the mineralogy of scale deposits and sediments.

Table 5. Technical specification of the experimental setup

Hot water bath	200 liters
Heater capacity	10 kW
Rotameter	Make: FM Engineers, scale: 10-100 LPM, connection: flanged, 1.5”
Water pump	Make: Kirloskar motor, power: 1 HP, Kirloskar pump, head: 23 m, monoblock centrifugal pump
Temperature controller	Make: Sriram, Accuracy of ±1°C, sensor- PT100
Test section	180 mm, SS 316

Fig. 4 Pipe without magnet having sediments, Pipe with magnet almost without sediments

The study was conducted to overview the mechanisms involved in the early stages of scaling (induction, nucleation, and crystal growth) on stainless steel pipes AISI 304 used in the condenser tube of most of the thermal stations (uncoated and coated). Scanning Electron Microscopy, as it is a well-established tool for monitoring the scaling process, is used. While varying experimental conditions, temperature, turbulence, and water hardness, the sediment formation on the test pipe is analyzed. Various factors impact the formation of calcium carbonate scales, such as temperature, time, nucleation, and induction. It was established that the adsorption rate was almost three times higher at 60 °C than at 25 °C for stainless steel. An assumption was made that heterogeneous nucleation is the one that occurs most and that the roughness of the surface has an impact on the scaling.

4. Result and Discussion

4.1. Mineralogy Study of Scale formation

The researchers conducted the mineralogy study of the scale formed on a test tube and sediments collected from the hot water tank. The tube was allowed to dry before removing the scale from the tube surface. The scale has to be removed carefully to avoid the scraping of metal from the tube surface, which can affect the elemental analysis of the scale sample. Sediment from the water tank is collected using filter paper. Filter paper is then dried, and the sediment cake is removed from the paper for further analysis. Table 6 shows the elemental analysis of scale sample from tube surface and sediment from hot water tank obtained from Energy Dispersive X-Ray Analysis, EDAX.

Table 6. Elemental analysis of tube scale and sediment from the water tank

Sample	Element	Weight (%)
Tube scale (With magnetic separator)	Cr	81.6
	Ca	1.1
	Mg	0
	Cl	0
Tube scale (Without magnetic separator)	Ca	1.8
	Mg	0.6
	Cl	0.7
Sediment (With magnetic separator)	Cr	0.9
	Ca	59.7
	Mg	1.9
	Cl	0
Sediment (Without magnetic separator)	Ca	5.36
	Mg	3.28
	Cl	1.16
	Cr	1.1

4.2. Energy Dispersive X-Ray Analysis

This technique provided a comprehensive sample map after evaluating the near-surface elements. The analysis evaluated the elemental composition at various positions. EDXA is associated with electron microscopes have the potential to conduct elemental analysis on areas as small as several nanometers. The electron beam affects the surface of the material. At the same time, the X-rays penetrate deep into the particle to find the properties of the element present above and nearby the surface of the sample. In EDXA, it is possible to identify the elemental composition of individual points or map out the aerial distribution of elements with the help of the scanning capability of the electron microscope. Sediment and scale samples were taken from the flow arrangement with the magnetic separator and the flow arrangement without a magnetic separator.

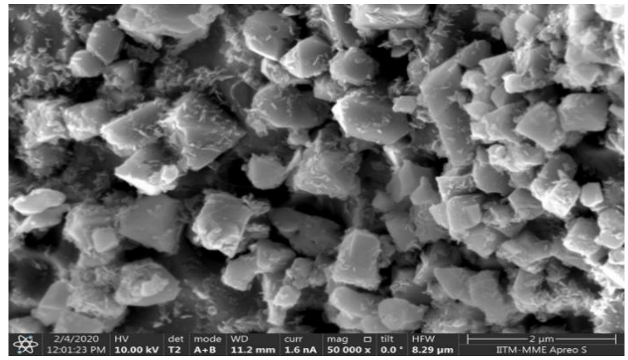

Fig. 5 SEM image of scale deposit from a test tube of system with 0ut magnetic separator

