Practical Challenges and Comparison of Laser Drilling: A Review

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Abstract

From its commercial inception in the industrial world, from the mid-19th century, cable tool and rotary drilling have been the only two techniques applied in the drilling operations during the exploration phase of oil and gas discovery. Even though the rotary drilling technique has proved very successful, considerations towards applying laser technology can bring up an alternative, which can serve as the potential of replacing both the conventional drilling operations. Laser drilling is one of the most significant and positive approach in manufacturing industry. Laser drilling in the past have seen its usage mostly in high-cost manufacturing product components such as jet engines and gas turbines. This paper through its review thereby focuses on the challenges faced in laser drilling and the cost effectiveness of the available conventional drilling practices. The work compares and contrasts the technicalities of laser drilling with that of the exiting conventional drilling methods and its application in the O&G industry. The different phases have been showed in the review paper to begin a list of laser drilling methods and technologies, as well as their advantages and disadvantages. Efforts of this review paper aims at catering benefits and a companion guide for the researchers who are indulged in the implementing the utility of laser drilling in the O&G industry. This review paper is to show cost representations for better understanding the product cost in early stages of the product development.

Keywords: subsurface, laser drilling, conventional drilling, rock cuttings.

Introduction

The growing preference and popularity for the promising renewable energy resources has been creating pressure on the drilling contractors to develop and implement better, faster and most importantly cheaper drilling methods for a achieving a safe and appropriate well depth and completion. Laser drilling is one of the major techniques to drill holes, and has improved very well, especially in the drilling of aerospace machineries. A good strategy of motion-control systems and beam delivery facilities is what keeping the laser technologies a cost effective and rigorous option. The current drilling approaches used in the O&G industry dates back to 100 years, when rotary drilling succeeded cable tool drilling as the standard method for reaching O&G formations in the subsurface. However, one of the major problems that persists with this method was the downtime and waste created by the circulating drilling mud. Lasers have been found as a feasible option to improve drilling (Islam and Wellington, 2001). By replacing the use of a drill bit with laser drilling, the downtime involved with the dull bits will be substantially reduced and the waste created due to drilling mud will be mitigated as well. This is particularly important in offshore fields, where space limitations are at its peak. Laser drilling seems to have a potential to increase penetration rate by greater than 100 times over the conventional rotary drilling methods (Graves and O'Brien, 1999).

The laser technique is much better than other industrial alternatives particularly when drilling of aerospace components is concerned. (Rockstroh, 2002**)** Due to high level of exactness and no direct contact with the material surface, laser drilling has wide spread applications in industrial sectors including automotive, aerospace and electronics. Its precision-based application is particularly used procedure to drill holes in nozzle guide vanes, combustion chambers and turbine blades, etc. Some challenges faced in laser drilling are:

Laser drilling parameters

Hole quality is a dominant concern to aerospace industries. To create a good quality hole with minimum cost, best process parameters selection is necessary as well as understanding the drilling process.

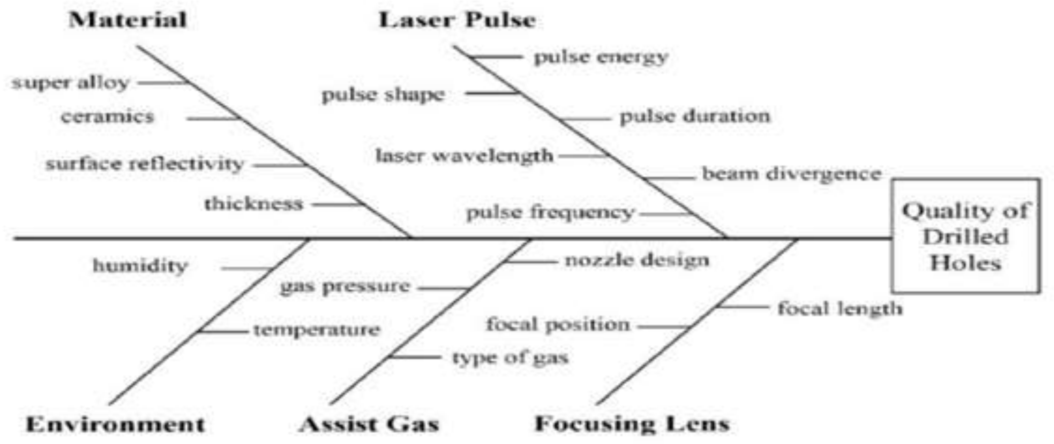

Figure 1. An effect of some operating parameters affecting the quality of laser drilled hole. (after Yeo C., et al 1994)

