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# PERFORMANCE ANALYSIS OF A SHELL AND TUBE HEAT EXCHANGER AT DIFFERENT OPERATIONAL AND DESIGN PARAMETERS

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**Abstract**

Shell and tube heat exchangers are widely used in the industrial chemical processes, especially in refineries, due to their main advantages over other types of heat exchangers. The concerned shell and tube heat exchanger that studied in the paper is used at ZWETINA OIL COMPANY. Extensive simulations of steady state thermal analysis were carried out by using MATLAB R2013a software in an attempt to determine quantitative combined and overlapping relationships among the heat exchanger performance and its associated design and operating parameters such as heat transfer coefficient, friction coefficient, length, and pressure drop. Different tube wall materials and fluid streams were also simulated in order to investigate their effect on the heat exchanger effectiveness. The results show the total heat transfer increases with the increase of tube length and decreasing the input temperature. The pressure drop on the shell side increases with increasing both the flow velocity and number of baffles. The pressure drop on the pipe side increases with increasing both the flow velocity and number of passages. The pressure drop increases with increasing the fluid density. The Nusselt number increases when the increase of internal heat transfer coefficient and decreasing the thermal conductivity.

**Keywords**: Shell and Tube Heat Exchanger, Thermal Conductivity, MATLAB

**المُلخص**

تُستخدم المبادلات الحرارية الغطاء والأنبوب على نطاق واسع في العمليات الكيميائية الصناعية، وخاصة في المصافي، نظرًا لمميزاتها الرئيسية مقارنة بأنواع أخرى من المبادلات الحرارية. المبادل الحراري ذو الغطاء والأنبوب الذي تمت دراسته في الورقة هو نفسه المستخدم في شركة الزويتينة للنفط. تم إجراء عمليات محاكاة مكثفة للتحليل الحراري في الحالة المستقرة باستخدام برنامج MATLAB R2013a في محاولة لتحديد العلاقات الكمية المجمعة والمتداخلة بين أداء المبادل الحراري ومتغيرات التصميم والتشغيل المرتبطة به مثل معامل انتقال الحرارة ومعامل الاحتكاك والطول وانخفاض الضغط. كما تمت محاكاة مواد مختلفة لجدار الأنبوب وتيارات السوائل من أجل معرفة تأثيرها على فعالية المبادل الحراري. أظهرت النتائج أن إجمالي نقل الحرارة يزداد مع زيادة طول الأنبوب وانخفاض درجة حرارة الدخول. كذلك يزداد انخفاض الضغط على جانب الغلاف مع زيادة كل من سرعة التدفق وعدد الحواجز. أيضا يزداد انخفاض الضغط على جانب الأنبوب مع زيادة كل من سرعة التدفق وعدد الممرات. كما أظهرت النتائج أن انخفاض الضغط يزداد مع زيادة كثافة السائل، ويزداد رقم نسلت مع زيادة معامل انتقال الحرارة الداخلي وانخفاض الموصلية الحرارية.

**الكلمات المفتاحية:** المبادلات الحرارية نوع الغطاء والأنبوب، معامل التوصيل الحراري، ماتلاب.



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## 1. INTRODUCTION

To transmit heat between two or more fluid streams that have been heated to different temperatures, devices known as heat exchangers are utilized. Air conditioning, refrigeration, electronics cooling, electricity generation, chemical processing, and automobile utilization are just a few of the uses for heat exchangers. Heat exchangers are engineering devices that efficiently transfer heat from a hot fluid flow to a cool fluid flow, often through a metallic wall medium and with no moving components. The most common type of heat exchanger used in oil refineries and other sizable chemical processing facilities is a shell and tube heat exchanger (Fig.1), which is suitable for higher-pressure applications. Many design and operational considerations affect how well a shell and tube heat exchanger conducts heat. Among these, thermal conductivities of the conductive metals and fluids involved, flow velocity, pressure drop, number of baffles, inlet and outlet temperatures, and other factors. It is seldom easy to create an accurate prediction about how a heat exchanger will operate under a given combination of loading, design, and operating circumstances.

