Heat Transfer and Fluid Flow over Wavy Channel or Surface

Amber Diwan[1] Surjeet Singh Chuohan[2]
[1,2]Department of Mechanical Engineering
[1,2]Scope College of Engineering Bhopal, India

Abstract— This paper concentrates to extensive review on the fluid flow and heat transfer over an wavy surface and channel. Wavy surfaces and channel have been employed in many environmental and industrial applications. The key factor for adopting such shaped (wavy) instead of using flat surface is due to improving the mass and heat transfer mechanisms, associated with large pressure variations.
Fundamentally, the fully developed flow over a wavy surface, in either laminar or turbulent regime, is much further complex than that over a flat surface because of the additional parameters to be utilized and the correlated flow phenomena to be deduced. Numerous researches perform numerical-computation simulations and experimentation in order to explore the flow characteristics over wavy surfaces are stated in this paper.
Key words: Wavy surface, Laminar, Turbulent, Pressure Drop

I. Introduction

Wavy wall flows take place under extensive variety of engineering applications and have, consequently, received significant interest [1–2]. One of the mainly imperative applications is the heat transfer enhancement in heat exchangers. The physical process of improving heat transfer in such relevance is to introduce some geometrical alterations on the wall in question with the intention of break the boundary layer that forms on the exchanger wall and reinstate it by a fresh fluid commencing the free stream flow [3]. In existent applications, engineers are also concerned in the additional pressure drop originated by such techniques. So, the best way out is that provides the least pressure drop and the largest heat transfer rate. Other parameters such as manufacturability, simplicity, maintenance, etc., are also significant parameters in the design period [3].

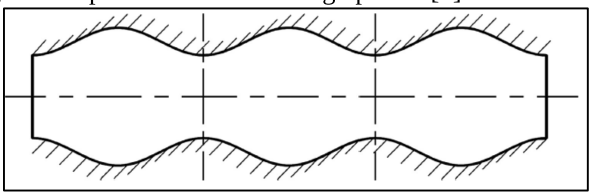

Fig. 1: Geometry of the wavy channel

II. Mathematical Modelling

For the fluid flow through pipe, duct and channel the conventional governing equations are the Navier–Stokes equations can be written in the most useful form for the development of the finite volume method:

$$\rho \frac{Du}{Dt} = -\frac{\partial p}{\partial x} + div(\mu\, grad u) + S_{Mx} \quad (1)$$

$$\rho \frac{Dv}{Dt} = -\frac{\partial p}{\partial y} + div(\mu\, grad v) + S_{My} \quad (2)$$

$$\rho \frac{Dw}{Dt} = -\frac{\partial p}{\partial z} + div(\mu\, grad w) + S_{Mz} \quad (3)$$

Governing equations of the flow of a compressible Newtonian fluid

A. *Continuity*

$$\frac{\partial \rho}{\partial x} + div(\rho u) = 0$$

B. *x-momentum*

$$\frac{\partial(\rho u)}{\partial x} + div(\rho u u) = -\frac{\partial p}{\partial x} + div(\mu\, grad u) + S_{Mx} \quad (4)$$

C. *y-momentum*

$$\frac{\partial(\rho v)}{\partial y} + div(\rho v u) = -\frac{\partial p}{\partial y} + div(\mu\, grad v) + S_{My} \quad (5)$$

D. *z-momentum*

$$\frac{\partial(\rho w)}{\partial z} + div(\rho w u) = -\frac{\partial p}{\partial z} + div(\mu\, grad w) + S_{Mz} \quad (6)$$

E. *Energy*

$$\frac{\partial(\rho i)}{\partial t} + div(\rho i u) = -p\, div u + div(k\, grad T) + \Phi + S_i \quad (7)$$

Using various correlation FEV results are been compared analytically

$$h_f = f \frac{LV^2}{D_h 2g}$$

Where,
f is the friction factor for fully developed laminar flow
L: length of the channel, duct, pipe
V: mean velocity of the flow
d: diameter of the pipe
f is the friction factor for fully developed laminar flow:

$$f = \frac{64}{Re} \text{ (For Re<2000)} \quad Re = \frac{\rho u_{avg} d}{\mu}$$

C_f is the skin friction coefficient or Fanning's friction factor.

