***Research Article***

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# The effects of transient radiant flow on pipe in contact with natural convection, for developed laminar flow of fluid with high Prandtl number, on enthalpy and entropy generation

Reza kakulvand[a, ∗]

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

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ABSTRACT

Convection flow is passed in a pipe wall possessing radiation-convection, in order to find the best case with at least enthalpy and minimum entropy generation, through pipe wall having radiant flow. Flow in developed laminar conditions is investigated. Radiant flow is simulated Passing the natural convection on the wall with for 6 cases. Variation of radiation along the pipe touching with natural convection causes to change temperature, entropy generation and enthalpy for each case. Different profiles are investigated distributions of temperature, entropy generation and enthalpy along the radius. Along the wall are shown variation in enthalpy and entropy generation. There have been increased in radiation-convection boundary conditions temperature, enthalpy as well as entropy generation. Along the radius and axis have appropriately been increased in radiation boundary conditions than convection, the amounts of enthalpy. Near the wall are occurred the most changes in temperature, enthalpy and entropy generation. Application the thermal boundary conditions are used for minimum entropy generation make fluid with high prandtl number to become high thermal carrier. Solar radiation application are used in Parabolic Trough, Parabolic Dish, Solar Chimney and tube furnace in various cases. Application are used for minimum entropy generation.

## 1. Introduction

the pipes are investigated Some applications of solar and flow radiation on by researchers [1-17]. Exergy and energy are studied of different solar and radiative operators in several cases [18-23]. Laboratory, numerical and theoretical studies on the solar collectors and radiation in different methods has been carried out [24-33]. Analysis of thermal solar systems has been tested based on vacuum tube technology [34, 35, 36]. Radiant flow are studied Economic analysis and environmental impact, storage, criteria Evaluation, modeling of solar system [37, 38, 39, 40, 41, 42, 43]. Solar water heaters and solar dryers have been tested on several occasions [44, 45, 46, 47, 48, 49, 50]. short pipe is studied Solar water-heater performance consisting of a ring separating welding current by Ziapour, et al [51]. evacuated pipe collector is checked the impact of tank water temperature on performance of solar thermal system equipped with heat pipe collector by Porras-Prieto, et al [52]. Solar collectors is studied development of evacuated tube by M. A. Sabiha, et al [53]. energy absorption/storage are surveyed solar systems with heat pumps of thermal by Grazia Leonzio et al [54]. Solar heat flux is tested heat transfer to super-critical water in a vertical pipe by Zhang, et al [55]. The feasibility of solar water heating system activation with evacuated pipe collector has been tested by Mazarrón, et al in 2016 [56]. Evacuated pipe and thermoelectric Modules are studied a novel solar still device equipped by Shafii, et al in 2016 [57]. Selective solar absorber coating in collector pipes for CSP- the process of energy generation and induction heating- has been represented in 2014 by Joly, et al [58]. Different liquids are investigated for laboratory and numerical analysis of researches, solar spiral pipe and photovoltaic/thermal

