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Effect of non-uniform temperature distribution on entropy generation and enthalpy for the laminar developing pipe flow of a high Prandtl number fluid

Reza Kakulvand [a,]*

[a]*Department of Chemical Engineering, Sistan and Baluchestan University, Zahedan, Iran*

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ABSTRACT

In this article, Entropy generation and enthalpy are investigated on the pipe wall in developed laminar flow for 7 cases. Variation of entropy generation and enthalpy are shown along the radius. Entropy generation and enthalpy along the radius are obtained. Heat transfer is increased with the flow of fluid through the pipe, in inlet of pipe points to the output. The amount of entropy generation in the pipes of higher temperature is more than other points. Enthalpy is proportional to temperature in surface variation of 7 cases. In the points of higher temperature in elementary cases, the enthalpy value is increasing and it is increasing in other cases. Fluctuations of enthalpy and entropy generation are producted in interface points of pipe surfaces. The diagram data can be used to measure the minimum entropy generation in pipe heat transfer. Minimum entropy generation is in surface whit high temperature. The enthalpy in centerline is constant and inlet enthalpy of the tube is greater than other point with higher temperatures in radial flow. The lowest enthalpy is obtained in tubes with lowest initial temperature (case 7). Minimum entropy generation is presented in surface whit high temperature at the beginning (case 1-3) or high at the ending (case 5-7).

1. Introduction

Pipes are used in different environments with environment temperature and pipe wall temperature variation in industry. In this work, distribution of temperature on the pipe is studied in different conditions. Boundary conditions are simulated for uniform temperature. The amounts of entropy generation and enthalpy are investigated radially and axially. Minimum entropy generation and enthalpy are cased in the pipe the most economic efficiency in industry. Theoretical and experimental studied temperature distribution and flow profile in evacuated tube solar collector, based on the boundary conditions of solar radiation are studied by Essa et al. [1]. Uses of non-uniform temperature distribution in pipes for several cases were showed [2, 3]. Clear calculations, temperature distribution, according to the absorber pipe, were checked and tested [4, 5]. Temperature distributions are investigated due to the similarity of pipes and channels mechanisms of channels in several cases [6-14]. Temperature distribution monitoring of a coiled flow channel in microwave heating using an optical fiber sensing technique are tested by Wada, et.al. [7]. Temperature distribution monitoring of a spiral flow channel in microwave heating using an optical fiber sensing technique by Irfan, et.al were tested [8]. Experimental simulation and CFD of temperature distribution of fluid flow and heat transfer in natural circulation of passive cooling system of an advanced nuclear reactor were provided by Pal, et.al.[15]. Natural convection in a porous rectangular enclosure with sinusoidal temperature distribution on both sides of the wall using a non-thermal equilibrium model was studied by Wu, et.al.[16]. Experimental study on startup and thermal peformance in high temperature insulation for pipes and cylindrical screen was offered by Wang, et al. [17]. Experimental study on the simultaneous measurement of temperature distribution and irradiative properties of oil-fired tunnel kiln were showed by Lou, et al. [18]. Development of semi-empirical model for uniform distribution of temperature in heat exchanger

* Corresponding author. Tel.: +989167077398; g-mail: rezakakulvand93@gmail.com

pipe wall was investigated by Park et. al.[19]. Natural frequencies and critical temperature of targeted sandwich plates under uniform and non-uniform temperature distribution were exhibited by Fazzolari, et. al. [20]. The least entropy generation on the pipes was analyzed.

Distribution of temperature for 7 cases possessing developed laminar flow was simulated. Because of the temperature distribution exerted on the pipe as well as non-slip wall conditions in the fluid with high prandtl number, entropy generation and enthalpy inside of the pipe are investigated. Profiles of enthalpy and entropy generation display basic data. Dimensionless numbers depending on the enthalpy and entropy generation, for each of the cases, are measured.

