UDC 628

PASSIVE METHODS ANALYSIS OF HEAT TRANSFER INTENSIFICATION OF HIGH VISCOSITY FLUIDS

АНАЛИЗ ПАССИВНЫХ МЕТОДОВ ИНТЕНСИФИКАЦИИ ТЕПЛОПЕРЕДАЧИ ДЛЯ ЖИДКОСТЕЙ ВЫСОКОЙ ВЯЗКОСТИ

©Wang W.,
ORCID: 0000-0001-8493-4828
Ogarev Mordovia State University,
Saransk, Russia, Willie_CN520@163.com
©Ван В.,
ORCID: 0000-0001-8493-4828
Национальный исследовательский Мордовский
государственный университет им. Н. П. Огарева,
г. Саранск, Россия, Willie_CN520@163.com
©Makeev A.,
Ph.D., ORCID: 0000-0001-5356-2144
Ogarev Mordovia State University,
Saransk, Russia, tggi@rambler.ru
©Макеев А. Н.,
канд. техн. наук, ORCID: 0000-0001-5356-2144
Национальный исследовательский Мордовский
государственный университет им. Н. П. Огарева,
г. Саранск, Россия, tggi@rambler.ru

Abstract. The article analyzes the methods of passive intensification of heat exchange processes. The dependence of hydraulic resistance for fluid flow through the heat exchanger on the value of the temperature head on it is considered. The most effective ways of improvement of heat exchange processes are defined.

Аннотация. В статье анализируются способы пассивной интенсификации теплообменных процессов. Рассмотрена зависимость гидравлического сопротивления для истечения жидкости через теплообменное устройство от величины температурного напора на нем. Определены наиболее эффективные способы улучшения теплообменных процессов.

Keywords: passive intensification of heat exchange, heat transfer coefficient, finning of heat exchange surfaces, turbulence of the coolant.

Ключевые слова: high viscosity fluids; heat transfer coefficient; comprehensive heat transfer performance; compound heat transfer enhancement.

Heat transfer in high viscosity fluids are widely applied in a variety of industrial processes such as food, light industry, power, petroleum, refrigeration, machinery, ships and other fields: high viscosity food disinfection and sterilization; various mechanical transmission equipment lubricants Cooling; removal of heat in the reactor during the polymerization reaction; heating or cooling of various high viscosity raw materials and finished products in the petrochemical industry. These processes all involve heat exchange, it is undoubted that the heat transfer about highly viscous fluids in industrial processes is very important. However, the heat transfer of high viscosity fluids generally has the disadvantage of low heat transfer coefficient and large pressure drop. Therefore, how to improve the heat transfer coefficient of high viscosity fluids and reduce the pressure drop are the key factors in heat transfer research.

1.The characteristics of high viscosity fluids flow and heat transfer

For high viscosity medium flow and heat transfer has its own characteristics, which are quite different from the medium of low viscosity and low Prandtl number. High viscosity liquid flow and heat transfer is a constant problem in the industrial fields of nuclear power, powering, food and etc, especially in heat exchanger about the lubrication as the working fluid. Therefore, it is critical to study its own characteristics of high viscosity liquids.

Viscosity is a macroscopic property of a fluid and refers to the relationship between the stress applied to a fluid and the resulting rate of deformation manifested as the internal friction of a fluid. The viscosity of a fluid is a measure of its resistance to flow induced by a force. That is defined as the amount of shear stress required per 1 cm2 of a liquid flowing at a velocity of 1 cm/s, and its physical unit is Pa•s [1]. As an important physical property of fluid, it largely determines the fluid flow form in the pipeline such as laminar flow, turbulence or transitional flow, which affects the properties of fluid in the heat transfer and pressure drop. There is no clear definition of a high viscosity fluid, that is compared to low viscosity fluids such as water and air. From this perspective, various oils, lubricants, polymer gums can be regarded as high viscosity fluids.

The greater the viscosity of the fluid, the harder to flow. Viscosity is divided into dynamic viscosity and kinematic viscosity. For high viscosity fluid, its kinematic viscosity is very large, when it is used as a heat transfer medium it will form a thick boundary layer which is hardly conductive to heat exchange. To solve this problem, we must start by understanding the characteristics of fluid flow and heat transfer.