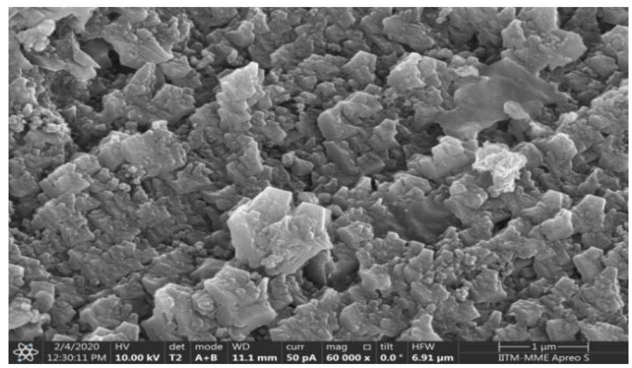

Fig. 6 SEM image of sediment from the hot water tank of system with magnetic separator

Fig. 5 and 6 respectively show the SEM images of tube scale deposit from a test tube of system with 0ut magnetic separator and sediment from flow arrangement with magnetic separator. It was observed from the mineralogy study that magnesium and chlorine salt is absent on the tube surface with a magnetic separator. In contrast, these salts are observed in the EDAX analysis of tubes from flow arrangement without a magnetic separator. The presence of calcium salts is reduced from 1.8 wt. % to 1.1 wt.% with the application of a magnetic separator. However, high levels of chromium salt were observed in the tube surface of flow arrangement with magnetic separator because of chromium present in the metal alloy of the pipe. The deposit was black. Scale deposit from the tube without a magnetic separator appeared to be brown.

There are different categories within which a crystal structure is formed. The 14 Bravais lattices describe these structures, explained in more detail in [11–13]. Most of the time, calcium carbonate appears in three anhydrous crystalline polymorphs Vaterite, aragonite, and calcite. Calcite belongs to the rhombohedral crystal structure, Aragonite to the orthorhombic structure, and Vaterite to the hexagonal structure. In aqueous solutions, polymorphs exhibit increased stability, whereas their solubility decreases in the order of vaterite → aragonite → calcite [15]. Environmental conditions like pH, supersaturation degree, and temperature decide the polymorphs' stabilization and crystallization discussed above [14,15]. Calcite has the highest stability among other calcium carbonate crystal structures and is the most common. It usually precipitates at lower temperatures. Ca2+ ions are consumed throughout the precipitation process, which reduces supersaturation, and more calcite is formed. With the increasing temperature in water, calcite becomes less soluble but can be dissolved with the help of acid. Natural calcite most often occurs in sedimentary rocks, such as limestone [15,19].

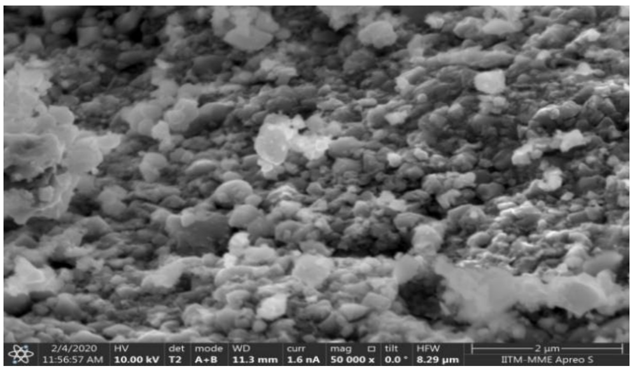

Fig. 7 SEM image of scale deposit from a test tube of the system without magnetic separator

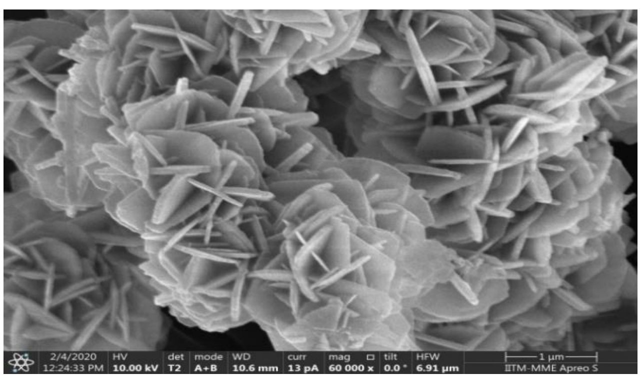

Fig. 8 SEM image of sediment from the hot water tank of system with magnetic separator

The crystal structure of calcite looks like a distorted cube (fig 5). Aragonite is one of the metastable crystal structures of calcium carbonate and is most often formed at high temperatures. Aragonite is "needle-like" (fig 8) but can be changed to either "flower-like" or "flake-like" depending on the crystallization conditions [14,15,16–18]. In this experiment, instead of temperature raise, a magnetic force was introduced by placing a permanent magnet in the path of water flow. This magnetic force, i.e., Lorentz forces from the permanent magnet placed in the path, creates a magnetic field that influences this system's behavior.

