

The Influence of Changing Heat Transfer Coefficient, Type of Fluid, and Pipe Material on the Efficiency of the Distillation Exchanger

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Abstracts: The fundamental purpose of the petroleum refining industry is to convert crude oil into refined products comprising more than 2,500 substances. Among the refined products are liquefied petroleum gasoline, aviation fuel, kerosene, fuel oils, diesel fuel, lubricating oils, and feedstocks, which have a variety of uses in the petrochemical and other industries. The petroleum refinery process begins with crude oil storage and continues with handling and refining operations before concluding with the separation process and shipping the refined compounds to their final destinations. A variety of methods are used in the petroleum refinery. The analysis of key components of the oil refinery will have a significant impact on the quality of the distilled products. Several scenarios, such as transfer coefficient, fluid type, and pipe materials, have been simulated to determine the most powerful example for the updated oil refineries, and their consequences are described.

Keywords: CFD Simulation, Fluid and Pipe Materials, Transfer Coefficient, Refinery Performance.

1. INTRODUCTION

Converting crude oil into refined products, which consist of more than 2500 compounds, is the main task done in the petroleum refining industry. The refined products are liquefied petroleum gas, gasoline, aviation fuel, kerosene, fuel oils, diesel fuel, lubricating oils, and feedstocks, which have huge applications in the petrochemical and other industries [1].

The bulk of the atmospheric and vacuum distillation as well as the light end recovery (gas processing) are produced during the first stage of refining activities, which involves three separation processes. Crude oil contains hydrocarbon molecules, a subset of which is a mixture of hydrocarbons, in the form of paraffinic, naphthenic, and aromatic hydrocarbons along with a few contaminants like inorganic substances (such as sulphur), nitrogen and oxygen elements, and a few heavy metals. These components are divided during the separation process into fractions with similar boiling points [2].

To meet the increased demand for high-octane petrol, jet fuel and diesel fuel, residual and fuel oils as well as the light ends are converted to petrol and other light fractions (Figure 1). For example, visbreaking, cracking, and coking are among of the procedures utilized to break down petroleum molecules into smaller ones. To join tiny petroleum molecules and create big links, further procedures like polymerization and alkylation are also used. In the end, it is feasible to reorganize the structure of petroleum molecules into higher-value molecules with the same molecular size through the processes of isomerization and reforming [3].

In the petroleum treatment procedures, less desirable components are isolated in order to stabilize and improve petroleum products. Chemical procedures including hydrodesulfurization (HDS), hydrotreating (HT), chemical sweetening (CS), and acid removal are used to separate impurities like S, N, and O components. Deasphalting, which is used to remove NaCl, inorganic contaminants, grit, and water from crude oil feedstocks, is the main procedure used to separate petroleum products prior to refinement. The weathering properties of asphalt are enhanced by asphalt blowing [4].

One of the key considerations in the design and operation of the process sector nowadays is minimizing energy waste. On the other side, when energy supplies are depleted, the cost of energy resources is rising daily, creating competition for innovative ideas and resource efficiency. The creation of ideal heat exchangers may significantly affect the preservation of fuel resources while also somewhat reducing prices. Thermal performance and lowering pump power are therefore the most crucial hydropower goals.

The purpose of thermal exchangers, which are pieces of machinery that create a stream of thermal energy between two or more fluids at various temperatures, is to exchange heat. In actuality, a fluid really transfers its energy from one fluid at a higher temperature to another fluid at a lower temperature through the process of heat transfer. Between gas-gas, gas-liquid, or liquid-liquid phases, this process is possible. Heat is transferred and conducted by thermal conduction in thermal exchangers. Chemical, electrical, manufacturing, coolers, power plants, air conditioners, and petrochemical refineries are just a few of the places where heat exchangers are used. The process of heat transmission is important in thermal exchangers. The refinery process flow diagram with a heat exchanger included is seen in Figure (1) [5].

