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Review on Graphene Oxide as a Nanofluid for Plate Heat Exchanger

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Abstract: *Heat transfer enhancement techniques are used in plate heat exchanger to increase rate of heat transfer. One of the technique is to use of nanofluid. As a working fluid in heat exchanger, nanofluid is used in various applications like radiator, automobile, space vehicle etc. Nanofluid is made by the suspending nanoparticles in the fluid like water, ethylene glycol and oil, hydrocarbons, fluorocarbons etc. Plate heat exchanger provides large surface area which is important for the increase in the rate of heat transfer. This work focuses on study of the heat transfer along with flow characteristics for plate heat exchanger using nanofluid of different volume concentrations. The scope of the project is to increase the effective heat transfer rate and efficiency of plate type heat exchanger. There is a need to enhance performance of heat exchanger by applications of nanofluid in the coming years.*

Keywords : *Nanofluid, Plate heat Exchanger, Graphene Oxide.*

I. Introduction

1.Plate Heat Exchanger

The plate heat exchanger was one of the first compact exchangers to be used in UK process industries, originally introduced 1923; were made of gunmetal. It is presently second to the shell and tube heat exchanger in terms of market share.. The most common variant of the Plate heat exchanger consists of a number of pressed, corrugated metal plates compressed together into a frame. These plates are provided with gaskets, partly to seal the spaces between adjacent plates and partly to distribute the media between the flow channels. The most common plate material is stainless steel[4][2].Plate heat exchangers were first used in the food and dairy industries where the ability to access plate surfaces for cleaning is imperative. There are numerous suppliers of the plate heat exchangers. While all the manufacturer follow the same basic construction method, the differences in performance claimed tend to be associated with the patterns on the plates that form the flow channels, and the choice of gasket materials. Newer designs can accommodate features such as grossly unequal flow rated on each side of the plate[1].

II. Construction

Fig 1.1 shows an exploded view of a typical plate heat exchanger. The heat transfer surface consists of a number of thin corrugated plates pressed out of a high grade metal. The pressed pattern on each plate surface induces turbulence and minimizes stagnant areas and fouling. Unlike shell and tube heat exchanger, which can be custom-built to meet almost any capacity and operating conditions, the plates for Plate heat exchangers are mass-produced using expensive dies and presses. Therefore, all Plate heat exchangers are made with what may appear to be a limited range plate designs. Although the plate heat exchangers are made from standard parts, each one is custom designed[4].The plate pack is clamped together in a frame suspended from a carrying bar. Gaskets are fitted to seal the plate channels and interfaces. The frame consists of fixed frame plate at one end and a moveable pressure plate at the other. The moveable plate facilitates access for cleaning or exchanging the heat transfer surfaces. A feature of this type of heat exchanger is the ability to add or remove surface area as necessary. The plates are grouped into passes with each fluid being directed evenly between the paralleled passages in each pass. Whenever the thermal duty permits, it is desirable to use single pass, counter flow for an extremely efficient performance. Although Plate exchangers can accept more than two streams, this is unusual. Two-pass arrangements are, however, common[1]. Plates can be produced from all pressable materials. The most construction materials are:

- Stainless steel (AISI304, 316)
- Titanium.
- Incoloy
- Hastelloy.

Where corrosion is a problem, some manufacturers offer plate exchangers in non-metallic materials, such as a graphene/fluoroplastic composites or a polymer. Usually the frame is made of coated mild steel, as it

should not, under circumstances, come into contact with the coatings vary according to the exchanger environment. Frames can be stainless steel or clad with stainless steel as an alternative to mild steel
Gasket properties have a critical bearing on the capabilities of a plate heat exchanger, in terms of its tolerance to temperature and pressure.

