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EFFECT THE FORM OF PERFORATION ON THE HEAT TRANSFER IN THE PERFORATED FINS

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ABSTRACT

Extended surface heat exchangers are easy in construction and extensively use in many of the industries. Continuous research is going on to improve its effectiveness by reducing the thermal boundary layer thickness and increasing the heat transfer surface area. Perforations in the fins one way that used to improve its effectiveness.

An experimental study submitted to investigate the heat transfer by natural convection in a rectangular perforated fin plates. Five fins used in this work first fin non-perforated and others fins perforated by different shapes these fins perforation by different shapes (circle, square, triangle, and hexagon) but these perforations have the same cross section area(113 mm^2. These perforations distributed on 3 columns and 6 rows. Experiments produced through in an experimental facility that was specifically design and constructed for this purpose.

The results show that the drop in the temperature of the non-perforated fin from 72 to 57 ^{o}C while the temperature drop in perforated fins, at the same power supplied (126 W) was (72-52 ^{o}C), (72-51.5 ^{o}C), (72-50 ^{o}C) and (72 -48 ^{o}C) for shapes (hexagonal, square, circular and triangular) respectively Figure(9). The largest value of RAF at triangular perforation and the smaller value occurred in circular perforation. Also, triangular perforation gives best values of heat transfer coefficient and then the circular, square, hexagonal, and non-perforation respectively.

Keywords: Heat transfer, Surface heat exchangers, Perforated fin plates

INTRODUCTION

The removal of excessive heat from system components is essential to avoid the damaging effects of burning or overheating. Therefore, the enhancement of heat transfer is an import subject of thermal engineering. The heat transfer from surfaces may in general be enhanced by increasing the heat transfer coefficient between a surface and its surroundings, by increasing the heat transfer area of the surface, or by both. In most cases, the area of heat transfer increased by utilizing extended surfaces in the form of fins attached to walls and surfaces [1]. Extended surfaces (fins) frequently used in heat exchanging devices for the purpose of increasing the heat transfer between a primary surface and the surrounding fluid.

Different types of fin heat exchangers, ranging from relatively simple shapes, such as rectangular, square, cylindrical, annular, Tapered, or pin fins, to a combination of different geometries that applied heat exchanger [2]. One of the primaries aimed in the design of modern thermal systems is the achievement of more compact and efficient heat exchangers. Reducing energy loss due to ineffective use and enhancement of energy transfer in the form of heat has become an increasingly important duty for the design engineers of thermal systems, considering the world wide increase in energy demand. This duty requires employing heat transfer surfaces with high heat transfer coefficients and high area

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compactness. A particular attention is required in surface area design when use the gas in heat exchangers [3].

Fins as heat transfer enhancement devices have been quite common. As the extended surface technology continues to grow, new design ideas emerge, including fins made of anisotropic composites, porous media, and perforated and interrupted plates [4]. The requirements of lightweight fins and economical, so the optimization of fin size is very important in fin's design. Therefore, fins must be designed to achieve maximum heat removal with minimum material expenditure, taking into account, however, the ease of manufacturing of the fin shape [5]. Large number of studies has been conducted on optimizing fin shapes. Other studies have introduced shape modifications by cutting some material from fins to make cavities, holes, slots, grooves, or channels through the fin body to increase the heat transfer area and/or the heat transfer coefficient [6]. One popular heat transfer augmentation technique involves the use of rough or interrupted surfaces of different configurations. The surface roughness or interruption aims at promoting surface turbulence that is intended mainly to increase the heat transfer coefficient rather than the surface area [7]. It was reported that non-flat surfaces have free convection coefficients that are 50% to 100% more than those of flat surfaces [8]. Several other researchers reported a similar trend for interrupted, perforated, and serrated surfaces, attributing the improvement to the restarting of the thermal boundary layer after each interruption, indicating that the increase in convection coefficient is even more than enough to offset lost area [7].

In 2007 A. M. &, the other [9]. Treats the natural convection heat transfer from perforated fins. The temperature distribution was examined for an array of rectangular fins (15 fins) with uniform cross-sectional area (100x270 mm) embedded with different vertical body perforations that extend through the fin thickness. The patterns of perforations include 18 circular perforations (holes). Experiments were carried out in an experimental facility that was specifically design and constructed for this purpose. The heat transfer rate and the coefficient of heat transfer increases with perforation diameter increased.

