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Research Paper

Heat Transfer Enhancement for site level indirect heat recovery systems using nanofluids as the intermediate fluid

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HIGHLIGHTS

- Using a nanofluid as an intermediate fluid for Heat Recovery Loops (HRL) was studied.
- The nanofluid provides passive Heat Transfer Enhancement for HRL heat exchangers.
- CuO/water (1.5 vol.%) nanofluid was modelled in a Heat Recovery Loop system.
- Liquid–liquid heat exchangers experienced a 5–9% increase in duty due to nanofluid.

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ABSTRACT

In this paper, implementation of nanofluids as a Heat Transfer Enhancement technique in Process Integration has been studied. A step by step flowchart is introduced and as a case study the effect of replacing water with various nanofluids as the heat transfer media in an industrial Heat Recovery Loop (HRL) has been modelled. Nanofluids are prepared by distributing a nanoparticle through a base fluid such as water, ethylene glycol or oils. Suspended nanoparticles slightly affect the thermal and physical properties of the base fluid. Primarily nanoparticles are added to improve the fluid's heat transfer characteristics by increasing its Reynolds number and thermal conductivity. HRL system in a large dairy factory in New Zealand has been studied as case study. Results show that by applying various HRL design methods and a nanofluid as an intermediate fluid, an increase in heat recovery is possible without the need for extra heat exchanger area and infrastructure. 1.5 vol.% CuO/water nanofluid has been chosen as an intermediate fluid and by using a constant temperature storage control strategy, heat recovery from liquid–liquid heat exchangers increases between 5% and 9%. The air-side heat transfer coefficient limits the impact of using a nanofluid for the air–liquid exchangers. In other cases, the total available duty from the process stream, such as a condenser, significantly nullifies the heat transfer benefit of using a nanofluid in a retrofit situation. Alternative to increasing heat recovery, results show that applying a nanofluid in the HRL design phase enables heat exchanger area to decrease significantly for liquid–liquid matches. Results show that the increase in pressure drop and friction factor effects in such a system is negligible.

1. Introduction

Intense competition to gain more share in markets and high energy prices motivate industries to apply energy saving methods as much as possible in their plants. Process Integration (PI) techniques have been commonly applied in a wide variety of industries to realise meaningful increases in energy efficiency through improved intra- and inter-process and plant integration [1]. Different concepts and methods have been proposed to minimise energy use in process plants ranging from heat recovery systems for individual processes to Total Site Heat Integration. In individual processes, various techniques have been applied to increase heat transfer rates in heat exchangers. These methods are known as Heat Transfer Enhancement (HTE). Generally speaking, HTE techniques are divided in two main groups: active techniques and passive techniques. In active techniques, an external force is required, such as surface vibration, electrical or magnetic field, or acoustic move on fluid. Passive techniques, on the other hand, require no external forces. Rather, passive techniques increase heat transfer by changing the surface geometry or by adding some additives to the fluids [2]. Active techniques due to their additional energy requirement are less often considered in PI methods, while passive technique are common in PI literature.

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Nomenclature

C_p	specific heat (J/kg °C)
CP	heat capacity flow rate (kW/°C)
f	friction factor
h	convective heat transfer coefficient (kW/m^2 °C)
HTC	convective heat transfer coefficient (kW/m^2 °C)
K	thermal conductivity (W/m °C)
NF	nanofluid
Nu	Nusselt number
P	pressure (Pa)
Pe	Peclet number
Pr	Prandtl number
Re	Reynolds number
T	temperature (°C)
U	overall heat transfer coefficient (kW/m^2 °C)

Greek symbols

Δ	difference
ϕ	volume percent of particle (%)
μ	viscosity (kg/m s^2)
ρ	density (kg/m^3)

Subscripts

bf	base fluid
min	minimum
nf	nanofluid
np	nanoparticle
s	supply
t	target

HTE procedure for Heat Exchangers Network (HEN) retrofit has been suggested by Zhu et al. [3]. His method is based on accounting for HTE effects in the application of Pinch Analysis techniques. Pan et al. [4] performed HTE tests for commercial shell and tube heat exchangers using turbulators for intensified tube side heat transfer. Optimisation of large scale HEN with different intensified heat transfer is their latest HTE study in PI area [5]. These techniques, such as inserting turbulators in tubes and using helical baffles in shells [6], are useful for shell and tube heat exchangers, which are a common heat exchanger type in chemical process industries. However, other techniques are presented for HTE of other heat exchanger types such as CFD analysis in plate-fin heat exchangers [7].

