13th Iranian National Chemical Engineering Congress
& 1st International Regional Chemical and Petroleum Engineering
Kermanshah, Iran, 25-28 October, 2010

A review of single-phase closed loop thermosyphon and simulating with ANSYS CFX

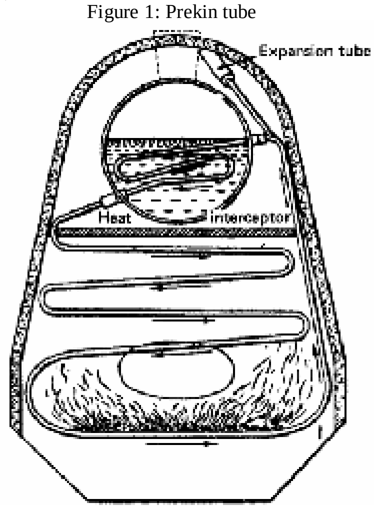
Seyed abdollah shojaie, Farhad Shahraki
Department of Chemical Engineering, University of Sistan and Balouchestan, zahedan, Iran
fshahraki@eng.usb.ac.ir

Abstract
Thermosyphon is an effective system in heat transfer. According to the applications, there are two important types: Open thermosyphon and Closed thermosyphon. In this paper, after a review on theoretical and experimental articles about single-phase loop thermosyphon, considering a single-phase thermosyphon , the influence of diameter on the mean velocity inside the loop is studied using ANSYS CFX software.

Keywords: single-phase closed loop thermosyphon, momentum equation, energy equation, simulation, ANSYS CFX software

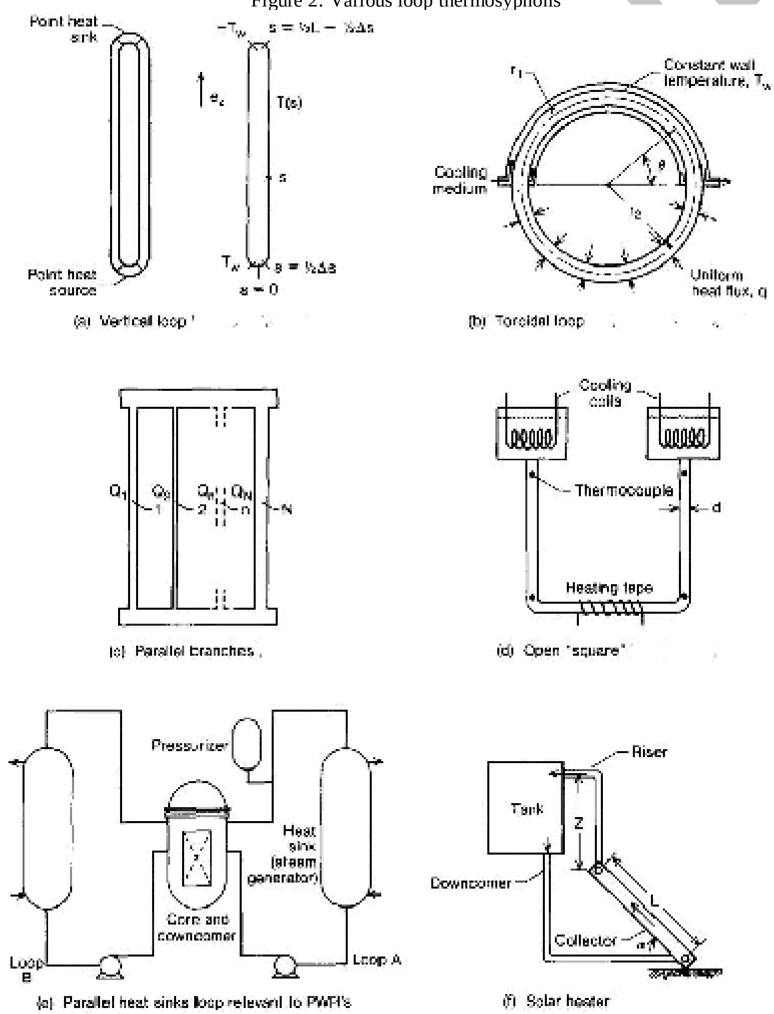
1-Introduction
Thermosyphon refers to a method of passive heat exchange based on natural convection which circulates liquid without the necessity of a mechanical pump. The history of thermosyphon, in particular the version known as the Perkins Tube (figure 1)[1].

