Concurrent Advances in Mechanical Engineering, Vol. 3(1) 2017, pp. 1-6

REVIEW ARTICLE

Prediction and Measurement Methods of Thermal Properties in Rock Drilling Process - A Review

[*]S Vijay Kumar[1], Ch.S.N Murthy[1], B.M Kunar[1]
[1]Department of Mining Engineering, National Institute of Technology Surathkal, Mangalore, Karnataka, India.

Received- 1 November 2016, Revised- 13 December 2016, Accepted- 10 January 2017, Published- 21 January 2017

ABSTRACT

Rocks are one of the oldest materials used in human history. Nowadays, since heat transfer from the rock is one of the most discussed topics, it is necessary to determine the thermal properties of the materials. Thermal property is one of the typically used parameters to assess the transfer of heat happening through any solid substance. In our case we have taken rock as a solid substance. The continuous increase in the temperature during the drilling process is generally transformed into heat. Several trials have been made to measure the temperature. The attempts include many functions like, dependent parameters and the independent parameters and also several practical techniques to make a direct calculation of the temperature. Selective predictive and analytical models are made in use to demonstrate the characteristics of drilling parameters like, the speed involved in drilling, torque, the rate of penetration, temperature, the specific energy, etc. Practical techniques involved to mainly calculate or evaluate the outcomes in analytical and experimental ways are not available. Our work offers a review of the logical and practical techniques used to calculate the temperature involved in cutting and drilling the rocks. Diverse approaches that demonstrate varied outcomes are offered in our work. The work of our review is briefed as follows. An approach which makes use of the fibre optic 2 colour pyrometer is explained to calculate the temperature on the cutting edges and the clearance faces on twist drills. To identify the temperature, a thermo vision technique, which makes use of an apparatus named, ISOMET2104 is used. To calculate the thermal conductivity of the given specimen a modified thermal block method is introduced. All these experiments were conducted in dry drilling conditions. Certain experiments were conducted using variety of techniques. All these outcomes were offered in our review as our work. Therefore to frame the thermal nature of the rock, the exact calculation of the thermal properties of rock is pretty commanding. The review of our work shows the different methods to represent the overall parameter of the drilling operation not only in the static condition but also measurement while drilling process will give different way of measurement.

Keywords: Temperature, Thermal properties, Drilling, Pyrometer, Thermo vision technique.

1. INTRODUCTION

The study about the transfer of heat has been persistent in observing the thermal action, particularly related to the calculation of heat flux happening in the underground. Thermal property determination tends to be evenly significant to study the balance of water and the mass exchange methods that happen through porous media surfaces [1, 2]. Most of the work reveals that movement of heat in a medium chiefly relies on its thermal resistivity. Thermal resistivity is demarcated as the capability of the material (in our case rock) to resist heat flow in it. The specific heat is demarcated as the capability of the material to accumulate heat and thermal diffusivity is a behaviour that associates the transfer and the storing behavior of the material, which indicates the rate of temperature variation within the material [3, 4]. A temperature

*Corresponding author. Tel.: +919663360566
Email address: vijaykumarstnp@gmail.com (S.V.Kumar)
Double blind peer review under responsibility of DJ Publications
https://dx.doi.org/10.18831/came/2017011001

(thermal) probe is used to find out whether the medium or material possess thermal resistivity or not by using the technique called, transfer heat technique.

2. TEMPERATURE MEASUREMENT

Measurements of temperature in different environmental circumstances during the drilling process are tremendously intolerant for several thermal sensors. Drill's tip is the location where a maximum number of measurements are tested. This drill tip is a place where the heat zone is surrounded by the drill flow. The cutting fluid during drilling process, due to the high pressure in Mpa is a major reason too. Even before 20 decades, the heat involved in material elimination procedures has been of importance. This is proved by an early work of Count Rumford which involved in calorimetric calculation of heat while the boring process of brass cannon is done in the field [4].

2.1. Thermal Response Test While Drilling (TRTWD)

TRTWD is the primary source used to detect the temperature during the drilling process and to recognize the constant heat flow throughout the bore hole of the drill area where the circulating fluid temperature is to be measured. In some of the cases the heat will be supplied from the outer source to increase the circulating fluid by electrical source. Instead of this, heating is caused by heat dissipation from drilling work. The heat dissipated from the rock takes place from the fluid circulating throughout the hole. The specific energy developed is different from different materials and it is depended on circulating fluid, process, and the methods of drilling and rock properties. When the performance of the work is considered, the TRTWD with a water circulation and the down hole management describes the same work and property distributions [5, 6]. For nearly 100 years, the movement of heat and power through porous media has paved way for a big exploration community. The study of thermal response and the heat passage in materials in a medium chiefly relies on the properties like resistance, conductance, specific heat and diffusion where the combinations of heat sources are available [7].

