Development and Experimental and CFD Analysis of Inclined Plate and Tube Heat Exchanger

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Abstract : **The Heat exchanger is the most important and widely applicable device in this sector so it is also area where these innovations are carried out regularly. Plate & Tube type Heat Exchangers have a number of applications in the pharmaceutical, petrochemical, chemical, power, and dairy, food & beverage industry. Recently, plate heat exchangers are commonly used when compared to other types of heat exchangers such as shell and tube type in heat transfer processes because of their compactness, ease of production, sensitivity, easy care after set-up and efficiency. The temperature approach in plate heat exchangers may be as low as 1 °C whereas shell and tube heat exchangers require an approach of 5 °C or more. However, plate and tube heat exchangers have inherent shortcomings such as the contact resistance between fins and tubes, the existence of a low performance region behind tubes, etc. The plate and tube heat exchangers which are in use are flat type if we incline the plates at some angle to the pipes we can get various data by experimenting the device at various angles. This data can be analyzed and we can have conclusion about its efficiency and effectiveness can be calculated.**

Index Terms - Plate & Tube type Heat Exchangers, efficiency and effectiveness.

I. INTRODUCTION

Recently, Fin And Tube Type Heat Exchangers Are Commonly Used When Compared To Other Types Of Heat Exchangers Such As Shell And Tube Type In Heat Transfer Processes Because Of Their Compactness, Ease Of Production, Sensitivity, Easy Care After Set-Up And Efficiency. The Temperature Approach In Fin And Tube Type Heat Exchangers May Be As Low As 1 °C Whereas Shell And Tube **Heat** Exchangers Require An Approach Of 5 °C Or More. However, Plate And Tube Heat Exchangers Have Inherent Shortcomings Such As The Contact Resistance Between Fins And Tubes, The Existence Of A Low Performance Region Behind Tubes, Etc.

II. THEORY

In an automobile, fuel and air produce power within the engine through combustion. Only a portion of the total generated power actually supplied to the automobile with power, the rest is wasted in the form of exhaust and heat. If this excess heat is not removed, the engine temperature becomes too high which results in overheating and viscosity breakdown of the lubricating oil, metal weakening of the overheated engine parts, and stress between engine parts resulting in quicker wear, among the related moving posts . A cooling system is used to remove this excessive heat. Most automotive cooling systems consist of the following components: radiator, water pump, electric cooling fan, radiator pressure cap, and thermostat. Of these components, the radiator is the most prominent part of the system because it transfers heat. As coolant travels through the engine's cylinder block, it accumulates heat. Once the coolant temperature increases above a certain threshold value, the vehicle's thermostat triggers a valve which forces the coolant to flow through the radiator. As the coolant flows through the tubes of the radiator, heat is transferred through the fins and tube walls to the air by conduction and convection.

A heat exchanger consists of heat transfer elements such as a core or matrix containing the heat transfer surface, and fluid distribution elements such as headers, manifolds, tanks, inlet and outlet nozzles or pipes, or seals. Usually, there are no moving parts in a heat exchanger; however, there are exceptions, such as a rotary regenerative exchanger (in which the matrix is mechanically driven to rotate at some design speed) or a scraped surface heat exchanger.

III. CLASSIFICATION OF HEAT EXCHANGER

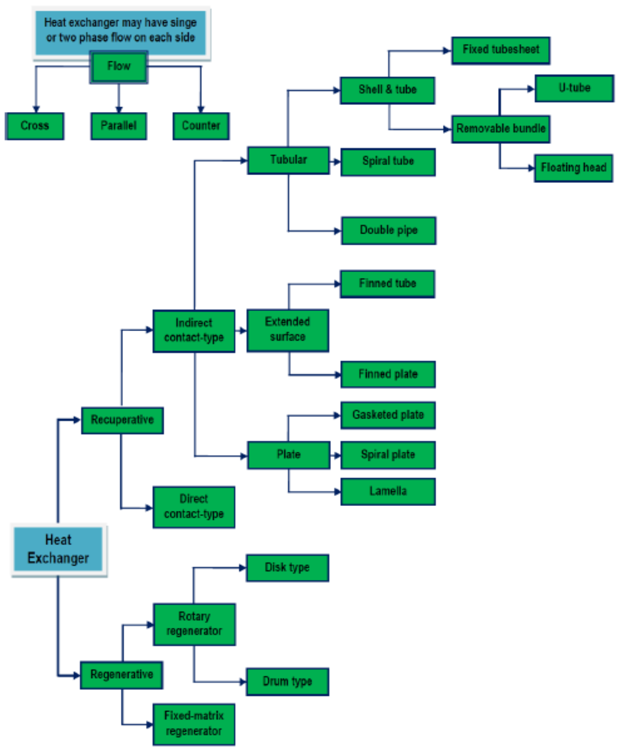

Fig. 1.

