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ADDITIVE MANUFACTURING IN THE OIL AND GAS INDUSTRIES - A REVIEW

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ABSTRACT

Additive manufacturing (AM), also known as 3D printing, is a process for creating prototypes and functional components achieved by consolidation of material layer upon layer. Applications of AM technologies have been witnessed in the healthcare, automotive, architecture, power generation, electronics and aviation industries. Some of the main benefits of AM include effective material utilisation, new design possibilities, improved functionality of the products and flexible production. The opportunities for the applications of additive manufacturing in the oil and gas industries are only just being explored. In this study, a review of the potential opportunities of AM technologies in oil and gas industries was reported. The adoption of the AM technologies necessitated the need for a rethink on design for manufacture and assembly of oil and gas component parts such as high-tech end burners, metal fuel nozzles, and submersible pump components amongst others. The possibility of employing AM technologies on-site for the production of spare parts for replacement of damage components in oil and gas equipment and facilities is commendable, as this brings about reduction in production downtime and replacement cost. The future of AM in the oil and gas industries is highly promising, however before AM can actualize its full-fledged potentials in these industries, further research is required in the area of new materials development and processing, improved surface finish of AM fabricated parts, enhanced fabrication speed and parametric optimisation to improve the mechanical properties of the fabricated components.

Keywords: Additive Manufacturing, Oil and gas industry, 3D printing, Product design.

1 INTRODUCTION

Additive manufacturing (AM) is a solid free-form fabrication technique which allows the development of any component from its 3D model by consolidation of materials layer upon layer with no tooling required [1]. Owing to the nature of the layer-upon-layer addition of material in the AM process, new design features and enhanced topology optimisation have become possible [2]. Hence, with AM, geometries and other design features in materials that were previously impossible to produce with conventional manufacturing owing to production constraints are now possible. Additive manufacturing offers the ability to produce complex shapes at no extra cost [2]. This indicates the more complex the product or part, the more suitable additive manufacturing is, as opposed to conventional techniques. The generic advantages of additive manufacturing include: free production cost for part complexity, low cost of small batch size production, component fabrication as and when and wherever needed with near zero-inventory cost and cost-effective material utilisation amongst others [3]. The oil and gas (O&G) industries have begun adopting additive manufacturing technologies into its regular workflow in several key areas, especially for the production of valuable tools and spare parts for replacement of damaged ones [4]. Additive manufacturing has found prominent applications in the area of healthcare, automotive, architecture, power generation, electronics and aviation industries [5]. In a report 'Hype Cycle for 3D Printing [6]', a graphic representation of the maturity and adoption of technologies and applications of 3D printing was presented as shown in Figure 1.

