Online ISSN:2249-4596
Print ISSN:0975-5861
DOI:10.17406/GJRE

Global Journal

of Researches in Engineering: A

Mechanical & Mechanics Engineering

Abrasive-Waterjet Technology

Implementation of Lean Six Sigma

Highlights

Effects of Biomass Properties

Radiator for Internal Combustion

Discovering Thoughts, Inventing Future

VOLUME 20 ISSUE 3 VERSION 1.0

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering

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Volume 20 Issue 3 (Ver. 1.0)

Open Association of Research Society

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USA Tax ID: 98-0673427

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Offset Typesetting

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Packaging & Continental Dispatching

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Contents of the Issue

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 20 Issue 3 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Review of Accomplishments in Abrasive-Waterjet Technology from Macro to Micro Machining - Part 2

By H.T. Peter Liu

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GJRE-A Classification: FOR Code: 861499

REVIEWOFACCOMPLISHMENTSINABRASIVEWATERJETTECHNOLOGYFROMMACROTOMICROMACHININGPART2

Strictly as per the compliance and regulations of:

Review of Accomplishments in Abrasive-Waterjet Technology from Macro to Micro Machining – Part 2

H.T. Peter Liu

Abstract- Abrasive- waterjet (AWJ) technology possesses inherent characteristics unmatched by most machine tools. The initial commercialization of AWJ in the mid-1980s took advantage of its superior cutting power for the raw cutting of thick, difficult-to-machine materials. Subsequently, considerable R&D effort was devoted to take full advantage of the above characteristics while refining machining processes toward precision machining and automation. This two-part paper presents the accomplishments that have advanced AWJ technology in terms of improving its cutting accuracy and efficiency, broadening applications for machining delicate materials from macro to micro scales, and enabling 3D capability for multimode machining. In Part 1, six topical areas are presented to demonstrate some of the important achievements in advancing AWJ technology, including control software, meso micro and stack machining, macro to micro machining, cold cutting, hole drilling, and gear making. Seven more topical areas are included in Part 2: biomedical applications, milling and etching, 3D machining, near-net shaping and hybrid machining, special applications, aerospace applications, and field deployment. The combined topics clearly demonstrate the technological and manufacturing merits and versatility of AWJ technology, which has been competing on equal footing with subtractive and additive manufacturing tools. With the "7M" advantage together with its green manufacturing properties, AWJ has considerable potential to become an all-in-one and one-in-all machine tool for machining from macro to micro scales. For extremely precise parts made from difficult-to-cut materials, AWJ preferably serves as a neat-net shaping tool that removes the bulk of the material quickly without damaging the parent materials. The parts can then be finished with light trimming using proper precision tools to minimize retooling and/or tool replacement costs while expediting the turnaround time.

I. Introduction

After joining Flow Industries, Inc., where waterjet technology was developed and commercialized, the author had the privilege of participating in R&D activities to advance the technology [1]. He was involved in the commercialization of the technology while witnessing its maturation and growth in the manufacturing community. In the early stages of the commercialization of abrasive-waterjet (AWJ) during the mid-1980s, a reasonable controller to maneuver the operation had yet to be developed. AWJ merely served as a raw cutting tool for difficult and thick materials to take advantage of its superior cutting power. As the technology advanced, additional technological and manufacturing merits were discovered and progressively verified. In addition to the superior cutting power, these merits include environmental friendliness, material independence, cold cutting, adaptability to automation, amenability to micromachining, low loading on work pieces, and 3D capability (Liu and Schubert, 2012; Liu, 2017a). Most of the development efforts in the last three decades, in addition to hardware improvements for improved cutting performance, were to develop controllers and smart software for easier operation and precision machining. Today, AWJ possesses technological and manufacturing merits that are superior to most other tools. It has been elevated as a modern machine tool competing on equal footing among lasers, electrical discharge machining (EDM), and precision milling tools.

AWJ is capable of machining most materials, from metals to nonmetals and anything in between, regardless of conductivity or reflectivity. In particular, AWJ will meet the challenge of machining nano-materials integrated with various material types possessing nonlinear material properties (Liu, 2017b). The diameter of a water-only-jet (WJ) is defined by the diameter of the jet's orifice. A single-phase WJ with diameters smaller than 100μm has been used to cut relatively soft materials such as fabrics, rubber, foam, thin plastics, and various food products (Yadav and Singh, 2016). With the entrainment of abrasives and air as well as the incorporation of the mixing tube, the diameter of three-phase AWJ is about three to four times that of WJ. At present, the smallest kerf width achievable with the AWJ is around 300 to 400 μm. Preliminary tests using a research μAWJ nozzle, with a ø0.076 mm orifice and a ø0.18 mm mixing tube, have shown that a kerf width of 200μm is achievable (Liu and Gershenfeld, 2020). Very thin materials that are too delicate to machine otherwise can be machined by stacking

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[1] The author, who began his employment with Flow Industries in 1973, had the honor to be supervised by the late Dr. John Olsen, who enabled the commercialization of waterjet technology by perfecting the ultra-high pressure intensifier pump.

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multiple layers of materials with AWJ. The increase in the thickness of the stack not only stiffens the individual layers for ease of fixturing but also enables the activation of the Tilt-A-Jet for machining nearly taper-free edges[2].

As a cold-cutting tool without the induction of a heat-affected zone (HAZ), AWJ often is capable of cutting one order of magnitude faster than solid-state lasers (pulsed at high frequencies) and wire EDM (cut with multiple passes) (Liu, 2019a). For extremely precise parts made of difficult materials, end mills and spindles are often subject to severe tool wear resulting in high retooling costs. AWJ can be preferably applied as a near-net shaping tool to remove the bulk of the materials. Near-net-shaped parts can then be finished via light trimming with precision CNC tools. Such a hybrid process would speed up the turnaround time while minimizing the labor and retooling costs.

Future advancement in AWJ technology is expected to develop an all-in-one and one-in-all tool for precision machining from macro to micro scales. Continued efforts are underway to improve the cutting accuracy and to further downsize µAWJ nozzles. In this two-part paper, recent advancements in AWJ technology that take advantage of its technological and manufacturing merits are described. In particular, several established and new trends in applying AWJ for precision machining will be presented, primarily based on the author's R&D and marketing experiences in the field.

II. R&D and Demonstration Facilities

OMAX Corporation is equipped with two laboratories for R&D and demonstration. The R&D Lab is dedicated to engineering research and development, including components and processes testing. The Demo Lab is mainly for demonstrating AWJ machining for prospective and existing clients. There are several JetMachining® Centers (JMC) from the four product lines installed in the two laboratories[3]. Two of the JMCs used most often for general and meso-micro machining are the OMAX 2652 and MicroMAX.

A number of accessories are installed on these machines to enhance AWJ machining[4]. Key accessories include but are not limited to:

- Tilt-A-Jet (TAJ) for edge compensation.
- Rotary Axis (RA) for axisymmetric machining
- A-Jet (or articulated jet) for beveling and countersinking.
- Precision Optical Locator (POL) for facilitating alignment and orientation of pre-machined components for precision machining.
- Vacuum Assist (VA) for low-pressure piercing and machining to mitigate nozzle clogging.

A combination of multiple accessories are often used to machine certain features. For example, the combined operations of the A-Jet and Rotary Axis can be used to machine rather complicated 3D features such as the "fish mouth" weld joints on pipes.

III. Advances in AWJ Technology

a) Biomedical applications

The "7M" advantage of waterjet technology, particularly the capability of meso-micro multimode machining of difficult-to-machine materials, has been demonstrated as a potential tool for a wide range of biomedical manufacturing due to the technology's versatility (Liu, 2017b, 2012). Many orthopedics and prosthetics, particularly implants, are made from biocompatible metals such as titanium, stainless steel, Inconel, Nitinol, and other materials that present a challenge to conventional machine tools. Figure 1 illustrates a collection of metal orthopedic components, including several forms of mini plates for implant fixation. The 5/10 nozzle was used with 320 mesh garnet. The majority of prosthetic and orthopedic components are made of titanium because of its physical qualities: high strength, toughness and durability with low density, corrosion resistance and, most importantly, biological compatibility. On the other hand, stainless steel remains the material of choice for surgical instruments because it is strong, durable, and able to withstand harsh sterilization procedures.

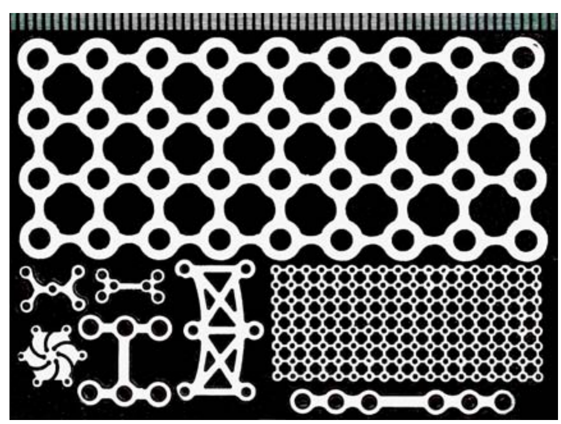

Figure 1: Metal orthopedic implants (Liu, 2012)

While there are considerable challenges to micromachining titanium with contact tools, AWJs cut titanium quickly and effortlessly (34% faster than machining stainless steel). In addition, the fatigue performance of AWJ-cut titanium could be greatly enhanced (by at least a factor of 3) through the use of a simple secondary process of dry-grit blasting (Liu et al.,

[2] The TAJ is ineffective for machining thin materials, as the cutting speed is too high for the TAJ to respond rapidly to compensate for the edge taper, however small.
[3] https://www.omax.com/products.
[4] https://www.omax.com/accessories.

