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Experimental Study of the Thermal Contact Resistance in Fin and Tube

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ABSTRACT

In this paper, experimental study has been done to showing the effect of the Thermal Contact Resistance ($1/h_c$) in fin and tube. Three types of fin-tube design Embedded, Welded and L-footed are used in the test. Vacuum chamber with dimensions (45 cm length, 35 cm height, and 15 cm width) has been used for testing the sample of fin-tube, that’s placed inside the vacuum chamber. Vacuum pump is used to providing surrounding approximate emptied from air. The sample of fin-tube consists of hot water tube and cold water tube, the fin is fitted between themes. The experimental results showed that the thermal contact resistance decreases as the heat supply (source) increase. And the thermal contact resistance decreases when temperature drop at interface contact surfaces decreases. The results obtained of ($1/h_c$) is least for embedded type and greatest for L-footed type. The thermal contact resistance ($1/h_c$) of L-footed finned tube is higher than the others, by (250%) than the Embedded fin- tube type, and by (160%) of welded fin-tube type.

Keywords: Thermal Contact Resistance, naturecontact at interface surface, fin and tube.

دراسه عملية لمقاومة الأتصال الحرارية المتكونة بين الأنبوب والزعنفة

الخلاصة

فيهذا البحث دراسه عمليه تبين تأثير مقاومة الأتصال ($1/h_c$) بين الأنبوب والزعنفه. أستخدمت ثلاثة أنواع من حالات الربط بين الأنبوب والزعنفه و ِه والحام و المثبته على شكل حرف L. أجريت الأختبارات للنماذج في غرفة مفرغه من الهواء بأبعاد 45 سم طول و35 سم أرتفاع و15 سم عرض. تمت الأستعانه بمضخة تفريغ ربطت مع الغرفه لتفريغها من الهواء لتوفير محيط مفرغ حول النموذج. يتكون نموذج الأختبار من أنبوب ماء حار (مصدر حراري) وأنبوب ماء بارد (بالوعة حراريه) والزعنفه متصله بين الأنبوبين. بينت النتائج بأن مقاومه الأتصال الحراريه($1/h_c$) تقل كلما أزدادت الحراره المجهزه وكذلك تنخفض قيمتها كلما كان أنحدار درجات الحراره عند سطح الأتصال البيني قليل. ومن النتائج المستحصله ايضاً ان القيمه الدنيا للمقاومه وجدت في نوع أنبوب-زعنفه مطموره ونوع المثبته على شكل حرف L هي ألأعلى بين الأنواع.

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حيث تبين ان مقاومه الأتصال الحراريه ($1/h_c$) لنوع زعنفه حرف L كانت أكثر بـ (250%) من قيمة المقاومه الحراريه لنوع زعنفه مطموره، وأكثر من(160%) من قيمة المقاومه الحراريه لنوع زعنفه ملحومه.

الكلمات المفتاحيه : مقاومة الأتصال الحراريه, طبيعة الأتصال بين السطوح المتداخله , أنبوب- زعنفه.

INTRODUCTION

The extended surface element is referred to asfin. Thus, heat is conducted through the fin and convicted from the fin (through the surface area) to the surrounding fluid. As a result, the addition of fins to the primary surface (surface's tube) reduces the thermal resistance on that side and thereby increases the total heat transfer from the surface for the same temperature difference. [1]

The contact between fin collar and tube surface of a fin-tube is secured through mechanical expansion of tubes and other mechanical ways. The interface between the tube and fin consist partially of metal-to-metal contact and partially of air. Because of the irregular contact of interface, thermal contact resistance represents a significant portion of the total thermal resistance in plate finned heat exchangers. So that the effects of the thermal resistance of the fin-tube bond are of considerable interest. [2]

Many researchers have studied this subject in the past. Dart [3], studied the importance of the thermal contact resistance for plate fin design in a heat exchanger having two passages, one for cold and the other for hot water, through adjacent tubes, connected by collared fins, and taking temperature measurements before and after each pass. By knowing the thermal conductivity of the tubes and fins, the temperature difference of the water, the mass flow rate of the water and eliminating convective heat transfer, by insulating the apparatus.

Eckels [4].Expanded upon the research performed by Dart. He developed a semi-theoretical correlation to predict the effect of varying fin number (fins per meter), fin thickness and tube diameter on thermal contact resistance for mechanically expanded, fin-tube heat exchangers.