2. Physical model

Non-uniform temperature distribution is investigated in pipes possessing 5 sections for 7 cases. The pipe length and section are 1 meter and 0.2 meter, respectively. Fluid enters into the pipes at a speed of Vi and temperature Ti. Enthalpy and entropy generation changes with a high Prandtl number are checked. Flow was considered in the developed laminar situation, incompressible fluid, in steady state and axial symmetry. Temperature is fixed at the center of pipe, while close to the wall varies radially and axially. Because of the constant flow rate in all cases, flow rate chart is constant in all seven cases. A schematic of simulated pipe for was illustrated in Figure 1.

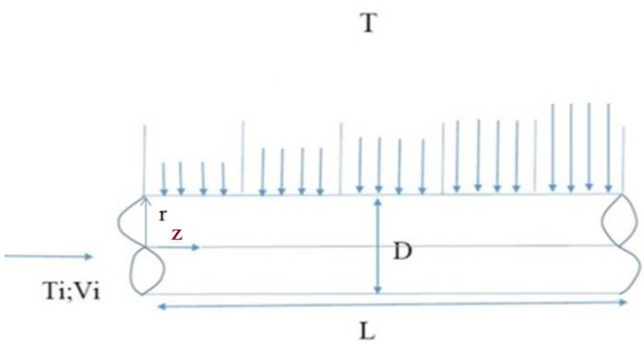

Figure 1, A schematic of simulated pipe

Independence of the meshes are applied with the number of 30×300, along the length and width and in the two-dimensional coordinate’s pipe. The meshes, near the walls, are closed together, because most of the variations are made in this area. Specifications of fluid are listed in the table.

3. Governing equations:

For the pipe, in two-dimensional coordinate x and r, the continuity, momentum and energy equations are provided by Bejan [28-29].

1.1. Continuity equation:

$$\frac{\partial \upsilon_r}{\partial r} + \frac{\upsilon_r}{r} + \frac{\partial \upsilon_z}{\partial z} = 0$$

Steady-state conditions are prevailed in the pipe. υ_r and υ_z are fluid velocity in r and z directions.

Table 1,

Fluid properties and pipe geometry specifications

Fluid properties	Variable	value
Specific heat transfer at constant pressure	$C_p\,(j/kgk)$	1845
Thermal conductivity	$k\,(w/mk)$	0.146
Density	$\rho(kg/m^3)$	889
Viscosity (at T_{ref})	$\mu(NS/m^2)$	1.06
Prandtl number , pr		13400
Inlet axial fluid velocity	$V_i\,(m/s)$	0.02
Inlet fluid temperature $T_i(k)$		273.15
geometry of pipe		
Pipe length	$D(m)$	0.025
Pipe diameter	$L(m)$	1

Momentum equation:

Momentum equation in the direction of r:

$$\rho\left(\upsilon_r \frac{\partial \upsilon_r}{\partial r} + \upsilon_z \frac{\partial \upsilon_r}{\partial z}\right) = -\frac{\partial P}{\partial r} + \mu\left\{\frac{\partial}{\partial r}\left[\frac{1}{r}\frac{\partial}{\partial r}(r\upsilon_r) + \frac{\partial^2 \upsilon_r}{\partial z^2}\right]\right\}$$

Momentum equation in the direction of z:

$$\rho\left(\upsilon_r \frac{\partial \upsilon_r}{\partial r} + \upsilon_z \frac{\partial \upsilon_z}{\partial z}\right) = -\frac{\partial P}{\partial z} + \mu\left\{\frac{1}{r}\frac{\partial}{\partial r}\left[r\frac{\partial \upsilon_z}{\partial r}\right] + \frac{\partial^2 \upsilon_z}{\partial z^2}\right\}$$

Where ρ, µ and p are density, fluid viscosity and pressure, respectively.