Abdullah H. AlEssa, Ayman M. Maqableh and Shatha Ammourah [10] were enhancement of natural convection heat transfer from a horizontal rectangular fin embedded with rectangular perforations of aspect ratio of two. The results of perforated fin compared with its equivalent solid one. An experimental study was carried out for geometrical dimensions of the fin and the perforations. The study investigated the gain in fin area and of heat transfer coefficients due to perforations. They concluded that, values of rectangular perforation dimension, the perforated fin enhances heat transfer. The magnitude of enhancement is proportional to the fin thickness and its thermal conductivity

M.R. Shaeri, M. Yaghoubi, K. Jafarpur [11] study the turbulent fluid flow and convection heat transfer around an array of rectangular solid with different number of perforation and different size. Experiments were conducted for the range of Reynolds no. from 2000 to 5000 based on fin thickness and pr= 0.71.

This Study is aimed mainly at examining the extent transfer enhancement from vertical rectangular fins under natural convection. Conditions as a result of introducing body modification (perforations) to the fin body. The modification in this work is circular, square, triangular, and hexagonal perforations made through the fin thickness. The study investigates the influence of perforations on heat transfer rate or heat dissipation rate of the perforated fin. The modified fins (perforated fins) are compared to the corresponding solid (Non perforated) fin in terms of heat transfer rate, also comparing will be between all fins.

MATHEMATICAL ANALYSIS OF FIN PERFORATED

Perforated fins can be used to increase the heat transfer coefficient and effective heat transfer area. The change in magnitude of the surface area depends on the geometry of the perforations (Abdullah and Mohammed, 2009)[12].

In this paper, the number of perforations (N_x) in the x- direction (L) and (N_y) in the y-direction (W) can be assumed. Also the dimensions of fin are known. The perforation cross sectional area (Ac) may be assumed, and then the dimension of any perforation can be calculated. The surface area of the uniform longitudinal rectangular perforated fin can be expressed as:

$$A_{fp} = A_{ps} + A_t + N_c A_{pc}$$

$$A_{fp} = (2W.L - 2N_c.A_c) + (W.t) + (N_c.A_c)$$

$$A_{fp} = A_f + N_C (A_{pc} - 2A_c) \ldots \ldots\ldots (1)$$

Equation (1) can be written as:

$$A_{fp} = A_f + N_x.N_y (A_{pc} - 2A_c) \ldots\ldots. (2)$$

In order to compare the heat transfer surface area of the perforated fin (A_{fp}) to that of the conventional one (A_f), the fin surface area ratio RAF is introduced and is given by:

$$RAF = \frac{A_{fp}}{A_f}$$

$$RAF = 1 + \frac{N_x \times N_y (A_{pc} - 2A_c)}{A_f} \ldots. (3)$$

The material volume of the perforated fin is compared with the volume of non- perforated fin by volume reduction ratio which given by:

$$RVF = \frac{V_{fp}}{V_f} = \frac{(L.W.t - N_x N_y A_c t)}{L.W.t}$$

$$RVF = 1 - \frac{N_x.N_y.A_c}{L.W} \quad \ldots\ldots. (4)$$

Similarly, perforated fin has less weight than that of equivalent non- perforated one. This aspect expressed by the fin weight reduction ratio RWF defined as follows:

$$RWF = \frac{W_{fp}}{W_f} = \frac{(W_f - N_x.N_y.A_c.t.\rho)}{W_f}$$

$$RWF = 1 - \frac{(N_x.N_y.A_c.t.\rho)}{L.W.t.\rho} = 1 - \frac{N_x.N_y.A_c}{L.W} \,..\, (5)$$