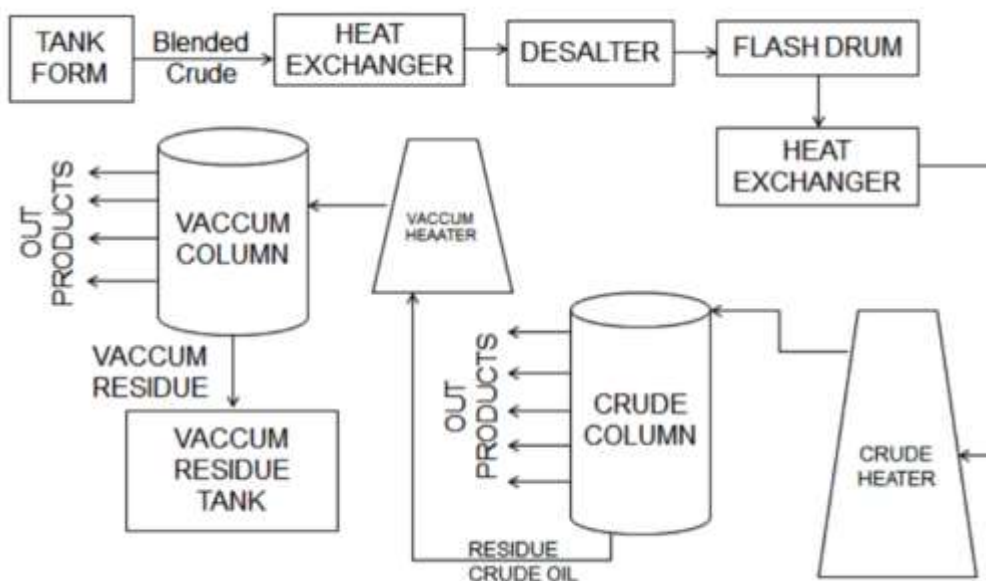


Figure 1. Flow process diagram of crude refining in oil industry.

One of the innovative models and techniques utilized for process control in order to enhance complicated systems and mathematically based method for numerically simulating fluid flow and heat transport using computational equations [6]. This approach makes the available for giving all essential input information is computational fluid dynamics (CFD). CFD is a particularly unique and effective for precisely analyzing flow and heat transfer. It can provide a thorough understanding of the potential procedures for diverse, non-linear transfers. High-reliable CFD simulations may be used to evaluate current performance, restore online control, and aid in industrial process operation optimization [7].

Though it should be emphasized that employing CFD for the modelling of big industrial processes and complex products is frequently difficult due to the occurrence of numerous scales for space and time in industrial processes and the limitations of numerical approaches, The numerical assessments in traditional CFD methods are discretized using mesh elements and are fully dependent on the mesh quality and the characteristics of the included phenomena, such as physical, chemical, and mechanical properties. The characteristics of microscale (e.g., boiling) and macroscale (e.g., burners) in industrial processes make it extremely difficult to create a suitable mesh and run simulation in a timely manner so that the findings may be utilized in the design or online control phases [8].

The aforementioned constraints, however, did not prevent the use of CFD for heat transfer and fluid flow

calculations. To obtain a precise answer, reduce the geometry of the process by smearing appropriate boundary conditions and simulating a tiny segment of the process [9].

2. SIMULATION AND METHODS

As previously stated, there are numerous techniques to investigate flow in heat exchangers; nevertheless, most of these approaches are based on steady-state conditions and are unable to predict the dynamic properties of the exchangers. Consider the unstable factors of the converter in the designs if there are several concerns in the industry that need to be adequately addressed. A dynamic situation or an unstable time function can be caused by a variety of circumstances. Changes in the input conditions of one of the hot and cold streams, for example, such as flow rate, temperature, physical qualities, changes in the converter's ambient circumstances, and so on, are all variables that might produce an unstable state.

3. RESULTS AND DISCUSSIONS

3.1. Changes in the heat transfer coefficient, environmental displacement, and their impact on converter efficiency

The environmental conditions of the heat exchanger can have different changes. In this case, the heat transfer coefficient outside the exchanger has different values. In this section, it is assumed that the surrounding environment of the converter is surrounded by air. But in general, you can choose any gender for the surrounding environment. According to the condition of insulation and two mechanisms of heat transfer with the environment and taking into consideration the required formula, three values for the coefficient of heat transfer with the environment have been considered. The first condition is $h=0$, which indicates the condition of insulation of the transducer, $h=3.6$, which indicates the condition of free movement, and $h=30.7$, which corresponds to the forced movement of the transducer with the environment in a forced state. The characteristics of the current inside the converter are given in Table.1.

The heat exchanger's surrounding conditions can alter. The heat transfer coefficient outside the exchanger has distinct values in this scenario. In this section, it is assumed that the converter's surroundings are surrounded by air and the geometric specifications of the converter are given in Table 2.