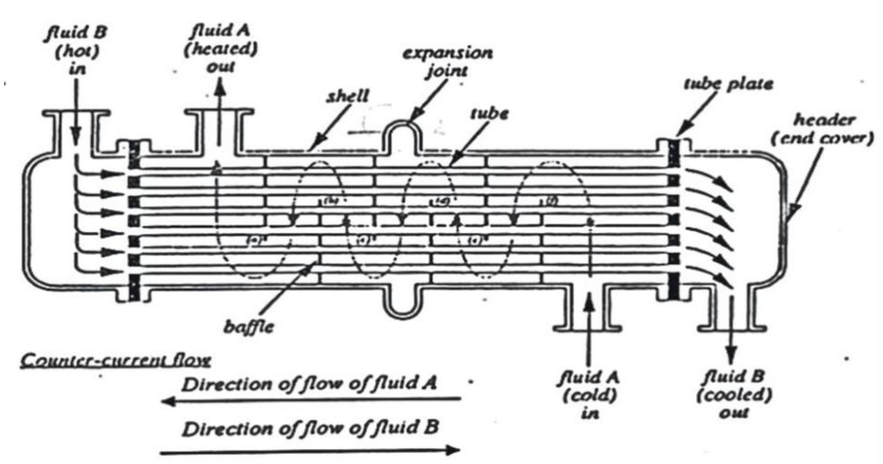


Fig.1. Illustrates schematic diagram of the shell and tube heat exchanger

Tinker proposed a conceptual flow pattern that split the shell-side flow into many distinct streams. The "Stream analysis method," was founded on the Tinker's concept which employs a rigorous iterative methodology and it is especially ideal for computer computations rather than manual calculations [6]. The development of computerized software for heat exchanger design may facilitate from explicit representations of LMTD Correction variables, according to Roetzel and Nicole [4]. Saunders offered in his book a workable approach with straightforward design considerations, and the method is quickly applied to a predefined set of geometrical parameters. His research uses correction variables for connections between pressure drop and heat transfer [5]. In their study, Wills and Johnston designed a stream analysis technique that may be shown by hand calculations. For the distributions of flow and pressure drop in shell and tubes, they introduced a new and accurate hand



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calculation technique [7]. Reppich and Zagermann presented in their study a computer-based design approach for determining the ideal shell-and-tube heat exchanger dimensions by computing the ideal shell-side and tube-side pressure drops using the equation presented in their work. Number of tubes, length of tubes, shell diameter, number of baffles, baffle cut, and baffle spacing are the six optimized dimensional parameters [3]. The optimization of a shell-and-tube heat exchanger is carried out using the optimizer software package, according to Liljana Markovska and Vera Mesko. The implicit constraint is defined together with the objective function. The equations describing the process are solved simultaneously using this technique [2]. A numerical approach of solution, developed by Lebele-Alawa and Victor Egwanwo, can take into consideration temperature-dependent change in fluid characteristics and heat transfer. Three separated industrial heat exchangers' field data were gathered, and fundamental controlling equations were used. The output temperatures, heat transfer coefficients, and heat exchanger performance are among the variables analyzed [1].

The main purpose of this study is to carry out steady state thermal analysis using MATLAB software in spite to simulate thermal performance of real shell and tube heat exchanger used in ZWETINA OIL COMPANY at different operating and design parameters such as thermal conductivities (**K**), tubes' lengths (**$L_{sh}$**), inlet temperatures (**$T_{ci}$; $T_{hi}$**), outlet temperatures (**$T_{co}$; $T_{ho}$**), heat transfer coefficient (**H**), flow velocity (V), pressure drop (ΔP), number of baffles ($N_b$), number of passes ($N_p$), fluid density (ρ) and friction factor (*f*).

## 2. METHODOLOGY

A set of tubes make up a shell and tube heat exchanger. The fluid that has been heated or cooled is contained in one set of these tubes. The second fluid flows across the heated or cooled tubes so that it can either generate or absorb the needed heat. ZWETINA OIL COMPANY's shell and tube heat exchanger was selected to be studied in this work because of its basic data availability and accessibility that listed in Table 1. Its thermal performance characteristics were investigated as a function of several operating and design parameters. These parameters are specifically heat loss as function of thermal conductivity, total heat transfer, pressure drop, Nusselt number, friction factor, flow velocity, inner heat transfer coefficient, inner cold temperature, length of shell, and calculated energy balance utilizing MATLAB R 2013 software. In a simple-to-use interface, it mixes computation, visualization, and programming while expressing issues and solutions using well-known mathematical notation. Math and computing, the creation of algorithms, modeling, simulation, and programming, data analysis, exploration, and visualization, scientific and engineering graphics, and application development, including the creation of graphical user interfaces, are examples of typical usage.

