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Experimental Investigation of Performance of Heat Pipe for Drilling Purposes

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Abstract

Nano science development introduces nano materials which are used into the heat transfer subfields as nano fluids which are produced by dispersing nano particles of metals in the working fluids. Effects of different important parameters in heat pipe drill configuration, such as heat pipe diameter, heat flux input magnitude, length of the heat input zone and depth of the heat pipe within the drill are investigated. A solid cylinder model with conduction mechanism for heat transfer is proposed to simulate the performance of drill approximately. Numerical results from the proposed model are verified by the experimental data. Results indicate the significant effect of using a nano fluid in heat pipe drilling in temperature field reduction. Also, results propose applicable criteria in manufacturing nano fluid heat pipe in drilling.

Keywords

Heat Pipe, Drilling, Modeling, Mechanism, Nano Fluid

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1. Introduction

Transferring the released heat to the machining tools accelerates the corrosion rate in the instrument and shortens the tool life [1, 2, 3]. On the other hand, several researches have been done to prepare nano fluids which can be applied in compact instruments and also in high temperature industries [4, 5]. Although the suspension contains metallic particles has higher thermal conductivities and proposes heat transfer augmentation in the heat exchangers, but they also cause erosion corrosion, pressure drop and pipe blockage. Nano science development introduces nano materials which are used into the heat transfer subfields as nano fluids which are produced by dispersing nano particles of metals in the working fluids. Since of higher thermal conductivity of the metal particles suspended in the fluid, so the nano fluid shows lower thermal resistance comparing the working fluid [4, 5].

Drilling in most machining processes is applied and heat removal from cutting zone by nano fluid heat pipe is a novel subject considered in this paper. Researchers considered in application of heat pipe cooling in drilling works [6]. However, using nano fluid in heat pipe cooling in drilling is interesting subject which investigates both heat pipe and nano fluid capacity in drill cooling. On the other hand, current cutting fluid cooling methods in drilling exposes working environment to fluids that may contaminate the environment. Also, the estimated operating cost due to coolant usage includes about 20% of total operating cost. Heat pipes are utilized in cooling purposes in several fields of technology, excessively. Since these parts are low in cost so they are named highly reliable equipment's. Their usage in high power cooling applications has been limited to custom applications requiring either low thermal resistance and/or having a severely restricted enclosure field. The thermal performance of heat pipe as one type of highly effective heat transfer part in heat exchange apparatus can be improved by using nano fluids [7, 8, 9].

Heat pipes are introduced as passive method of heat transfer which simply combines evaporation and condensation of

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working fluid through a closed system. Counter current flows of liquid and vapor in a small adiabatic annulus, transfer heat between external heat source and external heat sink, continually. Vapor flows in tube center due to vapor expansion and pressure gradient and liquid flows through a wick due to capillary force. Fast heat transfer occurs since of fast movement of fluids and convection - conduction mechanisms govern heat transferring. So, temperature difference between evaporator section and condensation section is low. Figure 1 shows a schematic of the heat pipe. Temperature difference in heat pipes is low enough to assume the pipe isothermal. The values of heat pipe thermal conductivity based on temperature difference in the system are much larger than that is measured from the solid rod with the same dimension. This is because the heat transfer in the heat pipe occurs due to the latent heat of evaporation and condensation [7, 8, 9 and 10].

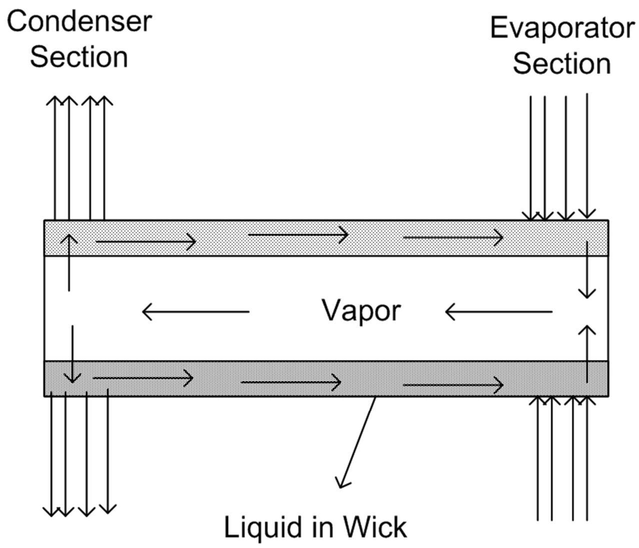

Figure 1. A schematic of heat pipe.