Table 1. Flow characteristics for different heat transfer coefficients of the surrounding environment

Sample time (Sec)	$\dot{m}_h \left[\frac{kg}{sec} \right]$	$\dot{m}_c \left[\frac{kg}{sec} \right]$	$Th_i (c^\circ)$	$tc_i (c^\circ)$	Type of flow arrangement
30	200	244.8	100	20	same direction

Table 2. Physical and geometric parameters of the heat exchanger in project mode

Fluid	Tube	Shell
	Water	Oil
Material	$\frac{55}{45}$ Cupro – Nickel =	C.S
$k \left[\frac{watt}{m.k^\circ} \right]$	23	60.5
$cp \left[\frac{J}{kg.k^\circ} \right]$	384	434
$\rho \left[\frac{kg}{m^3} \right]$	8920	7854

Figure (2) shows the time profile of the outlet temperature of the hot fluid for different values of the heat transfer coefficient of the ambient displacement. According to the shape, the maximum temperature of the hot fluid outlet is related to the insulation state. As the value of the heat transfer coefficient of the environment increases, the amount of heat loss from the surfaces of the converter increases. This causes a decrease in temperatures, including the outlet temperature of the hot fluid, and generally lowers the heat and temperature efficiency of the converter. Since the temperatures are in the lower range, the changes made in the temperature profiles of Figure (2) are not very noticeable. But in conditions where higher temperatures are considered inside the exchanger, the effects of changing the displacement heat transfer coefficient will be greater.

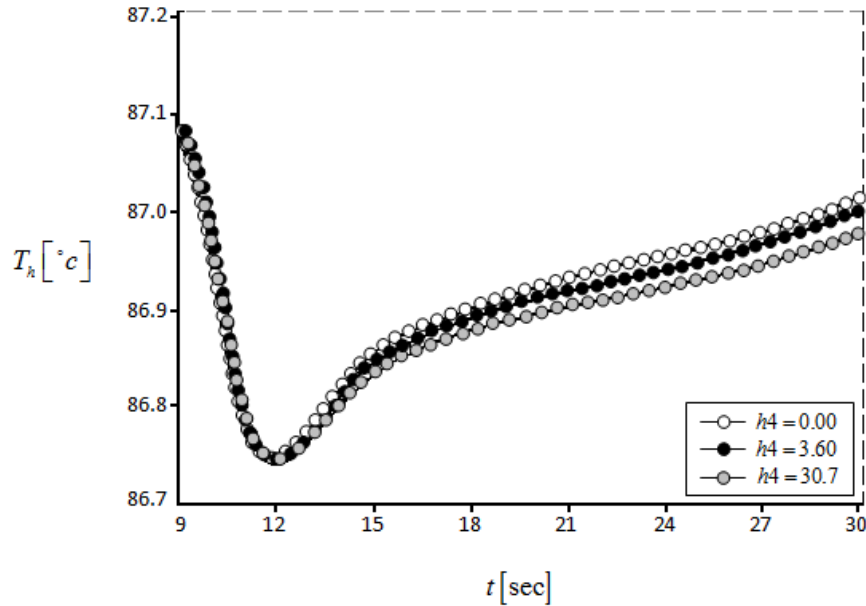


Figure 2. The diagram of hot fluid temperature changes at the outlet in terms of time for different h_4 .

3.2. Changing the fluid type and its effects

Another thing that has been taken into consideration is the choice of different genders for the fountain. Here, obviously, different types of hot fluid are considered. For this purpose, three types of oil, diesel and gasoline are considered. In this condition, the material of the cold fluid flowing in the tube is constant (water). The geometric specifications of the converter are listed in Table 2 and the flow specifications are listed in Table 3.

Table 3. Current specifications for changing the type of fluxes

Sample time (Sec)	$\dot{m}_h \left[\frac{kg}{sec} \right]$	$\dot{m}_c \left[\frac{kg}{sec} \right]$	$Th_i (c^\circ)$	$tc_i (c^\circ)$	Type of flow arrangement
30	200	244.8	100	20	same direction

Figure (3) shows the temperature profile of the cold fluid, which is water, in exchange for time changes for three types of hot fluid. The temperature profile of the cold fluid reaches a steady state more slowly for the case where the hot fluid is gasoline. This issue can have two reasons, firstly, the heat capacity of gasoline is higher than the other two types. Therefore, its thermal inertia is higher and it reaches a stable state more slowly. In this condition, the hot fluid (gasoline) will surely reach stability more slowly than other conditions as shown in Figure (3).