His experimental apparatus was almost identical to Dart's method, hot and cold water was circulated through adjacent tube rows so that heat flow through the tube walls, fin collars and fins would occur. Eckels made much more precise temperature and mass flow rate measurements than Dart; hence, his results are more accurate. Like Dart, convective effects were minimized by insulating the tested coils; hence, a conduction problem was studied. Eckels concluded that the contribution of thermal contact resistance to the overall conductive resistance ranged from being insignificant to 15% for the mechanically expanded, fin-tube heat exchangers tested.Abuebid[5].Investigated the thermal contact resistance with plate-finned tube heat exchangers placed in a vacuum. He performed an error analysis similar to the Eckels' method. But the error band was narrower.Heused the method of Eckels to determine the contact conductance of plate-finned, mechanically expanded tubes.For most applications where the joint (interface) temperature level is below 600°C,radiation heat transfer becomes negligible, and therefore it is frequently ignored. [6]

Thermal contact conductance is highly important in such applications as heatrejection from electronic components, cooling gas turbine blades, enhancement of heattransfer through plate-finned tubes in heat exchangers. In many cases, the demand for increased efficiency means that components need to withstand higher temperatures and heat transfer rates. So that knowledge and understanding nature of this thermal resistance is very important to find a solution to eliminate or reduce this thermal resistance.

EXPERIMENTAL WORK

Experimental investigation was carried out on The test rig is designed and manufactured to fulfil the requirements of the test system for three types of common fin and tube arrangement welded, L-footed, and embedded fin-tube. The experimental apparatus consist basically ofvacuum chamber and test section, vacuum pump, water flow rates supply section, as shown in figures (1) and (2).

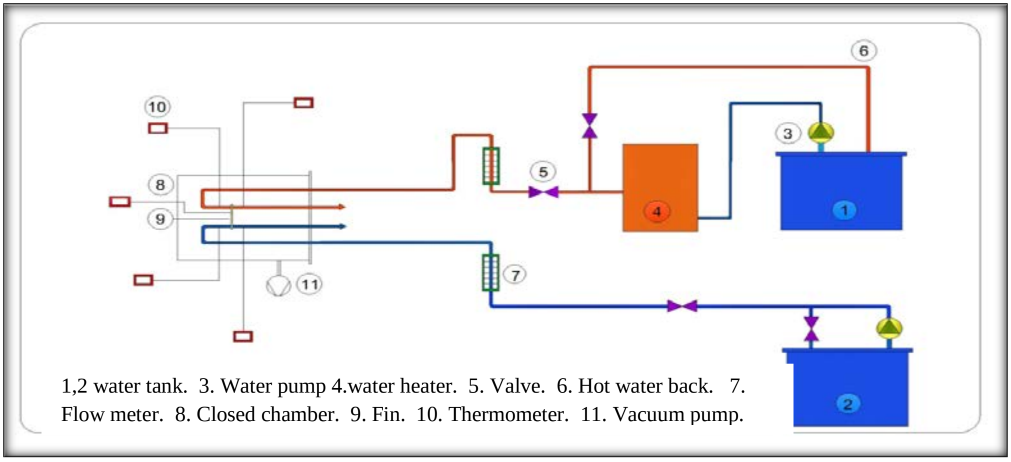


Figure (1)Schematic illustrationof experimental apparatus.

