

# TEMPERATURE MEASUREMENT DURING DRILLING: SCENARIO AND TECHNOLOGIES FOR LABORATORY AND FIELD INVESTIGATIONS

## Abstract

Drilling stands out as one of the most energy-intensive technological processes employed in the realm of mining exploration. The act of drilling into rocks gives rise to heat, stemming from the friction that arises between the rock and the drill bit. This thermal generation leads to the development of stress within the rock, ultimately causing it to fail. An overwhelming 80% of the energy supplied to the drill bit is consumed by the release of heat, with a certain proportion of energy serving residual bit alterations and rock fragmentation (Dreus et al., 2016). Predominantly, abrasion wear emerges as the chief contributor to bit deterioration, as the drill bit undergoes substantial abrasion when encountering rock formations, primarily attributed to the silica content present in the rock samples (Abbas, K., 2018). This article gives an overview of various kinds of drilling operations in laboratory and field investigations with temperature measurement devices at various locations is discussed to understand the concept of operational parameters influence on various mechanical properties and its orientations.

**Keywords:** Drilling, Temperature Measurement, Mechanical Properties, Heat Transfer.

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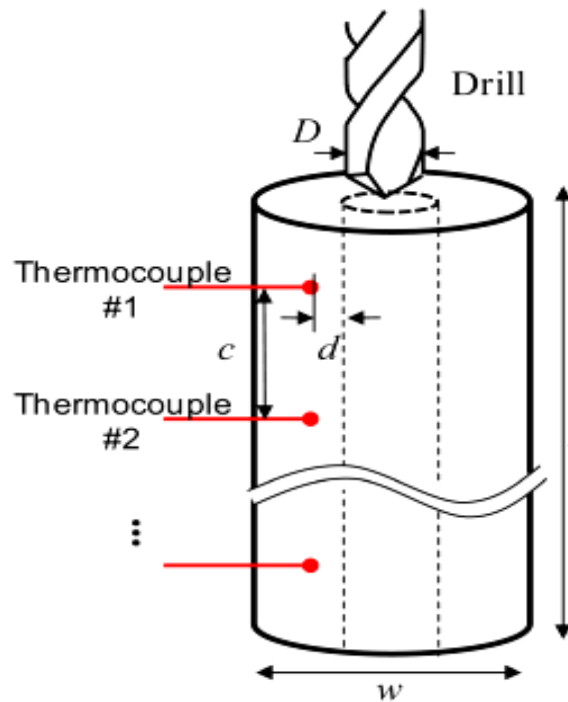
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## I. INTRODUCTION

Rock undergoes a multitude of operations, including drilling, cutting, crushing, milling, grinding, and polishing. Across these activities, the extraction of rock occurs primarily through the brittle fracturing of the material, resulting in the formation of chips. Rock drilling holds paramount importance in sectors like oil, mining, and construction. The drilling approach is contingent on factors such as rock characteristics, equipment availability, operational variables, and the unique demands of a given task. Central to drilling is the drill bit, the fundamental tool employed to break down rock. In specific geological scenarios, the optimal choice of drill bit poses a significant challenge, as it directly impacts operational costs. Currently, a diverse array of bits caters to distinct conditions and objectives. Thus, the meticulous selection of a bit aligned with precise requirements assumes critical importance. Opting for the right bit tailored to a particular rock type leads to heightened penetration rates and minimal bit wear during drilling, ultimately constituting an economically efficient drilling operation.

- 1. Drilling Temperature:** In the realm of mining industries, three primary drilling methodologies find application: percussive drilling, rotary drilling, and rotary-percussive drilling. Rotary drilling takes center stage in the production processes of large-scale open-cast and underground mines. As drilling progresses, the temperature of both the drill bit and the rock experiences an increase of several degrees Celsius, contingent on operational conditions, drilling duration, and the friction between the rock and the bit.