3. MEASUREMENT TECHNIQUES OF THERMAL PROPERTIES

The first method is that the thermal resistance of a material can be evaluated with the aid of the temperature probe also called as thermal probe (calculates the resistivity of rock) and the pyrometer. These instruments work on the basis of transient heat technique. As per the standard ASTM C 97, this technique evaluates the rocky materials' specific gravity. Similarly ISRM standard, calculates the porous and water absorption ability of the rock samples. The thermal probe that affords outstanding heat conduction and behaves as an electrically insulated material has a length of 95mm and a diameter of 6mm and has a heater wire that offers a resistivity of 0.042 Ohms per cm. This probe can be inserted without drilling a hole and the measurement measured using this probe is calculated by the effect of contact resistance [15].

The second method is the ISOMAT 2104. Using this method, the conductance and the volumetric heat capacitance were calculated. This cost-effective instrument applies a dynamic calculation technique, which minimizes the calculation period. This method gives a special etalon value of thermal conductivity. This verification of the measuring ability had been performed before the actual measurement had started. In this method also a probe called needle probe is used [16].

The third method is the temperature monitoring system conception. The temperature near the tool edge senses through non-contactable method, but at a very high temperature zone, this tool acts like a heat source because zone temperature is at a very high mode. Cutting tool or work piece is used as a heat source. In this method, the high temperature zone is of offline mode due to the continuous measurement of the heat aspect because of the distribution in linear direction from the cutting zone. The offline mode that involves a mathematical model which uses the data got from pyrometer, involves the measurement of the temperature which is not involved in the cutting zone, but involves the temperature to be measured from the section of hole wall surface and the hole bottom surface. We need to highlight the concept of identification of heat through the pyrometric method using sensors for point wise

measurement means at every depth of drill to comprehend the measurement as 1 point or 2 dimensional measurements [8-14].

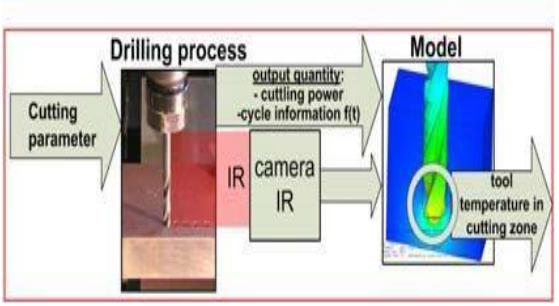

Figure 1.Temperature system observance during drilling process

Figure 1 expresses the idea behind the temperature system observance during drilling process. The idea of measurement of the temperature is by the use of an offline thermo vision camera, that releases the radiation where the point to be measured is got by the reflected radiation of the image. The drilled area is covered with the black surface where the image is to be highlighted to visualize that the tool temperature is maintained with a difference for every drill speed. This analysis of thermo graphic facts was comprehended with the help of NI Lab View software [8]. During this analysis, the parameter of the temperature matrix based on the properties of the visible surface of the radiated zone can find the emissivity coefficients represented as ε, considering the parameter to be identical. The methods involved for the progress, in the field of temperature calculations by the contactless methods, which the photo of the zone temperature is for the surface phenomenon of the cutting zone temperature field. The energy of the thermo vision method for drilling process is an effective system to monitor the visualization of the temperature at the cutting zone during drilling. The major objective of the cutting temperature identification in a parametric study at the cutting zone is to use simulation. The temperature that arises due to the simulation that happens during the drilling process of the hole wall surface gets distributed continuously throughout the drill so that, the simulation technique provides outcomes alike the outcomes gained from the experimental examination with the help of the pyrometric technique of temperature calculation. The difference in the disturbances of the experimental and the simulation results doesn't seem to be much when compared to the interpretation of the simulation results.

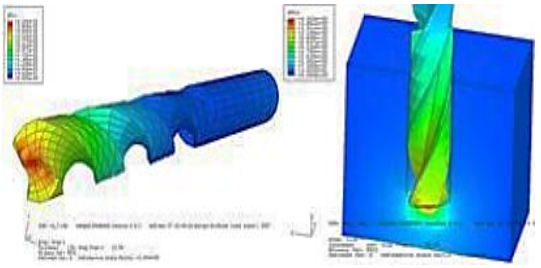

Figure 2.Performance of the temperature simulation outcomes, with respect to length of drill point to the heat simulation

Figure 2 given above shows the performance of the temperature simulation outcomes with respect to length of drill point to the heat simulation.

The fourth method is the modified thermal block method. In this method, the thermal conductance of limestone, granite and gneiss (a metamorphic rock with a banded or foliated structure, typically coarse-grained and consisting mainly of feldspar, quartz, and mica) are measured using a block device. The rapid and instant calculations of the thermal conductivities for authentication of the proof are done by the KD2 thermal analyzer [14].