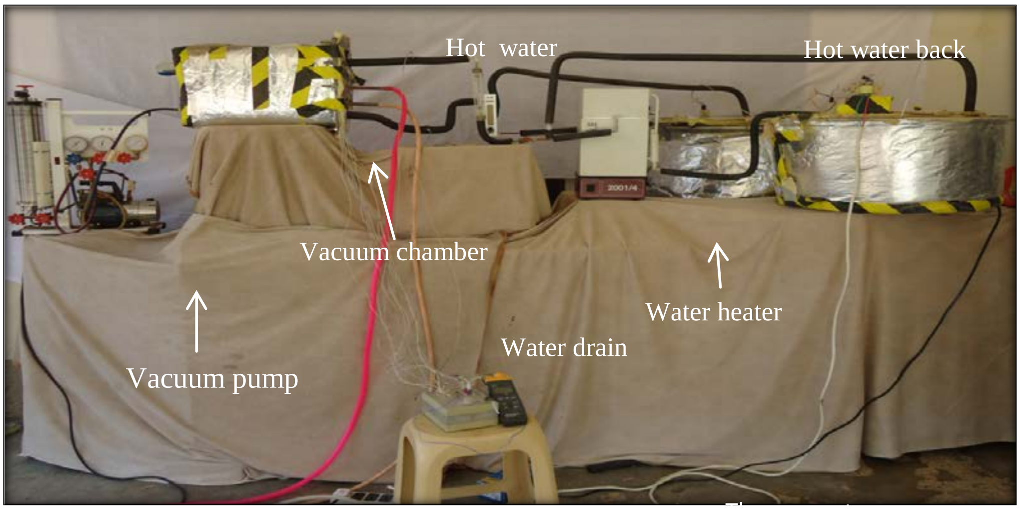


Figure (2)Photograph of experimental apparatus.

The vacuum chamber is a box manufactured from a carbon steel sheet with (4 mm) thickness to resist the force vacuum of the air atmospheric pressure it, is a rectangular cross section withthe following dimensions(45 cm × 15 cm × 35 cm). As well as the vacuum chamber is connected with vacuum pump.Three types of finned tube were manufactured in the present work, each one consists of a test finned tube (9.47 mm outer tube diameter), fin dimensions (7.5×15×0.135 cm) width, length, and thickness respectively, the fin and tube are made from same material. Test section is placed inside the vacuum chamber. Hot water flowing through one tube (hot water tube), represent a heat source. While the second tube (cold water tube) represent a heat sink. The fin is fitted between the hot water inlet tube & inlet cold water tube as shown in the figures (3, 4).

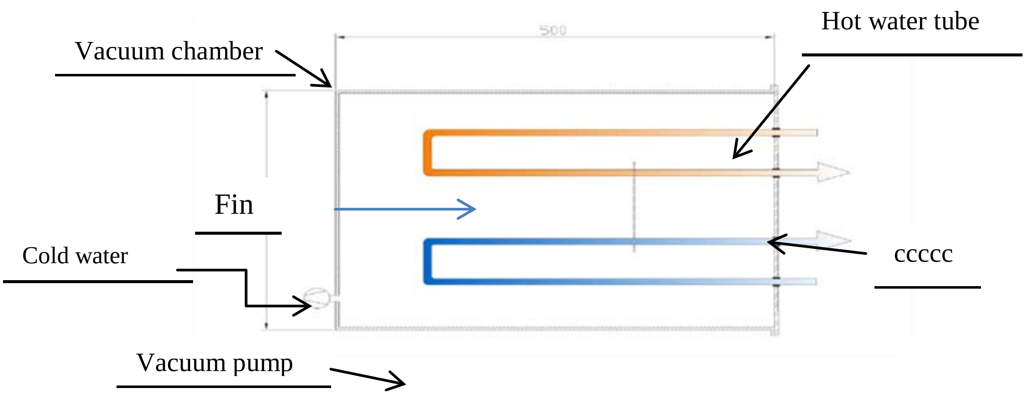
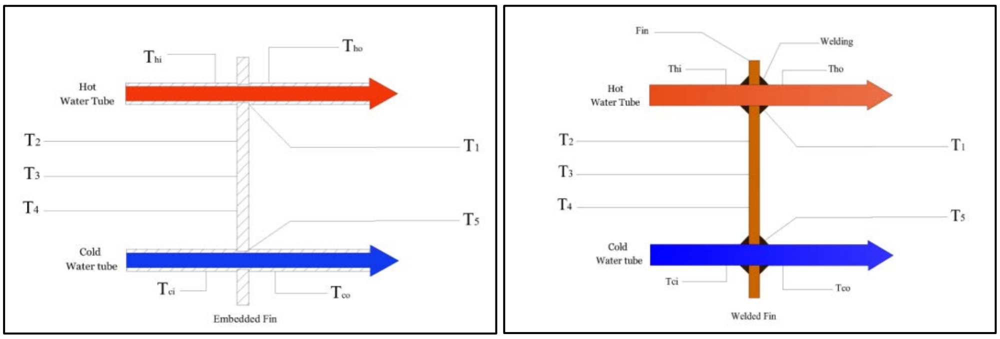
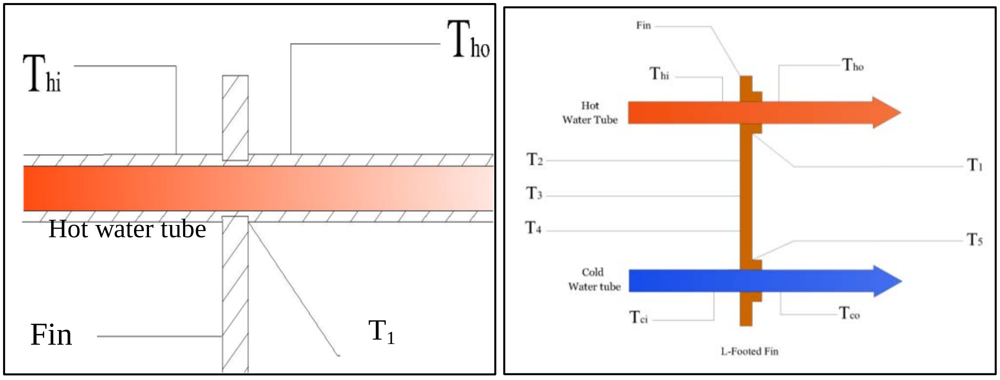


