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Analysis Of Heat Transfer Enhancement In Dimple Tubes

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Abstract: Enhancing heat transfer efficiency is essential for optimizing thermal systems used in heat exchangers, refrigeration units, and power plants. Traditional smooth tubes often exhibit limited heat transfer due to the formation of a stable thermal boundary layer, reducing overall performance. This project investigates the design and analysis of dimpled tubes as a passive heat transfer enhancement technique. Dimples introduce localized turbulence, disrupt the boundary layer, and promote secondary flow structures, leading to improved thermal performance with minimal pressure drop penalties.The study involves both experimental and computational fluid dynamics (CFD) analysis to evaluate the effects of dimple geometry, depth, spacing, and arrangement on heat transfer characteristics and flow resistance. Key performance parameters, such as Nusselt number, friction factor, and thermal enhancement factor, are analyzed to determine the optimal dimple configuration. The results of this study aim to provide insights into the effective design of dimpled tubes, balancing heat transfer enhancement with pressure drop considerations. The findings will contribute to the development of more efficient thermal systems, reducing energy consumption and improving industrial heat exchange applications.

Keywords---Heat transfer, thermal systems, Traditional smooth tubes, design and analysis of dimpled tubes, computational fluid dynamics (CFD) analysis, enhancement , dimple configuration, heat exchange applications.

I. INTRODUCTION

In modern thermal engineering, efficient heat transfer is crucial for the performance and energy efficiency of systems such as heat exchangers, air conditioning units, radiators, and power plants. With growing energy demands and environmental concerns, enhancing heat transfer without significantly increasing pressure drop or energy consumption has become a vital design goal. One of the promising techniques for improving thermal performance is the use of surface modifications—particularly, tubes with dimples.

Dimples, or concave indentations on the surface of a tube, disrupt the boundary layer and promote localized turbulence in the flow. This disturbance enhances convective heat transfer by improving mixing of fluid near the surface, leading to a higher heat transfer coefficient. Unlike traditional enhancement techniques that often lead to large pressure drops, dimpled surfaces offer a more balanced approach, combining heat transfer enhancement with relatively moderate flow resistance.

II. LITERATURE REVIEW

[1] The study identified a configuration with a dimple ring diameter of 3 mm, a spacing of 10 mm, and 3 dimples as the best setup for the given conditions. The results from computer simulations (numerical) closely matched the experimental data. The largest discrepancies were observed in Nusselt number (heat transfer) and friction factor (pressure drop), with errors around 6.7 % and 9.4 %, respectively.

[2] Dimples can change the cross-section temperature distribution. The core temperature gradient at the dimple section is evidently greater than that at the smooth section, while the differences at the dimple section (T s-T min smooth section (T s-T min) smooth . Through this phenomenon, the equation (h = q/(T s-T m) dimpled are less than the ones at)) is presented to clarify that dimples over the surface can improve heat transfer efficiency. Dimples can change the original flow condition of the inflow, with vortexes in the upstream and downstream of the dimple as well as second flows in the downstream. Thus, they enhance heat transfer by destroying the boundary layer, yet lead to a greater f low resistance and a higher pressure drop.

[3] Heat transfer coefficient increased with Reynolds number. Heat transfer enhancement was found to be in excess of 200% as compared to an equivalent smooth tube. Pressure drop enhancement ratio increased with Reynolds number in 500 Re < < 2000 1.8 in Re>2000 region. region while remained constant at Heat transfer enhancement was higher than pressure drop en hancement at any given operating condition, therefore resulting in higher PEC. The best performance (PEC = 1.55) was obtained at Reynolds number 3500–4500 for water. Glycol/water solution showed higher PEC in the Reynolds number range 150–2000. Numerical simulations adequately predicted the experimental data within ±15%. Theenhancedtubeisacombination of random sand grain rough ness and dimples. However, the dimples are found to have a dominant effect on performance enhancement.

[4] Heat transfer improves by approximately 16 % as the tape pitch decreases, driven by more intense fluid spiraling due to the higher number of tape turns. While pressure loss reduces with increasing tape pitch, PEC improves due to the diminished pressure loss. Equipping dimpled tubes with twisted tape is an effective method for further enhancing heat transfer. The Dimple Utility Indicator (DUI) is introduced, defined as the number of dimples through which fluid passes per unit time. DUI increases with greater tape height and smaller tape pitch, reflecting more intense fluid-wall interaction and disturbance near dimples, which enhances heat transfer. The DUI concept is valuable for optimizing structural design and analyzing heat transfer performance.

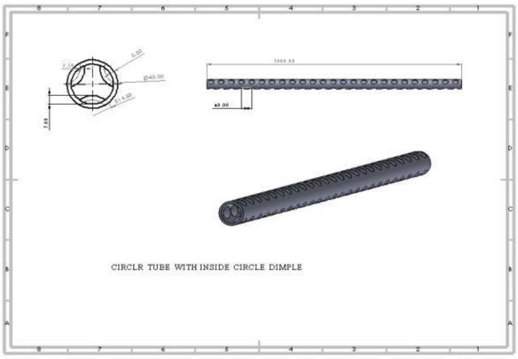
[5] An experimental investigation for both ellipsoidal dimpled tube and spherical dimpled tube was carried out. Dimpled tubes present a better performance than the smooth tube. Results for each tube were reduced and correlated to Rey nolds numberintheformof Nua =Nua(Re).The Nusselt number show to increase by 38.6–175.1% for the ellipsoidal dimpled tube and 34.1–158% for the spherical dimpled tube. Compared with the smooth tube, the friction factors of dim pled tube increased by 26.9–75% and 32.9–92% for the ellip soidal and spherical dimpled tubes, respectively. The friction factor of the two dimpled tubes were reduced and a correla tion in the form fa = fa(Re). The dimpled tubes with different geometry studied in the current work have been characterized. Correlations obtained for pressure drop and heat transfer can be directly employed for design purposes.

