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Entropy generation in a square cavity

Effect of porous block configurations in relation to cooling applications

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Abstract

Purpose – The purpose of this paper is to study flow over two heat generating porous blocks situated in a cavity, and examine the effects of porous blocks geometric orientations in the cavity (configurations) and the amount of heat generation in the blocks on entropy generation rate due to heat transfer and fluid flow.

Design/methodology/approach – Four configurations of blocks and three heat fluxes are accommodated in the simulations. The equilibrium flow equations are used to compute the flow field. Entropy generation in the flow system due to fluid friction and heat transfer is also computed. A control volume approach is used to discretize the governing equations of flow and heat transfer. In the simulations, flow Reynolds number is kept 100 at cavity inlet and blocks' porosity is set to 0.9726.

Findings – The volumetric entropy generation rate attains high values around the blocks and configuration 4 results in reasonably low values of entropy generation rate due to heat transfer and fluid flow.

Research limitations/implications – The simulations are limited to low Reynolds numbers due to practical applications. However, at high Reynolds numbers, flow separation in the cavity results in complex flow structure, which is difficult to simulate.

Practical implications – The thermodynamic irreversibility of the thermal system in the cavity becomes low for certain configuration of blocks in the cavity. The power loss, in this case, becomes less.

Originality/value – The work introduces original findings for cooling applications. When porous blocks are used for electronic cooling, the blocks configurations are very important. This is clearly demonstrated in this study.

Keywords Porous materials, Blocks, Thermodynamic properties, Cooling, Flow

Paper type Research paper

Nomenclature

a	aspect ratio
b	length of block (m)
c	height of block (m)
C_2	inertial resistance factor
Gr	Grashoff number
E_f	fluid energy (J/kg)
E_s	solid medium energy (J/kg)
K	permeability of porous block (m^2)
k_f	thermal conductivity of fluid (W/mK)
k_s	thermal conductivity of solid (W/mK)
k_{eff}	effective thermal conductivity (W/mK)
f	inertia coefficient
F	body force (N)

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L	width of channel (m)
n	any spatial coordinate
Nu	Nusselt number
P	pressure (Pa)
ΔP	pressure drop across the block (Pa)
$\dot{q}$	rate of heat flux (W/m^3)
S_{hf}	fluid enthalpy source term (W/m^3)
$\dot{S}'''_{gen}$	volumetric entropy generation rate (W/m^{3}K)
$\dot{S}_{TOT}$	total entropy generation rate in the fluid (W/K)
T	temperature (K)
u	velocity in x-axis (m)
Ui	mean velocity at block inlet (m/s)
v	velocity in y-axis (m)
V	velocity vector
x	distance in x-axis (m)
y	distance in y-axis (m)

Mass diffusivity (m^2/s)

α_T	thermal expansion coefficient (1/K)
ε	porosity
τ	shear Stress (N/m^2)
μ	viscosity (N.s/m^2)
ν	kinematic viscosity (m^2/s)

Density (kg/m^3)

$\forall$	volume (m^3)
$\forall_{fluid}$	volume of liquid in the porous structure (m^3)
$\forall_{total}$	total volume of structure (m^3)

Introduction

Porous structures are used to improve heat transfer in thermal systems. Depending on the permeability of the porous structure, its size, and orientation of the heat generating body, significant heat transfer rates can be achieved. In the practical applications, in general, porous structure is situated in open channels or in cavities and forced convection current passes over it. The working fluid is in contact with the large area of porous structure. Natural and forced convection currents generated in the structure enhances heat transfer rates for the heat generating body. However, working fluid experiences high resistance in the porous structure, which in turn increases the thermodynamic irreversibility in the thermal system. Moreover, thermodynamic irreversibility through entropy generation provides useful information on the performance of the thermal system. Consequently, investigation into entropy generation in the porous system becomes necessary.

Considerable research studies are carried out to examine flow over the porous structures. The performance of graphite foam and their potential use in the thermal management of the electric devices were investigated by Coursey *et al.* (2005). They indicated that foam size and density, temperature, and working fluid properties have significant effect on the performance of the graphite foam. Forced convection in porous channels with and without periodic baffles was examined by Tzeng *et al.* (2006). They showed that when baffles were attached on the heated wall, the wall temperature measured at baffles were slightly lower than those at the nearby points, especially at high Reynolds numbers. The effects on porosity and pore diameter on the hydrodynamic and thermal performance of finned tube heat exchanger were investigated by Yu *et al.* (2006). They suggested that in comparison to conventional finned-tube radiators, improvements of approximately 15 percent in thermal performance were possible through using the porous media. Convective heat transfer in parallel airflow over a layer of porous foam bonded onto a solid substrate was examined by Straatman *et al.* (2006). They indicated that heat transfer rates were independent of the effective conductivity over the range of conditions examined. Flow through a porous medium adjacent to open flow in a two-dimensional channel was examined experimentally by Agelinchaab *et al.* (2006). They showed that values of slip velocity normalized by the maximum velocity in the open flow depended on solid volume fraction, rod spacing, and fraction of channel filled by rods. The viscous coupling in two-plane flow through porous media was investigated by Ayodele (2006). He indicated that viscous coupling effect was negligible through out the normalized saturation range. Steady flow through a porous medium in a shallow two-dimensional cavity was studied by Daniels (2006). He showed that for a monotonic temperature distribution at the upper surface, the problem consisted of an interaction involving the horizontal boundary-layer equations and the vertical boundary-layer equations, which governed the flow near the colder sidewall. Steady flow near a stagnation point on a vertical surface in a porous medium was examined by Merrill *et al.* (2006). They showed that for values of the mixed convection parameter, the governing boundary value problem had more than one solution. The flow characteristics for the multiple plate porous insulation were examined by Lim *et al.* (2007). They showed that in the forced convection regime, mid-dimple peaking of the Nusselt number distribution might be related directly to the convective influence of distorted velocity profiles.

