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Experimental Study of Forced Convection Heat Transfer Ferrofluid in Pipe Exposed to Magnetic Field

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ABSTRACT: The steady state, 2-D fully developed forced convection laminar flow of Fe_3O_4/ethylene glycol subjected to a different Magnetic Field with constant property in horizontal pipe duct has been thoroughly investigated experimentally . Three different values of Reynolds number(100,250,450 and 750), volume fraction(0.1, 0.25, 0.5 and 1)% ,and Hartman number (44.8 and 62.4) were employed, and constant Heat Flux boundary condition was applied. Results are for compared with theoretical data available in the literature steady state condition, good agreements are showed. The results appeared that heat transfer rate become more remarkable when employing Ferrofluid than base fluid(Ethylene glycol). Heat transfer enhancement increases with the particle volume concentration increase for a given other parameters, and considerable reduction in time consuming for steady state condition. local and average Nusselt number, Temperature difference, friction factor, are introduced for various Reynolds numbers ,Hartmann numbers volume fraction of nanoparticles.

KEY WORDS: Pipe, Forced Convection, Ferrofluid, , Laminar flow and magnetic field.

I. INTRODUCTION

one of the most significant practical intendance that increase of heat transfer ratefor both researches and industries. main limitations for using conventional liquids such as water, oils, ethylene glycol etc. its low thermal conductivity . Several techniques that enhancing heat transfer rate such as changing geometry of flow, boundary conditions or by improving thermo- physical properties of fluid can be employed. consequently in latest years, add suspended nanoparticles(less than 100nm) sized will advance heat transfer capability since these nanofluids have a better thermal performance compared to base liquids. The metallic nanoparticles can be classified into two types, pure substance and oxides. These nanoparticles have a slight effect on friction factor due to a tiny scale compared to millimeters or microns which alter flow profile causing considerable increasing in pressure drop.

II. RELATED WORKS

nanofluids are so appropriate for applications where fluid flows through small passages because nanoparticles are small enough to perform as well to molecules of liquids[1]. several studies showing that heat transfer coefficient of nanofluids could be increased compared with base fluids until at low nanoparticles concentrations adoptions.[2,3]
The enhancement in convective heat transfer in in the laminar flow where increase with volume Concentration and Reynolds number showed experimentally by [4]. The reduction in thermal boundary layer thickness and the random motion due to adding the nanoparticles were the essential reasons of that augmentation [5]. However, the increase of nanoparticles concentration will lead to increase of heat transfer, as intensification of random motion will attached by increasing of interface and collision ratio. There are some articles existing associated to study the convective heat transfer of nanofluids, most of them are based on experimental investigation. The effect of adding Al_2O_3 nanoparticles to two types of fluid (ethylene glycol and water) on heat transfer in laminar flow regime were studied numerically by Maiga et al. [6]. Also, the effect of using Cu/water on heat transfer coefficient and friction factor were investigated by

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Li and Xuan [7] experimentally. A remarkable increasing in Nusselt number ratio (Nu when using nanofluid to that of pure fluid) up to 60% showed when using nanofluid with 2% volume fraction of Cu according to their experimental results. Fotukian and Esfahany. [8] investigated experimentally the effect of nanofluid on heat transfer rate in tube oriented horizontally. Some of penetrative parameters such as nanoparticles volume concentration, Reynolds number, temperature and nanoparticles source on heat transfer have been studied. The results illustrated thatwas no significant increase in heat transfer coefficient enhancement accompanied with the Reynolds number and particles concentration compared to conventional fluid. The convective heat transfer of laminar flow with oxide nanoparticles under constant heat flux in circular tube were studied experimentally Zeinali et al.[9]. Results showed that Nusselt number increase when volume fraction increase for all Reynolds number. M.H. Kayhani et al.[10] investigated Experimentally convective heat transfer and pressure drop of TiO_2/water nanofluid. the results showed that The enhancement at nanofluid with 2.0% nanoparticle volume fraction is about 8% of the Nusselt number.Rea et al. [11] were studied convective heat transfer for Laminar flow and viscous pressure losses of two types of nanofluids (Al_2O_3–water and zi–water) with different concentrations. Result presented that heat transfer increase in both the entrance and in the fully developed regions.

Duangthongsuk and Wongwises [12] were estimated performance of heat transfer of the (Al_2O_3+water) in main double copper pipe heat exchanger with turbulent regime. The major aim of this investigation to study the effect of magnetic field of fully, Newtonian, laminar flow forced convection with different nanoparticles concentrations as well as (**Re**) on the enhancement of heat transfer rate experimentally.

