CHAPTER 4

Heat Transfer Behavior of Flat Plate Having 45° Ellipsoidal Dimple Surface

4.1 Introduction

In this chapter, the thermal characteristic of air flow over flat plate having 45° ellipsoidal dimpled surface is studied. The effect of dimple arrangements, and dimple pitch will be included in this work. A total of 10 types of dimple surfaces are studied. The experiments are carried out with air stream flows over the heated surface with the ellipsoidal dimple similar to Chapter 3. The heat transfer coefficient of dimple surfaces is investigated and reported.

4.2 Experimental setup and procedure

This experiment is a further study from Chapter 3. The experimental setup for heat transfer measurements of air flow over the tested surfaces is described in Chapter 3.

Figure 4.1 and 4.2 present the geometric details of the tested surface, including dimpled geometry. Dimples were employed in an inline and staggered array and table 3.1 lists the details of the test samples.

During the experiment, the electrical power supply to heater, the tested surface temperature, the velocity and temperature of inlet air were measured. Then, the local and average heat transfer coefficients, Reynolds Number and Nusselt Number of air flowing over flat plat with dimpled surface can be obtained as explained in Chapter 3.

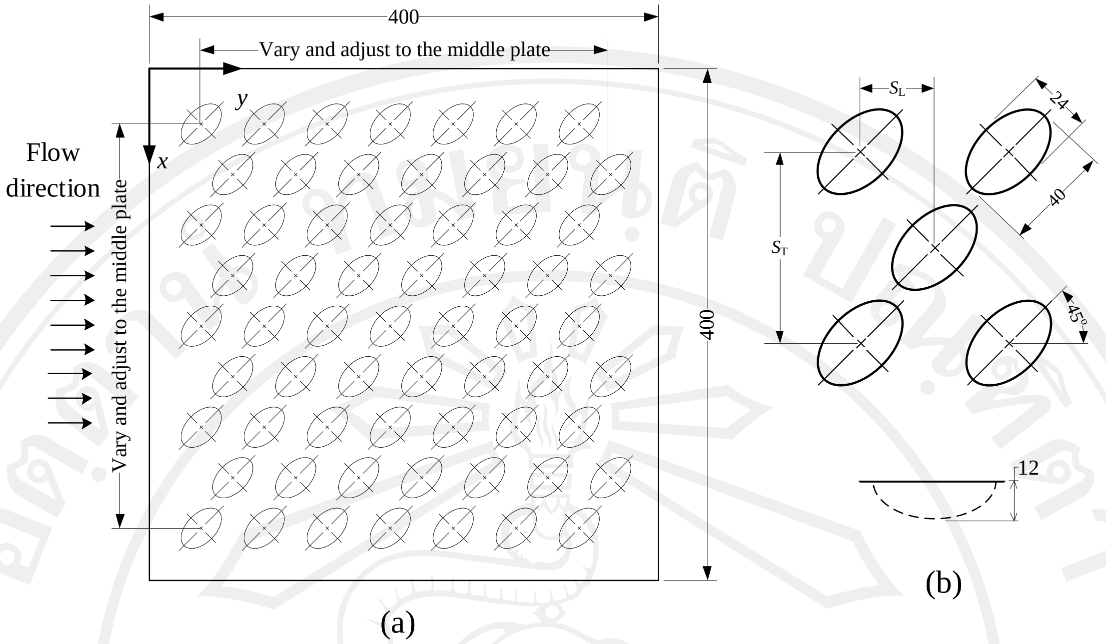

Figure 4.1 Details of: (a) dimpled-tested surface for staggered arrangement, and (b) individual dimple geometry. All dimensions are in mm.

