RREDICTION OF TEMPERATURE PROFILE IN OIL WELLS

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Abstract A mathematical model has been developed to predict the temperature distribution in wellbores either offshore or inshore. It is incorporated the different activities encountered during drilling operations. Furthermore, the effect of drill collar and casings and bit rotating in a well during completion has been considered. The two dimensional approach is presented in the form of a computer program which is adopted for solution of the finite difference equations describing the heat transmission in the wellbore in the form of a direct solution technique. The power law model has been selected for drilling mud and its indices have been calculated. Comparing measured data, recorded for a period of 82 hours during different activities in a drilling operation for 15/20A-4, an exploration well in the Central North Sea with calculated results, show there is a good agreement between the prediction and measured temperatures in the wellbore.

Key Words Drilling, Casing, Mud, Formation, Temperature, Transient, Finite Difference

INTRODUCTION

Drilling deep wells up to 10,000 m inshore and offshore in hostile environment, has caused severe problems which require complex analysis of the heat transmission encountered throughout the drilling operation. In addition, drilling of deep wellbores, coupled with the need for more casings to provide improved conditions from the safety point of view, may make the heat transmission between the formation and the borehole more complicated. Therefore, quantitative knowledge of the heat transmission in the wellbore is becoming more important. This knowledge requires the analysis of numerous variables which are used to predict and control the behavior of downhole condition.

One such variable is temperature. In the past, it is has been convenient to ignore the temperature distribution in the well and to assume an isothermal condition. But, as search for oil and gas is carried out in increasingly hazardous and hostile environments with higher geothermal temperature, it is necessary to find efficient ways to determine the downhole behavior and by doing so to reduce the costs of highly expensive operations.

Various temperature measuring devices and

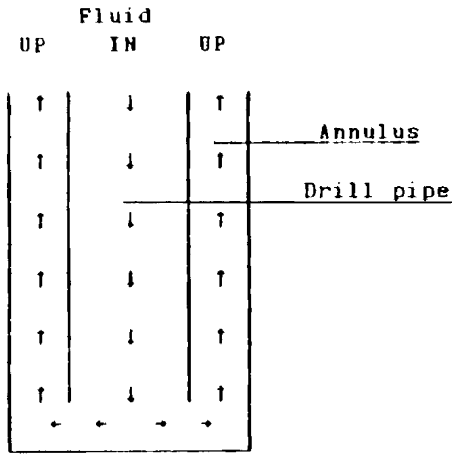

Figure 1. Effect of varying flow rate on temperature.

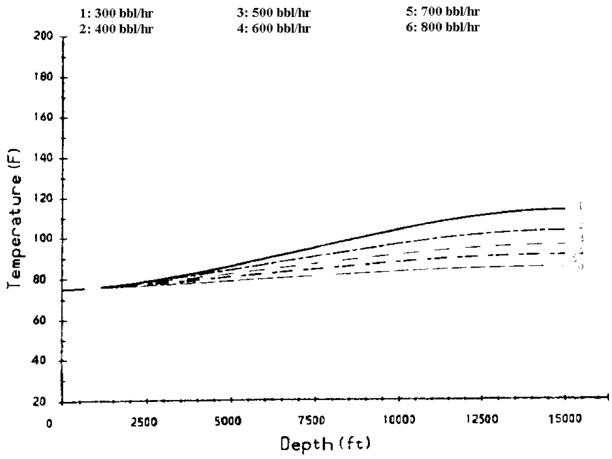

Figure 2. Schematic representation of mud in drill pipe during circulation [32] circulation in well bore.

charts have been developed in the past, [1,2,3,4] but there cannot provide a measure of how and at what extent variables influence the temperatures in the wellbores. It addition, mathematical models have been formulated to predict temperature distribution in the wellbore, but most of these have been simplified [5,1,6] and the transient heat behavior has been ignored (Figure 1) and some others factores have not been included, e.g. the history of the drilling operation.

To develop a transient model, incorporating the techniques developed for drilling fluid, transient heat flow from formation [7], the energy generated by frictional pressure losses [8,9,10,11], and the energy generated by the drill bit in rotation under different phases such as forward circulation, shut-in. and drilling, a numerical method is applied which may be used in conjunction with personal computers (PC) in practice.

DEVELOPMENT OF FLUID MODEL

During the drilling operations fluids are pumped down the drill string from the surface passing through the drill bit and then up the annulus surrounding the drill pipe tore-mergefrom the annulus at surface (Figure 2).

The fluid mud provides a variety of necessary functions to enable the hole to be drilled both safety and economically such as cooling bit and lubricating its teeth and drill string, transporting cuttings, balancing formation pressure, and etc.

The basis of any heat transfer model for a drilling process in the wellbore is the drilling fluid which has important influence on operations. Therefore, to investigate any consideration, a rheological model is required for the hydrodynamic conditions of the drilling mud in the well.