For Hagen-Poiseuille flow: $C_f = \tau_{wall} / \frac{1}{2} \rho u_{avg}^2 = \frac{16}{Re}$

For turbulent flow: $\frac{1}{\sqrt{f}} = 1.74 - 2.0 \log_{10}\left[\frac{\varepsilon_p}{R} + \frac{18.7}{Re\sqrt{f}}\right]$

Moody's Chart

R: radius of the channel, duct, pipe
ε_p: degree of roughness (for smooth channel, duct, pipe, $\varepsilon_{p=0}$)
$Re \to \infty$: Completely rough channel, duct, pipe.

III. Literature Survey

Dellil et al.[4] applied eddy viscosity turbulence model for the numerical modeling of convective heat transfer and turbulent flow over a wavy wall. Using k–ε turbulence model in the outer core flow with a one equation model for determine the near-wall region. It was observed that the two-layer model is successful been implemented and reveals the important physical features of a turbulent flow over a wavy wall with reasonable amount of memory storage and save computational time. The forecasted results show the inadequacies of the standard law of the wall for calculating such category of flows and thus recommend that direct assimilations to the wall must be used instead. Furthermore, Comparison of the obained results of a wavy surface with that of a straight channel indicates that the averaged Nusselt number increases until a critical value is reached where the amplitude wave is amplified. However, this heat transfer enhancement is accompanied by an increase in the pressure drop.

Sadia et al. [5] perform numerical investigation for irregular semi-infinite triangular wavy horizontal surface which is subjected to natural convection. In order to transform the boundary layer equation in to simplified form Coordinate transformation has been introduced. For obtaining solution for a simplified equation implicit finite difference iterative numerical scheme has been utilized

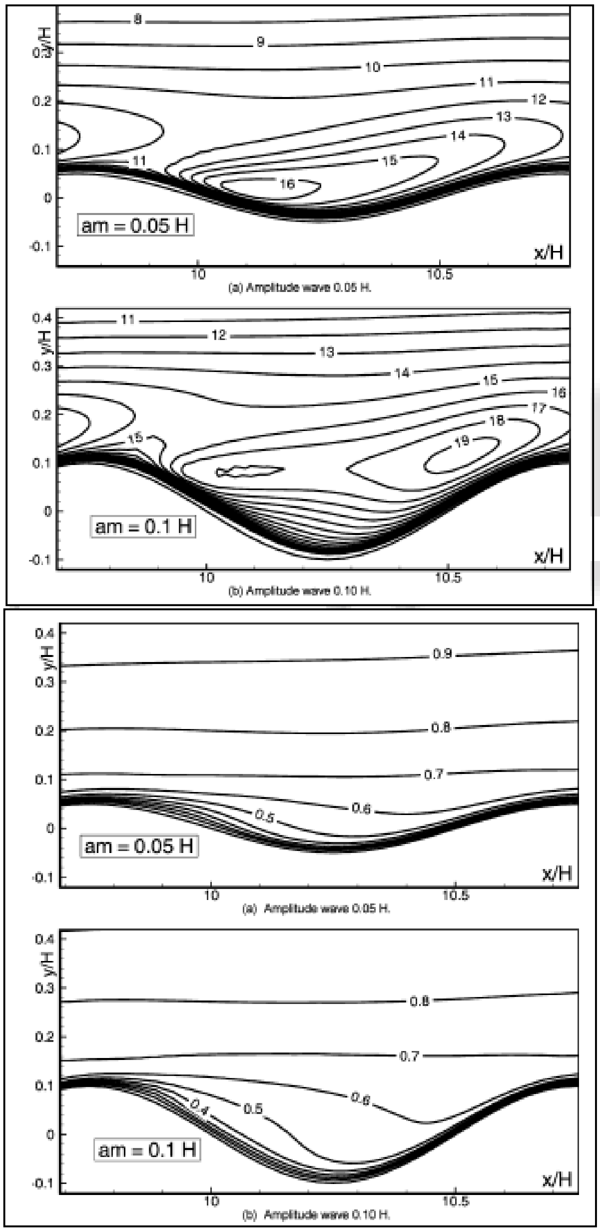

Fig. 2: Contours of turbulence intensity and a dimensional temperature [4]