Entropy generation provides information about thermodynamic irreversibility in thermal systems. Considerable research studies were carried out to investigate entropy generation in thermal systems associates with the porous structures. The second law analysis of a laminar viscous incompressible liquid film falling along an inclined porous heated plate was examined by Makinde and Osalusi (2006). They developed an analytical expression for entropy generation rate and irreversibility ratio. Entropy generation in the porous layer and the condensate film was investigated by Bin-Mansoor *et al.* (2005). They showed that for large porous layer thickness, entropy generation rate reduced considerably along the vertical axis. Entropy generation in a tilted saturated porous cavity due to laminar natural convection current was examined by Baytas (2000). He used the Darcy equation and employed Boussinesq incompressible approximation in the analysis. He indicated that using minimum entropy concept, angle of inclination of the cavity could be selected. The thermal performance and second law analysis of a double pipe heat exchanger with a porous medium filled the inner pipe was studied by Allouache and Chikh (2006). They showed that increase in the effective thermal conductivity of the porous medium provided thermodynamic disadvantageous in terms of thermal performance. Fully developed forced convection and entropy generation in a fluid saturated porous channel bounded by two parallel plates were investigated by Mahmud and Fraser (2005). They developed analytical expressions for velocity, temperature, Nusselt number, entropy generation rate, and thermodynamic irreversibility. They showed that the Dacry number was an important parameter to identify the flow characteristic. Entropy generation in porous media imbedded in elliptical passage was examined by Hooman (2005). He used the Darcy flow model and developed expressions for local entropy generation rate. Entropy generation due to flow in a pipe with fully as well as partially filled porous medium was investigated by Morosuk (2005). He discussed the effects of porous layer thickness and permeability of the layer on entropy generation rate for fully developed flow conditions. The steady-state conjugate natural convection in a fluid-saturated porous cavity was investigated by Al-Amiri and Khanafer (2008). They examined momentum and energy transport in the porous cavity through depicting the streamlines and isotherms for different domains of selected dimensionless groups. The internal heat generation in a tall cavity filled with a porous medium was investigated by Ansari (2007). He indicated that the flow depended on two-dimensional parameters, namely the Darcy-Rayleigh number and the cavity aspect ratio. In the open literature, the flow into and around the porous blocks are given in different geometric arrangements; however, the flow over the porous blocks resembling the cooling applications of electronic devices in a cavity for heat transfer enhancement has not been explored according to the authors' best knowledge. The cavity is mainly used to cover the devices for the protective purposes. However, heat transfer in the cavity is influenced by the orientation of the porous bodies; in which case, heat transfer rates from the devices can be improved for a certain geometric orientations and locations (geometric configuration) of the devices in the cooling applications. Consequently, investigation into the influence of the geometric configurations of porous blocks situated in a cavity on the heat transfer rates becomes essential.

In the present study, flow over two porous blocks situated in an open-ends square cavity is considered and entropy generation rate in the cavity is computed. The effects of geometric arrangements of the porous blocks in the cavity (configuration) and of heat generation in the blocks on entropy generation rate are examined. A numerical scheme using control volume approach is introduced to discretize the governing equations of flow and heat transfer.

Mathematical analysis

The equations governing the flow over a porous block situated in a channel can be formulated through considering the equilibrium conditions. In this case, porous medium can be defined as a material consisting of a solid matrix with an interconnected void and it is assumed that a single fluid (single phase) occupies the voids spaces. Moreover, assuming isotopic porosity and single phase steady flow, the volume-averaged mass and momentum conservation equations for a steady flow situation can be written in vector notation as:

$$\nabla \cdot (\varepsilon \rho V) = 0 \tag{1}$$

and,

$$\nabla \cdot (\varepsilon \rho V V) = -\rho \nabla p + \nabla \cdot (\varepsilon \tau) + \varepsilon F - \left(\frac{\mu}{\alpha} + \frac{C_1 \rho}{2}|V|\right) V \tag{2}$$

The last term in Equation (2) represents the viscous and inertial drag forces imposed by the pore walls on the fluid. Note that ε is the porosity of the media defined as the ratio of the volume occupied by the fluid to the total volume ($\forall_{fluid}/\forall_{total}$, where $\forall$ is the volume).