According to the perforation shape and dimension that can be cut out from the fin body, fin with the circular perforation pattern is studied. The number of perforation in a longitudinal direction (N_x), in the transverse direction (N_y), and the perforation diameter is (b). The directional perforations spacing S_x and S_y:

$$L = N_x.b + (N_x + 1) S_y$$

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$$S_x = \frac{L - N_x.b}{N_x + 1} \text{...... .... (6)}$$

$$W = N_y.b + (N_y + 1)S_y$$

$$S_y = \frac{W - N_y.b}{N_y + 1} \quad \text{... .... (7)}$$

The heat transfer surface area of the fin can be expressed as:

$$A_{fp} = A_f - 2N_c.A_c + N_c.A_p$$

$$A_{fp} = A_f + N_c(A_p - 2A_c) = A_f + \pi N_C.b\left(t - \frac{b}{2}\right) \quad \text{....... (8)}$$

The ratio RAF and RVF can be expressed as:

$$RAF = 1 + \frac{\pi.b.N_x.N_y\left(t - \frac{b}{2}\right)}{(2W.L + Wt)} \quad \text{.... (9)}$$

And

$$RVF = 1 - \frac{N_x.N_y \frac{\pi}{4} b^2}{LW} \quad \text{....... (10)}$$

ANALYSIS OF HEAT TRANSFER COEFFICIENT

An experimental correlation to estimate the convection heat transfer coefficient of the array of vertical oriented parallel flat plate given by (Simmons, 2002)[13]

$$Nu = \frac{h.B}{k} = \frac{Ra}{24}(1 - e^{\frac{-35}{Ra}})^{0.75} \text{...... (11)}$$

Where

B is the average space between adjacent fins.

$$Ra = \frac{\rho^2.g.\beta.C_p.B^4.\Delta T}{\mu.k.L} \quad \text{....... (12)}$$

Several studies (12, 13) reported that, the surface heat transfer coefficient of perforated surfaces is a function of open area ratio [ROA] of the perforated surface. The open area ratio defined as:

$$ROA = \frac{OA}{OA_{max}} \quad \text{......... .... (13)}$$

Where OA is the actual open area = $A_c.N_c$

$$OA = A_c.N_x.N_y \text{............(14)}$$

OA_{max} is the maximum possible perforations open area, which is defined as:

$$OA_{\max} = A_c.N_{c,\max} = A_c.N_{x,\max}.N_{y,\max} \ldots\ldots \text{ (15)}$$

Where $N_{x,\ max}$ and $N_{y,\ max}$, are the maximum possible number of the perforations. These numbers related with the perforation spacing equal zero. The perforated surface heat transfer coefficient ratio can be expressed as Kakaae [14]:

$$R_h = 1 + 0.75\frac{OA}{OA_{\max}} \ldots \ldots\ldots \text{ (16)}$$

The film heat transfer coefficient of the perforated surface (h_{ps}) is expressed as:

$$h_{ps} = (1 + 0.75\frac{OA}{OA_{\max}})h \ldots\ldots\ldots \text{ (17)}$$

EXPERIMENTAL WORK

The experiments were carried out in an experimental facility that was specifically designed and constructed for this purpose. Figure 1 shows draw of the Schematic drawing for the apparatus. The experimental setup includes a heat sink supplied with heating elements and data acquisition system. The heat is generated within the heat sink by means of one heating element power of 670 W. All the experimental data are recorded by the data acquisition system. The heat sink chosen for experiments is aluminum cylinder of 50.8 mm diameter and 270 mm length. One hole was drilled in the cylinder in which one heating element was pressed. The power supplied by the heating element was 670 W. Five aluminum straight fins were fitted radially Figure (2). The fins are 100 mm long, 270 mm wide and 2 mm thick. These fins were divided into five groups as Table 1.

Table 1. Fins used in research shown in following Figure (2).

Case	*Perforated Shape*	*Cross Section Area of Perforation (mm^2)*	*Number of Perforation in each fin*
1	Non-perforated	-	-
2	Circle	113	18 (3*6)
3	rectangle	113	18 (3*6)
4	triangle	113	18 (3*6)
5	Hexagonal	113	18 (3*6)

A variable transformer of type 50B with input 220 V and 50-60 Hz and output 0-240 V, 20 A and 7.5 kVA were used to regulate the voltage supplied to the heating elements (Figure 1). The experimental data measured by twenty seven calibrated thermocouples of type-K, to measure the temperature at different locations of fins..

