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Enhancing Thermal Efficiency of Nano fluid Flow within Single Pipes Using Helical Inserts under Steady Wall Temperature Conditions: A Numerical Analysis

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Abstract** - The thermal performance of a heat exchanger can be enhanced by external agencies or allowing fluid to pass through finned tubes, helical inserts, nano fluids etc. The external agencies can be a source of electrical power, electromagnetic field, and surface vibrations. Augmenting heat transfer by using helical inserts is attempted by many researchers, In the present study a single pipe of 40 mm internal diameter under constant wall temperature is investigated numerically. The fluid volume flow rate is varied from 0.25 to 4 liters/min covering laminar, transition and turbulent regions. Water flowing through the pipe without insert is as taken as the base for investigating the combined influence of helical inserts and silver nano fluids in enhancing heat transfer. Two types of inserts i.e., 3 meters long (HI-L, extending to full length of pipe) and 1.5meters (HI-S, centrally spaced) and three compositions of silver nano fluids (volume fractions of 0.3,0.6 and 0.9) are considered. It is observed that the exit temperature for pure water raises linearly with flow rate increasing from 0.25 to 0.2 lit/min and there after drops down slowly. On the other hand, the exit temperature remains constant for all silver nanofluid volume fraction investigated at all volume flow rates. The possible reason for above deviation could be due to superior thermal properties of silver nanofluids, which enables more heat transferred to the fluid irrespective of change in volume flow rate. Pure water flowing in the single pipe at 1liter/min has resulted in heat transfer coefficient (HTC) of 57 W/m²k, and is taken as base value. With silver nanofluids alone the HTC value has shown large enhancement Viz111,121,133 W/m².k with 0.3,0.6 and 0.9 volume fraction at same mass flow rate of 1liter/min. Compounding nano fluids and long insert has resulted in very large improvement in heat transfer viz 153,171 and 187 W/m².k. With pure water & long insert, HTC value has increased to 106 i.e.is 96% more than the base value. On the hand, compounding with short insert and silver nanofluids (1lit/min mass flow rate) has yielded HTC values Viz 122,137, &150 W/m². k, which are lower compared with values obtained with long insert indicating the length of inserts has a leading key role in augmenting heat transfer.

Key words -
Heat transfer coefficient, Augmentation, Silver nano fluids, Helical inserts (HI) .

1.INTRODUCTION

Using inserts in the fluid path in steam boiler is reported long back in nineteenth century(1896) by **Whitham [1]** .Hot gases flowing in the boiler tubes were allowed to pass through metal inserts for retarding the flow of gases .Extensive numerical and experimental work on improvement of heat transfer by using helical inserts in the fluid path and effect of variation of twist ratio, pitch and preformatted inserts ,relative spacing of inserts and using nano fluids is reported in detail in literature. Combined influence of helical insert and nano fluids in particular silver nano fluids would yield large heat transfer enhancement. **H. M. Shankara Murthy et al [2]** used graphene oxide with volume fractions of 0.05%,0.1% and 0.15% as the working fluid in the outer tube in their experimental study while maintaining constant flow rate of hot fluid in inner pipe of double pipe heat exchanger. Maximum enhancement was achieved with 0.15% nano fluid flowing past insert with twist ratio 9.8. **Ahmet Selim et al [3]** carried out

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experimental validation of Nusselt number and friction factor with standard analytical equations for pure water under constant heat flux and turbulent flow condition and achieved satisfactory results. **Gnanavela et al [4]** mathematically examined heat transfer heightening with nanofluid flow through spiral spring inserts with Reynolds number varying from 1000 to 10000.Increased pressure drop, heat transfer rate and Nusselt number and decreased frictional drop were noticed with the increase in Reynolds number.

