

Pellet impact drilling operational parameters: experimental research

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Abstract. The article deals with the study of particle-impact drilling that is designed to enhance the rate-of-penetration function in hard and tough drilling environments. It contains the experimental results on relation between drilling parameters and drilling efficiency, the experiments being conducted by means of a specially designed laboratory model. To interpret the results properly a high-speed camera was used to capture the pellet motion. These results can be used to choose optimal parameters, as well as to develop enhanced design of ejector pellet impact drill bits.

1. Introduction

Nowadays the pellet-impact drilling is being actively studied in Drilling Department, Institute of Natural Resources, Tomsk Polytechnic University. This drilling method has a great potential for enhancing the rate of penetration within hard and tough drilling environments and saving time for tripping, which will lead to well cost reduction. Besides, pellet impact drilling can be easily incorporated into the existing mechanical drilling technology without significant reconstruction of a drilling rig.

There are several operational parameters of pellet impact drilling that influence the efficiency of rock crushing, such as: pellet batch weight, diameter and pellet material properties, interval between a drill bit and a hole-bottom, circulation rate, drilling mud type and properties.

The relation between drilling parameters and efficiency of pellet impact drilling was studied and presented in the following works [1, 4-6]. However, the results interpretation seems controversial and unconvincing. It can be explained by the fact that previous testing equipment didn't make it possible to study the pellet dynamics in detail. Thus, the conclusions and recommendations made by the researchers were based on their deduction rather than factual proofs, and may contain inaccurate information.

2. Experiment procedure and statistical data processing

To study the technological processes of pellet impact drilling, a laboratory scale model [3] was designed; figure 1 demonstrates its general layout. A cup (10) is placed on a tray (1) and fixed with a special clinch (3). The cup is used to set a rock sample and observe the process of pellet aspiration and



journey. A support (5) is placed on the tray and fixed with a bar (4) in the upper part. To provide the desired distance between the sample and the drill bit and to ensure a smooth descent of the latter into the well model, there is a bit feed mechanism (6) based on friction and rack gear with a flywheel (12). Fluid supply is provided by means of a pumping main (7) and an adapter sub (8) to the drilling string (9). After exerting a drilling action the fluid with cuttings flows from the cup into the tray and then into a drain line (2). A pressure meter (11) is installed above the pellet-impact drill bit for measuring pressure in the pumping main. A cone-shaped arrester (13) ensures forced pellets supply to the ejector pellet impact drill string. Together with a centralizer (14) it lines up the bit in the cup.

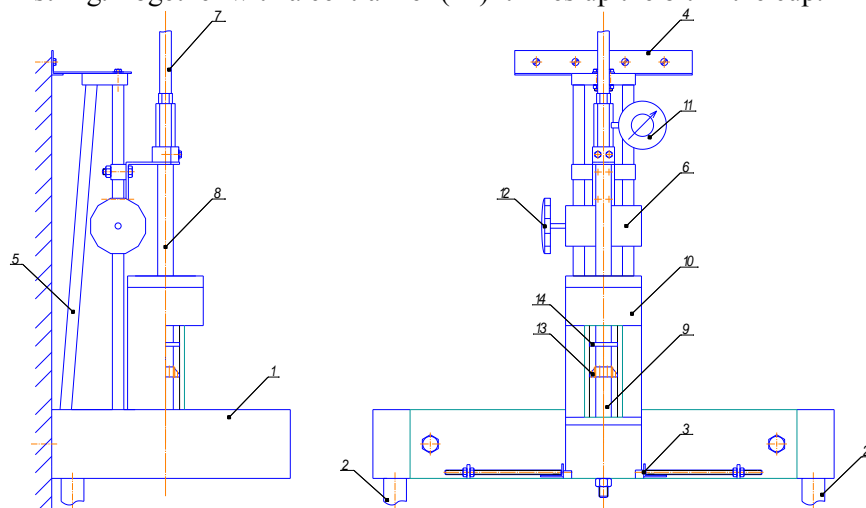


Figure 1. Laboratory model layout:

- 1- tray; 2- drain line; 3- cup clinch; 4 – bar; 5- support; 6- bit feed mechanism; 7- pumping main;
 8- adapter sub; 9 – ejector pellet impact drill string; 10 – cup; 11 – pressure meter; 12 –
 flywheel for feed process control; 13 - arrester; 14 – centralizer.