The standard energy transport equation in porous media regions is solved with modifications to the conduction flux and the transient terms only. In the porous medium, the conduction flux uses an effective conductivity and the transient terms includes the thermal inertia of the solid region on the medium:

$$\nabla \cdot (V(\rho_f E_f + p)) = \nabla \cdot (k_{eff} \nabla T - \tau \cdot V) + S_f^k \tag{3}$$

where the effective thermal conductivity in the porous medium, k_{eff}, is the volume average of the fluid conductivity and the solid conductivity.

$$k_{eff} = \varepsilon k_f + (1 - \varepsilon) k_s \tag{4}$$

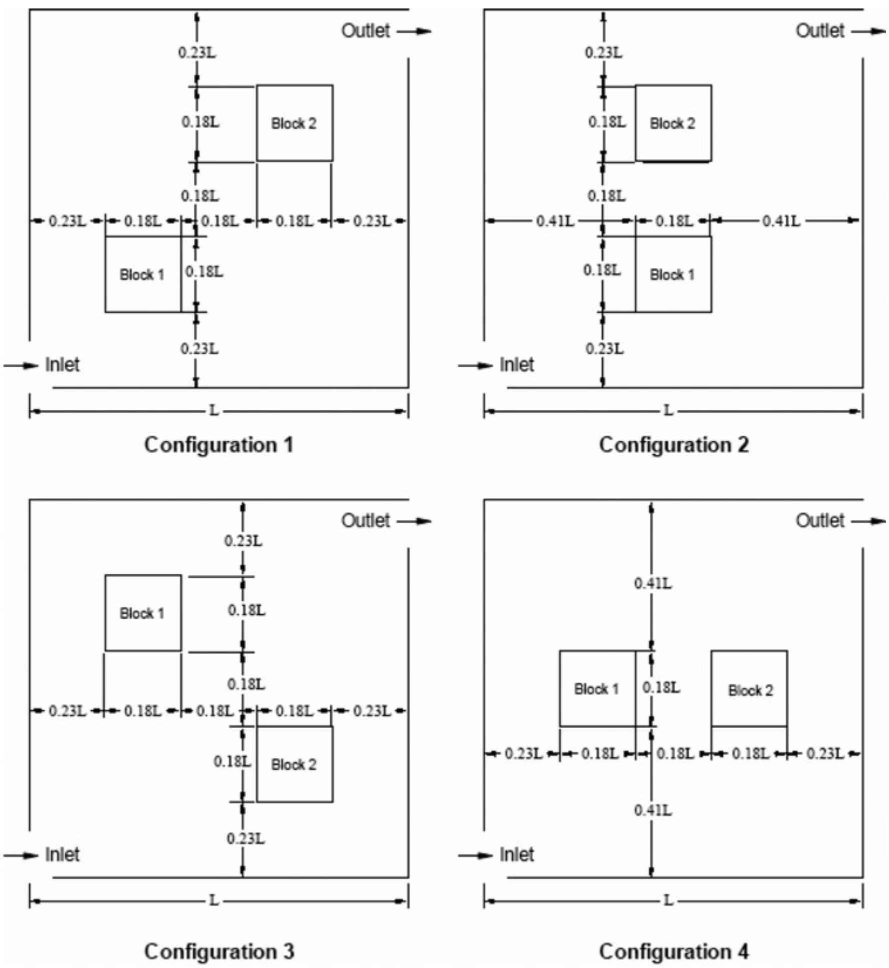
where E_f is the fluid energy per unit mass, E_s is the solid medium energy per unit mass,

k_f is the fluid phase thermal conductivity (including the turbulent contribution (k_t), k_s is the solid medium thermal conductivity, k_{eff} is the effective thermal conductivity of the medium, S_{hf} is the fluid enthalpy source term, ε is the porosity of the medium, V is the velocity vector, τ is shear stress, p is the pressure, and F is the body force including that due to buoyancy.

In the case of fluid side, the governing equations of flow are modified, and ε in equations (1)-(3) is set to 1. In addition, k_{eff} becomes k_f (fluid thermal conductivity) in Equation (4).

Boundary conditions

Fluid conditions. Two solid blocks with different geometric arrangements in open-ends cavity is considered. The square blocks are accommodated and the surface area of each block is kept the same. Figure 1 shows the schematic view of the solution domain



Note: L = 0.05 m

Figure 1.
Cavity and geometric configurations of the porous blocks in the cavity

(cavity and the geometric configurations of the blocks) while Table I gives the geometric dimensions of the solution domain. The blocks are numbered in such a way that the first block is defined as block 1 and the second block is named as block 2 in the cavity. The geometric arrangement of blocks in the cavity is named as configurations; therefore, four configurations of blocks in the cavity are employed in the simulations. Moreover, the velocity magnitude is normalized through dividing it by the cavity inlet velocity.

The adiabatic cavity walls with no slip and impermeable wall conditions for the velocity components are considered, i.e.,

$$\frac{\partial T}{\partial n} = 0, \quad u = v = 0.$$

The pressure boundary is assumed at cavity exit while the uniform flow and temperature are assumed at cavity inlet, i.e.,

$$\frac{\partial \varphi}{\partial n} = 0,$$

where φ is any property of the fluid.

The uniform heat generation is introduced within the rectangular porous blocks.

Porous media conditions. To obtain the porous coefficients, experimental data available in the open literature are used by Beavers and Sparrow (1969). In this case, the experimental data in the form of pressure drop against velocity through the porous component are utilized. The performance of porous body, in general, agrees well with the Forchheimer equation, which is:

$$\frac{dP}{dx} = \frac{\mu}{K} u + \frac{\rho f}{\sqrt{K}} u^2 \tag{5}$$

where P, μ, K, u, and ρ are pressure, dynamic viscosity, permeability of the foam, and linear velocity and density of the fluid, respectively. f is the inertia coefficient reflecting porous inertia effects. However, K and f are related to structure of the porous medium as given by Battacharya *et al.* (2002). The values of K and f are given in Table II for two porous blocks.

Air is used as the flowing fluid while solid block is considered to be steel. The properties of air at standard pressure and temperature and thermal properties of block are given in Table III.