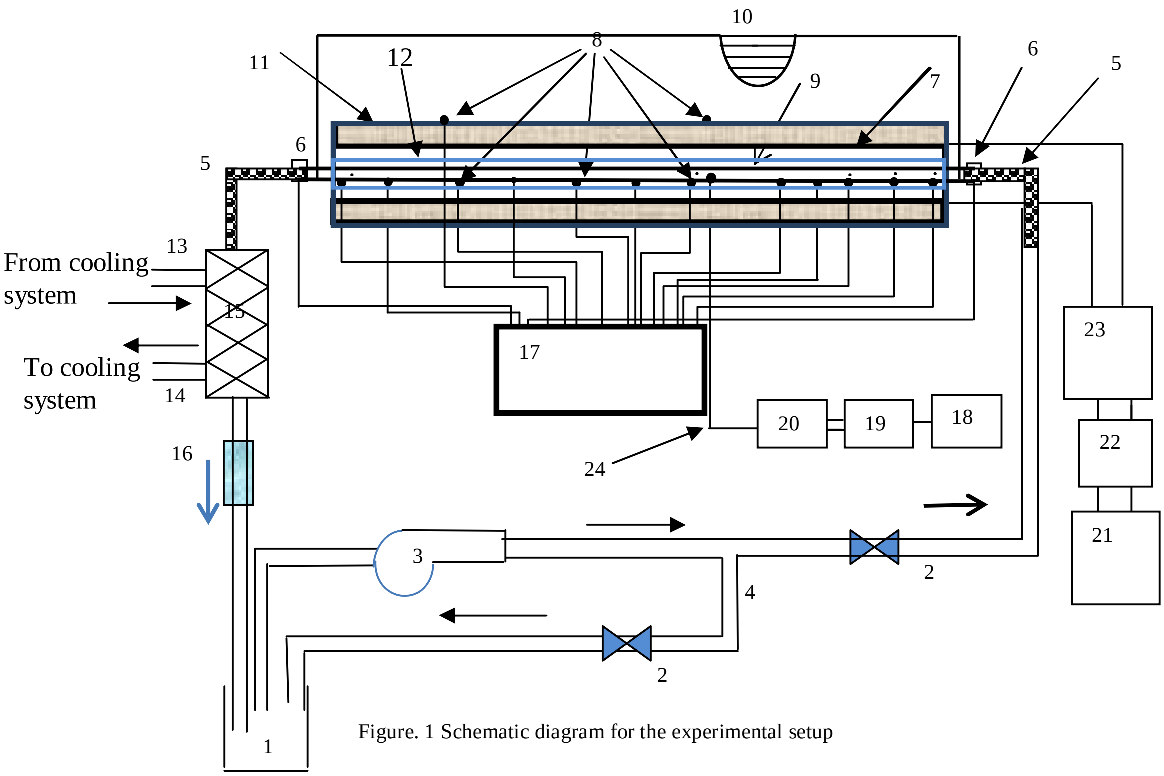

Figure. 1 Schematic diagram for the experimental setup

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1	Reservoir Tank	9	Test Section	17	Data logger
2	Global Valve	10	U-tube Manometer	18	Multi meter
3	Teflon Pump	11	Glass wool Insulation	19	Digital Electrical Temperature Controller
4	By-pass Connection	12	Magnetic Solenoid	20	Electrical Fuse
5	Flexible Tube	13	Cooling Water Inlet	21	AC Power Source
6	Insert Thermocouples	14	Cooling Water Outlet	22	Voltage Stabilizer
7	Electric enfolded heater	15	Double Helical Glass H.E	23	Transformer
8	Surface Thermocouples	16	Flow meter	24	Thermocouple J-type

III. EXPERIMENTAL SETUP

Figure.1 illustrates the schematic the experimental setup under consideration. The apparatuses work in this setup consists of a PVC tanks (reservoir), By-pass line, Teflon pump, Copper pipe(test section), flow meters, magnetic field generator (Magnetic Solenoid), electrical heating circuit and circuit of cold water. The purpose of employing plastic tank and Teflon pump to avoid Impedes nanoparticles and walls of two parts above. Two PVC receiver tanks are employed, one for store Ferrofluid (3.5L) and other (14L) for Cold water supplying and Preservation. The test section was Copper pipe of (6.35 mm, 0.25 inch) diameter and 150 mm length. In both ends of test section, two (T-type) thermocouple were insert to measure temperature during experiments then estimate bulk temperature of working Ferrofluid. An additional twelve T-type Thermocouples are fixed on the copper pipe surface at different positions.All thermocouples used have 0.1^{o}C inaccuracy and were calibrated before installation at specified positions. Furthermore, the thermocouple were attached to 24 channel Auto data logger (Ethernet Temperature Data Logger). The primary goal of by-pass line is to regulate the required flow rate and direct back excess ferrofluid to reservoir. Also, to obviate of the fluctuations that may be generated from pump during operation, the flow meter was placed after test section ending. The test section, heated by tape heater (600 W and 18m long) enfolded on external surface and a variac (digital Transformer) (0-250V & 15A)was employed to change the input supplied power of the heater as desired. To reduce the radiation losses, three layers of insulation that are asbestos tape, glass wool and reflective tape was used to insulated pipe carefully. A digital multimeter was employed to measure the heat power applied. Anyway, the cold water supplied from cooling system in Figure (2) was exploited to remove the adding heat from the experiments. Cooling water circuit consist of cold water reservoir , gear pump, chillier and double glass heatexchangers in series to increase of heat transfer capacity.To measure the pressure drop across the pipe, two taps for static pressure are subjected nearly the inlet and outlet sides of the Copper pipe. The Reynolds number and chosen heat flux were specified till steady-state was reached.