Figure 3.KD2 thermal analyzer probe in a drilled hole inside a sample slab

The figure 3 given above shows the KD2 thermal analyzer probe in a drilled hole inside a sample slab. Thermal Block device was made using Perspex (10 x 10 x 4 cm) with thermal conductivity =0.18568 W/mK, Cp = 1.728 x 10-4 J/m3K. Copper – constant thermocouple is arranged in the flat surface and also upward at depths of 2mm, 4mm,

8mm, 16mm and 32 mm distance from contact surface inside the block.

The thermal conductance of granite grew from 2.96 W/mK to 3.96 W/mK with 26 percentage of variation for the technique that uses the block method with TIM. As for the KD2 method, it increased from 2.93 W/mK to 3.96 W/mK showing 24 percent of variation. The thermal diffusion made a progress from 0.41 x 10-4 m^2/s to 0.67 x 10-4 m^2/s. For limestone, it increased from 2.02 W/mK to 2.69 W/mK showing 25 percent of variation for the block method with TIM and while using the KD2 measurement; it showed an increase from 1.90 W/mK to 2.59 W/mK with 27 percent variation. The thermal diffusion made a progress from 1.09 x 10-4 m^2/s to 7.38 x 10-4 m^2/s. For the gneiss sample, it increased from 1.64 W/mK to 2.20 W/mK showing 30 percent variation for the block method and for KD2 it grew from 1.54 W/mK to 2.18 W/mK showing 29 percent variation [16].

The fifth method is the fibre optic 2 colour pyrometer technique. This technique makes use of 2 measuring locations of the fibre so that the temperature at the two different locations can be found out. One fibre is placed at the outer and other is placed at the center of the drill. The calculations were taken place for the stationary work piece. Making use of a 2 colour pyrometer is that the calculated temperature, theoretically, does not rely on emissivity this makes 2 colour pyrometer advantageous. This system makes use of grey body assumption. This assumption represents that the emissivity relies solely on the wavelength and doesn't rely on the direction, temperature and the surface structure [16]. The observation of the dynamic range of the temperature signal level is not a part of the proposed work. The synchronization of the drill bit and the hole surface to retain a persistent distance within the ends of the starting tip and the final tip of the drill. The figure 4 explains how the system has been arranged with the clamp area of the drill zone and the bit zone. The linkages are between the fibre beneath the work piece along with a set of magnetic support on the spindle housing. The fibre is directed at the unchanged speediness as the spindle's displacement rate in the vertical path, maintains an unchanged distance [16].

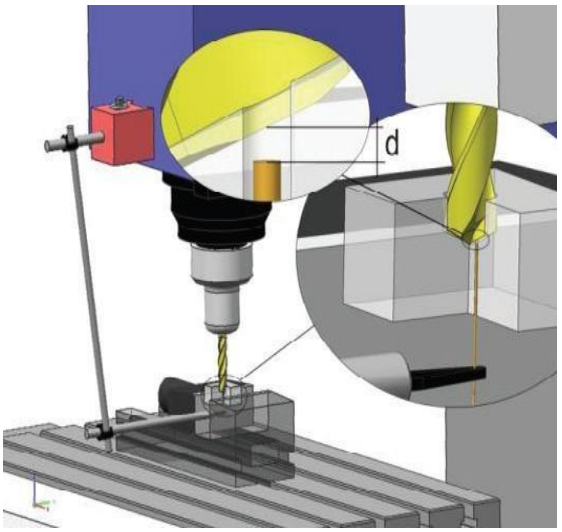

Figure 4.Arrangement for retaining constant distance (d) between the drill and the optical fibre

4. CONCLUSION

Based on the review the following conclusion is made. In thermo vision method, the technique of development is of a non contactable type by the radiation of heat generated during drilling and it suggests the possibility of application to identify the temperature in the field of the drilling process. In days to come, the thermo vision method can aid to be an active system to observe the temperature during the drilling process [8].

On the other hand, the thermal probe and the pyrometer methods portray that the laboratory probe and the development technique functions pretty well for finding the thermal resistance, thermal diffusion and the specific heat of the rocks. It is monitored that the rock's thermal property primarily differs with porosity and also with the outcomes stated in the literature [12].

Thermal block methods were applied to some rocks with a perspective of calculating the thermal properties. Correctness concern that results due to contact errors was faced with the help of thermal interface materials. The thermal conductivity and thermal diffusivity with TIM and no TIM revealed noteworthy variation at p, greater than 0.05 and effectiveness of TIM in reducing contact resistance errors [13]. In case of ISOMAT 2104 methods, it is obvious from the obtained results; the measured properties are very different. This is caused mainly by their mineral compositions and granularity. Hence it is really important to know where the specific rock comes from to measure specific properties

[15]. Pyrometer methods are usable for the experimental work. When the computer based data analysis is used, the defined technique uses larger size of data files and so the temperature data that is not valid is calculated while the signal is very low. Hence the pyrometer method will not give effective measurement through the computer based data [16, 17].