The heat transfer in this double-pipe arrangement could be calculated by the following formula (eq. (1)):

$$q = U\ A\ \Delta T_m \qquad (1)$$



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Where;

U = overall heat-transfer coefficient

A = surface area for heat transfer consistent with definition of *U*

$T_m$ = suitable mean temperature difference across heat exchanger

The temperature difference is called the log mean temperature difference (LMTD). Stated verbally, it is the temperature difference at one end of the heat exchanger less the temperature difference at the other end of the exchanger divided by the natural logarithm of the ratio of these two temperature differences as illustrated in eq. (2).

$$\Delta Tm = \frac{(Th2-Tc2)-(Th1-Tc1)}{\ln\left[\frac{(Th2-Tc2)}{(Th1-Tc1)}\right]} \quad (2)$$

The overall heat-transfer coefficient (eq. (3) and eq. (4)) may be calculated based on either the inside or outside area of the tube at the preference of the designer.

$$U_i = \frac{1}{\frac{1}{h_i}+\frac{Ai\ln\left(\frac{ro}{ri}\right)}{2\pi kl}+\frac{1}{ho}\frac{Ai}{A_0}} \quad (3)$$

$$U_o = \frac{1}{\frac{1}{h_0}+\frac{Ao\ln\left(\frac{ro}{ri}\right)}{2\pi kl}+\frac{1}{hi}\frac{Ao}{Ai}} \quad (4)$$

**Table.1. Tabulation of being studied shell and tube heat exchanger basic data**

| Physical quantity | Value |
|---|---|
| Length of shell ($L_{sh}$) | 12.19 m |
| Width of shell ($W_{sh}$) | 1.067 m |
| Inlet cold temperature ($T_{ci}$) | 29 ºC |
| Exit cold temperature ($T_{co}$) | 46 ºC |
| Inlet hot temperature ($T_{hi}$) | 69 ºC |
| Outlet hot temperature ($T_{ho}$) | 45 ºC |
| Thermal conductivity of fluid ($K_f$) | 0.92 |
| Nussle number ($N_u$) | 3.66 |
| Inner heat transfer coefficient ($H_i$) | 215 W/m$^2$.ºC |
| Outer heat transfer coefficient ($H_o$) | 15 W/m$^2$.ºC |
| Effectiveness (E) | 42 |
| Mass flow rate of hot ($M_h$) | 18.5 Kg/s |
| Mass flow rate of cold ($M_c$) | 81 Kg/s |
| Number of tubes ($N_t$) | 2200 |
| Fouling Thermal conductivity (K) | 70 W/m.k |
| Fouling factor of shell ($F_s$) | 0.001 |
| Fouling factor of tube ($F_t$) | 0.0005 |
| Internal pressure of cold ($P_{ci}$) | 262 KPa |
| External pressure of cold ($P_{co}$) | 255 KPa |
| Internal pressure of hot ($P_{hi}$) | 1703 KPa |
| External pressure of hot ($P_{ho}$) | 1509.9 KPa |
| Inner tube diameter ($D_{ti}$) | 0.0158 m |
| Outer tube diameter ($D_{to}$) | 0.02054 m |
| Shell-side velocity ($V_{sh}$) | 1.146 m/s |
| Tube-side velocity ($V_t$) | 0.2987 m/s |
| Viscosity (μ) | 0.000685 Kg/m.s |

| | |
|---|---|
| Heat capacity for cold material ($C_{pc}$) | 4.178 KJ/Kg.k |
| Heat capacity for hot material ($C_{ph}$) | 2.4 KJ/Kg.k |

## 3. RESULTS AND DISCUSSION

Findings obtained from the aforementioned computations were displayed, analyzed and discussed in this part of the study. Fig.1 shows a proportional relationship between the total heat transferred and the shell length, as when the length of the shell increases, the total heat transferred increases at different simulated thermal conductivities of the wall material. Fig.2 shows the effect of the inner cold temperature on the heat transfer amount. It can be seen that at different thermal conductivities the heat transfer amount decreases with the increase of inner cold temperature.

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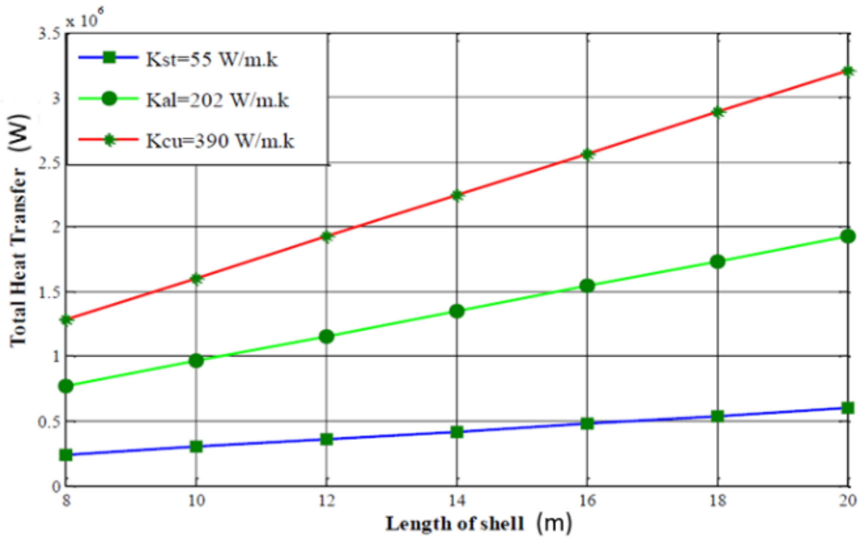


Fig.2 Effect of shell length on heat transfer at different thermal conductivities

Fig.3 depicts the relationship between the total heat transfer and the inlet hot temperature, illustrating how the total heat transmitted rises as the inlet hot temperature rises at different thermal conductivity of the metals.