The effect of amplitude on various flow characteristics such as skin friction, streamlines heat transfer rate and isotherms are examined and presented graphically. On the basis of obtained result they conclude that the amplitude of the wavy surface play significant role in enhancement in the heat transfer rate but it is complicated to accomplish numerical computations for a > 1.5. Hence, it has been concluded that heat liberation is more effective in sinusoidal wavy surface as compared to triangular surface.

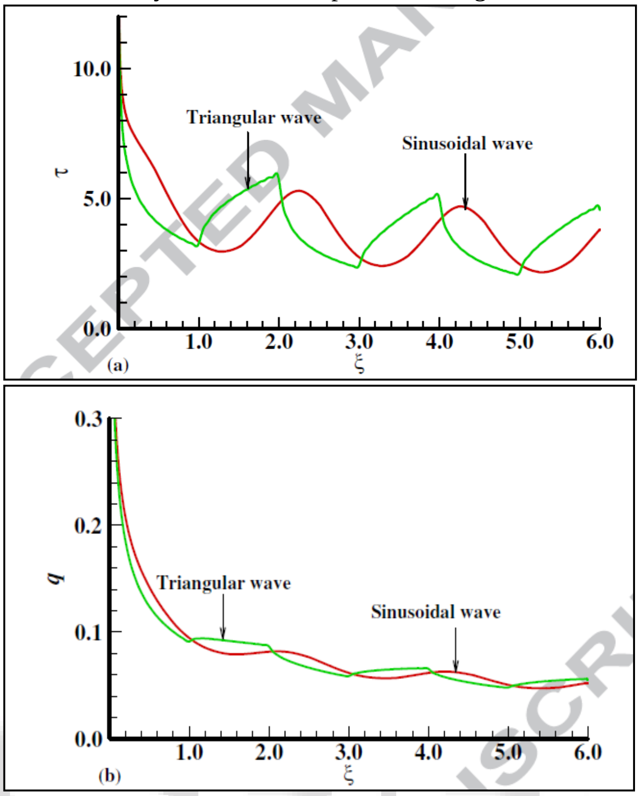

Fig. 3: Comparison of triangular wave and sinusoidal wave for a = 0.3, Pr = 0.02 and ω = π[5]

Stone and Vanka [6] perform transient state analysis for wavy channel consisting of 14 waves using a numerical scheme that solves the 2D energy equations. For wide range of Reynolds numbers Time-dependent simulations has been carried out. It is found that at low Reynolds number the flow is steady but on increasing Reynolds number the flow becomes unsteady which leads to increase in mixing between the wall fluids and core, thus increases the heat transfer rate.

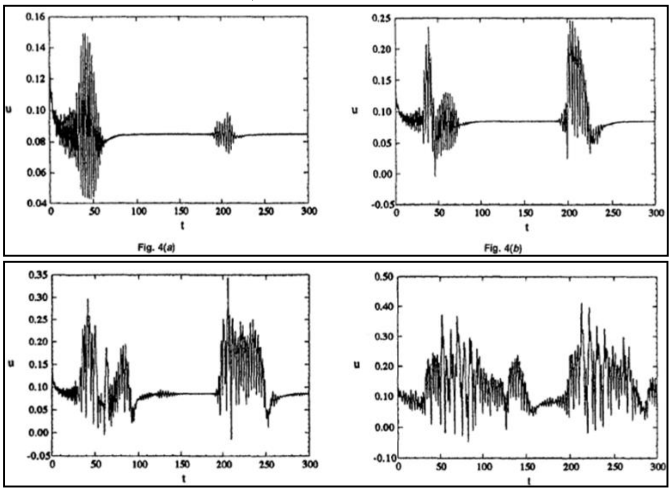

Fig. 4: Time signals for u-veiocity at Re = 300: (a) wavy section 8; (b) wavy section 10; (c) wavy section 12; (d) wavy section 14[6]

