Designing the ejector pellet impact drill bit for hard and tough rock drilling

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Abstract. There are many types of ejector pellet impact drill bit providing impact rock drilling. Basic types of drill strings have been regarded, the essential requirements for the most efficient facilities to drill hard and tough rocks are formulated. With regard to these requirements, the ejector pellet impact drill bit design appropriate for operating under given conditions has been proposed.

1. Introduction
Pellet impact drilling is provided by pellet drill bits, which produce the continuous circulation of pellets in the bottom-hole zone. This method of drilling was proposed in 1955 by Carter Oil Company’s scientists (USA). Initially, the method had inherent advantages over rotary drilling [1]:
- the length of the round trip increases as soon as it is limited by wear-resistance of pellet drill bits only, which is caused by the ability to replenish the pellets without pulling the drill string from the hole;
- the construction of the drill bit is simple;
- bit weight is not required;
- rotation is not required, which reduces drill pipe failures and at the same time allows the use of lighter drill pipe.
In the description of field work results, the term of “gravity-aspirator” (figure 1) was used to name the drill bit. In this construction, the drill string (1) with the primary nozzle (2) at the end is connected with the secondary nozzle (3) by bars (4). The construction is also supplied with bit feet (7), which contact with the hole bottom to space the drill bit off the hole bottom and to prevent it from destroying. When the pellets are at the hole bottom, the jet pump is started. The fluid accelerates in the primary nozzle (2) and runs with high velocity into the secondary nozzle (3). This results in discharge zone between the primary nozzle (2) and the secondary nozzle (3), which aspirates annulus fluid with suspended pellets (5) and cuttings (6). Then the two-phase mixture goes through the secondary nozzle and breaks the rock.

After that, the fluid draws pellets (5) to the annular space between the drill bit and the wellbore, which rise, partially recirculating, above the primary nozzle (2) and then slow down because of annular space extension and decrease in the amount of fluid in the result of injection to form the pellet cloud (8). Being subjected to gravitation, pellets then fall to be aspirated. The process repeats many times.

**Figure 1.** Gravity-aspirator drill bit
1 – drill string; 2 – primary nozzle; 3 – secondary nozzle; 4 – bars; 5 – rock-breaking pellets; 6 – cuttings; 7 – feet; 8 – pellet cloud.

**Figure 2.** Ejector pellet impact drill bit with the nozzle and circular mixing chamber
1 – calibrating device; 2 – sub; 3 – connector end; 4 – fluid delivery channel; 5 – calibrating and centralizing bars; 6 – circular nozzle; 7 – arrestor; 8 – drill bit holder; 9 – circular mixing chamber; 10 – drill bit body; 11 – hard alloy teeth; 12 – pellets.
The disadvantages of the construction are the following:

- high rate of feet wear because of their contact with rocks and circulating pellets impact;
- drill bit rotation required to break the hole bottom zone overlapped by the feet;
- large zone of the hole bottom overlapped by the feet;
- necessity to maintain the set flow rate: otherwise, if the flow rate decreases, the pellet cloud is located below the nozzle, and if the flow rate increases, the pellet cloud is above the nozzle, which results in fall of the amount of pellets in the secondary nozzle and drop of drilling rate.

These disadvantages of the ejector pellet impact drill bit and departure from the initial concept of pellet drill bit resulted in further research carried out by both scientists and production workers. Today, there are many different types of the ejector pellet impact drill bits [2] that provide:

- required well diameter throughout drilling process;
- necessary spacing between the drill bit and the hole bottom;
- optimal track of pellets race within the hole bottom zone.

To prove the choice of the ejector pellet impact drill bit to drill hard and tough rocks is an important objective for a scientist.