Pulse energy and pulse duration

In laser drilling process, pulse duration and pulse energy are the important process parameters. Pulse duration (D) and pulse energy (E) are related to the peak power (Pp) that can be delivered by the laser. (Mazumder J, 2010) There is a significant effect of peak power on material removal process. High peak power transfer more energy into the material and subsequently accelerate the liquid (molten metal) removal.

$$P_P = \frac{E}{D} = \frac{\text{joules (J)}}{\text{seconds (s)}} = \text{watt (W)} \ldots\ldots \text{Eqn (1)}$$

The power intensity of laser (I) is reflected to the peak power P_P and focused beam area (A). A watt per square centimeter is the unit of power intensity (I)

$$\text{Power intensity (I)} = \frac{P_P}{A} = \frac{W}{Cm^2} \ \ldots\ldots \text{Eqn (2)}$$

Hence, the short pulse duration and high pulse energy produce high power intensity which advances the material removal rate and so reduce the recast layer

Specific Energy

There are three basic phenomena evident in the process of radiant energy transfer to solids: reflection, scattering and absorption of radiation. The flow of energy of an incident electromagnetic wave (E_{INC}) is divided into these parts: As stated in (Graves & O'Brien, 2004).

$$E_{INC} = E_{REFL} + E_{SC} + E_{ABS} \ldots\ldots\ldots\ldots \text{Eqn (3)}$$

Where E_{REFL} , E_{SC} and E_{ABS} are reflected, scattered and absorbed fractions of the energy flow of the incident wave, respectively. If a surface is a planar one, like a mirror, then much of the energy is reflected. Rough surfaces mainly scatter the incident radiation. The reflectivity is determined by the However, for tightly packed grains, the warmth conductivity could reach higher values dissipating the warmth at a faster rate, reducing the quantity of melted material. Also, some minerals decompose and produce gas. As a result, the melt and gases require part of the laser energy for their creation, so a smaller percentage of the total laser energy is transmitted to rock. Fractures that form within the samples even have an impression on specific energy. It may be that fractures extending out from the laser created hole are beneficial to the removal process. Therefore, the fractures occur due to sample size and do not represent what will occur in the subsurface under in situ conditions. For the purposes of this study, fractures represent losses of energy, which result in higher SE values. Fractures are classified as macro- and micro- fractures. The behavior of fractures is different from one rock type to another. This difference depends on intrinsic factors such as mineralogy, thermal properties of the rocks, volume of void space, dimension of the sample and the amount of stress applied. Mineralogy also affects fracture formation. Clays contain water and by subjecting the clays to higher temperatures, water will escape in the form of vapor.

Pulse width and shape and pulse frequency

Generally, long pulse width produces big diameter and deep hole (JD Jones., 2004), though, with short pulse width is very minor difference that is found between entry hole and exit hole diameter. Along pulse breadth has enough energy to induce obviate liquified material, whereas, a quick pulse breadth provides improved hole quality. The suitable range recommended for pulse width is 0.1-2.5 m/s (Yeo C., et al 1994). Pulse frequency defines the quantity of energy entering the fabric per unit time. At large pulse frequency value, the irradiated surface will swiftly heat up to its melting temperature (Salonitis K., et al 2007). Therefore, it is very important to select the appropriate pulse width and pulse frequency values. In laser drilling, the progressive pulse shape is very important which unusually affect the material removal process. Long pulse length results in wastage of energy, this is because the plasma or vapor plume produced after irradiation absorbs the pulse energy. Spiked pulse produces high peak power as compared to continuous pulse and conjointly ends up in economical removal of fabric.

Short-term summary of drilling methods

Cable tool drilling is the first of those techniques. The hole boring is accomplished by constantly lifting and dropping a heavy string of drilling tool into the bore hole with the bit crushing the rocks into small fragments. Comparatively, much success wasn't achieved with this because it's time consuming, features a very low penetration rate, blowout preventers weren't easily adapted and it's almost limited to drilling consolidated formations. Though, by the turn of the 20th century, the rotary drilling technique was introduced and it nearly banished the cable tool from operation. The main difference between both is that with the cable tool drilling has to be stopped in other for cuttings to be removed from the hole, while with the rotary drilling, the mud mixes through the system and transports away cuttings from the entire at the same time as drilling continues. Laser (Light Amplification by Stimulated Emission of Radiation) drilling looks to be the first important change to the rotary drilling concept since more than 100 years ago. The laser drilling is built on the three common energy transfer processes between the laser and the rock: reflection, scattering and absorption. According to Graves and O'Brien 1998 "It is the absorbed energy that gives rise to rock heating and destruction". Some rock properties help the laser drilling process.