(1) The viscosity of the fluid leads to low Reynolds number, that is means the fluid is frequently in the laminar flow state in the conventional heat transfer equipment.

(2) The kinematic viscosity of the fluid reflects the ability of fluid to spread momentum due to the molecular motion. The larger the kinematic viscosity of the fluid, the further the effects of viscosity will transfer. For lubrication, its thermal diffusivity is much less than kinematic viscosity, thus Pr/a is large. Prandtl number is the relative thickness of the fluid thermal boundary layer and the fluid boundary layer, therefore, for the oil with high Prandtl number, the thickness of the velocity boundary layer is much greater than the thickness of the thermal boundary layer.

(3) The viscosity of the fluid significantly related to temperature and has almost nothing to do with the pressure. Especially for high viscosity fluids, their physical properties change dramatically with temperature, thereby during the research, the resulting flow resistance and heat transfer are also different. When the high viscosity fluid is cooled, the temperature of the fluid which is closer to the heat wall surface is quite low, which causes the sharp increases in viscosity of the fluid, resulting the fluid in the adherent wall being in a viscous state and the heat exchange effect deteriorates drastically. Therefore, on the process of cooling high viscosity fluids, extra attention should be paid to the issues in viscous insulation layer. On the one hand the wall temperature should not be too low, on the other hand to destruct the formation of viscous layer with additional disturbances. Such issues don’t occur when heating high viscosity fluid, the higher the temperature difference between the heat exchange wall and the fluid, the better.

(4) Due to the large viscosity, it causes great difficulties to stir the fluid flow, thereby the resistance of such fluids is greater and the heat transfer effect between the heat transfer surface is very poor. When a better heat transfer effect is expected while conducting the heat transfer enhancement, often accompanied by a greater resistance cost.

2. Current state of the scientific problem

As so far there are a few literature about enhancing the heat transfer of high viscosity fluids. In order to enhance the heat transfer of high viscosity fluids, the researchers mainly started from the aspects of improving the structure of the tubes, inserting various structures of the inserts and compounding. Xiao Jinhua et al [2-7] introduced various special-shaped tubes for the study of heat transfer enhancement about high viscosity fluids. The involved tubes include bellows, helical grooved tubes, dimpled tubes and spiral flat tubes. In order to enhance heat transfer, the researcher mainly starts from improving the geometric parameters of the tube and developing different tube types. Vicente et al [3] studied the bellows pitch and bellows height on the heat transfer. Cui Haiting et al [6] researched the improved W-type spiral groove heat transfer characteristics. Qiu Qi et al [10-14] presented a variety of finned tubes for enhancing heat transfer of highly viscous fluids. Akhavan-Behabadi et al. [15-23] investigated coiled and twisted-tape for the study of heat transfer enhancement in high viscosity fluids. In order to enhance heat transfer and reduce pressure drop, the researchers constantly change the geometric parameters of the insert and try to find the optimal structure, then reduce the pressure drop by adopting the segmented arrangement of the insert. Zhang Weijun et al. [24-26] conducted a related study of composite enhanced heat transfer. That includes the special-shaped tube, twisted-tape insert[24-25] and the combination of DC electric field and twisted ribbon [26].

3. The methods of high viscosity fluid in heat transfer enhancement

The purpose of heat transfer enhancement is to increase the heat transfer coefficient in order to reduce the consumption of tubing and improve energy efficiency, thereby saving installation costs. On the other hand, with the increase of heat transfer coefficient, pressure drop and pump power also increase, which increases the operating cost. Therefore, actions should be taken to balance the former and the latter. To this end, Webb [1] proposed a performance evaluation criterion in an attempt to evaluate method of heat transfer enhancement. The above evaluation criteria take both heat transfer coefficient and pressure drop into account, being a balance. Now the methods of high viscosity fluid heat transfer enhancement are mainly focused on the following aspects.

