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Impact of hardness and surface texture on cleaning action of various projectiles

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ABSTRACT

This study focuses on the hardness and surface texture of the rubber, sponge, notched and ribbed projectiles and their performance to clean tubular heat exchangers when the injection rate was varied from 1 inj./5 min to 1 inj./10 min. Fouling and visualization experiments were conducted in which $CaSO_4$ solution was used as foulant. The fouling experiments were performed to compare the cleaning ability of the different types of projectiles, while the visualization experiments were aimed at determining what caused the cleaning action of the projectiles. Injecting the projectile once every 5 and 10 min changed the propensity of the fouling resistance from a linearly increasing, as in the case of no injection to an exponentially decaying growth. The notched projectile had the best cleaning capability, while the smooth rubber projectile the least. The asymptotic fouling resistance for the notched projectile was 3 times less than that of the smooth rubber one in case of 1 inj./10 min, and 4 times less for 1 inj./5 min. For a better cleaning, the outer structure of the projectile should be made from a material that is stiff and rough in order to remove the fouling layer. It should also be flexible in motion such that it allows the brush mechanism to take place, i.e. compression of the projectile along the tube surface followed by its release then finally cleaning of the tube surface.

Keywords: Heat exchanger; Fouling; Cleaning; Mitigation; Desalination; Projectiles

1. Introduction

Shell and tube heat exchangers dominate 60% of the installed heat exchangers in the market (Heat exchanger, 2008) but, similarly to other types of exchangers, deposit formation represents a major uncertainty in their design and operation of tubular heat exchangers. Many techniques have been developed to abate fouling, and a summary of the main methodologies are discussed by Müller-Steinhagen et al. (2011). They advised that fouling can effectively be mitigated firstly by proper design of heat exchangers and secondly by on-line cleaning techniques. As for the latter, one viable approach is to inject projectiles (Hamed et al., 2007; Al-Bakeri and El Hares, 1993), e.g. sponge balls, through the exchanger tubes. Projectiles have been used extensively in condensers of power plants (TAPROGGE, 1984; Eimer, 1985) as a result of the drive towards higher plant efficiency. Projectile cleaning can be ideal as it can be applied in frequent intervals thus would mitigate fouling on a continuous basis. This provides exchangers with stable operation but limited to aqueous systems usually at temperatures below 120 °C, due to the stability of the projectile materials (Jalalirad et al., 2013a). Projectiles are also limited to internal cleaning of tubes and not externally.

Jalalirad et al. (2013b) performed a comprehensive set of crystallization fouling experiments with and without projectiles, and found that their cleaning was strong at the early stage of the fouling process and decreases as the deposit layer develops. Jalalirad and Malayeri (2013c) concluded that the structure, hardness, and morphology of the deposit layer are of prime importance. Many projectiles have been developed,

Abbreviations: FL, fouling layer; HE, heat exchanger; inj, injection; Proj, projectile; 2WV, two way valve; 3WV, three way valve; $CaSO_4$, calcium sulphate anhydrite; $Ca(NO_3)_2{\cdot}4H_2O$, calcium nitrate tetrahydrate; Na_2SO_4, sodium sulphate; $NaNO_3$, sodium nitrate.

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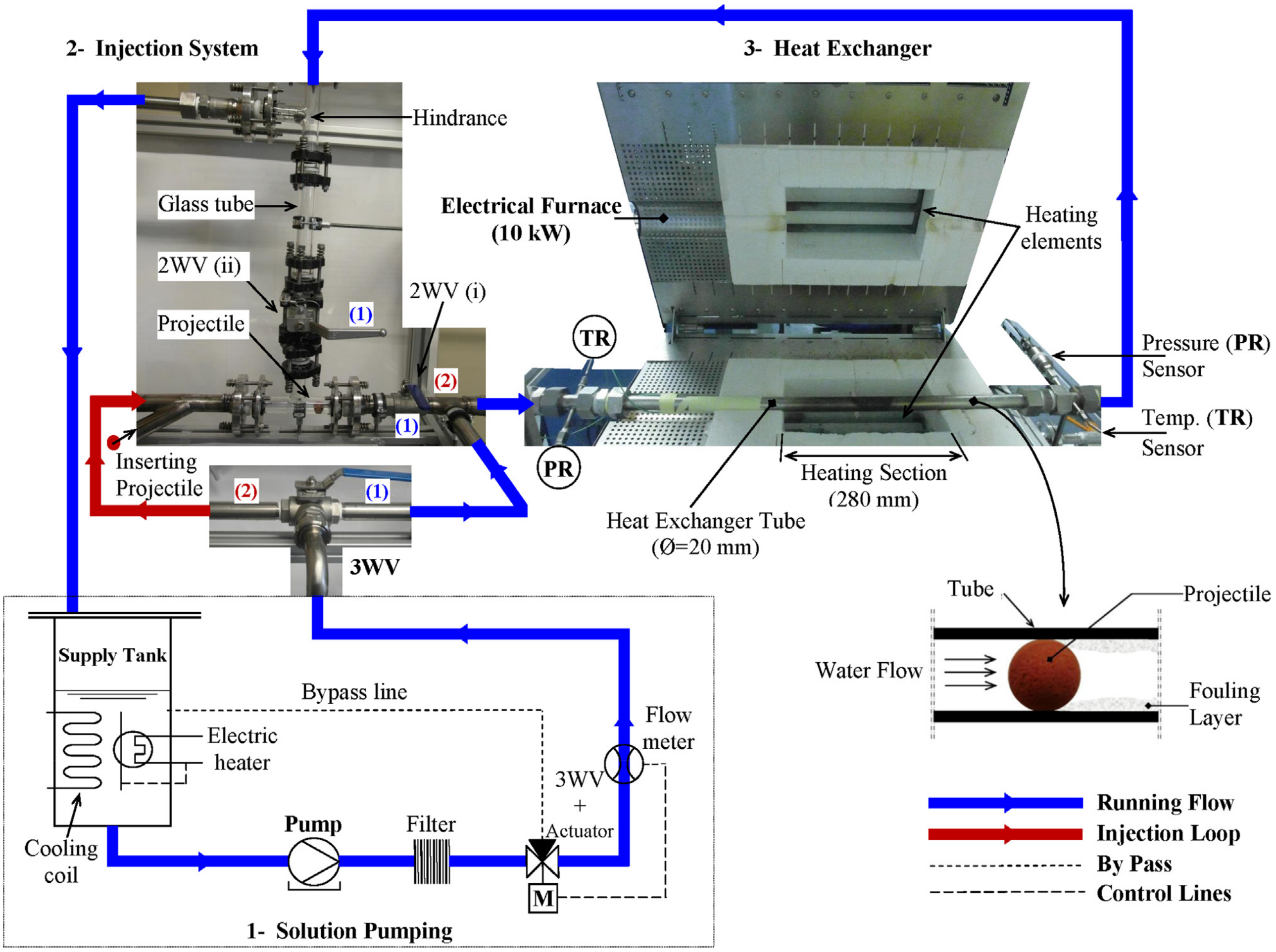

