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# Field synergy principle analysis on fully developed forced convection in porous medium with uniform heat generation ☆

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ABSTRACT

In the presence of uniform heat source, the energy equation for forced convective heat transfer in porous medium between two parallel plates is solved for fully developed flow. Field synergy analysis is performed with emphasis on the intersection angle between the velocity vector and temperature gradient vector with the inclusion of heat generation. Maximum local intersection angle corresponds to location with the highest resistance to heat convection. Relationship between Nusselt number and field synergy for forced convection in the presence of heat generation is studied. It is necessary to define a modified intersection angle in order to compare the wall heat transfer coefficient for convective heat transfer processes with uniform heat source.



## 1. Introduction

Convective heat transfer enhancement garners the attention of researchers, and techniques employed include fin attachment and turbulence promotion. Guo et al. [1] pointed out that, as the integral of the thermal boundary layer equation of a uniform free stream flow towards a cold flat plate represents the overall strength of the heat sources inside the boundary layer which is equal to the wall heat flux, convection enhancement can be accomplished by (a) an increase in the Peclet number (b) having flatter dimensionless velocity and temperature profiles and (c) having the intersection angle between the dimensionless velocity and temperature gradient vectors as small as possible. The third is the result of convection depending on the included angle between the velocity and temperature gradient vectors. In extending the concept to elliptic fluid flow and heat transfer, Tao et al. [2] looked into two-dimensional boundary layer. The reduction of intersection angle as a representation of energy transfer by convection is valid for parabolic as well as elliptic flows. To sum up the enhancement concept which is related to both the velocity and temperature fields, it is called field synergy principle. Field synergy principle was adopted by Tao et al. [3] to analyse numerically the flow and heat transfer for duct flow with or without inserts and a single circular cylinder with rectangular fins attached across it. It was found that with improved synergy between velocity and temperature gradients, convective heat transfer is enhanced. Cai et al. [4] solved the heat source distribution that fulfills the full synergy principle for a number of 2-dimensional heat transfer problems by making assumptions that simplify the governing momentum and energy equations. Gou et al. [5] presented field synergy analysis of forced convective heat transfer between two parallel walls that are penetrable. Liu et al. [6] computed numerically the synergy angles for a heat transfer problem in a two-dimensional parallel channel with two-cylinders interpolated along the flow direction. So far the field synergy principles are applied in understanding the heat transfer coefficient variation for some simple duct flows besides solving some possible analytical temperature, velocity and heat source distributions that satisfies the full field synergy requirement with certain assumptions.

In porous medium, Yang and Vafai [7] incorporated uniform heat generation terms in the two-equation model for forced convective heat transfer, and solved analytically the temperatures in the fluid and solid phases by adopting the Darcy model. There are also a number of studies [8–10] on forced convective heat transfer in porous medium with heat generation in the form of viscous dissipation that solve for the temperatures and hence *Nu* affected by viscous dissipation. However, to the best of our knowledge, there is yet any study that employs field synergy principle in evaluating convective heat transfer and heat transfer coefficient in porous medium with heat generation.

In this study, the temperature field for convective heat transfer in porous medium between parallel plates channel with uniform heat source generation is solved for fully developed flow subject to two different sets of boundary conditions which are adiabatic wall and isoflux wall. The effects of shape factors on heat convection rates are analysed by adopting field synergy principle and a comparison is made between the variation of intersection angles with different boundary conditions. For isoflux wall, the relationship between *Nu*, a dimensionless heat transfer coefficient at the wall and intersection angle that underlines field synergy principle is determined.

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