Nomenclature

Q	Heat flow through pipe, W
Nu	Nusselt number
m	Mass flow, kg/sec
k	Thermal conductivity, W/m. k
HTC	Heat transfer coefficient, W/m^2. k
Di	Inner diameter of pipe, m
Cp	Specific heat, J/kg, k
Ts	Surface temperature of wall, k
Ti	Inlet temperature of the fluid, k
Te	Exit temperature of the fluid, k
Tb	Bulk mean fluid temperature. k
Re	Reynolds number
ρ	Density of the fluid, kg/m^3
μ	Dynamic viscosity, $N\text{-}S/m^2$

Smith Eiamsa et al [5] investigated experimentally double pipe heat exchanger with screw tapes with/without core rods from laminar to fully turbulent flow condition with water as cold and hot fluids and concluded that inserts without core rod have performed better**. Papazian et al [6]** analyzed and compared fluid flow through porous metal foam and solid twisted inserts in the laminar region with titanium oxide suspended in pure water at 0.01% volume fraction and observed that inserts performed better than porous foam. However higher thermal efficiency is obtained with nano fluid and porous foam when compared with pure water. Mudit K. **Bhatanagar et al [7]** compared relative efficiency of improving the heat transfer using inserts and multi walled carbon nano tubes. It was concluded that increased twist ratio results in decrease of Nusselt number and friction factor while addition of nano fluid decreased friction factor and thermal resistance of the fluid **Jaafar Albadr et al [8]**experimentally investigated effect of adding Al_2O_3 nano particles and their study revealed that higher volume fractions and mass flow rate of Al_2O_3 nanofluids yielded higher heat transfer coefficient than for pure water and increased volume fraction resulted in larger frictional factor values. **Farajollahi et al [9]** investigated γ-Al_2O_3/water and TiO_2/water nanofluids for effect of peclet number, particle size, on heat transfer coefficient under turbulent flow. It was observed that TiO_2 nano particles had superior performance at certain peclet number. Sung-**Wen Kang et al [10]** conducted experiments using silver based nano fluids in heat pipe and observed that the thermal resistance is dependent on nano particle size and higher concentrations resulted in less increase in wall temperature when compared to water.

2. Technical data reduction [11]

Under constant wall temperature (Ts = constant), rate of heat transfer to or from a fluid flowing in a tube.

$$Q = h * As * \Delta Tavg = h * As * (Ts - Tb)avg \qquad (1)$$

ΔT avg can be expressed using, arithmetic mean temperature difference, AMTD or logarithmic mean temperature difference, LMTD.

Arithmetic mean temperature difference (AMTD),

$$\Delta Tavg \approx \Delta Tam = \frac{\Delta Ti + \Delta Te}{2} = \frac{(Ts - Ti) + (Ts - Te)}{2} = Ts - \frac{Ti + Te}{2} = Ts - Tb$$

(2)

Bulk mean fluid temperature: $Tb = \frac{Ti + Te}{2}$ (3)

With arithmetic mean temperature variance, it is assumed that the mean fluid temperature varies linearly along the tube, which is hardly ever the case when Ts = constant.

Therefore, a better way to evaluate ΔT avg is log mean temperature difference, LMTD.

$$\Delta Tln = \frac{(Ti - Te)}{\ln(Ts - Te) - (Ts - Ti)} = \frac{\Delta Te - \Delta Ti}{\ln\left(\frac{\Delta Te}{\Delta Ti}\right)}$$

this equation satisfies log mean temperature difference. (4)

3.Resuts and discussions

A single pipe of 40 mm internal diameter under constant wall temperature is investigated numerically. The fluid volume flow rate is varied from 0.25 to 4 liters/min covering laminar, transition and turbulent regions. Water flowing through the pipe without insert is as taken as the base for investigating the combined influence of helical inserts and silver nano fluids in enhancing heat transfer. Two types of inserts i.e., 3 and 1.5 meters long and three compositions of silver nano fluid (volume fractions of 0.3,0.6 and 0.9) are considered. The thermo physical properties of silver nano fluids are taken from experimental studies carried out vide reference **[12]**. The CAD model is imported into ANSYS CFX geometry module and meshing is done taking due care for strong curvatures present in the inserts. Grid independence study is carried out as part of achieving convergence criteria. The exit temperatures and mass flow rates obtained through CFD simulation are used for computing LMTD, HTC and Nu and the difference of these parameters with volume flow rate are presented in

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Figs 3.1 to 3.9 below. The numerical model is validated with experimental results vide reference **[13].**