Figure 1: Prekin tube



The thermosyphons classify to different types such as : Open thermosyphon, Closed thermosyphon[pipe thermosyphon (single or two-phase flow) and simple loop thermosyphon (single or two-phase flow)] and Closed advanced two-phase flow thermosyphon loop. We want to study single-phase closed loop thermosyphon in this review. A closed loop thermosyphon is a system in which flow is driven by heated and cooled processes. Working fluid is moving fluid inside the loop By suitable choice of working fluid and Container materials, it is possible to construct for thermosyphon use at temperatures ranging from 4K to in excess of 2300K Temperature difference is established in the working fluid inside the loop and consequently a density gradient is created. Thus, the lighter fluid rises and the heavier fluid falls and replaces on it. Applications of closed loop thermosyphons are solar heater, geothermal energy, energy storage, heat rejecting from nuclear reactor cores, cooling internal combustion engines, turbine blades and computers. Design of these engineering applications is needed in modeling of various kinds of thermosyphons. Fig. 2 includes schematics of some loops[2].

Figure 2: Various loop thermosyphons



In this work contain three part. review of theoretical and experimental and simulation by cfd software on single-phase closed loop thermosyphon.

2. Theoretical methods

Y.zivirn[2] presented one dimensional theoretical method. He assumed the average cross section temperature, T, is equal to the mixed mean (or bulk) temperature. Thus, he presented follow momentum and energy equations:

Momentum equation:

$$r_0 \frac{\partial u}{\partial t} = \frac{\partial p}{\partial s} - r\, g\, \hat{e}_z \,.\hat{e}_s - 4\frac{t_W}{d_H} \tag{1}$$

Energy equation:

$$r_0 c\left(\frac{\partial T}{\partial t} + u\,\frac{\partial T}{\partial s}\right) - k\,\frac{\partial^2 T}{\partial s^2} = 4\frac{q}{d_H} - 4\frac{h}{d_H}(T - T_0) + \frac{1}{A}\int \Phi\, dA \tag{2}$$

Then he could predict transient and steady state behavior of flow in thermosyphon and found that it is quite difficult to compare between various theoretical results, especially for different loops, and between theory and data. The reason is the lack of scaling laws or a general approach for chosen characteristic quantifies and dimensionless parameters. The first attempt in this direction has been made here .Finally, the existing analytical and numerical methods representing natural circulation loops are one-dimensional. The flows, however, have been observed to give rise to three-dimensional effects. These should be taken into account in future work, by more detailed analysis, using the three-dimensional conservation equations, and by more sophisticated experiments, including measurements of transverse velocity and temperature distributions.

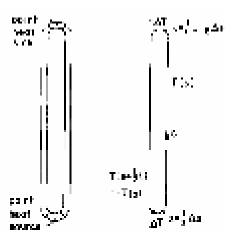
A transient behavior natural circulation is studied by Y.Zivirn and R.Greif[3]. They reported non-dimensional momentum and energy equations (eq. 3,4) and could model transient behavior loop thermosyphon. The loop is considered here shown in Fig. 3.

$$\frac{dQ}{dt} + eQ = a\int_0^1 T\, ds \tag{3}$$

$$\frac{\partial T}{\partial t} + Q\,\frac{\partial T}{\partial s} = 0 \qquad 0 \langle s \langle 1 \tag{4}$$

$$a = \frac{g\, b \Delta T L}{2(K\,\Delta s)^2} \qquad\qquad e = \frac{RL}{2K\,\Delta s}$$

Figure 3: The loop of two vertical branches, a point heat source and a point heat sink



