Tikrit Journal of Engineering Sciences (2023) 30 (1): 66-71
DOI: http://doi.org/10.25130/tjes.30.1.6

IRAQI Academic Scientific Journals

College of Engineering

ISSN: 1813-162X (Print); 2312-7589 (Online)
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Improving the Thermal Performance of a Heat Exchanger using a New Passive Technology

Manar A. Hameed *[a], *Harith N. Mohammed* [a,b], *Mohammed R. Abdullah* [a]

[a] *Chemical Engineering Department, College of Engineering, Tikrit University, Tikrit, Iraq.*

[b] *School of Chemical Engineering, Universiti Sains Malaysia, Pulau Pinang, Malaysia.*

Keywords:

Oscillation Technique; Heat Transfer Enhancement; Heat exchanger; Thermal Performance.

ARTICLE INFO

Article history:

Received	18 Jan. 2023
Accepted	16 Feb. 2023
Available online	19 Mar. 2023

Citation: Hameed MA, Mohammed HN, Abdullah MR. Improving the Thermal Performance of a Heat Exchanger Using a New Passive Technology. Tikrit Journal of Engineering Sciences 2023; 30(1): 66-71.
http://doi.org/10.25130/tjes.30.1.6

Corresponding author:

Manar A. Hameed
Chemical Engineering Department, College of Engineering, Tikrit University, Tikrit, Iraq.

Abstract: In this study, the oscillation technique was applied in a multi-tube heat exchanger with baffles. The Nusselt number was investigated in the heat exchanger (HE) over a wide range of operating conditions, Reynolds number (Re =205-3200), and oscillatory flow Reynolds number (Reo =0-3800). The results showed a significant enhancement in the tube-side Nusselt number, Nu. 5-fold heat transfer enhancement was achieved at maximum oscillatory and flow rates, the maximum Nu=180 at Re =1500 and Reo=3800. The flow rate had more impact on the heat transfer enhancement than the oscillatory flow by 1.25 when Re>1000. The thermal performance of the heat exchanger, TH, was also evaluated. TH decreased with the increasing flow rate and oscillatory flow due to the increase in the ΔP due to the increase in the mixing intensity. A high value of the thermal performance, TH=4.5, was achieved at Re=205, Reo=1500. According to the literature, this TH value indicated a significant improvement in heat transfer enhancement.

تحسين الأداء الحراري للمبادل الحراري باستخدام تقنية سلبية جديدة

منار عبدالجليل حميد[1]، حارث نوري محمد[1,2]، محمد رحيم عبدالله[1]
[1]قسم الهندسة الكيمياوية / كلية الهندسة/ جامعة تكريت /العراق. [2] مدرسة الهندسة الكيمياوية، جامعة العلوم الماليزية، بهانج، ماليزيا.

الخلاصة

في هذه الدراسة، تم تطبيق تقنية التذبذب في مبادل حراري متعدد الأنابيب مع وجود حواجز. تم فحص رقم Nusselts الخاص بالانتقال الحراري في المبادل الحراري (HE) على مدى واسع من ظروف التشغيل، وعدد رينولدز (Re = 205-3200) وعدد رينولدز المتذبذب (Reo = 0-3800). أظهرت النتائج تحسنًا معنويًا في عدد نسلت على جانب الأنبوب. تم تحقيق 5 أضعاف من تحسين انتقال الحرارة عند الحد الأقصى للتذبذب ومعدلات التدفق الصافي، والحد الأقصى Nu = 180 عند Re = 1500 وReo = 3800. كان لمعدل التدفق الصافي تأثير أكبر في تحسين انتقال الحرارة من التدفق المتذبذب بمقدار 1.25 عندما Re> 1000. كما تم تقييم الأداء الحراري للمبادل الحراري TH. انخفض TH مع زيادة معدل التدفق الصافي والتدفق المتذبذب بسبب الزيادة في الضغط نتيجة لزيادة كثافة الخلط. أعلى قيمة للأداء الحراري التي تم تحقيقها كانت 4.5 عند Re = 205، Reo = 1500.