Figure (3) Schematic illustrationof test section.



(a) Embedded fin (c) Welded fin



(b) illustration of Embedded fin (d) L-footed fin

Figures (4) a, b, c, d Schematic illustration of test sections.

Electrical heater was used to supply hot water quickly and continuously to the test section. The water outlet temperature can be controlled by a thermostat and then pumped to the test section by water pump.a circulation pump was used with water flow rates 0.052, 0.0714, 0.1, 0.25, 0.33 kg/min.

Fixation of Thermocouple and Temperature Measurement

Eleven thermocouples type K (Cr-Al) pin wires were used for temperature measurements, these thermocouples are fixed at the following positions:

a- Five thermocouples were fixed along the fin at different positions, (0, 2, 4, 6, and 8 cm), between the supply and sink of heat as shown in figure (5).

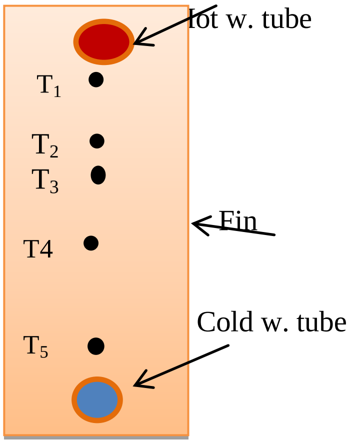


Figure (5)Schematic illustrationfor fixation of five thermocouples along the fin.

b- Two thermocouples were fixed on the hot water tube (inlet & outlet) of the fin test section of the hot water inside the vacuum chamber.

c- Two thermocouples were fixed on the cold water tube (inlet & outlet) of the fin of the cold water inside the vacuum chamber.

d- Two thermocouples were fixed on the inlet (hot & cold) water tube front outside the vacuum chamber.

During the experimental investigation, the main parameters measured are:

1. The inlet and outlet temperatures of hot water.
2. The inlet and outlet temperatures of cold water.
3. The temperatures at the contact between the tube and the fin.
4. The temperatures along the fin.
5. The flow rates of hot and cold water.

CALCULATIONS

Neglect the heat radiation between the test section and inside the vacuum chamber (very small due to relatively low temperatures).

1. **Water mass flow rate** can be calculate as follow:

$$\dot{m}_w = \rho_w \cdot V_w \qquad .....(1)$$

2. **Useful energy from hot water tube (heat source)** can be calculated as follow:

2. $Q_h = \dot{m}_w \bullet C_{pw} \bullet (T_{hi} - T_{ho})$ ……(2)

3. **Energy received to cold water tube (heat sink)** can be calculated from equation]

3.$Q_c = \dot{m}_w \bullet C_{pw} \bullet (T_{co} - T_{ci})$ …(3)

4. **Temperature drop** at interface contact surfaces between fin and tube, can be calculated as follow:

$\Delta T_c = (T_{hi} - T_1)$ ….. (4)

5. **Thermal contact resistance (1/ h_c)** that's formed at interface contact surfaces between the fin and tube because existence the gaps and imperfect contact between the composed surfaces. ($1/h_c$) can be calculated as follow:

$(1/h_c) = [(\Delta T_c \times A) / Q_h]$ …(5)

RESULTS AND DISCUSSION

Three types of fin-tube design are tested in this experimental work Embedded, welded and L-footed fin-tube. The results shows that's the thermal contact resistance ($1/h_c$) is inversely proportional with heat supply (Q), and it is direct proportional to temperature drop (ΔT_c) at the interface contact of the surfaces.