Surface groove

Surface groove has always been a crucial aspect of improving heat transfer efficiency. Compared with the traditional smooth tube, the trench enhanced heat transfer tube can economize the pipe, reduce equipment costs, also significantly improve the utilization of thermal energy and reduce energy consumption.

Xiao Jinhua et al [2] adopted the corrugated pipe as the enhanced tube and carried out a heat transfer enhancement when the mixed oil flow in the tube, it confirmed that the corrugated tube has a better turbulence promoting effect on the high viscosity fluid, which can greatly reduce the critical Reynolds number when laminar flow transit to turbulent flow. The study is only about heat transfer enhancement of the high viscosity fluid within the corrugated tube with one structure relative to the smooth tube. While Vicente et al [3] investigated the impact of the bellows pitch and height geometry structure parameters on the heat transfer coefficient and pressure drop by using ethylene glycol, made an conclusion that the optimized structural parameters make more sense to the corrugated tube design.

Rozzi et al. [4] employed the structure of spiral corrugated tube and researched the heat transfer and pressure drop performance of highly viscous fluid food in tube, obtained the best generalized Reynolds number range suitable for the flow of high viscosity food in the tube. Yang et al. [5] studied the influence of structural parameters such as groove depth, pitch and helix angle on heat transfer and pressure drop in a turbulent spirally corrugated tube. The results showed that compared with the smooth tube, the heat transfer enhancement of the fluid on the side of fortified tube is increased by 30% ~ 120% and the friction coefficient is increased by 60% ~ 160%. Cui

Haiting et al [6] discovered the heat transfer and flow resistance characteristics of oil in a spiral grooved pipe and W-type spiral grooved pipe with an improved structure. Experiments indicated that compared with the smooth tube, these two pipes both can significantly improve the heat transfer performance, but at the same time the pressure drop is also greater. Under the same Reynolds number, the heat transfer coefficient of the W-type spiral corrugated tube is 4% ~ 8% higher than that of the spiral corrugated tube, but the pressure drop is 3-7% lower, thus the comprehensive heat transfer performance is better, which is better structure suitable for high viscosity fluid.

In order to be able to enhance the heat transfer performance of reinforced pipe to a greater extent, a variety of new reinforced pipe types have been continuously developed. The dimpled pipe and the twisted pipe are the typical representatives. Compared with the corrugated pipes and spiral corrugated pipes, which have been used on a large scale for industrial applications, the research on these two pipes are deficient and the accumulated correlations are also seriously insufficient, which has greatly restricted the progress of these pipes on industrial purposes. Therefore, the research on them will surely become a critical aspect of heat transfer enhancement of high viscosity fluid in the future.

Vicente et al. [7] used ethylene glycol and water as experimental medium to investigate the influence of structural parameters such as pit density and depth on the heat transfer and pressure drop of the fluid in the pipe. The results manifested that resistance and heat transfer of all the dimple tubes are higher than that of the smooth tubes, in which the friction coefficient is increased by 150% ~ 350% and Nusselt number is increased by 150% ~ 250%. Liang Wenhu [8] and Huang Debin [9] analyzed the law of the heat transfer and resistance characteristics of oil products flowing in the twisted tube with change of the Reynolds number, tube pass and tube diameter. The experimental results suggested that both the heat transfer coefficient and the resistance coefficient magnify with the increase of Reynolds number. In the case of the same Reynolds number, the heat transfer coefficient inside the tube increases with the decrease of pass to the twisted tube with the same diameter, as well as the pressure drop; for the twisted tube with the same pass, the comprehensive heat transfer of large diameter is better.

Extended surface

The fundamental role of heat exchangers is to accomplish the heat exchange between the hot and cold mediums required by the process, and the various measures taken to make the process more efficient are called enhanced heat transfer techniques. The basic heat transfer formula is:

$$Q = KA\Delta T_m, \tag{1}$$

where:
K – heat transfer coefficient, W / (m2 · K);
A – heat exchange surface area, m2;
ΔT_m – differential temperature.