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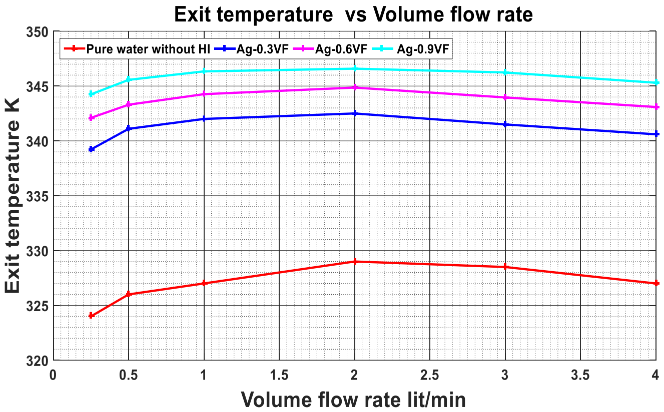

Fig :3.1 Pure water without HI & Silver nano fluids without HI

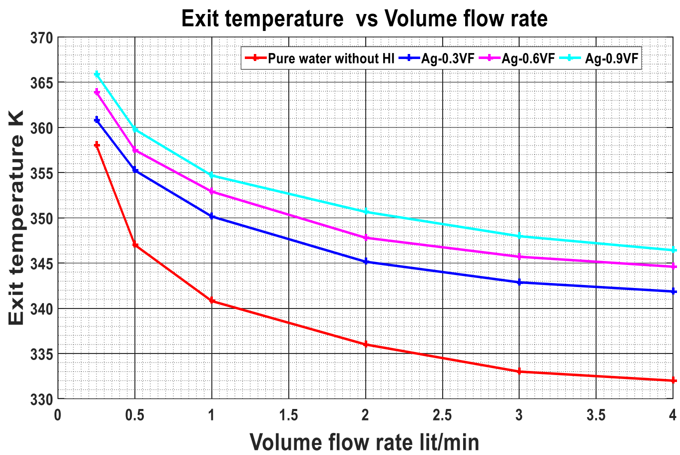

Fig :3.2 Pure water with HI-L & Silver nano fluids with HI-L

Referring to figures of 1 to 3 the exit temperature variation with increased volume flow rate without inserts shows marked deviation for pure water from variation in nanofluids. The exit temperature for pure water raises linearly with flow rate is increasing from 0.1 to 0.2 lit/min and there after drops down slowly while the temperature remains more or less constant for all silver nanofluid volume fraction investigated at all volume flow rates. The possible reason for above deviation could be due to increased thermal conductivity of silver nanofluids (0.8 to 1.2 W/m. k for volume fraction 0.3 to 0.9) compared to pure water (0.6 W/m. k). The enhanced thermal conductivity enables more heat transferred to the fluid irrespective of change in volume flow rate. On the other hand, for fluid flow with inserts (long & short), the exit temperature drops down continuously with variation of fluid mass flow rate for pure water as well as nanofluids. Also, the highest temperature raise is observed for long inserts, followed by short insert and without insert indicating that the heat transfer to the fluid is very high for long insert followed short insert and without insert

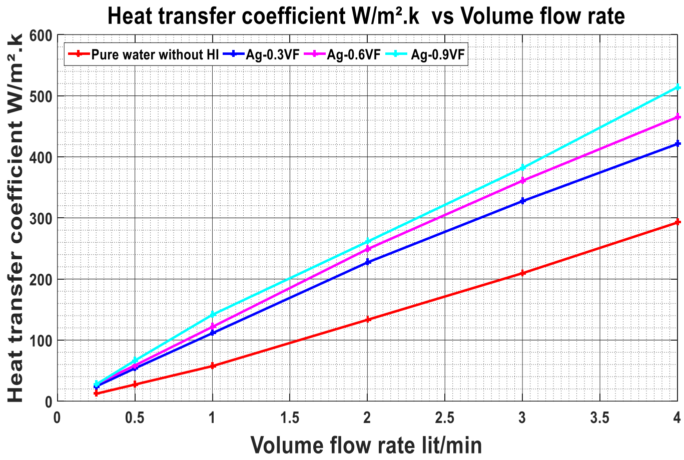

Fig :3.4 Pure water without HI & Silver nano fluids without HI

- Above figures 3.4 to 3.6 shows variation of HTC with volume flow rate increase from 0.25 to 4 lit/min. In all cases i.e., without & with inserts, all fluids investigated show linear tend i.e., the Heat transfer coefficient varies linearly with mass flow rate."