III. METHODOLOGY

A. Design Approach

Different dimple configurations (circular, elliptical) were tested with varying depths and spacing. Tube materials such as aluminum and copper were selected based on thermal properties.Develop initial design concepts by evaluating the effect of dimples on fluid flow and heat transfer.Generate multiple design configurations with variations in dimple shape, size, and spacing.Select the most promising concepts for further analysis.

FIGURE : DIMENSION OF CIRCLE AND ELLIPTICAL TUBES WITH DIMPLES

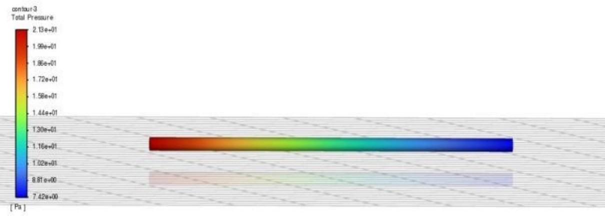


a) Circle Tube With Dimple

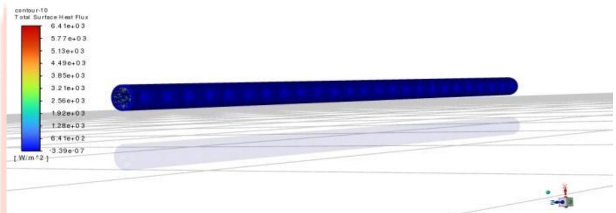
b) Circle Tube With Dimples

B. CFD Analysis

FIGURE : CFD ANALYSIS RESULT OF TUBES



a) Plain tube result



b) Circle tube with dimple

IV. RESULTS AND DISCUSSION

A. Heat Transfer Enhancement

CFD results indicate that tubes with internal elliptical dimples showed up to a 35% increase in Nusselt number compared to smooth tubes. Staggered dimple patterns yielded better results due to increased turbulence.

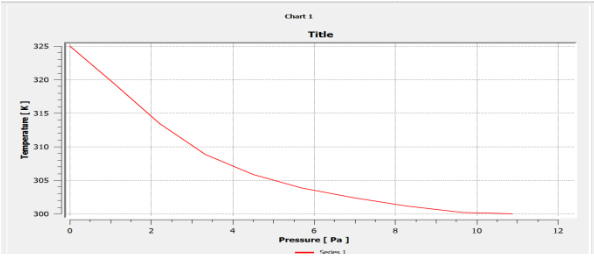
B. Pressure Drop

Though dimpled tubes introduced moderate increases in pressure drop (up to 52%), the Thermal Performance Factor (TPF) remained above 1.2 for optimal designs, indicating improved efficiency.

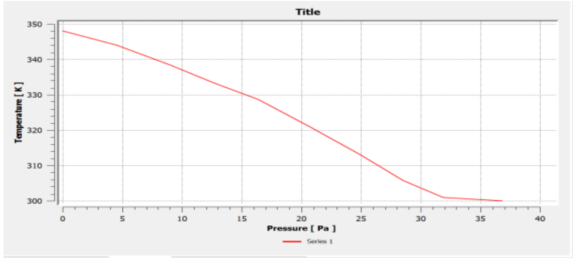
C. Parametric Study

- Optimal dimple depth-to-diameter ratio: ~0.1
- Optimal pitch-to-diameter ratio: 1.5–2
- Best performance: Inside elliptical dimples with staggered arrangement

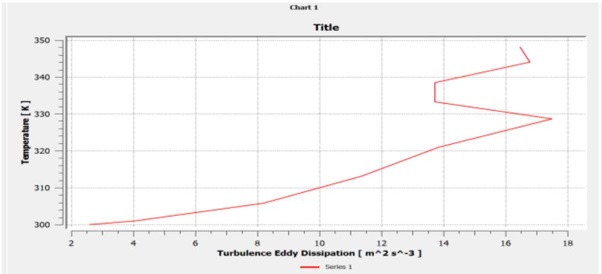
FIGURE : RESULTS GRAPH



a) Plain Circle Tube



b) Circle Tube With Circle Dimple



c) Circle Tube With Circle Dimple

V. CONCLUSION

The implementation of dimpled tubes presents a significant improvement in the thermal performance of conventional heat transfer systems. Through computational and/or experimental analysis, it is evident that dimples enhance heat transfer by promoting turbulence and disrupting thermal boundary layers, without causing a proportionate increase in pressure drop. This makes dimpled tubes a highly effective and energy-efficient solution for modern thermal systems. Future developments can focus on optimizing dimple geometry, spacing, and orientation to achieve even better performance for specific industrial applications.

The study confirms that dimples can enhance heat transfer significantly with manageable increases in pressure drop. Internal elliptical dimples, especially with staggered arrangements, offer a favorable trade-off between thermal performance and flow resistance. Dimpled tubes are promising for compact, efficient heat exchangers in various industries.

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