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

collector with different liquids have been investigated by Joly, et al [59]. The application of energy technologies based on heat and power generation has been presented by Modi, et al [58]. Numerical and experimental studies on natural convection, heat transfer properties and vertical heat exchanger tubes with different diameters have been carried out by Chen, et al [60]. Design and characteristics of a novel tapered tube bundle receiver for high-temperature solar system has been represented by Xu, et al [61]. Thermal performance of direct-flow coaxial evacuated-tube solar collectors with and without a heat shield has been performed by Zhang, et al [62]. Natural convective flow in a vertical tube inspired by alternate heat has been studied by Jha, et al [63]. Investigation of heat transfer liquids in collector tube utilized in concentrating solar thermal systems have been carried out by Benoit, et al [64]. Convective heat transfer of fluids is investigated, in supercritical pressure of the pipe, by Huang, et al [65]. Experimental and numerical investigation of pipe latent heat energy storage unit in the tank has been shown by Meng, et al [66]. Thermal modeling of evacuated tube solar air collectors has thermally been simulated by Paradis, et al [67]. Improvement of thermal performance of flat plate and evacuated solar tube collector has been investigated by Muhammad, et al [68]. A series of spiral absorber tubes for solar focus have been tested by Good, et al [69]. The effect of spiral tube dimensions in open-channel heat transfer followed by natural convection has been studied by Hao, et al [70]. Numerical analysis of a solar tower receiver tube operated with liquid metals has been investigated by Marocco, et al [71]. There are studied entropy generation of a solar collector and the effect of tube roughness, nanoparticle size, and various thermo-physical models have been by Mahian, et al [72]. Performance of a solar reactor possessing evacuated tube collector in the natural state have been realized by Singh, et al [73]. analytical results are performed with experimental investigation of the bending of solar absorber tube comparison with by Khanna, et al [74]. Three-dimensional numerical investigation of mixed laminar convection trough solar collector tubes has been shown by li et al [75]. The least amount of entropy generation on the tubes in different situations is analyzed [76, 77, 78, 79, 80, 81, 82, 83, 84, 85].
Experimental study of natural convection heat transfer in a physical model of a room, several times larger than a thermal thermosiphon, solar water heaters has been displayed [86]. Heat removal system are performed three-dimensional CFD simulations to study the effect of inclination of condenser tube on natural convection and thermal stratification in by Minocha, et al [87]. Bejan and Jiji [88, 89] have studied convective heat transfer in 2013 and 2016. By applying a constant Radiant and convective heat transfer in different parts of the pipe wall, developed laminar flow of the pipe for 6 cases is investigated. The effects of transient convective heat transfer on radiative heat transfer have been simulated. The significant amount of radiation than convection has been applied. For each case, distribution of temperature, enthalpy and entropy generation along the radius and axis have been studied. Finally, a simple with the minimum enthalpy and entropy generation, to achieve better economic efficiency, has been considered. Since the enthalpy and entropy generation are of basic concepts, other dimensionless numbers related to these quantities can be measured.

## 2. Physical model

A pipe with 0.025m diameter and 1m length has been divided to 5 parts. Transient changes in convective heat transfer on radiative heat transfer tube have been studied in six cases. The fluid velocity in the pipe is constant by Prandtl number of 13400 . Fluid regime is laminar and velocity profile is uniform for all cases. Temperature, enthalpy and entropy profiles for all cases are variable. Pipe geometry specifications and fluid properties have been utilized in Table 1

**Table 1,**
Fluid properties and pipe geometry

| **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 |
| | $\alpha$ | 0.9 |
| | $T(k)$ | 1500 |
| | $T_\infty(k)$ | 300 |
| **geometry of pipe** | | |
| Pipe length | $D(m)$ | 0.025 |
| Pipe diameter | $L(m)$ | 1 |

The 30 ×300 tube meshing in longitudinal and lateral direction for symmetry mode has been regarded. Permanent conditions govern the issue. There is non-condensing fluid and a high Prandtl number. A schematic of the tube in which heat flux is in contact with convection is given in Figure 1.

## 3. Governing equations

Heat transfer equations prevailing the pipe two-dimensional coordinates are given below [88].

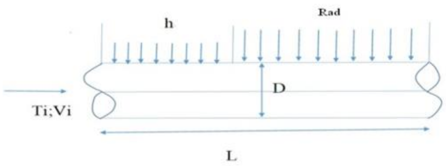



**Figure1**; A schematic of the pipe convective heat transfer and radiation

1.1. Continuity equation:

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

1.2. Momentum equation:

In the direction of r:

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

(3-2-1)

In the direction of z:

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

1.3. Energy equations in r and z coordinates:

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

Where energy loss is as follows:

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

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

1.4. Entropy generation in the direction of r and z:

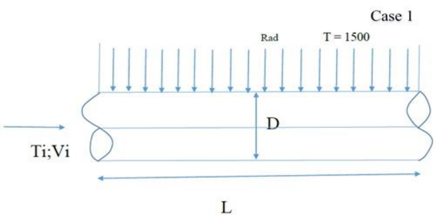
According to the high heat flux of walls and high Prandtl number of fluid with no, high amounts of enthalpy and entropy generation are created. The amounts of enthalpy and entropy generation, in uniform radiation, are dramatically more than the amount of convective heat transfer. Energy loss term shows radius velocity gradients in the direction x and z as well as axial velocity gradient in the direction of radius. Entropy generation displays thermal conductivity amounts, temperature changes long the radius and axis as well as the amount of energy loss.