الكلمات الدالة: تقنية التذبذب، تعزيز نقل الحرارة، التبادل الحراري، الأداء الحراري.

1.INTRODUCTION

The main goal of the advanced thermal systems design is to obtain the highest efficiency and effectiveness in heat transfer. It has become imperative to reduce the amount of energy lost through efficient use in energy production and transmission to avoid economic loss and to maintain workers' safety [1]. A heat exchanger is a device that thermal energy is transferred between fluids at significantly different temperatures [2]. The heat exchanger is widely used in industries such as chemical, petroleum, HVAC system, automotive, aerospace, electronics, power generation, and processing industries [3]. Due to the extensive uses of heat exchangers, their thermal performance significantly impacted energy requirements and system efficiency. Therefore, the thermal design must be developed to enhance heat transfer and reduce the low pressure within the heat transfer equipment. As a result, the energy demand of the fluid handling equipment within a system will be reduced [3,4]. Heat transfer devices are used to convert and recover heat in many industrial and domestic applications. Over the past decades, researchers have combined their efforts to develop a heat exchanger design to reduce energy requirements and save materials and other costs. Many types of heat transfer devices are used in industry, such as twin tube heat exchangers, tube and frame heat exchangers, air cooler heat exchangers, and fin heat exchangers. Heat transfer devices are used in chemical process plants due to STHE's high level of durability, diverse materials used in construction, ease of maintenance, and wide range of operating conditions [5]. Some techniques have been applied to enhance heat transfer by decreasing the thermal resistance by increasing the transfer surface area or fluid flow pattern within the device. Rough surfaces are used to increase the effective surface area. However, rough surfaces require higher pumping forces, which increases costs [6]. Baffles are commonly used to improve the flow pattern of fluids to enhance the mixing rates, i.e., heat and mass transfer. The baffles play a vital role in increasing the contact surface area and thus increasing the effective heat transfer rates [7]. Baffles' different configurations, such as integral, central, helical with rounded edges, and sharp helical edge; have been used to enhance heat and mass transfer [8]. Recently, the oscillatory flow technique has been used to improve the flow patterns by generating vortices due to interaction with baffles; as a result, the radial mixing of fluids and improved transport rates are improved [9–11]. The oscillation technology is one of the new methods that provide a uniform flow pattern, good mixing, high heat, and mass transfer. The oscillatory flow induces the radial velocity necessary to enhance the heat distribution in a vessel [12-14]. Few studies have been presented in thermal fields in oscillatory baffled reactors OBRs [11, 13, 15]. Mazubert et al. [11] numerically studied the diaphragm design effect on the pressure drop and energy density of 15 mm OBR. González-Juárez et al. [15] reported the orifice baffle design effect on pressure drops as the pressure drop increased by 3-fold in a 43-hole design compared to a single-hole. When scaling and designing heat transfer devices, it is necessary to overcome problems arising from operation at an inefficient fluid heat transfer rate, which results in a high process cost due to the extended cooling or heating time required to reach the fluids' required temperatures. Therefore, adding a new technology to heat exchanger designs has become necessary to achieve efficient heat transfer rates in a shorter time. As an alternative, a shell-and-tube type heat exchanger can be used with an oscillating flow inside the tubes to enhance the Nusselt number (Eq. 1) in a shorter time during the process.

2.EXPERIMENTAL SETUP

The flow of water inside the tubes is controlled by the water flow rate represented by Reynolds number (Eq. 2) and oscillation conditions (Eq. 3) [7, 8].

$$Nu = \frac{hD}{k} \quad \textbf{(1)}$$

$$Re = \frac{\rho u D}{\mu} \quad \textbf{(2)}$$

$$Re_o = \frac{(2\pi f Ao)\rho u D}{\mu} \quad \textbf{(3)}$$

where h is the heat transfer coefficient (W/(m^2·K), D *is* the pipe diameter (m), k is the thermal conductivity (W/m·K), ρ is the fluid density (kg/m^3), u *is* the net flow velocity (m/s), μ is the fluid viscosity (kg/m s), A_o is the center-to-peak amplitude of oscillation, and f is the frequency of oscillation (Hz).

