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PERFORMANCE ENHANCEMENT OF TUBULAR HEAT EXCHANGERS USING SURFACE-PROFILING INTENSIFICATION TECHNIQUES

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Abstract: This study investigates passive heat transfer enhancement techniques for tubular heat exchangers involving surface profiling methods such as knurled annular protrusions and spherical dimples. These geometric modifications promote boundary-layer disruption and intensified convective heat transfer while maintaining acceptable hydraulic resistance. Industrial implementations-including Ecoflux, Dimpleflo, and spiral-knurled tube systems-demonstrate significant improvements in thermohydraulic performance, providing up to a 300% increase in heat transfer, a 5-26% reduction in pump energy consumption, and a 30-61% reduction in material usage. The findings confirm that surface-profiling designs offer a highly effective and economically viable approach for modernizing heat exchange equipment in various industrial sectors.

Keywords: tubular heat exchanger, heat transfer enhancement, knurled tube, spherical dimples, thermohydraulic performance, passive intensification, surface profiling.

Introduction. Heat exchangers are among the most energy-intensive components in thermal engineering systems, widely used in power generation, chemical processing, oil refining, food production, and HVAC applications. Improving their thermal performance directly contributes to reductions in fuel and electricity consumption, operating costs, and environmental emissions. In many industrial processes, the growing demand for energy efficiency, compactness, and operational sustainability requires the development and implementation of advanced heat transfer intensification techniques. Therefore, studying the impact of tube surface modifications-such as knurling and spherical dimple profiling-on thermohydraulic characteristics is of significant scientific and practical importance. Tubular heat exchangers account for approximately 80-90% of heat transfer equipment used in modern industrial systems due to their wide operating range, structural simplicity, and reliability. However, conventional smooth-tube designs often exhibit limited heat transfer capability, resulting in oversized installations, excessive pumping power, and increased material consumption. To overcome these shortcomings, various passive heat transfer enhancement strategies have been developed. Among them, tube surface profiling-such as the creation of periodic annular protrusions or spherical dimples-offers substantial improvement in heat transfer without requiring complex modifications to heat exchanger assemblies. The present study focuses on the analysis of such intensification techniques and their potential contribution to maximizing the efficiency of tubular heat exchangers.

Literature Review. Research into heat transfer intensification has progressed considerably over the past decades [1]. Kalinin et al. [2] proposed knurled tubes with annular protrusions that induce turbulence in the near-wall boundary layer, resulting in higher convective heat transfer rates while preserving compatibility with existing tube bundle geometries. Industrial adaptation of this technology can be observed in the profiled Ecoflux heat exchangers by HRS Group (Spain), designed for use in energy and process industries [3]. For food and pharmaceutical sectors, Thermaline Inc. (USA) developed spiral-knurled tube heat exchangers employing high-grade stainless steels such as 304, 316, and AL6-XN [3]. Analytical results demonstrate that such discontinuous internal roughness can reduce the electrical energy consumption of thermal systems by 5-26% while simultaneously lowering tube material usage by 30–61%, depending on the Reynolds number [4]. More recent studies have investigated spherical-dimpled surfaces due to their favorable balance between heat transfer enhancement and hydraulic resistance. Dimpled tubes can achieve a 1.5-4.5-fold increase in heat transfer with only moderate pressure losses [3]. These designs have been successfully commercialized in the Dimpleflo series by Teralba Industries (Australia) and tube-in-tube heat exchangers by JBT FoodTech (USA). Their manufacturability and cost-effectiveness make spherical dimple profiling one of the most promising passive enhancement techniques available today.

Materials and methods. To further enhance the performance of tubular heat exchangers, it is necessary to employ heat transfer intensification techniques that provide both thermal and hydrodynamic efficiency. One effective approach involves forming circumferential or helical grooves on the tube's outer surface through a knurling process (Fig. 1). As a result of groove formation, small, smoothly contoured protrusions are simultaneously generated on the inner tube surface, which promote augmented convective heat transfer within the flow passage [3]. For this purpose, researchers from the Moscow Aviation Institute-E.K. Kalinin, G.A. Dreitser, Ye.V. Dubrovsky, S.A. Yarkho, and G.I. Voronin-developed periodically arranged annular protrusions specifically designed to intensify heat transfer in tubular heat exchangers [2]. The principle of this method is as follows: a series of annular grooves are produced on the external tube surface by knurling (Fig. 1), while corresponding smoothly shaped annular diaphragms form on the internal surface. These annular elements induce turbulence within the viscous laminar boundary layer, thereby significantly enhancing heat transfer on both the inner and outer sides of the tube. Additionally, this modification does not increase the overall diameter of the tube bundle and does not require changes in the existing manufacturing and assembly technology of heat exchangers.

