International Conference on PARALLEL COMPUTATIONAL FLUID DYNAMICS

PARALLEL CFD 2007

May 21-24 2007, Antalya TURKEY

Parallel CFD is an annual conference series dedicated to the discussion of recent developments and applications of parallel computing in the field of Computational Fluid Dynamics (CFD) and related disciplines. The inaugural conference was held in 1989.

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Authors are invited to submit *extended abstracts* of 3-5 pages with key figures and references. Please refer to the Author's Guide in preparing your manuscript. *Abstract/Paper submissions will be online.*

IMPORTANT DATES

Abstract submission	Friday, February 16, 2007
Notification of acceptance	March 15
Early Registration	Friday, April 13
Revised abstracts	Monday, April 30
Parallel CFD 2007	May 21-24
Final paper submission	September 1, 2007

ANTALYA

Antalya is a city in southwestern Turkey, located on the Gulf of Antalya. The city is the largest urban area on Turkey's central Mediterranean coast with a population of 600,000. People are attracted to Antalya's beaches and nearby ancient ruins. In addition to tourism, light industry is important, as is agriculture, particularly the harvest of citrus fruits.

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ParCFD-2007-044

The Analysis and Feasibility of Using Heat Pipe Cooling in Drilling Applications

A. Kianifar and F. Faridnia

A numerical study was performed to investigate the feasibility of using heat pipe cooling in drilling applications. The drill and heat pipe were modeled as concentric cylinders and for simplification only conduction heat transfer was considered.In this model the friction that is imposed to the rotating drill was simulated as constant heat flux. Also the effect of geometrical parameters such as heat pipe diameter, heat pipe depth, input heat flux was analysed. To validate the numerical results, they were compared with the experimental results which show a good compatibility. According to this results, using heat pipe in drilling applications can significantly reduce the field temperature. Also the optimized value of the diameter and the length of heat input zone were obtained.

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The analysis and feasibility of using heat pipe cooling in drilling applications .

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Abstract

A numerical study was performed to investigate the feasibility of using heat pipe cooling in drilling applications. The drill and heat pipe were modeled as concentric cylinders and for simplification only conduction heat transfer was considered.In this model the friction that is imposed to the rotating drill was simulated as constant heat flux. Also the effect of geometrical parameters such as heat pipe diameter, heat pipe depth, input heat flux was analysed. To validate the numerical results, they were compared with the experimental results which show a good compatibility. According to this results, using heat pipe in drilling applications can significantly reduce the field temperature. Also the optimized value of the diameter and the length of heat input zone were obtained.

Keywords: Heat pipe,Drill ,Temperature

1.Introduction

Cutting fluids is a source of environmental hazard and also incur a significant share of total manufacturing cost. Minimization and possible elimination of cutting fluids, by substituting their functions by some other means, is of current research interest.[1]

Cutting fluid may be applied to a cutting tool/workpiece interface through manual, flood or mist application .Manual application simply consists of an operator using a container, such as an oil can, to apply cutting fluid to the cutting tool/workpiece. Although this is the easiest and it is the least costly method of fluid application, it has limited use in machining operations and is often hampered by inconsistencies in application.Flood application delivers fluid to the cutting tool/workpiece interface by means of a pipe, hose or nozzle system [1] . Fluid is directed under pressure to the tool/workpiece interface in a manner that produces maximum results. Pressure, direction and shape of the fluid stream must be regulated in order to achieve optimum performance.Cutting fluids may also be atomized and blown onto the tool/workpiece interface via mist application. This application method requires adequate ventilation to protect the machine tool operator. The pressure and direction of the mist stream are also crucial to the success of the application.In metal industries, the use of cutting fluid has become more problematic in terms of both employee health and environmental pollution.

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Nomenclature

T	drill temperature, °C	a	drill radius, m
α_T	tool thermal diffusivity m^2/s	D	drill diameter, m
k_T	thermal conductivity, w/(mk)	θ	dimentionless temperature
λ	distance between the drill tip and heat pipe tip , m	T_0	ambient temperature, °C
		q_c^*	dimentionless heat flux
q_c''	constant heat flux , w	λ_z^*	dimentionless cutting zone length
L	drill length ,m	T_{hp}	heat pipe surface temperature, °C
r_0	heat pipe radius ,m	c_p	specific heat, J/(kgK)
λ_z	cutting zone length ,m		

But the use of cutting fluid generally causes economy of tools and it becomes easier to keep tight tolerances and to maintain workpiece surface properties without damages. Because of them some alternatives has been sought to minimize or even avoid the use of cutting fluid in machining operations. Some of these alternatives are dry cutting and cutting with minimum quantity of fluid (MQF) .To minimize the use of cutting fluid, two techniques have been intensively experimented: cutting without any fluid (dry cutting, also known as ecological machining) and cutting with a minimum quantity of fluid (MQF), where a very low amount of fluid is pulverized in a flow of compressed air[1].