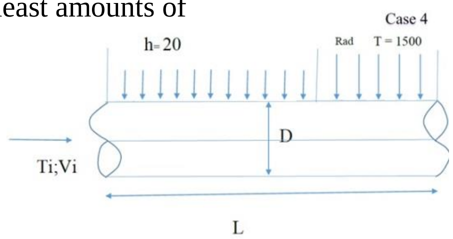
## 4. Problem definition

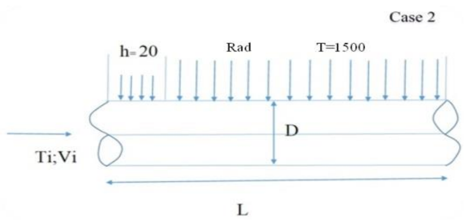
The aim of this research is to find the least amounts of entropy generation and enthalpy in industry along the pipe. Transient convective heat transfer on radiative heat transfer for 6 cases is reviewed. In radiation and convection, we have T=1500k and $h=20w/m^2k$. The obtained values for temperature, enthalpy and entropy generation along the r, z in various cases have been investigated. In the first case, only constant heat flux is applied to the wall and in the 6th case, only convective heat transfer boundary conditions is applied. In the other cases, transient convective heat transfer is applied. Finally in simulation, a case with the highest economic efficiency is considered.

## 5. Results and discussion

Regarding the Figures 2 and 3, due to the high amount of radiation rather than convection, temperature along the wall, in the boundaries with current radiation, is much more. Temperature in the pipe center is constant. In a certain length of the pipe, temperature near the wall is equal or more than the center. Within a specified radius along the walls, in the direction of the fluid, temperature increases. Changes in entropy generation along the radius, in 4 sections of the pipe for 6 cases, have been studied. Entropy generation in radiation is increasingly more than the convection. In the borders of radiative and convective heat transfers, entropy generation is significantly more than radiative and convective heat transfer. Entropy generation, in the middle of pipe up to a radius of 0.006 meter, is constant. The most changes of this range happen near the wall. For the first and last cases, possessing only radiation and convection respectively, entropy generation profiles versus the pipe radius are almost similar. For cases with radiative heat transfer boundary conditions, charts are coiled and have few concavities. For the case with convective heat transfer boundary conditions, two upward and downward concaves have been shown in Figure 4. As shown in Figure 5, the amount of enthalpy along the radius for radiation boundary conditions is more than convection boundary conditions. In a specified radius, the amount of enthalpy in the end of pipe is more than the beginning. Enthalpy in convection boundary conditions is negative. Radiative heat transfer along the radius and pipe is always positive. In these cases, as radius increases, enthalpy value enhances.