According to the above formula, increasing the heat transfer coefficient, expanding the heat transfer area, rising the heat transfer temperature difference. By the means of these three ways can increase the heat transfer. The former two methods of intensifying heat exchange have been widely used in many occasions and achieved good results. However, expanding the heat exchange area makes the heat exchange equipment more difficult to process, and increasing the heat transfer temperature difference is usually limited by the actual process conditions. Therefore, the positive measures to enhance heat transfer is still to improve the heat transfer coefficient K. Through the plan mural, the expression of heat transfer coefficient is:

$$K = \frac{1}{\frac{1}{h_1} + \frac{\delta}{\lambda} + \frac{1}{h_2}}, \qquad (2)$$

h_1, h_2 – heat transfer coefficients, respectively, from the hot heat carrier to the separating wall and from the wall to the cool heat carrier, W / (m2 · K);

δ – wall thickness, m;

λ – coefficient of thermal conductivity of the wall material, W / (m · K).

As the heat exchange surface is mostly metal, the change of thermal-conduction resistance is relatively small, it is difficult to strengthen the heat transfer to improve the heat transfer coefficient. The best measure is to strengthen one or both sides of the surface heat transfer coefficient h1 and h2, and achieve a good match. Therefore improving the surface heat transfer coefficient has become a key issue of concern in the study. By what factors control the surface heat transfer coefficient and how to improve the surface heat transfer coefficient have become the main research contents.

Chou Xingqi et al. [10] researched the heat transfer and flow resistance characteristics of 30# oil in the tube shell of longitudinal fins. The experimental results were compared with those of the smooth tubes with baffle plate. Experiments showed that the longitudinal fin can better strengthen the heat transfer performance of the shell-side fluid, and the effect was more obvious at lower Reynolds number. According to Bergles [11], longitudinal finned tubes have only two-dimensional surface geometry, therefore it can only be counted as second generation heat transfer enhancement technology, not the third generation. In order to further improve the heat transfer efficiency of finned tubes, the structure of all kinds of finned tube with three-dimensional geometries has been developed one after another, such as three-dimensional petal-shaped finned tubes and three-dimensional trapezoidal finned tubes. Ma Qiliang et al [12] used a new type of three-dimensional internal petal spiral ribbed tube to study the heat transfer and flow resistance characteristics of heavy oil in the tube. Zhang et al. [13] investigated the heat transfer and flow resistance characteristics of oil in the shell side of a three-dimensional petal-shaped finned tube, at the same time, the supporting structure of the shell side is improved and the supporting structure of spiral baffle is adopted, So that the shell-side fluid from bow baffle baffle into a spiral thrust of the push-flow, which improved the heat transfer coefficient and reduces the pressure drop. Zhu Dongsheng et al [14] also adopted a similar approach, except that he used a trapezoidal three-dimensional finned tube. The results showed that this combination was effective for the heat transfer of highly viscous fluids.

Tube insert

In comparison with the first two enhancement approaches, the tube insert has a notable advantage that it can transform the existing tube type conveniently without redesigning the tube type, so that it can save massive cost. For the time being, the commonly used in-tube cyclone inserts include twisted tapes, coils, extended surface devices and mesh inserts. Although there are many kinds of inserts, but the current large-scale applications are mainly coil and the twisted tape inserts. The main reasons for this situation are cost, pressure drop and scaling.

There are relatively more literature on the study of tube insert for high viscosity fluids in the heat transfer enhancement field. Akhavan-Behabadi et al. [15] studied the variation rule of Nusselt number and Fanning friction coefficient of engineering oil in the smooth tube with coil inserts of different pitches and diameters when Reynolds number changes, obtained the related rules of the heat transfer and pressure drop inside the tube in laminar flow. While Garcia et al. [16] used the heat transfer characteristics of coil inserted in the tube, within the mixture of the same quantity of water, propylene glycol and water at 20 □ and 50 □. Due to the adoption of different working mediums, at the same time, the fact that the viscosity of highly viscous fluids changes with the temperature is also considered, therefore, the physical properties range of heat transfer working mediums is greatly expanded, thus adaptability is more better. Garcia et al. [17] also adopted a hybrid working mediums to expand the physical properties range of the working mediums, but the difference was that he also expanded research to the extent of turbulence.

