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Investigation on Corrosion Behaviour and Heat Transfer Analysis of Cu-Ni Coated Aluminium Heat Exchanger

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ABSTRACT: Shell and Tube type Heat Exchanger is one type of Heat Exchanger which is used in almost all industries. It is necessary to improve the performance and lower the economic cost of the Heat Exchanger. In this work, material for Shell and tube type heat exchanger is replaced by Aluminium because of its better heat transfer rate and minimal economic cost, but corrosion is one type of failure when it works under the environment containing chloride ions. Cu-Ni coating is done on Aluminium by PVD(DC sputtering) process to prevent that from corrosion. FEA simulation and EIS measurement were carried out to predict heat transfer rate and corrosion rate respectively. The results reveal that heat transfer rate has been increased by changing the material and corrosion rate has been reduced by coating it with Cu-Ni.

KEYWORDS: PVD coating, heat transfer analysis in ANSYS, EIS measurements.

I. INTRODUCTION

A heat exchanger is a device to transfer the heat between two fluids maintained at different temperatures and separated by a solid wall. The purpose of a heat exchanger is just that-to exchange heat. Most processes require the heating or cooling of streams to produce a desired temperature before the stream can be fed to operations. Heat exchanger plays a significant role in the operation of many systems such as power plants, process industries and heat recovery units. Among of all type of exchangers, shell and tube exchangers are most commonly used heat exchange equipment Among the various types of heat exchangers, the shell and tube heat exchangers find a wide range of applications, while around 35–40% of all the heat exchangers, used in all kinds of industrial applications, are shell and tube heat exchangers (STHE)[1]. Therefore, The importance of heat exchangers has increased immensely from the view point of energy conservation and environmental concerns and also, it is of great importance to improve the thermal-hydraulic performance and lower the economic cost[2].

II. RELATED WORK

Heat exchangers usually provide a long service life with little or no maintenance because they do not contain any moving parts. However, there are four types of heat exchanger failures that can occur, and can usually be prevented: mechanical, chemically induced corrosion, combination of mechanical and chemically induced corrosion, scale, mud and algae fouling. Deterioration of metal is a common spontaneous phenomenon associated with almost all metals (except noble metals) while exposed to corroding environment. While exposing the metal surface to the moist environment for a longer period stimulates the dissolution of metal into their respective ions[3,4]. Among the different kinds of metals, Al and its alloys are a class of metals which possess excellent corrosion resistance even in the aqueous

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medium since the oxide film naturally formed on the surface is supposed to prevent further corrosion[5] . Although Al is passive towards the aqueous medium, it cannot withstand the attack of reactive chloride ions[6].

Corrosion protection of heat exchanger is very important since the system might work in environment containing different type of aggressive species. When the heat transfer surface becomes fouled, then the heat transfer efficiency and life of the heat exchanger will be reduced. Therefore, for engineering applications, various coating systems have been proposed by many researchers that effectively prevents the metal from corrosion[7].

Cu coating can be fabricated by electroless plating, electroplating method and physical vapor deposition (PVD) process . Among these coating methods, PVD process is able to fabricate uniform and dense coatings that possess good interfacial bonding with the substrate, which makes it widely used to fabricate functional films, hard coatings, wear-resistant coatings, low friction coatings, corrosion-resistant coatings and so on[8].

Electrochemical behaviour was studied by means of electrochemical impedance spectroscopy in order to evaluate the barrier properties of the coating[9].

Finite Element Analysis (FEA) is a numerical method for solving problems of engineering and mathematical physics. With the help of FEA, we can predict the approximate working condition of any system[10].

In this present work, material for shell and tube heat exchanger is replaced by Aluminium and Cu-Ni coating is made on it for to prevent from corrosion. Heat transfer rate in the heat exchanger was analyzed by using ANSYS 15.0(FEA tool). Cu-Ni is coated on the Al substrate by PVD sputtering process and corrosion rate between coated and uncoated substrate were analyzed by using Electrochemical Impedance Spectroscopy analysis.

III. FINITE ELEMENT ANALYSIS

Geometrical Description :

A single shell and single pass tube heat exchanger is taken for analysis. There are three number of straight baffles (25% cut segmental baffles) each having thickness of 10mm and which are equally placed in between the tubesheets at the distance of 1200mm. The model consists of shell with internal diameter of 566mm and thickness on shell and tubesheets are 16mm and 32mm respectively. The number of tubes modeled are 32 with the inner diameter and thickness of 11mm and 2mm respectively. The material for tube and shell are Aluminium and Cu-Ni was coated on the tube surface with the thickness of 10 microns.