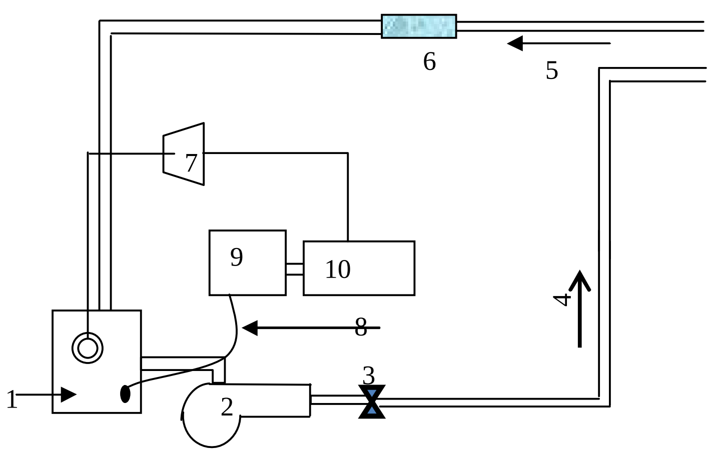

Figure (2) Representation diagram for the Cooling system

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1	Tank of Cold Water	5	Cooling Water Outlet	8	Sensor
2	Electric Pump	6	Flow meter	9	Electrical Fuse
3	valve	7	Chiller	10	Digital Electrical Temperature Controller
4	Cooling water inlet				

IV. EXPERIMENTAL DATA ANALYSIS

The heat transferred to ferrofluid is

$$Q = -\dot{m}\,Cp\left(T_i - T_o\right) \qquad (1)$$

The supplied power from electrical heater can be calculated as

$$Q = IV \qquad (2)$$

where(T_i) and(T_o) are the inlet temperature and outlet temperature of ferrofluid, respectively.

The balance between heat flux computed (Eq.1) and heat flux supplied (Eq.2) exhibited that the variation between them is about 7% because of good thermal insulation layers and high thermal conductivity of magnetite.

The local bulk temperature $(T_b)_x$ is calculated as

$$\left(T_b\right)_x = T_i + \frac{x}{L}\left(T_o - T_i\right) \qquad (3)$$

And the coefficient of heat transfer, is computed from following equation

$$h_{(\exp)x} = \frac{Q}{A\left(\left(T_w\right)_x - \left(T_b\right)_x\right)} \qquad (4)$$

and experimental Nusselt number (local)

$$Nu_{(\exp)x} = \frac{h_{(\exp)x}\,D}{k} \qquad (5)$$

similarly, the friction factor of the ferrofluid flowing during the pipe is estimated as

$$f = \frac{2\Delta P}{L}\frac{D}{\rho u_m^2} \qquad (6)$$

its noticeable to mention that all physical properties should evaluated at local mean temperature.