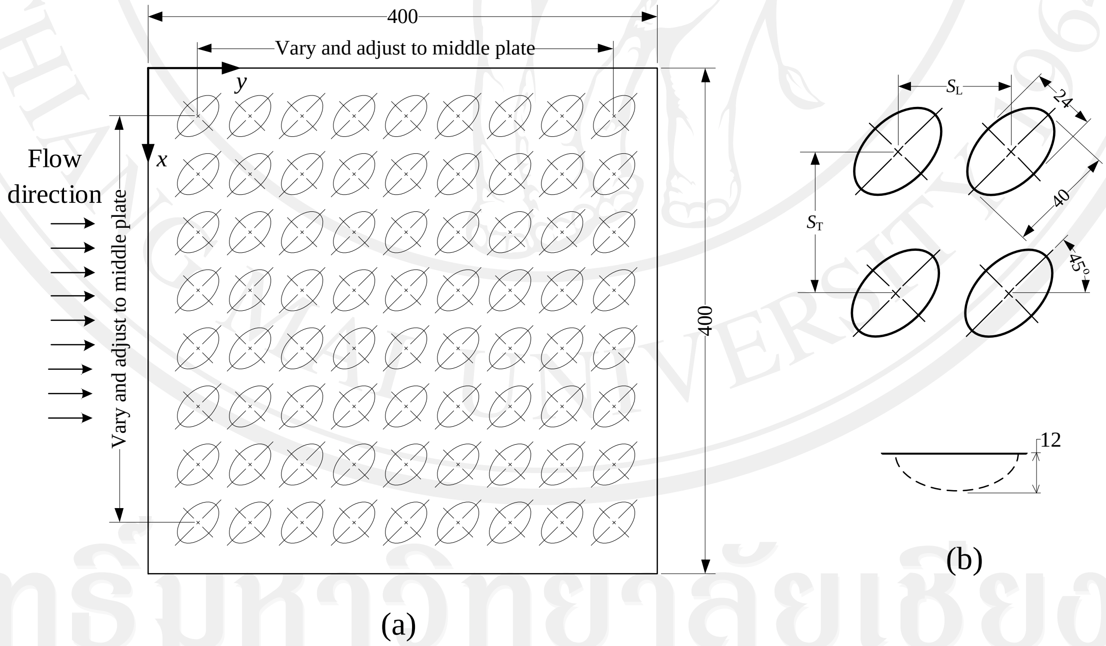

Figure 4.2 Details of: (a) dimpled-tested surface for inline arrangement, and (b) individual dimple geometry. All dimensions are in mm.

Table 4.1 Geometric dimensions of ellipsoidal dimple surface.

No	S_T (mm)	S_L (mm)	Arrangement	S_T/S_L
1	50	40	Staggered	1.25
2	50	45	Staggered	1.11
3	50	50	Staggered	1.00
4	60	45	Staggered	1.33
5	75	45	Staggered	1.67
6	40	40	Inline	1.00
7	40	45	Inline	1.89
8	40	50	Inline	0.80
9	45	45	Inline	1.00
10	50	45	Inline	1.11

4.3 Results and discussion

4.3.1 Case of staggered arrangement

There are five samples in the case of staggered arrangement as shown in Table 1. Geometries no. 1-3, S_T is constant and varies S_L. For Geometries no. 2, 4, and 5, S_L is constant and varies S_T. Figure 4.3 shows the temperature distribution along the dimple surface, which is captured by the infrared imaging camera of Geometry no.1. Flow direction for the Figure is from the left to right and frontal velocity is 2.9 m/s. As shown in the figure, the location of ellipsoidal dimples conforms to the ellipsoidal temperature contour. Whole area of plain surface is at lower temperature than dimple area. Higher temperature is located at the upstream halve and gradually increase along the downstream. The lowest temperature occurs in downstream rim of the dimples and obviously decreases along the downstream on plain surfaces.

Figure 4.4 shows the effect of S_T and S_L of the air side heat transfer performance. Results are termed as heat transfer coefficient vs. frontal velocity. As shown in the figure, for Geometries No.1-3, S_T kept constant, heat transfer characteristic is not varied in spite of the fact that S_L differs within 20%. This suggests that independence of heat convection characteristic to S_L. However, this may be because of the number of dimples is also decreased by 22%.