2009, 2012). Representative patterns of prosthetic and orthopedic components were obtained from “Atlas of Craniomaxillofacial Osterosynthesis” (Haerleet al., 2009) and websites of manufacturers of orthopedics (http://www.tecomet.com/cmf.htm).

For machining 3D orthopedics and prosthetics, a Rotary Axis, A-Jet, and/or combination of both can be used. Figure 2 shows AWJ-cut diamond-shaped holes on a stainless steel plate (Figure 2a) and a 6 mm O.D. titanium tube (Figure 2b). The titanium tube featuring the shaped holes is called titanium mesh cage TMC) and is used in spine surgery (Grob et al., 2004). The TMC is a rigid structure that is not amenable to bending about its axis. An alternate design with an interlocking link would have built-in flexibility about and stretch ability along its axis. Such interlocking features can be readily machined with the aid of the Rotary Axis, such as the TMC shown in Figure 2c.

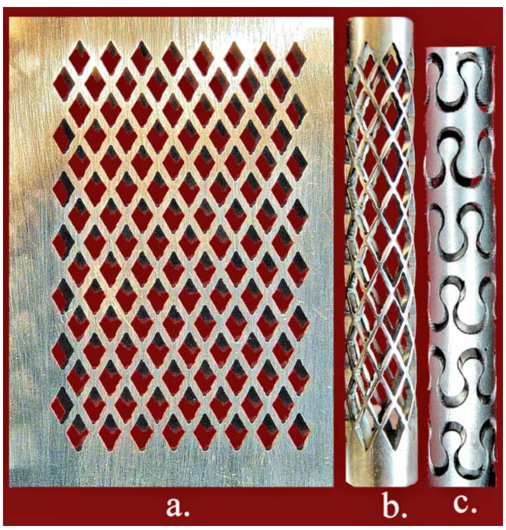

Figure 2: μAWJ-machined titanium mesh cage and interlocking link (Liu, 2012)

Composites such as carbon fibers and ultrahigh molecular weight polyethylene (UHMW) have been used extensively for many years in engineering and aerospace manufacturing to take advantage of their excellent strength-to-weight ratio. They were subsequently adopted for fabricating prosthetics for exterior fixation. Waterjet technology has been applied to machined biomedical components for all these materials (Liu, 2017b). Figure 3 shows two carbon fiber knee braces machined with a waterjet. 2D carbon fiber components were first machined with a waterjet and then thermally formed to their final shapes. For implants and internal fixation components, only few composites are biocompatible and free of contaminants. One such composite is polyether ether ketone (PEEK), which was originally launched by Victrex plc in 1998 and marketed as PEEK-OPTIMMA. Extensive laboratory and clinical tests have shown the superiority of PEEK to metals and UHMW as implant materials (Kurtz and Devine, 2007).

Figure 3: Two AWJ-machined carbon fiber knee braces (Liu et al., 2018b)

- The chemical structure of polyaromatic ketones confers stability at high temperatures (exceeding 300°C).
- Resistance to chemical and radiation damage.
- Compatibility with many reinforcing agents (such as glass and carbon fibers).
- Greater strength (on a per-mass basis) than many metals
- Compatibility with modern medical imaging techniques (i.e., no shadows in X-ray, CT or MRI images).

AWJ cutting tests of prosthetic and orthopedic components were conducted using PEEK materials supplied by Victrex and Invibio Ltd. Cranial implants, which must be sized to fit individual patients of all ages from infants to adults, are often made with PEEK. Figure 4 shows samples of AWJ-machined PEEK cranial implants with a thickness of 3.2 mm. The samples were machined in 2D and then thermally shaped to become a 3D spherical segment. Such implants can be fabricated in several hours, including the secondary processes necessary to meet FDA requirements. For remote areas where supplies are scarce and timely shipment from manufacturers is not an option, patient-specific implants can be fabricated locally by field-deployable waterjet and portable waterjet systems.[5,6]

a. Unfilled b. Filled

Figure 4: μAWJ-machined PEEK cranial implants thermally shaped to 3D form (Liu, 2019)

Figure 5 shows one half of a stainless steel surgical clamp machined with the AWJ in multiple steps.

[5] http://sme.org/MEMagazine/Article.aspx?id=78461
[6] https://www.protomax.com/

The surgical clamp consists of several teeth for clipping onto various objects, such as surgical tubes or blood vessels, during surgery. The clamp was cut in three separate steps from left to right, As elaborated in Section III.c.i. It is essential that there is no taper along the entire length of teeth so that the clamp will tightly grip objects. To ensure taper-free teeth and tips, the clamps were machined with the Tilt-A-Jet activated.

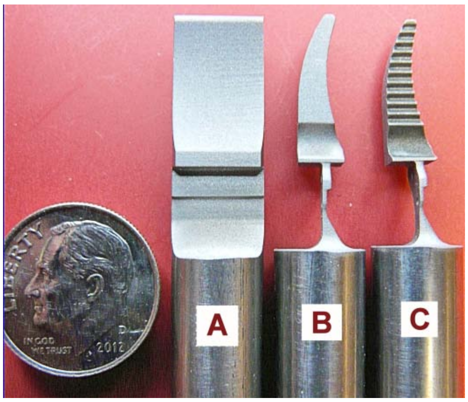

Figure 5: Surgical clamp by multi-step AWJ machining (Liu and Olsen, 2013)

For laparoscopic surgery using a trocar insertion, blind puncture access procedures are used. This could lead to complications due to over-puncture. When tissue membranes yield under applied stress, the tool can suddenly accelerate forward into the patient. A novel device that actively opposes forward acceleration of the tool was designed and tested (Begg, 2011). One of the critical elements of the device is a delicate flexure. Collaborating with the Precision Engineering Research Group at MIT, OMAX machined several aluminum flexures for constructing the novel device for testing, as illustrated in Figure 6[7].

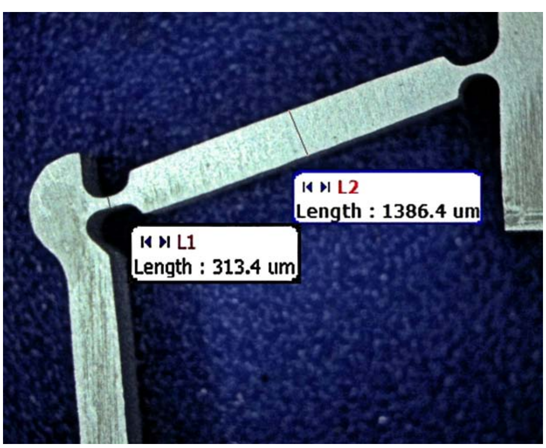

Figure 6: Aluminum flexure (Liu, 2012)

b) Milling and Etching

AWJ milling and etching have been niche applications that represent only a small percentage of AWJ machining operations. Since AWJ has considerable cutting power, precise control of the milling depth requires very high nozzle traversing speeds that are beyond the capability of current AWJ platforms. Since current nozzle traverse speeds are low, workpieces are instead mounted on rotating platforms capable of achieving high speeds to perform these operations. The size of the platform is governed by the size of the workpiece. For small workpieces, a small-sized platform rotating at high speeds will suffice; for large workpieces, a large rotating platform is required, as the rotational speed is proportional to $r\omega$, where r and ω are the radius of the platform and rotating speed, respectively. In addition, steel mask was often used to protect the areas that were not to be etched or damaged by stray abrasives (Miles, 1998). The masked milling approach has been successfully applied to a wide variety of structures ranging from 2.4-m diameter space-based optics, turbine engine components, and flow channels in flat heat-exchanger panels (Miles, 1998). Maskless milling would require control of the vector sum of the nozzle traversing speed and the speed of the rotating platform to machine the designed surface profile on the workpiece.

AWJ etching has also been used sparingly because of the complexity in setup and the etching process itself. A new approach was developed, Intelli ETCH, that utilizes a predefined height map. The height map is an image (e.g., a bitmap or jpeg file) that contains brightness levels that correspond to a grayscale ranging from "0" for black to "255" for white and all of the different shades of gray in between. The brightness values dictate how deep the etching should be at any particular point, with black being the deepest and white being the shallowest etch. The user defines the maximum and minimum speeds while the utility fills in the speeds for each shade of gray that falls in between. From there, the image is analyzed and speeds are assigned to each shade value encountered on the image. A machine may then be configured to modulate the speed at which the position actuator moves the nozzle across the workpiece, with slower speeds provide relatively more etch depth and faster speeds provide relatively less etch depth (Olsen, 2009). The approach enables users to change the speed of etching for a very high-resolution all-in-one process as opposed to handling depth variation with multiple processes and masking.