One thermocouple fixed on the outside diameter of the aluminum cylinder in order to measure the base temperature of the fin. One thermocouple is used to measure air temperature. Twenty five of thermocouples were divided into five fins equally. Each thermocouple was fixed to the surface of the test fin at equal space (20 mm) locations along the fin length. The apparatus was allowed to run for about 60 minute, until the steady state was achieved. The recording of temperature was begun after steady state had been reached.

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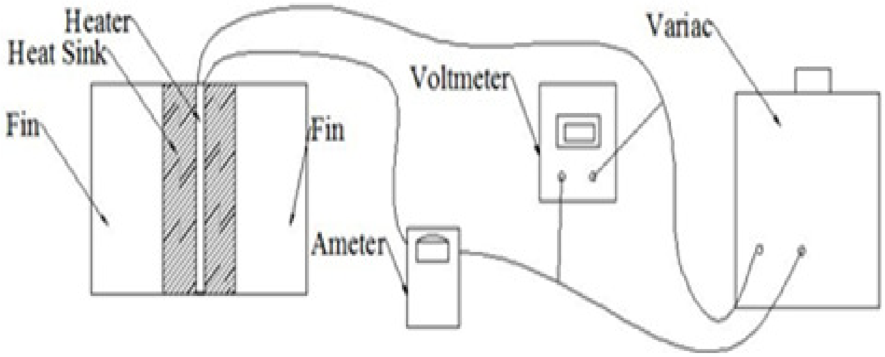

Figure 1. Schematic drawing for the apparatus and devices used

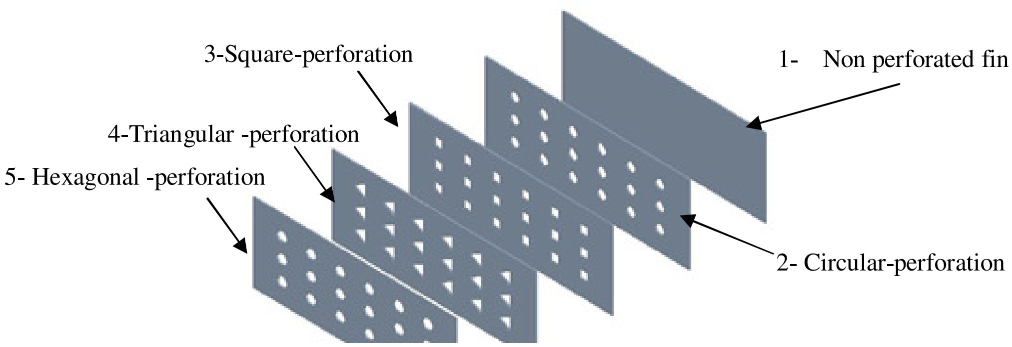

Figure 2. Fins used in apparatus

RESULTS AND DISCUSSION

In this experimental work was conduct to investigate the perforation shape geometry effect on the convection heat transfer from the fins by Natural Convection. Were the study will be compared between different shapes of perforations and then with non-perforated fin.

The temperature distribution along the fin is one of the factors that reflect the performance of the fins, which it can be used to compare between different fins. The results show that, the highest temperatures were along the non-perforated fin, and lower temperatures distribution along the perforation fins was along the perforation fin with triangular shape. Then the fin with a circular shape. These results are shown in Figure (3) for different values of the supplied power. Also, the difference between temperature in the base of fin and its tip regarded from the important factors in the perception of the work of the fin, which it can be used to compare this factor with other fins. and through the same graphics in Figure (3) can be say that, the highest drop of temperature between the fin's base and it is tip an event in the triangular fin holes. This happen because the triangle area destroyed the area of thermal boundary layer larger than the rest shapes because its width larger than rest shapes.

