Flow Assisted Erosion-Corrosion of High Speed Steel (HSS) in Nanofluid Coolant

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Keywords: Stress corrosion cracking, polarization diagram, corrosion rate, high stress carbon steel.

Abstract. The use of nano-coolant is suspected to have effects on erosion-corrosion of piping systems in heat exchanger. This study was carried out to determine the erosion corrosion of AISI 316 stainless steel in solutions containing nano particles. The experiments used rotating cylinder electrode (RCE) at rotational speed of 0 -1800 rpm under varying temperature of 30°C-70°C. Corrosion rate was measured using linear polarization resistance (LPR) method and erosion was indicated by measuring average depth of surface of the samples (surface roughness). The results showed that both corrosion rate and surface roughness of samples have increased when temperature and rotation speed increased. The erosion-corrosion effects of nano-coolant were lower in stagnant condition. Comparing with conventional coolant, the nano-fluid showed significant differences. In flow conditions, the effects were remarkable. It was also found that maximum synergism erosion and corrosion were occurred at higher temperature and high rotation speed for both of types solutions.

Introduction

Cooling system in heat exchanges is a crucial part in industrial applications. Technological developments which are operating at high speeds and high-power engines will increase thermal loads and require advance cooling. Water, oil, and other synthesis liquids are common fluids used in the cooling process, but its capability to transfer heat is limited. The conventional method for enhancing cooling is to increase the area available for exchange heat [1]. However, this approach is unsustainable due to high power consumption of the pumps and large amount of coolant are needed. Therefore, the development of advanced heat transfer fluids with higher thermal conductivity and enhanced heat transfer is in strong demand. A little percentage volume of solids could produce an impressive enhances of thermal conductivity [2]. Eastman et al. [3] stated that thermal conductivity of 0.3% copper nanoparticles of ethylene glycol is raised up to 40% compared to base fluid. Furthermore, Hwang et al. [4] agreed that thermal conductivity of nano-fluids is highly affected by the thermal conductivity of nano particles and base fluid. Thus, thermal conductivity plays a significant role in the construction of high efficiency heat transfer equipment.

In the recent development, nano-fluids have good potential to utilize many devices for better capability with its enhanced thermo-physical properties and heat transfer performance. Nano-coolant can extract higher quantities of heat at lower flow rates and improved thermal conductivity and may have enhanced energy efficiency [5]. The nano-coolant can also improve thermal efficiency in the cooling system. However, although nano-coolant are better compared to conventional fluids in terms of thermal efficiency, it is suspected to increase both corrosion and erosion [6]. So the erosion-corrosion research would have beneficial input in selecting coolant fluids.

Methodology

Preparation of specimen. The research used titanium dioxide as nano-crystals coolant and stainless steel AISI 316 as materials tested. The chemical, physical and thermal properties of nano-coolant are presented in Table 1. Table 2 shows chemical compositions of materials tested. The working electrodes were stainless steel AISI 316. The specimens have a diameter of 16 mm and thickness of 10 mm. The specimens surfaces are grinded and polished successively with 180, 320 and 600 grit Sic paper, then rinsed with methanol and dried it with dryer [7].

Table 1. Physical Properties of nano-fluid TiO_2.

Properties	Metric
Density (g/cm^3)	4.23
Molar Mass (gr/mol)	79.94

Table 2. Chemical compositions of AISI 316.

C	Si	Mn	P	S	Cr	Ni	Mo	Ti	N	Al	Co	Nb
0.055	0.75	1.5	0.02	0.004	16.4	13.9	2.3	0.08	0.0084	0.021	0.013	0.06

Corrosion Experiments. The experiments were performed in stagnant (static test) and rotating condition (dynamic test) in two different coolants which are conventional and nano-coolant. Static test is used to study the corrosion behavior where there is no flow rate in the solution. This experiment is conducted by using three electrodes system, while the dynamic test is conducted with different rotational speeds by using rotating cylinder electrode (RCE). Linear Polarization Resistance (LPR) is used as electrochemical method of monitoring corrosion rate. LPR method consists of three electrodes which are working electrode, working electrode and counter electrode [8].

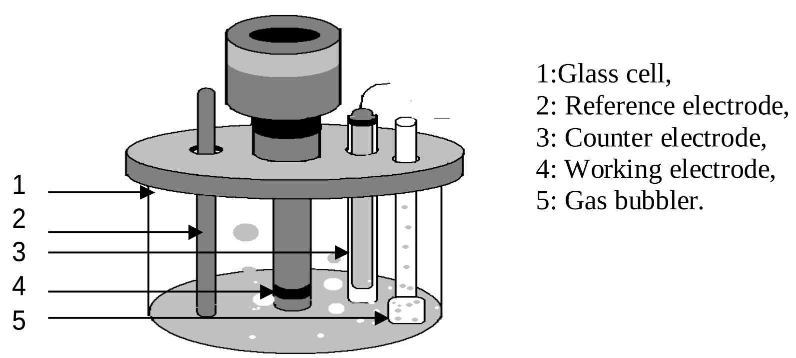
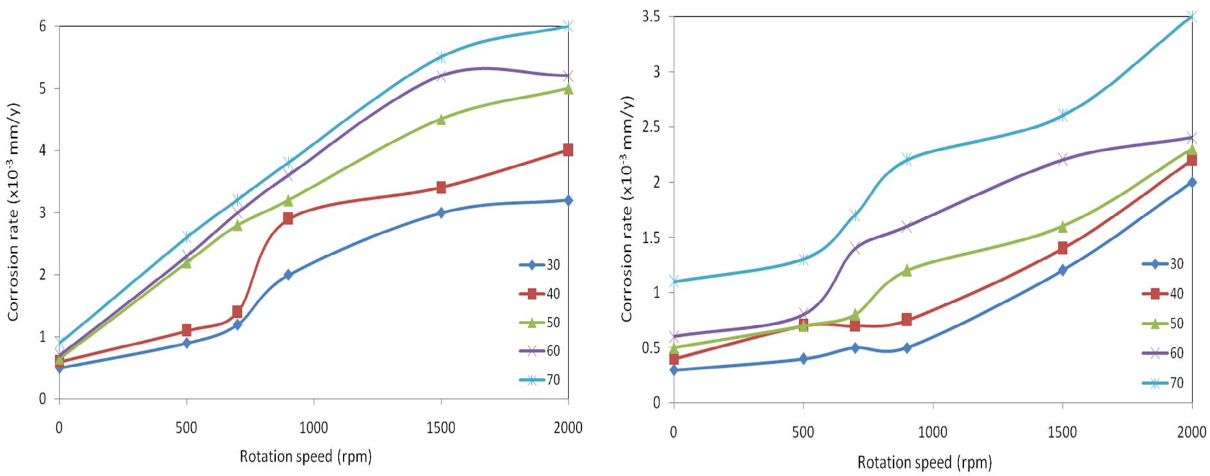