An obvious strategy is to decide upon a rheological model and investigate variations of parameters which are involved in the model. The model should be a representation of the nature of the fluid flow process [12], the velocity distribution in the fluid [13,14,15] and the properties of the fluid [16].

In general, drilling fluid can be classified according to their base such as water, oil, and gas. Drilling muds which contain more complex substances do not follow the Newtonian's law [17], and should be categorized as

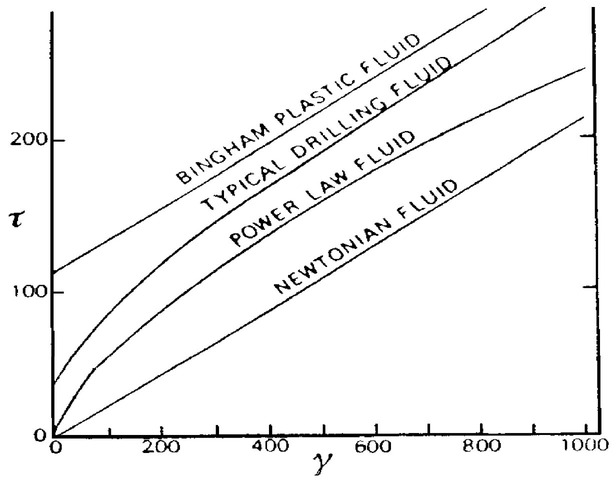

Figure 3. Reological model of fluids.

non-Newtonian fluids. Water is the best example of a Newtonian fluid but very few drilling fluids can be represented by this model.

Three main categories of non-Newtonian fluids are recognized, namely time independent, time dependent and viscoelastic. The time independent fluids can be divided into Bingham plastic, Pseudoplastic, yield pseudoplastic fluids [18]. The pseudoplastic model constitutes many and probably the most important class of non-Newtonian fluids, used in oil industry. The relationship between shear stress and shear rate in this model is non-linear, (Figure 3).

Whilst the yields-pseudoplastic model for drilling fluids is more desirable, the power law model (Eq. 1,2) is rather convenience mainly because most drilling fluids possess a yield value [19], which is not taken into consideration in this model.

$$\tau = k[\frac{dv}{dr}]^n \tag{1}$$

$$\tau = k[\gamma]^n \tag{2}$$

SELECTION OF AN APPROPRIATE RHEOLOGICAL MODEL

Complex rheological models are used to improve fluid mechanics representation [20,21]. Hence, a fundamental question arises of how good is the rheological model of the drilling fluid? Material properties of the fluids in a well influence the heat exchange between the well and formation.

There are two important contributory factores of heat transfer of the fluid. Firstly, transfer of energy up and down inside the well is accomplished by the fluid flow, which is depened on fluid properties. Secondly, radial heat conduction from the well must pass through the annular fluids, for which the properties again govern the heat flow [11]. Properties of the fluid are defined as viscosity, density, specific heat capacity, thermal conductivity, and etc. [22,23,16,24,25].

Although a great deal has been done about pressure and temperature behavior of fluid properties of simple Newtonian fluids, little knowledge exists on how to deal with the properties of non-Newtonian fluids.

Despite drilling fluids have progressed from being simple to complex substances to improve the drilling job, a few published information is available to determine heat transfer coefficient in non-Newtonian fluids and most authors on the subject of wellbore temperature distribution have ignored its influences. The procedures which most researchers, such as Raymond [9],Sullivan [26], Keller et. al. [27] and Sump and Williams [28], adopted are usually exensions of Newtonian.

However, the power law model is selected for this research and its indices have been calculated [28,29,12].

THERMAL MODEL

As the fluid flows through the well the heat exchange take place between the different

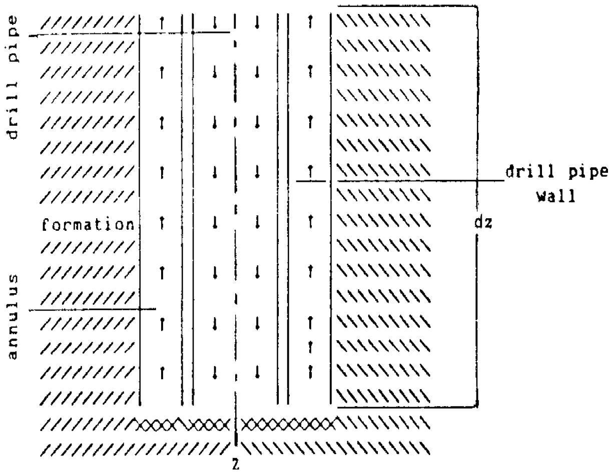

Figure 4. Schematic representation of a well.

boundaries of the string, annulus and formation (Figure 4). It depends upon the nature of the fluid, upon the velocity gradient, and upon properties of the fluid, steel, cement, and rock.