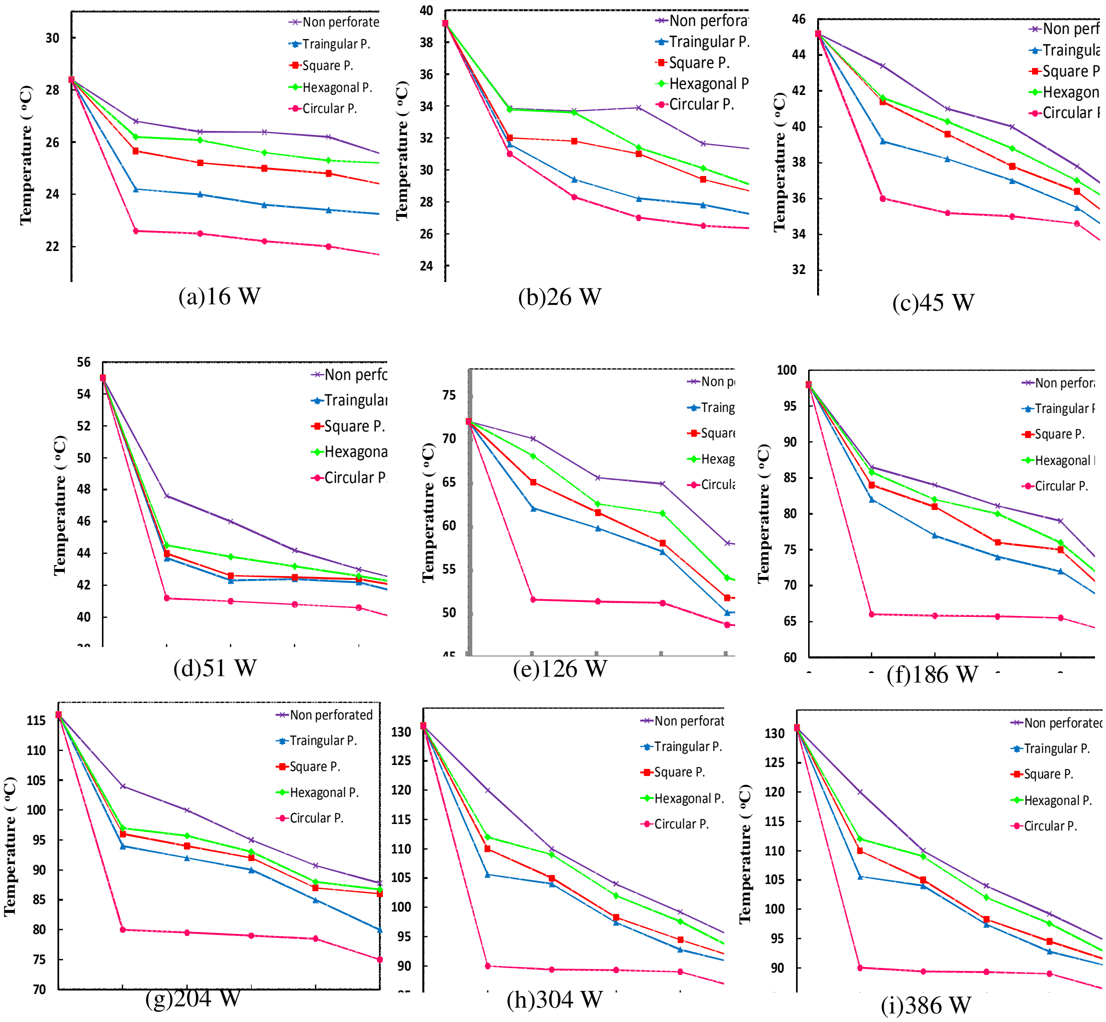

Figure 3. The Temperature Distribution along fins

Perforation shape, effects on the heat transfer surface area of the fins, which it one of the important factors on the fin's performance. Figure (4) shows the values of RAF with perforation shape. The results appear that the highest value of (RAF) at fin of triangular perforation while the lowest value of (RAF) at fin with circular perforations Despite the lack of difference between them.

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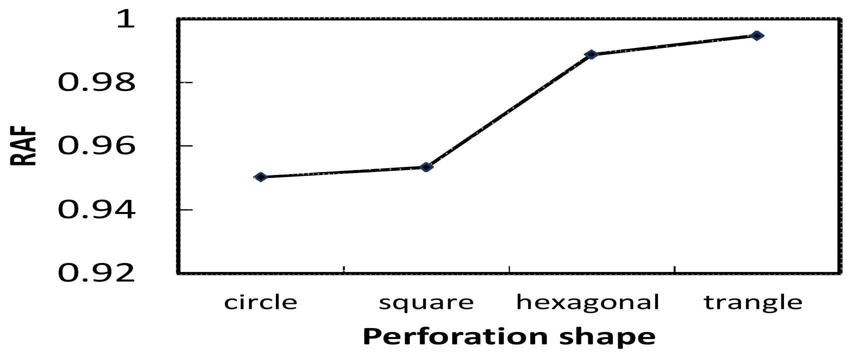

