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# OVERVIEW OF RESEARCH ON HEAT TRANSFER TECHNOLOGY FOR REINFORCEMENT OF SHELL AND TUBE HEAT EXCHANGER

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# ОБЗОР ИССЛЕДОВАНИЙ В ОБЛАСТИ ТЕХНОЛОГИИ ТЕПЛОПЕРЕДАЧИ ДЛЯ УКРЕПЛЕНИЯ КОЖУХОТРУБНОГО ТЕПЛООБМЕННИКА

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*Abstract.* The progress made in recent years in the field of reinforced heat transfer technology of shell and tube heat exchangers in China and abroad is reviewed. The energy-saving means and results of improving the heat transfer efficiency of shell and tube heat exchangers are introduced from the experimental research and numerical simulation respectively, and the future research of shell and tube heat exchangers to strengthen the heat transfer technology is also foreseen.

*Аннотация.* Рассмотрен прогресс за последние годы в области улучшения технологии теплопередачи кожухотрубных теплообменников в Китае и мире. Из экспериментальных исследований и численного моделирования соответственно вводятся энергсберегающие средства и результаты повышения эффективности теплопередачи кожухотрубных теплообменников, а также предусматриваются дальнейшие исследования кожухотрубных теплообменников с целью улучшения технологии теплопередачи.

*Keywords:* tube and shell heat exchanger, intensified heat transfer technology, experimental research, numerical simulation.

*Ключевые слова:* трубчатый и кожохотрубный теплообменник, интенсификация теплопередачи, экспериментальные исследование, численное моделирование.

Shell and tube heat exchanger due to it’s good environmental adaptability, pressure and high temperature resistance, reliable performance, high heat transfer efficiency in petroleum, chemical, power, electric power, metallurgy, refrigeration, heating and other fields play a pivotal role. Progress in industrialization needs to be based on energy, and the cost of energy consumption is environmental ecological damage. In order to protect the environment on which we depend, and to move away from our dependence on coal and petroleum-based energy sources, researchers in all countries are constantly looking for new energy alternatives to traditional energy sources, while researchers around the world are paying more attention to developing new energy-saving methods.

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Enhanced heat transfer development is a cutting-edge energy-saving application that not only uses energy more efficiently, but also saves on capital investment. Along with the common application of shell and tube heat exchanger, the research of strengthening heat transfer of shell and tube heat exchanger is getting more and more attention from scholars in various countries.

Domestic and foreign scholars have mainly used experimental studies and numerical simulations in their research on heat transfer by reinforced heat exchanger with tube and shell. Numerical simulation is the use of computer technology and a certain numerical solution to solve the mathematical model reflecting the object of the project, the use of image display methods to transmit the results of the calculation to the designer, thus facilitating the adjustment of the parameters in the mathematical model to achieve the purpose of matching the actual project. Numerical simulation can actually be understood as the use of a computer to conduct experiments, a common means of engineering design. Experimental research, on the other hand, is a method of collecting direct data.

The main objective of this paper is to analyze the existing tube and shell heat exchanger reinforced heat transfer technology in terms of both experimental research and numerical simulation and to predict its future development.

*1. Experimental progress on the enhanced heat transfer technology of shell and tube heat exchangers*

Due to the complexity of the fluid flow inside the heat exchanger shell side, the use of experimental methods is a practical means to study it. The experimental method is a traditional research method that is an important means of studying the properties of heat exchangers due to its realistic, direct and reliable advantages.

Experimental studies on the interior of the heat exchanger shell side were first conducted by O. P. Bergelin et al. [1–2] on the effect of the height and spacing of the folding plates on heat transfer and pressure drop. A large amount of experimental data was obtained and the effects of leakage and by-current on the heat exchanger performance were analyzed.

T. Tinker proposed the Tinker flow path method. He classifies the shell-side fluids as misfluid, side flow, leaky flow, etc. based on the characteristics of the shell-side fluid flow [3]. The F flow path was later added by J. W. Palen and J. Taborek, to form the now classical flow path analysis method [4]; In the 1960s, K. J. Bell proposed the Bell-Taihua flow path analysis method based on Tinker. This is actually a semi-analytical method, based on Tinker's assumption that the shell-side fluid all flows through the tube bundle in a misfluidic manner [5]. The leakage flow and bypass flow loss factors were then derived from the large number of experimental results obtained by introducing leakage flow and bypass flow through the experimental study of several small models. In 1957, R. K. Gupta and D. L. Katz used tracer spheres for the first time to roughly show the flow of the heat exchanger shell process fluid in a small heat exchanger model made of glass [6]; C. Berner used a square plexiglass shell as the heat exchanger's housing and no heat exchanger bundle was installed in the shell, the experimental method was to inject tracer fluid and aluminum tracer balls into the shell to demonstrate fluid flow through the folded flow plate baffle, and in the same year [7], P. Galindo made a cursory observation of the flow state in the heat exchanger bundle using oil lamp ink technique [8]; In his doctoral thesis experiment, P. W. Murray, who works for the Institute of Heat Transfer in the United States, proposed the use of liquid stains as a tracer for experiments to study the flow of fluid through the heat exchanger bundles in shell and tube heat exchangers [9]; L. E. Hasler proposed the use of nerve density particle technique and sensing pressure tube to measure the variation of fork flow velocity and pressure drop between the bundles of bowed fold plate heat exchanger tubes to provide a basis for a better computational model [10].