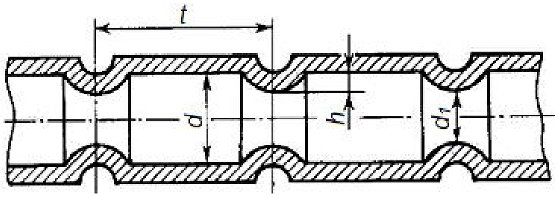

Fig. 1. Knurled tube with transverse annular grooves:

t-groove pitch; h-height of protrusion; d-inner diameter of tube; d_1-minimum tube diameter in the protrusion zone.

HRS Group (Spain) operates multiple subsidiaries in Germany, the United Kingdom, the United States, India, and the United Arab Emirates, and manufactures profiled-tube heat exchangers under the brand name Ecoflux (Fig. 2). This type of tube profiling significantly increases the heat transfer rate at low Reynolds numbers while maintaining minimal pressure losses. The enhancement effect is attributed to the earlier transition of gas and liquid flow from laminar to turbulent regimes within the channel. The profiled-tube heat exchangers produced by HRS Group (Spain) are designed for use as condensers, coolers, heaters, and evaporators in energy, food processing, petroleum refining, and chemical industries. Thermaline Inc. (USA) manufactures heat exchangers based on spiral-knurled tubes for applications in the food and pharmaceutical sectors (Fig. 3). The tubes are fabricated from stainless steels 316 and 304, as well as the AL6-XN high-alloy material.

Fig. 2. Configurations of profiled-tube heat exchangers manufactured by HRS Group (Spain).

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Fig. 3. Heat exchangers based on spiral-knurled tubes manufactured by Thermaline Inc. (USA).

Thus, the analysis of the thermohydraulic characteristics of discontinuously roughened channels allows the following conclusion: in the turbulent flow regime of heat-transfer fluids within tubes, transversal protrusion-type enhancement elements can reduce the electrical energy consumption of the thermal system by approximately 5-26%. Additionally, material savings during the manufacturing of tube bundles in heat exchangers may range from 30% to 61%, depending on the value of the Reynolds number [4]. In recent years, numerous studies have focused on heat transfer and friction behavior over surfaces containing spherical dimples. Their findings indicate that such dimples can substantially enhance heat transfer while causing only a moderate increase in hydraulic resistance. HRS Group (Spain) manufactures Ecoflux profiled-tube heat exchangers featuring spherical dimples on the external tube surface (Fig. 4) [3].

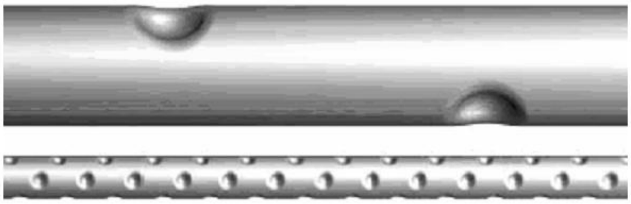

Fig. 4. Tubes with spherical dimples manufactured by HRS Group (Spain): large-dimple and small-dimple configurations.

Teralba Industries (Australia) manufactures Dimpleflo series shell-and-tube heat exchangers that incorporate profiled tubes with spherical dimples (Fig. 5). JBT FoodTech (USA) produces shell-and-tube heat exchangers and “tube-in-tube” type heat exchangers for the food industry (Fig. 6). The application of spherical-dimpled surfaces enables a 1.5-4.5-fold increase in heat transfer performance while causing only a moderate rise in hydraulic resistance. Currently, this technique is considered one of the most effective enhancement methods in terms of the balance between heat transfer improvement and pressure drop. The manufacturing process for creating dimples on smooth tube surfaces is relatively simple and does not significantly influence the overall cost of the heat exchanger.