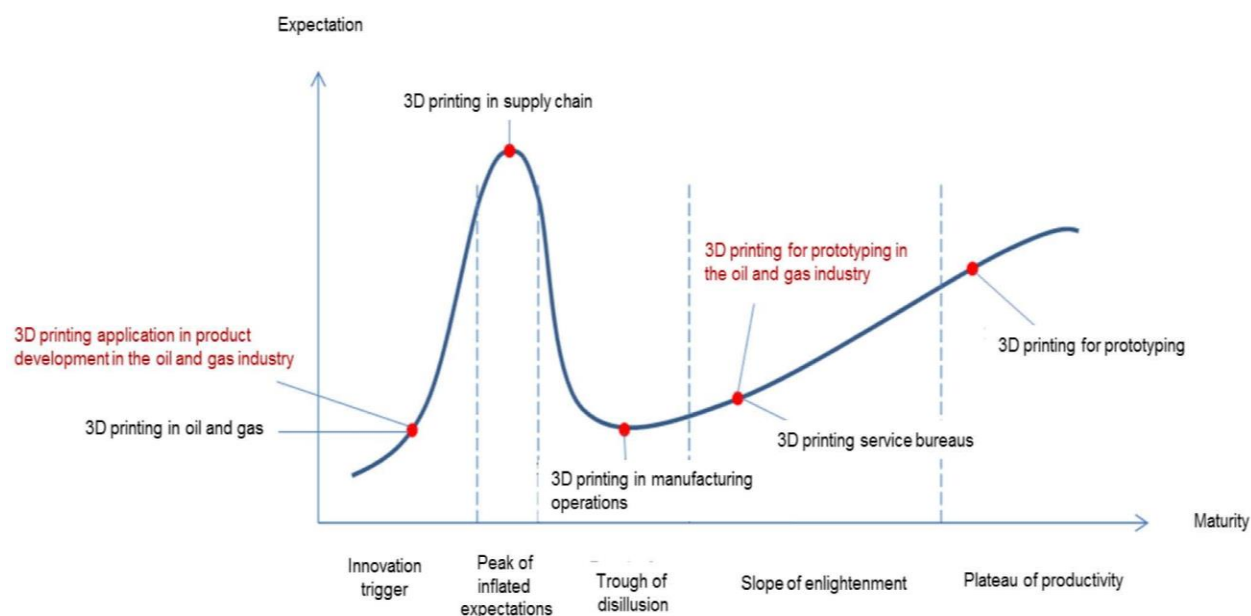








Figure 1- The status of 3D printing applications in the Gartner hype curve [6]


The Gartner hype curve shows that 3D printing for prototyping in oil and gas industries is at the stage of enlightenment which indicates the heightened level of awareness of AM technology for production of prototypes/visual aids for the construction of facilities in this sector. However, the adoption of AM techniques for production of functional parts to be used in oil and gas industries has just began as this is being triggered by the innovation AM processes can bring to their product development. This implies that more research work is required to be done in the area of 3D printing applications in oil and gas industries to enhanced component part design for high performance, to improve product quality and rapid tooling for production. The limitations of additive manufacturing among the stakeholders within the oil and gas industries are the lack of required strength and potential failure of parts fabricated via the AM techniques. To enhance the effectiveness of additive manufacturing technologies in the oil and gas industries, the characterization of the materials such as functional metal, ceramics and polymer being used in 3D printing should be researched upon in order to determine the best mechanical properties which will be well suited with the international standard in the oil and gas equipment facilities. This will prevent sudden equipment failure resulting from the use of replacement parts fabricated via additive manufacturing technologies. Recently, the three most common uses in AM are for prototyping, product development, and innovation [7]. Hence, this paper discusses some key areas in which additive manufacturing technology has been used for the production of prototypes/functional parts, identifies challenges facing the adoption of AM in order to meet their pressing demands and also proffer possible solution to promote the deployment of AM functional parts in oil and gas industries. This study was structured to serve as guide to researchers with interest in the application of additive manufacturing in the oil and gas industries.

2. TECHNOLOGIES FOR ADDITIVE MANUFACTURING

It is of paramount importance to define different AM processes that can be of advantage to oil and gas industry of producing functional parts. The American Society for Testing and Materials (ASTM) has classified AM into seven technologies as presented in Table 1.

Table 1 Categories of Additive Manufacturing according to ASTM (F2792-12a) [8]

AM Printing	Technology – Definition	Materials	Typical Market
	Vat polymerization/ Stereolithography (SLA), digital light processing (DLP) An AM process in which liquid photopolymer in a vat is selectively cured by light activated polymerization.	Photopolymers	Prototypes Jewellery Industry
	Material jetting/ Multijet modeling (MJM) An AM process in which droplets of build material are selectively deposited.	Polymers Waxes Biomaterial	Prototypes Moulds for castings Jewellery industry
	Binder jetting/ Powder bed and inkjet head (PBH), plaster-based 3-D printing (PP) An AM process in which a liquid bonding agent is selectively deposited to join powder materials	Gypsum Foundry sand Polymers Metals	Prototypes Patterns for castings Creative industries Final parts (metals)
	Sheet lamination/ Laminated object manufacturing (LOM), ultrasonic consolidation (UC) An AM process in which sheets of material are bonded to form an object.	Metals Paper	Prototypes Tooling Final part (metals)
	Material extrusion/ Fused deposition modeling (FDM) An AM process in which material is selectively dispensed through a nozzle or orifice.	Polymers	Prototypes Consumer goods Tooling Final parts
	Powder bed fusion/ Electron beam melting (EBM), selective laser sintering (SLS), selective heat sintering (SHS), and direct metal laser sintering (DMLS) An AM process in which thermal energy selectively fuses regions of a powder bed.	Polymers Metals	Prototypes Tooling Final parts