Fig. 1: Experimental arrangement for static test and rotating test conditions.

Surface Roughness Tester. Surface roughness tester is used to measure the roughness depth (R_z) of the specimen. Roughness depth (R_z) is the arithmetic mean value of the single roughness depth of consecutive sampling lengths.

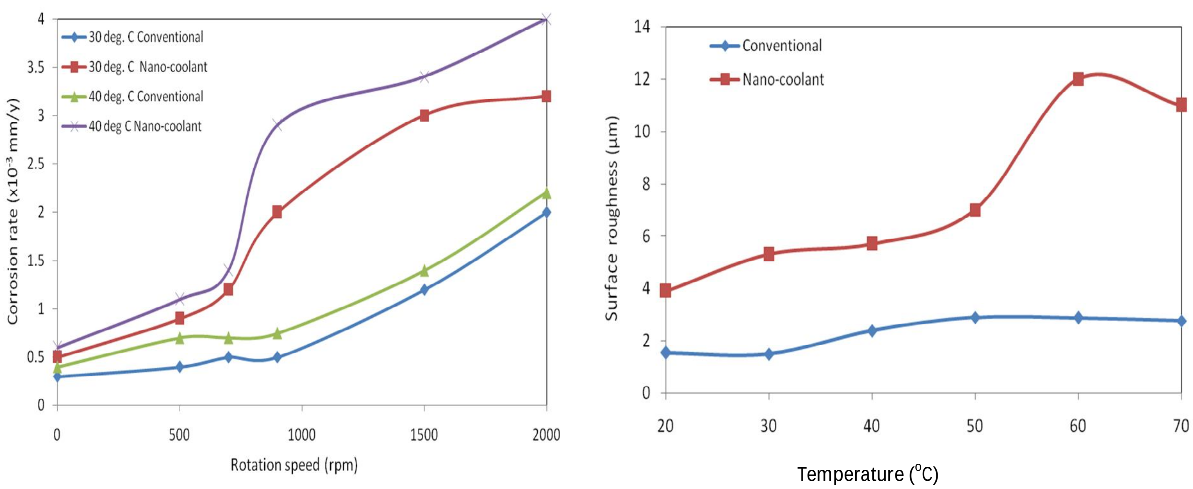
Results and Discussion

Effect of rotational speed and temperature on corrosion rate. In Fig. 2.a, it is shown the variations of corrosion rate at several rotational speed and temperature due to nano particles. Fig. 2.b, is presented corrosion rate of conventional coolant under several temperature and rotational speeds. As shown in the both figures, the corrosion rate tend to increase with increasing temperature and rotational speed. This result shows that temperature and rotational speed have synergism effcets in increasing corrosion rate. Generally, temperature accelerate corrosion rate through thermo dynmics mechanism. The effects of temperature can be more complex. For many materials, oxygen content of the water directly affects on controling corrosion rate [8]. The corrosion rate can be stationary or decerase due to diffusion mechanism. Increase temperature will increase the solubility of oxygen in the water which promote film formation on the metal surfaces. This film will act as a barrier to reduce corrosion rate [9].



(a) (b)

Fig. 2: Corrosion rate versus rotational speed for nano coolant (a) and conventional coolant (b) in different temperature.



(a) (b)

Fig. 3: (a) Comparison of corrosion rate between nana-coolant and conventional coolant at several rotational speeds. (b) Comparison of surface roughness (surface depth) versus temperature for nana-coolant and conventional coolant.

Comparing nano-coolant and conventional coolant, it shows that nano-coolant have negative effects on samples surfaces (Fig. 3.a, Fig. 3.b). Nano particles affect corrosion rate through hydrodynamic momentums which can increase mass transport of metal ions and shear stress [10]. Due to high temperature, Fe^{2+} ions produced during metal dissolves quickly from the electrode surface to the bulk solution [11]. At the higher rotational speed, corrosion rate will be accelerated by wear mechanism as an increas of dynamical momentum of solid particles in the solutions. Solid particles separates the layer of adsorbed Fe^{2+} and cause more desorption of the metal surface.

Conclusions

- Corrosion rate is higher in the nano-coolant than conventional coolant.
- Nano-coolant using TiO_2 nano particles affect the erosion rate and corrosion arte simultaneously.
- The particles damages were caused by synergy effect of erosion and corrosion.
- The effects were significant in high flow conditions and higher temperature.
- The mechanical wear caused by erosion accelerated damages the surface of the specimen.

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