IV. AUTOMOTIVE RADIATOR

A radiator is a type of heat exchanger. It is designed to transfer heat from the hot coolant that flows through it to the air blown through it by the fan. Most modern cars use aluminium radiators. These radiators are made by brazing thin aluminium fins to flattened aluminium tubes. The coolant flows from the inlet to the outlet through many tubes mounted in a parallel arrangement. The fins conduct the heat from the tubes and transfer it to the air flowing through the radiator. The tubes sometimes have a type of fin inserted into them called a turbulator, which increases the turbulence of the fluid flowing through the tubes.

Auto radiators are generally of two types--a cross flow radiator and a vertical or down flow radiator. They are named after the mode of flow of liquid through the radiator. Cross flow radiators have the coolant moving sideways through the radiator. The core of the radiator is made of aluminium while the tanks are made of plastic or copper-brass. It consists of tanks on the sides of the radiator, with a tank of tubes connecting them. Between these tubes are the metal fins which dissipate heat from the coolant to the outside air.

The coolant flows into an inlet on the top of one side of the radiator, through the tubes connecting both the tanks and out of the bottom of the opposite tank. Cross flow and down flow radiators both use separate tubes and cooling fins flanked by the tubes; hot coolant flows through the top inlet of one tank and the bottom outlet of the other.

V. WORKING OF RADIATOR

The pump sends the fluid into the engine block, where it makes its way through passages in the engine around the cylinders. Then it returns through the cylinder head of the engine. The thermostat is located where the fluid leaves the engine. The plumbing around the thermostat sends the fluid back to the pump directly if the thermostat is closed. If it is open, the fluid goes through the radiator first and then back to the pump [1]. There is also a separate circuit for the heating system. This circuit takes fluid from the cylinder head and passes it through a heater core and then back to the pump. On cars with automatic transmissions, there is normally also a separate circuit for cooling the transmission fluid built into the radiator. The oil from the transmission is pumped by the transmission through a second heat exchanger inside the radiator.

VI. ADVANTAGES OF CROSS FLOW RADIATOR

Cross flow designs offer a greater area for heat dissipation while allowing more low profile hood designs. They allow more pressure at the radiator inlet before the cap vents, since the cap is located on the low pressure end of the radiator. Since the cap is at the suction side of the radiator, it prevents the pressure formed by a high-flow water pump to force the coolant through the cap at high RPM. The hood lines of the down flow radiator are taller than the hood lines of the cross flow radiator, thereby making the cross flow radiator wider, attaining a greater surface area.

The design and manufacture of cross flow radiators is easy and cheap. Owing to the smaller and wider sie of the cross flow radiators, they can be chosen to be mounted higher than the engine. This offers many advantages. The cap, being the highest point of the system allows air to migrate to areas lower than it and in case it opens due to pressure, the air will escape first. Even at high engine RPMs, the air and coolant won't mix because of the low velocity of air. In case the system is not a cross flow radiator, it necessitates the use of a surge pump and a bleed line.