The governing equations for the fluid energy balance regions may determined from fundamental thermodynamics related to radial heat convection and vertical heat conduction. The radial heat convection into and out of the volume is :

$$E_c = hA\Delta T \tag{3}$$

The heat transfer in the flowing fluid is more complex than a simple conduction of heat. A change in the flow energy along a streamline is the sum of change in enthalpy, potential energy and kinetic energy. For steady flow of specific volume of fluid, the total energy is:

$$Dq^f = DH_{enth} + DP_E + DK_E \tag{4}$$

The temperature model of the drilling string was developed by means of an energy balance along a short pipe segment, (Figure 5).

$$q_P = m\,C_P \frac{\Delta T_P}{\Delta z} \tag{5}$$

As a result of fluid motion, convective heat transfer occurs which may be categorized by the nature of the flow as a forced or natural

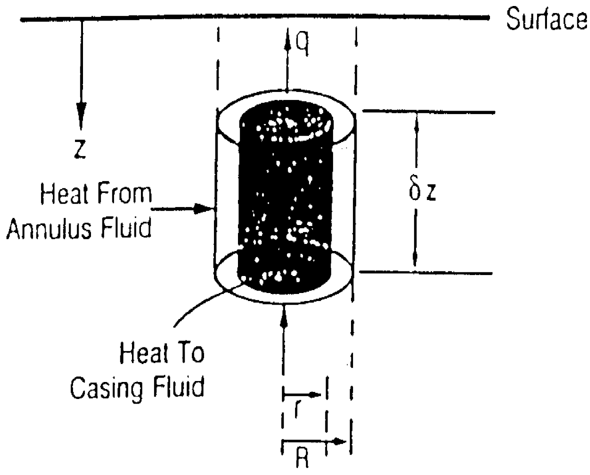

Figure 5. Heat transfer in a segment of drill pipe.

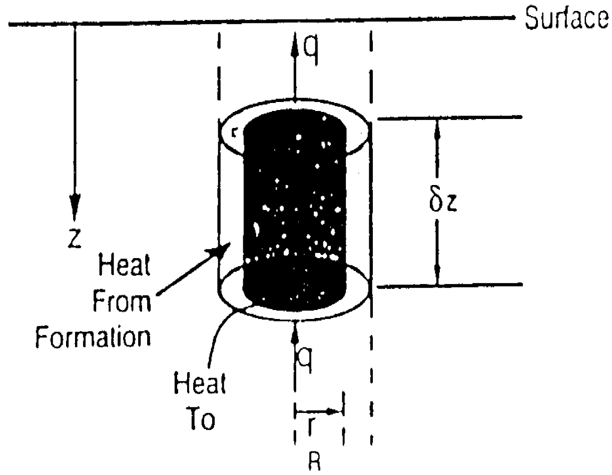

Figure 6. Heat transfer in a segment of annulus.

convertion (Figure 6).

The difference between the temperature of the inlet fluid and outlet fluid, must in some manner reflect the net heat gained by the fluid from the formation. The heat loss from the

$$q_p = 2\pi r_p h_p \left(T_a - T_p\right) \tag{6}$$

formation affects the temperatures of fluid in the borehole and alter the temperature distribution along the wellbore.

Edwardson et.al. [7] developed a thermal process in the wellbore as a function of time to determine the temperature disturbances in the formation and its variation throughout the life cycle of a wellbore. The diffusion of heat into or

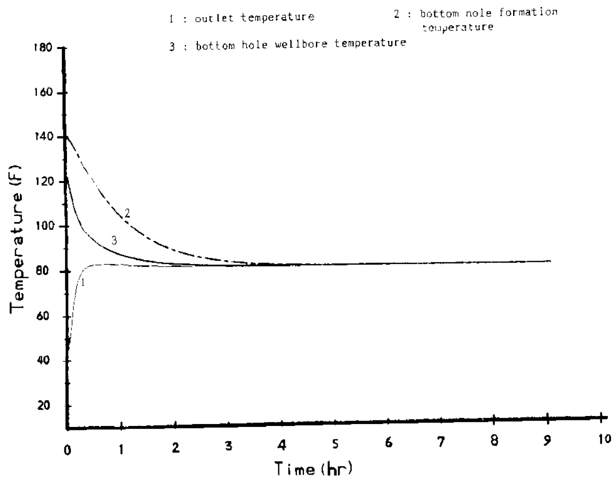

Figure 7. Effect of time on the bottom hole and.

out of the formation is defined by the following two dimensional Fourier's conduction equation:

$$\frac{\partial T_{(rw,\,z,t)}}{\partial t} = \frac{k_f}{\rho_f C_{pf}} \; \frac{1}{r} \frac{\partial}{\partial r} \left[\frac{r \partial T_{f\,(rw,z,t)}}{\partial r} \right] \qquad (7)$$

Ramey [8] proposed a model for the wellbore heat transmission problem. This method is approximate solution of the expanding Edwardson's technique. It gives the bottom-hole circulating temperatures numerically as a function of well depth, casing size and thermal properties, hole size, flow rate and fluid properties. The solution assumes that heat transfer in the wellbore is steady state, while in the formation it is transient. This method also fails to describe a general technique for considering the effect of the radial heat conduction from the formation into the wellbore.