2.1.Apparatus and Procedures

The heat exchanger used in the present study was connected with the required apparatuses to facilitate, obtain, and analyze the experimental heat transfer data. A shell-and-multi tubes heat exchanger (HE) was used in the vertical orientation to heat transfer experiments (Fig. 1 (*a* and *b*). The tube used was stainless steel 316 with a 50 mm inside diameter. Coils were inserted in the tubes to enhance the heat transfer rate. Four 6 mm diameter programmable digital thermocouples were connected to the heat exchanger terminals to record the temperature data. Two rotameters were used to set the OBR net flow and shell-side flow rate. The heat exchanger was insulated to avoid experimental error. The operating conditions ranges are listed in Table 1, and the schematic diagram is shown in Fig. 1. The average standard deviation was estimated for the Nu results (≤6.4%) and for the ΔP data (≤ 7.3%).

Table 1 List of equipment and fluids used.

Equipment	Made	Properties
Heat exchanger	Homemade system	Stainless-steel 316.
Oscillation system	Homemade system	Disc diameter= 100mm
Thermocouples with data logger	K-type DS18b20 - Germany	±0.5 °C precision
Pressure sensor	Gems Sensors - USA	1-12bar Accuracy ±1.5%
Water bath	Germany	Temp -0-120 °C
Rotameters	ZYIA and LTZ G-15	0-6 L/min
Water pump	China	Q $_{max}$=35L/min
Fluid inside the shell	-	Cold water (tap water)
Fluid inside the tubes	-	Hot water at °C

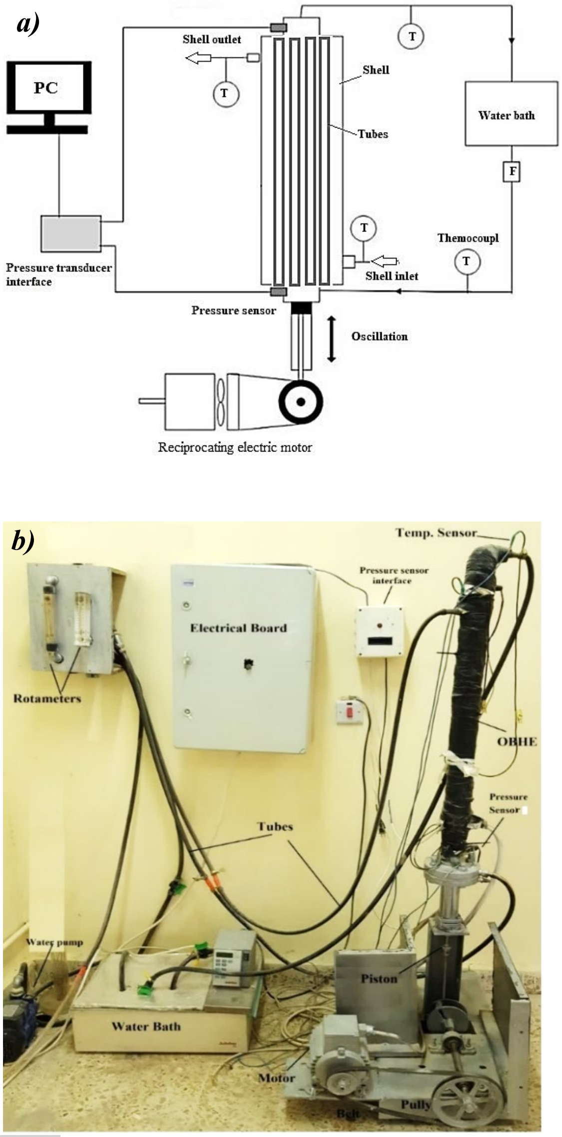

Fig.1 (a) the test rig setup schematic diagram (b) Photography.

3.RESULTS AND DISCUSSION

3.1. Nusselt number

3.1.1. Effect of oscillation on Nu

Fig. 2 shows the Nusselt number, Nu, results under a wide range of flow rates (Re=205-1500) and oscillation conditions (Re_o= 200-2000).