Cavity length	L (0.05 m)
Cavity width	L (0.05 m)
Area of each block	$(0.18L)^2$ ($8.1 \times 10^{-5} m^2$)
Cavity inlet port size	0.2L (0.01 m)
Cavity exit port size	0.2L (0.01 m)
Cavity inlet velocity	0.1544 m/s
Re_{Inlet}	100
Rate of heat generation	2×10^5 W/m^3: 3×10^5 W/m^3: 4×10^5 W/m^3
Porosity for each block	0.9726

Table I. Block and cavity dimensions and porosity used in the simulations

Entropy analysis

The volumetric entropy generation due to fluid friction and heat transfer in the cavity including the porous structures can be written as (Bejan, 1995):

$$(\dot{s}'''_{gen})_{solid} = \frac{k_f}{T^2}\nabla^2 T + (1-f)\frac{\mu}{T}\phi + \frac{f\mu_f}{KT_s}(\bar{v}^2) \tag{6}$$

where K is the permeability and ϕ is the viscous dissipation term in the working fluid which is:

$$\phi = \left\{\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2\right] + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2\right\}$$

It should be noted that $f = 0$ for the working fluid in the cavity without porous structure while $f = 1$ for the porous structure. However, entropy generation rate in the working fluid is considered. Volumetric entropy generation rate due to heat transfer in the cavity is:

$$\dot{S}'''_{gen} = \frac{k_{fluid}}{T^2}\nabla^2 T \tag{7}$$

And volumetric entropy generation rate due to fluid friction outside of the porous blocks in the cavity is:

$$\dot{S}'''_{gen} = \frac{\mu}{T}\phi \tag{8}$$

Total entropy generation rate is determined through volume integration of Equation (6) in the working fluid. Therefore,

$$\dot{S}_{TOT} = \int_{\forall} \dot{S}'''_{gen} d\forall \tag{9}$$

Table II. Properties of porous blocks used in the simulations

Porosity (ε)	f	K ($\times 10^7$ m^2)
0.9726	0.097	2.7

Table III. Properties of the fluid and solid block used in the simulations

	Air
Density (kg/m^3)	1.177
Specific heat (J/kg K)	1,005
Thermal conductivity (W/m K)	0.02565
Viscosity (m^2/s)	1.544×10^{-5}

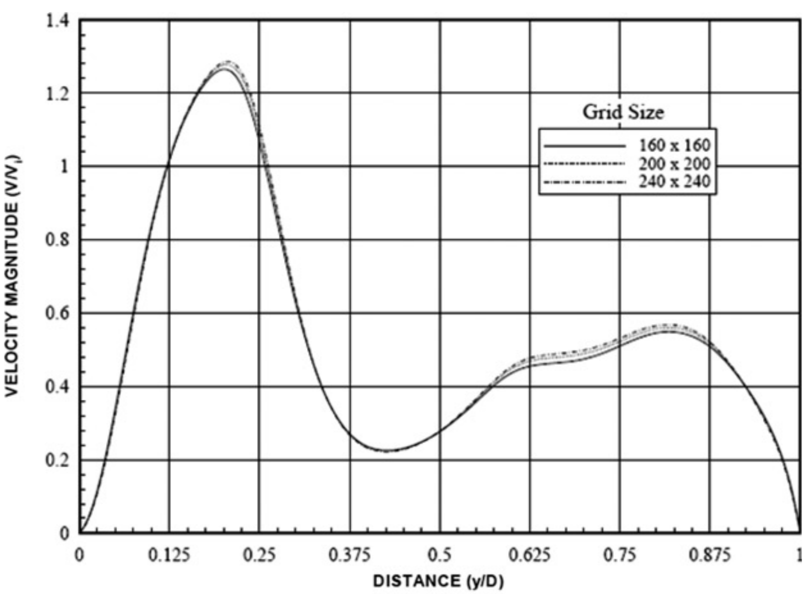
Equations (7) and (8) are used to compute entropy generation rate due to heat transfer and fluid friction, respectively, while Equation (9) is used to determine the total entropy generation rate.

Numerical solution

The flow domain is overlaid with a rectangular grid as shown. The control volume approach is employed in the numerical scheme. All the variables are computed at each grid point except the velocities, which are determined midway between the grid points. The details of control volume approach are given by Patankar (1980). The grid-independent tests are carried out and 200×200 grid size are selected on the basis of grid-independent solutions with less computation time. Figure 2 shows the grid-independent results. It is evident that the grid used in the simulation results in grid-independent results. The maximum percentage difference between the fine grid and the grid used in the simulations is in the order of 2 percent.

A staggered grid arrangement is used in the present study, which provides the pressure linkages through the continuity equation and is known as SIMPLE algorithm as presented by Patankar (1980). This procedure is an iterative process for convergence. The pressure link between continuity and momentum is established by transforming the continuity equation into a Poisson equation for pressure. It should be noted that the steady flow situation is considered and the time-averaged data are used in the analysis.

In the simulations, the Reynolds number at cavity inlet is kept at 100. Moreover, the Reynolds number of 100 at the cavity inlet avoids the flow separation and/or vortex shedding from the blocks in the cavity Shuja *et al.* (2009).