EDUARDO RAMOS et al[4] presented a steady state analysis for variable area one-two thermosyphon loop. With presenting of governing equations on loop themosyphon, They could model single or two-phase closed loop themosyphon. They assumed direction of flow is one dimensional and in single phased equation 3 is established.

$$r = r_0[1 - b(T - T_0)] \quad (5)$$

$$m\frac{de}{dx} = q + \frac{uAp}{r}\frac{dr}{dx} + Aku^2 \quad (6)$$

$$ru\frac{du}{dx} = -\frac{dp}{dx} - ku - \bar{g}\,r \quad (7)$$

$$r_0u\frac{du}{dx} = -\frac{dr}{dx} - ku - \bar{g}\,r_0[1 - b(T - T_0)] \quad (8)$$

By integrating of differential equations is calculated the amount of heat flax and velocity in the loop.

A torodial thermosyphon is presented by E. WACHOLDER et al[5]. They considered some assumptions for this case such as: Axial heat conduction in the energy conservation equation is neglected, Gravity is the only significant body force, Temporal derivative of pressure term in the energy equation is ignored and etc. then by this assumption they presented follow governing equations:

$$\frac{\partial r}{\partial t} + \frac{1}{R}\frac{\partial G}{\partial q} = 0 \quad (9)$$

$$\frac{\partial G}{\partial t} + \frac{1}{R}\frac{\partial M}{\partial q} + \frac{1}{R}\frac{\partial P}{\partial q} + \frac{4f\,|G|G}{2rD_e} + rg\sin q = 0 \quad (10)$$

$$\frac{\partial(rH)}{\partial t} + \frac{1}{R}\frac{\partial E^*}{\partial q} = 2q''/r \quad (11)$$

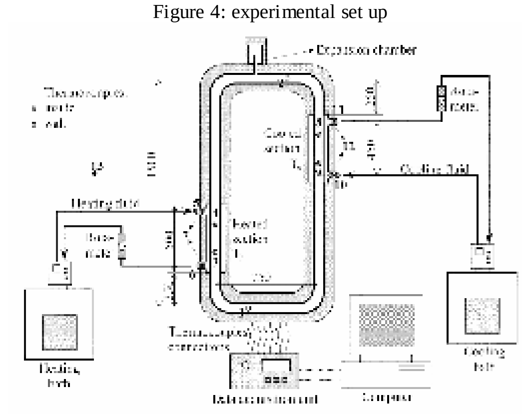
These equations are solved by numerical methods and compared with experimental results available. They obtained a good agreement between the present predictions and experimental results available in the literature.

3-Experimental work on single-phase loop thermosyphons

Tahsin basran and serhan Kucuka[6] studied of a single-phase closed loop thermosyphon using experimental and numerical techniques. In this study they showed that there's numerical analysis was appropriate for estimating the heat transfer and the flow characteristics of the loop at the uniform wall temperature.

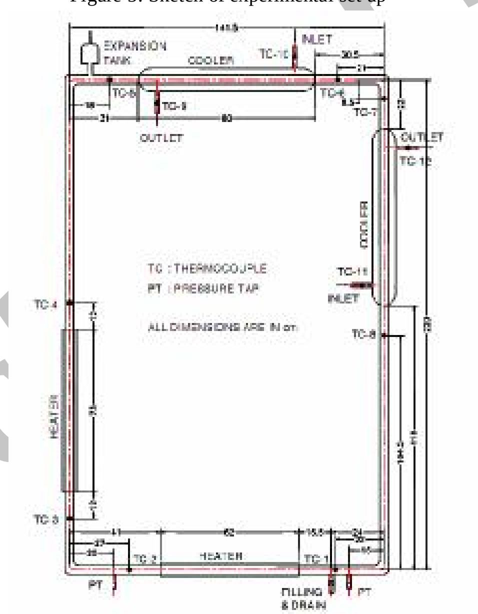
In the fig.4 is shown the experimental apparatus.