1.1. Energy equations:

$$\rho C_p\left(\upsilon_r \frac{\partial T}{\partial r} + \upsilon_z \frac{\partial T}{\partial z}\right) = k\left\{\frac{1}{r}\frac{\partial}{\partial r}\left[r\frac{\partial T}{\partial r}\right] + \frac{\partial^2 T}{\partial z^2}\right\} + \mu\phi$$

The specific heat capacity, radial and axial temperature gradients, the energy dissipation and thermal conductivity and fluid velocity are studied in energy equation. C_p, k and φ are specific heat capacity, thermal conductivity and energy dissipation, respectively.

The amount of energy dissipation is obtained as follows:

$$\phi = 2\left[(\frac{\partial \upsilon_r}{\partial r})^2 + (\frac{\upsilon_r}{r})^2 + (\frac{\partial \upsilon_r}{\partial r})^2 \right] + (\frac{\partial \upsilon_r}{\partial z} + \frac{\partial \upsilon_z}{\partial r})^2$$

Velocity gradients are measured in the radial direction and length of the pipe in dissipation term,.

Entropy Generation:

$$\dot{S}'''_{gen} = \frac{k}{T^2}\left[\left(\frac{\partial T}{\partial r}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2\right] + \frac{\mu}{T}\phi$$

Using entropy generation, the effects of thermal conductivity, temperature gradient in the radial and longitudinal directions, viscosity, temperature, power loss, or the radius, the radial velocity gradient radial and axial velocity on each other are shown. As thermal conductivity, temperature gradient, viscosity and energy dissipation increase, entropy generation increases. Entropy generation is reduced with increasing temperature.

4. Problem definition

The amounts of entropy generation and enthalpy are determined for non-uniform temperature distribution of pipe in this research. In a pipe that is placed in different environments with different temperatures, Non-uniform temperature distribution along the tube wall is created and here, the standard length of one meter is intended as shown in Figure 2, temperature distribution of pipe has been investigated for 7 cases. For cases 1-3, the temperature along the pipe in order to enter the fluid is reduced. For the cases 5-7, temperature distribution in the direction of flow is associated with a decrease in temperature. For the first and 7th cases, the temperature difference of consecutive sections is 20k, for the second and 6th case is 10k, and for 3th and 5th is 5k. For the 4th case, there is a uniform temperature equal to 290k on the pipe wall. Average temperature in each case is equal to 290k along the pipe. For all cases, the temperature at the center of the pipe equal to the average temperature of all cases and constant temperature of the fourth case.

5. Results and discussion

Furthermore, this amount of entropy generation for the first case is dramatically more than the third case. The temperature is reduced in pipe inlet to outlet (cases1-3). Temperature for the first case is higher than the second case. Temperature is constant in the 4th case (290k). Entropy generation is reduced continues along the radius. Enthalpy figure branches are shown several positive and negative concavities. There is the turning point near the pipe (cases1-3). Entropy generation is obtained to the minimum value in on the pipe (cases1-3). Increase the temperature of the wall is caused increasing the entropy generation (case 4). Temperature is increased and entropy generation is decreased in the fifth case. The highest temperature is created in the pipe wall for the 6th case. entropy generation has its maximum value. In the first three cases graphs, curves possess several concavities, while graphs of the fifth to seventh cases are only ascending, shown in Figure 3. Enthalpy is shown along the radius in different pipe lengths, for the cases 1-3. The temperature is lower inlet of the pipe, in areas with higher temperature, near the wall, the amount of enthalpy is higher. For the 4th case, along the pipe, the enthalpy near the wall is constant approximately, because the temperature is constant on the wall. In the fifth and sixth cases, the temperature is increased on the other side of pipe (cases 5-7). Temperature and enthalpy are increased with flow in tube (cases 5-7). In case 4, enthalpies, in all charts of different lengths of pipe, meet at a point. In the fifth and sixth cases, enthalpy profiles are upside. The negative value is continued for the enthalpy, with decreasing temperature. Minimum temperature is produced at the beginning of the pipe in the first part of the seventh case. Enthalpy value are investigated along the pipe wall in figure 5. There is caused the maximum temperature and enthalpy at the beginning of the pipe. As temperature decreases, the amount of enthalpy is decreased along the pipe wall. This process is caused and enthalpy decreases with increasing the length of the pipe. Enthalpy is less in the second case in comparison with the first case, because of the lower temperature in the beginning of the pipe and being more at the end of the pipe enthalpy is less in the second case. Enthalpy is reduced in different parts of the pipe. Variation enthalpy is reduces interval along the pipe generally. The enthalpy is increased along the wall due to the constant temperature at the wall in the case 4. The amount of enthalpy is increased along the wall in the cases 5-7. There is caused the highest temperature and enthalpy on the wall in the case 7, at the end of the pipe. Moreover, Minimum enthalpy is produced at the end of the first pipe and the beginning of the last pipe. The amounts of entropy generation variations are shown along the wall for 7 cases in Figure 6. There is shown the maximum amount of temperature at the end of the pipe, the maximum amount of enthalpy in the first case. In the second and third cases, enthalpy was lowered. Enthalpy values are descending in cases 1-3, for each 5 sections. For each of the sections, figure of entropy generation get started with a maximum value and reach to the minimum value in their section. In the case 4, entropy generation is almost constant value. In the cases 5-7, the amounts of entropy generation along the pipe are on the downside status. On the other hand, the pipe wall temperature value is higher, entropy generation increased in the 6th and 7th cases.