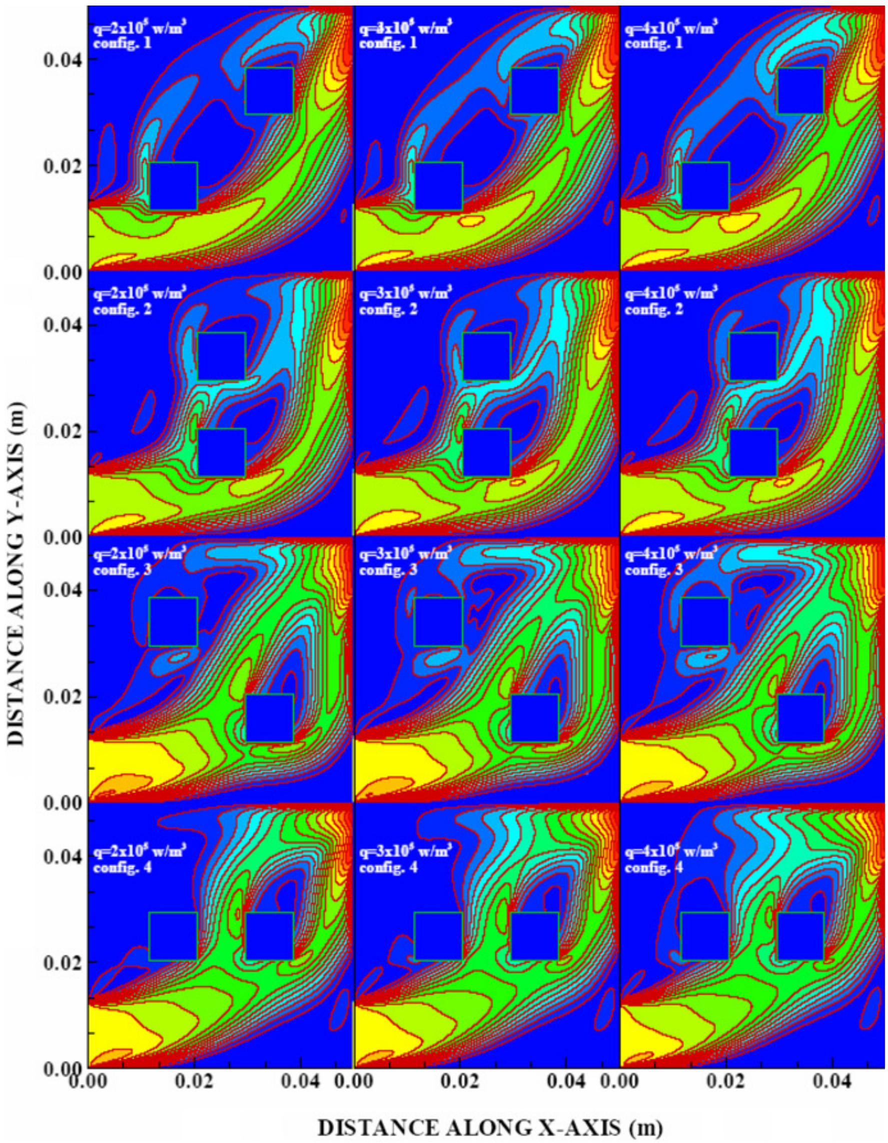
Notes: V/V_i, V_i is the cavity inlet velocity; y/L, L is the length of the cavity; x = L/2

Figure 2. Grid-independent results for the normalized velocity magnitude and the normal y-axis at x-axis location is the mid point of the cavity

Results and discussions

Entropy generation rate due to flow over porous blocks situated in the open-ends cavity is considered and the effects of heat generation rate and configurations of the blocks on entropy generation rate is examined.

The normalized velocity magnitude contours are depicted in Figure 3 for different porous blocks configurations in the cavity. The configuration of the porous block has considerable effect on the flow field; in which case, the natural and forced convections



Notes: V/V_i, where V_i is velocity at cavity inlet

Figure 3.
Velocity contours for different configurations of blocks

around the blocks play a major role in the flow field development in the cavity. Moreover, the natural and forced convection currents mix in the down stream of the blocks. This results in flow acceleration in the cavity towards the cavity exit. Therefore, the flow pattern in the cavity changes, particularly, around the blocks once the blocks configuration changes. The convective current passes below the blocks reaching the cavity exit port, which is more pronounced for the blocks configuration 1. However, the forced convection current breaks up before reaching the blocks due to blockage effect in the cavity and it joins in the down stream of the blocks. This situation is true for the other configurations. In the case of configuration 4, the shear layer formed, due to high rate of fluid strain between the blocks, causes the flow circulation between the blocks. The development of the high rate of shear strain is because of the natural and forced convection currents. The flow emanating from the porous blocks has low forced convection current due to the internal resistance of the porous blocks; consequently, the low velocity region is developed above the blocks. Moreover, enlarging the low velocity region in the cavity, due to different configurations, causes a complicated flow structure in the down stream, particularly at the cavity exit region.