In this section, examples of AWJ masked milling and AWJ etching are presented. An example of maskless milling is presented in the next section. A novel approach for masked milling for small workpieces is described herein. A dual-disc anemometer (DDA) was developed with the ability to measure water droplet and abrasive speeds 1000 m/s and higher in waterjets and abrasive waterjets (Liu et al., 1998). This capability was

[7] http://pergatory.mit.edu

enabled by incorporating a low-cost router with a maximum rotating speed of 23,000 rpm to 27,000 rpm. The DDA was subsequently modified foran AWJ milling workstation to take advantage its high rotating speeds, as shown in Figure 7. All the rotating components were enclosed in a protective steel casing as a safety measure. A steel mask on top of a workpiece was mounted just under the cover plate on the end of the shaft of the router. A radial slot was machined on the cover plate along which the AWJ traversed during milling operations.

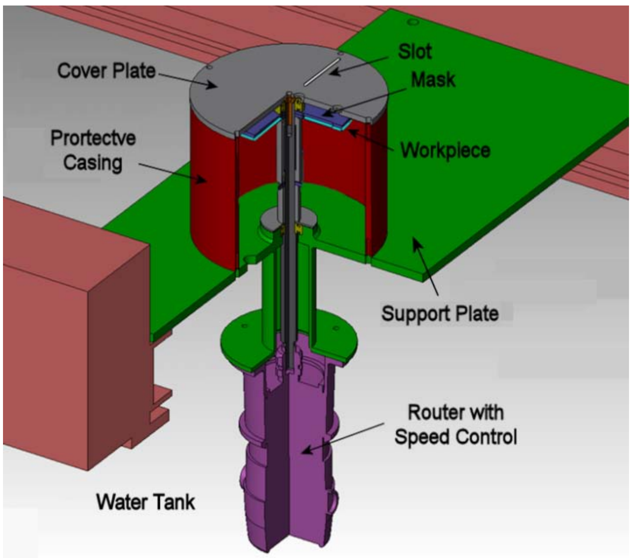

Figure 7: Modified DDA for AWJ masked milling (Liu et al., 2008)

The material removal rate is inversely proportional to the vector sum of the rotating speed of the workpiece and the traverse speed of the AWJ nozzle. For a 10-cm diameter workpiece, for example, the linear speed at a radial position of $r = 5$ cm is nearly 2 m/s. At such a high speed, the material removal rate per AWJ traverse was very low. Materials on the workpieces were removed where the slots were present on the mask. Milling was carried out by installing the modified DDA in one of the AWJ platforms. The router was first turned on until a stable rpm was established followed by traversing the AWJ back and forth along the slot to mill the workpiece. The number of traverses depended on the milling depth and the machin ability of the material.

Figure 8 shows a steel mask on which a set of slots was machined. Three workpieces made of Lexan, aluminum, and stainless steel were milled. The rotational speed was set to 10,000 rpm. The MAXJET 5 nozzle with a 0.36 mm/0.76 mm orifice/mixing tube combination, operating at 240 MPa, was used. Milling was conducted using 220 mesh garnet with a mass flow rate of 0.16 kg/min. The radial traverse of the AWJ nozzle was 1.27 m/min. The number of traverses for the aluminum and Lexan runs were 20 and 10, respectively.

a. Mask b. lexan c. Aluminum d. Stainless steel

Figure 8: AWJ milling using a modified DDA (Liu et al., 2008)

Based on the depth of these milled surfaces, the rates of the milling depth on the aluminum and Lexan workpieces were measured to be 6.4 microns and 15 microns per traverse, respectively. The above results demonstrate that milling blind micro channels on various substrates with rates of milling depth in the micron or submicron range per revolution can be achieved by using finer abrasives at relatively lower pressures, particularly for materials with relatively low machinability such as stainless steel and titanium. It is interesting to point out that both the mask ribs and the workpiece channels are distorted slightly in the radial direction due to high centrifugal forces. The milled pattern on the workpieces were identical to that on the mask, as expected. Further process optimization could be achieved by adjusting the rotational speed of the DDA based on the geometry of the mask and its material properties to mitigate this observed distortion.

Figure 9 shows the surface profiles of the blind channels on the Lexan (a) and stainless steel (b) parts. The profiles were measured with a COBRA Scanner. The abscissa and ordinate represent the radius from center of the part and the depth of the blind channels, respectively. The average depths of all but the outer-most channels were approximately 0.4 and 0.25 mm, respectively. The difference is attributed to the difference in machinability (517 versus 81) although the milling cycles were 10 and 20 for the two parts. The effect of the centrifugal distortion of the parts was evident from the profiles and resulted in very narrow and shallow outer-most channels.

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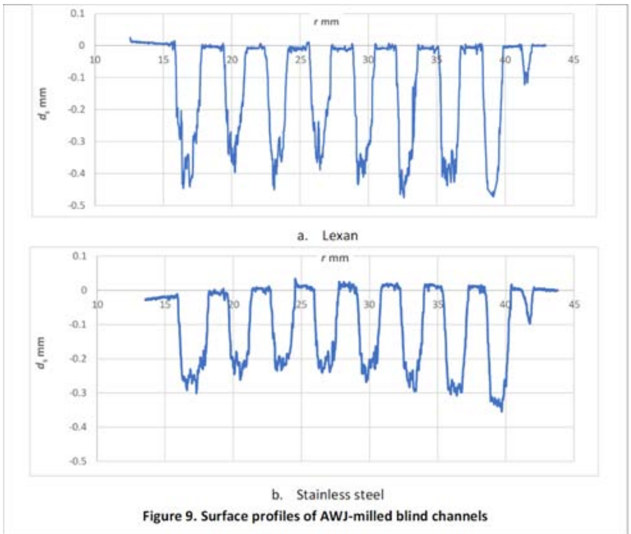
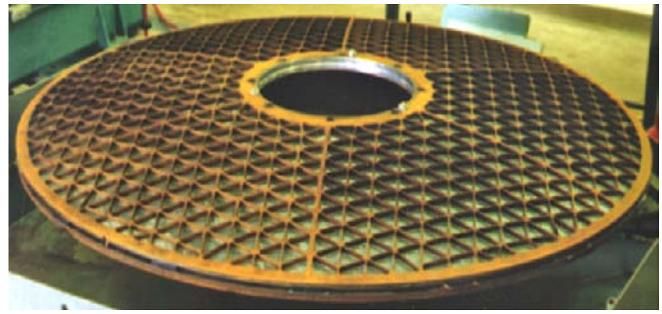


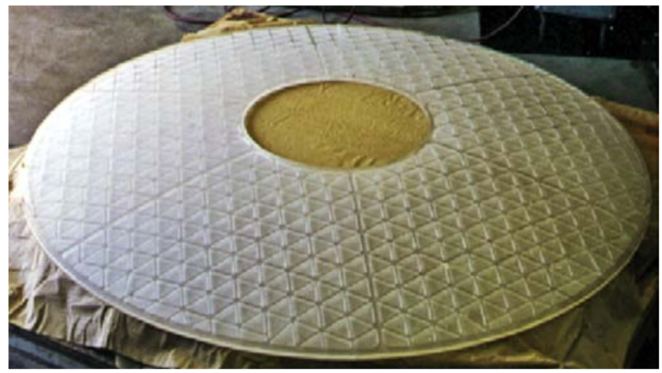
Figure 9: Surface profiles of AWJ-milled blind channels

The material removal rate of AWJ milling was several orders of magnitude higher than that of chemical milling. At the maximum traversing speed of 7.6 m/min, each AWJ traverse over a 0.13 m milling tray takes only 1.2 seconds to complete. At a milling rate of 1 micron per traverse, for instance, it would only take a couple of minutes to mill 100-micron-deep features on multiple workpieces per load for virtually any materials. Chemical milling, on the other hand, would take many hours to complete the same parts—and only for materials amenable to that process. Furthermore, the working fluidsused for chemical etching are often toxic, while AWJ is a green manufacturing tool.