Hafez et al.[7] investigates the turbulent flow over a sinusoidal solid surface using two versions of the standard k–

e turbulence model for examining the mainstream where periodic pressure gradient, successive acceleration and deceleration associated with multiple fluid flow separations and reattachments takes place. In order to verify the obtained results an exclusive comparison has been made between DNS and experimental

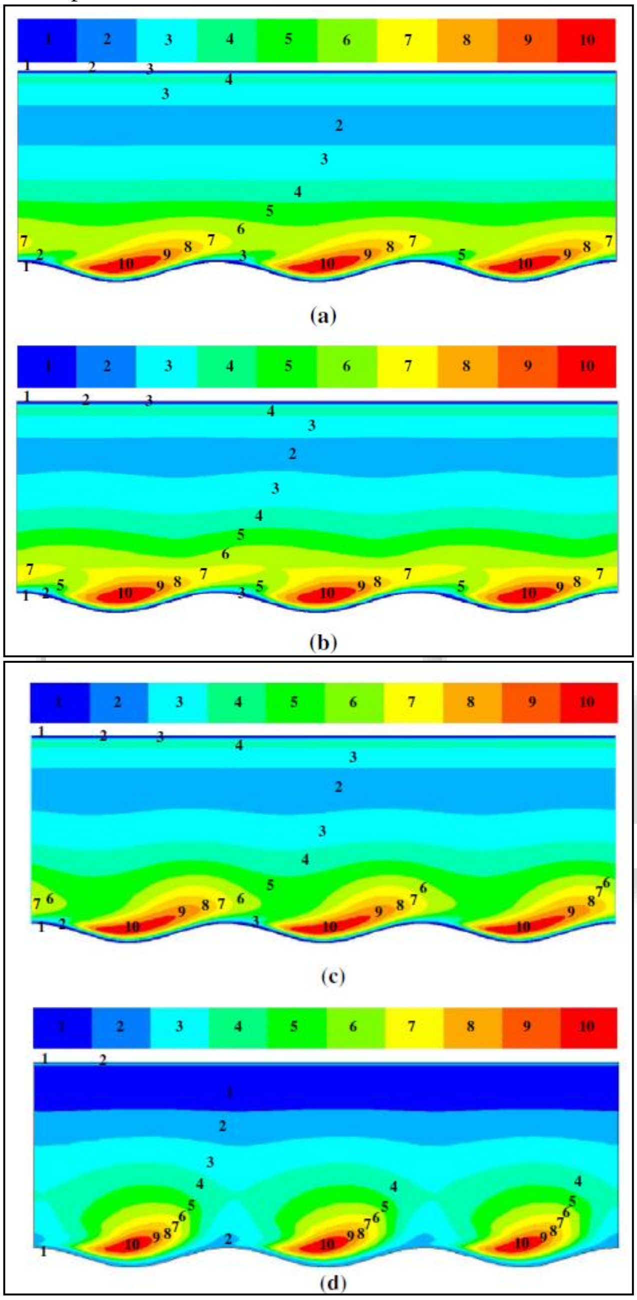

Fig. 5: Contours of turbulence intensities for the case of EWF (a= 0.05H, Re= 6760): (a) $2k=U^2b$; (b) $u0u0=U^2b$; (c) $u0v0=U^2b$; (d) $u^0v^0=U^2b$.[7]

Patel et al. [8] describe steady flow in a two-dimensional channel with a wavy wall using numerical method for to solve Reynolds-averaged Navier-Stokes equations along with two-layer turbulence model. The effects of alternating pressure gradients induced by alternating surface curvatures, and multiple separations and reattachments has been illustrated by comparing the obtained result with experimental work. The numerical scheme and the turbulence model are demonstrates the overall features of such a flow, comprising the collapse of the logarithmic law of the wall due to strong pressure gradients and due to separation in flow.