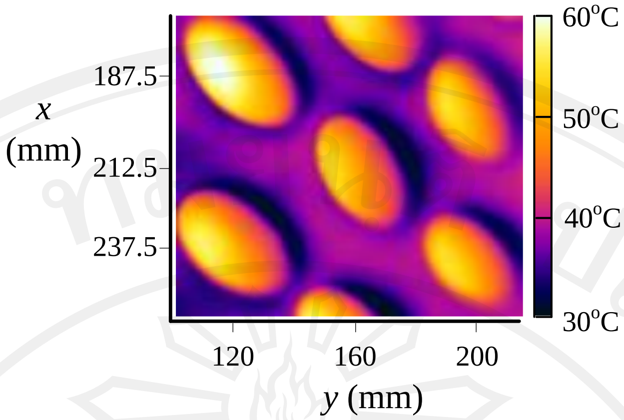

Figure 4.3 Temperature distributions of Geometry No.1 at frontal velocity = 2.9 m/s.

Similarly, for Geometries No.2, 4 and 5, as S_T varies by 30%, heat transfer characteristic does not change significantly, but it increases distinctively by 15.8% when S_T is 75 mm.

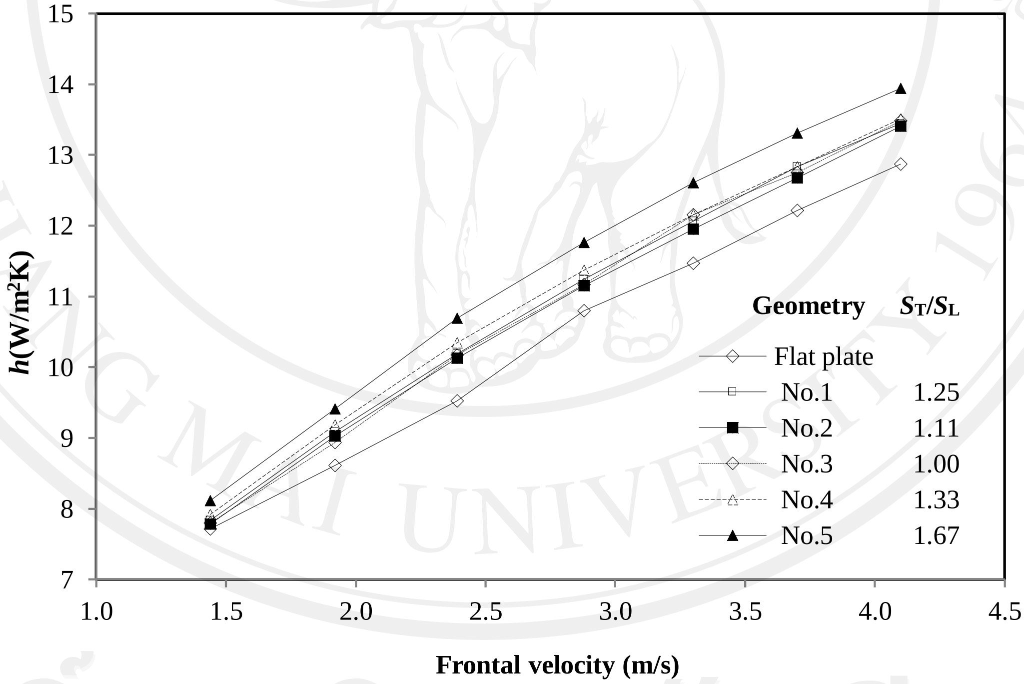

Figure 4.4 Effect of dimple arrangement on heat transfer coefficient for staggered arrangement.

Figure 4.5 shows the heat transfer coefficient of this study in comparison with that of spherical dimple surface of Chapter 3. The result shows that, for staggered arrangement, the spherical dimple surface significantly yields higher heat transfer coefficient than ellipsoidal dimple surface.