To gain some insight into problems a pseudo-steady-state model, developed by Raymond [9]. This model incorporates the silent thermal phenomena which occurs between the formation and the drilling fluid in the wellbore and employs a steady state flowing stream at the time of circulation (Figure 7). Raymond has developed a transient model for prediction of temperature profile in the wellbore, using an iteration method.

The governing equation has been applied with a bi-linear geothermal gradient as an initial condition by Sullivan [26] using a finite difference technique.

Sump and Williams [28] modified the heat transfer model developed by Raymond to predict the fluid temperature profile during circulation. The method does not consider the effect of heat generation in the wellbore such as friction, pipe rotation and bit rotation in the well.

Keller et al. [27] extended Raymond's equation to include both effect of several casings and energy sources in the wellbore. Although, this model includes the effect of energy sources , no indication is given of how the numerical value can be calculated.

Wooley [25] proposed a new model including energy sources in the wellbore by using a modified Gauss-Siedel iteration method. The solution of Keller's and Wooley's had the obvious disadvantages of long time solution and the problem of stability tan convergence in the iteration process.

To deal with these problems, Marshall [30] developed a model. He investigated the effect of non-Newtonian fluid behavior on the drilling flow in a circulation temperature profile.

THEORY AND DEVELOPMENT OF THE MODEL

Temperatures in a well are important in many operations. Such an operation is the placement of cement between the formation and a casing to provide zonal isolation along the well and render stability to the casing [31], (Figure 8).

Deeper drilling and consequently hotter formation can decrease the setting time and consequently not achieving the correct setting time can cause problems with the drilling

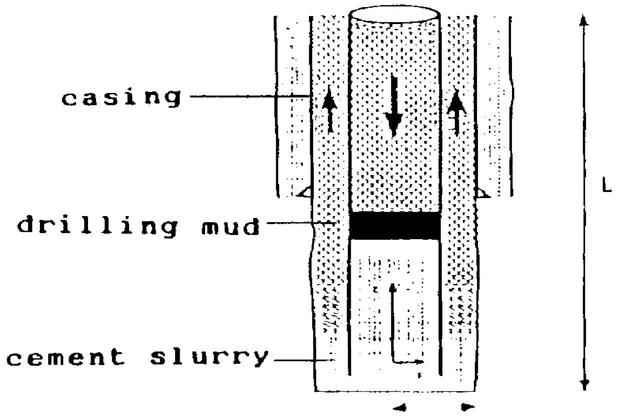

Figure 8. Cementing operation in wellbore outlet temperature in borehole with 10000 ft depth [32].

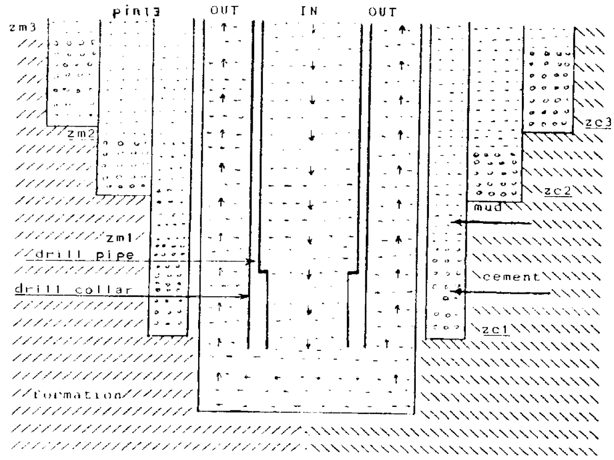

Figure 9. Schematic representation of a well.

operations.

If the cement sets prematurely it will set while it is inside and therefore block the hole which has just been completed.

The drilling operation can be split into different phases, shut-in phase, circulation phase, and drilling phase. The first three mechanisms have been already dealt. Therefore, another energy which must be investigated is the heat generation in the wellbore. Some important energy sources are generated by drilling fluid friction in the pipe, annulus, and drill bit, rotation of the drill string and drill bit, chemical reaction, such as cement hydration.

WELLBORN DESCRIPTION

In the present study, a wellbore with three casing strings is considered. It consists of four annuli from the injection fluid to the formation (Figure 9). At the bottom of the hole there is no casing string and is only one annulus between drill pipe and the formation. At the surface of the hole there are three casing strings and four annuli. The number of casings and annuli varies between these extremes.