Figure 4: experimental set up



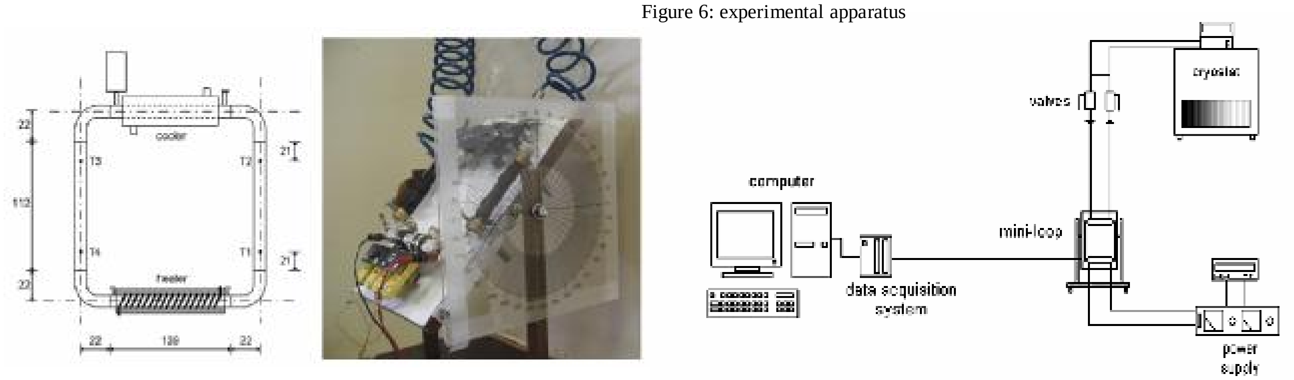
They perused laminar flow in the loop in another article.[7]
A single-phase rectangular closed loop thermosyphon ,with different situation of hot and cold sections, is studied by D.S. Pilkhwal et al[8]. They modeled this system with one-dimensional and computational fluid-dynamic models. The apparatus is shown in fig. 5.

Figure 5: Sketch of experimental set up



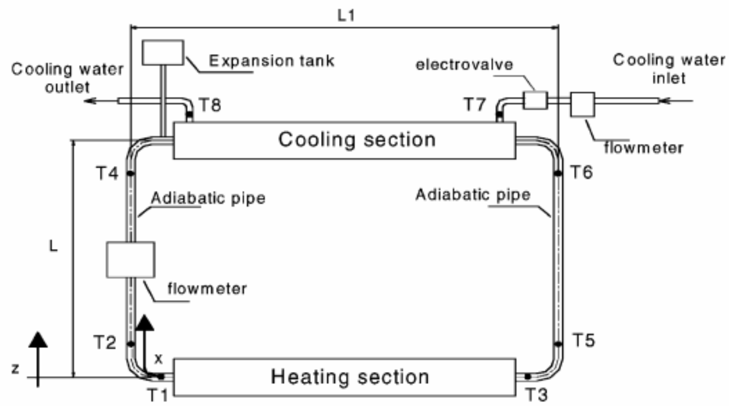
M. Misale et al.[9] presented a single-phase natural circulation mini-loop. In this study, The parameters investigated during the experiments were: power transferred to the fluid and inclination of the loop. The experimental device is shown in fig. 6.

Figure 6: experimental apparatus



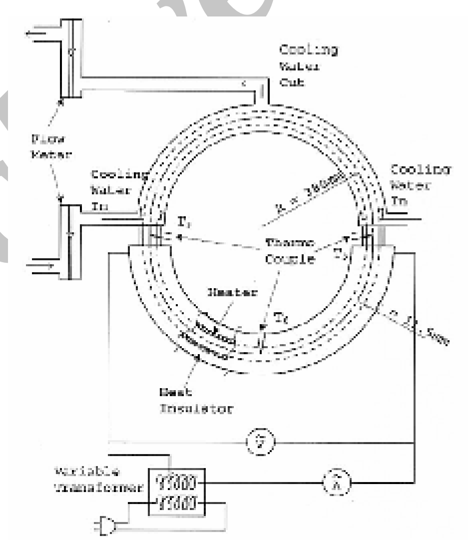
A rectangular natural circulation loop is studied by A. Fichera and A. Pagano[10]. There's aim from this paper is to address the problem of suppressing unstable dynamics occurring in rectangular natural circulation loops on the base of a reliable model-based controller. The experimental setup is shown fig.7.