Figure 4. The Relation between RAF and Perforations shape

The values of (Rh) appears in figure (5) for each perforated fin, the results show that the maximum value of Rh at triangular perforated fins and the minimum at square perforated fins

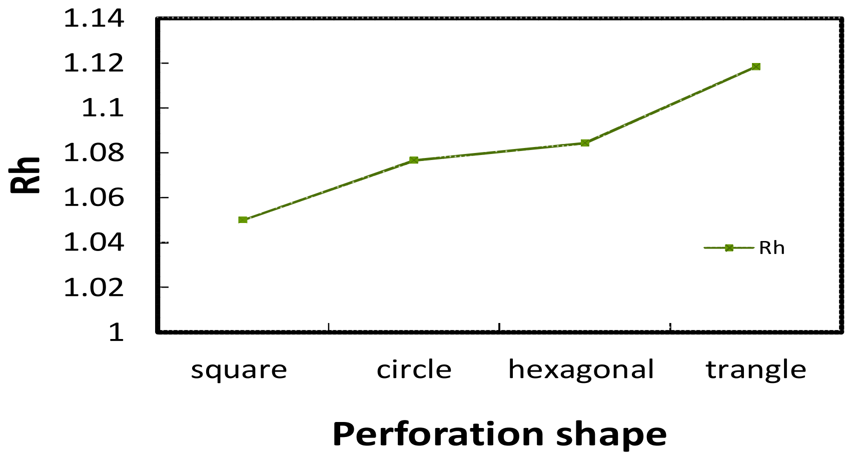

Figure 5. The Relation Between Rh and Perforations shape

The Heat Transfer Coefficient regarded one of the main factors on the performance of fins, which varies with the perforation shape. From figure, (6) the Heat Transfer Coefficient appears with different values of supplied energy, for each perforation shape, where the results show that the highest values of the heat transfer coefficients were in the fins with holes triangular shape and then circular. The lower values for the heat transfer coefficient were a non-perforated fin, and it shows in the results of the form (6).

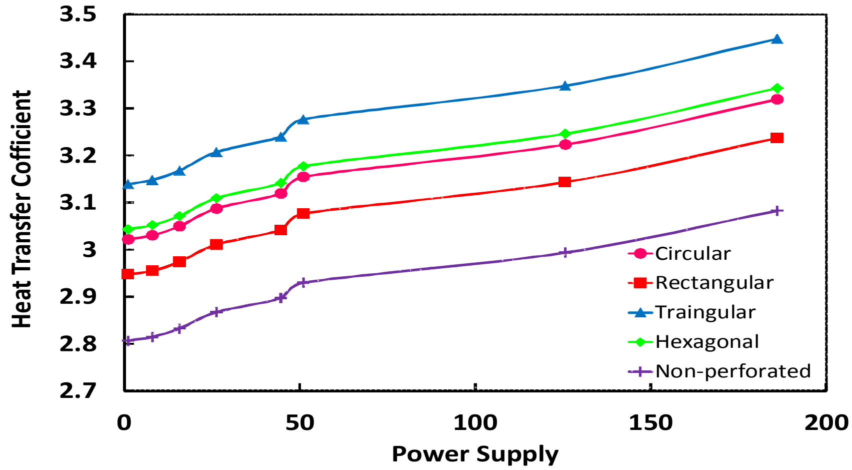

Figure 6. The Relation between Heat Transfer Coefficient and Power Supplied

CONCLUSION

The temperature drop along the perforated fins length is consistently higher than, that in the non-perforated fin. It contains a larger number of perforations higher than the perforated fin that contained a small number of perforations. The gain in heat dissipation rate for the perforated fin is a strong function of the perforation dimension and lateral spacing. Decreasing the perforation dimension reduces the rate of temperature drop along the perforated fin. Heat transfer coefficient for perforated fin that contained a larger number of perforations higher than the perforated fin that contained a small number of perforations.

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