2. Analysis of ejector pellet impact drill bit constructions

S. Zaurbekov in his work [3] pointed at the small number of pellets in the mixing chamber (called “secondary nozzle” in [1]) of the impact drill bit with the nozzle and the tubular mixing chamber arranged consequently in line. Pellet loss is no more than 140 pellets per second. As a result, the drill bit depicted in figure 2 was proposed. The construction is supplied with the nozzle (6) and the circular mixing chamber (9) and breaks the rock in the central part of the hole bottom with the drill bit holder (8) having hard alloy teeth (11) (figure 2). This construction provides the necessary spacing between the drill bit and the hole bottom. In addition, the arrestor (7) allows reaching the maximum flow rate and drawing the pellets into the inlet ports.

However, the construction is characterized by the following disadvantages:

- the slot nozzle makes the process of drill bit constructing more complicated;
- fast drill bit holder wear, especially when drilling hard and tough rocks;
- rotation and bit weight are required, which is in contradiction to the initial concept of pellet drill bit and causes challenges to drilling process;
- the combined method of breaking the hole bottom rock being applied (pellet impact drilling in border zones and rotary drilling in the central part), different time periods are required for rocks failure, which, according to the works [1, 4, 5], gives less drilling rate;
- the maximum diameter of pellets is less than that of pellets used in the impact drill bit with the nozzle and the tubular mixing chamber, which, according to the works [1, 4, 5], gives less drilling rate.

Some scientists [6, 7] consider the ejector pellet impact drill bit the most efficient when there are the nozzle and the tubular mixing chamber arranged consequently in line while the border zones are broken with blade (figure 3) and shot mechanical devices (figure 4). However, there are limitations connected with combined rock failure in the hole bottom zone: mechanical devices wear, need in rotation and bit weight, challenges of drilling control.

3. Requirements for drill bits appropriate for hard and tough rocks drilling

To sum up, ejector pellet impact drill bit constructions described above are efficient to drill soft and medium-hard rocks. To construct the ejector pellet impact drill bit for drilling hard and tough rocks, the following requirements are essential:

- there should be no constant contact of the drill bit with the hole bottom, which means that drill bits with feet, holders and shoes are unacceptable;
- rotation and bit weight are not acceptable as soon as they make the drilling process more complicated;
the construction should be designed on the basis of the drill bit with the nozzle and the tubular mixing chamber arranged consequently in line;

- there should be a diffuser at the edge of the mixing chamber which increases the efficiency of pellet impact in the border zones of the hole bottom; it also helps to provide the minimal spacing between the drill bit and the hole bottom, which gives higher impact drilling rates;

- the arrestor is necessary to provide high and sustainable flow rate essential to break hard and tough rocks;

- spacing between the drill bit and the hole bottom and the well diameter should be under control throughout the drilling process;

- pellets should be replenished during the round trip without pulling the drill string from the hole;

- the facilities should be simple to construct and operate.

Figure 3. Blade ejector pellet impact drill bit
1 – body; 2 – rock-breaking piston shoe; 3 – seat; 4 – jet apparatus; 5 – nozzle; 6 – mixing chamber with inlet ports; 7 – pellets.

Figure 4. Shot ejector pellet impact drill bit
1 – body; 2 – jet apparatus; 3 – rock-breaking pellets; 4 – rock-breaking circle; 5 – seats; 6 – turbine driver; 7 – drill string; 8, 10 – holes; 9 – axis.

4. Ejector pellet impact drill bit for hard and tough rocks drilling
The authors of this work propose the construction of the ejector pellet impact drill bit (figure 5) deprived of constant contact with the hole bottom. The construction includes the cone-shaped arrester
(3), which provides the necessary flow rate and directs the pellets to the inlet chamber (4). There is a diffuser at the end of the drill bit to provide the required well diameter throughout drilling process in case of less space between the drill bit and the hole bottom.

Today, the authors are investigating the problem of control methods to provide optimal spacing between the drill bit and the hole bottom and to maintain the set well diameter while drilling with these facilities. The pellet supplier is also being designed for the pellets to be replenished within the round trip.

**Figure 5.** Ejector pellet impact drill bit  
1 – discharge sub; 2 – nozzle, 3 – arrester; 4 – inlet chamber; 5 – mixing chamber; 6 – diffuser.

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