Advantages of Cable Tool Drilling

- A relatively cheaper drilling method
- Efficient use of personnel. The cable-tool rigs are repeatedly operated by one or two persons.
- Appropriate for water poor areas and remote locations.
- Qualitative and quantitative data; with good flow estimates, temperature, water chemistry measurement and static water level, can be obtained while drilling.

Disadvantages of Cable Tool Drilling

- Directional drilling is impossible as this method is restricted to vertical holes.
- Depth and penetrating rates are very low, particularly through hard rock formations.
- In unconsolidated developments, casing must be determined as drilling progresses. Failing or caving in of the formation is nearly unavoidable without immediate casing.
- Blowout preventers are not easily adapted.

Advantages of Rotary Drilling

- It can drill through most rock formations.
- Water and mud support unstable formations
- It has a high penetration rate.
- Process is possible above and below the water-table.
- It is likely to drill to depths of over 14,000ft

Disadvantages of Rotary Drilling

- It is capital intensive.
- Frequently requiring pumping water in large volume.
- Regularly requires mud mixing equipment and dug pits or metal tanks for circulation.
- It needs fundamental knowledge of bentonite and additives needed to attain adequate penetration rates and stabilize formations.

Advantages of laser drilling

- Non-contact technique. The drilling medium is a beam of light, so there is no physical contact between parts and workpiece.
- High aspect ratios possible. With lasers, holes with aspect ratios of for example 30:1 are easily produced
- Drilling of difficult to process materials. Lasers can be used to drill a extensive spectrum of materials from rubber and wood to very hard metals such as diamond and ceramics.

Disadvantages of laser drilling

- High capital investment. The capital investment required to purchase a laser can be significant.
- Thermal effects. Due to heating, a HAZ may be present around the hole, particularly with pyrolytic processes
- Through pyrolytic developments, due to melting and evaporation of material, a changed layer and dross build up at the entrance and exit of the hole may be present.
- Mainly in holes with large aspect proportion a substantial taper may be present, which may be unacceptable.

Comparison of laser drilling with conventional drilling

- It drills 100 times faster than other means of drilling as rate of penetration is high in laser drilling.
- It makes more precise holes that is horizontal and vertical drilling.
- Reduces downtime due to dull bits

- Eliminates waste created by drilling mud so the cuttings vaporize
- It makes a ceramic surface that closures the wall of the well
- It removes influx/out-flux of fluids hereafter formation damage is removed as well.
- It is extra cost-effective both in saving time and reducing extra cost of paying, for example steel wall casing.
- It has low reflectivity of rocks which results in good coupling of laser radiation with rocks.
- It also has deep penetration of laser energy into rock which results in volumetric absorption of laser energy.
- It requires the power of 10HP (7.5 Kw) as this latest hybrid-mechanical technology as in conventional drilling it requires the power of 2000HP (1.5 MW) that is the small in comparison with conventional drilling

Conclusion

Laser drilling is showing to be an effective method as compared to other conventional means. It shortens work and allows you to consume mass production of the same items within a quick period. Laser drilling, the latest hybrid laser-mechanical technology can intensely reduce energy requirements for drilling purposes. Cutting drilling costs is not only important for oil and gas business, but becomes a challenge for cost-effective misuse of geothermal resources. Some drilling technologies have been selected and presented here. A study of the drilling methods showed that some of them may be applicable for deep drilling while most of them have been enhanced for drilling oil and gas wells. Even though the use of applying laser technology in petroleum well drilling is only a fairly new development, the improvement so far has shown that it is very feasible. The use of laser technology in petroleum well drilling is a very recent thought. Substantial progress has to be made both experimentally and numerically in order to utilize laser techniques to enhance the drilling phase. An important costs reduction for petroleum well drilling can be achieved through new well construction concepts, but new technologies are required to achieve such goals. In conclusion, the quality of laser drilled hole can be better by controlling the process parameters. However, cost effective solution is also essential along with expected performance and quality.

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