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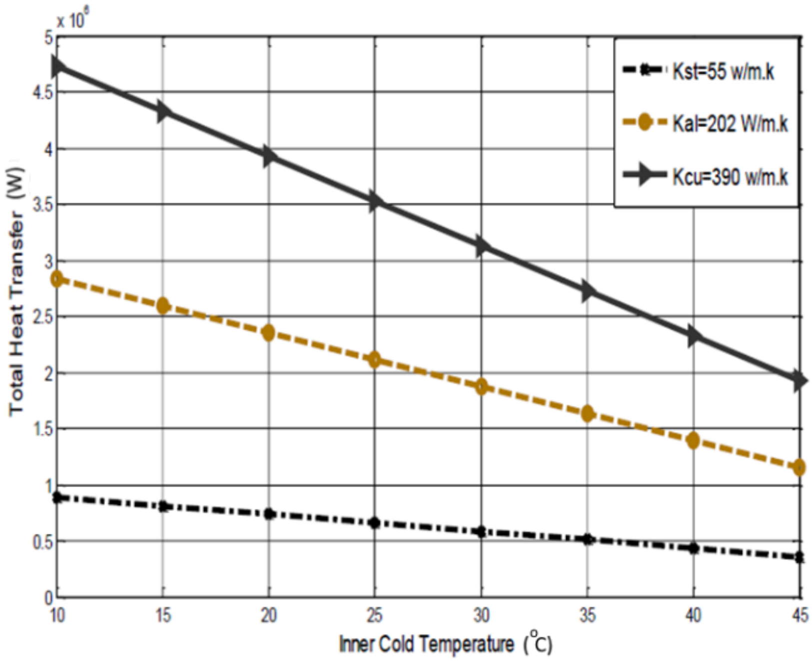


Fig.3. Effect of inner cold temperature heat transfer at different thermal conductivities

Figure 4 shows the effect of inlet hot temperature on the heat transfer at different material thermal conductivities. The results show that the heat transfer value increases with the increase of inlet of temperature and the thermal conductivity.

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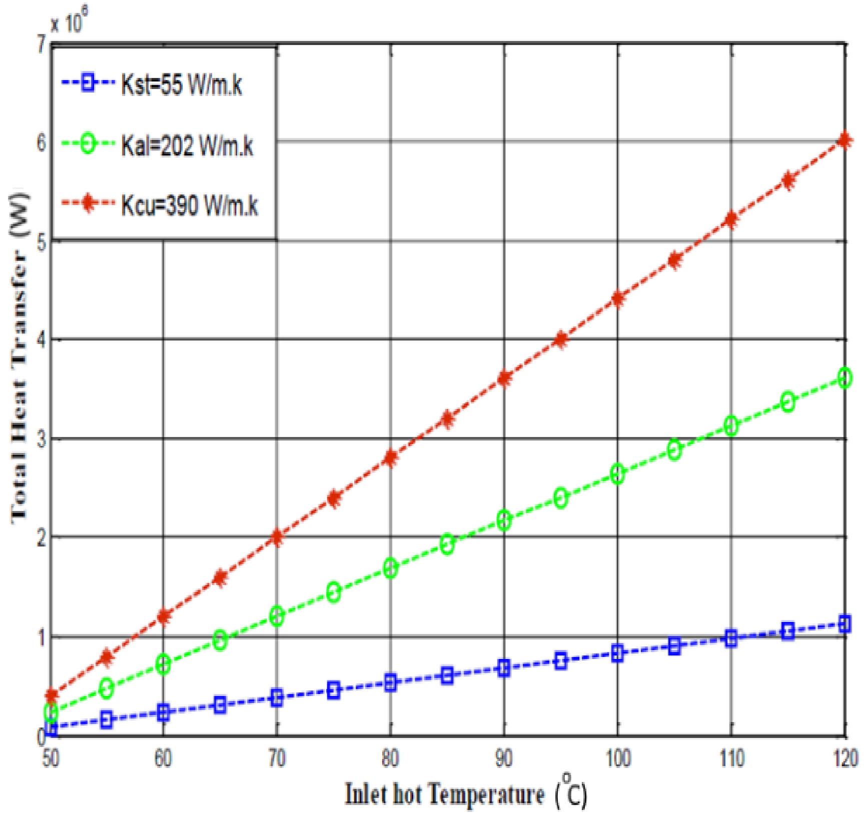


Fig.4. Effect of inlet hot temperature on heat transfer at various thermal conductivities

Figure 5 shows the effect of inner heat transfer coefficient on the Nusselt number at different fluid thermal conductivities. It can be seen that the Nusselt number increases with the increase of inner heat transfer coefficient while it decreases with the decrease of fluid thermal conductivity.



