STUDIES ON
COILED FLOW INVERTER HEAT EXCHANGER

by

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1. Coiled flow inverter
2. Heat exchanger

Dedicated

to

My Parents

CERTIFICATE

This is to certify that the thesis entitled, '***Studies on Coiled Flow Inverter Heat Exchanger***' being submitted by **Mr. Vimal Kumar** to the Indian Institute of Technology, Delhi for award of Doctor of Philosophy is a record of bonafide research work carried out by him under my guidance and supervision in conformity with the rules and regulations of Indian Institute of Technology, Delhi.

The research report and results presented in this thesis have not been submitted, in part or full, to any other university or institute for the award of any degree or diploma.

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ABSTRACT

Heat transfer is an essential component of nearly all industrial processes, ranging from power production, chemical and food industries, electronics, environment engineering, waste heat recovery, manufacturing industry, air-conditioning, refrigeration and space applications. Consequences of improper heat-transfer include non-reproducible processing conditions and lowered product quality, resulting in the need for more elaborate downstream process system and increased heat-transfer area. Helically coiled tubes find applications in various industrial processes like solar collectors, combustion systems, heat exchangers, and distillation processes due to their simple and effective means of enhancement in heat and mass transfer, narrower residence time distribution and compact structure.

In the present study a new device "Coiled Flow Inverter" has been introduced based on the phenomenon of flow inversion by changing the direction of centrifugal force in helically coiled tubes. The main mechanism generating the flow in the production of spatially chaotic path by changing the direction of flow in helical coils (alternating Dean flow). If the direction of centrifugal force is rotated by any angle, the plane of vortex formation also rotates with the same angle. Thus in coiled flow inverter (CFI) complete flow inversion is achieved by 90° shift in the direction of centrifugal force, which also produces the stretching and folding in flow and thermal profiles.

The attempts have been made to investigate the hydrodynamics and heat-transfer characteristics of a coiled flow inverter (CFI) as heat exchanger on pilot plant scale. The experiments have been carried out in counter-current mode operation with hot fluid in the tube side and cold fluid in the shell side of coiled flow inverter heat exchanger (CFIHE).

Experimental study has been carried out over a wide range of Reynolds numbers using DM water in the tube side of the heat exchanger. The shell side fluids used is either cooling water or ambient air. The tube side of CFIHE comprised of alternate helical coils and 90^0 bends which are inserted in a closed shell. The heat exchanger is fitted with three types of baffles (central rod, square members and wedge shaped cut plates) to provide higher turbulence and avoid channeling in the shell side. The bulk mean temperatures at various downstream positions are reported for different flow rate on tube side. The heat transfer efficiency of the heat exchanger is also calculated. Pressure drop and overall heat-transfer coefficient is calculated at various tube and shell side process conditions. The outer and inner heat-transfer coefficients are determined using Wilson plot technique. The results show that at low Reynolds number, heat-transfer in CFIHE is higher as compared to coiled tubes, while at high Reynolds numbers, the configuration has less influence on heat transfer enhancement. New empirical correlations have been developed for friction factor and Nusselt number predictions in the (CFIHE).

The convective heat transfer in CFIHE has been numerically investigated by varying Dean number, Prandtl number and number of bends under laminar flow conditions with constant wall temperature (T_W) and constant wall flux (Φ_W) as a boundary condition. The three-dimensional governing equations for momentum and energy under the laminar flow conditions are solved with a control-volume finite difference method (CVFDM) with second-order accuracy. The stretching and folding phenomenon in Coiled flow inverter is observed and discussed for flow and thermal development, heat transfer coefficient and flow resistance in the coiled flow inverter. The cyclic oscillation behavior in the heat transfer coefficient with downstream distance in the coiled flow inverter and coiled tube is also observed and discussed. It appeared that heat transfer is strongly influenced by flow inversion. The effect of boundary conditions on heat transfer performance in the Coiled flow inverter as well as in the coiled tube has also been studied. The effect of Prandtl number on fully developed heat transfer coefficient is also reported. It is observed that heat transfer increases with increase in Prandtl number.

The study has been further extended to predict hydrodynamics and heat transfer with temperature-dependent properties (density, viscosity, thermal conductivity and specific heat) in the coiled tube and coiled flow inverter. The secondary flow induced due to centrifugal force distorts the velocity and temperature profiles when the effect of temperature-dependent properties is taken into account. It is observed that the heat transfer under heating condition with temperature-dependent viscosity is higher as compared to the constant viscosity result while friction factor shows the reverse phenomenon in CFI. A new model is also developed in the present study based on the property-ratio technique for both friction factor and Nusselt number.

In another study the hydrodynamics and heat transfer characteristics of a tube-in-tube helical heat exchanger at the pilot plant scale has also been investigated both experimentally and numerically. The experiments are carried out in counter current mode operation with hot fluid in the tube side and cold fluid in the annulus area. The outer tube is fitted with semicircular plates to support the inner tube and also to provide turbulence in the annulus region. The heat transfer coefficients are calculated in the inner as well as outer tubes using Wilson plots. The flow and thermal development in tube-in-tube helical heat exchanger are carried out numerically for both inner and outer tubes. The numerically obtained Nusselt number and friction factor values in the inner and outer tubes are compared with the experimental data collected in the present study as well as reported in the literature. The numerical predictions are in good agreement with the present experimental data. The performance of CFIHE and tube-in-tube heat exchanger is compared.

The technology transfer of CFIHE has also been done for the fertilizers industry in INDIA. The basic engineering package (BEP) and detailed drawings of the CFIHE is prepared and given to the concerned fertilizers industry. The design of the CFIHE is carried out for the following two process streams: (a) installation of a new water cooler in CO_2 compressor suction knock out drum and (b) replacement of a liquid-liquid heat exchanger for heat recovery in Urea Plant. It is found that the there will be a 25 % energy saving if the CFIHE is replaced with the existing heat exchanger in the fertilizers industry.

TABLE OF CONTENTS