T. Pekdemir, T. W. Dives et al. conducted an experimental study on shell process flow and pressure loss in a plexiglass heat exchanger model and found that the flow resistance changed dramatically with the Reynolds number, the increase in the number of straight folded flow plates was equivalent to the increase in the Reynolds number, and the pressure at the center was higher than the pressure near the shell [11]; P. Stehlik et al. analyzed the respective advantages and disadvantages of straight-folded and spiral plates as a basis [12], and D. Kral et al. studied the performance of spiral plate heat exchangers of different structural forms by experimental methods and discussed their prospects for industrial applications [13].

In China, Xiaoqiong Yang, Qijie Wang et al found six flow patterns of shell-side heat exchanger flow by conducting experimental studies on F-type heat exchangers used in the petroleum industry, and fitted the pressure drop of shell-side two-phase flow with a lot of experimental data [14–15]; Bin Xu et al. proposed a shell-side unit flow model and a simplified two-phase flow path analysis method based on the experimental study and the homogeneous-phase flow model, and the experimental study showed that the method has a certain accuracy in predicting the shell-side pressure drop and is suitable for estimation in the early engineering stage [16]; Deng Bin and Tao Wenquan conducted a cold-state experimental study on the turbulent flow characteristics of the shell and tube heat exchanger at the State Key Laboratory of Multiphase Flow in Dynamics Engineering of Xi'an Jiaotong University in "Experimental study of numerical simulation of shell and tube heat exchanger shell-side turbulent flow", and the experimental results showed that the experimental data on the shell-side pressure distribution and pressure drop of the heat exchanger are basically consistent with the results calculated by numerical simulation, and the maximum deviation between the calculated and experimental values is about 20% [17]; Liu M. Shan et al. added a divider to the side of the shell while increasing the notch height of the fold plate. This method effectively reduces the dead zone size and shell side pressure drop on the basis of reinforced shell side flow heat transfer, thus improving the performance of the tube bundle against fluid-induced vibration, with good engineering application prospects [18]; Xie Gongnan et al. from Xi'an Jiaotong University conducted an experimental study on the heat transfer and flow resistance of bow and spiral folded plate heat exchangers in the study of the shell-side heat transfer and resistance performance of tube-shell heat exchangers, which showed that the flow resistance of bow and spiral folded plate heat exchangers is less than the flow resistance of spiral folded plate heat exchangers at the same shell-side flow rate [19]; Yu Jiuyang et al. from Wuhan Engineering University conducted experimental studies on various shaped orifice plates by making holes in the folded plates, and obtained the optimal orifice plate form relative to the bow-shaped folded plates [20].

## *2. Research advances in numerical simulation of enhanced heat transfer by shell and tube heat exchangers*

The earliest numerical simulation studies of tube-shell heat exchangers were performed by S. V. Patankar and D. B. Spalding [21]. They proposed for the first time the application of computational fluid dynamics (CFD) to conduct numerical simulation study on the shell and tube heat exchanger, they used the shell process of the shell and tube heat exchanger as the object of study, used porous media and distributed resistance method, and conducted numerical simulation study on the shell side flow field, which laid the foundation for future research. Although research progress was slow due to conditions such as computer hardware technology at the time. However, they present three guiding hypotheses — the porous media model hypothesis, the distributed resistance hypothesis, and the tubular one-dimensional flow hypothesis; C. C. Gentry proposed the view of surface permeability based on the former study, and conducted two-dimensional numerical simulations of the heat exchanger shell side flow conditions and characteristics, which were compared with experiments with good results [22]; Invoking the concept of volumetric porosity, C. Zhan et al. of Canada conducted a numerical simulation of the condenser and applied a finite volume algorithm to solve the control differential equations established therein, and the simulation results were in good agreement with experimental results. A few years later, numerical simulations were performed on the steam condenser of the power plant, which also yielded better simulation results [23–24]; M. Prithivraj and M. J. Andrews, simulated the flow and heat transfer in the shell process of a bow-folded sheet and tube heat exchanger using a three-dimensional, homogeneous coordinate controlled volume technique and a physical model of distributed resistance and volumetric porosity, and obtained the effect of the modified κ-ε model on the turbulence simulation and built a mathematical model based on the physical model [25]; In 2002, J. H. Ko et al. verified the reinforced heat transfer performance of needle-winged surface-reinforced tubes for compact heat exchangers under low Reynolds number operation by using flow-field visualization software techniques [26].