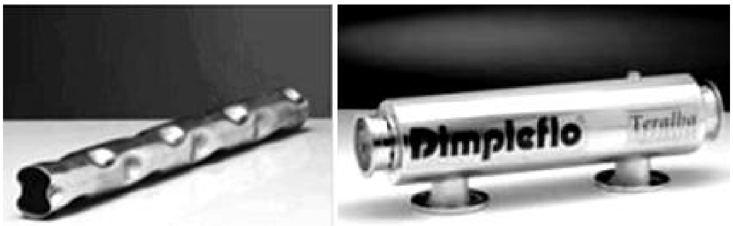

Fig. 5. Dimpleflo series shell-and-tube heat exchangers with spherical-dimpled profiled tubes manufactured by Teralba Industries (Australia).

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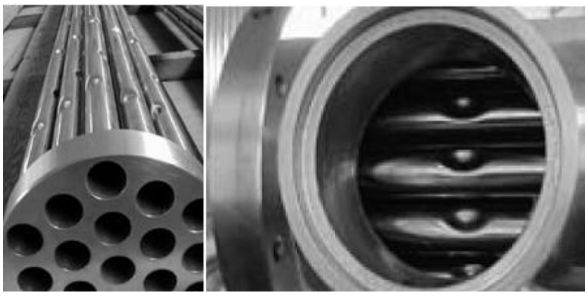

Fig. 6. Shell-and-tube heat exchangers with spherical-dimpled profiled tubes produced by JBT FoodTech (USA).

Discussion. The reviewed technical solutions confirm that tube surface geometry plays a decisive role in heat exchanger performance. Knurled annular protrusions effectively trigger earlier transition to turbulence at relatively low Reynolds numbers, making them suitable for laminar or mixed-flow conditions, especially when working fluids are viscous. Meanwhile, spherical dimples provide improved flow mixing and secondary circulation zones without introducing excessive friction penalties. The adoption of such technologies across multiple industries highlights their versatility and strong industrial viability. However, design optimization remains a critical task, including the determination of dimple size, pitch, depth, and layout relative to specific working fluids and flow regimes. Future thermal-hydraulic modeling supported by experimental validation will be required to establish standardized design rules and broaden the application of these technologies in compact and high-performance heat exchangers.

Conclusion. Surface-profiling intensification techniques-including knurled annular protrusions and spherical dimple structures-offer substantial benefits for the modernization of tubular heat exchangers. These modifications enable:

- up to 300% improvement in heat transfer for viscous flows,

- 5-26% reduction in energy consumption of pumping systems,

- 30-61% reduction in tube bundle material,

- 1.5-4.5 heat transfer enhancement with limited pressure drop penalty.

Furthermore, their manufacturing simplicity and compatibility with existing assembly technologies enhance their potential for widespread commercial deployment. Continued research focusing on geometric optimization and application-specific performance evaluation will support the development of more compact, cost-efficient, and environmentally sustainable heat exchange equipment in industrial systems.

References.

1. Ibragimov U.Kh., Mukhiddinov D.N., Uzakov G.N. Current State of the Problem of Heat Transfer Intensification in Industry (Review). Scientific and Technical Journal of FerPI, Fergana:

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FerPI, 2018 (Special Issue), pp. 81–86.

2. Kalinin E.K., Dreytsyer G.A., Kopp I.Z., Myakochin A.S. Effective Heat Transfer Surfaces. Moscow: Energoatomizdat, 1998. 408 p.

3. Popov I.A., Makhyanov Kh.M., Gureev V.M. Physical Fundamentals and Industrial Applications of Heat Transfer Intensification: Heat Transfer Intensification. Monograph. Edited by Yu.M. Gortyshov. Kazan: Center for Innovative Technologies, 2009. 560 p.

4. Gortyshov Yu.F., Olimpiev V.V., Popov I.A. Efficiency of industrially promising heat transfer intensifiers // Izvestiya RAS. Power Engineering. 2002. No. 3. P. 102.