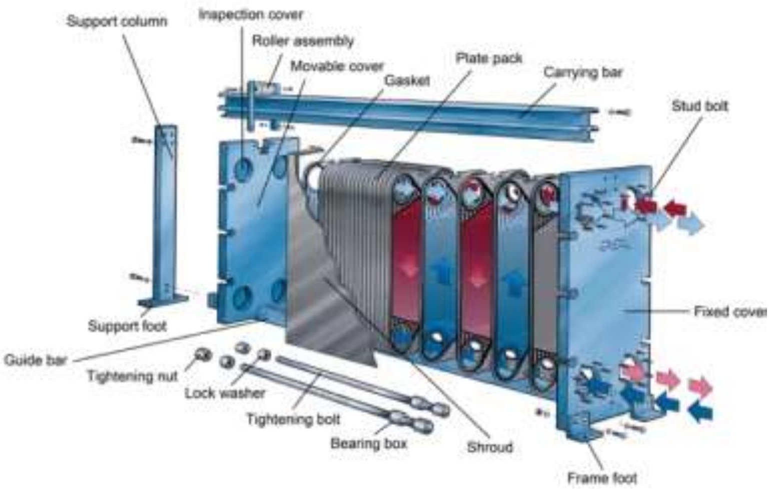

Fig. 1.1 Exploded view of a typical plate heat exchanger

Gaskets are commonly made of
- Nitrile rubber.
- Hypalon.
- Viton.
- Neoprene
- EPDM.

Originally, most manufacturers used glue to fix the gaskets to the plates. Several proprietary fixing techniques are available that eliminate the need to use glue, and most manufacturers have adopted these methods. These so-called 'glueless' gaskets are suitable for some heavy duty industrial applications.

Care should be taken in locating the gaskets during reassembly, as sealing is the main disadvantage of the plate heat exchanger[2][4].

III. Operating Limits

The operating limits of gasketed Plate heat exchanger vary slightly from manufacturer to manufacturer. Typically, the operating temperature range of the metal plates is from -35°C to +200°C. Design pressures up to 25 bar changes vary can be tolerated, with test pressures to 40 bar.Heat transfer areas range from 0.02 m to 4.45 m (per plate). Flow rates of up to 3,500 $m^{3/}$hour can be accommodated in standard units, rising to $m^{3/}$hour with a double port entry. Approach temperatures as low as 1°C are feasible with plate heat exchangers. The surface pattern on the plates tends to induce good mixing and turbulence and in general this type of heat exchanger has a low propensity for fouling. Fouling resistances of typically 25 % of those for shell and tube heat exchangers have been measured by the Heat Transfer Research Incorporated (HTRI) in the USA.
Where fouling is a concern, the gap between the plates can be widened. For example, one manufacturer offers plates with a 13 mm gap and coarse contours for viscous liquids and fluids containing fibers, solids, crystals, pulp etc.[4].

IV. Principal Applications

Gasketed Plate heat exchangers have a large range of applications typically classified in term of the nature of the streams to be heated/cooled as follows:
- Liquid-liquid
- Condensing duties. .
- Evaporating duties

Gasketed units may be used in refrigeration and heat pump plants and are extensively used in the processing of food and drinks the ease of plate cleaning and re-gasketting are important. In the chemical sector, a substantial list of heating and cooling applications includes cooling isoparaffin, sulphuric acid, salt solutions, hexane and kerosene. Heating glycerine and condensing ethanol are other routine uses. The offshore chemical industry is also a large user in the UK There are potential applications for plate heat exchangers on most chemical plants.[4]

V. Nanofluids

1. Introduction

Nano fluid, first suggested by S.U.S. Choi of Argonne National Lab in 1995. It is an innovative working fluid for heat transfer created by dispersing highly thermal conducting solid particles smaller than 50 nanometres in diameter in traditional low thermal conducting heat transfer fluids such as water, engine oil, and ethylene glycol.The main goal or idea of using nano fluids is to attain highest possible thermal properties at the smallest possible concentrations (preferably<1% by volume) by uniform dispersion and stable suspension of nano particles (preferably<10 nm) in hot fluids. A nano fluid is a mixture of water and suspended metallic nano particles. Since the thermal conductivity of metallic solids are typically orders of magnitude higher than that of fluids it is expected that a solid/fluid mixture will have higher effective thermal conductivity compared to the base fluid[5][6].

2. Nanofluids as heat transfer fluids

Low thermal conductivity is a primary limitation in developing energy efficient heat transfer fluid which is required for ultrahigh performance cooling. Nanomaterials have unique mechanical, optical, magnetic and thermal properties. Nanofluids are made by suspending nanoparticles with average size below 100 nm in fluids such as water, oil and ethylene glycol. Nanoparticles when dispersed in fluids can provide improvements in thermal properties of host fluid. The goal of nanofluid is to achieve highest possible thermal properties in smallest possible concentration by uniform dispersion and stable suspension.This technique is used to increase cooling rates to disperse millimeter or micrometer sized particles in heat transfer fluids. The major problem with suspension containing these particles is the rapid settling of these particles. If the fluid is kept circulating to prevent particle settling, these particles would wear out pipes, pumps and bearings. These fluid suspensions are not practical because they require addition of large number of particles (usually >10 vol%), resulting in significantly greater pressure drop and pumping power[6][8].