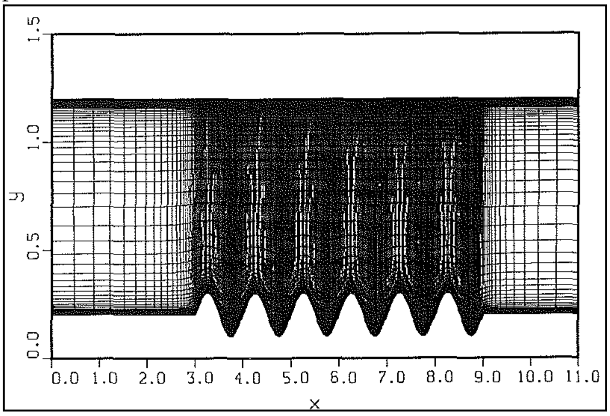

Fig. 6: Solution domain and grid for 2a/A = 0.20 [8]

Jafar [9] propose a flow modeling in a baffle-fitted one millimeter labyrinth-channel. It has found that the classical turbulent models didn't replicate the characteristics ofa low Reynolds number flow. One of the chief applications of their work is for understanding the hydrodynamics of micro-irrigation emitters. certainly, one of the major drawbacks of this method is the clogging of the emitters; and this clogging is strongly related with the flow conditions. In their paper, the results of three low Reynolds number models are evaluated with those of the standard k-ε, and the RNG k-ε . Remarkable differences are observed between the different low Reynolds number models. This work raises questions about the dissipation process and its role in such a flow.

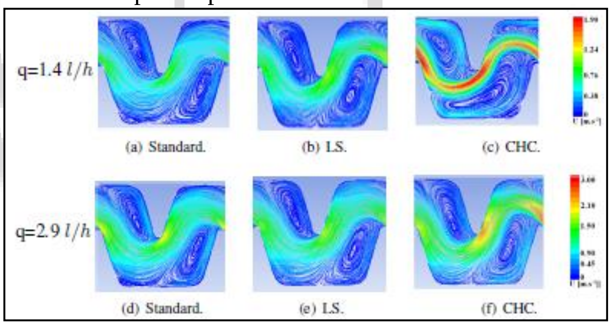

Fig. 7: velocity fields [9]

Selvaraja et al. [10] develop a numerical procedure for examining the fluid motion during flow in a channel. The boundary conditions are applied at the mean surface of the channel and the primitive variables are inflated in a series with the wall amplitude as the perturbation parameter using pseudo-spectral collocation method the key attribute of this method is not restricted by the reynolds number of the flow and the wave number and frequency of the wavy-walled channel. The obtained result shows the and wall shear stresses, reattachment, the positions of flow separation and variation of velocity and pressure with frequency of excitation are well presented.

Assato and Lemos [11] examines the performance of linear and nonlinear eddy-viscosity models when employed to calculate the turbulent flow in periodically sinusoidal-wave channels. Two geometries are examined, namely a channel with concave-convex walls and a converging-diverging channel. The numerical method utilized for the discretization of the equations is the control-volume method in a boundary-fitted non-orthogonal coordinate system. The SIMPLE algorithm is exercised for correcting the pressure field. The flows near the wall are described by classical wall function and a low Reynolds model. Comparisons between those two approaches using nonlinear and linear turbulence models are stated. Here, a new implicit numerical treatment has been proposed for the nonlinear diffusion terms of the momentum equations in order to amplify the robustness. The obtained results shows that by decomposing and treating terms as presented, solutions using nonlinear models and the high Reynolds wall treatment, which combine accuracy and economy, are more stable and easier to be obtained.