	<p>Direct energy deposition/ Laser metal deposition (LMD) An AM process in which focused thermal energy is used to fuse materials by melting as they are being deposited.</p>	<p>Metals</p>	<p>Final parts Refurbishment and repair</p>
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3. APPLICABILITY OF ADDITIVE MANUFACTURING IN OIL AND GAS INDUSTRY

Additive manufacturing technologies are playing a vital role in the oil and gas industry research and facility development, these trends are expected to spread into all organs of oil and gas equipment facilities such as oil field service, power generation plant, subsea equipment services, and turbomachinery equipment service amongst others. With the advent of additive manufacturing, oil and gas companies will no longer need to wait for replacement parts, but will have the capability to additively fabricate parts at the location where such replacement or spare parts is promptly needed [4]. The availability of 3D printing technologies on the various oil field service sites will annihilate unnecessary delay in area where standard parts are urgently requested for. Full implementation of 3D printing techniques in oil and gas industries will eliminate over-dependency of these industries on imported replacement parts to maintain oil and gas equipment facilities. According to Scott J Grunewald [4], on-site 3D printing can be deployed to fabricate new parts for use in drilling for oil and gas exploration, where flexibility and adaptability are both important to the successful extraction of the petroleum products.

4. METALLIC-BASE ADDITIVE MANUFACTURING METHODS

3D printing in additive manufacturing can be used to produce some spare parts in oil and gas industries, these functional parts can be built using various metallic-base additive manufacturing technology methods such as Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM), and Direct Metal Deposition (DMD).

4.1 Direct Metal Laser Sintering (DMLS)

Direct Metal Laser Sintering (DMLS) is an additive manufacturing technology that operates by sintering very fine layers of metal powders layer-by-layer from the bottom up until the build is complete. The available materials for direct metal laser sintering include titanium, aluminium, cobalt-chrome, stainless steel, Inconel 625 and Inconel 718 amongst others.

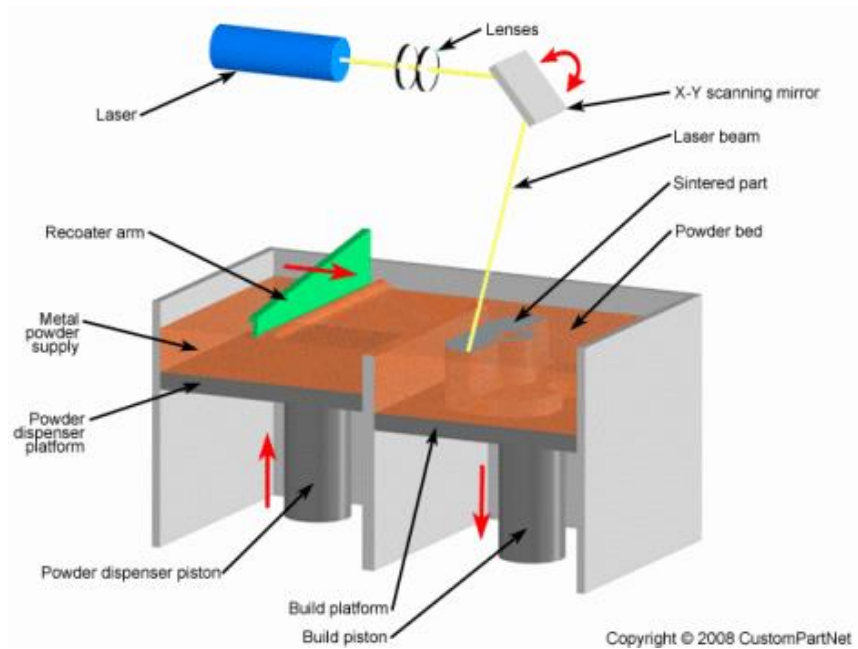


Figure 2: A typical schematic of Direct Metal Laser Sintering [9]