Here calcite salts of calcium carbonate are carried in the water flow, which causes a velocity for the electric force present in the Ca2+ ions. As explained, the stability of the colloid depends on electrostatic repulsion versus intermolecular attraction forces. The magnetic force available in the experimental set up by molecular converter the force influences the electric force of the scale-forming calcium chemical elements of Calcite structure (fig 5) present in the water. It deforms to Aragonite structure into the orthorhombic (fig 8). It is one of the metastable crystal structures of calcium carbonate. Aragonite is "needle-like" but can be changed to either "flower-like" or "flake-like," depending on the crystallization conditions.

Similarly, Fig. 7 and 8 show the SEM images of tube scale with magnetic flow arrangement and sediment from flow arrangement without a magnetic separator. The SEM images show the crystalline structure change into a needle-like structural form. This deformation results in the momentary reduction of the repulsion barrier. Accordingly, the coagulation tendency of the dispersed particles gets increases. The particles get redirected, which in turn enhances the frequency. Based on this frequency, the oppositely charged ions collide and integrate to produce a mineral precipitate or an insoluble compound. As the reaction occurs in a low-temperature region of the heat exchange system, the scale formed remains non-adherent at the condenser tube.

The total dissolved salt in the hot water tank with a magnetic separator after 143 hours of operation is 243 ppm, whereas a hot water tank without a magnetic separator is 164 ppm. Levels of magnesium in the hot water tank of flow arrangement with a magnetic separator were only half of that in the case of the water tank of flow arrangement without a magnetic separator. Chlorine was absent in the sediment of the magnetic separator flow arrangement. Fig. 9 and 10 show the EDAX data of tube scale and sediment from flow arrangement with magnetic separator. Fig. 11 and 12 show the EDAX data of tube scale and sediment from flow arrangement without a magnetic separator.

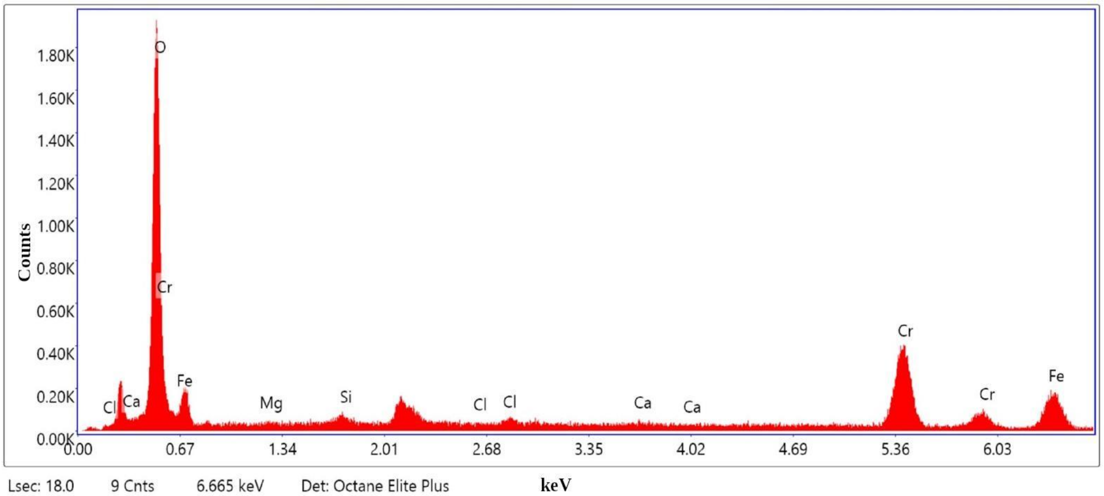

Fig. 9 EDAX spectrum revealing the major elements in scale deposit from test pipe of system with magnetic separator