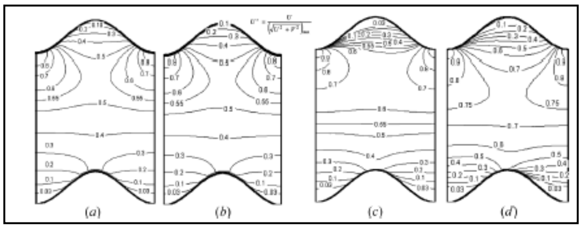

Fig. 8: Dimensionless velocity distribution U for the channel with concave-convex walls. (a) L HRN; (b) NL HRN; (c) L LRN; and (d) NL LRN. [11]

Hang et al. [12] simulates the large eddy of turbulent flow and heat transfer in a channel with one wavy wall for prandtl number 0.7 and the wall wave amplitude has been changed in three steps. Has been observed that increasing the wall wave amplitude, a flow separation bubble comes to appear and a separated turbulent shear layer develops above the separation bubble. Moreover, in the up-slope region of the bottom wavy wall, near-wall stream-wise vortices are generated with huge quantity these two characteristics play an vital role for the heat and momentum transfer near the wavy wall. So, the characteristics of the near-wall streamwise vortices and the separated shear layer are well illustrated in relation to the turbulent heat transfer.

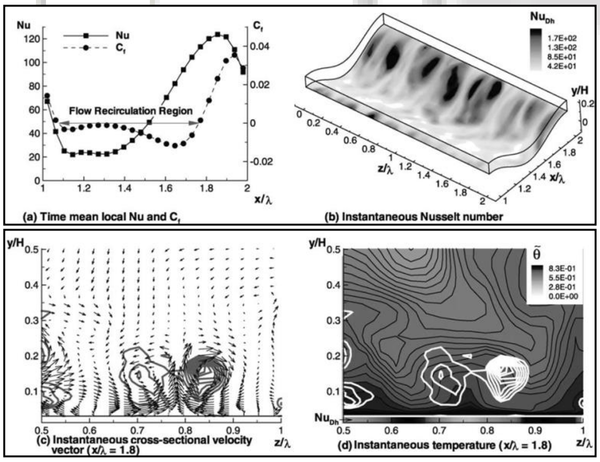

Fig. 9: Time mean local quantities and instantaneous turbulent flow and thermal fields in the case of W01 [12]

IV. CONCLUSIONS

- In comparison with straight surface wavy surface creates much turbulence at higher Reynolds number.
- The averaged Nusselt number increases until a vital value is attained where the amplitude is increased of the wave of wavy surface or channel.
- The pressure drop can be reduced by implementing wavy surface instead of flat surface.
- On reduce pitch distance between the two wave the rate of heat transfer can be amplified.
- Increasing the number of wave in the channel increases the rate of turbulence intensity.
- the separation of shear layer and the formation of vortex at near-wall stream, play an important role for the heat and momentum transfer near the wavy surface.
- Increasing wavy amplitude the better heat transfer can be achieved.

V. RESULT

Using Ansys fluent the governing equation of channel and channel with wavy surface i.e. The Navier stokes continuity equation has been solved. On the basis of this FEV work the hydrodynamic characteristic of channel and channel with wavy surface has been evaluated with a grid size of 10^6 shows good agreement during the grid dependence test. Moreover, the performance of channel and channel with wavy surface are illustrated in the corresponding results.

The precision of obtained results has been validated by comparing the present result with available literature of Cokljat and S.E. Kim and kuzan whose works are based on experimental, analytical and FVM results.