4.2 Electron Beam Melting (EBM)

Electron Beam Melting (EBM) is a type of additive manufacturing which is similar to selective laser sintering as they both print on a 3D printer powder bed. The metal powder or wire is put under a vacuum and fused from heating by an electron beam. A high energy beam comprising of electrons is used to solidify the metal. The available materials include nickel super alloys, stainless steel, tools steels, aluminium, titanium and copper.

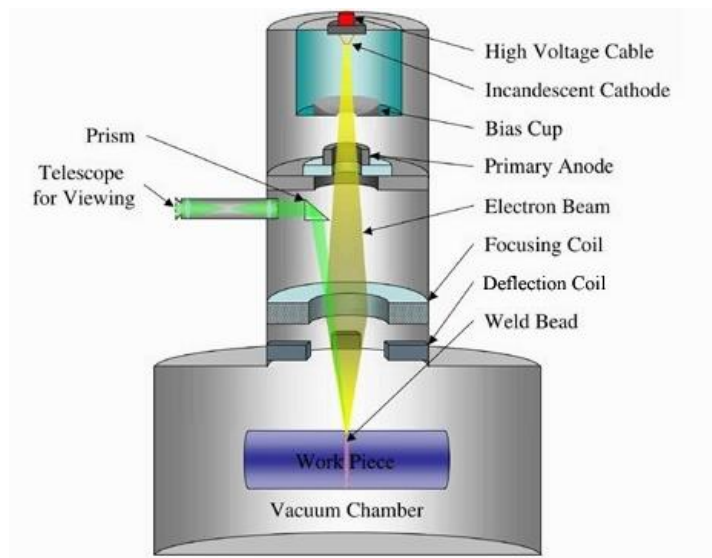


Figure 3: A typical of Electron Beam Melting (EBM) [10]

4.3 Direct Metal Deposition (DMD)

The Direct Metal Deposition is an additive manufacturing technology using a laser to melt metallic powder. This process is similar to Fused Deposition Modelling as the nozzle can move to deposit the fused metal. Direct Metal Deposition extrudes fully dense, functional parts from CAD model by depositing metal powders layer by layer using laser melting.

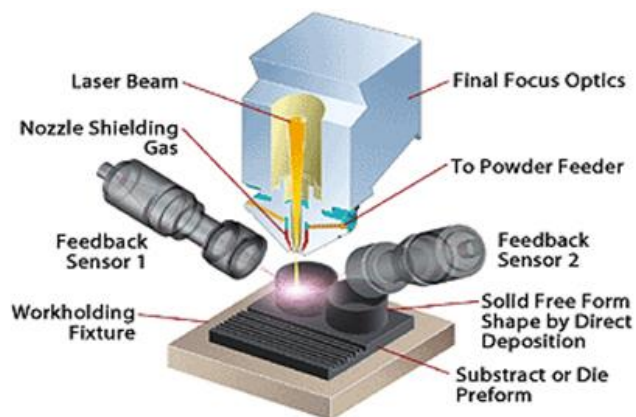


Figure 4: A typical Direct Metal Deposition system showing a component being built layer by layer [11]

5. CURRENT APPLICATIONS OF AM IN OIL AND GAS INDUSTRIES

In recent times, oil and gas industry has come to the point of complete serial production with AM for producing functional components, and the trend is that the number of parts and applications is gradually increasing as indicated in Wohler's reports 2015. Figures 5, 6, 7 and 8 presented different typical prototypes/functional parts fabricated using 3D printing for application in oil and gas industries.