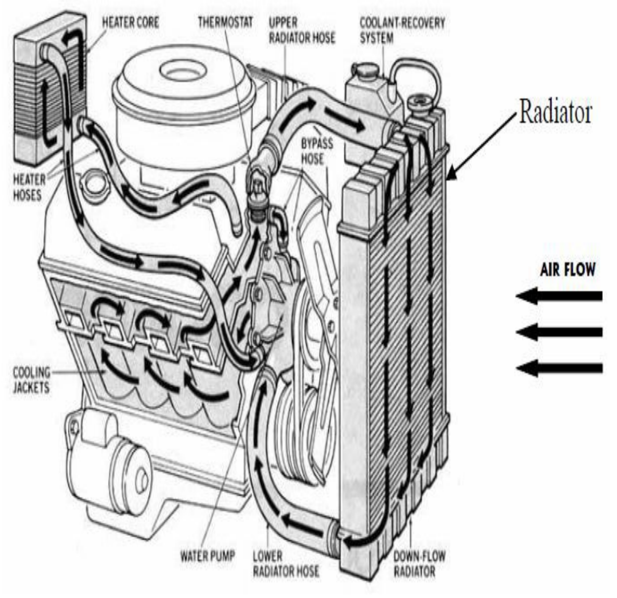

Fig. 2. Working of Radiator

VII. DISADVANTAGES OF CROSS FLOW RADIATOR

Though cross flow radiators have several advantages over the down flow radiators, there are a few disadvantages too. Since cross flow radiators are wider than down flow radiators, they are difficult to incorporate in vehicles with engine modifications. Their complex coolant flow makes it hard for people to clean it. It is also important to understand that the vertical flow radiator has a larger coolant capacity than the cross flow radiator. Critical positioning of the cross flow radiator is required to get the maximum potential.

VIII. IDENTIFICATION OF PROBLEM & OBJECTIVES

It is clearly evident from the research studies and survey that very small amount of work is carried out on the performance of inclined plate and tube type heat exchanger. The inclination of plate of the heat exchanger will affect on the various parameters like efficiency, effectiveness which will directly or indirectly affect the performance of the heat exchanger. Based on the above facts a research proposal to check the performance of the inclined plate and tube type heat exchanger is to be developed and carried out experimental analysis in order to explore the best possible outcomes at various plate angles.

IX. OBJECTIVES:-

- Learn about Plate and tube type heat exchanger.
- Know the primary considerations in selection of heat exchanger.
- Design of inclined plate and tube type heat exchanger.
- Manufacturing of experimental setup inclined plate and tube type heat exchanger.
- Perform experiments at various heat exchangers angles.
- Investigate the effect of operating conditions on heat transfer into heat exchangers.
- To determine overall heat transfer coefficient and perform general analysis on heat exchanger.

- Comparison of the results with standard plate and tube heat exchanger.
- Validation of results.

X. Existing Evaluation Methods For Engine Cooling Systems

Existing methods employed in the automotive industry worldwide are classified into three approaches;

1. Analytical
2. Experimental
3. Computational methods.

A. Analytical Methods

According to theory of heat exchanger, radiator performance can generally be determined using either one of the following approaches; The Log Mean Temperature Difference method (LMTD) and The Effectiveness - NTU method (ε-NTU).

1) Log Mean Temperature Difference

In this method specific radiator operating condition, including coolant flow rate, inlet temperatures and intended outlet temperatures of both fluids are considered, the LMTD method can be conveniently used to calculate the correct size (the heat transfer area) of the radiator core in order to achieve the required outlet temperatures. The heat transfer equation for cross-flow heat exchangers using the LMTD method is given by,

Q =U.A.F.ΔT log-mean
Where Q = overall heat transfer rate of the radiator
U = overall heat transfer coefficient of the radiator
A = surface area for heat transfer
F = the correction factor
ΔT log-mean = log mean temperature difference (LMTD) of the two fluids for a Counter-flow heat exchanger

$$\Delta Tlog - mean = \frac{(Th,i - Tc,o) - (Th,o - Tc,i)}{In[(Th,i - Tc,o)/(Th,o - Tc,i)]}$$

Here T = temperature; subscripts h = hot fluid (coolant) c = cold fluid (air)
Effectiveness – NTU

In comparison with the LMTD method, this method is more effective when the radiator geometry, the coolant flow rate and the inlet temperatures of both fluids are known for a particular radiator. The outlet temperatures in association with the heat transfer rate of the radiator are subsequently calculated. This approach involves several dimensionless parameters to be calculated it consisting of Number of Heat Transfer Units (NTU), Effectiveness (ε) and Capacity Ratio (Cmin/Cmax). In this method each parameter affects the performance of the heat exchanger and has its own physical significance. A general relationship between the parameters is expressed by the following formula,

$$\varepsilon = f(NTU, \frac{C_{min}}{C_{max}}, flow\ arrangement)$$

Once the radiator effectiveness (ε) is determined, the heat dissipation rate (Q) from the radiator can be obtained by applying the following equation;

$$Q=(Thi-Tci)$$

B. Experimental Methods

Experimental evaluation method is carried out by on-road and wind-tunnel testing. On road testing offers a direct assessment of the true behaviour of engine cooling performance as well as providing airflow over the vehicle under "real" conditions. However, weather conditions, particularly the inability to control atmospheric winds (and associated turbulence) and ambient temperatures, prejudice repeatability and accuracy of on-road testing. On the other hand, wind tunnels provide an approximation of on-road flow conditions that are replicated in controlled environments (involving a stationary vehicle with respect to movement of air).