ENERGY EQUATIONS IN THE WELLBORE

As a result of fluid motion in the well, the viscous energy is generated from frictional pressure losses in drill pipe, annulus, and drill bit.

The circulating system can be divided into four sections, surface connections, and pipes including drill pipe, heavy walled pipe , drill collar, and annular areas around drill pipes and drill collars, and drill bit.

The energy equation can be written for different radial increments of the well dimension. The prediction of temperature distribution in the wellbore formulated with a two-dimensional model with respect to the time variable for the flow history of the wells. It leads to a set of partial differential equations for variable well dimension such as :

Energy balance in a drill pipe:

$$Q_p - q_m \rho_m C_m \frac{\partial T_p}{\partial z} - 2\pi r_{ip} h_{wp} (T_p - T_w) + \frac{2k_w}{Ln \frac{r_2}{r_{ip}}} (T_w - T_p) = \pi r_{ip}^2 \rho_m C_m \frac{\partial T_p}{\partial t} \tag{8}$$

where:

$$r_2 = \frac{r_{op} + r_{ip}}{2} \tag{9}$$

Energy balance in drill string:

$$(T_w - T_a) + \frac{2k_w}{Ln\frac{r_{op}}{r_2}}(T_a - T_w) = \rho_w C_{pw}\frac{\partial T}{\partial t} \tag{10}$$

Energy balance in annulus fluid:

$$Q_2 + \rho_{ma}q_m C_p\frac{\partial T_a}{\partial z} + 2\pi r_{op}h_{op}(T_w - T_a) +$$

$$2\pi r_{ai}h_{ac}(T_{c1} - T_a) + \frac{2\pi k_{cf}}{Ln\frac{r_4}{r_{c1}}} =$$

$$\rho_{ma}C_p\pi(r_{ia}^2 - r_{op}^2)\frac{\partial T_a}{\partial t} \tag{11}$$

where:

$$r_4 = \frac{r_{oc1} + r_{ic1}}{2} \tag{12}$$

Energy balance in the casing strings:

$$k_{c1}\frac{\partial^2 T_{c1}}{\partial z^2} + 2\pi r_{ia}h_{ac1}(T_a - T_{c1}) - k_{(c1,c2)}$$

$$(T_{c1} - T_{c2}) = (r_{ia}^2 - r_{ic2}^2)\rho_s C_s\frac{\partial T_{c1}}{\partial t} \tag{13}$$

$$k_{(c1,c2)} = \frac{1}{k_{h2}Ln\frac{r_3}{r_{ic2}} + k_{c1}Ln\frac{r_{ic2}}{r_4}} \tag{14}$$

Energy balance in the formation:

$$\frac{\partial^2 T_f}{\partial r^2} + \frac{1}{r}\frac{\partial T_f}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T_f}{\partial \theta^2} + \frac{\partial T_f^2}{\partial z^2} = \frac{\rho_f C_f}{k_f}\frac{\partial T_f}{\partial t} \tag{15}$$

Equation can be written in two-dimensional cartesian coordinate system to represent the heat flow in the formation as follows:

$$\frac{\partial^2 T_f}{\partial r^2} + \frac{1}{r}\frac{\partial T_f}{\partial r} + \frac{\partial T_f^2}{\partial z^2} = \frac{\rho_f C_f}{k_f}\frac{\partial T_f}{\partial t} \tag{16}$$

SOLUTION

Most investigators such as Raymond, Sump and Williams , simulate the thermal model by using the formation temperatures as a boundary condition and applying the iterative method to calculate the temperature profile in wellbore ignoring the casing and heat generation in the system. Some others, such as Keller et. al., and Beirute developed a solution technique using an explicit finite difference method in radial direction and implicit in vertical direction. Their solutions involved iterative methods which has the drawback of poor stability and especially long computational solution time. For this reason, a two-dimensional implicit technique which was developed by Marshall has been adopted to expand Keller's equations in order to evaluate temperature distribution in the wellbore with multiple casing and drill collar using non-Newtonian drilling fluid.

The method adopted has been subdivided into three seperate evaluation taking into consideration the "history" of the drilling operations.

A grid system has been selected on two space variables, i. e. in the radial and vertical directions. The tow dimensional system is constructed with radial boundaries. Starting from the center line of the wellbore, the boundary for the first differential equation is taken at the axis of the drill pipe. The following six elements have boundaries at different interfaces. There are three more elements which arbitrary boundaries outside the outer annulus but within the formation.

In the vertical direction, the number of vertical elements are variable and depend on the well depth.

To solve the partial differential equations by the finite difference method, the finite difference qotients replaced the partial derivatives for each node of the grid to describe the transient heat flow in that element.

The method is based on the theorem that the first order derivatives are approximated by using two-point differences to represent spatial derivatives in the radial and vertical direction and two-point differences formulated for the time derivatives in implicit form.