Friction force made by rotating drill, generate heat in cutting zone , that transfer to tool and workpiece[2]. Elimination of fluid because of environmental regards result in increasing heat , shortening tool life , poor dimensional control in workpiece.In spite of researches on another cutting operations , research on drilling is rare[3-6] . in drilling processes tool temperature is important because the chips that absorb heat generated ,are confined.this cause to significant temperature increase. As a resulte drill temperature is higher than another machining operations. An effective cooling method other than fluid coolants, is necessary to decrease drill tool temperature[7].

Heat pipe offer an effective alternative to remove heat without significant increase in operating temperature.heat pipe is a device totransfer heat with low temperature difference without the need for an external power supply.heat pipe is a sealed container that has working fluid and internal wick structure for supplying capillary action. heat pipe has three sections, evaporator section , adiabatic section and condenser section. In first section liquid absorb generated heat in cutting zone and are evaporated ,it passes through adiabatic section and condensed in condenser section then working fluid is pumped back to first section by capillary action.The operation of a heat pipe can be analyzed using a fundamental thermodynamic cycle for the working fluid, in which the thermal energy is converted to In some cases,such as a home heating system , gravity is used to return the condensed liquid to the evaporator instead of the wick structure.

The published works related to rotating heat pipe are relatively rare.T.C.Jen,G.Gutierrez have simulated a two dimensional drill with an internal heat pipe and transient effects[7] . A detailed review will be provided as follows. The concept of a rotating heat pipe was first proposed by Gray [9], who found that a rotating heat pipe could transfer significantly more heat than a similar stationary heat pipe due to the centrifugal pumping effect. By assuming a very thin film with a negligible slope, Ballback [10] found a closed form solution for the total heat transfer from the condenser region of a rotating heat pipe. Daley [11] extended Ballback's work to include the effect of wall thermal resistance, and determined the temperature drop across the wall. Chan [12] developed a theory for a rotating heat pipe and obtained an analytical solution to predict the heat transfer rate of a wickless heat pipe that is conical in shape and rotates about its longitudinal axis. Daniel and Al-Jumaily [13] developed the correlation for interfacial shear stress for the rotating heat pipe. Harley and Faghri [14] studied a two-dimensional rotating heat pipe with transient effects. They also accounted for the vapor pressure drop and the interfacial shear stress of the counter-flowing vapor. The interfacial hear stress was calculated directly. Schmalhofer and Faghri [15-17] developed a three-dimensional model for an axially rotating heat pipe. Heat transfer mechanism in present model is pure conduction, if the thermal conductivity is measured based on the temperature difference in the system with the same amount of heat transferred, the thermal conductivity of the heat heat pipe system is much larger than pure conduction in the solid rod with the same dimension of the heat pipe. A large latent heat of evaporation and condensation result in the process .

In this paper , a study is performed to investigate the feasibility of using heat pipe technology in a drilling tool , also the influence of geometrical parameters such as depth of the heat pipe within the drill , heat pipe diameter, heat flux magnitude and heat input zone length in drilling applications is performed . Physical configuration of system is shown in figure 1

2.Modeling

The drill and heat pipe , for simplification are modeled as concentric cylinders .Conduction mechanism transfers heat generated in cutting zone.Governing equation is :

$$\frac{\partial^2 T}{\partial r^2}+\frac{1\partial T}{r\partial r}+\frac{\partial^2 T}{\partial z^2}=\frac{1\partial T}{\alpha_T \partial \tau} \qquad (1)$$

Where T is the drill temperature , α_T is tool thermal diffusivity.Heat generation is modeled as a heat source surrounding the cylinder , this assumption is reasonable due to the high rotation speed of the drill [7] , heat transfer in z direction through the top end of drill is negligible . A hollow cylinder is modeled as heat pipe in the center of the drill , pipe wall is maintained in a fixed temperature , this is due to large latent heat cause to small variation in the heat pipe wall temperature [7] .