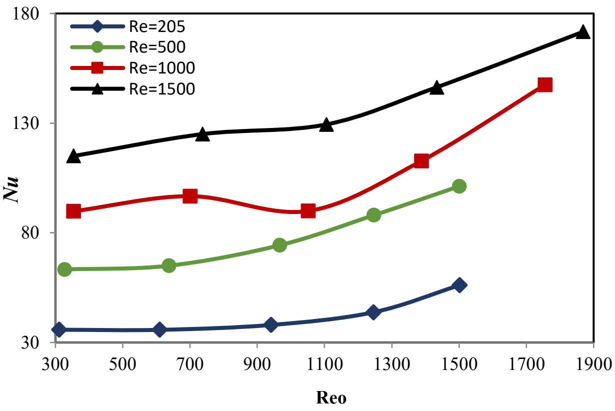

Fig. 2 Effect of Oscillation on Nusselt Number.

It can be seen from Fig. 2 that *Nu* increased with increasing the oscillation and flow rate conditions. The oscillation effect increased the redial mixing rather than the axial mixing, which increased the contact area. As a result, the heat transfer rate was improved. The maximum Nu achieved was 171 at *Re*=1500 and Re_o= 1870, indicating a 4-fold heat transfer enhancement. It can be noticed from Fig. 2 that at a low flow rate, Re=205, *Nu* slightly increased with oscillation. However, at Re>205, Nu sharply increased, especially at Re_o>1000. This behavior could occur because the required turbulence in the flow was achieved at Re>205 and Re_o>1000.

3.1.2. Effect of flowrate on Nu

Fig. 3 shows the Nu results for Re=205-3200 and different oscillation conditions.

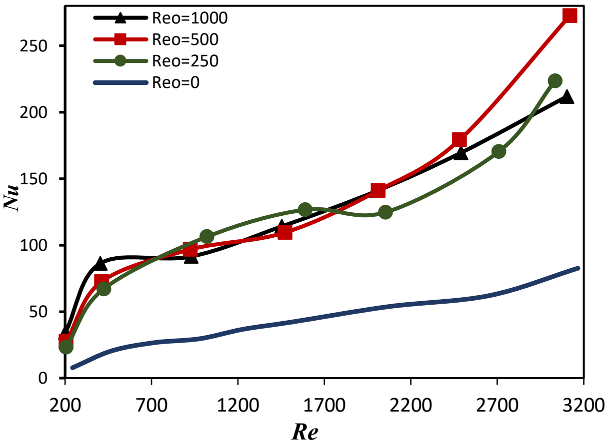

Fig. 3 Effect of Flowrate on Nusselt Number.

Fig. 3 shows a clear dependence of Nu on the oscillatory flow. A 4-fold enhanced at the oscillation condition, Re_o=500, and Re=3200. This enhancement was caused by the vortices generated that improved the temperature distribution and thus enhanced the heat transfer. It can be observed that at low net flow, Re<1000, Nu sharply. Then at higher flowrates values, Re>1650 for all oscillation conditions, Nu slightly increased. Nu behaved like that due to diminishing the oscillation effect as the oscillation increased until the net flow dominated the flow structure. Therefore, the oscillation had an insignificant effect on heat transfer. This behavior agrees with that in the literature [14]. The oscillation effect decreased with increasing the net flow associated with a counter flow. As a result, less contact surface area was achieved, causing less heat transfer enhancement. According to the above results, the oscillation application significantly increased Nu because the turbulence caused by the oscillatory flow dominated the flow structure. In Fig. 3, the enhancement in Nu is apparent at Re_o=0, i.e., no oscillation, compared with that at Re_o>0, i.e., with oscillation, which indicated the role of applying the oscillation technique [14]. Heat transfer was enhanced by 4-fold. Therefore, it can be confirmed that Nu was strongly dependent on the oscillatory flow.