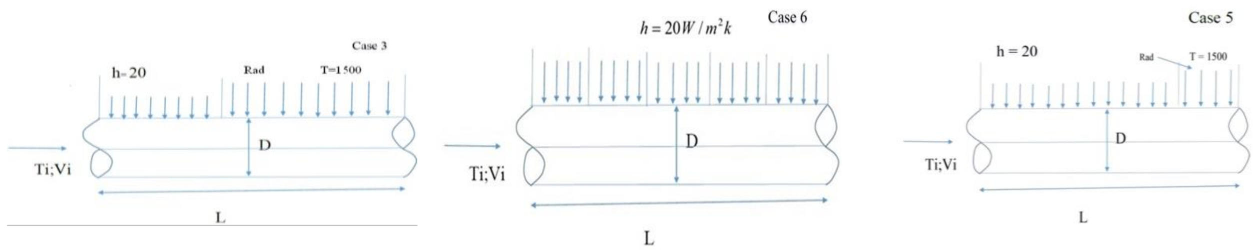



**Figure 2.** Convective heat transfer and radiation in contact with the wall for 6 case

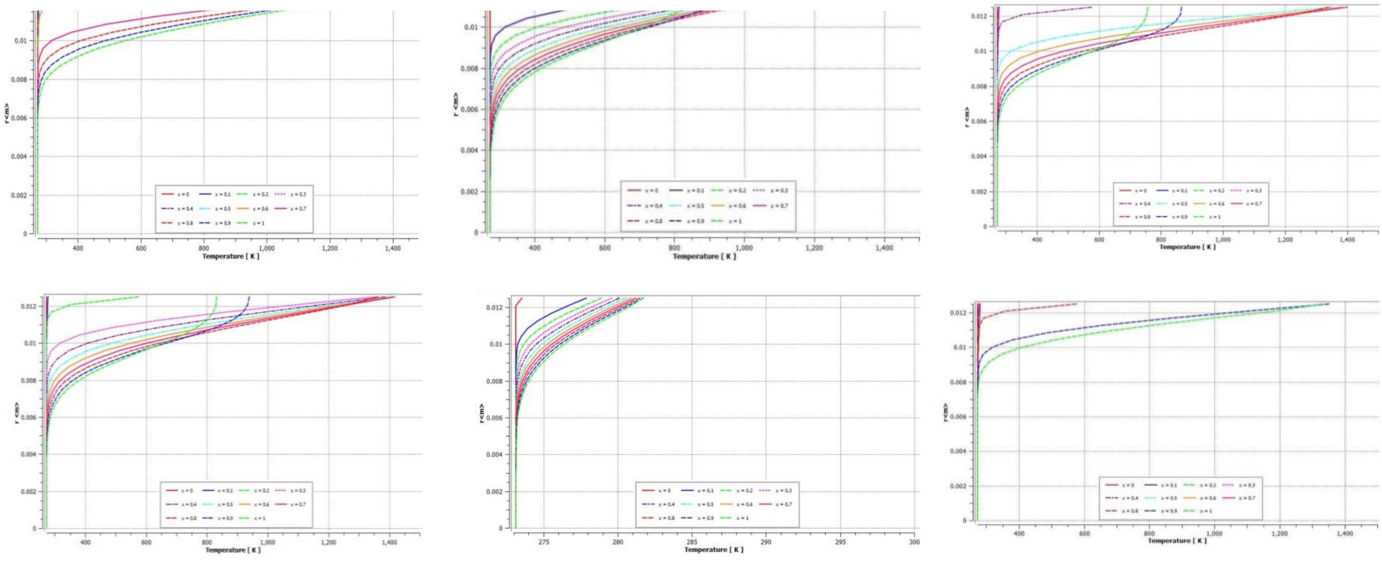


**Figure 3.** Distribution of temperature along the radius for 6 cases

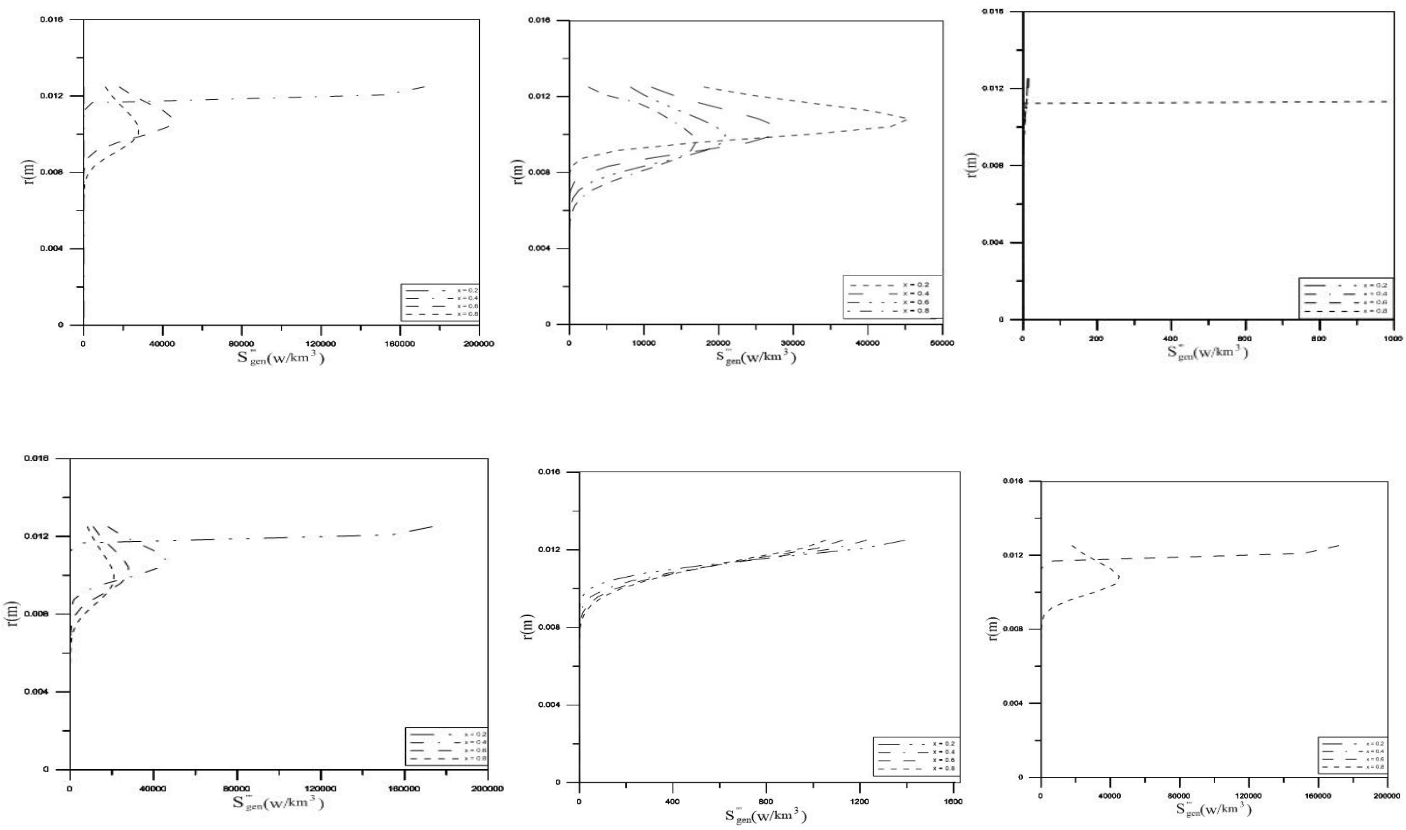


**Figure 4.** Distribution of entropy generation along the radius in 6 cases

Applying heat transfer, enthalpy changes as well as its amounts along the wall increase. The amounts of radiative heat transfer is significantly higher than that of convective heat transfer. For cases 2-5, the amounts of enthalpy along the pipe wall, under convective and radiative heat transfer boundary conditions are ascending, but the rate of increase in enthalpy of convective heat transfer boundary conditions compared with radiative heat transfer is negligible. In comparison with radiative heat transfer, the amount of convective heat transfer along the the pipe axis is constant, as illustrated in Figure 6.