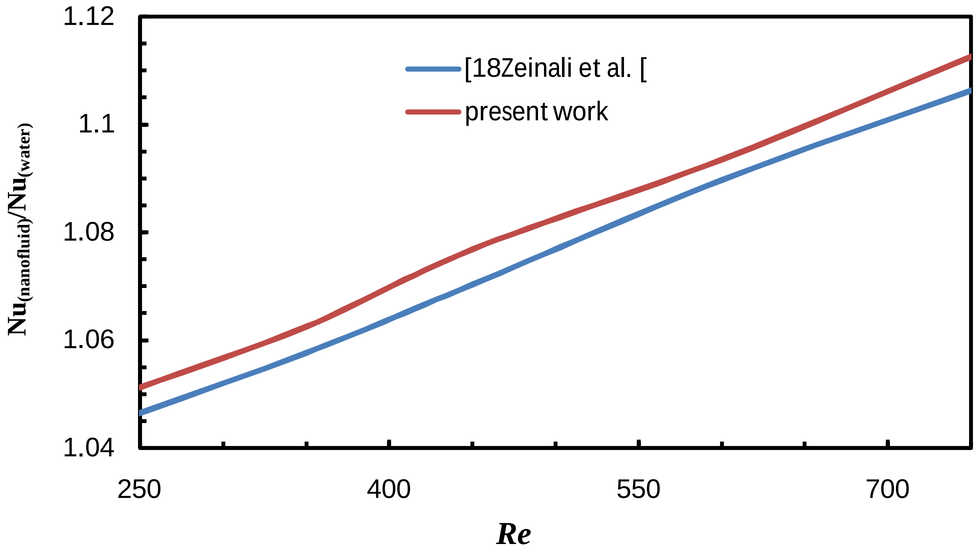

Figure.(3) Comparison between investigated results and results estimated by mod of ZeinaliHeris et al. (2006) [9]

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V. NANOFLUID PREPARATION AND VALIDATION

the first essential step in applying nanophase particles is preparation of nanofluids.The physical properties of Copper powder were taken of the sheet of producer and scheduled in Table 1. The suspending fluid media was Ethylene glycol. The volumetric ratios of nanoparticles were transferred to equivalent weight and gradually added to liquid while agitated in a glass flask. Then, the mixture was mixed in a stationary mechanical mixer after switching iron arm with glass one, for one hour. The suspensions were subjected to ultrasonic vibration (Elmasonic P180H) for 3-5 hours to find regular suspensions and pulverize the huge clusters. Thereafter, the prepared ferrofluid is ready to employed in the experiments. To check accuracy and durability of the set-up, primary experiments were implemented with distillated water as working fluid before performing the experiments of ferrofluid.
Fig.3 shows The experimental results were comparing with the Zeinaliet al. (2006) [9] . this figure indicate the comparison of average Nusselt number ratio which calculated numerically with those values estimated from the present work.

VI. PREPARATION OF NANOFLUID (FERROFLUID)

To compute the thermal and physical properties of ferrofluids such as the specific heat ,density, thermal and electrical conductivity and viscosity, It must be estimated first based on the single phase model. All essential properties of Ethylene glycol and (Fe_3O_4)nanoparticles are given in table.1.The thermophysical properties of nanofluid differ about base fluid and nanoparticles properties. So, the new physical and thermal properties must be calculated first based on single phase hypothesis.

-Heat capacity $(Cp)_{nf} = (1-\phi)(Cp)_f + \phi(Cp)_p$ (7)

-Density $\rho_{nf} = (1-\phi)\rho_f + \phi\rho_p$ (8)

-Thermal conductivity $\kappa_{nf} = \kappa_f (28.905\phi^2 + 2.8273\phi + 1)$ (9)

-Viscosity $\mu_{nf} = \mu_f (306\phi^2 - 0.19\phi + 1)$ (10)

The electrical conductivity of ferrofluid is given by

$$\frac{\sigma_n}{\sigma_f} = 1 + \frac{3\left(\frac{\sigma_s}{\sigma_f} - 1\right)\phi}{\left(\frac{\sigma_s}{\sigma_f} + 2\right)\phi - \left(\frac{\sigma_s}{\sigma_f} - 1\right)\phi} \quad (11)$$

The volumetric fraction (ϕ)of the Ferrofluid will be obtained as:

$$\phi = \frac{m_p/\rho_p}{(m_p/\rho_p) + (m_f/\rho_f)} \times 100\% \quad (12)$$

Properties	Ethylene glycol	Fe_3O_4
density (Kg/m^3)	1114	5370
heat capacity (J/Kg.k)	2415	663
viscosity (Kg/m.sec)	6851E-6	———
thermal conductivity (W/m.k)	0.258	82.6

Table (1). Thermal physical properties of Ethylene glycol & Fe_3O_4 at $T=298^oK$

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VII. RESULTS AND DISCUSSIONS

Figures .4 illustrate the experimental wall temperature results for different nanoparticles volume concentrations. However, the applied heat flux habitually followed by firstly increasing in wall temperature and secondly lower increasing in nanofluid temperature. So, The rapid increase of surface temperature noted when heat flux applied suddenly initially of conduct experiment due to high difference between initial wall temperature and that generated by applying heat flux. Ejection of nanoparticles from the wall to the bulk of the flow may be responsible for considerable