Figure 7: Schematic of the experimental rectangular circulation loop



Yu Yan Jiang et al[11] perused boundary condition e ects on the flow stability in a toroidal thermosyphon. The device of this work is shown fig.8.

Figure 8: Schematic of the experimental set up

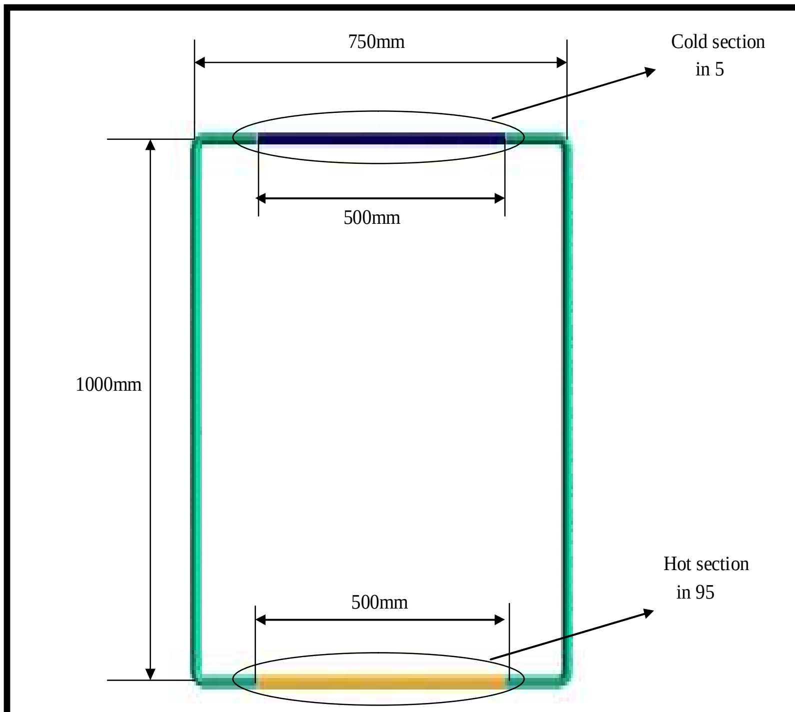


4- simulation by CFX software

Whereas this software capability is high to predict distribution temperature and velocity inside loop but there was no efficient work in this subject. CFD software can simulate different shapes of closed loop thermosyphon and two or three dimensional and one or two phase flow. This software can solve governing equations in transient and steady states.

D.S. Pilkhwal et al.[8] studied the unstable behavior of a single-phase natural circulation loop by CFD. They viewed CFD models indeed provide improved modeling capabilities which are quite promising for solving the classical problems raised by the use of 1D codes.
We simulated assumed single phase closed loop thermosyphon with follow characteristics (fig.9).

Figure 9.assumed closed loop thermosyphon



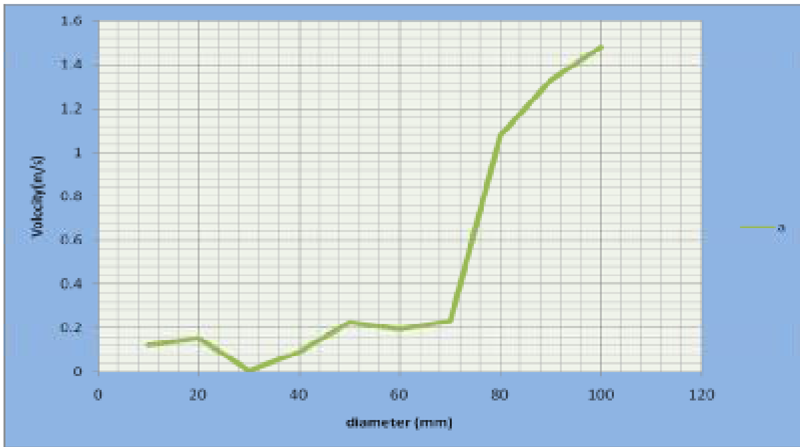
This thermosyphon is simulated in 3D and water is as working fluid in the steady state ,temperature of cooled part is 5 and of hot part is 95 and both of them is constant. Chosen diameters is shown in table 1.