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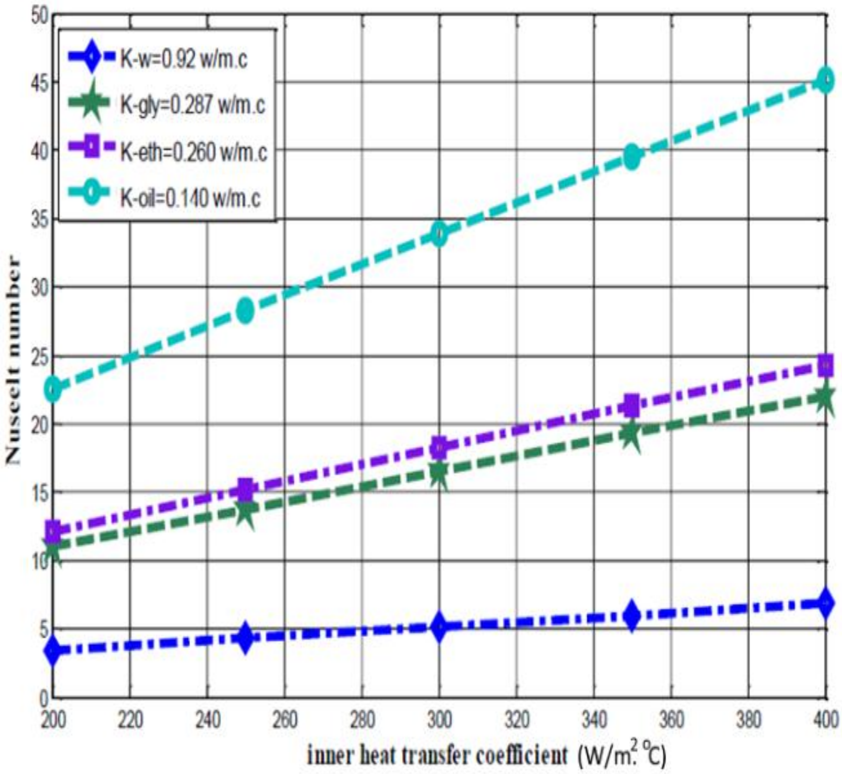


Fig.5. Effect of inner heat transfer coefficient on Nusselt number at different fluid thermal conductivities

Figure 6 shows the effect of inlet cold temperature on the heat transfer value at different shell lengths. It can be noticed that at all tested shell lengths it was found that the heat transfer value decreases with the increase of inlet cold temperature. At constant inlet cold temperature it can be seen that heat transfer value increases with increasing shell length**.**



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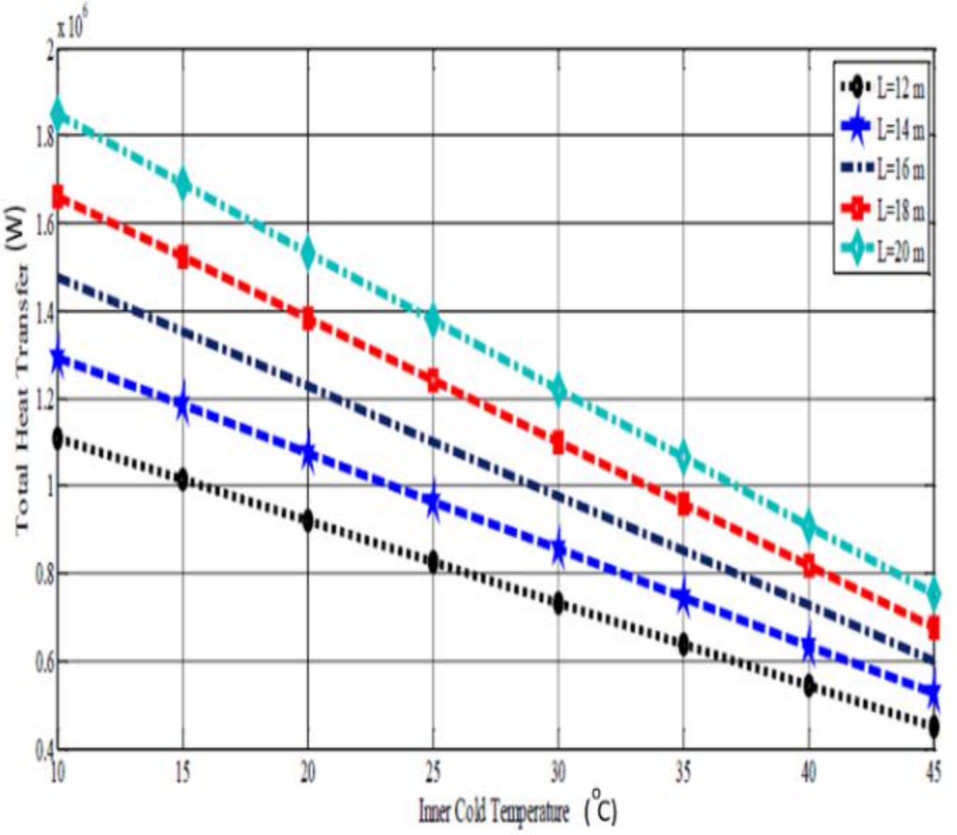