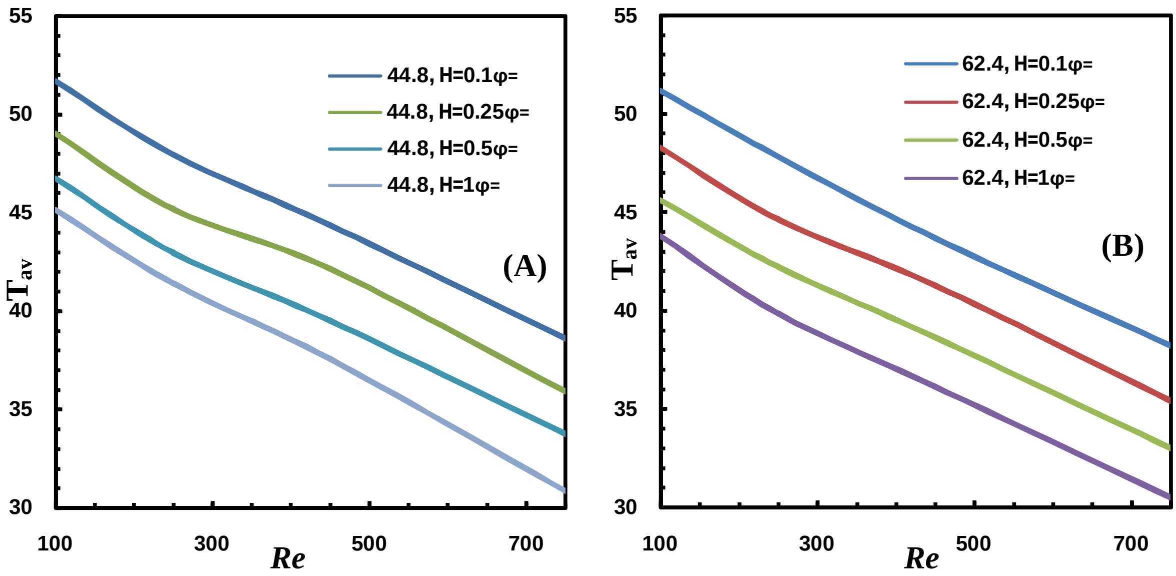

Fig.(4). Variation of average wall temperature with Re for different volume fraction of ferrofluid where (A) H=44.8., (B) H=62.4

augmentation of heat reduction on walls by add of nanoparticles to the liquids. Furthermore, increase in Reynolds number has inversely influence on temperature of wall because increasing of Reynolds will enhance heat transfer rate between wall and nanofluid molecules causing noteworthy decrease in wall temperature.

The local Nusselt number for pipe with different values of nanoparticles concentrations are testifying in sequential Figs. (5) and (6). It's clear that an important enhancement in rate of heat transfer can be found when suspending small volume of nanoparticles in liquid. The local Nusselt number has a higher value at the entrance of the channel, due to the high difference between the wall temperature and bulk of nanofluid temperature (the developing flow presents an optimal performance than the developed flow).

At the entrance of the channel, the hydrodynamic Boundary layer thickness is almost zero, hence there is no resistance against heat transfer, which leads to raise the value of the Nusselt number to a maximum value. And after a short distance, the Nusselt number decreases through axial position increasing due to decreasing the difference between the bulk nanofluid and surface temperatures and as the thermal boundary layer thickness growth. At a given Re. The time period required to reach the steady state condition is inversely proportional with the particle loading in a monotonic manner, moreover, the local Nusselt number is proportional to (ϕ) at the same time instance.