REFERENCES

[1] Silviu Berbinschi, Virgil Teodor and Nicoale Oancea, Experimental Research Regarding the Temperature Along the Cutting Edge of Drills, The Annals of Dunarea de Jos University of Galati, Fascicle, Vol. 1, 2012, pp. 17-26.

[2] C.Gruescu and A.Giraud, Effective Thermal Conductivity of Partially Saturated Porous Rocks, International Journal of Solids and Structures, Vol. 44, No. 3–4, 2007, pp. 811–833, http://dx.doi.org/10.1016/j.ijsolstr.2006.05.023.

[3] D.A.Gunn, I.D.Jones, M.G.Raines and D.C.Entwisle, Laboratory Measurement and Correction of Thermal Properties for Application to the Rock Mass, Geotechnical and Geological Engineering, Vol. 23, No. 6, 2012, pp. 773-791, http://dx.doi.org/10.1007/s10706-003-3156-6.

[4] Andreas Hartmann, Volker Rath and Christoph Clauser, Thermal Conductivity from Core and Well Log Data, International Journal of Rock Mechanics and Mining Sciences, Vol. 42, No. 7, 2005, pp. 1042-1055.

[5] Ki-Iti Horai, Thermal Conductivity of Sediments and Igneous Rocks Recovered During Deep Sea Drilling Project Leg 60, Initial Reports of the Deep Sea Drilling Project 60, Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York, 1982, pp. 807-834.

[6] Krzysztof, Lis and J.Kosmol, Temperature Identification of Drilling Process using Thermo Vision Methods, 14th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT 2010, Mediterranean Cruise, 2010.

[7] Michael Alexander Kant, Dustin Becker, Dragana Brkic, Thierry Meier, Martin Schuler and Philipp Rudolf von Rohr, Investigation of a Novel Drilling Technology – Influence of the Surface Temperature for Hydrothermal Spallation Drilling, Proceedings World Geothermal Congress, Melbourne, Australia, 2015, pp. 19-25.

[8] Michael Alexander Kant, Dustin Becker, Dragana Brkic, Thierry Meier, Martin Schuler and Philipp Rudolf von Rohr and U.Hulling, Experimental Research Regarding the Temperature along the Cutting Edge of Drills Regarding Thermic Transfer, Vol. 42, 2012, pp. 146.

[9] S.Krishnaiah, D.N.Singh and G.N.Jadhav, Article in press a methodology for determining thermal properties of rocks, pp. 1–6.

[10] T.N. Singh, S.Sinha and V.K.Singh, Prediction of Thermal Conductivity of Rock through Physico-Mechanical Properties, Building and Environment, Vol. 42, No. 1, 2007, pp. 146-155, http://dx.doi.org/10.1016/j.buildenv.2005.08.022.

[11] Steingrimsson, Benedikt and A.Gudmundsson, Geothermal Borehole Investigations during and after Drilling, Proceedings at Workshop on Decision Makers on Geothermal Projects in Central America, El Salvador, 2006.

[12] Bobok and Zoltan Szarka–Elemer, Determination of the Temperature Distribution in the Circulating Drilling Fluid, Geosciences and Engineering, Vol. 1, No. 1, 2012, pp. 37-47.

[13] O.D.Akinyemi, Y.S.Onifade and B.S.Badmus, Determination of Thermal Properties of Rock Samples Using Modified Thermal Block Method, Earth Science India, Vol. 5, No. 2, 2012, pp. 38-50.

[14] S.Krishnaiaha, D.N.Singha and G.N.Jadhavb, A Methodology for Determining Thermal Properties of Rocks, International Journal of Rock

Mechanics and Mining Sciences, Vol. 41, No. 5, 2007, pp. 877-882.

[15] Dana Konakova, Eva Vejmelkova and Robert Cerny, Thermal Properties of Selected Sandstones, Advances In Modern Mechanical Engineering: Proceedings of the 4th International Conference on Fluid Mechanics and Heat & Mass Transfer (FLUIDSHEAT'13), Dubrovnik, Croatia, 2013, pp.100-104.

[16] T.Beno and U.Hulling, Measurement of Cutting Edge Temperature in Drilling, Procedia CIRP, Vol. 3, 2012, pp. 531-536, http://dx.doi.org/10.1016/j.procir.2012.07.091.

[17] S.Udhayakumar, N.Dinesh Krishna, S.Chandra Sekaran, B.Sharan and K.Sadesh, Development of Strain Gauge based LED Stumps, Journal of Advances in Mechanical Engineering and Science, Vol. 1, No. 2, 2015, pp. 28-32, http://dx.doi.org/10.18831/james.in/2015021004.