The boundary conditions imposed the model are:

An insolated condition and constant temperature are imposed for two end of drill .

$$\frac{\partial T}{\partial z}\Big|_{z=0}=0, T\Big|_{z=L}=T_0 \qquad (2)$$

Where T_0 is the ambient temperature.A constant heat flux is imposed for cutting zone.

$$k_T\frac{\partial T}{\partial r}\Big|_{r=a}=q''_c \; for\, 0\le z\le \lambda_c \qquad (3)$$

Where λ_c is cutting zone length and k_T is thermal conductivity.Also an adiabatic condition is imposed for outside surface of drill, that has no coolant .

$$\frac{\partial T}{\partial r}\Big|_{r=a}=0 \; for z\ge \lambda_c \qquad (4)$$

$$T\Big|_{z=L}=T_0 \qquad (5)$$

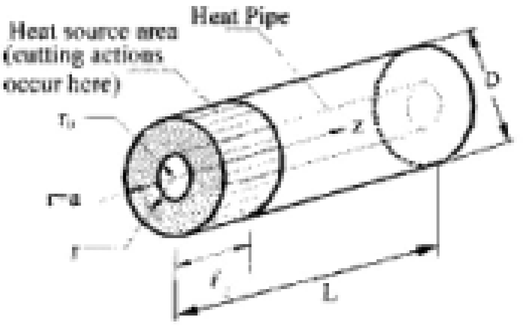

Fig1. Physical configuration of an idealized drill with heat pipe

$$T\Big|_{z=L} = T_{hp}\ for 0 \le r \le r_0 \qquad (6)$$

$$T\Big|_{r=r_0} = T_{hp}\ for z \ge \lambda \qquad (7)$$

Where λ is distance between the drill tip and heat pipe tip , and T_{hp} equale to water boiling temperature.

Some dimensionless parameters are defined that will use in results. They are as follows :

$$\lambda_{s}^{*} = \frac{\lambda_{s}}{D} \qquad (8)$$

$$\lambda^{*} = \frac{\lambda}{D} \qquad (9)$$

$$\theta = \frac{T - T_0}{T_{hp} - T_0} \qquad (10)$$

$$q_{c}^{*} = \frac{Dq_{c}^{'}}{k_{T}(T_{hp} - T_0)} \qquad (11)$$

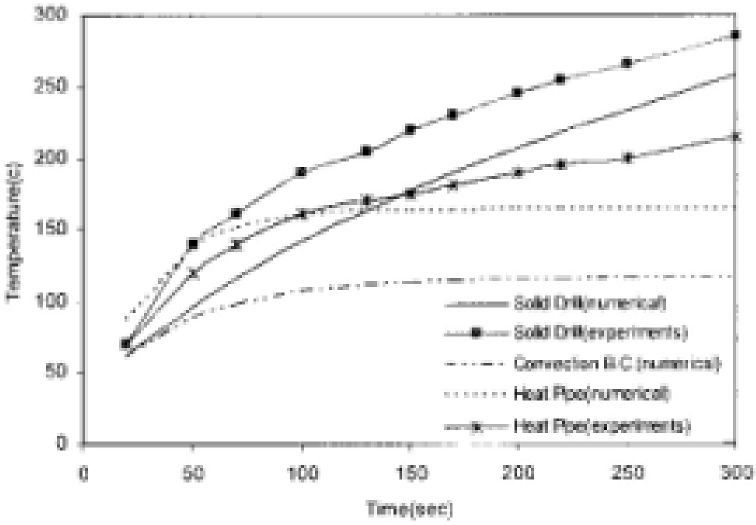

Fig.2.Drilling temperature in the cutting zone

3.Numerical analysis

Numerical computation was carried out by Fluent software . The method used was finite volume .Numerical scheme solves a 3D conduction heat transfer problem which results in temperature field. A cylindrical rod with 0.216m length and 0.0254m diameter was drawn .The diameter of the heat pipe was 0.00635m. The model was meshed in Gambit and the boundary condition of the heat pipe wall was assumed as isothermal. The solution is converged when residuals from solving energy equation are smaller than convergency criterion .

4.Results and discussions

The analyse was performed on a cylindrical rod with a diameter of 0.0254 m and total length of 0.216 m. High speed steel was used for rod.The diameter of heat pipe was 0.00635 m. A constant heat input of 85W was used in cutting zone. The thermal conductivity of material is 40 W/m.K, the density and the specific heat of the drill is 7850 kg/m^3 and 460 J/kgK respectively [7].