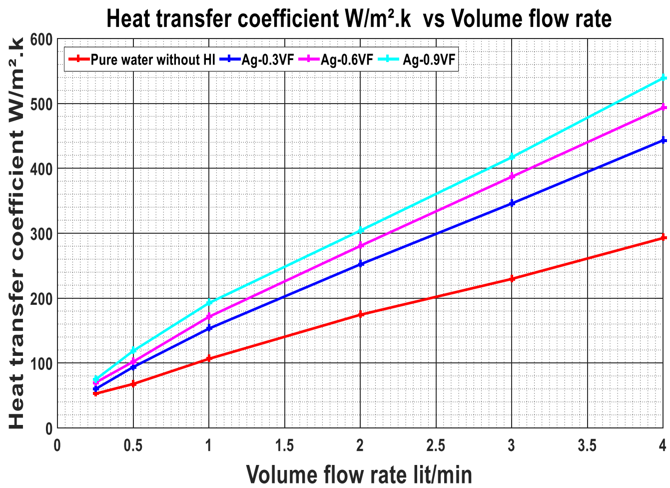

FIG :3.5 PURE WATER WITH HI-L & SILVER NANO FLUIDS WITH HI-L

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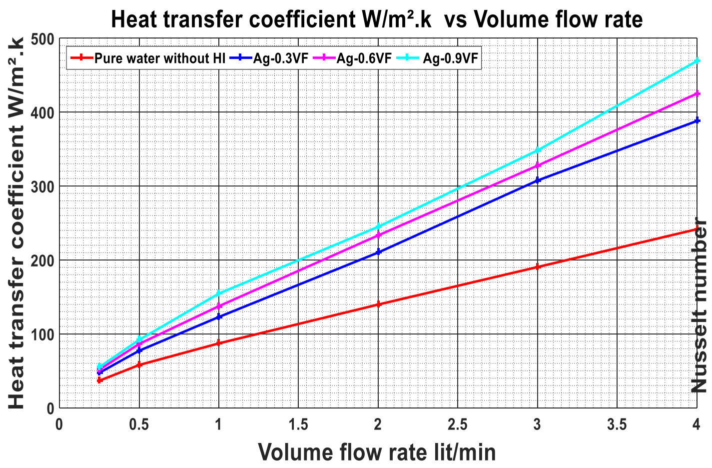

FIG :3.6 PURE WATER WITH HI-S & SILVER NANO FLUIDS WITH HI-S

With pure water without HI insert Heat transfer coefficient has least range of values, 12 to 210 and when fluid flow is through the long insert, the HTC values have shot up to 52 to 292, while for short insert the range is 36 to 241. The Heat transfer coefficient enhancement is due to the helical inserts impeding the fluid flow passing the tube wall and also causing swirl motion which further aggravates as the Reynolds number increases. In case of silver nano fluids, the Heat transfer coefficient range is 24 to 421 for volume fraction 0.3 while the range has shot up to 59 to 442 and 49 to 387 for long & short insert respectively. However very large augmentation is noticed for volume fraction of 0.9 is 130 (1 lit/min) without insert to 187 and 150 for long & short insert respectively (for comparison pure water without insert has only 57 (0.5 1lit/min). The large improvement is due to the combined influence of helical insert and enhanced thermal conductivity of silver nano fluids.