3. Thermal Properties of Nanofluid.

a. Volume concentration

$\Phi=(W_{nanoparticle}/\rho_{nanoparticle})/\ (W_{nanoparticle}/\rho_{nanoparticle}+W_{water}/\rho_{water})$

b. Density of nanofluid

$\rho_{nanofluid} = \{\Phi*\rho_{nanoparticle}\}+\{(1-\Phi)\rho_{water}\}$

c. Specific heat capacity of nanofluid

$Cp_{nanofuid}=([\Phi\{\rho_{nanoparticle}\}*Cp,_{nanoparticle}+ (1-\Phi)*\{\rho_{water}*Cp,_{water}\}])/\rho_{nanofluid}$

d. Thermal conductivity of nanofluid

$K_{nanofluid}=([\{K_{nanoparticle}\}+\{2*K_{water}\}+ \{2*(K_{nanoparticle}-K_{water})*\Phi\}])/([\{K_{nanoparticle}\}+\{2*K_{water}\}-\{(K_{nanoparticle}-K_{water})*\Phi\}])$

4. Nano Fluid Preparation

The nano particles in the form of powder when dispersed in the base liquid, it is called nano fluid. In order to improve the thermal conductivity of the nano fluid, preparation of nano fluid using nano particles is important task. There are mainly two methods of producing nano fluids.

a. Single step method
b. Two step method.

These methods have been utilized using different types of chemical and physical techniques to make sure that the solid-liquid mixture is stable to avoid agglomeration, additional flow resistance, possible erosion and clogging, poor thermal conductivity, and poor heat transfer. It is observed in the literature that nano fluids with oxide nano particles and carbon nano tubes are produced well by the two-step method, while it is not suitable for nano fluids with metallic nano particles[10].

5.1 One step Method

one-step technique, the nano particles are simultaneously made and directly dispersed into the base fluid as shown in Fig 4.1. There are many different methods used to produce nano particles. This method is preferable to produce nano fluids containing high thermal conductivity metals to avoid erosion and oxidation of particles. The advantage of this process lies on minimizing of nano particles agglomeration.This behavior increases the stability of the suspensions and uniform dispersion in the host liquids. The disadvantage of one-step technique is the limit of quantity of the production due to the slow of the production process, low concentration of nano particles, and the high cost. Different methods have been used to reduce the time and cost using evaporation, physical or chemical.[9].

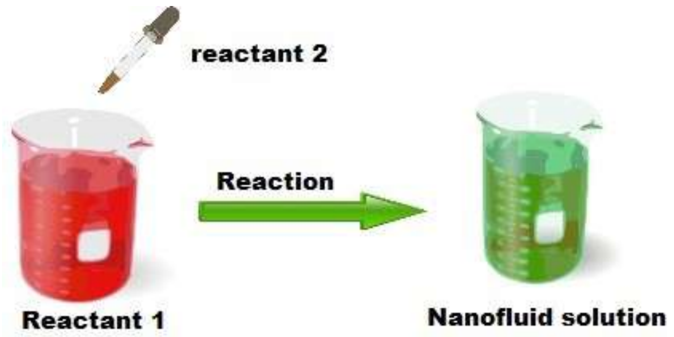

Fig 4.1 One-step preparation process of nanofluids

5.2 Two Step Method

In two-step method of producing nano fluid, the nano particles are produced first separately and then these nano particles are dispersed into a base fluid into particular measured quantity as shown in Fig 4.2.The advantage of this method is that it is easily and economically produced. On the other hand, the disadvantage of this method is the quick agglomeration of individual particles before the achievement of complete dispersion due to Vander Waals attractive forces between nano particles. This agglomeration is a big obstruction to achieve high heat transfer performance due to the quick settling of particles out of the base fluids and it becomes worse as the volume concentration increases. The agglomeration is not only a problem in nano fluid technology, but it is also a critical issue in all nano powder technology especially during drying, storage, and nano particle transportation stage[10].