Many researches documented that by adding nanoparticles, such as aluminum oxide, copper oxide, and titanium dioxide, to a liquid base fluid can enhance the thermal conductivity [6, 10]. Due to Fourier's law (conduction heat transfer) and Newton's law of cooling (convection heat transfer) at the wall surface, an increase in the thermal conductivity promotes higher convective heat transfer coefficient.

In this paper, the effect of using nano Al_2O_3 fluid in heat pipe cooling in drilling work is investigated. Experiments are held to find the influence of some manufacturing parameters on the drill cooling performance. These parameters are such as depth of the heat pipe within the drill, heat input zone length and heat flux magnitude in drilling applications. Also, theoretically a mathematical model is presented to survey the effect of mentioned manufacturing parameters on the performance of heat pipe cooling.

2. Mathematical Model

Unsteady state conduction equation is applied to model the drill and the heat pipe which are assumed as concentric cylinders shown in Figure 2. Heat transfer in radial (from drill surrounding to the heat pipe) and axial direction (from tip to the top of drill) are considered and temperature variation in angular direction is neglected due to symmetry in this direction. Temperature dependence in time is considered as energy accumulation term in the equation.

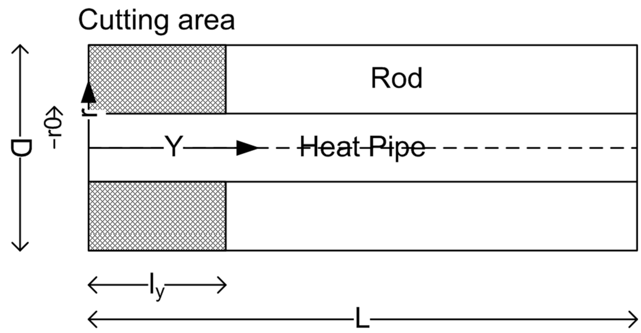

Figure 2. Parameters of drill and heat pipe as concentric cylinder model.

Finally, energy equation is solved by finite element method. So, the energy balance conduction equation with constant thermal properties is written as Equation 1.

$$\frac{1}{\alpha T}\frac{\partial T}{\partial \tau} = \frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial T}{\partial r}) + \frac{\partial^2 T}{\partial y^2} \quad (1)$$

Where T is the temperature and α_T is the tool thermal diffusivity.

Two conditions in y direction and two conditions in r direction are described due to drill conditions. An insulated boundary condition at the tip of drill ($y = 0.0$) and constant temperature condition at the end cap of drill ($y = l$) is imposed.

$$\frac{\partial T}{\partial Y}\Big|_{Y=0.0} = 0.0, T\Big|_{Y=L} = T_0 \quad (2)$$

Constant heat flux condition for heat pipe drill surrounding is assumed due to heat input in cutting zone. Where l_y is length of cutting zone, l is the distance between the drill tip and the heat pipe tip and q_c'' is the input heat flux (W / m^2).

$$KT\frac{\partial T}{\partial r}\Big|_{r=0.0} = q_c'' for 0.0 \le y \le l_y \quad (3)$$

Heat transfer is negligible since no coolant is used in the cutting operation so an adiabatic condition is imposed for surface area outside the heat input zone.

$$\frac{\partial T}{\partial r}\Big|_{r=o.o} = 0.0 \, for y \geq l_y \tag{4}$$

The large amount of latent heat of working fluid in the heat pipe presents small temperature drop in the heat pipe. So, constant surface temperature is assumed for the inner surface of drill. For the end cap of the heat pipe, boiling temperature of working fluid, constant temperature is assumed.

$$T\Big|_{r=ro} = T_{hp} \, for y \geq l \tag{5}$$

$$T\Big|_{y=l} = T_{hp} \, for 0.0 \leq r \leq r_0 \tag{6}$$

3. Results and Discussion

Effects of nano fluid as the work fluid in heat pipe on important parameters in drilling performance are investigated, experimentally and numerically. The experimental drill instrument is manufactured with l*=0.2 and tested by different input heat fluxes. Numerical results are compared with experimental data so, good criteria in design of drill cooling system with nano fluid heat pipe are presented.