Table 1. the characteristics of themosyphons

Cases	Diameter (mm)	Length of cold section(mm)	Length of hot section(mm)	Temp. of cold section( )	Temp. of hot section( )	Working fluid
1	10	500	500	5	95	water
2	20	500	500	5	95	Water
3	30	500	500	5	95	Water
4	40	500	500	5	95	Water
5	50	500	500	5	95	Water
6	60	500	500	5	95	Water
7	70	500	500	5	95	Water
8	80	500	500	5	95	Water
9	90	500	500	5	95	Water
10	100	500	500	5	95	Water

Here, we perused effect of varies of diameter of loop on velocity variety in closed loop thermosyphon by CFD software and viewed increasing of diameter would cause increasing the amount of velocity, often(fig.10).

Figure 10. Variation velocity va diameter



Conclusion

Thermosyphone is a kind of heat exchanger. There have been many studies on thermosyphones due to their wide applications in many fields such as solar energy, solar heater, heat rejecting from nuclear reactor cores, cooling internal combustion engines, turbine blades and etc. In this paper, some theoretical and experimental works which has been already done on the single-phase loop thermosyphones, is reviewed. A loop thermosyphone is a system which is capable of conducting heat to a far region using only buoyancy forces.

In the fourth part, using ANSIS CFX SOFTWARE, a closed loop thermosyphone whose operative liquid is water, was investigated. The results show that in general, increasing the thermosyphone diameter, causes increasing the operative fluid velocity without changing the boundary conditions.

Studying thermosyphone as a main part of thermal process in the solar heating thermally and hydrodynamically is notable. Using CFX SOFTWARE for prediction of different models, both time and cost would be reduced.

NOMENCLATURE

, cross section of the loop; A
, specific heat; c
, hydraulic diameter; D_e
, hydraulic diameter; d_H
, energy flux along loop axis; E^*
, unit vector in s direction; $\hat{e}_s$
, unit vector in vertical(z) direction; $\hat{e}_z$
, friction factor for axial flow; f
, acceleration due to gravity; g
, axial mass velocity; G
, enthalpy; H
, heat transfer coefficient; h
, thermal conductivity; k
, defined by $h/\rho_0 cA$; K
, length; L
, momentum flux along loop axis; M
, pressure; P
, heat flux; q''
, volumetric flow rate; Q
, major radius of torus; R
, minor radius of torus; r
, coordinate along the loop; s
, temperature inside the loop; T
; time; t
, reference ambient temperature; T_0
, mean velocity inside loop; u

Greek symbols

, dissipation function; Φ
, dimensionless parameter; a
, thermal expansion coefficient; b
, dimensionless parameter; e
, angular coordinate along the loop; q
, density; r
, density in reference temperature; r_0
, shear stress at the wall; t_W

References

[1] D.A. Reay, P.A. Kew, Heat Pipes, fifth ed, Elsevier, Great Britain, 2006.

[2] Yoram ZVIRIN, A REVIEW OF NATURAL CIRCULATION LOOPS IN PRESSURIZED WATER REACTORS AND OTHER SYSTEMS, Nuclear Engineering and Design 67 (1981) 203-225.

[3] Y. ZWRIN, R. GREIF, TRANSIENT BEHAVIOR OF NATURAL CIRCULATION LOOPS: TWO VERTICAL BRANCHES WITH POINT HEAT SOURCE AND SINK, In: J. Heat Mass Transfer (1979). Vol. 22. pp 499-504.