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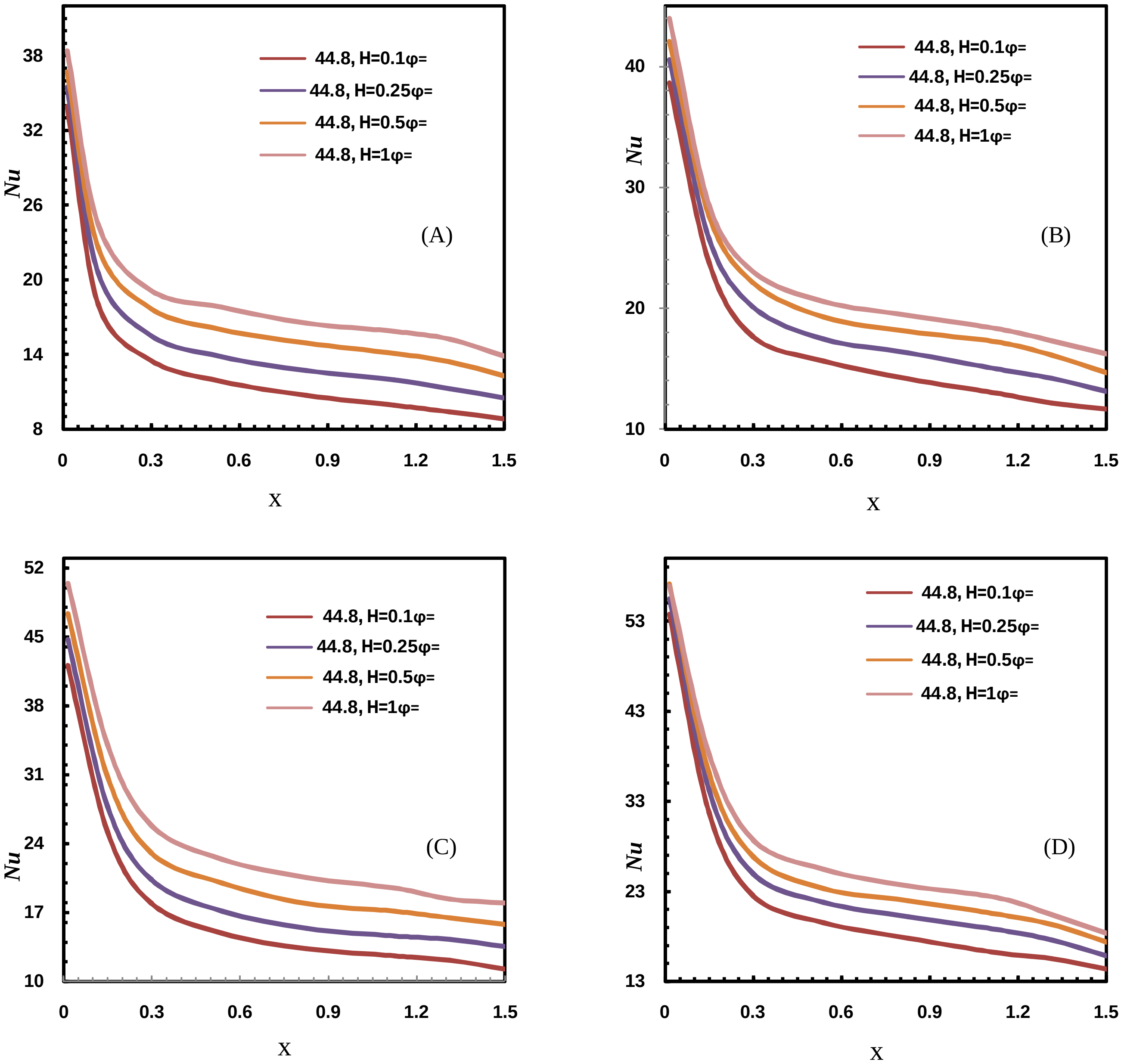

Figure (5). Nusselt number for various concentrations of Ferro-particles at Hartmann No=44.8 where (A) Re=100 (B) Re=250 (C)t Re=450 (D) Re=750

Figure (7) epitomize average Nusselt number for different volume concentration. It can be seen that the heat transfer rate increases with nanoparticles concentration. Also, it's clear that the heat transfer characteristics enhancement with nanoparticles volume fraction increased efficiently with **(Re)** for all values of volumefraction, and this increment recapitulate in two ways. The first is the increase in the Nu, and the second as time saving. however, the Magnetic field has a little effect on averageNusselt number ratio for all other parameters constancy.