3.2. Thermal Performance (TH)

The thermal performance (TH) of the OBHE was evaluated using the proposed correlation (Eq. 4) by [20].

$$Thermal\ performance\ (TH) = (\frac{Nu}{Nu_o})/\ (\frac{\Delta P}{\Delta P_o})^{1/3} \quad \textbf{(4)}$$

where *Nu* is the OBR-side Nusselt number, Nu_o is the smooth tube-side Nusselt number at Re_o=0, ΔP is the OBR-side pressure drop (bar) at Re_o>0, and ΔP_o is pressure drop (bar) for the smooth tube at Re_o=0.

3.2.1. Effect of flow rate on TH

Fig. 4 (a and b) shows the flow rate effect on the thermal performance of the HE at a range of Reynolds number 205-3500 and different oscillation values.

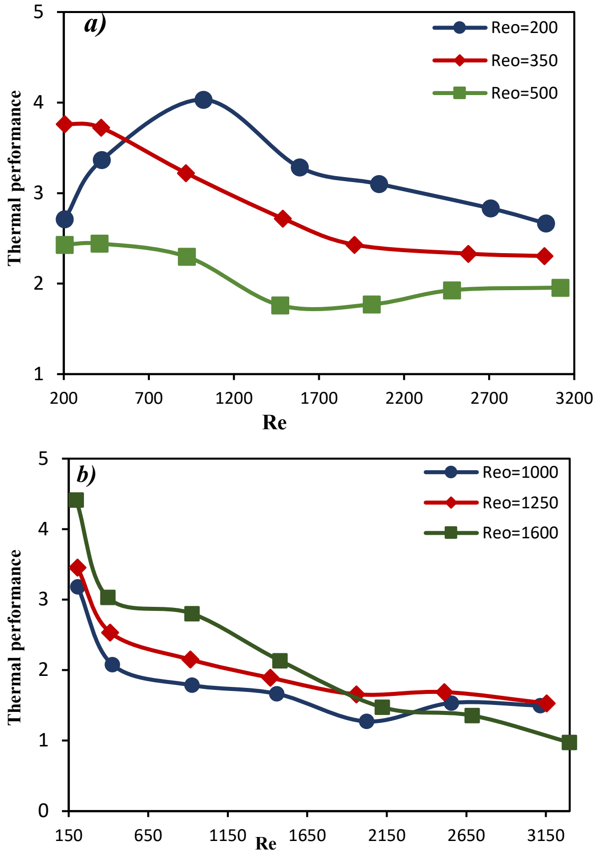

Fig. 4 Effect of Flowrate on the Thermal Performance at Amplitudes = (a) 0,002m, and (b) 0.004m.

As seen from Fig. 4 (a and b), the thermal performance gradually decreased with the flow rate increasing until Re ≈ 2000, when TH became constant. The reduction in TH occurred due to the significant pressure drop due to the initiation of turbulence in the flow. Also, the pressure drop penalty increased faster than the Nu improvement, which increased with Re. As a result, the overall thermal performance decreased. The maximum TH achieved was 4.4 at the lowest oscillation condition and highest flow rate, indicating the dual effect of the flow rate and oscillation on the heat transfer rate and flow pattern [13]. The minimum TH achieved was ≈1.0 at the highest flow rate indicating the lowest effect of oscillation [13-17].

3.2.2. Effect of oscillation on thermal performance

Fig. 5 (a and b) shows the effect of oscillation on the thermal performance of HE for a range of flow rates.