In the border areas of the pipe, the temperature varies; so the dramatic fluctuations was observed in the entropy generation. Pipe surface temperature is variable, when the pipe is passed through environments with different temperatures, and temperature distribution is created on the pipe wall. Temperature distribution is created on the channel wall the results of this article are applicable for the channels that are passed through different environments. Electric and diesel furnace, solar water heaters, refrigerant tube and tubes in hot and cold weather are the applications of temperature distribution tubes.

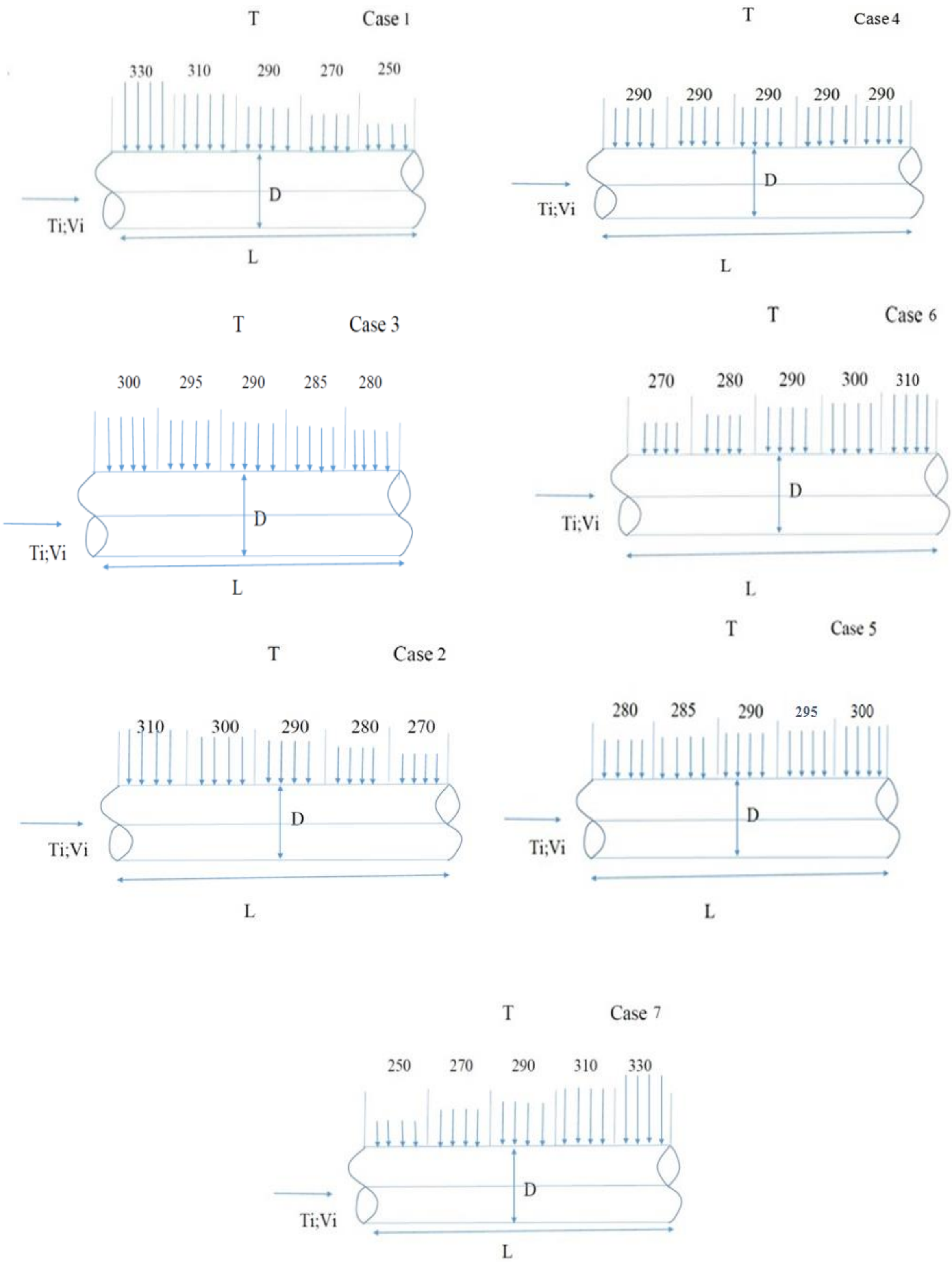

Figure 2: Distribution of pipe temperature for 7 cases

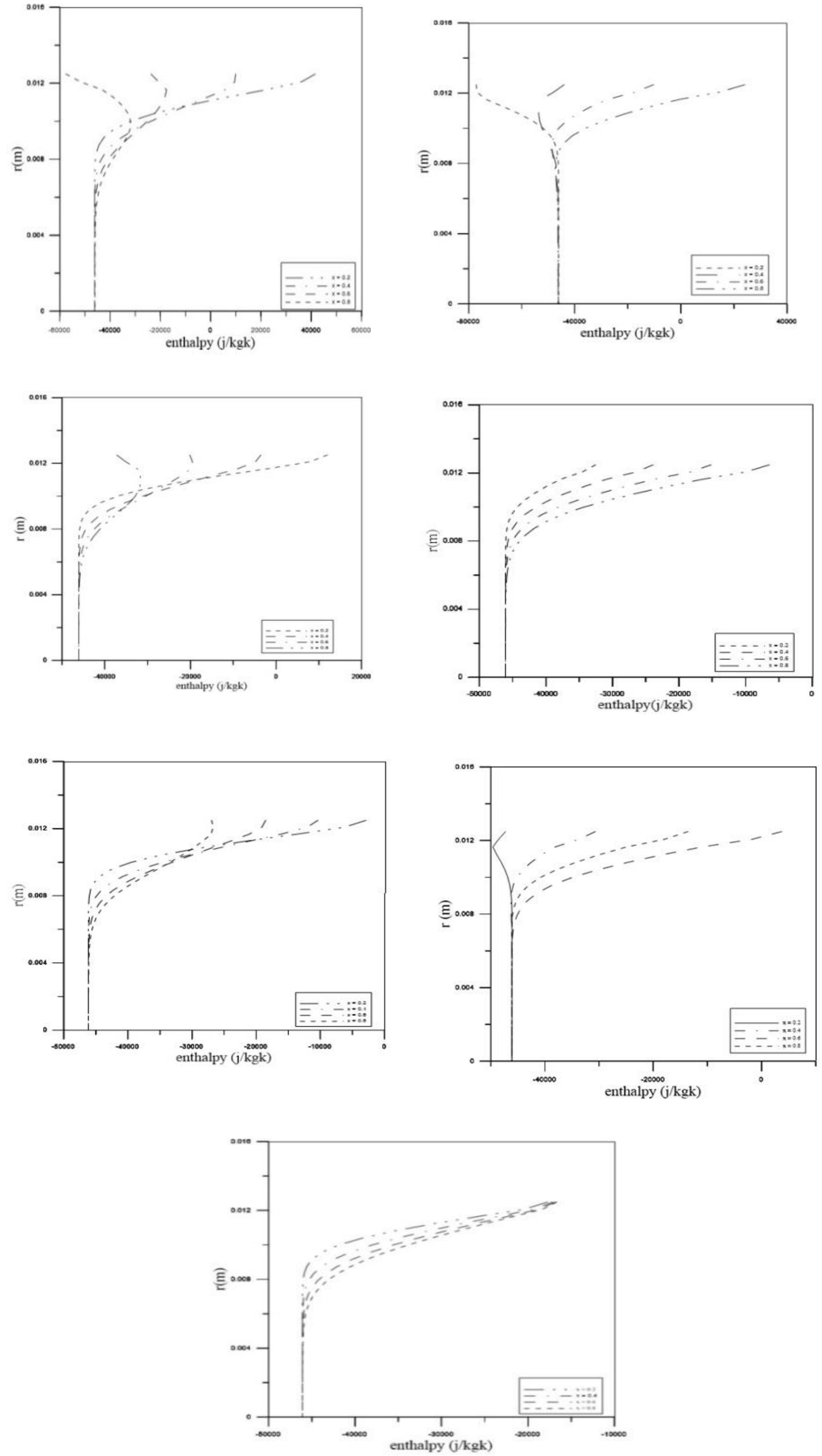

Figure 3. Enthalpy changes along the radius for 7 cases

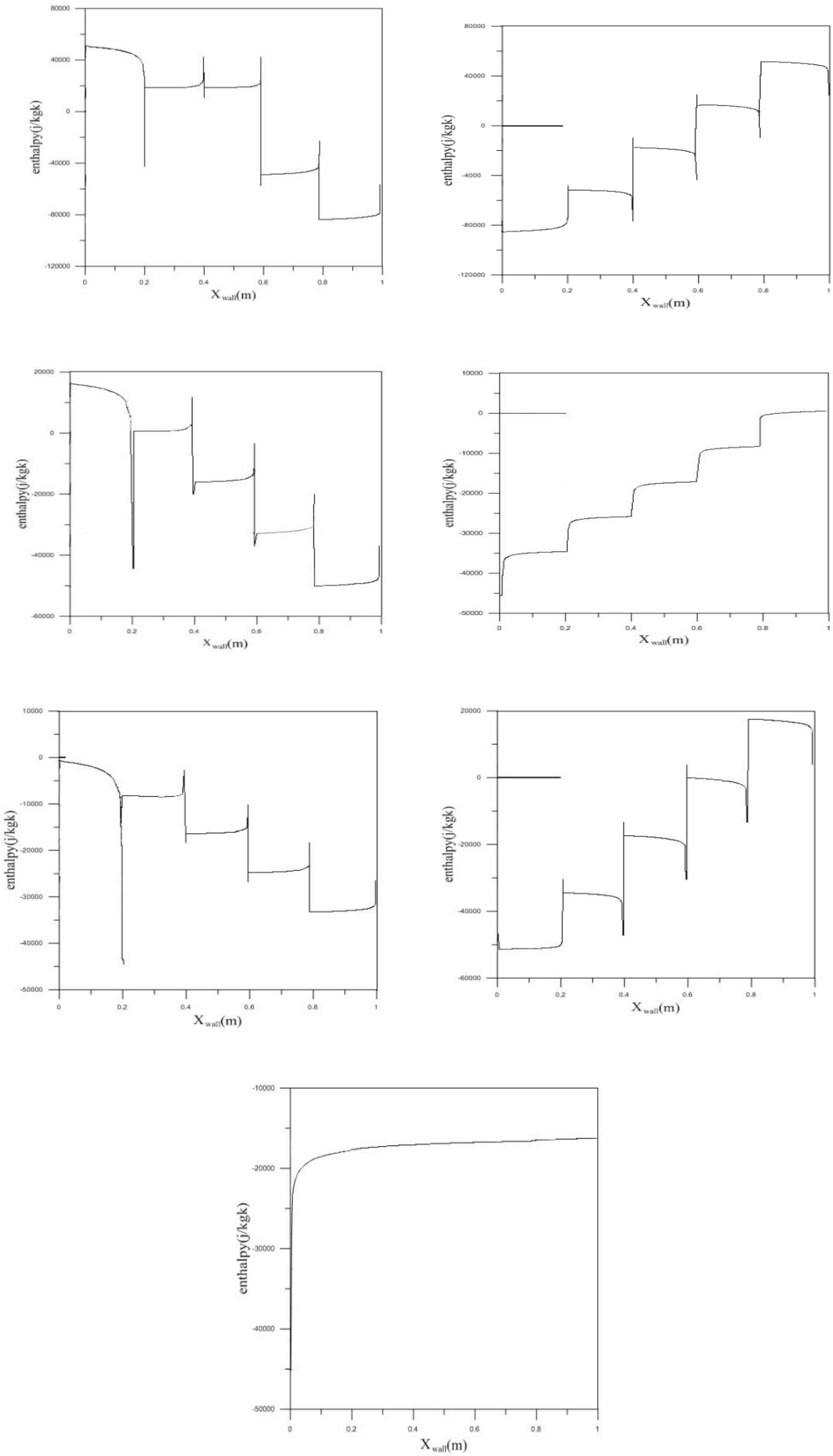

Figure 4. Enthalpy changes along the wall for 7 cases

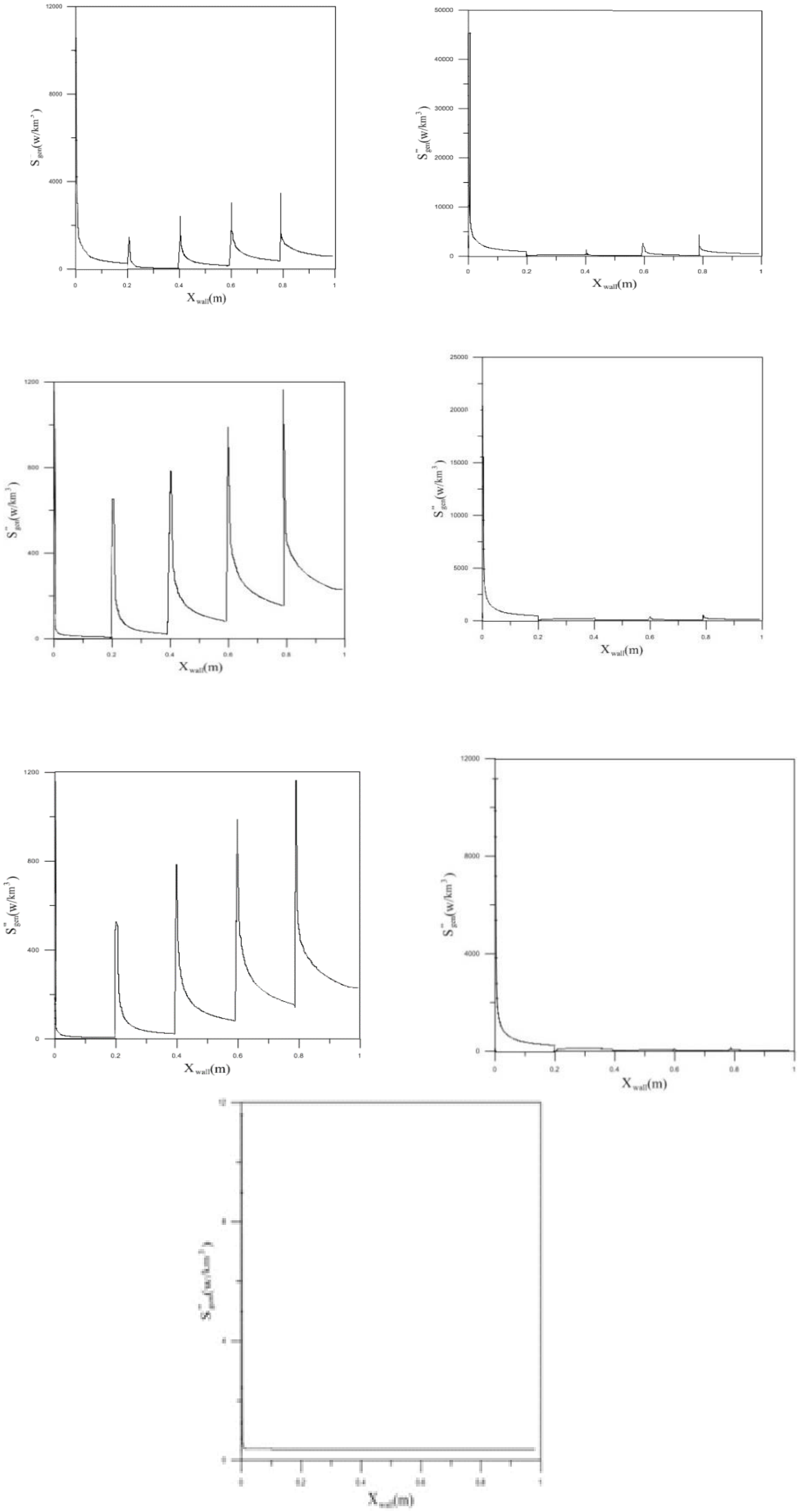

Figure 5. Entropy generation changes along the wall for 7 cases

6. Conclusion

In this research, the effect of non-uniform temperature on entropy generation and enthalpy of a pipe are shown. The results are as follows:

- Turning point the near the pipe and enthalpy figure branches are shown several positive and negative concavities (cases1-3).
- The enthalpy is ascendant in cases of 4-7.
- For all cases, the enthalpy in centerline is constant.
- Enthalpy at the initial points of the tube is greater than the points with higher temperatures in radial range by passing the constant enthalpy range.
- Enthalpy has ascendant value and the amount at the beginning of the pipe is less than the end of the pipe in the surface constant temperature.
- Enthalpy is proportional to temperature in surface variation of tube.
- Enthalpy in lower surface temperature is lower than higher surface temperature significantly. The highest enthalpy is in high temperature points where fluid is flowed at end of the tube. The lowest enthalpy is in tubes where fluid flowed at the beginning of the tube and with lowest initial temperature (case 7).
- Fluctuations of enthalpy and entropy generation are shown in interface of surfaces.
- In the distinct point of the surface that temperature changes, the enthalpy and entropy generation change has a jump.
- Entropy generation is increased whit temperature in sections with constant temperature, at the tube surface at a non-uniform temperature generally. Minimum entropy generation is in surface whit high temperature. This occurs in case that temperature is high at the beginning (case 1-3) or high at the ending (case 5-7).
- Electric and diesel furnace, solar water heaters, refrigerant tube are the applications of temperature distribution tubes. The amount of heat and enthalpy and Minimum entropy generation are investigated in these applications.

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