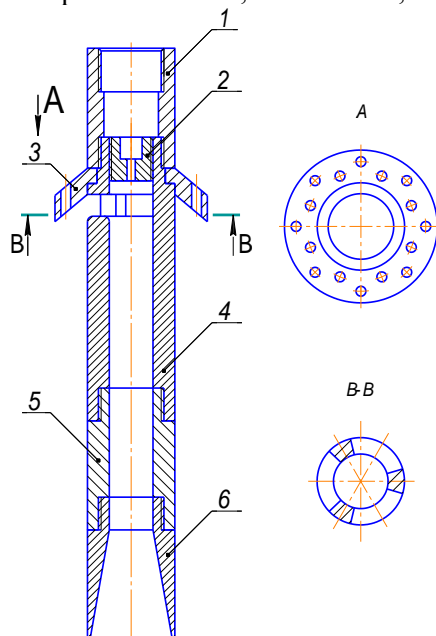


Figure 2. Ejector pellet impact drill bit

- 1 – discharge sub; 2 – nozzle, 3 – arrester; 4 – inlet chamber;
 5 – mixing chamber; 6 – diffuser.

The design of the ejector pellet impact drill bit is shown in figure 2. The drill bit consists of a changeable nozzle (2) and a cone-shaped arrester (3), an inlet chamber (4), a mixing chamber (5) and a

diffuser (6). The operation principle of such device is the following: high velocity fluid jet passes through the discharge sub, accelerates in the nozzle and then flows out into the mixing chamber (5). The suction pressure that occurs in the vicinity of the nozzle output ensures aspiration of the fluid with suspended pellets and cuttings from the bore-hole annulus through the holes into the inlet chamber. Then the two-phase mixture passes into the diffuser through the mixing chamber, impinges against the rock and exerts a crushing action. The arrester is used to overcome limitations on circulation rate, as well as to direct the pellets into the inlet chamber perforations.

The experimental research was conducted according to the following methods:

1. Spudding. Drilling was carried out on porcelain tile samples within a set period without lowering the drill bit, well geometrical parameter measurement following this process.
2. Observing. Pellet impact drilling with a transparent bit was filmed with a high-speed camera (3600 frames per second). The video was then analyzed with special computer programs.
3. Reciprocating. Marble samples were drilled. After a definite penetration the drill bit was placed on the hole bottom and then was lifted to keep a set interval between the drill bit and the hole bottom. The reciprocation was carried out at intervals t_{recipr} . The experiment was followed by measuring the parameters: well diameter D_{well} , total well depth h , cylindrical section depth h_{cyl} and bit-hole bottom contact depth h_{bot} .

Minimal number of replications was 3, then arithmetical mean, dispersion, mean square deviation and variation coefficient of the measured parameter were calculated [2]. The variation coefficient did not exceed 10%, which indicates good reproductability.

3. Experimental research of relation between drill bit-hole bottom distance and pellet impact drilling efficiency

The relation between bit-hole bottom distance and pellet-impact drilling efficiency while spudding was studied, other factors being equal. Reference parameters were: $d_n=2$ mm, $d_{mc}=8$ mm, $r_{nmc}=12$ mm, $l_{mc}=92$ mm, $\alpha_{exp}=10^\circ$, $d_{db}^o=16$ mm, $D_p=3$ mm, $M_p=25$ g, $Q_n=6.7$ liter/min, $P_n=1.1$ MPa, the material under crushing - porcelain tile, the cone-shaped arrester, $t=2$ min.

It was found out that the increase in distance between the drill bit and the hole bottom results in well diameter and well volume decrease (figure 3). In this case the penetration rate drops.

The well diameter increase can be expressed by the following formula:

$$(1)$$

where R_{well} – well radius, mm; R_{mc} – mixing chamber radius, mm; R_{bb} – distance between the drill bit and the hole bottom, mm; α_{exp} – expansion angle of the diffuser.

As known [4], well volume V_w is calculated according to the formula:

$$(2)$$

where V_p – crater volume resulted from one pellet impact, mm³; Q_p – pellet flow in the mixing chamber, p/sec; t – drilling time, c; ρ – coefficient that takes into account velocity reduction in real conditions.

