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Study on Heat Transfer of Non-Newtonian Power Law Fluid in Pipes with Different Cross Sections

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Abstract

In industrial applications, most of fluids have non-Newtonian fluid characteristics. It is of great significance to the economic development and energy consumption reduction to study the heat transfer of non-Newtonian power law fluid. In this paper, the heat transfer of non-Newtonian power law fluid in pipes with different cross sections are studied. The mathematical model and physical model of the non-Newtonian fluid are briefly introduced first, and the physical model is divided by the structured mesh. Then the numerical simulation of the laminar heat transfer of non-Newtonian fluid in different cross sections is carried out. On the basis of discussing the distribution of temperature field, many parameters which have influenced on the temperature field and the heat transfer is analyzed in this paper, such as tube shape, the power-law index (*n*) the Peclet number (*Pe*) and so on. The results show that the heat transfer characteristics of non-Newtonian fluid are related to the parameters we mentioned.

Keywords: Non-Newtonian power law fluid; Heat transfer characteristics; Peclet number; Shape of cross sections;

Nomenclature

n	the power-law index
Pe	the Peclet number
ρ	the density,kg/m^3
t	time step, s

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F	the force,N
T	thetemperature,℃
u	the speed,m/s
p	the pressure,Pa
U	the single-phase velocity vector
μ	the coefficient of kinetic viscosity,kg/m·s
φ	the single-phase conservation term
Γ_φ	the diffusion coefficient of φ
S_φ	the source term of φ

1. Introduction

In recent years, the application of non-Newtonian fluid materials has been gradually extended because of its special rheological properties[1]. Therefore, the study of the flow and heat transfer of non-Newtonian power law fluid is of great importance to the development of economy and the reduction of energy consumption. In addition, the study of non-Newtonian power law fluid has very important practical significance in various fields[2].

A large number of studies have shown that the research of Newton fluid has been relatively mature. But due to the complicated composition of the non-Newtonian fluid, a lot of problems still need to be discussed and studied. In order to investigate the complex flow and heat transfer characteristics of non-Newtonian fluid, many scholars have studied the power-law fluid by taking the viscosity and shear rate of non-Newtonian fluid as the breakthrough point [3]. Baptista and others[4] numerically simulated the temperature distribution and got the *Nu* number of the power-law fluid in the fully developed laminar flow. Meanwhile, they simplified the connection between the power-law index and the *Nu* number. The Professor Dong and others in China University of Petroleum[5] studied the influence caused by the coupling of velocity field and temperature field of non-Newtonian power law fluid in annular flow. Mukherjee etc[6] studied the flow and heat transfer characteristics of power-law fluids and Bingham fluids through a series of non-circular cross section of the tube in laminar flow.

In this paper, CFD method is applied to the theoretical analysis and numerical simulation of non-Newtonian power law fluid. It provides a theoretical reference for the heat transfer characteristics of non-Newtonian power law fluid. Meanwhile, the research and analysis on the heat transfer of non-Newtonian fluid in different cross sections not only has the engineering background, but also has a good application prospect.

2. Mathematical model

The governing equations[7]which describes fluid flow and heat transfer in pipes are as follows:

Continuity equation: $\frac{\partial \rho}{\partial t} + div(\rho u) = 0$ (1)

Momentum conservation equation: $\rho \frac{\partial u}{\partial t} + \rho \frac{\partial u u_i}{\partial x_i} = F - gradp + \mu \nabla^2 u$ (2)

Energy conservation equation(no dissipation): $\frac{\partial T}{\partial t} + div(\rho u T) = a \cdot div(gradT)$ (3)

Taking into account the relation among the kinematic viscosity coefficient, thermal diffusivity, velocity gradient and temperature gradient of non-Newtonian power law fluid, and ignoring the energy dissipation in the low-speed flow range in this paper, the governing equation of the non-Newtonian powerlaw fluid in steady laminar flow is presented as follows:

$$\frac{\partial(\rho\varphi)}{\partial t} + \frac{\partial}{\partial x_j}\{\rho U \varphi - \Gamma_\phi \frac{\partial \varphi}{\partial x_j}\} = S_\varphi \quad (4)$$

where U is the single-phase velocity vector, φ is the single-phase conservation term, Γ_φ is the diffusion