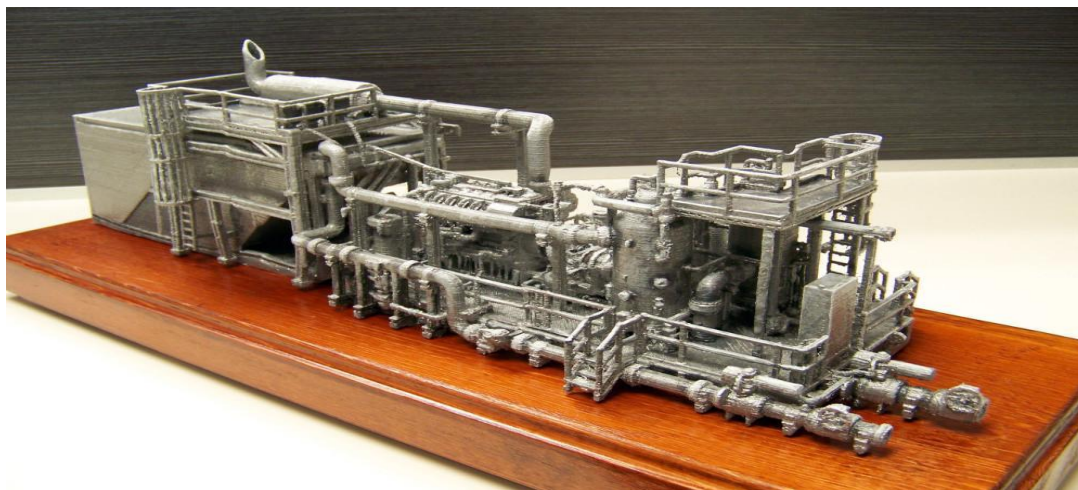


Figure.5: 3D printed oil processing facility conceptual model [4]



Figure. 6: 3D printed oil pump prototype [4]

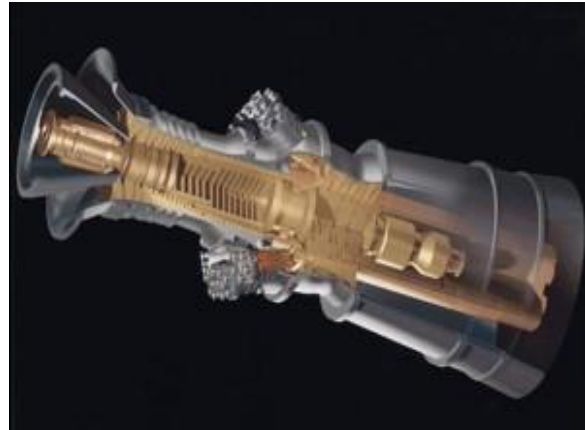


Figure.7: AM fuel nozzle for oil extracting machinery [4]



Figure. 8: 3D Printed Gas Cap Oil Cap & Rear cap [4]

6. CHALLENGES FACING THE ADOPTION ADDITIVE MANUFACTURING IN OIL AND GAS INDUSTRY

6.1 Development of relevant standards

The development of AM standards relevant to oil and gas industrial parts is one of the key challenges facing the widespread acceptability of additive manufacturing technologies in oil and gas industries. Setting of standard in additive manufacturing would provide a foundation for creating products that conform to internationally recognise standard specifications which are compatible with products provided by different suppliers seeking the same quality, performance and interchangeability [12]. Additive manufacturing standards will prevent incessant failure of the components and improve upon the quality of product, increasing reliability, safety and accuracy of equipment and processes.

6.2 3D digitalization data management

To improve the widespread adoption of additive manufacturing in oil and gas industries, there is need for a robust digital infrastructure to be put in place to manage the 3D data system. By doing this, the adoption of large-scale additive manufacturing process in fabricating spare parts in the oil and gas industries will be promoted, such that the 3D data of any parts required can be made available on site and fabricated for replacement purpose. Hence, there will be no need to keep inventory of some of the equipment parts for oil and gas services. The transferring of CAD

model saved in STL files into the 3D printing machine should be properly checked for better dimensional accuracy before fabrication process is initiated in the AM machine software.

6.4. Effect of Electrical power [13]

The impact of power quality on additive manufacturing equipment is one of the challenge that need to be well researched upon. Power variations can have strong effect on the quality of the item being produced using additive manufacturing by introducing defects that may not be discovered easily during the course of printing the components. Research is needed to evaluate the power quality characteristics of AM equipment that will have better influence on the best mechanical properties of the fabricated parts.