3D model for shell and tube Heat Exchanger was modeled and it is converted into IGES format that allows digital exchange of information. The 3D model for Shell and Tube Heat Exchanger is shown in fig.1

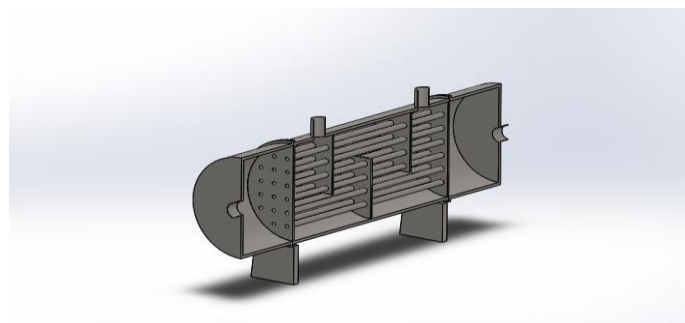


Fig.1 cut sectional 3D model for STHE

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Meshing and Simulation

The 3D model which is developed by the modeling software was imported into the analysis software. The model was meshed by using tetrahedral element which is a semi-automated meshing module and presents rapid generation of unstructured volume meshes. A very fine mesh was used in the coating zone for accurate analysis of heat transfer rate and also mesh refinement were performed to enable more accurate analysis. The meshed model for STHE is shown in fig.2.

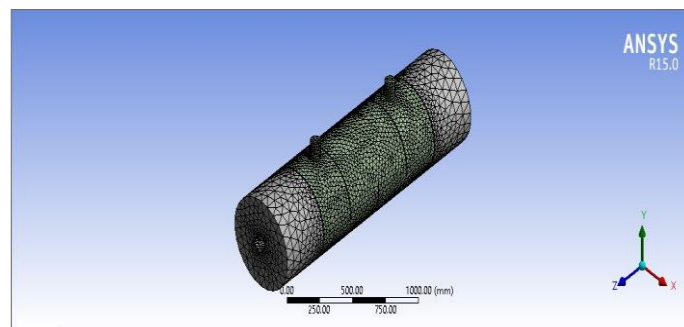


Fig 2. Meshed model for STHE

Coupled steady-state thermal and fluent analysis was carried out in which temperature distribution in the tube as well as shell can be calculated simultaneously. There are two separate boundary conditions that are applied, one is for steady-state thermal and another is for fluent analysis. In steady-state thermal module, fluid-solid interference was given on inside and outside surface of the tube which is necessary condition for to carry out coupled analysis. In fluent module, volumetric flow rate and temperature of the hot fluid are 95 m³/h and 105°C which were applied at inlet of the tube side and volumetric flow rate and temperature of the cold fluid are 4.75 m³/h and 22 °C which were applied at inlet of the shell side.

IV .EXPERIMENTAL INVESTIGATION

It is necessary to justify whether Cu-Ni coating on Al substrate prevent it from corrosion or not, for that some experimental investigation were carried out.

Coating Process

Aluminium substrate were ultrasonicated washed in ethanol, and then they were put in the PVD equipment and further washed by Ar ions for 15 min to eliminate impurities on the surface. Then the PVD chamber was evacuated to a high vacuum condition less than 0.005 Pa. The PVD process of Cu on the surface of graphite films was controlled by a magnetic field. The magnetic field was generated by an electric current with magnitude of 10 A. After introducing an argon flow with flow pressure of 1 bar into the chamber, the bias voltage between the Cu-Ni target and the Aluminium substrate was set to 100 V to start the coating process of Cu-Ni. After the coating process, the magnetic field, bias voltage and argon flow were shut down and the Cu coated graphite films were put out from the PVD chamber. The thickness of the Cu coating on the graphite films was controlled by the deposition time of the PVD coating process.

Corrosion studies by EIS

The corrosion resistant property of Cu-Ni coated Al were studied by dipping in 3.5% NaCl solution using electrochemical workstation (Model: CHI600C, CH Instruments, Inc, USA). The electrochemical measurements were performed by a conventional three-electrode system in which Cu-Ni coated Al sample was used as working electrode, the platinum wire as a counter electrode with silver/ silver chloride (Ag/AgCl) as the reference electrode. Prior to electrochemical corrosion studies, open circuit potential tests were carried out by stabilizing in 3.5% NaCl solution for 2 h. The polarization measurements were carried out by fixing the scan rate at 0.01 V/s. Tafel extrapolation method was done to determine the corrosion potential (E_{corr}), the corrosion current density (i_{corr}), polarization resistance (R_p), etc. to evaluate the corrosion resistance property of the coated Al substrate.

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V .RESULTS AND DISCUSSIONS

Results From Simulation

Heat transfer rate on a shell and tube heat exchanger were evaluated by using FEA tool. Water was used as the cooling medium in the shell and tube heat exchanger. A steady state computational fluid dynamics (CFD) and steady state thermal module coupled analysis was simulated by system coupling module in analysis software. The temperature distribution on tube side contours for both Cu-Ni coated Aluminium and Cu-Ni alloy shell and tube heat exchanger are shown in Fig 3 & 4.