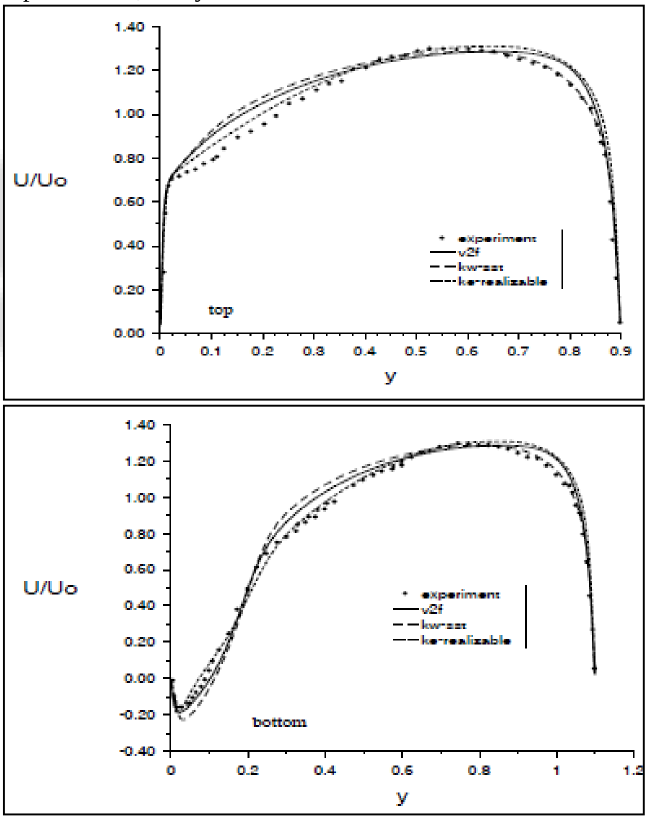

Fig. 10: Velocity profile of wavy channel

REFERENCES

[1] Vijay KG; Maji PK (1988) Laminar flow and heat transfer in a periodically converging diverging channel. Int J Numer Meth Fluids 8: 579–597
[2] Patel VC; Tyndall Chon J; Yoon JY (1991) Turbulent flow in a channel with a wavy wall. J Fluids Eng 113: 579–586
[3] Wang G; Vanka SP (1995) Convective heat transfer in periodic wavy passages. Int J Heat Mass Transfer 38(17): 3219–3230

[4] A.Z. Dellil, A. Azzi, B.A. (2004) Jubran, Turbulent flow and convective heat transfer in a wavy wall channel, Heat and Mass Transfer 40, 793–799
[5] Sadia Siddiqa, M. Anwar Hossain, Rama Subba Reddy Gorla (2014), Natural convection flow of viscous fluid over triangular wavy horizontal surface, http://dx.doi.org/10.1016/j.compfluid.2014.10.001
[6] K stone and Vanka, (1999) Numerical Study of Developing Flow and Heat Transfer in a Wavy Passage, Journal of Fluids Engineering, 121, 713-719
[7] K.A. Hafez, O.A. Elsamni, K.Y. Zakaria (2011), Numerical investigation of the fully developed turbulent flow over a moving wavy wall using k–e turbulence model, Alexandria Engineering Journal 50, 145–162
[8] V.C Patel, J. T. Chon, J.Y Yoon (1999,), Turbulent Flow in a Channel With a Wavy Wall, Journal of Fluids Engineering,, 113, 579-586
[9] Jafar AL-MUHAMMAD, S´everine TOMAS and Fabien ANSELMET, Modeling a weak turbulent flow in a narrow and wavy channel: case of micro irrigation, 21eme Congr`es Franc¸ais de M´ecanique Bordeaux, 26 au 30 aoˆut 2013
[10] S. Selvarajan, E.G. tulapurkara and V. Vasanta ram, (1998) A Numerical study of flow through wavy-walled channels, international journal for numerical methods in fluids, vol, 26, 519-531
[11] Marcelo Assato a & Marcelo J. S. de Lemos (2009), Turbulent Flow in Wavy Channels Simulated with Nonlinear Models and a New Implicit Formulation, Numerical Heat Transfer, Part A, 56: 301–324, 2009
[12] Hang Seok Choi , Kenjiro Suzuki (2005), Large eddy simulation of turbulent flow and heat transfer in a channel with one wavy wall, International Journal of Heat and Fluid Flow 26, 681–694G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. (references)