Agarwal et al. [18] introduced the effect of different twist ratios of tube in heat transfer efficiency. The results manifested that the friction coefficient and Nusselt number both increase with the twist ratio of the twisted band decreasing, and when the twist ratio is at 2.41, the Nusselt number in the tube is 2.28 ~ 5.35 times and 1.21 ~ 3.70 times higher than that in the smooth tube under the condition of steady flow and constant pressure, at the same time, the friction coefficient is also improved to some extent. Al-Fahed et al. [19] also used twisted tapes as inserts in the tube while considering the influences of the twist ratio and the width of the coils on the heat transfer efficiency. The results indicated that the influence of twist width on the heat transfer is related to the twist rate, when the twist ratio is the same, changing the width of the twist can further improve heat transfer efficiency. As a commonly used heat transfer enhancement device, twist band can greatly lead to the secondary flow in the tube, but at the same time the pressure drop is too large. Therefore, researchers began to consider a twisted tape device with a segmented spaced sub-interval arrangement, in order to reduce the pressure drop and improve the comprehensive performance of heat transfer resistance. Saha et al. [20] applied the viscous oil to investigate the heat transfer and flow resistance characteristics of a short twist band in a smooth tube, and concluded that the short twist band has a better overall performance of heat transfer resistance. Wu Shuangang et al [21] conducted a experiment on the heat transfer of the tubes inserted with segmented twisted tape of smooth tube when they were forced, and proved that the segmented twisted tape is a better heat transfer enhancement element.

Compound enhancement

Compound heat transfer enhancement refers to the simultaneous use of two or more heat transfer enhancement measures to play their respective advantages, in order to obtain a better effect of heat transfer enhancement. Favored means is to add a variety of swirling device in various special-shaped tubes. Deng Xianhe et al. [23] pointed out that the enhanced heat transfer tubes with rational rough ribs (such as spiral corrugated tubes, various types of finned tubes and draft tubes) through effective disturbance on the boundary layer have greatly reduced the thermal resistance from the viscous sublayer and the transitional flow layer. As a result, the proportion of the thermal resistance of the mainstream flow area in the total heat resistance is increased. At this time, the heat transfer enhancement method with simply employing the rough pipes can no longer effectively reduce the thermal resistance of the mainstream flow area, therefore it is necessary to cooperate with other enhanced heat transfer technologies to achieve better heat transfer effect.

Zhang Weijun et al [24] employed the transformer oil as the working medium, conducted a research on complex heat transfer enhancement. The experiment adopted 3 kinds of experimental devices, namely, smooth tube, inner rib tube and inner rib tube with a spoiler coil inserted. Experiments indicated that the comprehensive heat transfer factor of inner rib tube is 1.17, while inner rib tube with twisted type is 2.23. Liao et al. [25] applied three-dimensional finned tubes and twisted strips of different structures as the compound heat transfer devices. The arrangement of the twisted tapes was divided into two cases of continuous and segmented. The experimental results demonstrated that the segmented twisted tape can not only improve the heat transfer coefficient, but also reduce the pressure drop, and its comprehensive heat transfer performance is better than continuous tape. Liu et al. [26] carried out an experiment on the heat transfer enhancement of oil in smooth tube with inserted spiral wire coil under DC electric field by taking NO.15 lubricant as experimental medium. The experiment displayed that the heat transfer coefficient increases greatly, but little pressure drop. The biggest drawback is the consumption of external power, but it is still quite ideal if it is purely from the standpoint of enhancing the overall heat transfer enhancement properties of highly viscous fluids in the pipe.

Conclusions

This article starts with four aspects, namely improved tube type, extended surface, inserted inserts and composite heat transfer enhancement, and the related literature about the heat transfer enhancement of high viscosity fluid is reviewed. In general, from the initial spiral groove tubes to the improved W-spiral groove tubes, from simple two-dimensional finned tubes to a variety of three-dimensional finned tubes, from single heat transfer enhancement to compound heat transfer enhancement which combines a variety of advantages of heat transfer enhancements technologies. Researchers have been trying constantly to achieve the purpose of strengthening heat transfer and reducing pressure drop by improving the structure. In addition to the above traditional shell-and-tube heat exchangers used for heat transfer enhancement of highly viscous fluids, researchers now use new and efficient heat exchangers for enhancing the heat transfer of high viscous fluids. As Ren Hongli et al. [27] discussed the heat transfer of high viscous fluids isoprene in plate heat exchanger. At present, a lot of research have been conducted on the heat transfer and flow resistance of high viscosity fluids under various conditions, and many results with industrial application and popularisation value have been achieved, however, there is still a lot of work to be done.