One of the largest and most delicate AWJ-milled workpieces, which featured light weighting pockets, was the face sheet of a 2.4 m diameter ULE (ultra-low thermal expansion by Corning) glass mirror (Miles1998). Figure 10 shows the steel mask placed on top of the mirror (a) and the finished part with 9-mm-deep triangular pockets (b). The mask and mirror were mounted on a large rotating platform with a diameter of around 2.5 m. The time required to mill the part was two weeks as opposed to the eight-month estimate for conventional glass machining processing. Since there was no hard tool used to machine this multi-million dollar mirror, the process was considered a safe milling process in comparison with the conventional process. The cost effectiveness, fast turnaround, and process security were the primary reasons that AWJ was chosen for the extremely risky application.



a. Mask



b. Finish part

Figure 10: Pocket milling of 2.4 m ULE face sheet for light weighting (Miles, 1998)

Figure 11 shows two maple leaves with features positively (a) and negatively etched (b), respectively. With a total etching depth of 256 levels, the 3D features were reasonably discernable.

a. Positively etched b. Negatively etched

Figure 11: AWJ etching of maple leaves

c) 3D Machining

AWJ is amenable to 3D machining but must be carried out with discretion. One of the properties of AWJ is that the spent abrasives, if not "tamed" or captured, still possess considerable residual cutting power that could damage other parts of the workpiece and pose a potential hazard to operators. In other words, AWJ is not inherently suitable for 3D machining by simply mounting the nozzle on a multi-axis manipulator. Although there are such AWJ systems available commercially, their 3D capability is limited because of the difficulty in building and maneuvering a "perfect" catcher to block the spent abrasives completely, particularly on workpieces with complex 3D features. Because the simplest and most effective means to dissipate the residual energy of spent abrasives is to let the spent abrasives shoot down into a column of still water, most AWJ systems are built on top of a water tank that also serves to support the traversing mechanism. Such AWJ systems that are operating within the limitations of safety are mainly designed for 2D machining (Olsen, 2012).

Novel approaches have been developed to facilitate AWJ 3D machining while ensuring operational safety by either manipulating the workpiece or incorporating accessories onto the 2D AWJ platform (Olsen, 2012). Several machining processes have adopted these approaches to broaden the utility of a 2D AWJ platform for 3D machining (Liu and Olsen, 2013). These processes may be divided into two main categories: those that do require accessories and those that do not. 3D parts may be machined with these processes by manipulating workpiece either during or after the machining process, and by adding accessories to enable 3D machining. Novel multi-axis accessories, for example, the Tilt-A-Jet (TAJ), Rotary Axis, and A-Jet were developed for edge taper compensation, machining axisymmetric features, and machining bevels and countersinks, respectively. [8, 9, 10] In addition, a Motorized Z-Axis was made available to follow the contour of non-flat workpieces.[11] With the combination of these accessories, complex 3D machining can be carried out on AWJ platforms (Liu, 2019b; Liu et al.; 2018b).

i. *3D machining without accessaries*

Examples of 3D AWJ processes that do not require accessories include the assembly of 2D components into 3D parts, secondary processing, cutting parts multiple times, stretching/rearranging 2D parts, AWJ etching and milling, secondary processing, unfolding followed by folding, and layer manufacturing (Liu and Olsen, 2013).

An example of the assembly of 2D components into 3D parts is illustrated in Figure 12, which shows 3D models of a Boeing 777 and an F-22 fighter jet. Several components of the B777 (wing, nacelle, and stabilizer segments) and all of the F-22 were made from carbon fiber, stainless steel, and aluminum, respectively.

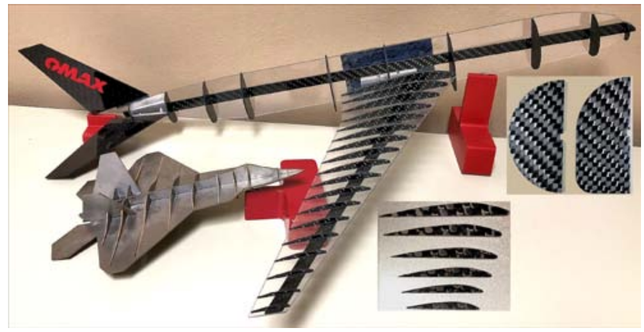


Figure 12: Two AWJ-cut 3D model aircraft assembled from 2D components (Liu et al., 2018a)

The surgical clamp shown in Figure 5 was machined in three separate steps with the part rotated 90 degrees each step. First, the overall shape was cut (A), then it was trimmed to the specific shape (B) prior to machining the grooves (C). Another example of parts that required multiple cutting steps is another version of a model F-22 fighter jet shown in Figure 13. The prospective, end, side, and top views of the jet and the aluminum block it was cut out of are shown in Figures 13a through d, respectively. The jet was cut in three orientations from a 2 in (5.1 mm) x 2 in (5.1 mm) x 1 in (2.5 mm) aluminum block. There is one tool path that corresponds to each orientation.

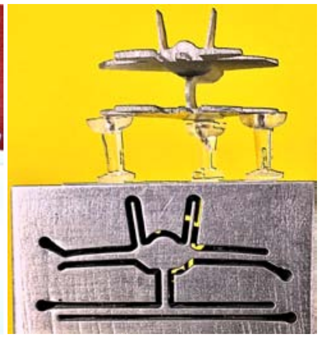
First, the block was set up to cut along the axis of the jet (Figure 13b). A home position was established at one of the corners of the block. Cutting began after the nozzle traversed to the established home position. After the first cut, the block was turned 90 degrees counterclockwise to cut along the orientation perpendicular to the jet axis (Figure 13c). After the second cut, the block was turned another 90 degrees to cut on the top of the jet (Figure 13d). After completing the cutting in all orientations, the fighter jet could then be retrieved from the block (Figure 13a). For step-by-step instructions and a demonstration of cutting the fighter jet, refer to the reference video given in the footnote.[12]

ii. *3D machining with accessories*

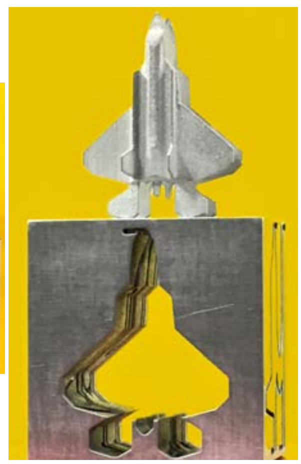
Accessories that enable 3D machining with AWJ include the Rotary Axis and A-Jet. The Rotary Axis is a water-resistant submersible rotary axis head that allows AWJ to cut axisymmetric features in tubes, pipes, and bar stock. Constant rotational control allows for continuous cutting around a shape. The A-Jet is a software-controlled multi-axis cutting head with a cutting range from 0° to 60° for creating beveled edges, angled sides and countersinks, as well as performing taper compensation. By combining the operation of the Rotary Axis and the A-Jet, the IntelliMAX Software Suite is capable of controlling both accessories to achieve 6-axis complex machining of 3D parts with multi-faceted shapes and geometries. Machining operations include

[8] https://www.omax.com/accessories/tilt-a-jet
[9] https://www.omax.com/accessories/rotary-axis
[10] https://www.omax.com/accessories/a-jet
[11] https://www.omax.com/accessories/motorized-z-axis
[12] https://www.youtube.com/watch?v=GCH2BSfLJ70

facing, drilling, turning, milling, countersinking, and beveling on most materials.

a. Perspective view b. End view

c. Side view d. Top view

Figure 13: Model F-22 jet cut in three orientations

Figure 14 shows a chess set made from multiple materials. The chess pieces are aluminum with a copper base for stability and weight. The main checkerboard is aluminum and carbon fiber trim with dark granite and white onyx. Machining was conducted by using the Rotary Axis. The most complicated piece was the knight, which was first modeled in Fusion 360 and then silhouette DXF images were projected as silhouettes at predetermined angles around the whole model. A Rotary and XY movement program was created using these angles and DXF files. Machining was performed at predetermined angles using rotary command and then cut along the associated DXF shadows at those angles. Multiple machining modes, including but not limited to facing, turning, drilling, and etching, were performed in a single operation without removing the part from the Rotary Axis.

Figure 14: AWJ-machined chess set and board (Liu, 2017a)

For modern aircraft engines operating at a very high temperatures, inclined and shaped air-breathing holes must be drilled to achieve efficient and maximum cooling. AWJ was applied successfully to drill such holes on refractory metals with and a without thermal barrier coatings. Figure 15 illustrates these holes drilled with AWJ. By mounting the workpiece on the Rotary Axis, the inclined angles of the holes can be drilled. The geometries of the holes were drilled by controlling the tilting of the A-Jet. Within certain limitations, the inclined angle and shape can vary simultaneously along the hole axis. In the test samples shown in Figure 15, the inclined angles of the holes are fixed. The AWJ nozzle consisted of a 0.18mm I.D. diamond orifice and a 0.38mm I.D. mixing tube. A 220 mesh garnet with a flow rate of 45 gm/min was used. Seven hole geometries were drilled into these samples to demonstrate the flexibility of the AWJ hole drilling process.

Note that the hole geometries of each column in Figures 15a and 15b are shown in Figure 15c. The actual shapes of the holes were modified as a result of the inclined angle. In Figure 15d, the geometries of the holes drilled on the thermal-barrier-coated (TBC) metal are shown to be different from those drilled in the other two workpieces. Most importantly, there was no delamination between the coatings and substrates and no HAZ on the hole edges in the substrates. The current practice requires a two-step process to drill inclined and shaped holes on TBC metal. First, the nonconductive TBC is removed with a laser. Then, the hole in the substrate is drilled with an EDM process.