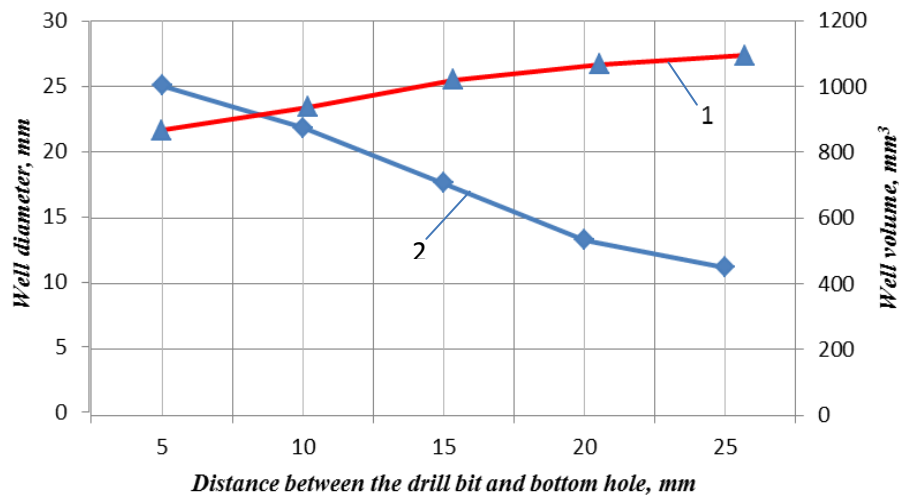


Figure 3. Well diameter (1) and volume (2) dependence on bit –hole bottom distance

The high speed camera made it possible to determine Q_p value with varying the distance between the drill bit and the hole bottom in series 5-10-15 mm (table 1). It is obvious that pellet flow in the mixing chamber decreases on increasing the bit-bottom distance. With the distance increase from 5mm to 10 mm, Q_p value reduces by 10.3% and if the distance increases from 5 to 15 mm, Q_p value becomes less by 29.9%. The well volume should reduce due to pellet flow decrease according to the formula (2), which is proved by the results shown in figure 4.

Table1. Pellet flow in the mixing chamber with bit-bottom distance variations

Distance between the drill bit and the bottom R_{bb} , mm	5	10	15
Pellet flow in the mixing camera Q_p , pellets/sec	583	529	497

While observing the pellet motion we discovered that pellet clouds occurring under the bit cannot leave the area quickly. As the bit-hole bottom distance increases, the number of clouds increases, which results in reduction of pellet flow in the mixing chamber. If the distance is short, the interaction between up-flowing and down-flowing fluids facilitates the pellets to return up the bore-hole annulus after striking against the bottom. If the distance is long, the pellets of the down-flowing fluid bombard the up-flowing pellets, making them accumulate under the bit.

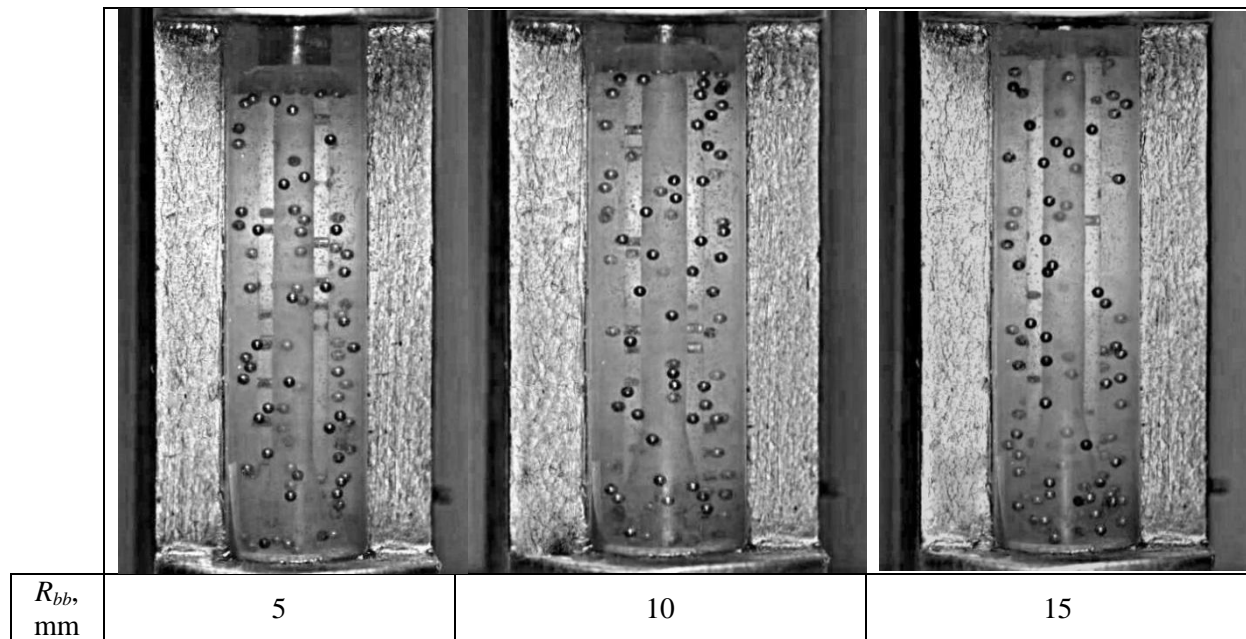


Figure 4. Interaction between pellet concentration in the bore-hole annulus and bit-hole bottom distance

The research in influence of bit –hole bottom distance on marble drilling efficiency was conducted. Drilling with reciprocation was carried out with the bit-hole bottom distance being 5, 10 and 15 mm.