Numerical simulation studies of heat exchangers have also been conducted by a number of domestic scholars.

Xinghua Huang of Shanghai Jiao Tong University applied the porous media model to numerical simulations of the cold and hot state of the heat exchanger and proved the usefulness of the porous media model [27]. In the same year, Tao Wenquan and Wang Qiuwang of Xi'an Jiaotong University conducted numerical simulations on the flow field in the head and outlet nozzle to confirm the influence of the baffle in the heat exchanger head on the uniformity of the flow field in the outlet nozzle; Xie Heng and Gao Z. used a porous media approach to establish a three-dimensional flow model of the heat exchanger and compared it with the experimental flow field to verify it, which provided a basis for the optimal design of the heat exchanger [28]; Deng Bin and Tao Wenquan applied the porous media model and used the improved κ-ε model to consider the effect of the tube bundle on the turbulence generation and dissipation, and conducted three-dimensional numerical simulations on the shell-side flow of the tube-shell heat exchanger, and the simulation results are in good agreement with the experimental results [29]; Qi-Wu Dong et al. conducted 3D numerical simulations to address the problem of dead zones on the shell side of the heat exchanger with a single bow-shaped flow plate, and improved the shell side flow state by adding a divider between the flow plates, nearly achieving no dead zone flow on the shell side, reducing the shell side pressure drop, and to some extent also improving the performance of the tube bundle against fluid-induced vibration [30]; Hu Yan and Sun Zhongning carried out numerical simulations of the flow fields of the bowed fold plate heat exchanger and the continuous spiral fold plate heat exchanger shell processes [31]. The shell side temperature and pressure drop were analyzed and the calculations were experimentally verified.

The results show that there is a significant flow hysteresis zone in the shell process of the bow-shaped folded plate heat exchanger, while the flow field distribution in the spiral folded plate heat exchanger is more uniform. At the same flow rate, the flow pressure drop of the spiral plate heat exchanger shell process is only about 32% of that of the bowed plate heat exchanger and the heat transfer capacity is slightly lower than that of the bowed plate heat exchanger, but the heat transfer coefficient per unit pressure drop is much higher, about 1.3 times that of the bowed plate heat exchanger. The numerical calculations were in good agreement with the experimental values. Description the mathematical model used is reasonable and reflects the actual situation of the heat exchanger more realistically; Xin Gu and Qi-Wu Dong, from the Thermal Engineering Research Center of Zhengzhou University, proposed a periodic model and built a three-dimensional solid model of the tube-shell heat exchanger based on the structural characteristics of the tube-shell heat exchanger [32].

The method makes up for some of the shortcomings of the existing numerical simulation modeling methods and achieves numerical simulation of the flow and temperature fields of the shell and tube heat exchanger shell processes with complex shell process structures. The method provides a good aid for reproducing and simulating the real flow conditions of the shell and tube heat exchanger shell process, as well as for analyzing the effect of various components on the fluid flow and heat transfer properties of the shell process; Lin Cheng, Xu-Dong Gao and other scholars conducted three-dimensional numerical simulations of shell and tube heat exchangers in which the heat transfer medium is water, and discussed the effect of different fold plate shapes on heat exchanger performance, heat exchanger performance evaluation factors and shell side scaling factors.

Yu Jicheng of Peking Petroleum University also carried out three-dimensional numerical simulations for the shell-side fluid flow of the tube-shell heat exchanger, he pointed out that the reduction of the shell-side folding plate spacing greatly increased the shell-side pressure drop of the heat exchanger, but the shell-side heat transfer increase was not significant; Hongyu Gao used FLUENT software to simulate the effects of different refractory plate structures and plate spacing on the pressure drop and heat transfer coefficient of the shell process for curved bowed refractory plate heat exchangers [33]; Liu Lei et al. performed the distribution of velocity field, temperature field and pressure field on the shell flow characteristics through FLUENT software, which is consistent with the experimental results and provides reference value for the design and improvement of shell and tube heat exchangers [34].

## *3. Conclusion*

With the continuous development and advancement of related technologies, more and more new processes and technologies have emerged. The emergence of these new processes and technologies provide the basis and support for our research on the strengthening of the heat transfer technology of shell and tube heat exchangers. Future directions for research on enhanced heat transfer technology for shell and tube heat exchangers should include:

1. New types of shell and tube heat exchanger equipment are being developed to improve the heat transfer effect with new high efficiency heat exchangers.

2. There is less research on fluid-induced vibration and tube fatigue damage in shell and tube heat exchangers, and the next research work should be theoretical as well as experimental and simulation for such problems.

3. The performance of the heat exchanger is improved as much as possible with a reduced Reynolds number.

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