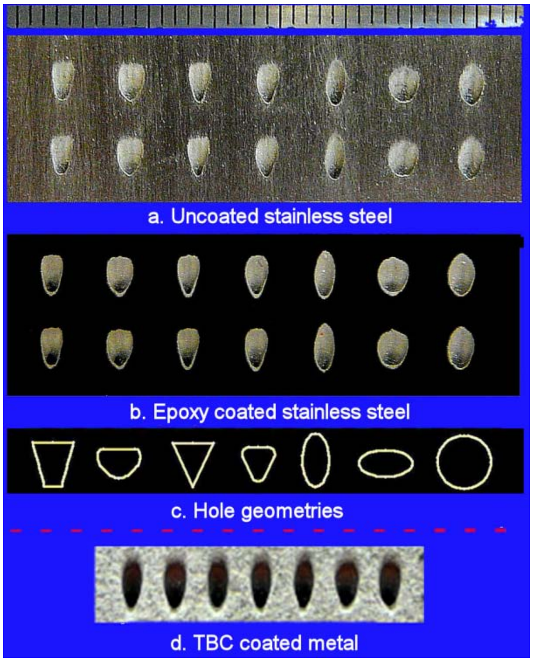


Figure 15: AWJ-drilled inclined and shaped holes on uncoated/coated metals (Liu, 2017a)

By combining the operations of the Rotary Axis and A-Jet, 3D parts with complex geometries can be machined. Figure 16 shows several such AWJ-cut steel pipe joints and steel pipe "fish mouth" weld joints that are weld ready. In other cases, the combination of the Rotary Axis and TAJ may be used to compensate for edge taper when machining axisymmetric features.

a. Steel pipe joints

b. Fish-mouth weld pipe joints

Figure 16: Weld joints machined with pairing of Rotary Axis and A-Jet

d) Near-net shaping and hybrid machining

There are advanced materials that are very difficult to cut with most machine tools, such as Inconel, titanium, and certain hardened steels. These materials tend to wear out mechanical tools quickly, which leads to very high retooling and tool replacement costs. On the other hand, materials that are prone to heat damage, such as fiber-reinforced composites, must be cut very slowly with thermally based tools such as solid-state lasers and mechanical tools.

The material-independent, cold-cutting AWJ, with its superior cutting power, is most suitable for machining these advanced materials. For most applications, its cut time is typically much faster than that of most thermally based tools. The AWJ-cut parts do not require secondary process such as the time-consuming and labor-intensive grinding to remove HAZ induced by oxy fuel and plasma cutting. For extremely precise machining operations that exceed the capability of AWJ, it can be used as a first-choice near-net shaping tool to remove the bulk of materials. The net-shaped parts can then be finished by light trimming with precision CNC tools. This hybrid process not only minimizes the retooling or tool replacement costs but also shortens turnaround times. Furthermore, trimming also serves to remove the AWJ-induced striation pattern on the cut edges and residual abrasives embedded in the parts. Such a removal process is required for fatigue-critical applications (Liu et al., 2009a).

e) Abrasive Slurry Jet

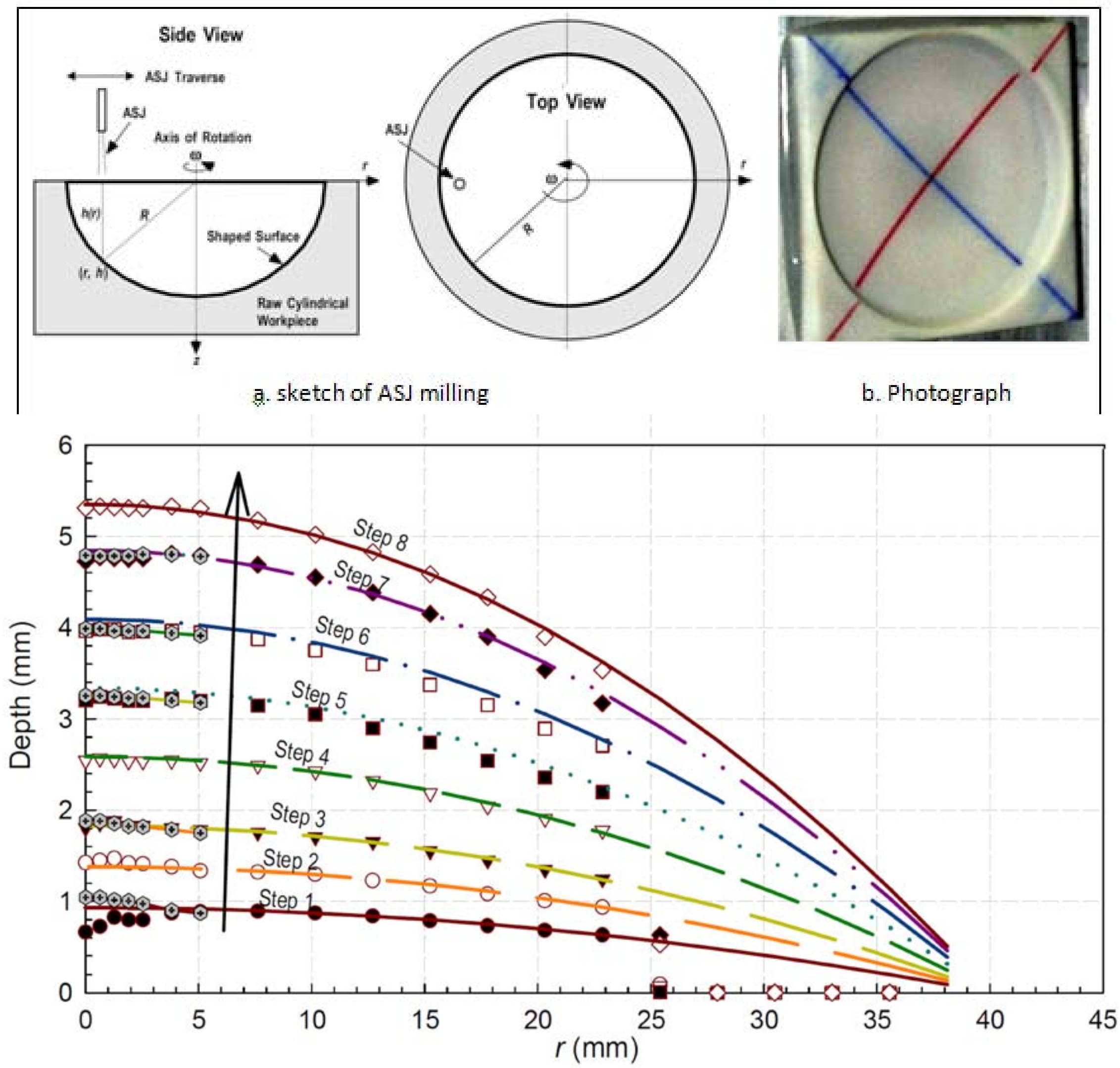
With funding from the National Center for Manufacturing Sciences and the National Science Foundation, a prototype of an abrasive slurry jet (ASJ) was developed by directly pumping a premixed abrasive slurry (Hashish, 1989). The ASJ system was developed for pressures up to 345 MPa and abrasive concentrations of up to 50% by weight. In contrast, the optimum abrasive concentration for the AWJ was about 12% by weight. The abrasive speed in the ASJ when directly pumping the slurry through the orifice reached better than 90% of that of the speed of the waterjet. Conversely, the abrasive speed in an AWJ through the entrainment process was only about 54% to 67% of the speed of the waterjet depending on the abrasive mass flow rate (Liu et al., 1998). The combination of the higher abrasive loading and speed in the ASJ resulted in up to five times the cutting power of AWJ with the same hydraulic power. Furthermore, the abrasives in ASJ can be considerably finer than those used in AWJ, greatly increasing the precision and surface finish of ASJ-milled parts.

The ASJ prototypes operated in a batch mode with two cartridges of abrasive slurry. After the first cartridge was empty, the second cartridge was loaded while the first cartridge was filled with fresh slurry. The prototypes were equipped with a two-degree-of-freedom robotic manipulator, including a linear traverse to move the ASJ nozzle and a rotating arm to maneuver the workpiece. The rotational axis was a precision air spindle driven by a 5.6hp brushless D.C. servo motor capable of speeds up to 10,000 rpm. For the near-net shaping tests, the ASJ pressure was set between 52 and 69 MPa to slow down the milling process for in-depth study.

Milling convex surfaces can be achieved by either ASJ/AWJ turning or milling. For concave surfaces with flat or three-dimensional profiles, only ASJ or AWJ milling can be applied. In principle, the depth of material removal, $h(r)$ where r is the radial distance, is inversely proportional to the vector sum of the traversing speed of the ASJ nozzle and the rotational speed of the workpiece, ω, at the point of impact. Several milling algorithms based on this principle and the motions of the manipulator and the workpiece were designed and tested to shape axisymmetric surfaces on float glass, aluminum nitride (AlN), and other materials. The author developed a milling algorithm applying the ASJ for near-net shaping of optical lenses on float glass and aluminum nitride (AlN). For each algorithm, a set of ASJ parameters was selected to achieve the required accuracy in the material removal rate according to the operational range of the manipulator. Tests were then conducted to calibrate and verify the algorithms. The algorithm with superior performance was selected for implementation and optimization. The manipulator was programmed to control the rotational speed of the workpiece and the traversing speeds of the ASJ.