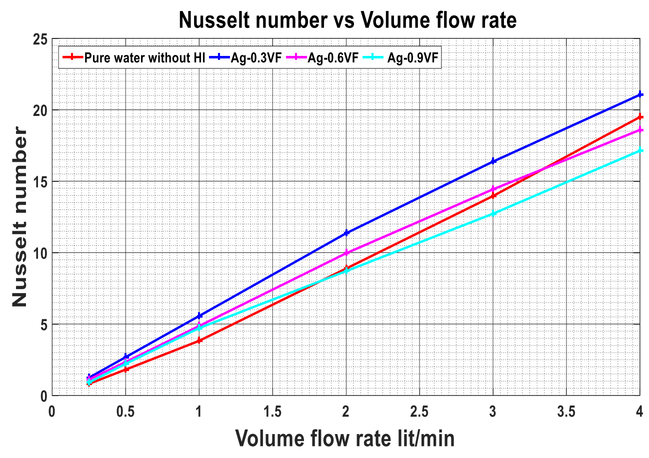

Fig :3.7 Pure water without HI & Silver nano fluids without HI

With reference to Figures 7 to 9 the Nusselt number variation with volume flow rate varying from 0.25 to 4 lit/min shows uniform increase for all fluids investigated. The Reynolds number covers laminar region up to 1lit/min flow tare and later enter transition/ turbulent region,

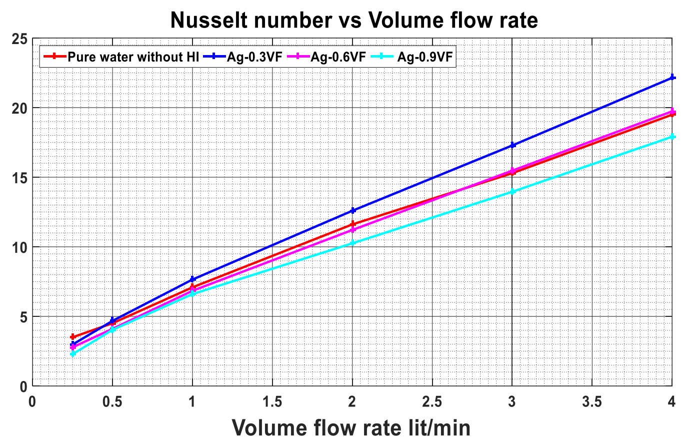

***Fig :3.8** Pure water with HI-L & Silver nano fluids with HI-L*

In the laminar flow region, Nusselt number for pure water with long insert has resulted 4 times increase when compared with the value without insert, while in turbulent region, the increment is 1.34 times. On the other hand, with short insert improvement is 2 times in laminar and 1.1times in turbulent regions. For silver nano fluids, both long &short inserts yielded 2 times rise in Nusselt number in laminar region and less than 1.5 times in turbulent region indicating superiority of pure water over silver nano fluids.The possible reason is due to the dependence of thermal conductivity on Nusselt number. Hence it would be preferable to compare Nusselt number only for same fluids rather than with different fluid (0.8 to 1.2 for silver v nano fluid and for water 0.6).

Figs3.10 to 3.16 represents total temperature contours at outlet of pipe for all compositions investigated at 1 lit/min. Extreme outside of fluid in contact with solid wall is at 370K for all contours .Temperature for pure water with insert has resulted in increase in temperature from 327K (without insert) to 340K

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as seen in figures 3.10 & 3.13.For silver with 0.3 volume fraction, the temperature raise with insert is 8K over temperature without insert (342K without insert and 350K with HI-L) and 8K for silver 0.6 volume fraction (344K to 352K) and 9K for silver- 0.9 volume fraction (346K to 355K).Combined influence of nano fluid &insert has resulted in significant temperature raise of 28K for 0.9 volume fraction (with insert-HI-L) when compared to the pure water without insert.

Figs 3.10 to 3.16 represents total temperature contours at outlet of pipe for all compositions investigated at 1 lit/min. Extreme outside of fluid in contact with solid wall is at 370K for all contours

