The Oil Drum
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Drilling through Rock

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There are times when new technologies are proposed as being better ways of drilling for oil and natural gas. However, to understand how these are better (or more likely not) than existing technologies, you have to know how the industry commonly drills through rock. There are two basic ways of doing so, depending on how hard the rock is. The first is the one that made the Hughes family very rich (if you ever saw the film The Aviator, Howard Hughes extravaganzas were paid for because his father had invented an effective way of drilling oil wells). The other, somewhat slower, was developed the last time that we had an energy crisis, and uses artificial diamonds, in the main, to gouge into and scrape off thin layers of rock.

Before I describe the diamond bit, let me borrow a bit from a post I did four years ago, and describe the idea behind the Hughes bit, which for reasons that I will explain, is usually referred to as a tri-cone bit.

The three cones of a tri-cone bit.

I have put together a number of tech talks in the past. This is the first in a series of updates.

To start one can go back to the mining industry (can we call it one of the older professions) where holes were drilled, until about a hundred years ago, by taking a chisel in one hand and holding a hammer in the other with which one whacked the upper end of the chisel as it was held against the rock. This is called **hand steeling** and if you want to try it or see it, there is a video here and student competitions at various places. A skilled miner can drill a 1-inch hole at the rate of about 8 inches in five minutes, using a 4-lb hammer.

Now what he does (if you watch the video you will see this) is to hit the chisel, turn it about a quarter turn between blows, and then hit it again. The turning is the critical bit. Because when you hit the chisel it crushes the rock directly underneath it, but the wedge head pushes sideways against the rock on either side. So if the driller turns the chisel between blows he will not only crush the rock, but will also chip out the thin layer between the second blow and where the first hit. This removes a lot more rock for the same amount of energy. In fact it is the skill of the driller that will make bigger chips, for less muscle power, by turning the bit, rather than using brute force to crush the rock just under the chisel into powder. (On a larger scale the same idea is used to drill very large tunnels. Bit disks roll over the surface of the rock crushing the rock immediately below them, but the rock in the inches of spacing to the next disk spalls out of the face without direct contact with the tool).

When it came time to drill the first oil wells this was the technique that they used. Except that they made the chisel much larger and heavier, so that, by lifting it and dropping it, it's own weight would act as the hammer. Normally a larger spudding bit was used first to make a larger diameter hole from 4 to 22 inches in diameter, and down for 50 ft or more. Once this starting hole had been drilled (using a cable over the derrick to a crank to raise and drop the bit) a steel pipe was lowered into the hole and cemented in place. This pipe provided a base for the deeper hole, and provided a case around it. Thus it became known as casing, and it protected the hole as it went through the top soil and weakest of the upper layers of the ground.

Once the hole had been spudded-in, and this initial conductor pipe installed, then the normal sections of steel tubes could be strung together to form a pipe (hence the name **drill string**), and the drilling bit (in those days around 4 to 5 inches across) would be raised and dropped by a walking beam engine. As the hole was drilled they would stop, perhaps every couple of feet, to pull the bit out, and sharpen it, and to bail the crushed rock or cuttings, out of the hole.

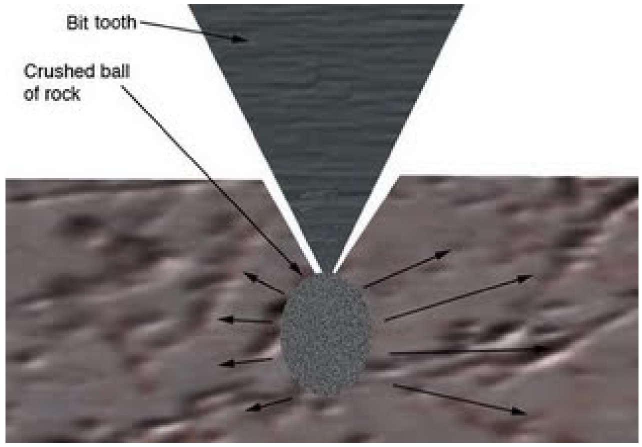
Progress was, as you can imagine, slow, and this tool is very difficult to steer, particularly as the drill goes down several hundred feet. And so the industry was ripe for a better way of drilling.