（1）Broaden the types of heat transfer medium. Throughout the relative literature, it can be seen that the working medium used for heat transfer research is mainly oil, diesel or their mixtures, other heat transfer mediums with higher viscosity such as various polymer fluids are rare reported.

（2）Expanded the types of special tubes for heat transfer enhancement of high viscosity fluids. Currently, there are a few literature about the types of special-shaped tubes used in high viscosity fluids for heat transfer enhancement, mainly bellows and spiral groove tubes, the types of special tube are definitely needed to be enriched.

（3）Compound heat transfer enhancement can effectively improve the heat transfer enhancement coefficient of high viscosity fluids but also result in high pressure drop. Though the issue of maximising its overall heat transfer performance is explored in the literature [25-26], it remains to be further studied.

References:

1. Webb, R. L. (1981). Performance evaluation criteria for use of enhanced heat transfer surfaces in heat exchanger design. *International Journal of Heat and Mass Transfer,* 24, (4), 715-726

2. Xiao, J., Qian, C., & Wang, F. (2007). Heat transfer enhancement by corrugated tubes with high viscosity fluids. *Journal of Beijing University of Chemical Technology: Natural Science Edition,* 34, (1), 53-57

3. Vicente, P. G., Garcia, A., & Viedma, A. (2004). Mixed convection heat transfer and isothermal pressure drop in corrugated tubes for laminar and transition flow. *International Communications in Heat and Mass Transfer,* 31, (5), 651-662

4. Rozzi, S., Massini, R., Paciello, G., & al. (2007). Heat treatment of fluid foods in a shell and tube heat exchanger: Comparison between smooth and helically corrugated wall tubes. *Journal of food engineering,* 79, (1), 249-254

5. Yang, D., Li H. X., Chen, T. K., &al. (2001). Pressure drop, heat transfer and performance of single-phase turbulent flow in spirally corrugated tubes. *Experimental Thermal and Fluid Science,* 24, (3-4), 131-138

6. Cui, H., Yao, Zh., & Yang, Y. (2001). An experimental investigation on the heat transfer and flow resistance of the single phase oil in the spiral fluted tubes with various structures. *Chemical Engineering & Machnery,* 28, (3), 132-134

7. Vicente, P. G., Garcia, A., & Viedma, A. (2002). Heat transfer and pressure drop for low Reynolds turbulent flow in helically dimpled tubes. *International Journal of Heat and Mass Transfer,* 45, (3), 543-553

8. Liang, L. (2001). Characteristics of spiral flat tube heat exchanger and its commercial application. *Petroleum Refinery Engineering,* 31, (8), 28-32

9. Huang, D., Deng, X., Wang, Ya., & al. (2003). The experiment research of heat exchanger of spiral elliptical flat tube. *Petro-chemical Equipment,* 32, (3), 1-4

10. Qixing, Q., Li, H., Chen Ya., & al. (2003). Experimental research on the heat transfer and flowing resistance of the longitudinal fin tube. *China Petroleum Machinery,* 29, (3), 8-10

11. Bergles, A. E. (1999). Enhanced heat transfer: endless frontier, or mature and routine? *Applied Optical Measurements,* 3-17.