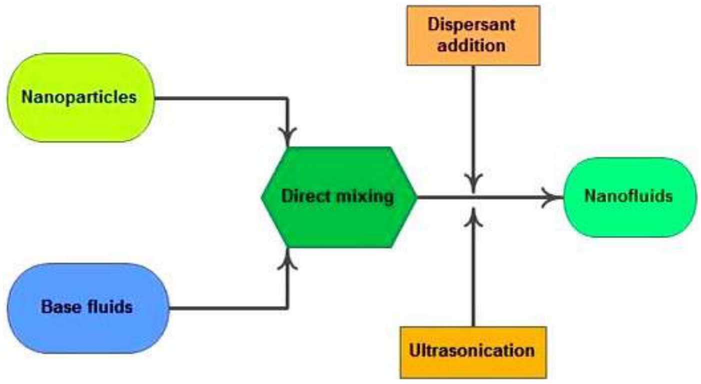

Fig 4.2 Two-step preparation process of nanofluids

I. **TABLE 1 -OBSERVATIONS FROM LITERATURE SURVEY**

Property	Water	Ethylene Glycol	CuO	Al_2O_3	TiO_2	Graphene Oxide
Thermal Conductivity k (W/mK)	0.608	0.252	20	40	8.95	3000
Density ρ (kg/m3)	992	1111	8933	3970	4250	440
Heat Capacity Cp (J/kg K)	4182	2415	765	765	686.2	2100

VI. Graphene Oxide as Nanofluid

1. Introduction

Graphene oxide (GO) is a monolayer material synthesized through oxidation of graphene followed by exfoliation treatments with ultrasonication. As a two-dimensioned carbon material, GO owns excellent properties, such as mechanical stress (63 GPa for facture stress) and large surface area. Fig 3 shows chemical structure of grapheme oxide[11][12].Graphene oxide, formerly called graphitic oxide or graphitic acid, is a compound of carbon, oxygen, and hydrogen in variable ratios, obtained by treating graphene with strong oxidizers. The maximally oxidized bulk product is a yellow solid with C:O ratio between 2.1 and 2.9, that retains the layer structure of graphene but with a much larger and irregular spacing[11]. The bulk material spontaneously disperses in basic solutions or can be dispersed by sonication in polar solvents to yield monomolecular sheets, known as graphene oxide by analogy to graphene, the single-layer form of grapheme. Graphene oxide sheets have been used to prepare strong paper-like materials, membranes, thin films, and composite materials. Initially, graphene oxide attracted substantial interest as a possible intermediate for the manufacture of graphene. The graphene obtained by reduction of graphene oxide still has many chemical and structural defects which is a problem for some applications but an advantage for some others [16].

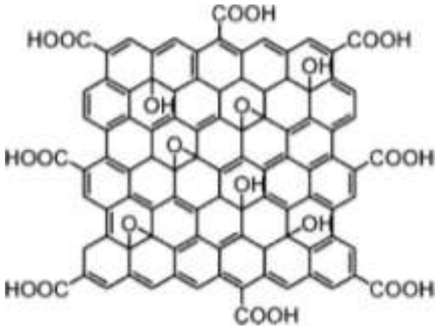

Fig 3. Structure of graphene oxide[19]

2. Preparation of GO/water nanofluids

GO/water nanofluids are prepared by dispersing GO nanoparticles into water as a base fluid. GO nanoparticles in this study were manufactured by the method of chemical vapor deposition (CVD). Chemical vapor deposition method is a chemical process used to manufacture high purity and performance materials and to produce thin films. It is well-known that the properties of nanofluids depend on the shape and size of the nanoparticles. To identify the morphology of the nanofluids, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were performed[17]. The process of preparation of GO/water nanofluids is as follows:

(1) weigh the mass of GO nanoparticles with a digital electronic balance; (2) put the GO nanoparticles into the weighed water. and prepare the GO/water mixture (3) sonicatethe mixture continuously for three hours with a sonicator of the bath type to obtain a uniform dispersion of GO nanoparticles in the water. Through this preparation, the temperature of nanofluids increases from 24 to 55 C.s.[17]

VII. Conclusion

In this study , thermophysical Properties of Water, Ethylene Glycol, CuO, Al_2O_3, TiO_2 and Graphene Oxide are observed. Working of plate heat exchanger and preparation methods of nanofluid are studied. Graphene Oxide has highest thermal conductivity that is 3000 W/mK. Thus, use of Graphene Oxide is recommended for further experimentation as it gives high heat transfer.

Conflict of interest the authors declare that there is no conflict of interests regarding the publication of this paper.

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