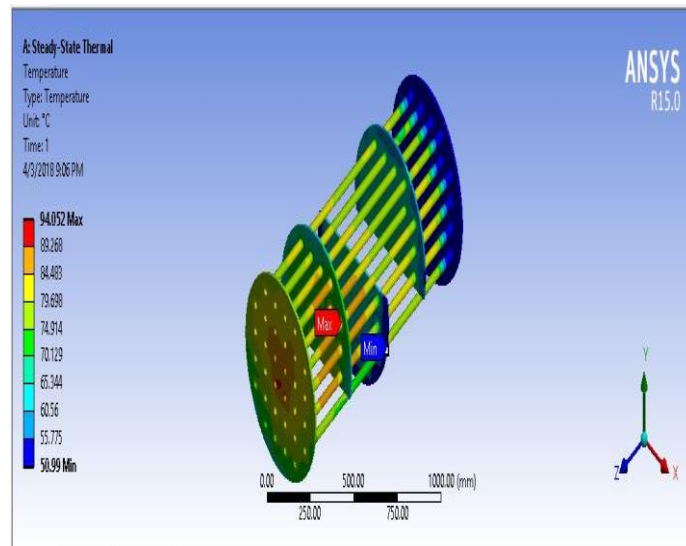


Fig.3 Temperature Distribution contour for Cu-Ni coated Al Heat Exchanger

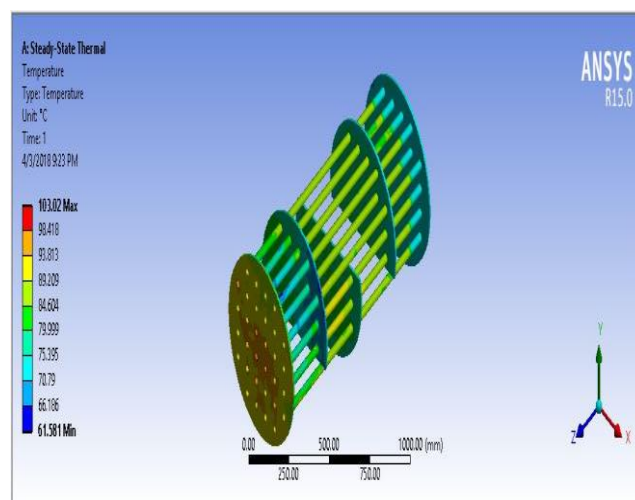


Fig.4 Temperature Distribution contour for Cu-Ni Heat Exchanger

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The hot fluid on the tube side transfer heat to the cold fluid as it flows along the length of the shell. The cold fluid on the shell side absorbs heat from the hot fluid as it flows along the length of the tube. It is observed that the temperature of the hot fluid stream on tube side is decreasing as it flows from inlet to outlet and simultaneously the temperature of the cold fluid stream on shell side is increasing as it flows along the length of the tube. The Temperature Distribution contour for shell side and tube side fluid for both Cu-Ni coated Al and Cu-Ni alloy Heat Exchanger are shown in fig.5 and fig.6 respectively.

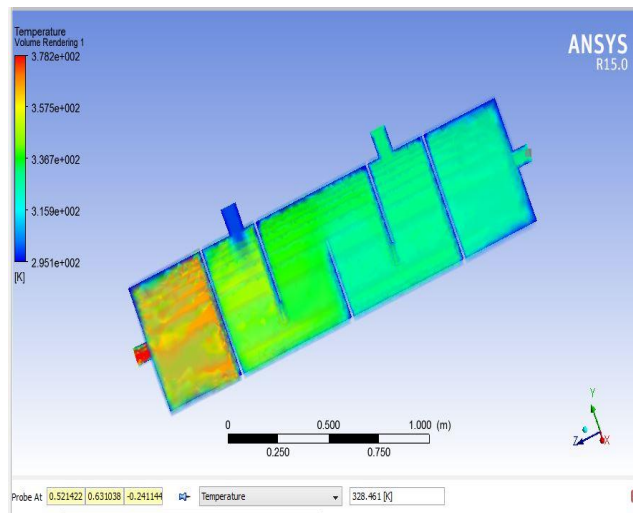


Fig.5 Temperature distribution contour for fluid in Cu-Ni coated Al heat exchanger