This was invented by the older Howard Hughes who realized that if very small chisel shapes could be set around a roller they would do the same thing as the dropping bit, but could be moved around by rolling, and pushed into the rock by the weight of the connecting rods to the surface. To spread the load over the face of the hole, and to balance the bit, he used 2 rollers which tapered towards the center of the bit.

Hughes, along with his partner Walter B. Sharp, formed the Sharp-Hughes Tool Co. and produced a model of his new bit. Rather than sell his bits to oil drillers, Hughes and Sharp opted to lease the bits on a job basis, charging U.S. $30,000 per well. With no competitors to duplicate their drilling technology, they soon garnered the lion's share of the market. Flush with their success, the partners built a factory on 70 acres east of downtown Houston, where they turned out the roller-cone bits that quickly revolutionized the drilling process.2

This later evolved into a 3-cone assembly and what is now known as a tri-cone bit, a modern version of which is pictured above. (The shape of the teeth vary as a function of the hardness of the rock that is being drilled. As a rough rule, the tougher the rock the smaller the teeth are, and the smaller the chips that are generated).

The way the tri-cone bit works has a lot common with the earlier methods. While the bit crushes the rock immediately under the bit teeth their most productive work comes in creating chips from the rock between two adjacent tooth indentations by a combination of wedging and uplift that breaks the rock under tension and shear.



Simplistic view of bit tooth penetrating rock.

As the bit is pushed into the rock it crushes the rock immediately under the tooth, and this crushed rock distributes the applied force around the edge of the zone as it plastically deforms. This gives the lateral and upward forces on the surrounding rock that causes it to crack and spall from the solid as a chip.

This bit has a number of problems under different conditions (it is harder to control in directional drilling since if the pushing force varies too much it can wander off in odd directions) and there has to be a way of getting the rock out of the hole. These have led to other drilling ideas, including the “diamond bit” drilling idea, that I discuss in the second section of this post.

But as you watch the movie "The Aviator" remember that all those shenanigans were paid for with the money that came from that drilling bit, and that Hughes (the company) is still reported to have 40% of the world market share of oil well drill bits.

Drilling with Diamonds

One of the problems of a tri-directional bit is that some rock is too hard to be able to push the tooth into the rock and create a big enough crushed zone to do much good with conventional materials. So, obviously, the next step is to go to a harder bit material. And to make sure that we can cut into the hardest rock material, it is logical to want to use the hardest material, diamond, for the bit tooth.

Historically, however, finding and being able to afford diamonds in the sort of half-inch size we need for the bit tooth was a bit difficult. The ones that were affordable were the very small diamonds known as industrial diamond, in the very small sizes. So the way in which we had to cut the rock was changed. Instead of having a few teeth that rotated over the surface of the rock, instead the face of the bit was coated with a thin layer of small diamonds set in what is called the matrix.

Diamond coring bit, the dark specks are individual diamonds (Source)

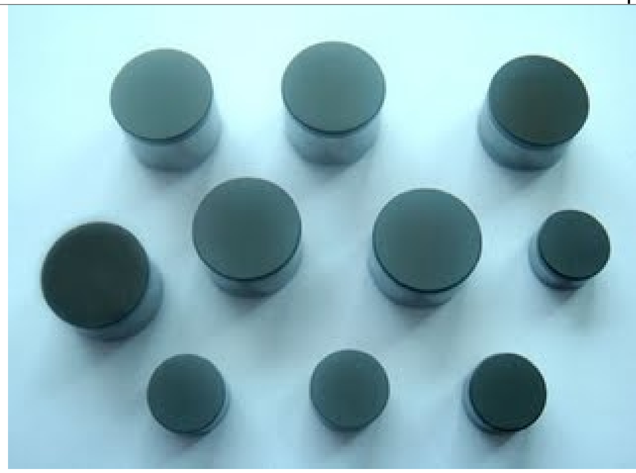
The very small diamonds scratch into the surface of the rock, in the same way that a diamond in a ring might cut into a glass plate. Individually the scratches are small, but if the core bit is pushed into the rock, they accumulate and remove rock, although quite slowly. A tri-cone bit might go through rock over 100 feet an hour, while a conventional diamond bit which is taking much smaller bites, will go at only a few feet an hour. It also turns faster than a conventional bit, which is why they are often combined with a down-the-hole motor on the bottom of the drilling string to give this faster speed.