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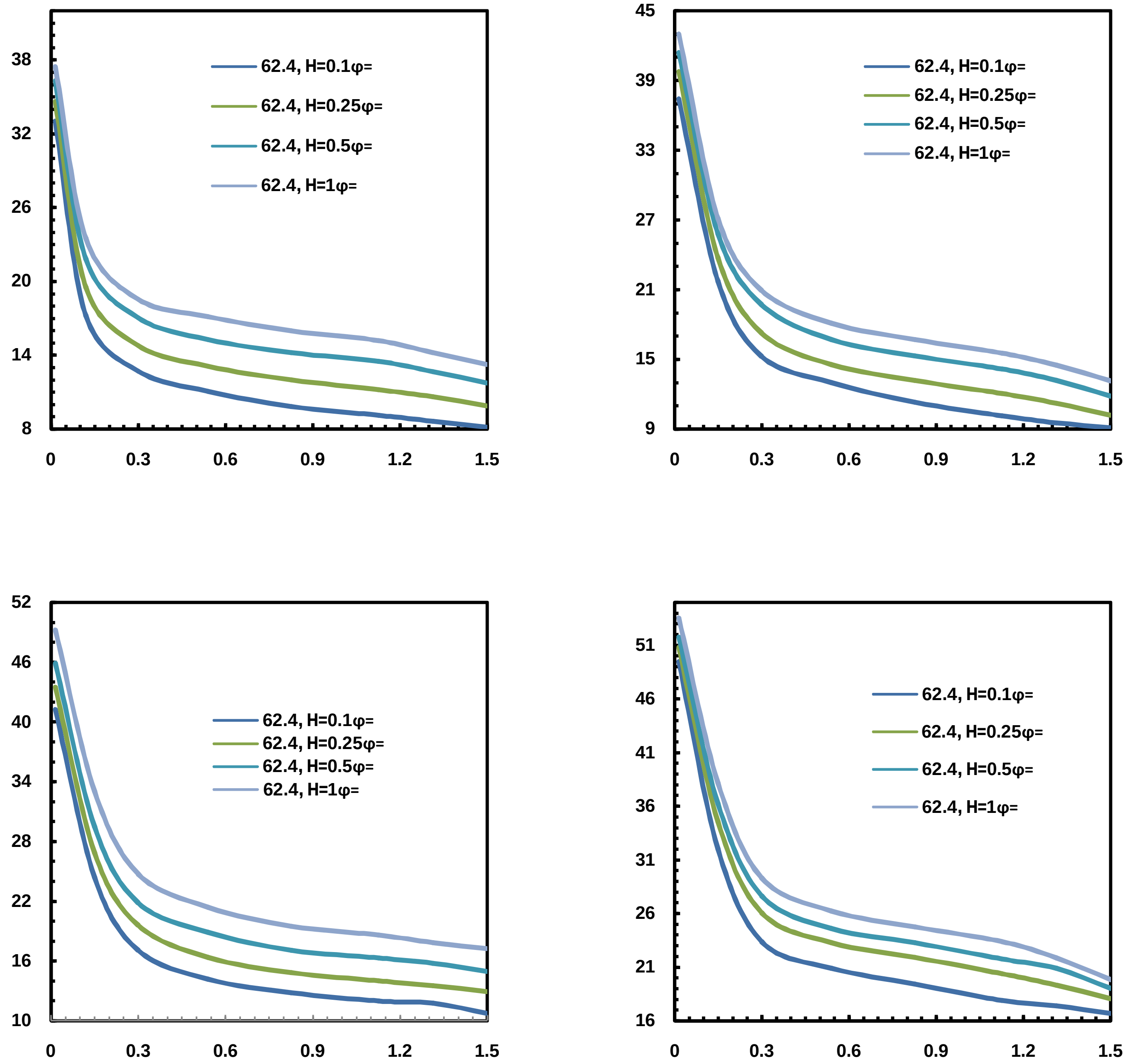

Figure (6). Nusselt number for various concentrations of Ferro-particles at Hartmann No=62.4 where (A) Re=100 (B) Re=250 (C)t Re=450 (D) Re=750

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Fig.8 showed the relationship between the particles concentration and Hartmann number with friction factor at various Reynolds number. Generally, the ratio of the pressure drop to the losses of kinetic – energy called the friction factor. The friction factor (*f*) decrease when decreasing flow velocity or by increases with the volume fraction. At high Reynolds number, the friction factor is unrelated with pressure drop because the kinetic – energy losses are high. If the Reynolds number is low, and particle size is small, the kinetic – energy losses become important , for that, the friction factor will be increase. however, the representation of all nanofluid concentrations reveal that friction factor is convergent closely. That is because the friction depend essentially on Re and size of nanoparticles .