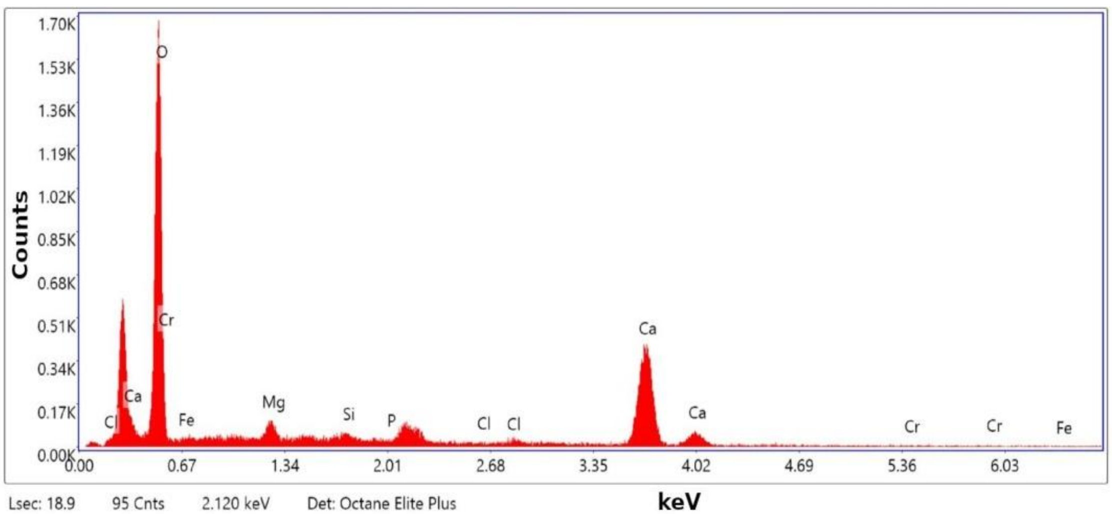

Fig. 10 EDAX spectrum revealing the major elements in scale deposit(sediments) from the hot water tank of system with magnetic separator

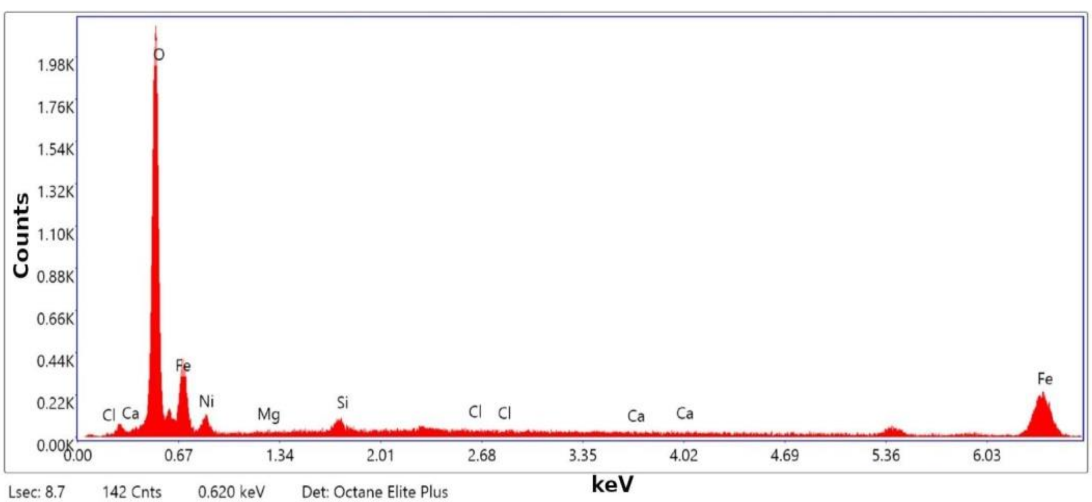

Fig. 11 EDAX spectrum revealing the major elements in scale deposit from test pipe of the system without magnetic separator