A multitude of researchers have conducted experiments to assess the temperature fluctuations during rock drilling operations (Bergman et al., 1966; Che et al., 2012; Dreus et al., 2016; Zancy et al., 2004). Observations indicated that parameters like rotary speed and bit weight played a role in affecting bit bearing temperatures. Notably, research unveiled a peak temperature increase of 196.1°C at the bearing surface (Karfakis and Heins, 1986). However, the response time of thermocouples, typically in the order of 10 microseconds, posed limitations for assessing transient temperatures in solids. To address this, the embedded thermocouple method, boasting a response time on the scale of 10 microseconds, was employed (Rittle, 1998). Given the high thermal inertia of welded thermocouples, temperature measurements utilized thin-wire insulated thermal junctions inserted into the workpiece to better capture transient temperature data (Agapiou and Stephenson, 1994). Various measurement approaches—contact and non-contact—were adopted, including K-type thermocouples and FLIR E60 infrared thermal imaging cameras, with differing operational parameters like spindle speed and feed rate. These studies consistently indicated that temperature elevated proportionally with the augmentation of operational parameters (Samy and Thirumalai, 2017). Multiple techniques were integrated to determine workpiece temperature, with the type, size, and shape of the thermocouple junction profoundly influencing output signal accuracy. The single-pole thermocouple method (Figure 1.1) demonstrated effectiveness within predictive models (Batako et al., 2005; Bruce et al., 2012).



**Figure I:** Temperature at the interface utilizing the inverse heat transfer technique (Bruce et al. 2012)

As the sample diameter expands, the maximum temperature difference at the center surface continually escalates in accordance with the pyrolysis process (Ma et al., 2018). Within space engineering, particularly in vacuum conditions, the temperature dynamics and their influencing factors during drilling have emerged as substantial concerns (Cui et al., 2014). In laboratory settings, micro bit drilling experiments were conducted on sandstone to ascertain the impact of pressure and temperature. Engineers prioritize the combined effects over individual influences (Zhang et al., 2016). A predictive model was constructed to analyze how the surrounding rock's drilling area radius influences the process. Ultimately, the deviation between recorded temperatures and model-derived values was under 10%, signifying the predictive model's effective capacity to estimate the geothermal gradient (Xu et al., 2016). Drilling operations have broad applications across manufacturing, mining, and petroleum industries. The generation of heat during drilling presents a challenge for predicting temperature changes within rock samples or drill bits. Temperature stands out as a key factor impacting the physico-mechanical properties of rocks. Throughout drilling, both the drill bit and rock samples can reach temperatures of several hundred degrees Celsius. Various methods are employed to forecast this temperature, chosen based on specific requirements and applications. Consequently, there exists a demand for a device and method tailored to measuring temperatures during rock drilling. Techniques utilized for temperature measurement in metal machining have been adapted for rock cutting, albeit with minor adjustments. In rock drilling, temperature-measuring instruments known as thermocouples are deployed in alignment with distinct purposes and requisites.

**2. Studies on Temperature during Drilling:** Drilling serves various purposes, including creating holes for explosives used in rock blasting across mining, oil and gas industries, as well as construction. In the realm of mining, three prominent drilling methods find application: Percussive drilling, rotary drilling, and rotary-percussive drilling represent distinct techniques. Notably, rotary drilling assumes a significant position in sizable open-cast mines and subterranean metal mines, especially in production drilling. As drilling activities progress, the temperature within both the drill bit and the rock undergoes an elevation by a few degrees Celsius, influenced by operational variables, drilling duration, and the characteristics of the rock. In this context, Che et al. (2012) conducted an extensive evaluation of the PDC cutter-rock interface throughout rock cutting and drilling procedures. There have been several introduced temperature measurement techniques that come from the metal machining and rock drilling sectors. With only minor modifications, conventional measures from metal machining operations, such as embedded thermocouples and infrared radiation pyrometers, have been applied to rock cutting. Cui et al. (2017) compared the Fiber Bragg grating temperature measuring method to a one-dimensional transient heat transfer model to study sample drilling temperature in high vacuum conditions. The results demonstrated outstanding agreement between estimated and experimental results, highlighting the model's consideration of radiation effects, drill bit arrangement, and heat sources.

Dreus et al. (2016) constructed a numerical model for the warming process on the working face during drilling, validating it through test research of thermal drilling models. A close correspondence between determined and experimental data, with contact temperature averages differing by no more than 12%, underscored the reliability of numerical simulation results. Tri-cone roller cone drill bits and rotary drilling hammers were tested by Hung et al. (2015) to increase penetration rates in hard rock formations with the goal of improving hard rock drilling performance. The Brazilian tensile strength, elastic modulus, triaxial compressive strength, and uniaxial compressive strength were particularly important in determining the penetration rates.