A sketch of the algorithm used to mill the concave surface on the AlN workpiece is shown in Figure 17a. This was an example of a maskless milling process as there was no mask where the milling took place. However, a steel mask with a hole of 30 mm in diameter was used primarily to protect the material outside the milled area. In the vicinity $r = 0$, which coincides with the rotational center of the spindle, there is an anomaly of overcutting. The overcutting is the consequence of the vanishing of the rotational speed near the center of rotation. The nozzle was intentionally sped up near $r = 0$ to mitigate the overcutting. As a result, there was a small bump near $r = 0$. The bump was removed by mechanical grinding as described below. Milling was carried out by a multistep process, and optimization was conducted by aniterative process to match the measured and target surface profiles. Because of the hardness of the AlN, a mixture of garnet and aluminum oxide particles with size 320 mesh were used as the abrasive. Corrections of the test parameters governing the depth of material removal were made iteratively to minimize the deviations between the measured and target surface profiles after each step. For a detailed description of the setup and milling process, refer to the original paper (Liu, 1998).

Figures 17b and 17c show the ASJ-milled AlN part with a concave surface and the corresponding surface profiles. In Figure 17c, the target and measured surface profiles for each of the eight steps are represented by colored-coded curves and symbols, respectively. The material removal rate that was accelerated by adding aluminum oxide into the garnet was measured to be approximately 500μm per step. After each milling step, the surface profile was measured and compared with the target profile. Mechanical grinding was used to flatten the bump near $r = 0$ when the discrepancy between the two was large enough to require correction. The hexagon symbol represents the corrected surface profiles.



c. Profiles of progressive milling in steps

Figure 17: ASJ milling of concave surfaces (Liu, 1998)

The surface roughness of the AlN part was measured with a COBRA Scanner. Figure 18a shows a surface profile measured from r = -10 to 10 mm, the best-fit 2nd degree polynomial. The roughness profile of the AlN lens after trend removal is shown in Figure 18b. The surface roughness (R_a) estimated from the profile was 3.4 µm. This was only two to three times that of a mechanically milled surface with R_a ranges from 1 to 1.5 µm. Following the ASJ milling process, the workpiece surface may then be precision ground to optical quality. For comparison, Figure 18c shows the roughness profile on the bottom of the AWJ-milled stainless steel blind channel (Figure 8d). The ASJ-milled surface was considerably smoother than that of the AWJ-milled counterpart as can be observed visually from the two photographs in Figures 8d and 17b. This is resulted from the differences in the pressure, the abrasive size, the vector sum of speeds of the nozzle and rotary platform, and the number of passes of the two processes.

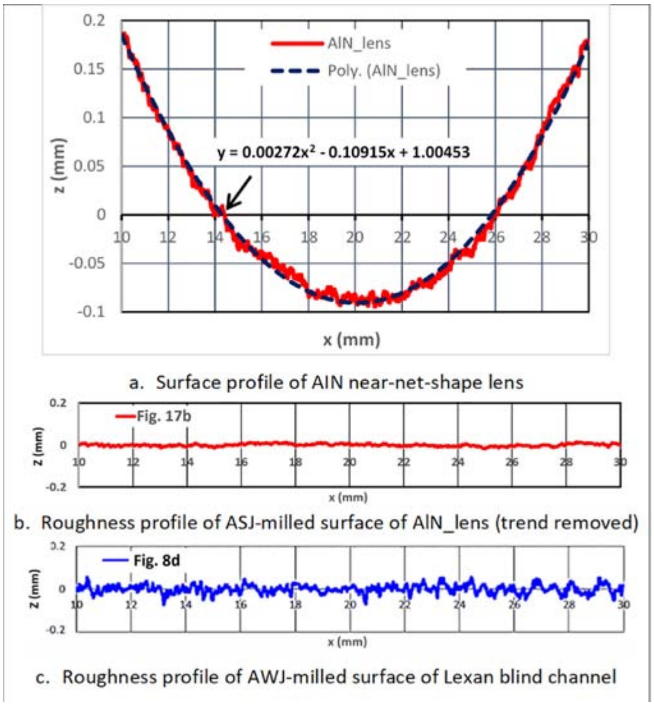


Figure 18: Measured profiles of ASJ- and AWJ-milled surfaces

f) Special Applications

One recent trend is to apply AWJ for manufacturing jewelry, musical instruments and artwork due to the technology's cost effectiveness, the ability to machine delicate and difficult materials, and multimode machining capability. Representative examples of such applications are given herein.

Niobium is a very interesting metal. It is naturally hypoallergenic and highly malleable, lightweight, highly resistant to corrosion, and hard.[13] When it is heated and anodized, it can result in a vast array of iridescent colors. It is often used in a number of medical devices including prosthetics and implants, such as pacemakers. It has been a popular jewelry making materials because of the above properties, particularly the hypoallergenic nature that a safe choice for anyone with metal allergies. Figure 19 shows two sets of earrings and one bracelet made from AWJ-cut niobium metal (Liu, 2017a). The 2/2.5D patterns on the large earrings were formed by laminating two layers of niobium metal with different patterns. The bracelet was first cut out of flat stock with AWJ and then mechanically shaped to the designed form. The spectrum of brilliant color was achieved by anodizing the niobium at different voltages. A stainless steel tube with an O.D. of 12.7 mm served to support the bracelet.

Figure 19: AWJ-cut Niobium earrings and bracelet (Liu et al., 2018; Curtesy of Holly Yashi)

The strength and durability of carbon fiber has been taken advantage of for fabricating musical instruments that are traditionally made from wood. Carbon fiber holds up a lot better than wood against all sorts of environmental conditions such as changes in temperature and humidity and the beating musical instruments take on the road. According to mezzo-forte, the sound of carbon fiber violin and cellos can be designed to produce a rich, warm, and brilliant sound that rivals even the most expensive Stradivarius. Many of the carbon fiber stringed instruments are often handmade.[14] Semi automating the fabrication process with AWJ can substantially reduce the manufacturing costs of instruments like these. Figure 20 shows an assembled AWJ-machined ukulele made of carbon fiber sheets, wood, steel strings, and stainless steel (Liu, 2017a). For violins or violas, the AWJ-machined front faces can be formed precisely to their curved shape with a post-thermal-pressing process (Liu et al., 2018b).

Figure 20: AWJ-cut carbon fiber Ukulele (Liu, 2017a)

Known as a strong and brittle material, glass has a variety of applications across virtually all industries, including the creative sector. When illuminated by various light sources, the transparent/translucent properties of glass, together with a spectrum of rich colors, enable the creation of brilliant displays. And for artistic purposes, AWJ technology is ideal for generating glass works of art. Capable of working at a

[13] https://www.thesprucecrafts.com/what-is-niobium-2051218

[14] https://www.rockwestcomposites.com/blog/carbon-fiber-musical-instruments-are-they-really-just-as-good/

variety of scales, the AWJ process remains the same with slight adjustments made depending on the delicacy, intricacy and complexity of the design (Cutler, 2012).

Figure 21 shows two examples of art created by assembling multiple layers of AWJ-machined glass pieces. The design process for this type of art can begin in a variety of different ways, such as importing a vector file from any software capable of saving a drawing as a vector file (e.g., Rhino, AutoCAD, Illustrator and Solid Works). As a 2D cutting process, only a single outline is required. The initial programming was performed using various software packages and loaded into the machine's software prior to cutting. The files were made and saved in a vector format such as a DWG or DXF file. Performing precision cutting of multiple glass layers with conventional tools would be much more challenging, as thin glass pieces are prone to breakage during cutting and handling.