3.1. The Effect of Nano Fluid in Time and Temperature

Temperature field reduction is the most important parameter investigated in Figure during 300 sec time interval of working. Three states are investigated to compare the performance of usual drill without heat pipe (SD), drill which is equipped by heat pipe with water working fluid (HPD) and drill with heat pipe contained Al_2O_3 nano fluid (HPNFD). According to the Figure working temperature is increased by time at the work beginning till 50 sec., in three states. After 50 sec. the increasing slope in HPNFD is the least comparing with usual drill and HPD. Also, temperature is approximately constant after 200 sec. working with HPNFD type. The temperature field reduction of HPD and HPNFD is about 9% and 32%, respectively. Maximum difference in temperature between cases HPNFD and SD is 124 C and also between HPD and SD is 37 C. So, nano fluid shows the significant cooling in drilling. So, increase in temperature using SD may damage the instrument. Dashed lines show the calculated temperatures for three cases by numerical method. According to Figure 3 numerical solution predicts temperatures near the experimental results. However, numerical results are smaller than experimental temperatures in all cases.

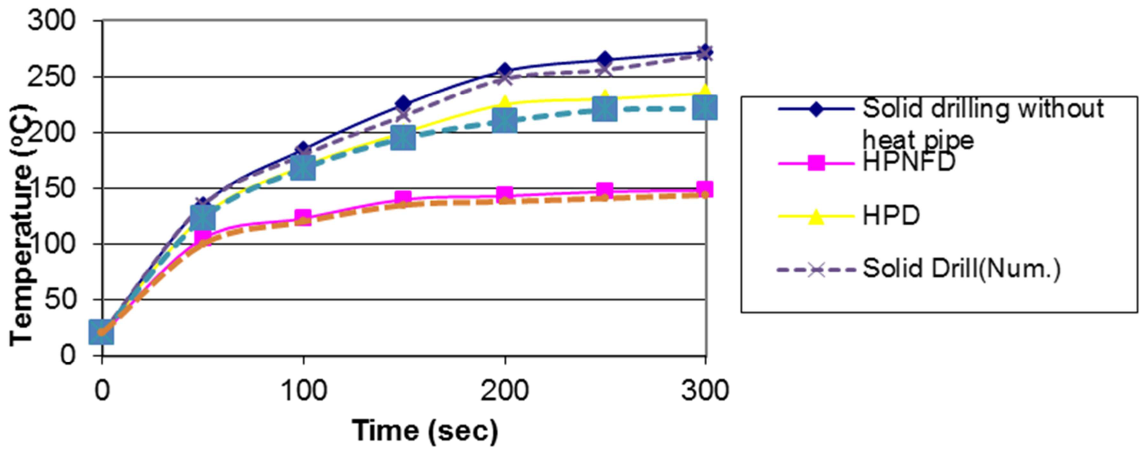

Figure 3. The effect of nano fluid in operation temperature in cutting zone.

3.2. Role of Heat Pipe

The results show the performance of drilling purposes can be enhanced when the heat pipe applied in drilling apparatus. In fact, the heat pipe role as cooling source.

4. Conclusions

Temperature reduction in compact instruments and high temperature processes has been considered in many industries. In this work, the influence of nano Al_2O_3 fluid in heat pipe cooling system is studied in drilling work. Also, an experimental drill without heat pipe is manufactured and is modeled theoretically to compare the temperature distribution with one is obtained in heat pipe cooling drilling.

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Biography

Ehsan Ghaedi studied reservoir engineering in Islamic Azad University, science and research in Fars province. He is interested in reservoir simulation, drilling, exploring and in-well facilities. He is now in Bachelor degree and works on well drilling, simulation and related fields.

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