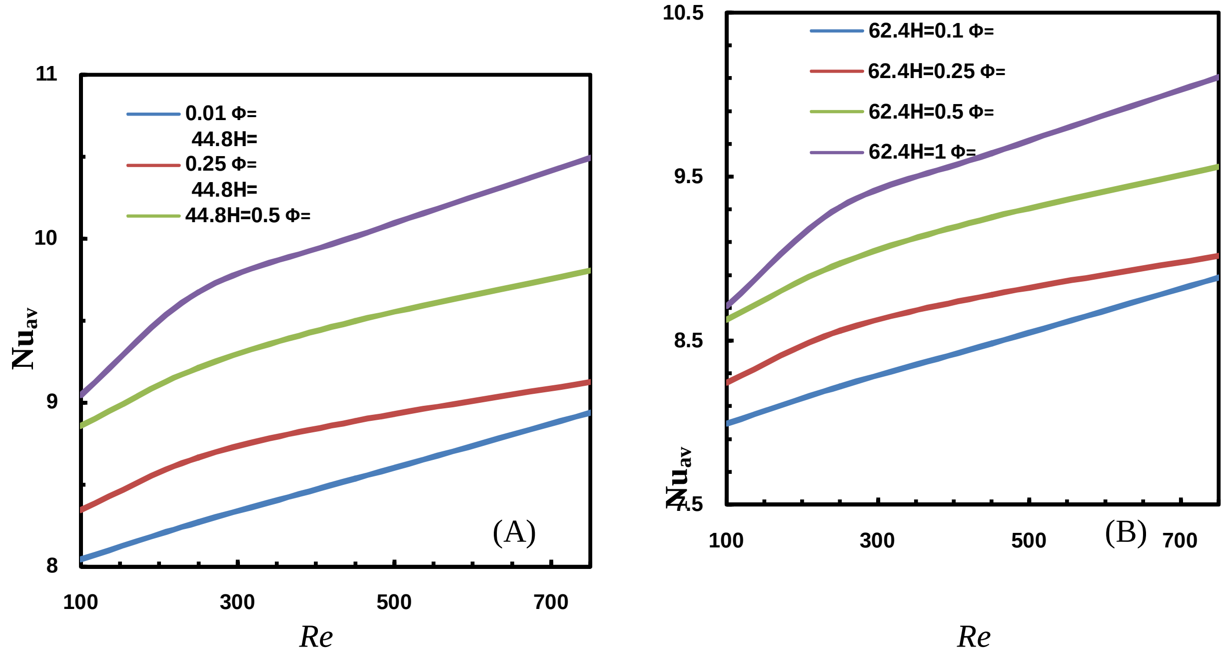

Fig.(7). Variation of Average Nusselt number with Re for different volume fraction of ferrofluid where (A) H=44.8, (B) H=62.4

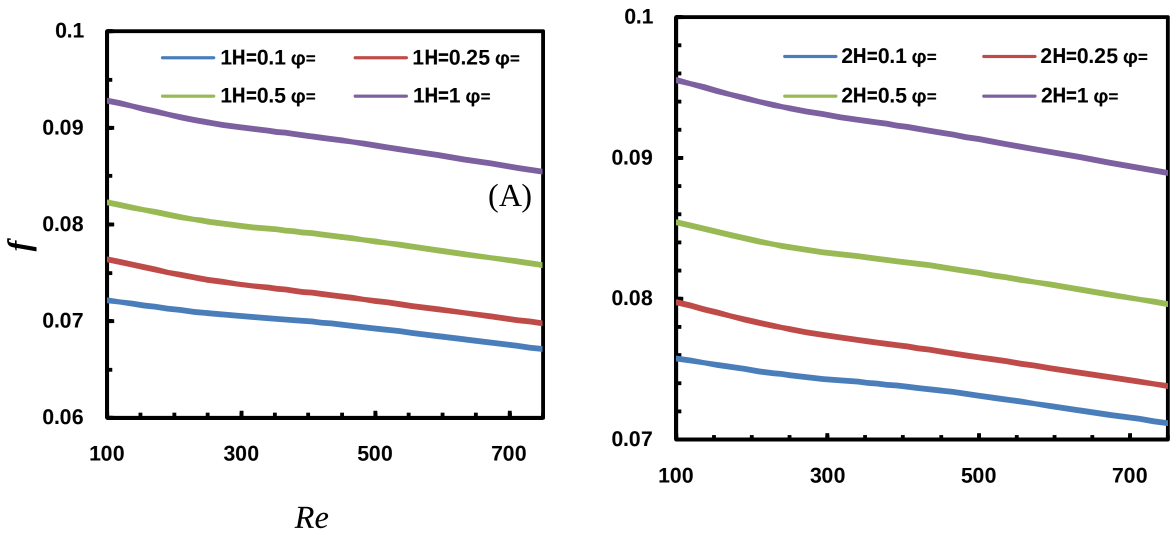

Fig.(8). Variation of friction factor with Re for different volume concentration of ferrofluid where (A) H=44.8, (B) H=62.4

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IX. CONCLUSIONS

This work was implemented to represent the forced convection laminar flow of Ferro-fluid (Fe_3o_4– Ethylene glycol) in a pipe oriented horizontally for different Reynolds numbers, Hartmann No. and nanoparticles volume fractions under different magnetic field intensity. The results proved that increasing of nanoparticle concentrations have a positive influence on heat transfer improvement at a specified Reynolds number,. Moreover, there is an augmentation in heat transfer rate when Ferrofluid employed as compared as pure liquid. As well as, the Nusselt number is strongly reliance on the nanoparticles concentration. It should be noticeable that additional investigations are necessary to be capable of recognize on the key phenomena of the enhancement of heat transfer with using the Ferro-fluids in laminar flow.

NOMENCLATURE

A	Surface area	(ϕ)	solid volume fraction
C_p	Specific heat at constant pressure	μ	dynamic viscosity
D	diameter of pipe	ρ	density
h	Coefficient of Heat transfer	σ	Electrical conductivity
I	Current	**Subscripts**	
k	Thermal conductivity	bf	Bulk fluid
L	Length of pipe	i	Inlet
Nu	Nusselt number	w	Wall
p	Pressure	P	particles
q"	Heat Flux		Local position
Re	Reynolds number	o	Outlet
T	Temperature	**Abbreviations**	
Greek symbols		CHF	Constant Heat Flux
α	thermal diffusivity	SS	Steady State

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