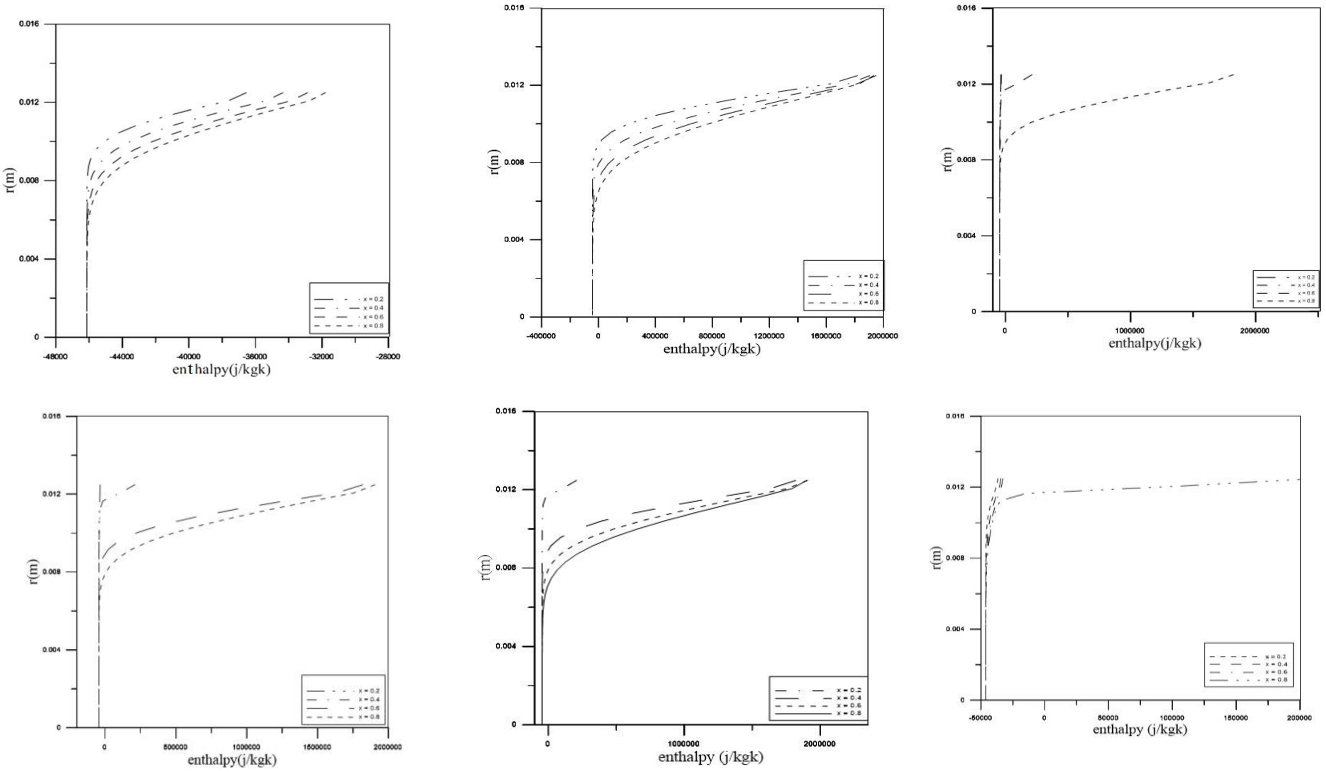



**Figure 5.** Enthalpy distribution along the pipe radius for 6 cases

When convective heat transfer passes radiative heat transfer, except under convective and radiative heat transfer boundary conditions, increasing the pipe lenghth decreases entropy generation. The maximum amounts of entropy generation, in these cases, are created in convective and radiative heat transfer boundary conditions. As investigated in Figure 7, the amount of entropy generation for the first case in radiative heat transfer boundary conditions is greatly more than the sixth one in convective heat transfer boundary conditions.