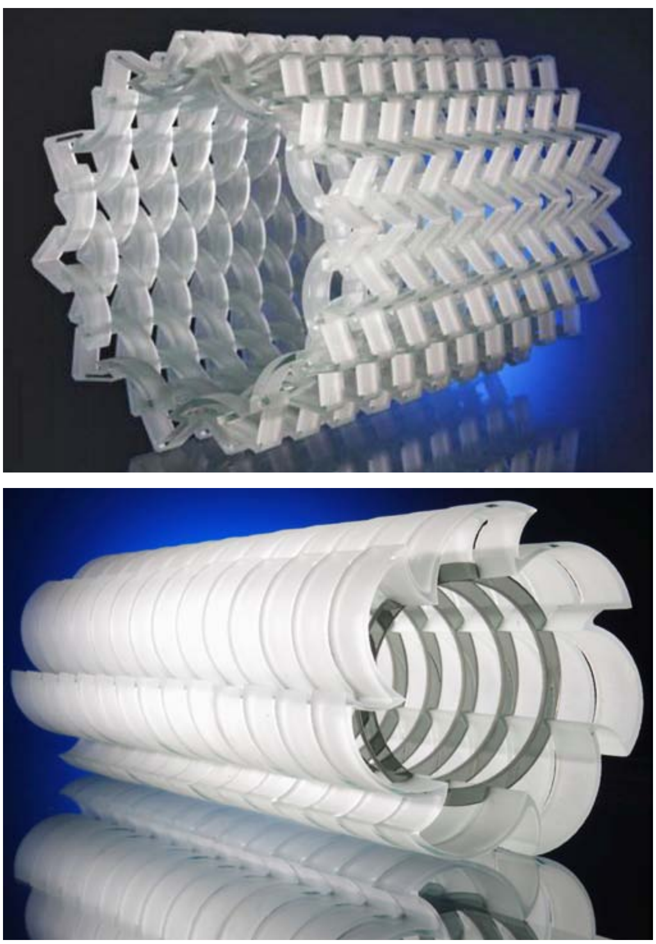


Figure 21: Samples of AWJ-cut glass art pieces

g) Aerospace Applications

As a versatile tool with the "7M" advantage together with its superior cutting power, cost effectiveness, and the absence of HAZ, AWJ has been a popular tool for machining various aerospace metals and composites.

i. *Aerospace metals*

AWJ cutting inherently induces striation patterns that may initiate fatigue and premature micro cracking under repeated high cyclical loading. Consequently, AWJ-cut metal parts intended for use in aerospace structural applications must go through subsequent conventional machining processes to meet the Class 1 requirements for fatigue-critical applications. Even for the fatigue non-critical parts (Classes 2 through 4), the default is Class 1 due to the aerospace industry's inherent conservatism.

Requiring secondary processes for AWJ-machined parts negatively impacts the cost effectiveness of waterjet technology. Some cost savings may be realized if it can be shown that AWJ net-cut parts have comparable durability properties as conventionally machined parts. Recognizing the tremendous cost advantages made possible by AWJ machining and the significant advancements in waterjet technology for precision machining, OMAX launched an R&D plan in collaboration with Boeing to investigate the fatigue characteristics of AWJ-machined aluminum and titanium. "Dog-bone" specimens were prepared for independent fatigue tests at Boeing and Pacific Northwest National Laboratory (PNNL) (Liu et al., 2009a, 2009b, 2010).

As a part of the test matrix, OMAX prepared three sets of dog-bone specimens made of aluminum alloys (2024-T3 and 7075-T6) and annealed titanium alloys (6Al-4V). Boeing provided all the test materials. The geometry of the dog-bone specimen together with a typical AWJ-cut sample is illustrated in Figure 22. Conventional milling and AWJ were used to machine the dog-bone specimens. Five samples of each material were cut and four were tested to improve the statistical significance of the test results. Milling with R_a better than 1.6μm was conducted at Boeing. The milled specimens served as the reference for the AWJ-machined specimens. The AWJ machining was conducted using two nozzles with ratios of orifice and mixing diameters in mm (orifice/mixing tube) 0.36/0.76 (MiniJet) and 0.25/0.53 (MAXJET5), respectively. The garnet abrasive sizes ranged from 80 mesh to 320 mesh. For each nozzle, the specimens were cut for five quality levels: Q1, Q2, Q3, Q4, and Q5. A secondary dry-grit blasting process using 180 mesh aluminum oxide as the media was applied to some of the AWJ-cut specimens to investigate whether the fatigue performance can be improved by smoothing and/or removing the striation pattern. Table 1 presents the naming convention and a description of the specimens.

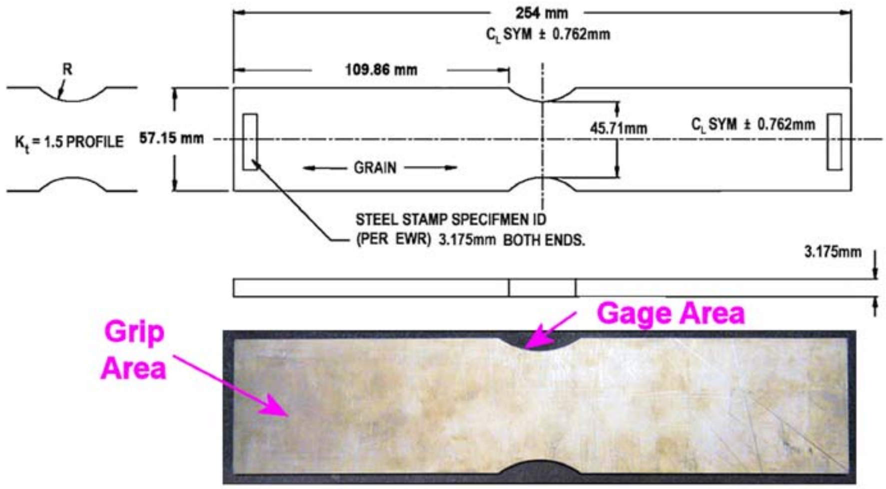


Figure 22: Geometry of dog-bone specimen and AWJ-cut sample (Liu et al., 2012)

Table 1: Naming convention and description of dog-bone specimens

Specimen ID	# of Sample	Alloy	Gage mm	Conditions for Specimen Preparation	
2OMS125-1/-5§	5	2024-T3	3.175	Machined (R_a 63 or better)	Baseline
2OAS125-1/-5[15]	5	2024-T3	3.175	AWJ-cut, Quality Level 3 + Sand to R_a 125	80 mesh, MAXJET5
2OAQ380-1/-5	5	2024-T3	3.175	AWJ-cut, Quality Level 3	80 mesh, MAXJET5
2OAQ580-1/-5	5	2024-T3	3.175	AWJ-cut, Quality Level 5	80 mesh, MAXJET5
2OAQ1220-1/-5	5	2024-T3	3.175	AWJ-cut, Quality Level 1	80 mesh MAXJET5
2OAQ3220-1/-5	5	2024-T3	3.175	AWJ-cut, Quality Level 3	220 mesh MiniJet
2OAQ5220-1/-5	5	2024-T3	3.175	AWJ-cut, Quality Level 5	220 mesh MiniJet
2OAQ5220T-1/-5	5	2024-T3	3.175	AWJ-cut to Quality Level 5/w Tape	220 mesh MiniJet
2OAQ5220G-1/-5[16]	5	2024-T3	3.175	AWJ-cut to Quality Level 5	220 mesh MiniJet

§The first two characters designate the material type [2O – 2024 (T3), 7O – 7075(T6), Ti–Titanium (6Al-4V)]; the third character designates milling (M) or AWJ-cut (A).

Selected dog-bone specimens were fatigue tested in the Fatigue and Fracture Laboratory at Pacific Northwest National Laboratory (PNNL). For this test, the specimen was gripped at its two ends and cyclic loading was applied until it failed. The number of cycles at which the specimen fails at the gage area is defined as the fatigue life of that specimen, N_{max}. However, the number of cycles is lower than the N_{max} if the failure takes place outside of the gage area. For this investigation, the fatigue tests were stopped when the test cycle reached the run-out conditions without failure, which were defined as 1 and 2 million cycles for the aluminum and titanium specimens, respectively. In those cases, N_{max} was greater than the measured life cycle. The test system used in this study was an MTS 50 Kip servo hydraulic test frame (MTS model 312.31) that was controlled with an Instron 8800 digital controller. The load cell was an MTS 25 metric ton model 661.23A.01. The wedge action grip was an MTS model 647 controlled with an MTS model 585.60 grip supply.

Specific test parameters appropriate for the aluminum and titanium specimens were chosen according to Boeing's recommendations (Liu et al., 2009a). Fatigue testing was performed in accordance with ASTM standards E466-96 and E468-90. Specimens were prepared per section 5.2.2.2 of E466, providing a continuous radius between ends of a rectangular cross section. These parameters were in specified guidelines in applicable ASTM standards and required a maximum axial stress limit of 207 MPa for aluminum and 483 MPa for titanium at the reduced gage section.

The stress ratios were specified for all tests in the form of a ratio of minimum to maximum stress that cycled between full tension and slight compression. All fatigue testing was performed at ambient room temperature using constant amplitude loading. Standard lab practices were used for testing all fatigue specimens. Alignment of each test specimen was set and checked using mechanical stops against the

[15] Sanding was conducted at Boeing

[16] Dry-grit blasting was conducted at Boeing

hydraulic grips. Grip pressure was set to19.3 MPa (2.8 ksi). Limits were set on the digital controller to protect the sample during loading and to detect fractures in the sample. The constant amplitude sine wave was observed on an oscilloscope during testing as a secondary verification of the load values that were set and displayed on the digital controller. The load cell in the test frame was verified prior to testing and post testing against a calibrated load cell.