Fig. 1 – A schematic of the experimental setup equipped with the projectile injection system. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Adopted from Abd-Elhady et al. (2014a).

however the ability of cleaning of such projectiles is still questionable. Jalalirad and Malayeri (2013c) also concluded that the most important parameter that affects the cleaning ability of the projectile is the contact area between the projectile and the tube inner wall, such that the best performance is achieved if the diameter of the projectile is 10% larger than the tube diameter. However this percentage is profoundly dominated by the stiffness of the projectile. Increasing the diameter of the projectile haphazard irrespective of the diameter of the exchanger tube and the stiffness of the projectile could lead to (i) sticking of the projectile, (ii) large pressure loss and (iii) not a substantial improvement in the cleaning ability of the projectile (Jalalirad and Malayeri, 2013c). Abd-Elhady et al. (2014a) investigated the influence of the injection rate and multiple projectile injections on the cleaning action of spherical projectiles, and found that multiple injections retard the fouling process significantly such that the asymptotic fouling resistance is much lower to that of a single injection.

The objective of this research is to compare the cleaning ability of various projectiles with different hardness and surface texture. Four types of projectiles have been examined: (i) rubber, (ii) sponge, (iii) notched, and (iv) ribbed. The ribbed projectile has been developed at the Institute of Thermodynamics and Thermal Engineering (ITW), the University of Stuttgart, for high temperature applications. Two sets of experiments have been performed in tandem, i.e. crystallization fouling experiments in which calcium sulphate was used as foulant and visualization experiments. The first was performed to compare the cleaning ability of the attempted projectiles, while the visualization experiments were aimed at determining what caused the cleaning action of the projectiles. Crystallization fouling is formed when salts precipitate on a heat transfer surface, only if the surface temperature is sufficient to cause supersaturation of the salt. For heating purposes in processes such as desalination plants or preheat trains in oil refineries, salts such as $CaSO_4$ and $CaCO_3$ with inverse solubility, can only form when the surface is increased (Bott, 1988). It can also occur similarly for cooling purposes such as cooling towers for salts, i.e. NaCl, which their solubility decreases by reducing the surface temperature. Accordingly, in the present study, calcium sulphate ($CaSO_4$) as a hard deposit was used as foulant in the present study. The fouling runs were performed at accelerated conditions due to laboratory restrictions and also to rigorously characterize the impact of the projectile cleaning.

2. Experimental setup and experimental procedure

Abd-Elhady et al. (2014a) have fully described the attempted test facility and experimental procedure thus only will shortly be discussed here for the sake of brevity. An important feature of the test rig was that projectiles can be shot at different injection rates and velocities if required. A schematic of the test rig is shown in Fig. 1. As indicated in this figure, the test rig consists of 3 main parts, (1) a pumping system, (2) a projectile injection system and (3) the tubular heat exchanger.

The pumping system consisted of a solution supply tank, a centrifugal pump to circulate the flow. A supply tank of 60 l was also used which was equipped with a cooling coil and 3 jacket heaters, each of a power of 500 W to adjust the bulk temperature of the working fluid which is 40 °C in this study. The $CaSO_4$ solution was prepared separately then added to the supply tank. The $CaSO_4$ solution was pumped from the

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