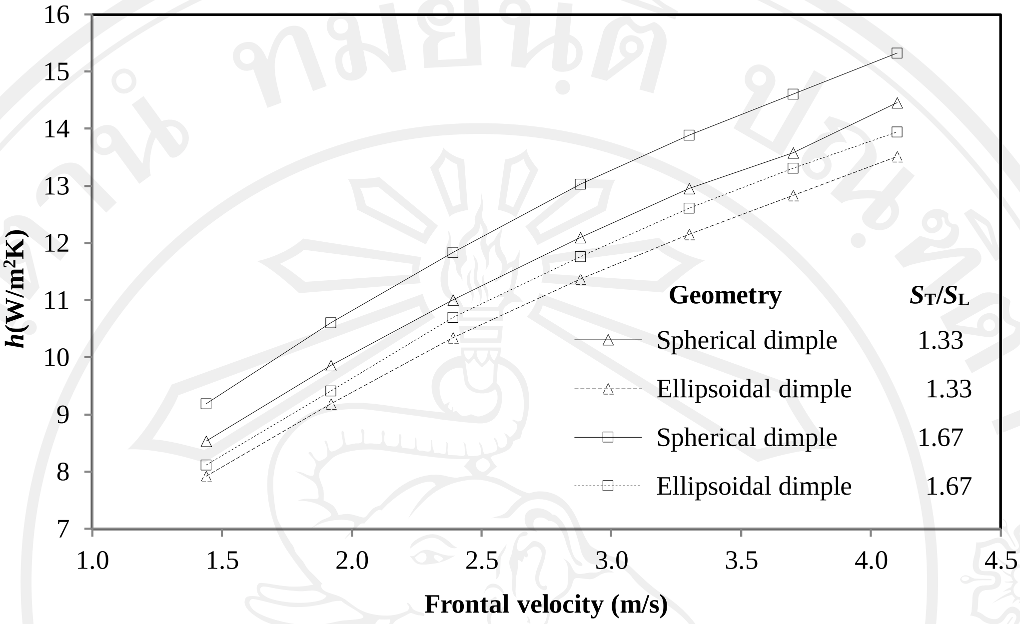

Figure 4.5 Comparison of heat transfer coefficient for staggered arrangement of spherical dimple surface and the ellipsoidal dimple surface.

4.3.2 Case of inline arrangement

In the case of inline arrangement, there are five categories shown in Table 1. For Geometries No. 6-8, S_T is constant and S_L is varied. While Geometry No. 7, 9, and 10, S_L is constant and S_T is varied. In Figure 4.6, the temperature distribution along the tested surface is shown, with an air flow direction from left to right. As the Figure, it shows that the temperature distribution inside and around the dimples is similar to staggered arrangement. The temperature distribution is higher in the upstream halves of the dimples and decrease progressively along the downstream of the dimples and then, it becomes lowest near the downstream edges.

Figure 4.7 shows the effect of dimple arrangement on heat transfer coefficient. Geometry No. 6 shows heat transfer coefficient lower flat plate because the temperature of the inner side of dimple is high, and too many dimples cause less heat transfer. As show in the Figure, as S_L increases heat transfer coefficient slightly increases. This is possibly due to the enhanced heat transfer area increases. Similarly, heat transfer coefficient increases while S_T increases from 40 mm to 45 mm because of the increasing of enhanced heat transfer area. However, heat transfer coefficient decreases while S_T increases beyond 45 mm but less than 50 mm. This finding is similar to staggered arrangement. From the Figure, The Geometry No.9 yields the highest heat transfer coefficient about 21.2% better than the flat plate and Geometric No.6 yields the lowest heat transfer coefficient.

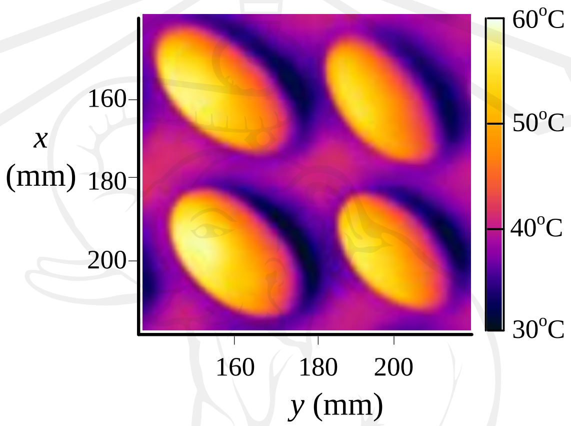

Figure 4.6 Temperature distributions of Geometry No.6 at frontal velocity = 4.1 m/s.