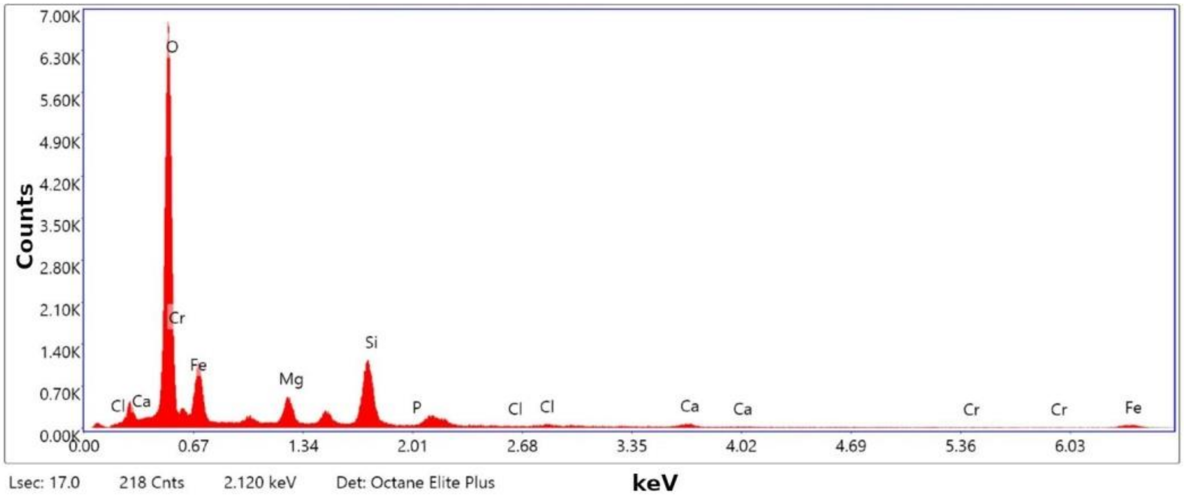

Fig. 12 EDAX spectrum revealing the major elements in scale deposit(sediments) from the hot water tank of the system without a magnetic separator

Fig. 13 shows the variation of total scale deposited on the tube surface of the two-flow arrangement with the same duration of operating time. It was observed that after 143 hours of the total operation, the scale deposit in a tube without a magnetic separator is 1.45 times higher than that in the tube with a magnetic separator.

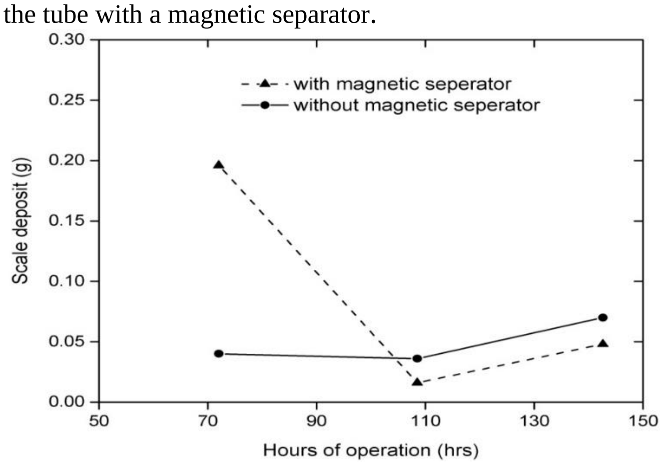

Fig. 13 Variation of scale deposit with operation time for flow arrangement with and without magnetic separator

5. Conclusion

It can be concluded from the experiments that by the application of a magnetic molecular separator, magnesium and chlorine do not stick to the tube surface. Calcium was deposited in the hot water tank as sediments that used the magnetic separator in the waterline. It could be concluded that by using the magnetic separator, there is an overall reduction in the calcium, magnesium, and chlorine getting deposited on the tube surface. However, chromium is present in the deposit, which increases the scale deposit weight.

References

[1] W. D. Steinmann, and C. Prieto, Thermal Storage for Concentrating Solar Power Plants, In Advances in Thermal Energy Storage Systems, Woodhead Publishing. (2021) 673-697. Doi:10.1016/B978-0-12-819885-8.00024-3.

[2] S. Dewanjee, S. M. H. Kabir, and U.D. Das, Performance Enhancement of Induced Draft Counter Flow Wet Cooling Tower with Different Types of Modified Shaped Fill Assembly, Journal of Engineering Research and Reports. (2020) 41-53.

[3] M. S. Kim, K. S. Lee, S. Song, Effects of Pass Arrangement and Optimization of Design Parameters on the Thermal Performance of a Multi-Pass Heat Exchanger, Int. J.Heat Fluid Flow. 29(1) (2008) 352–363.

[4] K. Chung, K. S. Lee, W. S. Kim, Optimization of the Design Factors for Thermal Performance of a Parallel-Flow Heat Exchanger, Int. J. Heat Mass Transf. 45(24) (2002) 4773–4780.

[5] W. Faes, S. Lecompte, Z. Y. Ahmed, J. Van Bael, R. Salenbien, K. Verbeken, M. De Paepe, Corrosion and Corrosion Prevention in Heat Exchangers, Corrosion Reviews. 37(2) (2019) 131-155.

[6] M. M. Awad, Fouling of Heat Transfer Surfaces, INTECH Open Access Publisher. (2011) 505-542.