Using the thermal spallation method, Hu et al. (2018) measured heat flux and temperature on the surface of rock samples and contrasted the results between sandstone and granite samples. The rate of penetration and temperature differences between the two samples were compared. A thermal sensor, created by Kato and Fujii in 1996, maps the temperature distribution at cutting tools and can be used for sensitivity analysis in drilling and cutting processes. Loui and Rao (1997) conducted temperature measurements during drag-pick cutting for soft (limestone) and hard (granite) rocks in the laboratory, observing increased temperatures attributed to frictional heat. Temperatures above a critical threshold (500°C) led to heightened wear rates. Li et al. (2012) analytically and experimentally explored the impact of temperature gradient on rock failure. Their findings showcased that temperature gradients significantly promoted rock failure during drilling, with a 22.4% average increase in penetration rate as the temperature differential rose from 30°C to 180°C in relation to sandstone.

To evaluate the temperature distribution of wells drilled for shale gas and geothermal energy, Mao and Zhang (2018) developed a predictive model. Lowering of the upper wellbore was connected with longer fluid circulation times and increased drill displacement. The temperature of drilling fluid within the drilling string declined

alongside rising viscosity. Oort et al. (2018) devised a drilling temperature model aimed at reinforcing wellbores for testing oil and gas wells. This model's utility extends to mitigating lost circulation incidents, associated well downtime, and expenses during drilling, particularly benefiting wells with shallow drilling angles.

Tian et al. (2018) investigated the performance difference in rock breaking between a novel drilling tool and existing ones through numerical simulations. The innovative design of the new drilling apparatus holds the potential to enhance core drilling efficiency and process quality. The model offers insightful information for future studies aimed at enhancing drilling efficiency and rate of penetration (ROP), particularly in intricate and big displacement wells. A five-point incendiarity categorization for rocks was developed by Ward et al. (2001), and the results were correlated with petrographic structure, mineralogy, and pertinent chemical characteristics. During rock-on-rock collisions, a temperature increase of 1500°C happened quickly in less than a second, coming from the point of contact or the heat trail that was linked with it rather than from incandescent particles released during the frictional process.

Wu et al. (2014) presented a model predicting changes in fluid and rock temperatures during fluid circulation within wellbores. Dimensional analysis identified dominant dimensionless parameters, with injection rate significantly influencing downhole temperature. The cooling fluid flowing back through the annulus could induce thermo-mechanical changes in the rock near the wellbore, potentially initiating hydraulic fracturing.

Yang et al. (2017) devised comprehensive models to elucidate temperature distribution during drilling, revealing significant temperature interactions between the drill collar and the drill pipe. The temperature distribution in the drilled section exhibited minimal variation. Yang et al. (2019) built an integrated heat transfer model that included drill bits fracturing rock and hollow balls. In cases involving dynamic drilling, improved heat transfer between the annulus and formations caused a gradual increase in bottom hole temperature over time. Zhang et al. (2019) introduced a novel temperature measuring system for deep lunar drilling. This system facilitated temperature measurements (utilizing thermocouples and platinum resistors) at various points within the lunar vacuum environment, including the rotating drill tool and lunar simulant, reaching depths of up to 2 meters. The system exhibited high efficacy in accurately measuring temperature at these locations. Zhao et al. (2018) ascertained that the majority of calcite within downhole tests underwent disintegration within the combustion front, particularly within the temperature range of 550°C to 650°C. This study demonstrated how variations in oil compositions from different reservoir regions could serve as direct indicators of chamber expansion occurrences.

## II. CONCLUSIONS

This chapter encompasses an extensive review of the literature pertaining to rock drilling. It begins with an overview of the rotary drilling procedure and then on to a discussion of temperature measurement methods for rock drilling. It is clear that a variety of approaches, focused on crucial operational factors including thrust, torque, and spindle speed, have been offered for temperature assessment during drilling. The correlation between

temperature and the rate at which the drill bit wears, however, has not been investigated by earlier studies. The purpose of this work is to fill in these knowledge gaps by improving understanding of the rock drilling process and examining the effects of operational factors and rock characteristics on temperature during rotary drilling operations.

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