The main advantage of wind-tunnel testing is that the tests can be conducted more conveniently, time-effectively and accurately. Two types of wind tunnels are currently employed in aerodynamic development for automotive vehicles; aerodynamic wind tunnels and climatic wind tunnels. These have been used by vehicle manufacturers worldwide for many years. Aerodynamic wind tunnels provide good external aerodynamics, and are used for assessing the forces and moments on the vehicle and, increasingly, wind noise. On the other hand, climatic wind tunnels are facilities that were designed to replicate thermal characteristics experienced on the road, providing the capability of controlling ambient air temperature and humidity as well as simulating engine loads on a chassis dynamometer. It is recognized that the flow quality in climatic wind tunnels is generally not as good as that in aerodynamic wind tunnels.

1) Selection Criteria For Design Cosideration

- Water tank capacity: – 15 litres
- Air temp: - 30-35^{0}C
- Heated water Temp: - 60^{0}C
- Heat exchanger

1. Inlet temp :- 60^{0}C
2. Mass flow rate (hot) = 0.5 litre/sec

2) Working Cycle

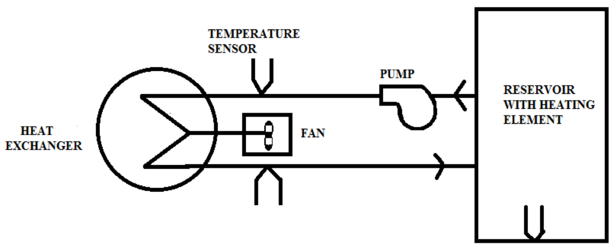

Fig. 3. Working cycle of the setup

3) Parts

1) Heat Exchanger - 1
2) Motor with pump - 1
3) Fan - 1
4) Heater - 1
5) Tank - 1
6) Energy meters - 2
7) Temperature sensors - 4
8) Hose

9) Miscellaneous

a) Part Specifications

Heat Exchanger
Manufacturer – Maruti Suzuki
Maruti 800
Dimensions
Length = 33 cm
Height = 30 cm
Width = 04 cm
Tubes
Number of tubes = 2 x 18 = 36
Diameter of tube = 10 mm
Length of tube = 30 cm
Fins
Number of fins = 8 fins/cm
Total fins = 240 fins
Weight = 15 kg
Pump with motor
Manufacturer – Lakshmi
Power = 0.5 Hp
Flow rate = 0.4521 kg/s
Fan
Max. Speed = 2700 rpm
Heater
Manufacturer – Roxy
Power = 1500 watts = 1.5 kW
Other features –
100% copper rod
ISI marked
Cool touch handle
Heavy power cord
Easy hanging strip
Shock Proof
Tank
Material – Plastic
Total capacity – 20 litre
Usable capacity – 15 litre
Energy Meters
Manufacturer – Powertech Measurement System
Type – PTS -01
Voltage = 240 v
Frequency = 50 Hz
Impulse rate = 3200 Imp/kWhr
Accuracy class = 1.0
Temperature sensors
Type – Digital Thermometer
Temp. Range = -50 oC ~ +85 oC
Accuracy = 0.1 oC
Hose
Material – Reinforced Plastic
Length = 12 ft
Diameter = 1.875 cm = 3/4’’
Miscellaneous
Electric Power Cable
Electric wire, etc.

C. Experimentation:-

1) Procedure

Check all pipe and electrical connections for security.
Fill water in tank up to 15 litres level.
Start electric supply and provide the electric connection to heater, fan and motor.
Start water heater.
Take energy meter reading for heater energy consumption for heater and fan.
Heat water at the temp 600C.
When water reaches at the temp 60oC then start motor.
Take initial temperature readings of the water tank and air.
Start fan and measure energy meter readings for fan motor energy consumption.
Take readings by placing heat exchanger at idle (vertical) position; various fan speeds and various distances between fan and heat exchanger.
Take readings by placing heat exchanger at inclined position (0, 15, 30); various fan speeds, various distances between fan and exchanger.
Analyze the readings and conclude the results with the help of observation table.
Calculate
Heat required 2) LMTD 3) Effectiveness/ Efficiency

2) Observation Table:-

TABLE I.