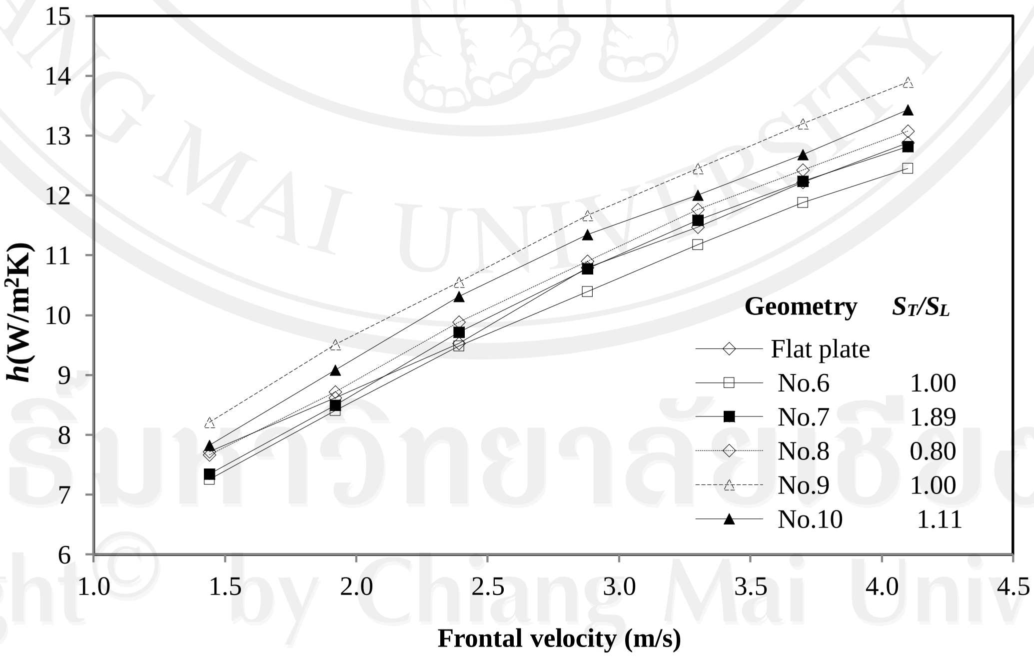

Figure 4.7 Effect of dimple arrangement on heat transfer coefficient for inline arrangement.

Figure 4.8 shows the comparison of the heat transfer coefficient of the ellipsoidal dimple surface of this study to those of spherical dimple surface [9]. The result shows that, for inline arrangement, the spherical dimple surface yields lower heat transfer coefficient than those of ellipsoidal dimple surface significantly.

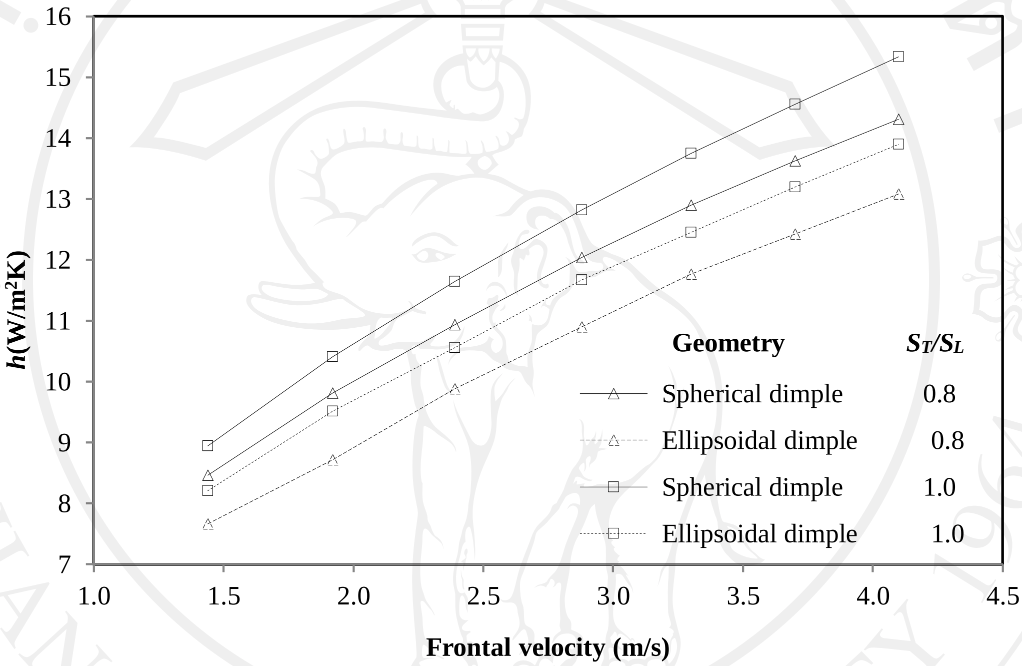

Figure 4.8 Comparison of heat transfer coefficient for staggered arrangement of spherical dimple surface and the ellipsoidal dimple surface.