For all record data have been found the Embedded fin type has lower temperature drop, L-footed fin type gave highest temperature drop among these types. And so the Embedded fin type is to allow with receive greatest amount of the heat source across the interface contact comparison tally with the others types of fin-tube design.The larger mass flow rate of hot water, the littlest of thermal contact resistance, that's means the mass flow rate ($\dot{m}_w$) is important factor to providing the heat (Q, heat supply).

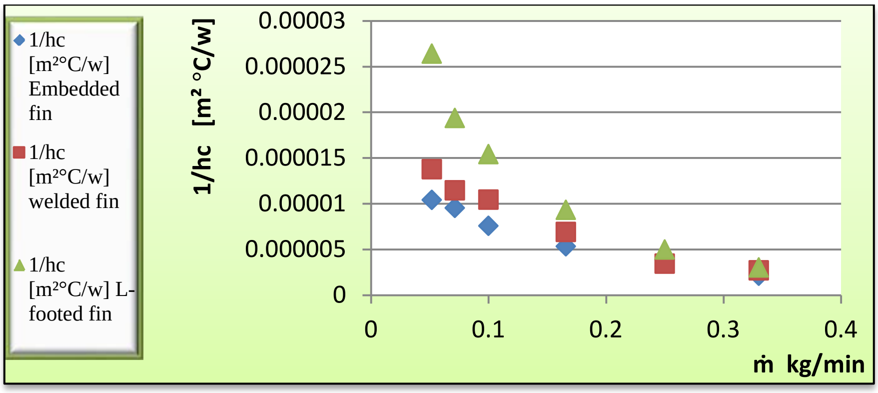


Figure (6),($1/h_c$) for Embedded, welded, and L-footed fin with mass flow rates.

For three fin-tube types, figure (6)show the behaviour of thermal contact resistance with mass flow rates of water.In Embedded fin type the thermal contact resistance was found to decrease from 10.04082*10^{-6} m^2 °C/W to 2.08968*10^{-6} m^2 °C/W, a decrease of 79.9%, as the mass water flow increased from 0.052 kg/min to 0.33 kg/min. In welded fin type the demeanor of ($1/h_c$) is similar to its manner in embedded fin type, but the values of ($1/h_c$ are higher than that in the embedded fin type. This means heat flows is better in embedded fin type. In L-footed fin typethe demeanor of ($1/h_c$) is similar to other two types discussed before. But the values of ($1/h_c$) are the highest among these types. This means the heat flow in L-footed fin type through interface contact is meeting more difficulty to pass.Where the thermal contact resistances ($1/h_c$) of L-footed fin type are about (250%)are that Embedded fin type, and about (160%) of welded fin type. Thermal contact resistance ($1/h_c$) of welded fin type equal to (155%) of Embedded fin type.

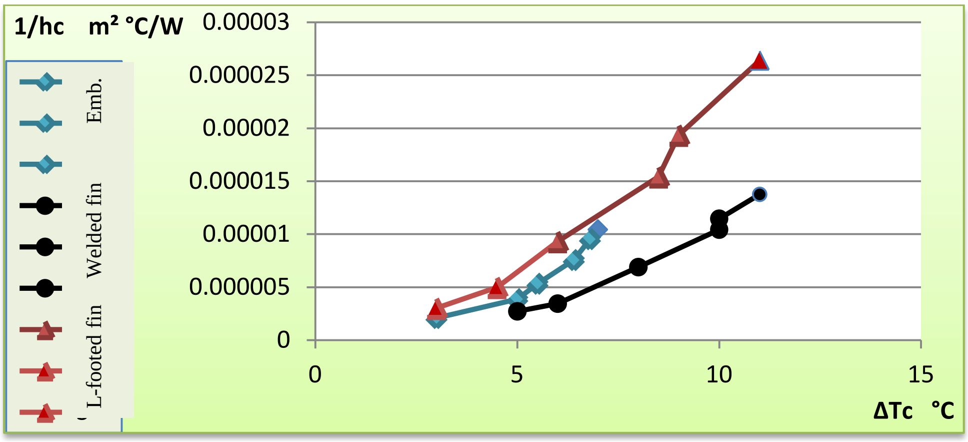
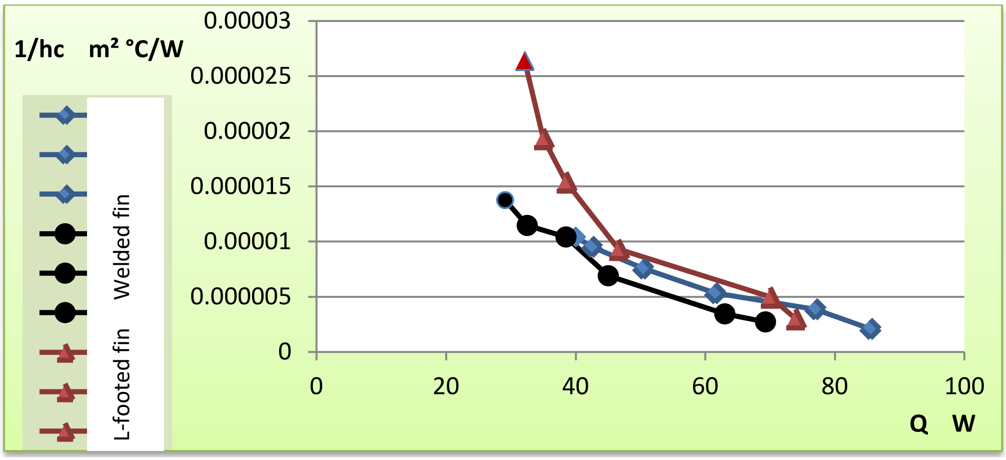