12. Ma, Q., Lei J.-ch., & Xiao M. Ya. (2001). Experimental Investigation for Augmentation Heat Transfer of The Heating Oil Exchanger Made of Three Dimensional inside Petal Helically Finned Tube. *Power Engineering,* 21, (1), 1166-1168

13. Zhnegguo, Z., Tao, X., Xiaoming, F. (2004). Experimental study on heat transfer enhancement of a helically baffled heat exchanger combined with three-dimensional finned tubes. *Applied Thermal Engineering,* 24, (14-15), 2293-2300

14. Zhu, D., & Jiang, X. (2005). Enhanced heat transfer investigation on high viscosity fluid in shell and tube exchanger. *Journal of Chemical Industry and Engineering,* 56, (8), 1451-1455

15. Akhavan-Behabadi, M. A., Kumar, R., Salimpour, M. R., & al. (2010). Pressure drop and heat transfer augmentation due to coiled wire inserts during laminar flow of oil inside a horizontal tube. *International Journal of Thermal Sciences,* 49, (2), 373-379

16. Garcia, A., Solano, J. P., Vicente, P. G., & al. (2007). Enhancement of laminar and transitional flow heat transfer in tubes by means of wire coil inserts. *International Journal of Heat and Mass Transfer,* 50, (15-16), 3176-3189

17. Garcia, A., Vicente, P. G., & Viedma, A. (2005). Experimental study of heat transfer enhancement with wire coil inserts in laminar-transition-turbulent regimes at different Prandtl numbers. *International Journal of Heat and Mass Transfer,* 48, (21-22), 4640-4651

18. Agarwal, S. K., & Rao, M. R. (1996). Heat transfer augmentation for the flow of a viscous liquid in circular tubes using twisted tape inserts. *International Journal of Heat and Mass Transfer,* 39, (17), 3547-3557

19. Al-Fahed, S., Chamra, L. M., & Chakroun, W. (1998). Pressure drop and heat transfer comparison for both microfin tube and twisted-tape inserts in laminar flow. *Experimental Thermal and Fluid Science,* 18, (4), 323-333

20. Saha, S. K., Dutta, A., & Dhal, S. K. (2001). Friction and heat transfer characteristics of laminar swirl flow through a circular tube fitted with regularly spaced twisted-tape elements. *International Journal of Heat and Mass Transfer,* 44, (22), 4211-4223

21. Wu Sh., & Xin M. R. (1995). Experimental on forced convective heat transfer of oil in tubes with Twisted-Tape inserts. *Journal of Chongqing University: Natural Science Edition,* 18, (1), 113-117

22. Kim, J., Seo, Y., Chang, D. (2016). Economic evaluation of a new small-scale LNG supply chain using liquid nitrogen for nature-gas liquefaction. *Applied Energy,* (182), 154-163.

23. Deng X., & Hong M. (2007). Technical of compound heat transfer enhancement with self-sustaining swirl flow and rough tubes. *Chemical Industry and Engineering Progress,* 26, (10), 1400-1403

24. Zhang, W., Zhang, Ya., & Jin, Zh. M. (1998). Experimental studied on combined enhancement heat transfer of viscidity fluids in tubes. *Physics Examination and Testing,* (1), 31-33

25. Liao, Q., & Xin, M. D. (2000). Augmentation of convective heat transfer inside tubes with three-dimensional internal extended surfaces and twisted-tape inserts. *Chemical Engineering Journal,* 78, (2-3), 95-105

26. Liu, Z. H., & Yi, J. (2004). Augmentation of laminar forced convective heat transfer of an oil flow in an enhanced tube by EHD effect. *Journal of heat transfer,* 126, (1), 131-133

27. Ren, H., Zhang, G., Zhang, Ya., & al. (2009). The engineering study of plate heat exchanger in high viscosity fluids. *Chemical Engineering Design,* 19, (2), 20-22

Работа поступила в редакцию 24.02.2018 г.

Принята к публикации 28.02.2018 г.

Ссылка для цитирования:

Wang W., Makeev A. Passive methods analysis of heat transfer intensification of high viscosity fluids // Бюллетень науки и практики. 2018. Т. 4. №3. С. 112-120. Режим доступа: http://www.bulletennauki.com/van-makeev (дата обращения 15.03.2018).

Cite as (APA):

Wang, W., & Makeev, A. (2018). Passive methods analysis of heat transfer intensification of high viscosity fluids. *Bulletin of Science and Practice,* 4, (3), 112-120