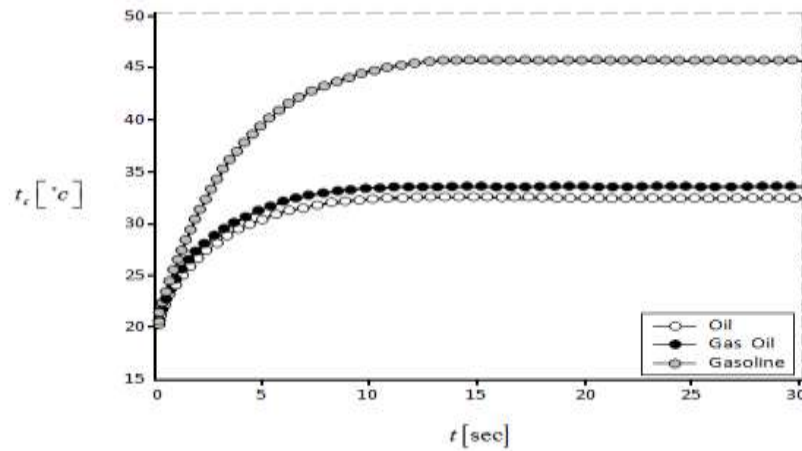


Figure 3. Cold fluid outlet temperature; according to time for different types of hot fluid.

The second issue is the high heat transfer rate. According to the properties of the desired fluids, the highest viscosity is related to oil and the lowest viscosity is assigned to gasoline. In similar conditions of speed and geometry based on relations (1) to (4).

$$\dot{E}_{in} - \dot{E}_{out} = \dot{E}_{store}$$

$$\frac{c_{w_0}}{2} \frac{\partial}{\partial t} (T_{W_n}) = + \frac{h_3 \cdot A_3}{2} (T_n - T_{W_n}) - \frac{h_4 \cdot A_4}{2} (T_{W_n} - T_\infty) + q_{cond} \quad (1)$$

$$\frac{\partial}{\partial t} (T_{W_n}) = + \frac{h_3 \cdot A_3}{c_{w_0}} (T_n - T_{W_n}) - \frac{h_4 \cdot A_4}{c_{w_0}} (T_{W_n} - T_\infty) - 2 \frac{k_{w_0} \cdot A \cdot w_0}{c_{w_0} \cdot \Delta x} (T_{W_n} - T_{n-1}) \quad (2)$$

$$\frac{\partial}{\partial t} (T_{W_n}) = P (T_n - T_{W_n}) - q (T_{W_n} - T_\infty) - 2S_0 (T_{W_n} - T_{n-1}) \quad (4)$$

$$\frac{\partial}{\partial t} (T_{W_n}) = 2S_0 \cdot T_{W_{n-1}} - (P + q + 2S_0) T_{W_n} + P \cdot T_n + q \cdot T_\infty \quad i = n \quad (4)$$

The highest heat transfer is related to gasoline and the lowest is related to oil. Temperature changes in oil are less than gasoline, which is due to the high heat transfer coefficient of gasoline. Although the Prantel number of oil is much larger than that of gasoline and diesel, the effect of the Reynolds number (which is higher in diesel and gasoline than oil) is much greater. This will increase the transfer of heat from the hot fluid (gasoline and gasoline) to the cold fluid (water). The minimum temperature changes of the cold fluid are also due to the minimum heat transfer for the oil type (as a hot fluid).

Similarly, Figures (3) and (4) are analyzed dynamically. The lowest stabilization time of the hot and cold fluid profile is related to the type of oil and the longest time is related to the type of gasoline. The reason for this, as mentioned above, is the lower heat capacity and the lower Reynolds number, and as a result, the lower heat transfer for the oil type compared to the others. Therefore, it can be concluded that the heat transfer inside the converter is directly proportional to the Reynolds number and the Prantel number, but the Reynolds number is much more effective.