Figure 4 shows contours of volumetric entropy generation rate in the cavity due to heat transfer for different heat generation rates and configurations of the porous blocks. The effect of heat generation rate on volumetric entropy generation rate is not significant for the top block as compared to its counterpart corresponding to bottom block in the cavity. This is more pronounced for configuration 1. In this case, increasing heat flux from 2×10^5 to $4 \times 10^5\,\mathrm{W/m^3}$ modifies entropy generation around the bottom block. Temperature gradient in the region of the bottom block, in particular where the convective current is high, becomes large, which in turn, increases volumetric entropy generation rate. However, the influence of configuration of the blocks has significant effect on volumetric entropy generation rate. This is because of the direction of forced and natural convection currents, which changes with the orientation of blocks in the cavity. Forced convection current carries relatively cooler air from the cavity inlet port resulting in relatively higher temperature gradients around the blocks. Once the natural convection and forced convection currents mixes, temperature gradient in the flow reduces so that volumetric entropy generation rate reduces. It should be noted that natural convection current carries the heated gas in the cavity, since it is generated around the heat generating blocks. Moreover, volumetric entropy generation rate becomes high in the region close to the blocks, particularly when thermal boundary layer is thinner. However, volumetric entropy generation rate is low at the bottom of the cavity. In this case, forced convection current is high and only cool air carried from the cavity inlet port occupies this region, i.e., temperature gradient remains low. Similar situation is observed for configurations 1 and 2, provided that low entropy generation region is smaller than that of configuration 4.

Figure 5 shows contour plots of volumetric entropy generation rate due to fluid friction in the cavity. Entropy generation rate varies with heat flux and the configuration of blocks in the cavity. Volumetric entropy generation rate due to fluid friction is considerably smaller than that of heat transfer. This is because of the frictional losses in the cavity, which is less than the thermodynamics irreversibility associated with temperature gradient. Moreover, volumetric entropy generation rate is high in the region of blocks where the rate of fluid strain is high. This is particularly true for configuration 1 in the region of the bottom block. Moreover, shear layer developed between the forced convection current and thermal boundary layer is responsible for the attainment of high rate of entropy generation around the bottom

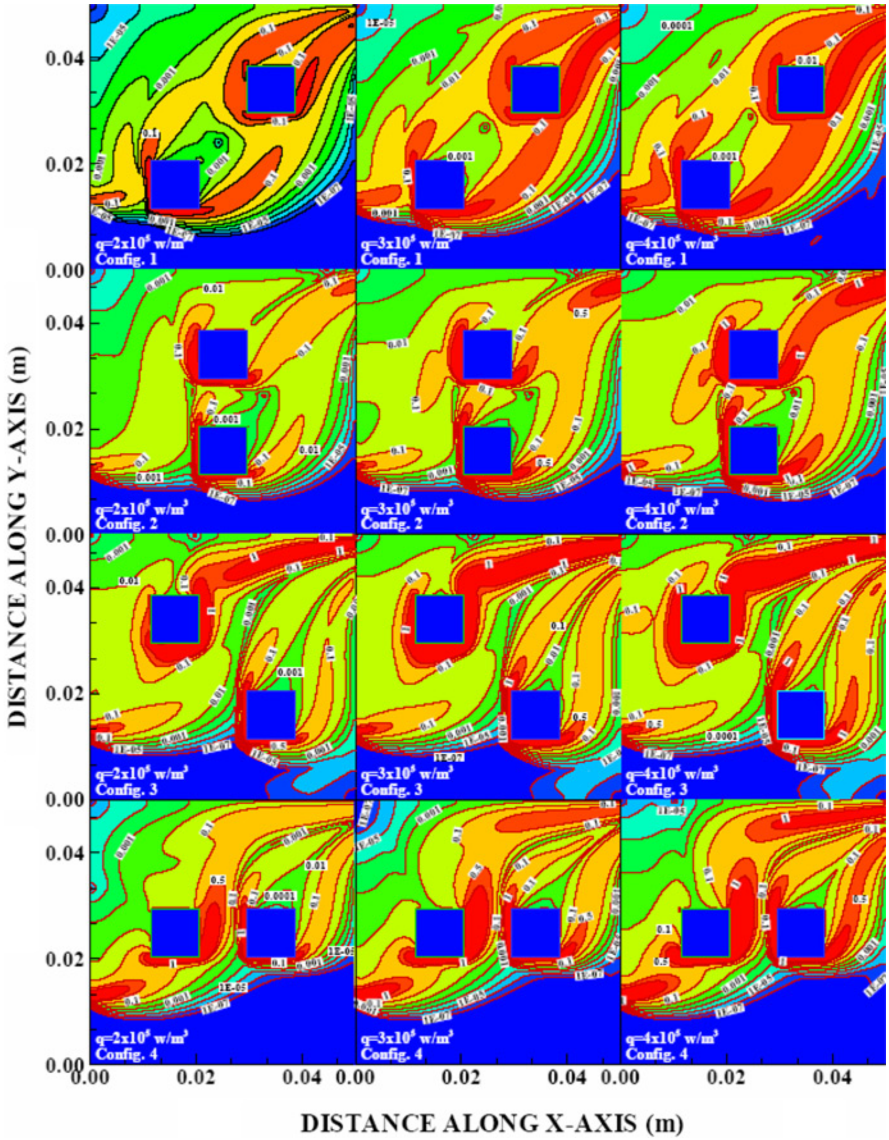


Figure 4.
Contour plots of volumetric entropy generation rate due to heat transfer in the cavity for different configurations of the porous blocks and heat fluxes

block. When the forced convection current is low in the region of cavity walls, volumetric entropy generation becomes low. In the down stream region of the blocks, where natural and forced convection currents mix, viscous dissipation in the mixing region enhances volumetric entropy generation rate.