6.5 Other challenges

Another challenges involved in the process is poor fabricated part properties, limited material selection, resolution, repeatability, and poor surface finish of the printed parts. Strength of the RP parts is low when compared to part fabricated by conventional machining and also removal of support structure from part fabricated may cause surface damage and affect the surface finish [14, 15].

7. RESEARCH ON ADDITIVE MANUFACTURING IN OIL AND GAS INDUSTRY

Allan Zhong *et al.* [16] worked on a survey of existing metallic AM technologies with their advantages and disadvantages and reported also on the effect of build direction on mechanical properties. Challenges encountered in the application of AM were discussed, which include printability, printed material properties design for AM, and technical competency in AM. Selected work on printing various downhole tools, such as flow control related flow manifold and an extrusion limiter is used to illustrate the benefit of metallic AM. Mechanical properties of printed metals, such as yield strength, elongation at break, and impact strength, are measured using specimen made in-situ along with the parts and compared to those of wrought materials. Microstructure analysis was also performed to compare 3D Printed Inconel 718 alloy to the wrought material to evaluate the effect of the processes involved in the AM.

Ivanova, *et al.* [17] reported on the application of nanomaterials in AM. It was noted that there are many opportunities in the marriage of AM and nanotechnology, but there exist also some significant technical and scientific challenges. The addition of metal nanoparticles generally decreases sintering temperatures, improves part density, and decreases shrinkage and distortion of printed parts. Metal nanoparticles embedded into polymer materials can also provide improved electrical conductivity in fabricated objects.

BSR Report [18] reported the use of 3D printing to produce lighter parts in jet turbine engines by General Electric (GE) Company. With AM technology, a fuel nozzle was fabricated for one of its best-selling jet engines in which a 25% weight reduction was achieved. 3D printing has also allowed GE to manufacture the nozzle in a single piece, while previous manufacturing processes require the assembly of 20 different parts.

In World Economic Forum White Paper [19], a major environmental benefit of 3D printing was proposed to be the reduction of CO₂ emissions by 2 million tonnes. 3D printing of spare parts, as and when required, will reduce inventory levels by an estimated 2%, and the cost of repairs, maintenance and transporting parts by an estimated 3%. However, a major barrier to adopting 3D printing for this purpose is that companies do not want to be liable for potential part failures, and require warranties on their parts

In another study, it was reported that Shell Oil Company used 3D printers to fabricate a prototype of its Stones Oil and Gas station in the Gulf of Mexico – the deepest drilling station in the world. The team used a 3D printer to produce a scaled-down plastic version, including all components, in only four weeks. This version helped the team understand how to improve components before building the real-life buoy in the construction yard, and even helped to work out the most efficient assembly sequence for the buoy. Shell saved \$40 million by highlighting design flaws at an early stage. The 3D-printed prototype also showed US authorities exactly how the finished design would function in a real sea environment, and helped Shell secure government approval [20].

8. CONCLUSION

Additive manufacturing could be a source of positive change, as there are a number of challenges that need to be overcome for it to realize its full potential in the oil and gas industry. There are few research work that has been done in the area of additive manufacturing within the oil and gas industry. To this regard, many research work in AM need to be done in order to facilitate the effective usage of AM in fabricating functional component parts, spare parts in the oil and gas industries. Implementing 3D printing effectively in the oil and gas industries will require re-training of the operator to enhance their knowledge in the fabrication of the replacement parts from their digital signatures. However, 3D printer operations and maintenance are required to successfully implement and adopt these new technologies into a full-scale operation in the oil and gas industries. In spite of the impediments, the future of additive manufacturing in the oil and gas industries is highly promising and expected to continue to expand in the next few years. Going by the Gartner reports who also predicted that by 2019 more than ten percent of all oil and gas companies, include oilfield service providers, will be transitioning from traditional manufacturing methods to more advanced additive manufacturing methods.

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