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# Experimental study of thermo-hydraulic and fouling performance of enhanced heat exchangers ☆

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**Abstract**

The present study investigated the effect of two tube inserts (wire coil and wire mesh) on the heat transfer enhancement, pressure drop and mineral salts fouling mitigation in tube of a heat exchanger. A 3/4-in. tube that is heated by band heaters, is used which simulated a tube of heat exchanger. Working fluid is water with certain quality. The heat transfer rate averagely increased by 22–28% for wire coil ($p/d$=0.125, $e/d$=0.00375) and 163–174% for wire mesh (medium density) over a plain tube value, depending on type of tube insert, density of wire torsion and flow velocity. However, the pressure drop also increased substantially by 46% for wire coil and 500% for wire mesh. Wire coil insert with vibration mitigate mineral salts fouling (scaling) about 34%, and wire mesh have no effect on scaling, however it sometimes increased deposit rate.


*Keywords:* Tube insert; Heat transfer enhancement; Fouling mitigation; Pressure drop; Friction factor; Wire coil; Wire mesh

## 1. Introduction

The efficiency of heat transfer equipment is essential in energy conversion. The efficient heat transfer and low fouling reduce the size of the heat exchanger, and as a result, the reducing of the costs is associated with material, manufacturing and maintenance of the heat exchanger.

Recently, many researches have been conducted with regards to heat transfer enhancement (tube inserts effect on the heat transfer coefficient and pressure drop) as proven by a large number of papers in the literature [1–8].

Wire coils (Helical coiled wires) provide ribs at the wall (Fig. 1a). These ribs result in disruption to the ‘boundary layer’ and thereby increase the heat transfer coefficient. Collins et al. [1] survey heat-transfer performance and resulting pressure loss for a matrix of wire coils, fabricated with a series of different pitches and several wire diameters. Garcia et al. [2] have experimentally studied thermohydraulic behavior of Helical-wire-coils fitted inside a round tube in laminar, transition and turbulent flow for water and water–propylene glycol mixtures.

Wire mesh elements (such as the HiTran inserts provided by Cal Gavin Ltd.) consist of multiple loops of wire bound by a central core (Fig. 2a). The elements have a larger diameter than the tube and are therefore drawn into a

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## Nomenclature

| | |
|---|---|
| $A_f$ | Cross section of tube ($m^2$) |
| $A_I$ | Carbon steel tube inner surface area ($m^2$) |
| $d$ | Diameter (m) |
| $d_h$ | Hydraulic diameter at inner tube (m) |
| $h$ | Heat transfer coefficient ($J\ s^{-1}\ m^{-2}\ °C^{-1}$) |
| $K_b$ | Thermal conductivity of carbon steel block ($J\ m^{-1}\ s^{-1}\ °C^{-1}$) |
| $K_{pipe}$ | Thermal conductivity of tube ($J\ m^{-1}\ s^{-1}\ °C^{-1}$) |
| $L$ | Length of heating section (carbon steel block) (m) |
| $m$ | Mass rate (kg/s) |
| $Q$ | Heat transfer rate (W) |
| | Radius (m) |
| $R_f$ | Fouling resistance ($m^2$ K/W) |
| $S$ | Slope |
| $T$ | Temperature (°C) |
| $T_{fluid}$ | Bulk mean temperature (°C) |
| $T_I$ | Inner surface temperature of carbon steel block (or outer surface temperature of tube) (°C) |
| $T_i$ | Temperature for $i$th situation in carbon steel block |
| $t$ | Time (s) |
| $u$ | Fluid velocity (m/s) |
| $\Delta P$ | Pressure drop (Pa) |
| $x$ | Foul layer thickness (m) |

*Dimensionless groups*

| | |
|---|---|
| $f$ | Friction factor |
| $Nu$ | Nusselt number |
| $Re$ | Reynolds number |
| $Re_{Dh}$ | Reynolds number based on hydraulic diameter |
| $Pr$ | Prandtl number |

*Greek symbol*

| | |
|---|---|
| $\rho$ | Density ($kg/m^3$) |
| $\mu$ | Viscosity ($kg\ m^{-1}\ s^{-1}$) |

*Subscripts*

| | |
|---|---|
| $i$ | $i$th situation in carbon steel block (Fig. 3) |
| I | Inner surface of carbon steel block |
| b | Carbon steel block |
| f | Fouling layer |
| d | Deposition |
| r | Removal |
| s | Surface |

chevron shape as they are pulled into the tube. The edges of the wire loop make contact with the tube at regular points around its periphery. These provide a number of enhancement mechanisms. Under otherwise laminar flow conditions, they impart bulk motion way from the tube wall and thereby disrupt the boundary layer and promote bulk mixing. Under turbulent flow conditions they act as turbulators which disrupt the wall boundary layer. Crittenden et al. [3] surveyed the effects of wire mesh on the fouling mitigation for crude oil with its effects on the heat transfer coefficient and pressure drop, simultaneously. There are several types of insert available and each works in a different manner.

Twisted tapes (simply flat metal strip twisted into a 'cork-screw' shape) impart a swirl to the flow and thereby increase the velocity of the fluid contacting the tube wall (Fig. 1c). Eiamsa-ard et al. [4] experimentally investigated heat transfer and friction factor characteristics in a double pipe heat exchanger fitted with regularly spaced twisted tape elements. This type of insert has not been considered in this study.

Fouling is the formation of unwanted deposits on heat exchangers, which act as a thermal insulator, thereby reducing the heat transfer rate. Fouling also increases the pressure drop across a heat exchanger by increasing flow resistance. In general, the type and concentration of mineral salts and operating conditions, such as temperature, pH, pressure, time, flow velocity, radiation, mechanical motions, and impurities, determine the severity of fouling and scale formation [9–11]. There are six