The three-point central approximation is of a higher order and is used for the second order spatial derivative equations. The second order derivatives in the block are the difference quotient of the first order derivatives given by :

$$\frac{\partial T}{\partial z} = \frac{T_{(z+\Delta z,r,t)}}{۲\Delta z} \tag{17}$$

MATHEMATICALMODEL

The finite differential equations are written in implicit form for each vertical element "j", and radial element "k", for a time step of Dt, e.g. the general equation for temperature distribution in the formation in drilling, circulating, and shut-in phases is:

Pipe fluid energy balance:

$$Q_p - q_m \rho_{mp} C_m \frac{T^{n+1}_{1j} - T^{n+1}_{1,j-1}}{\Delta z_j} - 2\pi r_{ip} h_{wp}$$

$$(T^{n+1}_{1,j} - T^{n+1}_{2,j}) - \frac{2k_w \pi}{Ln \frac{r_2}{r_{ip}}} (T^{n+1}_{1,j} - T^{n+1}_{2,j}) =$$

$$\pi r^{۲}_{ip} \rho_m C_m \frac{T^{n+\text{١}}_{\text{١},j} - T^{n+\text{١}}_{\text{١},j}}{\Delta t} \tag{18}$$

Pipe or drill collar wall energy balance:

$$\frac{k_w}{\Delta z_j}\left[\frac{T^{n+1}_{2,j+1} - T^{n+1}_{2,j}}{\Delta z_{j+0.5}} - \frac{T^{n+1}_{2,j} - T^{n+1}_{2,j-1}}{\Delta z_{j-0.5}}\right] +$$

$$\frac{2r_{ip}h_{ip}}{(r^2_{op} - r^{۲}_{ip})} [T^{n+1}_{\text{١},j} - T^{n+1}_{2,j}] + \frac{2r_{op}h_{op}}{(r^2_{op} - r^2_{ip})} \times$$

$$[T^{n+1}_{2,j} - T^{n+1}_{3,j}] + \frac{2k_w}{Ln \frac{r_{op}}{r_2}} [T^{n+1}_{3,j} - T^{n+1}_{2,j}]$$

$$= \rho_m C_{pw} \frac{T^{n+1}_{2,j} - T^n_{2,j}}{\Delta t} \tag{19}$$

where $T^{n+\text{١}}_{۳,j}$ is the drilling fluid temperature, F in the annulus

Energy balance in annulus fluid:

$$Q_2 + q_m \rho_{ma} Cp \frac{T^{n+1}_{3,j} - T^{n+1}_{3,j}}{\Delta z_j} + 2\pi r_{ai} h_{ac}$$

$$[T^{n+1}_{c1} - T^{n+1}_a] + 2\pi r_{op} h_{op} [T^{n+1}_{2,j} - T^{n+1}_{3,j}] =$$

$$+ \frac{2\pi k_{c1}}{Ln \frac{r_4}{r_{c1}}} [T^{n+1}_{4,j} - T^{n+1}_{3,j}] = \rho_{ma} C_p \pi (r^2_{ia} - r^2_{op})$$

$$\frac{T^{n+1}_{3,j} - T^n_{3,j}}{\Lambda t} \tag{20}$$

where $T^{n+1}_{4,j}$ is the first casing temperature, F

First casing energy balance:

$$k_{c1,j}\left[\frac{T^{n+1}_{4,j+1} - T^{n+1}_{4,j}}{\Delta z_{j+0.5}} - \frac{T^{n+1}_{4,j} - T^{n+1}_{4,j-1}}{\Delta z_{j-0.5}}\right] +$$

$$2\pi r_{ia} h_{ac1} [T^{n+1}_{3,j} - T^{n+1}_{4,j}] - k_{(\langle c1,c2\rangle,j)}$$

$$[T^{n+1}_{4,j} - T^{n+1}_{5,j}] = (r^2_{ia} - r^2_{ic2}) \rho_s C_s$$

$$\left[\frac{T^{n+1}_{4,j} - T^{n+1}_{4,j}}{\Delta t}\right] \tag{21}$$

where $k_{(\langle c1,c2\rangle,j)}$ is the average thermal conductivity between first casing and second annulus and is given by:

$$k_{(\langle c1,c2\rangle,j)} = \frac{1}{k_{h2,j} Ln\frac{r_5}{r_{ic2}} + k_{c1,j} Ln\frac{r_{ic2}}{r_4}} \tag{22}$$