The well geometrical parameters were measured after the drilling (table 2). The obtained results show that the bit-hole bottom distance increase leads to the increase in well diameter but reduces its depth and volume, thus proving the dependences mentioned above.

Table2. Interaction between well geometrical parameters and bit-bottom distance values

Distance between drill bit and a hole bottom R_{bb} , mm	Well geometrical parameters				
	Well volume V_w , mm ³	Well diameter D_w , mm	Cylindrical section depth h_{cyl} , mm	Drill bit-hole bottom contact depth h_{cont} , mm	Total depth h , mm
5	31800	25.5	52	65.2	69.9
10	29800	26.5	44	57	61
15	27000	27	36	52.1	56.7
Reference data: $d_n=2$ mm, $d_{mc}=8$ mm, $r_{nmc}=6$ mm, $l_{mc}=92$ mm $\alpha_{exp}=10^\circ$, $d_{db}^p=16$ mm, $D_p=3$ mm, $M_p=25$ g, $Q_n=6.7$ liter/min, $P_n=1.1$ MPa, rock sample – marble, cone-shaped arrester, $t_{trip}=4$ min, $t=40$ min.					

4. Experimental study of relation between pellet batch weight and pellet impact drilling efficiency

The first stage of the research was carried out while spudding. The reference parameters were: $d_n=2$ mm, $d_{mc}=8$ mm, $r_{nmc}=12$ mm, $l_{mc}=92$ mm $\alpha_{exp}=10^\circ$, $d_{db}^p=16$ mm, $D_p=3$ mm, $R_{bb}=10$ mm, $Q_n=6.7$ liter/min, $P_n=1.1$ MPa, porcelain tile as a sample material under crushing, a cone-shaped arrester, $t=2$ min.

It was found that there is weak dependence between increasing weight of pellet batch and well diameter (figure 5). As it concerns the well volume, it starts to rise with the increasing weight of pellet batch, however, further increase in pellet batch weight results in well volume decrease. It proves the fact that there is an optimal pellet batch weight value for particular drilling environment. At the beginning of the experiment the well volume is less due to smaller number of pellet impacts. Then, the

increase in well volume is observed to a definite extend with reaching optimal value of pellet batch weight. Further increase in the value leads to well volume reduction and on reaching the critical pellet batch weight the drilling process ceased due to pellet jamming under the arrester.

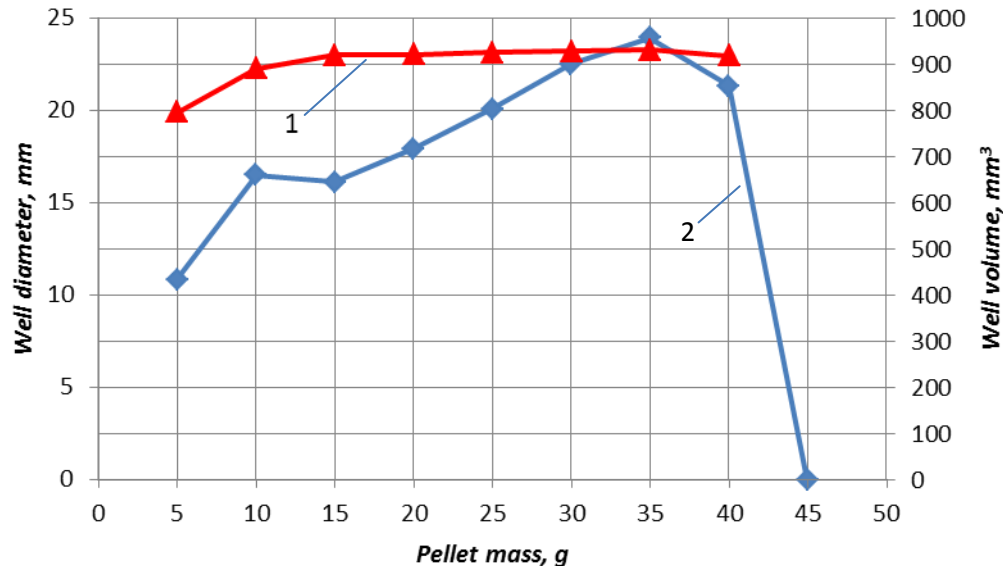


Figure 5. Dependence of well diameter (1) and volume (2) on pellet batch weight

The drilling process with varying pellet batch weight in series 5-15-25 g was recorded on a video. The video data analysis allowed identifying the number of pellets passing the mixing camera per time unit (table 3). According to the data, the pellet flow in the mixing chamber increases with the pellet batch becoming heavier, which results in better drilling efficiency.