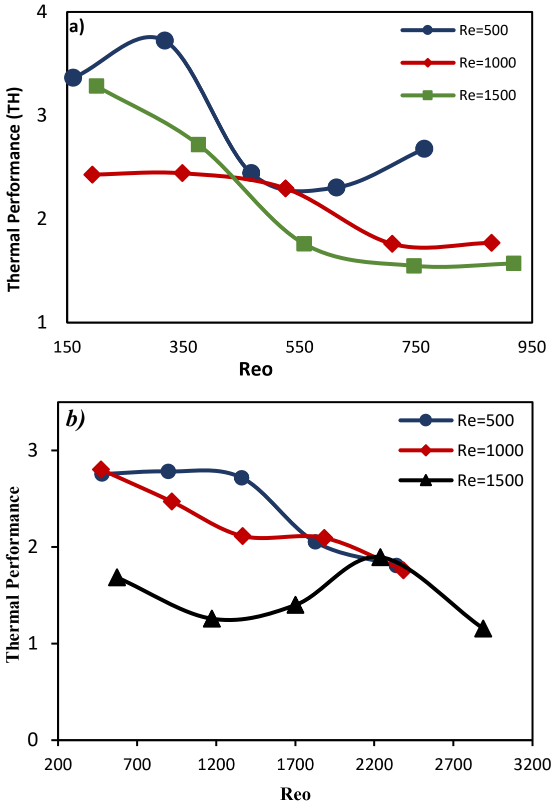

Fig. 5 Effect of Oscillation on Thermal Performance at Amplitudes: (a) 0.004m, and (b) 0.006m.

Fig. 5(a and b) shows that TH decreased as Re_o reached its minimum value, TH=1.5, at Re_o =950 and Re> 1500, indicating the dominance of the flowrate over the flow behavior resulting in a slight effect of oscillation on the heat transfer enhancement [14-17]. In contrast to Fig. 4(a and b), the trends in the thermal performance data in Fig. 4 changed due to the fluid characteristic flow pattern when oscillation was applied, in which vortices were formed [13,18, 19]. However, beyond Re_o=400, TH significantly decreased due to the high intensity of the oscillation, which produced a chaotic flow pattern resulting in low heat transfer enhancement [9,11].

4.CONCLUSIONS

The Nusselt number in a modified design of heat exchanger was experimentally studied over a wide range of Reynolds numbers, Re=205-3200, and oscillatory Reynolds number, Re_o=0-4000. The results showed the importance of adding baffles and oscillations to the heat exchanger to enhance the heat transfer rate. A high value of Nu, 171, was achieved (compared to literature) at Re = 1500 and Re_o = 1500. In addition, at lower flow rates, Re > 2000, the oscillatory flux significantly affected TH as the oscillatory effect gradually decreased for Re>2000. The thermal performance (TH) of the heat exchanger was also investigated. The results showed significant enhancements in Nu at all operating conditions, especially with applying oscillation. It was found that TH decreased with the flow rate and oscillatory flow due to the increase in ΔP due to the mixing intensity increase. The highest TH value achieved was 4.5 at Re=205 and Re_o=1250 indicating the ability of the design used in this study to achieve a significant heat transfer rate.

NOMENCLATURE

Symbol	Description	Unit
Ao	Oscillation amplitude	m
f	Oscillation frequency	Hz
D	Diameter	M
u	Velocity	m/s
Re	Reynolds number	-
Re_o	Oscillatory Reynolds number	-
Nu	Nusselt number	-
TH	Thermal performance	-
HE	Heat exchanger	-
ΔP	Pressure drop	bar
h	Heat transfer coefficient	W/(M^2.K)

Greek letters		
μ	Dynamic viscosity	Pas
ρ	Density	kg/m^3

ACKNOWLEDGEMENTS

The authors are grateful for the financial support towards this research by the Chemical Engineering Department, College of Engineering, Tikrit University. Postgraduate Research Grant (PGRG) No.TU.G/ 2021/ HIR/ MOHE/ENG/39 (2895-7-3).

REFERENCES

[1] Bejan A, Convection Heat Transfer, 2nd ed. New York: John Wiley & Sons, France, 1995.

[2] Moses OP, Ademola D. **Numerical Investigation of the Concave-Cut Baffles Effect in Shell-and-Tube Heat Exchanger**. *Journal of Engineering Sciences* 2019; **6** (1): 1–9.

[3] Uday CK, Satish C. **Modeling for Shell-Side Pressure Drop for Liquid Flow in Shell-And-Tube Heat Exchanger**. *International Journal of Heat and Mass Transfer* 2006; **49**: 601-610.