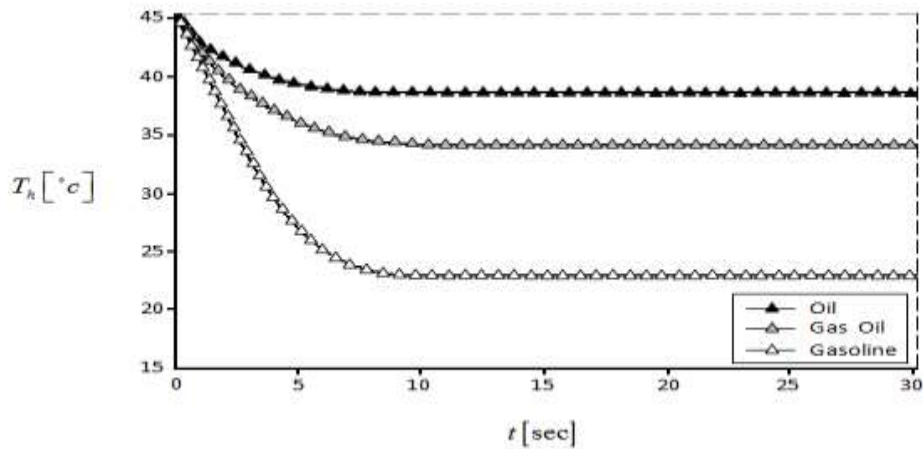


Figure 4. Hot fluid outlet temperature; according to time for different types of hot fluid.

3.3. The effect of pipe material on dynamic parameters

The pipes used in the heat exchanger structure can be selected from different materials. As previously mentioned, the characteristics given in Table 2 for internal and external pipes are respectively related to COPRO-NICKLE 55/45. In this section, the effect of different types of pipes has been investigated. Figures (5) and (6) show the effect of the type of inner tubes for the dynamic and static characteristics of hot and cold fluids. In this case, four types of inner tubes are considered. These four types are STEEL, BRASS, COPPER and COPRO-NICKLE 55/45; flow specifications are given in Table 4 and converter geometry specifications are given in Table 2. The internal fluid is made of water and the external fluid is made of oil.

Table 4. Flow specifications for different types of pipes

Sample Time (s)	$\dot{m}_h \left[\frac{kg}{sec} \right]$	$\dot{m}_c \left[\frac{kg}{sec} \right]$	$Th_i (c^\circ)$	$tc_i (c^\circ)$	Type of flow arrangement
30	200	244.8	100	20	same direction

In all four cases, all other specifications, such as flow rate, type of fluxes, duct sizes, thicknesses, etc., are similar, and only changes are made in the material of the inner pipe. According to Figure (6), in the case where the inner tube is made of BRASS and COPPER, compared to the other two cases, the temperature profile of the hot fluid at the outlet reaches stability later.

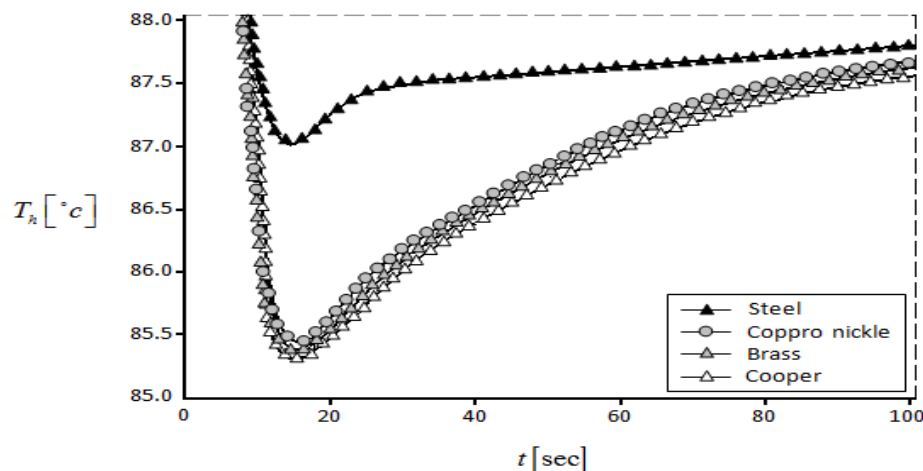


Figure 5. Hot fluid outlet temperature; according to time for different types of inner tube.

The same situation is observed in cold fluid (Figure 6). That is, in this case, the temperature profile of the cold fluid for BRASS and COPPER pipes has a phase delay compared to the other two cases. The reason for this should be found in the difference between the heat capacity of these two pipes and other cases.