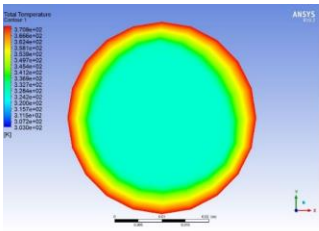

Fig :3.10 Water without HI

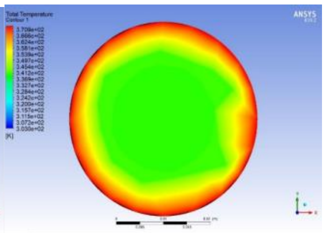

Fig :3.14 Water with HI-L

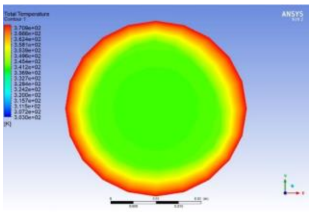

Fig :3.11 Ag without HI-0.3VF

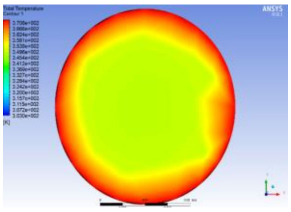

Fig :3.15 Ag with HI-L 0.3VF

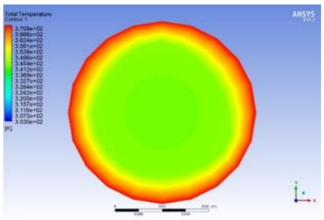

Fig :3.12 Ag without HI-0.6VF

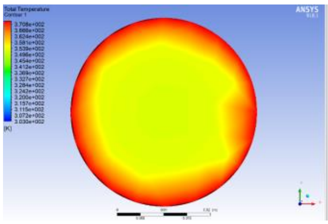

Fig:3.16 Agwith HI-L0.6 VF

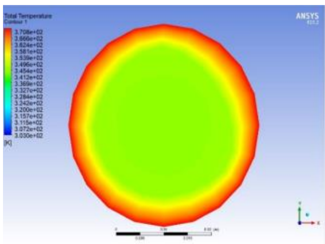

Fig :3.13 Ag without HI-0.9VF

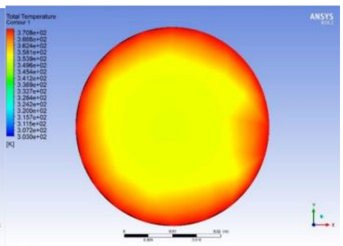

Fig :3.17 Ag with HI-L 0.9 VF

Temperature for pure water with insert has resulted in increase in temperature from 327K (without insert) to 340K as seen in figures 3.10 & 3.13.For silver with 0.3 volume fraction, the temperature raise with insert is 8K over temperature without insert (342K without insert and 350K with HI-L) and 8K for silver 0.6 volume fraction (344K to 352K) and 9K for silver-0.9 volume fraction (346K to 355K).Combined influence of nano fluid &insert has resulted in significant temperature raise of 28K for 0.9 volume fraction (with insert-HI-L) when compared to the pure water without insert.

4.CONCLUSIONS

1) The exit temperature for pure water raises linearly with flow proportion increasing as of 0.1 to 0.2 lit/min and there after drops down slowly while the temperature remains more or less constant for all silver nanofluid volume fraction investigated at all volume flow rates.
2) Here augmentation of heat transfer rate only depends percentage of Ag volume fraction suspended in the circulating of pure water in the SPHE.
3) Improvement in the heat transfer coefficient only when volume flow percentage and pace of the nano fluid flowing through the pipe.
4) Combination of helical insert and nano fluids improved extreme heat source from wall to circulating fluid in the inside pipe with comparison between without insert and with inserts at HI-L & HI-S.
5) the HTC range is 24 to 421 for volume fraction 0.3 while the range has shot up to 59 to 442 and 49 to 387 for long &short insert respectively. However very large growth is noticed for VFR of 0.9 is 130 (1 lit/min) without insert to 187 and 150 for HI-L &HI-S respectively (for comparison pure water without insert has only 57 (0.5 1lit/min). The large perfection is due to the combined stimulus of helical insert and sophisticated thermal conductivity of silver nano fluids.
6) The possible region is due to the dependence thermal conductivity on Nusselt number. Hence it would be preferable to complete Nusselt number only for same fluids rather than with different fluid (0.8 to 1.2 for silver v nano fluid and for water 0.6).
7) Combined influence of nano fluid &insert has resulted in significant temperature raise of 28K for 0.9 volume fraction (with insert-HI-L) when compared to the pure water without insert.

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