Difference equation for other annuli:

$$k_{hith,j+0.5}\frac{T^{n+1}_{5,j+1} - T^{n+1}_{5,j}}{\Delta z_j \Delta_{j+0.5}} - k_{hith,j-0.5}$$

$$\frac{T^{n+1}_{5,j} - T^{n+1}_{5,j-1}}{\Delta z_j \Delta z_{j-0.5}} + \frac{k_{(\langle c1,c2\rangle,j)}}{r_5 \Delta r_5}[T^{n+1}_{4,j} - T^{n+1}_{5,j}]$$

$$- \frac{k_{(\langle c2,c3\rangle,j)}}{r_5 \Delta r_5}[T^{n+1}_{5,j} - T^{n+1}_{6,j}]$$

$$= \rho_{c2} C_{c2} \frac{T^{n+1}_{5,j} - T^{n}_{5,j}}{\Delta t} \tag{23}$$

where $k_{(\langle c2,c3\rangle,j)}$ is the average thermal conductivity between the second and third

$$k_{(\langle c2,c3\rangle,j)} = \frac{1}{k_{h2,j} Ln\frac{r_6}{r_{ic3}} + k_{h3,j} Ln\frac{r_{ic3}}{r_5}} \tag{24}$$

$$r_6 = \frac{r_{ic3} + r_{oc3}}{2} \tag{25}$$

$$k_{hith,j+0.5} = \frac{2\Delta_{j+0.5}}{\frac{\Delta z_{j+1}}{k_{hi\,j+1}} + \frac{\Delta z_j}{k_{hi\,j}}} \tag{26}$$

$$k_{hith,j-0.5} = \frac{2\Delta_{j-0.5}}{\frac{\Delta z_{j-1}}{k_{hi\,j-1}} + \frac{\Delta z_j}{k_{hi\,j}}} \tag{27}$$

Difference equation for the formation:

$$\frac{k_{h_0}}{\Delta z_j}\left[\frac{T^{n+1}_{i,j+1} - T^{n+1}_{i,j}}{\Delta z_{j+0.5}} - \frac{T^{n+1}_{i,j} - T^{n+1}_{i,j-1}}{\Delta z_{j-0.5}}\right]$$

$$+ \frac{k_{im}}{r_i \Delta r_i}[T^{n+1}_{i-1,j} - T^{n+1}_{i,j}] +$$

$$+ \frac{k_{ip}}{r_i \Delta r_i}\left[T^{n+1}_{i,j} - T^{n+1}_{i+1,j}\right] = \rho_f C_{\rho f}$$

$$\left[\frac{T^{n+1}_{i,j} - T^{n}_{i,j}}{\Delta t}\right] \tag{28}$$

where

$$k_{im} = \frac{k_{ho}}{Ln\frac{r_i}{r_{i-1}}} \tag{29}$$

$$k_{ip} = \frac{k_{ho}}{Ln\frac{r_{i+1}}{r_i}} \tag{30}$$

For i=Imax $K_{ip} = 0$

The finite difference equations can be arranged in the form

$$B_{i,j} T^{n+1}_{i,j-1} + D_{i-1,j} T^{n+1}_{i,j} + E_{i,j} T^{n+1}_{i,j} + F_{i,j} T^{n+1}_{i+1,j}$$

$$+ H_{i,j} T^{n+1}_{i,j+1} = C_{i,j} \tag{31}$$

Where the number of the vertical increments of the wellbore is N, the coefficient matrix is of the order N*10 block and for each node a pentadiagonal matrix is divided into 10*10 submatrices, which each submatrix is of the order N*N matrix.

To achieve a numerical solution which satisfies the specified initial and boundary conditions, it is necessary to modify the coefficient matrix. To solve this coefficient matrix of the order 10N*10N which requires (N*10)*(N*10)*2^2 bytes storage capacity for single length arithmetic and (N*N)*(N*N) for double length arithmetic or double precision.

An algorithm with exploitation of non-entries was written for the coefficient matrix to change the matrix into a band storage matrix. The band storage matrix solved by a direct band algorithm technique involving factorization of decomposition matrix into lower and upper triangular matrices.

COMPUTER MODEL

A computer program, called "Nooshien.For" has been developed for predicting transient temperatures in the wellbore [32]. The program is constructed from equations developed in the previous sections taking into consideration different casings, the effect of the energy sources, the history of the drilling operation and other aspects encountered either inshore or offshore oil well. The program consists of a main program and sixteen subroutines.

VALIDATION

It has been felt that it would be beneficial if the theoretical model of temperatures could be validated and the range of parameters could be verified by comparing measured field data with the numerically derived data.

For this purpose one complete set of measured field data "15/20A-4, an exploration well in the Central North Sea drilled from the treasure Seeker ",has been acquired from one of the petrolium companies "BP" for which gesture the author is greatly in debt.