[4] EDUARDO RAMOS, MIHIR SEN, CESAR TREVINO, A steady-state analysis for variable area one- and two-phase thermosyphon loops, Int. J. Heat Mass Transfer,(1985). Vol. 28, No.9,pp. 1711-1719

[5] E. WACHOLDER, S. KAIZERMAN, E. ELIAS, NUMERICAL ANALYSIS OF THE STABILITY AND TRANSIENT BEHAVIOR OF NATURAL CONVECTION LOOPS, Int. J. Engng Sci (1982). Vol. 20, pp. 1235-1254.

[6] Tahsin basran, serhan Kucuka, Flow through a rectangular thermosyphon at specified wall temperature, Int. Comm. Heat Mass Transfer (2003), Vol. 30, pp. 1027-1039.

[7] Tahsin basran, serhan Kucuka, Laminar flow modelling of a thermosyphon loop at specified wall temperatures, Heat Mass Transfer (2007), Vol. 43, pp.1203-1302.

[8] D.S. Pilkhwal, W. Ambrosini, N. Forgione, P.K. Vijayan, D. Saha, J.C.Ferreri, Analysis of the unstable behavior of a single-phase natural circulation loop with one-dimensional and computational fluid-dynamic models, Annals Nuclear Energy (2007), Vol. 34, pp. 339-355.

[9] M. Misale, P. Garibaldi, J.C. Passos, G. Ghisi de Bitencourt, Experiments in a single-phase natural circulation mini-loop, Experimental Thermal and Fluid Science 31 (2007) 1111–1120.

[10] A. Fichera, A. Pagano, Modelling and control of rectangular natural circulation loops, International Journal of Heat and Mass Transfer 46 (2003) 2425–2444.

[11] Yu Yan Jiang, Masahiro Shoji, Masashi Naruse, Boundary condition e ects on the flow stability in a toroidal thermosyphon, International Journal of Heat and Fluid Flow 23 (2002) 81–91.

مروری کلی بر ترموسیفون حلقوی بسته تک فازی و شبیه سازی با ANSYS CFX

سید عبدالله شجاعی[1]، فرهاد شهرکی[2]
گروه مهندسی شیمی، دانشگاه سیستان و بلوچستان، زاهدان، ایران
fshahraki@eng.usb.ac.i

چکیده

ترموسیفون سیستمی موثر جهت انتقال حرارت می باشد. با توجه به کاربرد، ترموسیفون ها به دودسته مهم ترموسیفون های باز و ترموسیفون های بسته تقسیم بندی می شوند. در این مقاله برآنیم تا نگاهی کلی بر مقالاتی که بصورت تئوری و تجربی در زمینه ترموسیفون حلقوی تک فازی ارائه شده اند، بیاندازیم. در پایان نیز با در نظر گرفتن یک ترموسیفون حلقوی بسته تک فازی، اثر قطر بر روی سرعت متوسط در داخل لوله توسط نرم افزار ANSYS CFX مورد بررسی قرار گرفته است.

واژه‌های کلیدی: ترموسیفون حلقوی بسته تک فازی، معادله ممنتوم، معادله انرژی، شبیه سازی، نرم افزار ANSYS CFX

1- دانشجوی کارشناسی ارشد مهندسی شیمی دانشگاه سستان و بلوچستان
2- دانشار گروه مهندسی شیمی دانشگاه سستان و بلوچستان

A review of single-phase closed loop thermosyphon and simulating with ANSYS CFX

Seyed abdollah shojaie, Farhad Shahraki
Department of Chemical Engineering, University of Sistan and Balouchestan, zahedan, Iran
fshahraki@eng.usb.ac.ir

Abstract
Thermosyphon is an effective system in heat transfer. According to the applications, there are two important types: Open thermosyphon and Closed thermosyphon. In this paper, after a review on theoretical and experimental articles about single-phase loop thermosyphon, considering a single-phase thermosyphon , the influence of diameter on the mean velocity inside the loop is studied using ANSYS CFX software.

Keywords: single-phase closed loop thermosyphon, momentum equation, energy equation, simulation, ANSYS CFX software