Fig.6. Variation of total Effect of inlet cold temperature on heat transfer at different shell length

Figures 7 and 8 show the effect of fluid flow velocity on the pressure drop through the heat exchanger at different number of barriers It can be seen that the pressure drop rises with both the flow velocity and the number of barriers

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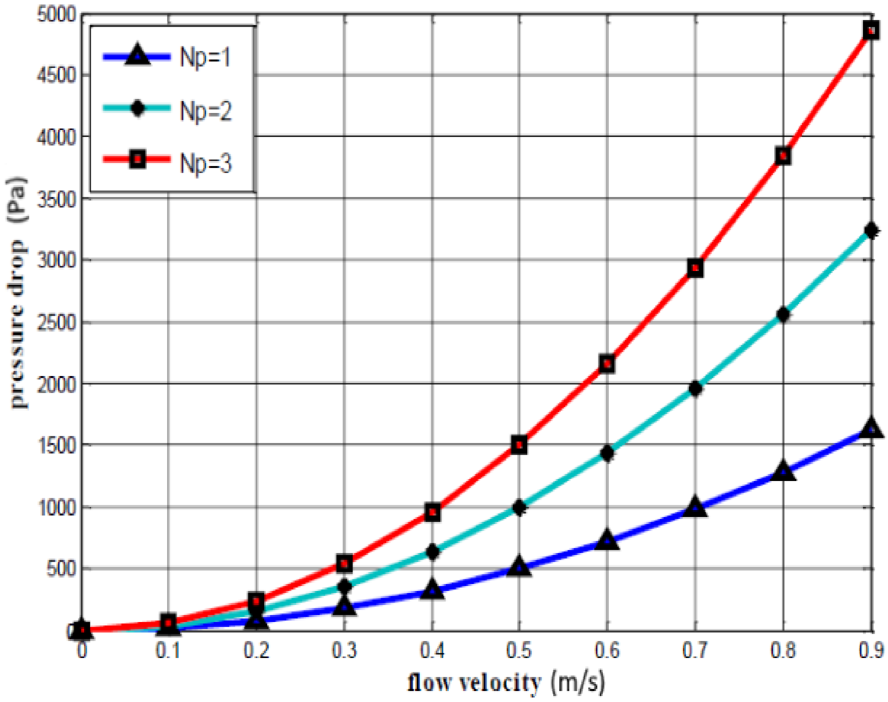