[7] A. Rico Palacios, Theoretical Analysis of the Last Stage LP Steam Turbine Blades Repair Employing Welding. (2018).

[8] N. Kumar, P. Besuner, S. Lefton, D. Agan, D. Hilleman, Power Plant Cycling Costs (No. NREL/SR-5500-55433), National Renewable Energy Lab. (NREL), Golden, CO (United States). (2012).

[9] J. MacAdam, S. A. Parsons, Calcium Carbonate Scale Formation and Control, Re/Views in Environmental Science & Bio/Technology. 3(2) (2004) 159-169.

[10] J. MacAdam, P. Jarvis, Water-Formed Scales and Deposits: Types, Characteristics, and Relevant Industries, In Mineral Scales and Deposits. (2015) 3-23.
[11] A. S. Al-Ghamdi, Performance Analysis of Automated Control System for Condenser Water Treatment Unit. (2012).
[12] A. Howell, G. Saxon Jr, The Practical Application and Innovation of Cleaning Technology for Condensers, In ASME Power Conference. 41820 (2005) 109-117.
[13] Z. Xu, J. Wang, Y. Jia, X. Geng, Z. Liu, Experimental Study on Microbial Fouling Characteristics of the Plate Heat Exchanger, Applied Thermal Engineering. 108 (2016) 150-157.
[14] S.L. Percival, J.S. Knapp, D.S. Wales, R. G. J Edyvean, The Effect of Turbulent Flow and Surface Roughness on Biofilm Formation in Drinking Water, Journal of Industrial Microbiology and Biotechnology. 22(3) (1999) 152-159.
[15] W. T. Ji, C. Y. Zhao, D. C. Zhang, Z. Y. Li, Y. L. He, W. Q. Tao, Condensation of R134a Outside Single Horizontal Titanium, Cupronickel (B10 and B30), Stainless Steel and Copper Tubes, International Journal of Heat and Mass Transfer. 77 (2014) 194-201.
[16] J. Olsson, M. Snis, Duplex—A New Generation of Stainless Steels for Desalination Plants, Desalination. 205(1-3) (2007) 104-113.
[17] H. Richaud-Minier H, Marchebois P, Gerard, Titanium and Super Stainless Steel Welded Tubing Solutions for Sea Water-Cooled Heat Exchangers, Materials Technology. 24(3) (2009) 191-200.
[18] E. Nebot, J. F. Casanueva, T. Casanueva, D. Sales, Model for Fouling Deposition on Power Plant Steam Condensers Cooled with Seawater: Effect of Water Velocity and Tube Material, International Journal of Heat and Mass Transfer. 50(17-18) (2007) 3351-3358.
[19] M. Glazer, G. Burns, Space Groups for Solid State Scientists, Academic Press. (2013) 423.
[20] W. Massa, Crystal Structure Determination, Springer Science & Business Media. (2010) 232.
[21] Y. B. Band, Y. Avishai, Quantum Mechanics with Applications to Nanotechnology and Information Science, Academic Press. (2013) 993.
[22] T. M. Pääkkönen M. Riihimäki E. Puhakka, E. Muurinen, C. J. Simonson, R. L. Keiski, Crystallization Fouling of CaCO3 – Effect of Bulk Precipitation on Mass Deposition on the Heat Transfer Surface. (2009) 8.
[23] (2014). M. A. Popescu, R. Isopescu, C. Matei, G. Fagarasan, V. Plesu, Thermal Decomposition of Calcium Carbonate Polymorphs Precipitated in the Presence of Ammonia and Alkylamines, Advanced Powder Technology. 25(2) 500–7. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0921883113001684
[24] (2011). Kh. N. Islam, M. Z. B. A. Bakar, M. M. Noordin, M.Z.B. Hussein, N.S.B.A. Rahman NSBA, Md. E. Ali, Characterization of Calcium Carbonate and its Polymorphs from Cockle Shells (Anadaragranosa). Powder Technology. 213(1) 188–91. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0032591011003664
[25] (2008). M. Ni, B. D. Ratner, Differentiation of Calcium Carbonate Polymorphs by Surface Analysis Techniques – An XPS and TOF-SIMS Study, Surf Interface Anal. 40(10) 1356–61. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4096336/
[26] (2018). Aragonit, In: Wikipedia. [Online]. Available: https://sv.wikipedia.org/w/index.php?title=Aragonit&oldid=43433772