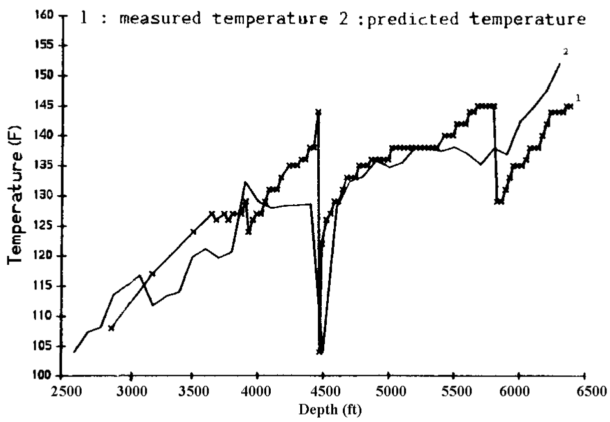

Figure 10. A comparison between predicted and with completion measured temperatures in the wellbore.

The temperature measured by the MWD tool is plotted as a function of wellbore depthfor a period 82 hours during different activities with different drilling muds in a drilling operation (Figure 10).

The figure shows variation of temperature during different activities such as shut-in, circulating, and drilling. It is believed that there are some difficulty which respond to data collection or time recording. It can also be seen that: (1) the temperature at the bottom of the hole is increasing with depth and (2) at same sections e.g. at a depth of 3900, 4500,5900 ft, the temperature has been reduced very sharply which indicates a lowering of inlet temperature of circulating mud for shallow deep wells.

CONCLUSION

The aim of the work presented in this study was to evaluate a method and apply it to enable the calculation of temperature distribution in the wellbore during the fully history of the drilling operation.

A fully transient model has been developed to include varies heat transfer mechanisms between the wellbore and the formation. In addition, several other features have been implemented in the model to improve the prediction of temperatures in the wellbore.
These additional features are:
- an appropriate technique has been applied for the drilling fluid to calculate the mechanical energy dissipation in the wellbore
- a geometry evaluation approach has been developed to take into account the well completion with multiple casings and drill collars
- a new technique has been employed in the

model to consider the temperature distribution in the wellbore as drill bit advances in depth.

- the model has been developed to incorporate different activities such as shut-in, forward circulation, and drilling which encountered in drilling operations.

The model has been investigated under different parameters and the following conclusions have been reached and are listed in order of their importance:

-the geothermal gradient has a significant effect on the temperatures in the wellbore, if its value is increased, the temperature distribution in the wellbore will increase as well,

-with increasing depth, the temperature encountered in the wellbore will be increased,

-bottom hole temperature decreased very rapidly and then follows a steady state in circulation but it is reverse for shut-in condition which the temperature recovers fast after circulating of fluid.

NOMENCLATURE

τ	shear stress, lbf/ft^2
k	consistency of fluid, constant
n	flow behavior index, constant
dv	velocity difference between particles, ft/sec
dr	distance between particles, ft
γ	shear rate, sec^{-1}
E_c	the rate of heat convection in the volume, Btu/hr
h	the heat transfer coefficient, Btu/(hr.ft^2.F)
A	the surface area, ft^2
ΔT	the difference temperature, F
Dq^f	the total energy
DH_{enth}	the difference enthalpy
DP_E	the rate of change in potential energy per second, lbf.ft/sec
DK_E	the change in the kinetic energy at unit time, lbf.ft/sec
q	the heat transfer rate , Btu/hr
C_p	the heat capacity in the drill pipe, Btu/(lb.F)
z	depth, ft
T	temperature, F
p,a,w,f,i,o,m,c,1,2,3,4 indices	refer to pipe, annulus, wall, formation, inside, outer, mud, casing, casing number respectively
ρ	the density, lb/ft^3
U	the overall heat transfer coefficient between the annulus and the formation
k	thermal conductivity, Btu/(ft.F.hr)
Q_2	the energy source in the annulus
t	the time, sec
i,j,k	the grid points in the radial direction, depth , and time step

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$$Q_p - q_m \rho_m C_m \frac{\partial T_p}{\partial z} - 2\pi r_{ip} h_{wp} (T_p - T_w) + \frac{2k_w}{Ln \frac{r_2}{}} (T_w - T_p) = \pi r_{ip}^2 \rho_m C_m \frac{\partial T_p}{\partial t}$$

$$Q_p - q_m \rho_m C_m \frac{\partial T_p}{\partial z} - 2\pi r_{ip} h_{wp} (T_p - T_w) + \frac{2k_w}{Ln \frac{r_2}{r_{ip}}} (T_w - T_p) = \pi r_{ip}^2 \rho_m C_m \frac{\partial T_p}{\partial t} \tag{8}$$

$$k_w \frac{\partial^2 T_w}{\partial z^2} + \frac{2 r_{ip} h_{ip}}{(r_{op}^2 - r_{ip}^2)} (T_p - T_w) + \frac{2 r_{op} h_{op}}{(r_{op}^2 - r_{ip}^2)} (T_w - T_a) + \frac{2k_w}{Ln \frac{r_{op}}{r_2}} (T_a - T_w) = \rho_w C_{pw} \frac{\partial T}{\partial t} \tag{10}$$