Figure 6 shows total entropy generation rate, due to fluid friction, in the flow system with configurations of the porous blocks for different heat fluxes. Entropy generation rate attains high values for configurations 1 and 2 while it reduces sharply for configurations 3 and 4. The attainment of high entropy generation rate is due to high rate of fluid strain generated in the region next to the thermal boundary layer. In this

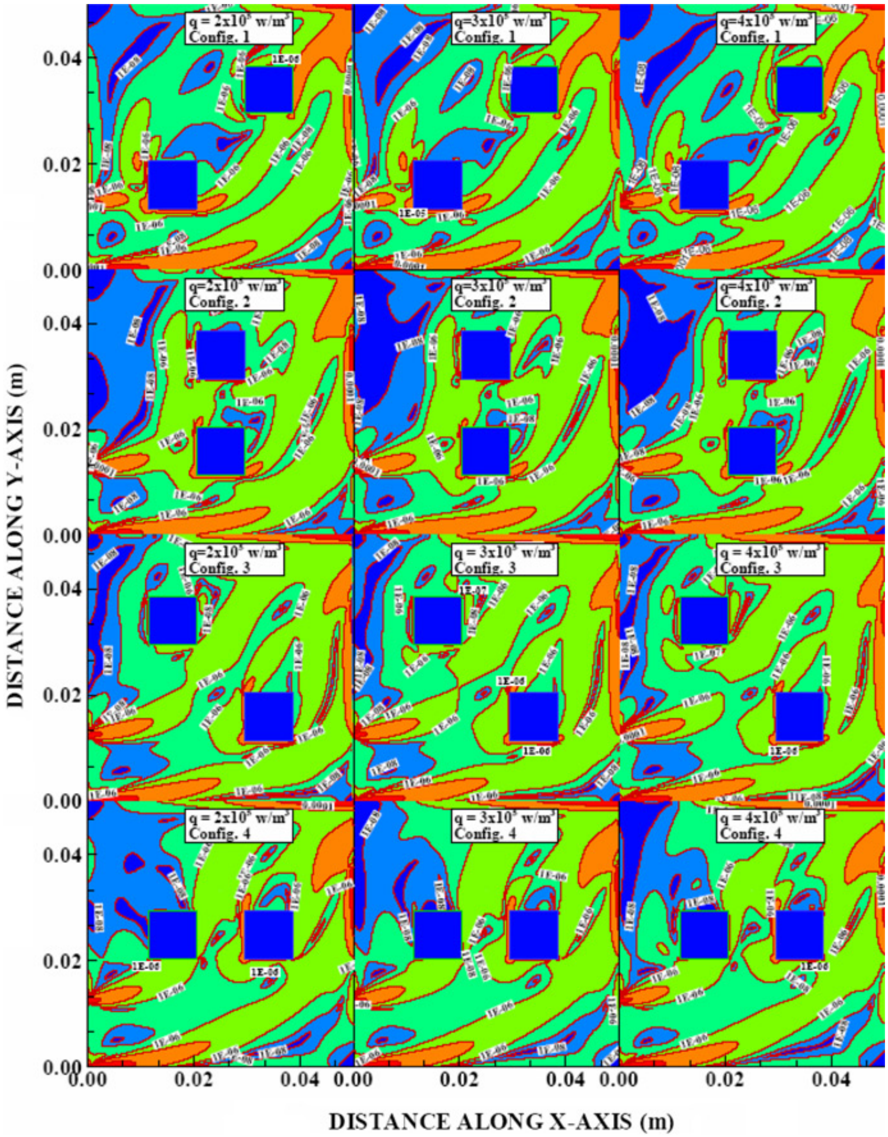


Figure 5. Contour plots of volumetric entropy generation rate due to fluid friction in the cavity for different configurations of the porous blocks and heat fluxes

case, natural convection current generated around the solid body has lower velocity than that of forced convection current. Consequently, rate of fluid strain in the regions of interface of two currents becomes high. This causes enhancement of entropy generation rate in these regions. Moreover, flow mixing in the down stream of the block towards the cavity exist contributes to the enhancement of entropy generation rate. When natural and forced convection currents mix in the down stream of the blocks, they generate high rate of fluid strain in the mixing region. This contributes to the enhancement of entropy generation rate. In the case of configurations 3 and 4, small thermal boundary layer formed around the blocks causes slow natural convection current and shear rate between forced and natural convection becomes small. In addition, flow mixing in the down stream of the blocks is not substantial. Consequently, entropy generation rate becomes small in the flow field.

Figure 7 shows total entropy generation, due to heat rate transfer, in the flow system with configurations of porous blocks in the cavity for different heat fluxes. Entropy generation rate attains high values for configuration 3 and entropy generation rate for configuration 4 is slightly higher than that of configurations 1 and 2. The attainment of high entropy generation rate is because of temperature gradient, which remains high in