Fig.7. Effect of flow velocity on pressure drop at different number of baffles

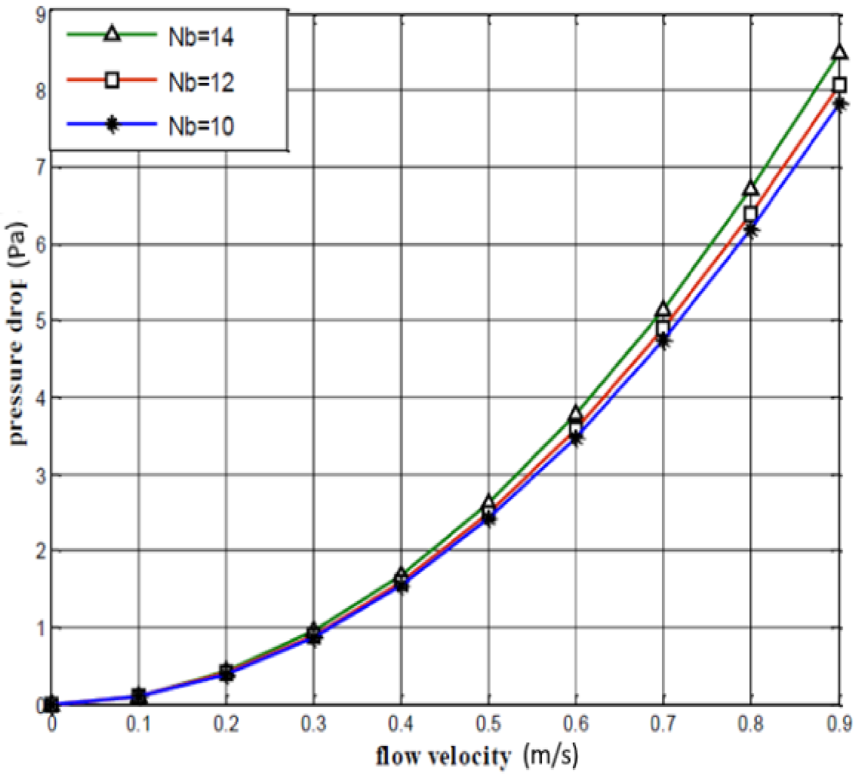


Fig.8. Effect of flow velocity on pressure drop at different number of baffles

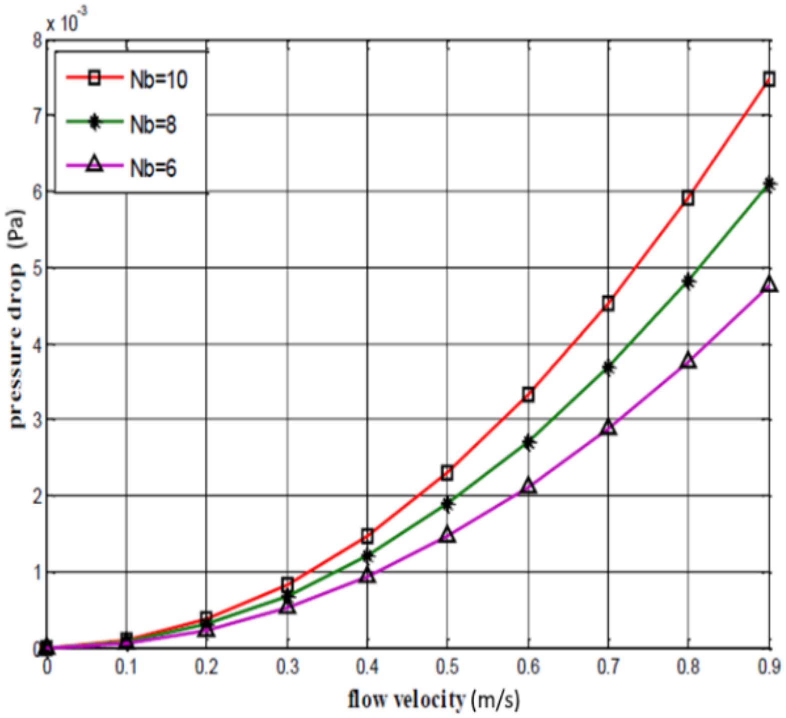


Fig.9 Effect of flow velocity on pressure drop at different number of baffles

Figure 10 shows the effect of flow velocity on the pressure drop at different densities. It can be seen that glycerin has the highest pressure drop while the water was the lowest. Also it can be noticed the pressure drop difference increases at high values of flow velocity.



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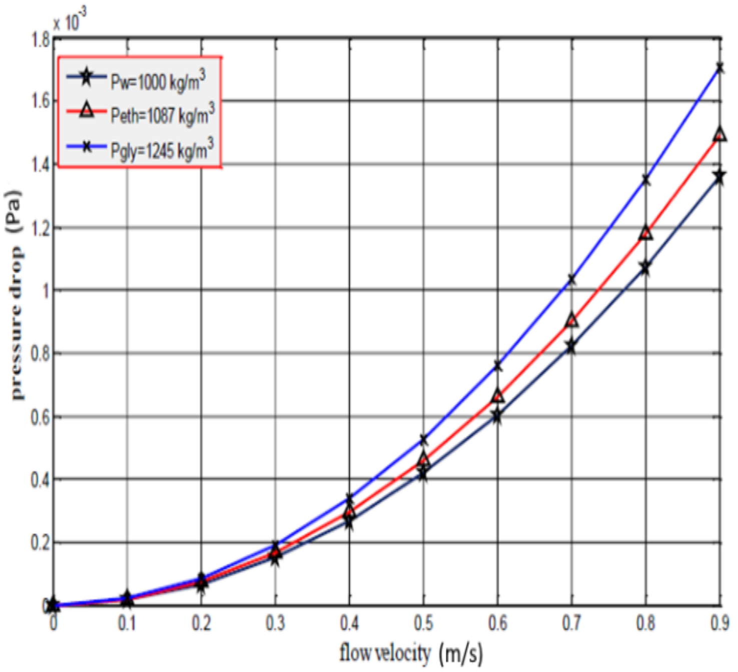


Fig.10. Effect of flow velocity on pressure drop at different fluid densities

Figure 11 shows the relationship between the friction factor and the flow velocity at different inner tube diameters. It can be seen as the flow friction factor increases with the increase of flow velocity at all tested diameters.