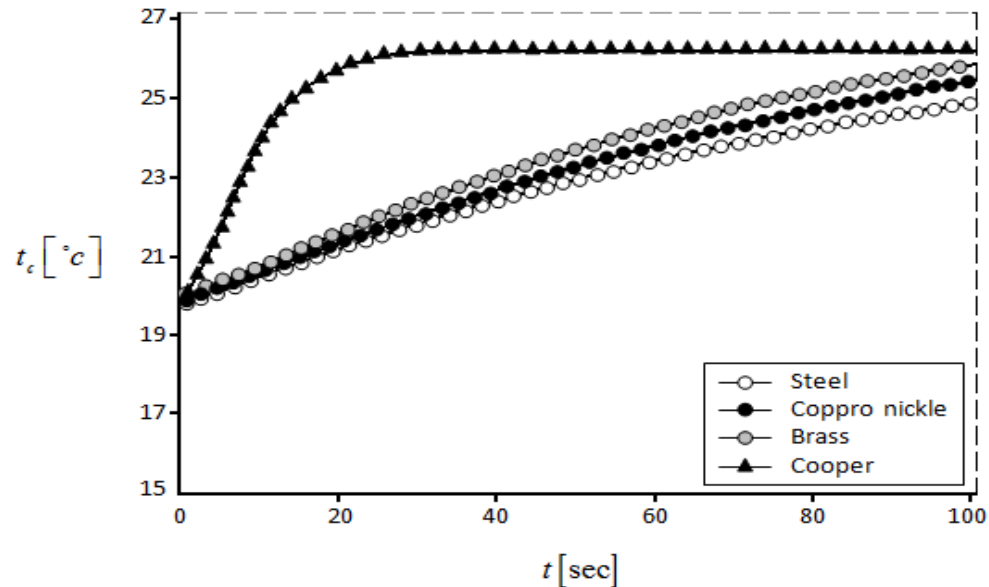


Figure 6. Cold fluid outlet temperature; according to time for different types of inner tube.

In these two cases, the heat capacity is much higher than the other two cases, i.e. the type of pipe - COPRO 55/45 NICKLE and STEEL. Therefore, more heat is used to change the temperature of the inner wall in these two genders. In this situation, the hot and cold temperature profile has a time delay compared to other types of pipes. Of course, in terms of the steady state, the temperature of the fluxes also decreases in the case of copper and steel pipes.

Therefore, it can be said that with the increase in the thermal inertia of the walls, which can be caused by changes in their material, the stability time in all the components of the converter increases and the thermal efficiency of the converter decreases.

CONCLUSIONS

Heat and flow exchange in tiny tubes has numerous design and industrial uses. It has always been the subject of numerous hypothetical, numerical, and test concerns. The most frequent numerical techniques for stimulation are the restricted volume strategy and the coordinate numerical reproduction, both of which are numerically expensive to solve in circumstances requiring complicated design challenges. The Poiseuille flow is one of the most studied tube streams because of its available expository arrangements and countless previous numerical and test exams covering a variety of logical and design elements.

Poiseuille flow happens in a few vital design applications, such as exchangers, chemical reactors, engines, generators, etc. This classical issue has been subject to numerous explanatory, numerical, and test analyses. The stream field for such a stream is ordinarily separated into two diverse locales: the hydrodynamic entrance locale and the completely created locale. In the entrance locale, the hydrodynamic boundary layer of laminarity develops quickly due to the thick constraint at the dividers. The layers' boundaries from the first to the last dividers develop until they consolidate and the flow comes to a state where the speed profile no longer changes. In low Reynolds numbers, the entrance locale is exceptionally brief, and the Poiseuille stream hypothesis can be utilized to get the arrangement.

The maximum temperature of the hot fluid outflow is connected to the insulation status based on its form. The quantity of heat loss from the converter's surfaces rises as the value of the environment's heat transfer coefficient

increases. This reduces temperatures, especially the output temperature of the hot fluid, and reduces the converter's overall heat and temperature efficiency.

According to the parameters of the desired fluids, oil has the highest viscosity and petrol has the lowest viscosity. The largest heat transfer is associated with petrol, whereas the lowest is associated with oil. Because petrol has a high heat transfer coefficient, temperature variations in oil are smaller than in petrol.

Four types of inner tubes are considered. These four types are STEEL, BRASS, COPPER and COPRO-NICKLE 55/45 were simulated to show the effects of pipe materials on the thermal characteristics of the distillation process, as a result, in the case where the inner tube is made of brass and copper, compared to the other two cases, the temperature profile of the hot fluid at the outlet reaches stability later. A comparable behavior happens with cold liquids. That is, as compared to the other two cases, the temperature profile of the cold fluid for brass and copper pipes has a phase delay. The differential in heat capacity of these two pipes, as well as other factors, should explain this.

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