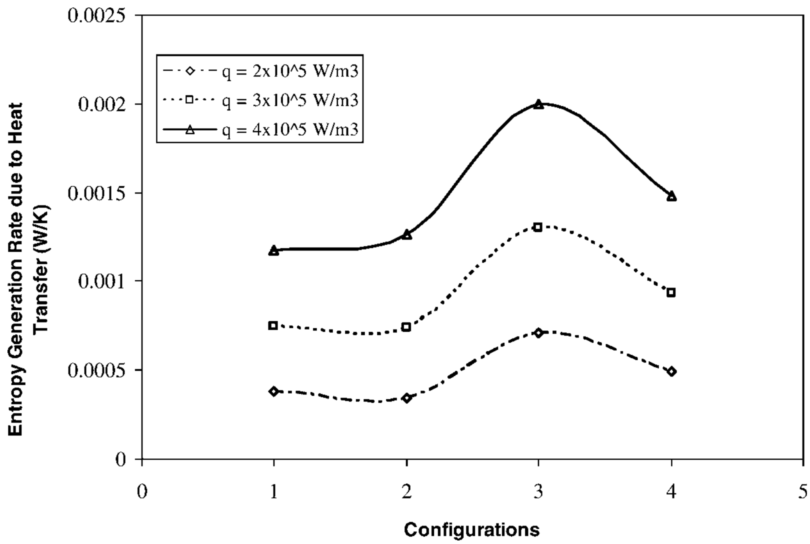


Figure 6.
Total entropy generation rate, due to heat transfer, with configurations in the working fluid for different heat fluxes

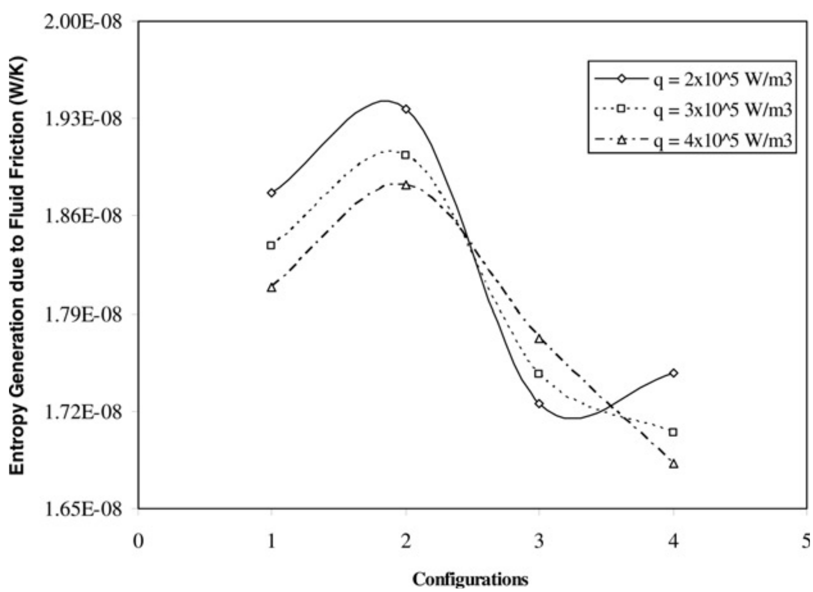


Figure 7.
Total entropy generation rate, due to fluid friction, with configurations in the working fluid for different heat fluxes

the region of the cavity entry, i.e. in the upstream flow, forced convective current is at low temperature while natural convection current around the blocks is at high temperature. Flow mixing in the cavity reduces temperature difference between the natural and forced convection currents while lowering temperature gradient. This lowers entropy generation rate in this region. The effect of heat flux on entropy generation rate is significant. Increasing heat flux enhances entropy generation rate in the flow system. This is because of the attainment of high temperature, as a consequence of high temperature gradient in the working fluid. When comparing entropy generation rate due to heat transfer and fluid friction, entropy generation rate is considerably higher due to heat transfer than that of due to fluid friction. This is because of temperature gradient developed in the flow system, which is high. Since the magnitude of the heat flux is high, which result in high temperature gradients in the flow field in the cavity. In addition, Reynolds number is low ($Re = 100$) which in turn develops low flow velocity in the cavity. This situation results in low magnitude of rate of fluid strain in the flow system. However, when comparing entropy generation rate for each configuration, it can be observed that configuration 4 gives reasonable low entropy generation rate for both due to fluid friction and heat transfer. Other remaining configurations result in either low entropy generation rate due to fluid friction while high entropy generation rate due to heat transfer or vice versa.

Conclusion

Flow over porous blocks situated in a cavity is considered and effects of blocks configurations (locations in the cavity) and heat flux generated in the blocks on entropy generation rate are examined. In the simulations four configurations and three heat fluxes are accommodated while air is used as working fluid. It is found that volumetric entropy generation rate due to fluid friction attains high values within the shear layer developed between the natural and forced convection currents. Consequently, entropy generation rate due to fluid friction attains high values around the blocks. Moreover, natural and forced convection currents mix in the down stream of the blocks towards the cavity exist. In the flow mixing regions, volumetric entropy generation rate becomes high due to high rate of fluid strain. Total entropy generation rate due to fluid friction is high for configurations 1 and 2 while it reduces considerably for configurations 3 and 4. In the case of volumetric entropy generation rate, it attains high values in the region prior to mixing of natural and forced convection currents. In this region, temperature gradient remains high because of temperature difference in both currents. Increasing heat generation in the blocks enhances temperature gradient in the flow system. This, in turn, increases volumetric entropy generation rate around the blocks. When comparing the magnitude of total entropy generation rate due to fluid friction and heat transfer, it remains low for fluid friction. This is because of high temperature gradient as a result of high heat fluxes in the blocks and low Reynolds number of the flow at the cavity inlet. Configuration 4 results in reasonable low entropy generation rate for both due to fluid friction and heat transfer. Consequently, thermodynamic irreversibility of the thermal system in the cavity is low for configuration 4. It is expected that the findings of the present work are useful to identify the thermodynamic irreversibility for the flow over porous blocks within the cavity system. This will provide information for porous system designers to improve the system efficiency through minimizing the entropy production rate.

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