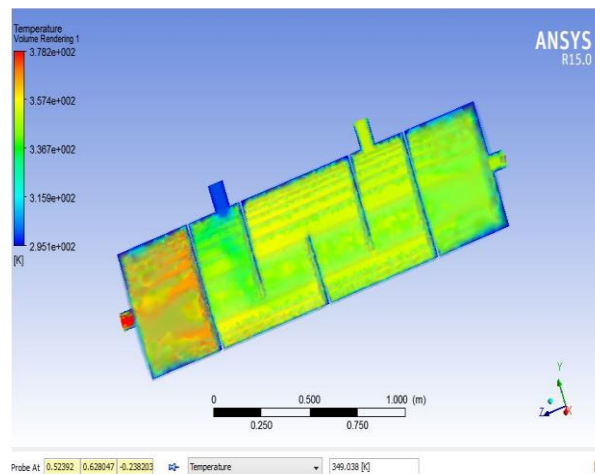


Fig.6 temperature distribution contour for fluid in Cu-Ni Alloy heat exchanger

From CFD post results, the exit temperature of the hot fluid from the Tube side is found to be 750C for Cu-Ni alloy heat exchanger and .89 °C for Cu-Ni coated Aluminium Heat exchanger. The exit temperature of the hot fluid from the Tube side is found to be 55⁰C and .31 °C respectively in Cu-Ni Alloy heat exchanger and Cu-Ni coated Aluminium Heat exchanger. It is observed that Cu-Ni coated Aluminium heat exchanger exhibit higher heat transfer rate than the heat exchanger having Cu-Ni alloy as a material.

Results from EIS analysis

The change in corrosion behaviour is visualized clearly for bare Al at -0.85 V. Such corrosion process can be protected by Cu-Ni coating .Cu-Ni coating shifted the E_{pit} value to more positive potential (-0.40) with the diffused potential

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plot. This indicates that the PVA coating resists the pitting corrosion to a certain extent. Further, the exact corrosion rate were calculated by giving surface area, weight, density and number of electrons. The Tafel plot for bare aluminium and Cu-Ni coated aluminium are shown in fig.7 and fig.8 respectively.

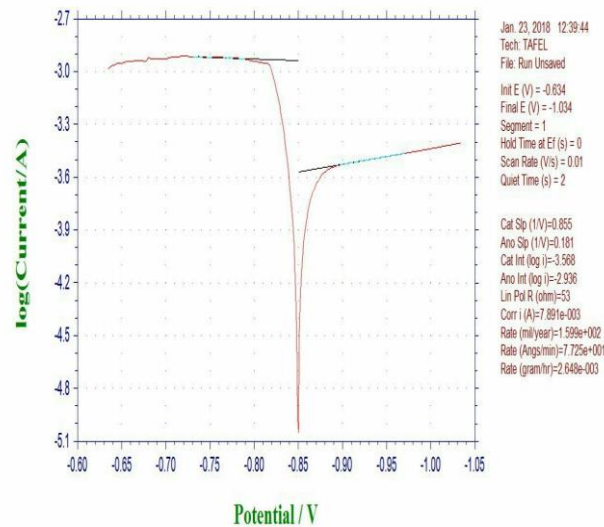


Fig.7 Corrosion rate on bare Al

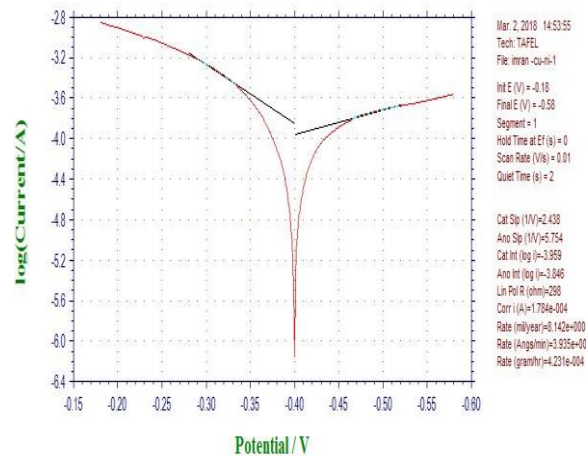


Fig.8 corrosion rate on Cu-Ni coated Al

From Tafel Plot, it was observed that corrosion rate on bare aluminium and Cu-Ni coated aluminium are 4.2 and 0.2 mm per year respectively.

VI. CONCLUSION

The results of the Finite element Analysis carried on Cu-Ni alloy tube heat exchanger and Cu-Ni coated Aluminium heat exchangers reveals that the heat transfer in Cu-Ni coated Aluminium tube heat exchangers is better than in the case of Cu-Ni ally tube heat exchangers. Also the corrosion test carried out on specimens of bare aluminium (4.2 mm per year) and Cu-Ni coated Aluminium (0.2 mm per year) hows that the corrosion rate in Cu-Ni coated aluminium is much lower than bare

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aluminium tubes. Hence it is evident that Cu-Ni coated aluminium tubes have good performance in terms of the heat transfer rate and corrosion resistance.

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