Sr. No.	Heat Exchanger Position	Fan distance (cm)	Fan Speed (rpm)	Tank Temp T1(oC)	Air inlet T2(oC)	Air outlet T3(oC)	H.E. inlet T4(oC)	H.E. outlet T5(oC)
1	0^o	30	1350	60.3	36.2	46	59.4	58.7
2			2700	63.6	35.4	51.4	62.1	61.2
3	15^0	30	1350	60.4	34.7	40	59.2	58.7
4			2700	61.3	35.8	42.4	59.7	58.8
5	30^0	30	1350	63.6	35.9	43.8	61.9	60.6
6			2700	60.1	34.6	46.2	59.3	57.9

3) Calculations:-

Total heat transfer of water
(Q)water = m Cp (Thi – Tho)
= 0.4521 x 4180 × (2)
= 3779.56 J =3.77956 KJ
Total heat transfer of air
(Q)air = m cp (Tco-Tci)
=10 X 1.0082 X 12.4
=125.01 J = 0.125 KJ
To find LMTD
LMTD for Cross flow is equal to LMTD for Counter flow
LMTD= (T1-T2)/ ln(T1/T2)
Where,
T1= Thi – Tci = 61-34.4 = 26.6
T2 = Tho – Tco= 59-46.8 = 12.2
LMTD =18.48 OC
Area of single pipe = π D L
= π x 0.01 x 0.3
=9.4248 x 10-3 m2
Total Area = No. of pipes X Area of single pipes
= 36 X 9.4248x10-3
= 0.3393 m2

Q = U × A × LMTD
3779.56 = U X 0.3393 X 18.48
U =602.78 W/m2K
Where,
U = Overall heat transfer coefficient
= 602.78 W/m2K
Effectiveness = Qactual / Qmax
Qactual = (m Cp)max x (Thi - Tho)
= 0.4521 x 4180 x (61 -59)
= 3779.56 J
Qmax = (m Cp)max x (Thi - Tci)
= 0.4521 x 4180 x (61 - 34.4)
= 50268.10 J
Effectiveness = 0.075 = 7.5 %
Efficiency = (Energy output) / (Energy input)
Energy output = m Cp δT
= 0.4521 x 4180 x 2
=3779.56 J
Energy input = (3600 x t) / (3200 x10)
= (3600 x 12) / (3200 x10)
= 1.35 x 3600
= 4860 J
Efficiency = 0.7777
= 77.77 %

D. CFD Analysis:-

Computational Fluid Dynamics (CFD) analysis of plate type heat exchangers is a powerful tool used to optimize the design and performance of these systems. Plate heat exchangers are commonly used for heat transfer in a variety of industries including HVAC, refrigeration, and chemical processing.

To perform a Transient Thermal analysis of a plate type heat exchanger, the geometry of the heat exchanger must first be modeled using specialized software such as ANSYS thermal analysis. The model should include the plates, channels, inlet/outlet ports, and any other relevant components of the heat exchanger.

1) Temperature distribution:

CFD analysis provides detailed information on the temperature distribution within the heat exchanger, allowing engineers to identify hot spots and areas with poor heat transfer.

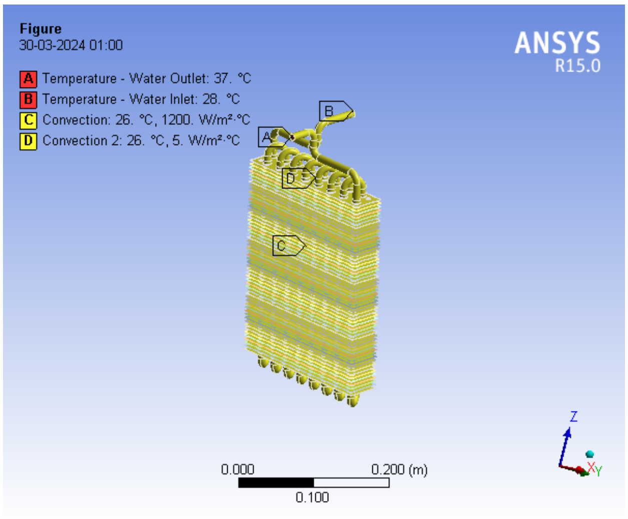

Fig. 4.