4.3.3 Empirical Correlation

Based on the previous results, the test data of inline and staggered arrangements yield the complex behavior. The corresponding correlations are reported separately by inline and staggered configuration. The multiple linear regression technique is performed to obtain the relevant correlations. The corresponding correlations are obtained as follows:

Correlation of the Nusselt numbers for the staggered arrangement:

$$\frac{\mathrm{Nu}}{\mathrm{Nu}_0} = 1.1067\left(\frac{S_T}{S_L}\right)^{0.0992} \tag{4.1}$$

Correlation of the Nusselt numbers for the inline arrangement:

$$\frac{\mathrm{Nu}}{\mathrm{Nu}_0} = 0.904\left(\frac{S_L}{S_T}\right)^{0.0944}\left(\frac{S_\mathrm{T}}{D}\right)^{0.3995} \tag{4.2}$$

The comparison of the experimental results with the proposed correlations is showed in Figure 4.9. The aforementioned can predict 97% and 95% of the experimental data, with ±5%. The standard deviation of the correlations Eqs. (4.1) and (4.2) are 1.3% and 2.54% respectively.

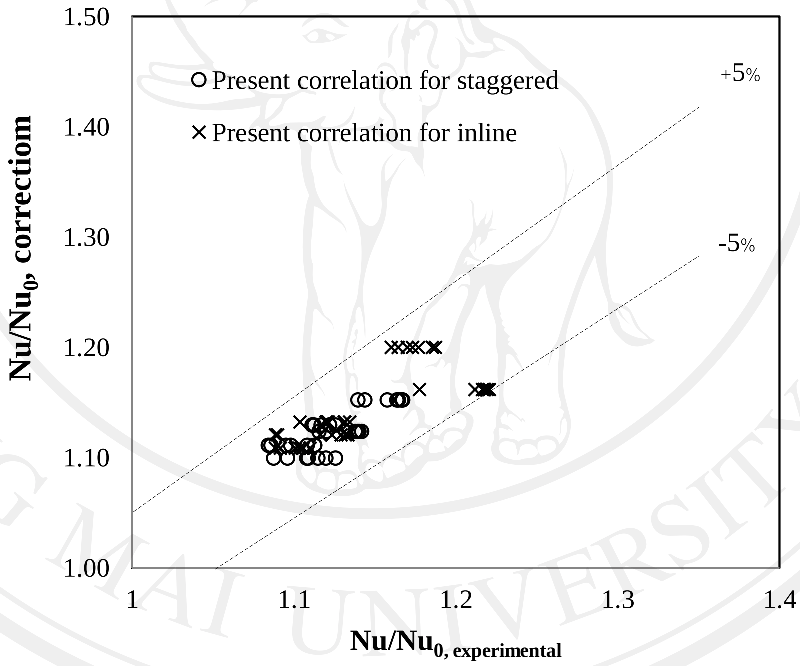

Figure 4.9 Comparison of heat transfer correlations with experimental data.

4.4 Summary and conclusion

The present work reports the heat transfer performance of external air flow over the ellipsoidal dimple surface. The dimples arrangement and dimple interval are examined. Based on the previous result and discussions, the conclusions are obtained:

1) The air side heat transfer performance is augmented approximately 10-22% at all Reynolds Numbers and all dimple arrangements.

2) For staggered arrangements, the dimples pitch of S_L/D_{minor} = 1.875 and S_T/D_{minor} = 3.125 yields the optimum heat transfer coefficient value about 15.8% better than flat plate.

3) For inline arrangements, the dimples pitch of S_L/D_{minor} = 1.875 and S_T/D_{minor} = 1.875 yields the optimum heat transfer coefficient value about 21.2% better than flat plate.

4) Correlations of the present experiment in both staggered and inline arrangement are obtained and the proposed correlations yield fairly good predictive ability against the present test data.