For many decades, adding solid micron-sized particles to conventional fluids for HTE has been considered due to their high thermal conductivity. However, in practice, operational problems, such as fouling, sedimentation and increased pressure drop, occur by using these additives which dissuades industry from applying this type of HTE technique. Recent progress in nanomaterials technology has made it conceivable to overcome these problems by producing particles at a nano-scale. Compared to micron-sized particles, nanoparticles are engineered to have larger relative surface area, high mobility, less particle momentum and higher suspension stability. Suspended nanoparticles in a fluid creates a new category of fluids called nanofluids. Nanofluids are a class of fluids with a suspension of nano-sized particles, which aims to enhance a fluid's heat and mass transfer performance [8]. Water, ethylene glycol, transformer and turbine oil, and liquid paraffin are usually used as the base fluid, while metals and metal oxides, such as Cu, CuO, Al_2O_3, SiO_2, TiO_2, as well as non-metallic particles, such as Multiwall Carbon Nanotubes. The size of the nanoparticles are typically <100 nm.

Peyghambarzadeh et al. [9] showed that using a nanofluid can increase the heat transfer coefficient, h, of car radiators by up to 40%. Later they showed the overall heat transfer coefficient, U, increased with the application of dilute nanofluids in the car radiator [10]. This research group demonstrated that using 0.4 vol.% CuO/water nanofluid can increase the overall heat transfer coefficient by up to 8% in car radiators [11]. Wu et al. [12] presented the thermal performance of MWCNT/water nanofluids in helical heat exchangers. Tohidi et al. [13] showed the combination of chaotic advection and nanofluids flow in helically coiled tubes offers higher heat transfer coefficient. Pantzali et al. [14] studied the efficiency of CuO/water nanofluid with 4 vol.% of CuO nanoparticles as coolants in commercial plate heat exchangers. Tabari and Heris [15] studied heat transfer coefficient of milk pasteurization plate heat exchanger using MWCNT/water nanofluid, and recently, the effect of hybrid MWCNT/water and Al_2O_3/water nanofluid mixture in plate heat exchangers has been studied by Huang et al. [16]. Each of these studies was at the laboratory scale, meaning the implementation of nanofluids in large scale industrial applications is not reported yet. Furthermore, the application of nanofluids, in combination with an integrated process's utility system has not been investigated.

Along with other principles of Process Integration techniques, Pinch Analysis has been established as one of the most useful tools for analysing and optimising energy systems of process plants. These standard techniques can be applied for targeting energy use and developing heat exchanger networks for single plants [17]. On a wider scale, Total Site Integration offers energy conservation opportunities for sites with multiple processes and plants. Dhole and Linnhoff [18] introduced the Total Site concept to describe a set of processes serviced by and linked through a central utility system. By considering inter-plant integration, Total Site Analysis has the potential to identify further energy savings. By using an intermediate fluid such as steam or hot oil (for high temperature processes) or hot water (for low temperature processes) through a central utility system, indirect integration offers greater advantages of flexibility and process control but has a lower energy recovery target compared to direct integration.

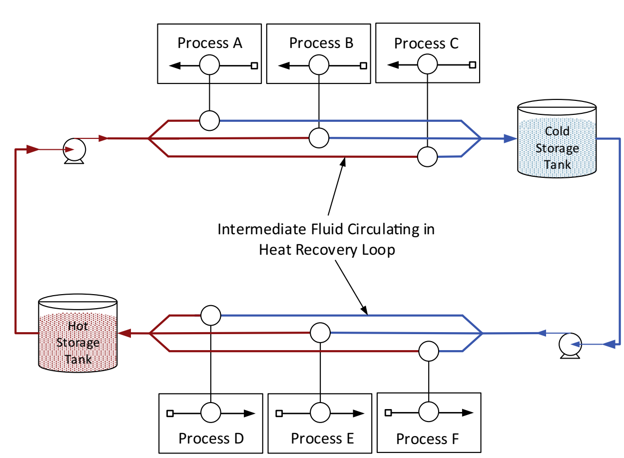

Fig. 1. A schematic of conventional Heat Recovery Loop.