Figure (7) the variation of ($1/h_c$) with ΔT_c.

Figure (7) sh ance ($1/h_c$), and the temperature drop at interface contact surfaces (ΔT_c), ($1/h_c$) is direct proportional to (ΔT_c), (ΔT_c) is very important factor, where it has high affect to raise ($1/h_c$) which holds up the heat flow.Temperature drop at interface arising from existence the gaps formed between them. These gaps are creating between the surfaces assembly because the effect of surfaces roughness.

Figure (8) shows The thermal contact resistance ($1/h_c$) is inversely proportional to the heat transfer rate (heat supply, Q) across the contact surfaces.in Embedded fin, the heat transfer across the contact surfaces is greatest as the mass flow rate increased from 0.052 kg/min to 0.33 kg/min.



Figure(8)($1/h_c$) for Embedded, welded, and L-footed fin with heat transfer passed across the contact surfaces.

Comparison between the presented work with some references.
Table (1) reviews the thermal contact resistance which experimentally accounted for by many researchers.

Table (1), Review ($1/h_c$) for some researchers.

Researcher	$(1/h_c)\times10^5$ [m²°C/w]	Note
Chang Nyung KIM, et al.	7.779	plate fin type
Jin Jeong, et al. (OD,9.52mm)	5.8309	L-footed fin type
Present work	2.63966	L-footed fin type

From the table (1), the disagreement in the results referred to different type of the fin-tube, material used, manner of testing and the boundary conditions of the experimental test. Jin Jeong et. al, the near side of the present work where ($1/h_c$) were equal to (5.8 and 2.6 m^2 °C/w) respectively. So the two works used the same type of fin-tube.

CONCLUSIONS
From the results of the present work, the following conclusions are deduced:

1. In general the thermal contact resistance ($1/h_c$) from the test section is directly proportional to the interface contact surfaces temperature (temperature drop, ΔT_c)
2. The thermal contact resistance ($1/h_c$) from the test section isinversely proportional to the heat transfer rate (heat supply, Q_h) across the contact surfaces.
3. The Embedded fin-tube design lesser temperature drop (ΔT_c), lesser thermal contact resistance ($1/h_c$), better heat transfer rate across the contact surfaces.

4. The thermal contact resistance ($1/h_c$) of L-footed finned tube is higher than the others, the ($1/h_c$) of L-footed finned tube was greater by (250%) of Embedded fin-tube type, and by (160%) of welded fin-tube type.

Nomenclature

A	Heat transfer area	m^2
C_{pw}	Specific heat capacity of water	J/kg. °c
$1/h_c$	Thermal contact resistance	m^2 °C/W
$\dot{m}_w$	Mass flow rate of water	kg/min
Q_h	Heat source	W
Q_c	Heat sink	W
ΔT_c	Temperature drop	°C
T_1	fin's temperature at interface contact surface	°C
T_{hi}	Hot inlet temperature	°C
T_{ho}	Hot outlet temperature	°C
T_{ci}	Cold inlet temperature	°C
T_{co}	Cold outlet temperature	°C
V	Volume flow rate	m^3/s
ρ_w	Density of water	kg/m^3

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