Table 3. Interaction between pellet flow in the mixing chamber and pellet batch weight values

Pellet batch (portion) weight M_p , g	5	15	25
Pellet flow Q_p , pellet/sec	176	525	824

5. Experimental study on dependence of pellet diameter on pellet impact drilling efficiency

The research was carried out by drilling marble sample with drill bit reciprocating to discover the relation between pellet diameter and marble crushing efficiency. The results shown in table 4 prove that such dependence does exist for well diameter, depth and volume.

Table 4. Dependence of drilling efficiency on pellet diameter

Pellet diameter D_p , mm	Well volume V_w , mm ³	Well diameter D_w , mm	Well cylindrical section depth h_{cyl} , mm	Drill bit-hole bottom contact depth h_{cont} , mm	Total depth h , mm
2	19000	23	31.2	45	49.9
3	26600	23.9	41.6	55	58.7
3.5	29800	25.8	45.8	58.7	63.3
Reference data: $d_n=2$ mm, $d_{mc}=8$ mm, $r_{nmc}=6$ mm, $l_{mc}=92$ mm, $\alpha_{exp}=10^\circ$, $d_{db}^p=16$ mm, $M_p=30$ g, $R_{bb}=10$ mm, $Q_n=6.7$ liter/min, $Pn=1.1$ Mpa, rock sample –marble, cone-shaped arrester, $t_{recipr}=4$ min, $t=40$ min					

To interpret the obtained data a high speed camera was used. The video data processing allowed identifying pellet flow rate and pellet velocity in the mixing chamber when using pellets of different diameters (table 5).

Table 5. Flow and average velocity of pellets with different diameters in particular sections of the mixing chamber

Pellets diameter D_p , mm	Weight of a pellet m_p^l , g	Pellets flow Q_p , pellet/sec	Total number of crushing pellets N_p , pellet	Mixing chamber section	Average pellet velocity V_{av} , m/sec	Average kinetic energy of a pellet E_{kin} on leaving the mixing chamber, mJ
2	0.033	1461	304	initial	7.42	2.682
				final	9.03	
3	0.111	529	90	initial	7.08	7.023
				final	7.95	
3.5	0.175	252	57	initial	6.62	9.816
				final	7.48	

The data analysis showed that the increase in well volume with the increase in pellet diameter occurs due to the fact that a bigger pellet transfers more kinetic energy to the formation (rock sample) causing more destruction.

6. Conclusions

The experimental research discovered the influence of such factors as bit-bottom distance, pellet batch (portion) weight and pellet diameter on the efficiency of pellet impact drilling. These relations can be used for designing new sophisticated drill strings, and calculating optimal operational parameters. The obtained relations are well grounded by using high speed video.

The following challenges can boost further investigation:

- to develop optimal pellet batch weight calculation methods;
- to find the reasons and solve the problem of pellet jamming in bore hole annulus under the arrester;
- to study the rate of impact of different parameters on the well diameter;
- to conduct theoretical and experimental research on relations between fluid properties, flow rate, as well as pellet material and pellet impact drilling efficiency.

• Abbreviations

d_n	Nozzle diameter [mm]	T_{recipr}	Reciprocation frequency [min]
d_{mc}	Mixing chamber diameter [mm]	D_w	Well diameter [mm]
r_{nmc}	Distance between the nozzle outlet and the mixing chamber [mm]	h	Total depth of the well [mm]
l_{mc}	Mixing chamber length [mm]	h_{cyl}	Cylindrical section depth [mm]
A_{exp}	Expansion angle of the diffuser [°]	H_{cont}	Bit-hole bottom contact depth [mm]
d_{db}^p	Drill bit outer diameter [mm]	V_w	Well volume [mm ³]
D_p	Pellet diameter [mm]	Q_p	Pellet flow in the mixing chamber [p/m]
M_p	Pellet batch weight [g]	N_p	Total number of crushing [p]
R_{bb}	Distance between the drill bit and the hole bottom [mm]	m_p^l	Pellet weight [g]
Q_n	Fluid flow from the nozzle [l/min]	V_{av}	Average pellets velocity in the mixing chamber [m/c]
P_n	Upstream nozzle pressure [MPa]	E_{kin}	Average kinetic energy of a pellet on leaving the mixing chamber [mJ]

t Drilling time [min]

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