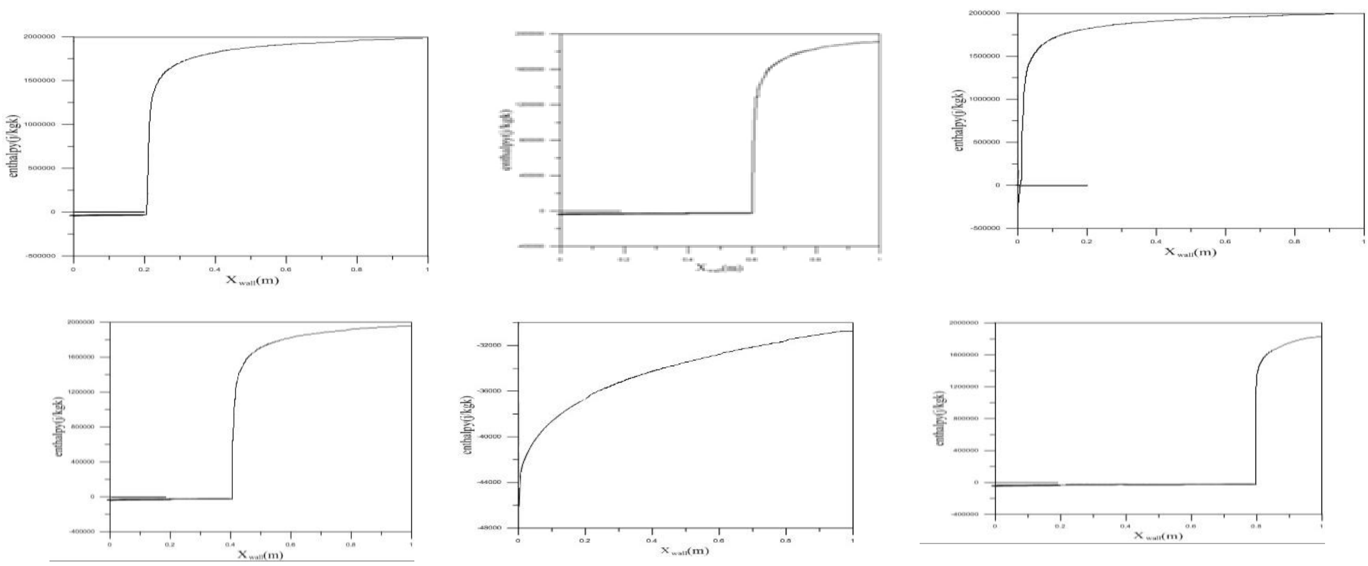



**Figure 6.** Enthalpy distribution along the axis in 6 cases

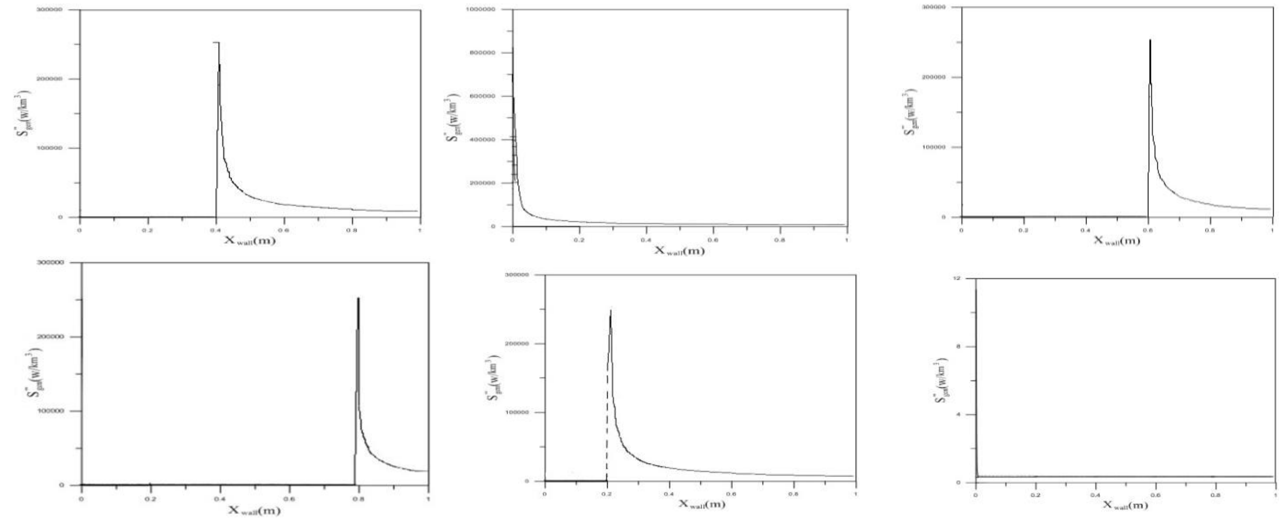


**Figure 7.** Entropy generation distribution along the pipe axis for 6 cases

## 6. Conclusion

By solar radiation and heating containers such as glass jars and other applications mentioned in literatures, radiative heat transfer is created on the pipes or channels. Convective flow is also provided by natural or forced convection on the pipes or channels. Observed results and Figure are created Passing convection through the pipes or channels having radiative heat transfer. Solar radiation application are used in Parabolic Trough, CRS, Parabolic Dish, Solar Chimney, Fresnel Collector, and Parabolic Trough Solar and tube Furnace in various cases for minimum entropy generation.

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