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Flow and Heat Transfer in Turbulent Channel Flow over Asymmetric Dimples

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Dimpled surfaces has attracted many attentions due to its advantages over other heat transfer enhancing methods it is easy to manufacture, and can potentially yield heat transfer increment with less pressure loss penalty (Chen et al, 2014; Chen et al. 2013; Chen et al. 2012). The superior thermal performance of dimples is attributed to the strong ejections and secondary rotating motions near the downstream side of dimple (Ligrani et al., 2001; Isaev et al.,2010; Turnow et al., 2011).

Though deeper dimple (depth ratio between depth h and diameter D, h/D > 30%) enjoys an advantage in having high heat transfer rate, it suffers greater pressure loss, thereby restricting their applications. In light of this, to get a higher effective heat transfer efficiency, researchers are looking for new means to enhance the thermal performance of (symmetric/spherical) dimple rather than only increasing its depth ratio, such as teardrop shaped dimples (Chyu et al., 1997); dimples with streamwise ridge (Doo et al.,2010) and oval shaped dimples (Isaev et al., 2003). Asymmetric dimples, capable of both increasing heat transfer rate and suppressing pressure loss, are potentially more effective than symmetric ones in heat exchanger. However, these modified dimples may encounter difficulties in manufacturing (Chyu et al., 1997; Doo et al., 2010) or the drawback of smaller coverage area of dimple surface (Isaev et al., 2003).

The motivation of the current study is to investigate the asymmetric dimple created by skewing the deepest point, thus keeping the shape of dimple's rim as circular, so that the coverage area of dimpled surface remains unchanged. Additionally, multiple dimples instead of a single dimple (Isaev et al., 2003) are arranged in the channel to investigate the interactions between them. The friction factor, Nusselt number, area and volume goodness factors (Shah and London, 1978) of the newly designed asymmetric dimples were numerically investigated in turbulent flow between two opposite plates with dimples. The numerical simulation is conducted at the Reynolds number Re2H (based on bulk velocity and full channel height) ranging from 4,000 to 6,000 and Prandtl number Pr of 0.7. The effects of different depth ratio, skewness and skewing directions are also evaluated.

It is found that skewing the deepest point of shallow dimples (h/D < 20%) in the downstream direction provides a more efficient way to enhance heat transfer efficiency than only increasing its depth ratio (h/D ≥ 20%). Quantitatively, downstream skewness increases the Nusselt number by 23% with only 8% increase in drag compared to the symmetric dimple at h/D = 15%. Thus, both the area goodness factor and volume goodness factor have been significantly increased. In contrast, skewing the deepest point of the dimple upstream evidently reduces the drag, but heat transfer decreases more because of a larger region of recirculation. As such, it leads to a reduction of the area goodness factor or volume goodness factor for such asymmetric dimple.

Furthermore, the flow field structures show that the skewing of the deepest point of dimple downstream produces stronger ejection around the downstream rim of dimple, resulting in further enhancement of the Nusselt number. On the other hand, it is also demonstrated that by skewing the dimple's deepest point downstream, the recirculation region in the upstream portion of dimple is suppressed. As is known, recirculation decreases heat transfer, thus reducing the recirculation region leads to increased heat transfer rate.

In summary, the asymmetric dimple with center skewed downstream makes for a more competitive heat exchange surface than symmetric dimple keeping to the same h/D and circular shape print diameter. The better performance of the asymmetric dimple is broadly attributed to its stronger flow ejection and weaker recirculation zone. Still, more work is required to further optimize other parameters of the asymmetric dimple, such as channel height, spacing of dimples, print diameter and rounded edge radius. Besides, future experimental investigations on non-symmetric dimple may be helpful to validate and support the findings herein.

References

[1] Y. Chen, Y. T.Chew, B. C. Khoo, "Heat transfer and flow structure on periodically dimple-protrusion patterned walls in turbulent channel flow," *International Journal of Heat and Mass Transfer*, vol. 78, pp. 871-882, 2014.

[2] Y. Chen, Y. T. Chew, B. C. Khoo, "Heat transfer and flow structure in turbulent channel flow over protrusions," *International Journal of Heat and Mass Transfer*, vol. 66, pp. 177-191, 2013.

[3] Y. Chen, Y. T. Chew, B. C. Khoo, "Enhancement of heat transfer in turbulent channel flow over dimpled surface," *International Journal of Heat and Mass Transfer*, vol. 55, no. 25-26, pp. 8100-8121, 2012.

[4] M. Chyu, Y. Yu, H. Ding, J. Downs, F. Soechting, "Concavity enhanced heat transfer in an internal cooling passage," In: *ASME*, Paper No. 97-GT-437, 1997.

[5] J. Doo, H. Yoon, M. Ha, "Study on improvement of compactness of a plate heat exchanger using a newly designed primary surface," *International Journal of Heat and Mass Transfer*, vol. 53, no. 25-26, pp. 5733–5746, 2010.

[6] S. Isaev, A. Leont'ev, A. Mityakov, I. Pyshnyi, A. Usachov, "Intensification of tornado turbulent heat exchange in asymmetric holes on a plane wall," *Journal of Engineering Physics and Thermophysics* vol. 76, no. 2, pp. 266–270, 2003.

[7] S. Isaev, N. Kornev, A. Leontiev, E. Hassel, "Influence of the reynolds number and the spherical dimple depth on turbulent heat transfer and hydraulic loss in a narrow channel," *International Journal of Heat and Mass Transfer*, vol. 53, no. 1, pp. 178–197, 2010.

[8] P. Ligrani, J. Harrison, G. Mahmmod, M. Hill, "Flow structure due to dimple depressions on a channel surface," *Physics of fluids*, vol. 13, pp. 3442–3451, 2001.

[9] R. Shah, A. London, "Laminar flow forced convection in ducts: a source book for compact heat exchanger analytical data" *Academic Press*, New York, NY, 1978.

[10] J. Turnow, N. Kornev, S. E. H. Isaev, "Vortex mechanism of heat transfer enhancement in a channel with spherical and oval dimples," *Heat Mass Transfer*, vol.47, pp. 301–311, 2011.