[4] Nasiruddin MH, Kamran S. **Heat Transfer Augmentation in a Heat Exchanger Tube using a Baffle**. *International Journal of Heat and Fluid Flow* 2007; **28** (2): 318-328.

[5] Chirag M, Jeetendra V, Ramesh A. **The Heat Transfer Enhancement Techniques and their Thermal Performance Factor**. *Beni-Suef University Journal of Basic and Applied Sciences* 2018; **7** (1): 1-21.

[6] Dipankar D, Tarun K, Santanu B. **Helical Baffle Design in Shell and Tube Type Heat Exchanger with CFD Analysis**. *International journal of heat and technology* 2017; **35** (2): 378-383.

[7] Stephens G, Malcolm M. **Heat Transfer Performance for Batch Oscillatory Flow Mixing**. *Experimental Thermal and Fluid Science* 2002; **25**: 583-594.

[8] Stonestreet P, Van Der Veeken P. **The Effects of Oscillatory Flow and Bulk Flow Components on Residence Time Distribution in Baffled Tube Reactors**. *Chemical Engineering Research and Design* 1999; **77**(8): 671-684.

[9] Mazubert A, Fletcher D, Poux M, Aubin J. **Hydrodynamics and Mixing in Continuous Oscillatory Flow Reactors—Part I: Effect of Baffle Geometry**. *Chemical Engineering and Processing: Process Intensification* 2016; **108**: 78-92.

[10] Xiongwei N. **Continuous Oscillatory Baffled Reactor Technology**. *Innovation Pharma Technology* 2006; 20: 90-96.

[11] Mazubert A, Fletcher DF, Poux M, Aubin J. **Hydrodynamics and Mixing in Continuous Oscillatory Flow Reactors—Part II: Characterization Methods**. *Chemical Engineering and Processing: Process Intensification* 2016; **102**: 102–116.

[12] Mackley MR, Stonestreet P. **Heat-Transfer and Associated Energy-Dissipation for Oscillatory Flow in Baffled Tube**. *Chemical Engineering Science* 1995; **50**(1): 2211-2224.

[13] Juan S, Herrero H, Espín S, Anh NP, Adam PH. **Numerical Study of the Flow Pattern and Heat Transfer Enhancement in Oscillatory Baffled Reactors with Helical Coil Inserts**. *Chemical Engineering Research and Design* 2012; **90** (6): 732–742.

[14] Eiamsa-ard S, Yongsiri K, Nanan K, Thianpong K. **Heat Transfer Augmentation by Helically Twisted Tapes as Swirl and Turbulence Promoters**. *Chemical Engineering and Processing: Process Intensification* 2012; 60: 42–48.

[15] González-Juárez D, Herrero-Martín R, Solano J.P. **Enhanced heat transfer and power dissipation in oscillatory-flow tubes with circular-orifice baffles: a numerical study**. *Applied Thermal Engineering* 2018; 141, 494-502.

[16] García A, Vicente P, Viedma A. **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* 2005; **48**(21–22): 4640–4651.

[17] Zhang D, He Z, Guan J, Tang S, Shen C. **Heat Transfer and Flow Visualization of Pulsating Heat Pipe with Silica Nanofluid: an Experimental Study**. *International Journal of Heat and Mass Transfer* 2022; 183: 122100

[18] Muñoz-Cámara J, Solano JP, Pérez-García J. **Non-Dimensional Analysis of Experimental Pressure Drop and Energy Dissipation Measurements in Oscillatory Baffled Reactors**. *Chemical Engineering Science* 2022; 262: 118030.

[19] Muñoz-Cámara J, Solano JP, Pérez-García J. **Experimental Correlations for Oscillatory-Flow Friction and Heat Transfer in Circular Tubes with Tri-Orifice Baffles**. *International Journal of Thermal Sciences* 2020; 156; 106480.

[20] Zimparov V. **Enhancement of Heat Transfer by a Combination of a Single-Start Spirally Corrugated Tubes with a Twisted Tape**, *Experimental Thermal and Fluid Sci* 2002; 25: 535–546.