At first an investigation was performed on feasibility of using heat pipe for cooling in drilling operations.Temperature in the same location for three different configuration were tested, one configuration was a solid drill, without any coolant or heat pipe, the second configuration was a drill cooled by convection and the last configuration was a drill with heat pipe. The experimental results of solid drill and heat pipe drill obtained from refrence [7] have been denoted in figure 2.It can be seen from the figure 2 that temperature distribution in numerical solid drill and experimental model have the same trend. Also the results of numerical analyse and experimental data for temperature of heat pipe drill (drill with heat pipe) have a reasonable agreement . Lastly the temperature in convective cooling case are shown in which a heat transfer coefficient of 5000 W/m^2 °C was simulated . The predicted temperatures in heat pipe drill are closest temperatures to convective case.This result implies that using a heat pipe as a coolant method is feasible.Another study was performed by varying the effective parameters. It was assumed the problem became steady state. Figure 3 illustrates numerical and experimental results comparison for dimensionless temperatures, when the parameter of λ^* is variable .The analyse was carried out with a constant heat flux and heat input length in order to deduse the effect of parameter λ^* that is the distance between drill tip and end cap of heat pipe divided by the total length of the drill .It can be seen from the figure with decreasing the distance between drill tip to heat pipe end cap, the temperature decrease because the heat pipe is closer to cutting zone and absorption and transfer of heat by heat pipe is large. When the λ^* is less than 0.1 there is not a considerable reduction in temperature .

This results indicate when $\lambda^*=1$ (i.e solid drill) increase of temperature is very large and it can cause to thermal damages.Another investigation toward to parametric study was to vary input heat flux and input heat length. In figure 4 has been illustrated the result of this study . In this figure the heat flux input is for three different heat input zone length(0.009525,0.01905 and 0.028575 m for a 0.01905 diameter drill or $\lambda_z^* = .5$,1and 1.5) the value of λ^* based on results in figure 3 has been considered 0.1 .

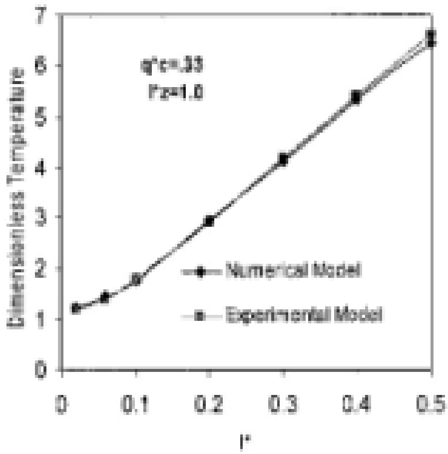

Fig 3.The effect of distance between drill tip and heat pipe end on temperature

It can be found out the temperatures increase with increasing in heat input zone length and does not change significantly when the heat flux input varies from 0.33 to 1.12 .

In this study the effect of the heat pipe diameter has been investigated . This results in figure 5 indicate that increase of d/D decrease the temperature significantly because the heat pipe is closer to the drill wall , thus the value of heat transferred is large due to decreasing in conductivity resistance in the drill wall.

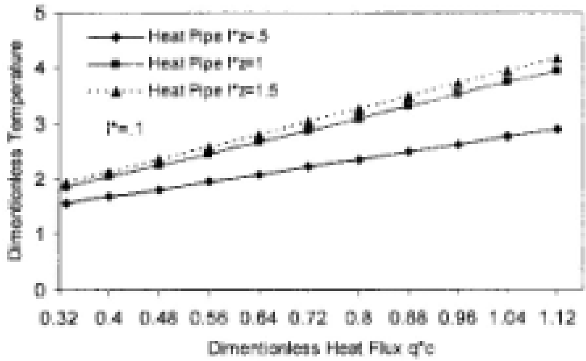

Fig 4. Effect of heat flux and heating zone size on temperature

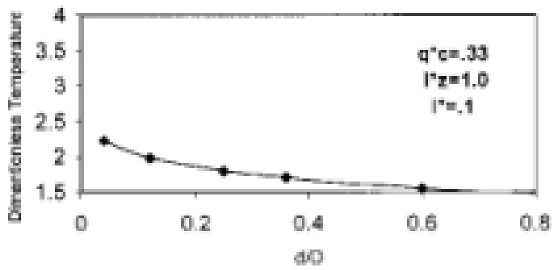

Fig 5. Effect of heat pipe diameter on cutting zone temperature

5.Conclusions

The results show using heat pipe in drilling applications can significantly reduce the temperature.Also the effect of the variable parameters such as diameter, length of heat pipe and input heat flux was investigated. Increase of the diameter and heat pipe length can reduce the drill temperature According to them an optimum design can be made.The optimized diameter and heat input length that were obtained, are 0.3 and 0.1 respectively. Future analyse under the effect of rotating is to model a rotating drill.

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