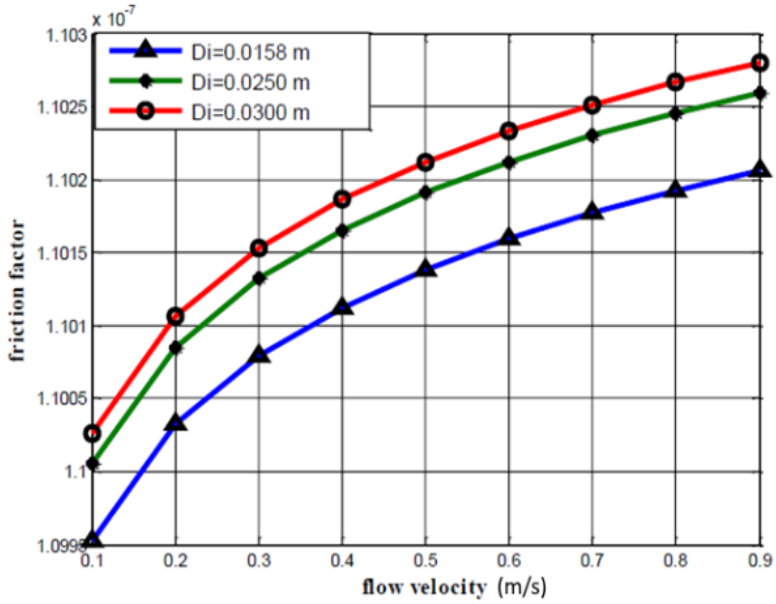


Fig.10. Effect of flow velocity on pressure drop at different inner tube diameters

Figure 12 shows the effect of flow velocity on the friction factor at different densities. It can be seen that glycerin has the highest pressure drop while the water was the lowest.

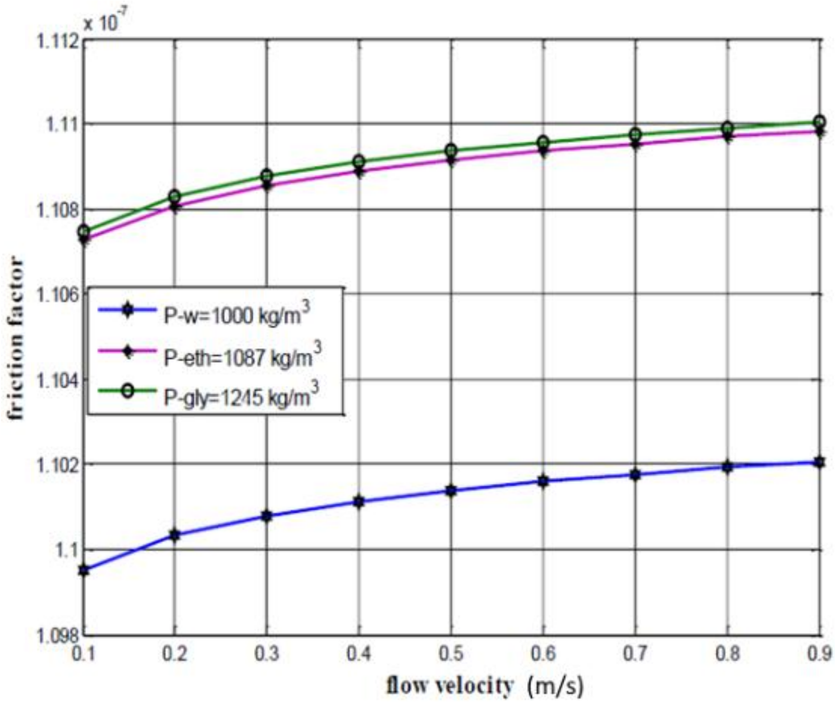


Fig.12. Effect of flow velocity on the friction factor at different fluid densities

## 4. CONCLUSION

The following points were concluded:

- The total heat transfer increases with the increase of tube length and decreasing the input temperature.
- The pressure drop on the shell side increases with increasing both the flow velocity and number of baffles.
- The pressure drop on the pipe side increases with increasing both the flow velocity and number of passages.
- The pressure drop increases with increasing the fluid density.
- The Nusselt number increases when the increase of internal heat transfer coefficient and decreasing the thermal conductivity.



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