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Size distribution and shape characteristics of ice cuttings produced by an electromechanical auger drill

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ABSTRACT

The size distribution and shape characteristics of ice cuttings have a large influence on the efficiency of the transportation of cuttings by electromechanical auger drills and eventually determine the maximum possible rate of penetration. The size of ice cuttings is usually controlled and estimated by visual examination, but this is insufficient for the precise control and prediction of performance of ice cutting removal. To determine the patterns of ice cuttings, sixteen ice cuttings were sampled in the course of drilling in natural lake ice by an electromechanical auger drill at a temperature below −5 °C. The cutter is 19 mm in width, with a rake angle of 45° and a relief angle of 15°. Sensors are employed to measure the drilling-depth, drilling-time and rotation speed of the coring auger. This paper presents the size distribution and shape characteristics of cuttings under various drill head rotation speeds and rates of penetration by using a sieving and computer image-based method. The size distribution of the cuttings has an asymmetrical shape similar to a chi-square distribution. Approximately half of the ice cuttings by weight are classified as small sized (<0.6 mm). In all of the sieving samples, the ice cuttings have prolate form with a ratio between the major and minor axis within the range of 1.35 to 1.97, averaging ~1.55.

1. Introduction

Shallow ice core drilling has become increasingly important in the prevailing research of climate prediction and environmental contamination. Electromechanical auger drills are widely used in shallow ice coring on mountain glaciers and polar ice caps and sheets due to their lightweight, convenient transportation and installation; high rates of penetration; and low power consumption (Gao et al., 2012; Ginot et al., 2002; Zagorodnov et al., 2000, 2005 and others). The inability to promptly remove ice cuttings from the bottom of a hole during drilling results in their being broken repeatedly into progressively finer size cuttings, making drilling very inefficient, and in extreme cases this issue halts the drilling process altogether, resulting in low penetration rates, abnormal power consumption and high rotation torques (Zacny and Cooper, 2007). The efficiency of ice cuttings transportation systems of electromechanical auger core drills depends largely on the size of the ice cuttings (Hong et al., 2014).

The main properties of the cuttings – the size distribution (CSD) and shape characteristics (CSC) of the cuttings – were studied in many drilling applications that were related to the minimum flow rate of air circulation, the cost of cleaning the borehole, the stability of the borehole wall and the drill pipe erosion (Li et al., 2012), the reduction formation damage and improvement of well productivity in sandstone reservoirs (Mohamed, 2011), the design parameters of a drill bit and a tool string and flushing rate in the electric impulse disintegration of rocks (Vazhov, 2012), the selection of measures to reduce spreading and deposition of cuttings and components in drilling fluids and to avoid contamination of drilling site (Saasen, 2013), and the rock disintegration mechanism of DTH hammer with air reverse circulation (Huang, 2012).

The only experimental work for a CSC study in ice drilling was conducted for determining the minimal clearances in the circulation system of the drill as well as the pressure losses in the chip chamber in deep ice electromechanical drills (Talalay, 2006), which differs from dry shallow drilling. This paper presents the results and analysis of CSD and CSC in the course of drilling in natural lake ice by an electromechanical auger drill with a single cutter and a variable rate of penetration (*ROP*), from 0.72 to 3.18 m/h, and an auger rotation speed from 50 to 200 rpm.

2. Ice cuttings sampling

To extract the ice cuttings, an electromechanical auger drill rig (Fig. 1) was used with one-cutter drill head to ensure that the cuttings were produced with the same cutting depth, a 0.6-m core barrel with a EC50D10-P6DR-1024C type sensor to monitor the rotation speed with 1 rpm accuracy, a motor-reducer system to drive the core barrel and the ability to run from 0 to 220 rpm, a top wheel with an EC50V15-H6M5R-1024C type encoder to record drilling depth with a 1-mm accuracy, a winch powered by a servo motor to control the drill lowering speed with an accuracy of 0.1 mm/s, and a control system to record data and control the drill and winch motors. The cutter (Fig. 2) was made from tool steel (W18Cr4V) with a 19-mm width, a rake

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Fig. 1. Testing stand: A — encoder for the registration of the drilling depth; B — RPM sensor; C — thermometer fitted into the ice.

angle of 45°, a relief angle of 15° and a 100-mm ID. To sample the cuttings as close to the real drilling conditions in the field as possible, blocks of the natural lake ice with sizes of ~0.7 × 0.6 × 0.5 m were used for test drilling. A thermometer of DTM-280 type was fitted into the ice to measure temperature with an accuracy of 0.1 °C.

Samples were taken at four different rotation speeds of the drill head: 50, 100, 150 and 200 rpm, with fluctuations of ±5 rpm. There were no shoes used in this experiment, and the *ROP* was controlled by the feeding speed of the cable. The measured average *ROP* was equal to the drilling depth divided by the penetration time, and the instantaneous state of the *ROP* usually fluctuated within the runs in the range of 0.1 m/h due to the moderate vibration of the drill.

For every constant rotation speed of the drill head, four tests were carried out with increasing *ROP* up to the maximal possible values when the cable became loose, indicating that the cutter load was equal to the total weight of the drill (except testing with a rotation speed of 200 rpm, wherein the maximal *ROP* was equal to the feeding speed of the cable). It was not possible to maintain the same *ROP* at different rotation speeds of the coring auger.

Fig. 2. Cutter.

At first, three cutters were assembled on the drill head to start a new hole and to ensure the verticality and stability of further one-cutter drilling. Then, two cutters were removed and drilling with one cutter was accomplished at a depth of ~70 mm per run. After drilling, ice cuttings were collected from the drill's flights. In total, sixteen samples of ice cuttings were taken and marked by rpm values and test numbers (e.g., 50-1, 50-2, …, 200-4) (Table 1). The experiments were conducted from 5 p.m. to 6 a.m. to avoid the possible melting of ice cuttings caused by sunlight.

3. Method for measuring the size distribution and shape of the cuttings

A set of sieves (GB/T 6003.1 1997, Table 2), a microscope (NSZ-806) with a magnification of 20×/1× (a coefficient of magnification of 0.8) and a CCD camera (H-694C) with a resolution 2736 H x 2200 V were used to determine the size distribution and shape characteristics of the cuttings (Fig. 3). A plastic container was placed under the drill head to catch the ice cuttings that were dropped from the auger, which was triggered by a plastic spoon to ensure that the cuttings were sampled randomly and weighed no less than 100 g. The cuttings were weighed using a balance (JY 5002 type) with an accuracy of 0.01 g before and after sieving. A second plastic container was used to hold the ice cutting droppings during hand sieving. The ice cuttings were carefully poured out using a soft brush from the second container to the next sieve held by a third container.

Table 1
Sampling parameters.

Test series number	Ice temperature (°C)	Air temperature (°C)	ROP (m/h)
50-1	−8.3	−5.1	0.72
50-2	−8.5	−5.1	0.81
50-3	−9.1	−6.2	0.83
50-4	−11.5	−7.5	0.89
100-1	−13.3	−8.7	1.01
100-2	−12.4	−9.7	1.42
100-3	−8.3	−5.4	1.57
100-4	−8.4	−5.7	1.72
150-1	−8.4	−5.7	0.85
150-2	−9.3	−5.7	1.57
150-3	−9.4	−5.9	2.45
150-4	−10.5	−6.7	2.92
200-1	−10.7	−7.4	0.91
200-2	−11.2	−7.6	2.12
200-3	−9.8	−7.0	2.71
200-4	−6.8	−5.4	3.18