And if you push too hard on the bit, then you can push the diamonds down into the matrix, so that the matrix is rubbing against the rock, rather than the sharp diamond edge, and this slows things down. (This is particularly a problem if drilling through granite, which I once spent a summer doing). And so the question came as to how to make this sort of drilling faster. We would still need the diamonds, to cut into the harder rock, but couldn't we find a better way of making an artificial diamond – after all we only need to have it on the surface of the bit, and perhaps just apply it as a coating to a bit.

Well it turns out that this was possible, and depending on which convention you adopt the Polycrystalline Diamond Compact (PDC), or the PolyCrystalline Diamond (PCD) was born. Simply put (and the technology is actually anything but) a thin layer of diamond power is put into a mold and a central core of tungsten carbide is then nested in the middle of the mold. The mold is then put into a special press where the assembled powder is subjected to extremely high pressure and temperature, using specially designed anvils. Temperatures are in the 2,000 oC range, and pressures around 60,000 bar (882,000 psi). The result is an element (they come in a variety of shapes) where the carbide bit is coated with a thin layer of a polycrystalline diamond, since all the diamond particles have fused together to form the surface layer.

(In reality the technology is a bit more complex, since a single thin layer of diamond is brittle in the way the shell of an egg is, without strong back support, and so there are graded layers to make this "diamond" shell tougher so that it does not shatter when it hits the rock hard).

The most typical shape that is used in oil and gas well drilling is a small cylindrical insert, with the bit made up of a number of these individual cutters.



Individual PDC cutters. The dark portions are the diamond coated segments (Source).

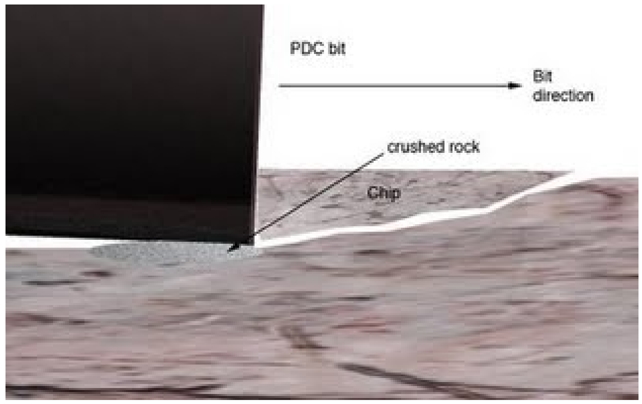
There was a considerable effort put into designing the best way of combining these cutters, back during the last Energy Crisis, with a lot of the work being done at Sandia Labs. The bits that have emerged are now much larger and more robust, and are quite widely used. Energy Tomorrow featured a picture of one back in May.

Large drill bit combining the buttons of a tri-cone (the silvery points) with polycrystalline diamond cutters (the dark circles). (Source)

Notice that the diamond cutters are along the edge of the rigid parts of the drill bit. This is because the diamond, although a very powerful cutter, is very sensitive to temperature. Since the cutter is being dragged over the surface plowing up and peeling off a slice of the rock, there is a lot of friction under the cutting point, and if the cutter heats up above about 300 degrees then it softens, which is not good. So by placing it on the face of the bit, and with an open passage to the face, cooling mud (of which I will write more next time) can now flow across the face of the cutter, keeping it cool, and thus sharp, and able to cut through all the rock in the way. (If you were to look at the full face there are more cutters in the center of the bit and along the edge to make sure that none of the cutters is asked to cut too much – remember that the whole bit is turning, so the cutters on the outside also move faster over the rock).

This type of cutter is now large enough that can now cut deeply enough into the rock that it can chip some of the rock out ahead of it and so the process also becomes a little more efficient. (But I will revisit that topic when I talk about the energy of different rock drilling methods in a later post).

One of the reasons that the support for the cutter is so long is that the edge of the cutter is pushed into the rock, and still has to crush the rock under it, to get enough purchase to be able to chip out the rock ahead of it. (Though once that starts less rock has to be crushed as the bit moves forward).



Schematic showing how dragging a PDC cutter across a rock surface will crush the rock under the bit, and then create a chip as the cutter gets under the rock ahead of it.

As usual with these tech talks, I have simplified the description in order to keep this short and to the point. If those knowing more wish to comment, please do so.