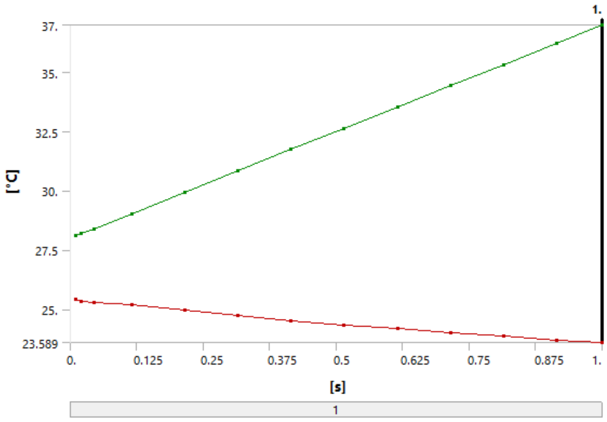

Fig. 5.

2) Heat transfer coefficient:

By analyzing the heat transfer coefficient, engineers can evaluate the efficiency of heat transfer within the heat exchanger and identify areas for improvement.

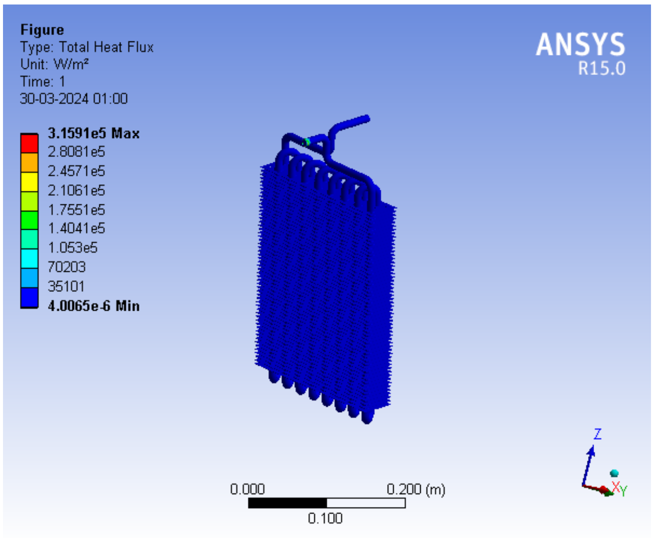

Fig. 6.

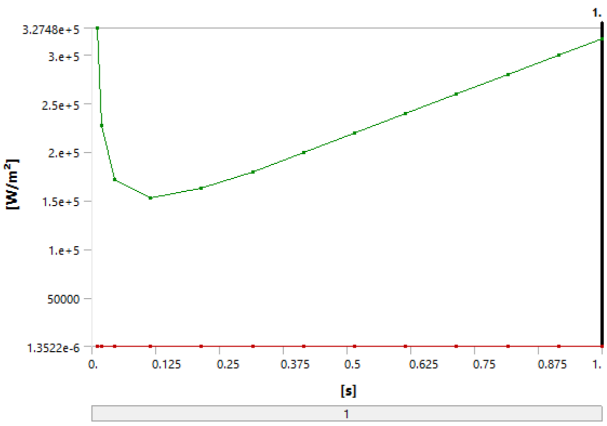

Fig. 7.

To Evalute the total heat flux, you need to determine these parameters specific to your heat exchanger and the conditions under which it operates. Often, this involves a combination of theoretical calculations and experimental data.

XI. CONCLUSION

Heat exchanger used to increase the efficiency of experimental setup. To change the parameter properties with inclination of heat exchanger and analyse the temperature drop in air medium. Take the reading of heat exchanger with angle of (0^o,15^o ,30^o) so seen that, change the temperature with increase in angle of heat exchanger.

At the optimal angle of heat exchange is 15o, we achieve more temperature of hot water and cold air

We calculated

TABLE II.

1.	Total heat transfer of water	3779.56 J
2.	Total heat transfer of air	125.01 J
3.	Overall heat transfer coefficient	602.78 W/m2K
4.	Effectiveness	7.5 %

So, for 15^o inclination at 0 cm distance of fan and 60^o C hot water effectiveness is 7.5 %.

CFD analysis of plate type heat exchangers is a powerful tool that enables engineers to optimize the design and performance of these systems. By simulating the fluid flow and heat transfer within the heat exchanger, engineers can identify areas for improvement and make informed design decisions to enhance efficiency and reduce energy consumption.

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