Figure 23 shows one of the four specimens tested for the 2024-T3 aluminum dog-bone set. The specimen IDs are (a) 2OMS125-1(baseline), (b) 2OAQ1220-1, (c) 2OAQ3220-3, (d) 2OAQ5220-5, and (e) 2OAQ5220G-1 (grit blasted). The number of cycles at failure, N_{max}, was marked and has been highlighted in red rectangles on each sample. It is evident that N_{max} increases with the quality level of the AWJ-cut samples, although this varied within a range for each of the four samples tested. The N_{max} for the milled sample (a) and the AWJ-cut sample at Q5 (d) was considered to the same within the experimental error. Q5 represents the highest quality AWJ surface. Notably, the grit-blasted AWJ-cut sample failed at 1,047,468 cycles at the grip but not the gage. This meant that the grit blasting increased the tensile strength of the gage area. In other words, N_{max} would have exceeded that number provided the grip had not failed.

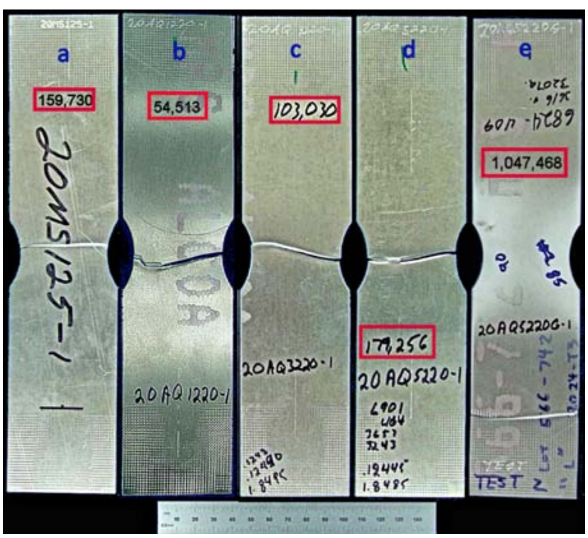


Figure 23: Fatigue test results of 2024-T3 specimens (Liu et al., 2009a)

Figure 24 shows the test results of the titanium specimens. The test procedure was the same except that the maximum axial stress limit was set from 207 MPa to 483 MPa to take the greater tensile strength of the material into consideration. The specimen IDs were the same as those in Figure 23 with the first two characters changed from "2O" to "Ti". Again, higher-quality AWJ-cut samples were observed to have higher N_{max} results. However, N_{max} for the milled samples was considerably higher than that of the AWJ-cut counterpart at Q5. Again, the grip of the grit-blasted AWJ-cut specimen failed at 2 million cycles. Therefore, the expected N_{max} for the titanium sample would exceed 2 million cycles.

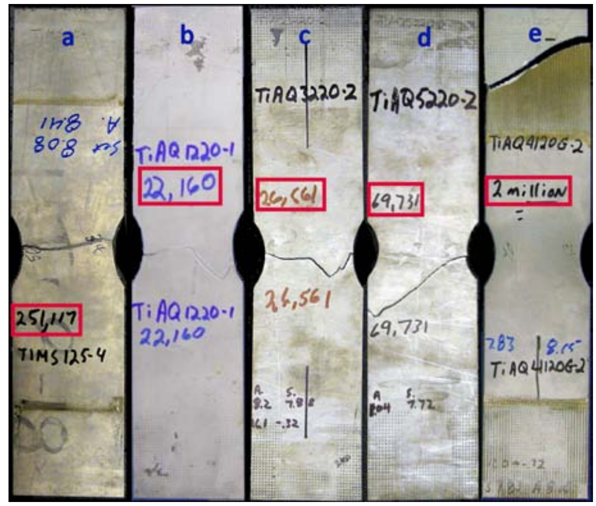


Figure 24: Fatigue test results of titanium specimens (Liu, et al., 2012)

The measured fatigue life cycle of the aluminum and titanium specimens were plotted against the R_a of the cut edges to compare the performance of the milled and AWJ-cut dog bone samples in Figures 25 and 26, respectively. It should be pointed out that the fatigue life cycle in the figures is not the same as the N_{max} for those samples that did not fail at the gage area. For those cases, the fatigue life cycle would be lower than the N_{max}, and significantly lower in certain cases. In these figures, the error bars represent the spread of the measured fatigue life cycle for the four samples tested. For those samples with life cycles that reached the run-out conditions (1 and 2 million for the aluminum and titanium specimens, respectively), a question mark indicates that N_{max} is greater than the run-out cycles.

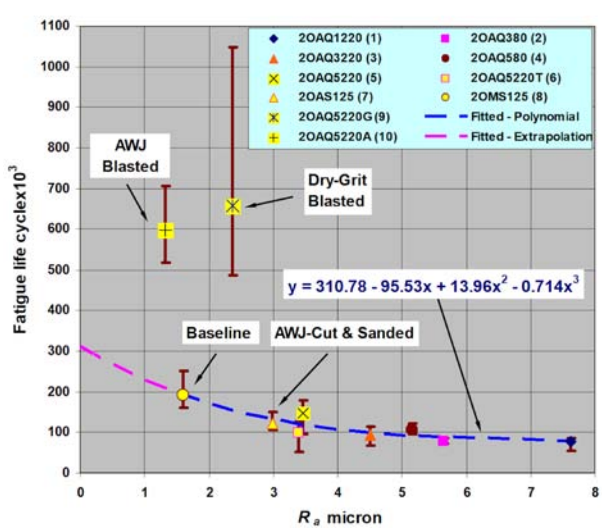


Figure 25: Fatigue life versus R_a of 2014-T3 specimens (Liu et al., 2009b)

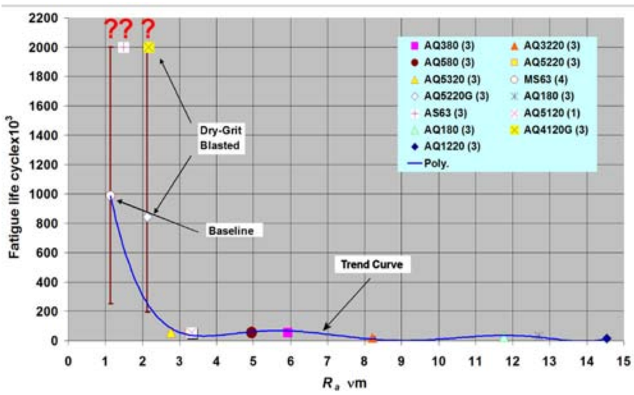


Figure 26: Fatigue life versus R_a of titanium specimens (Liu et al., 2012)

In both figures, the fatigue life cycle decreased with the increase in the R_a, which is inversely proportionally to the edge quality levels of the AWJ-cut sample. The fatigue life cycle of the milled (base-line) specimen was higher than that of the AWJ-cut counterpart without grit blasting (Figure 23). With grit blasting, the fatigue life cycle of the AWJ-cut sample was at least 2.5 times higher than that of the milled counterpart for aluminum and in the same range for titanium (Figure 24). However, more grit-blasted AWJ-cut titanium samples reached the specified run-out conditions than the milled samples.

The presence of AWJ-induced striation patterns on the cut edge can initiate microcracking under high cyclical loading. The microcracks grow progressively under loading and lead to premature fatigue failure. Removing this striation pattern was one of the reasons that AWJ-cut metal parts for fatigue-critical applications had to undergo secondary machining with conventional tools. One of the primary reasons that grit blasting improved the fatigue performance was that the process smoothed the AWJ-cut edge and reduced the R_a. The extraordinary boost in the fatigue performance could also be attributed to the induction of residual compressive stresses through dry grit blasting. The ability to induce residual compressive stresses has been observed in related processes of "waterjet peening", "abrasive-waterjet peening", and "shot peening" (Arola et al., 2006; Dai and Shaw, 2007; Meged, 2006; Ramulu et al., 2000; 2002; and Wang et al., 1998a, 1998b). Liu et al. (2009b) also conducted a finite element analysis to confirm that the fatigue failure would shift from the gage to grip areas provided the compressive stresses induced by grit and AWJ blasting are sufficiently large.

Selected 2024-T3 specimens were sent to the x-ray diffraction facility at the NIST Center for Neutron Research to measure the residual compressive stresses at the gage (Liu et al., 2009b). Figure 27 illustrates the test results. The abscissa and ordinate are the surface roughness and residual compressive stresses, respectively. The error bars correspond to one standard deviation. The results show that the residual compressive stresses induced by conventional machining are the minimum for all specimens. The average residual compressive stresses induced by dry-grit and AWJ blasting processes are nearly 4 times those induced by conventional machining. These results correlate well with the increase in the fatigue life of the specimens machined with the combined process of AWJ and grit blasting, as illustrated in Figures 23 and 24.It is interesting to point out that, although the compressive stresses of AWJ as-cut specimens were higher, their fatigue lives were shorter than that of the baseline case, as shown in Figures 25 and 26. It is evident that R_a generally dominates residual compressive stresses. Induced compressive stresses become effective in enhancing fatigue performance only when their magnitudes are comparable to or larger than that of the loading of fatigue tests, particularly for specimens with small R_a such as the AWJ- and grit-blasted samples.

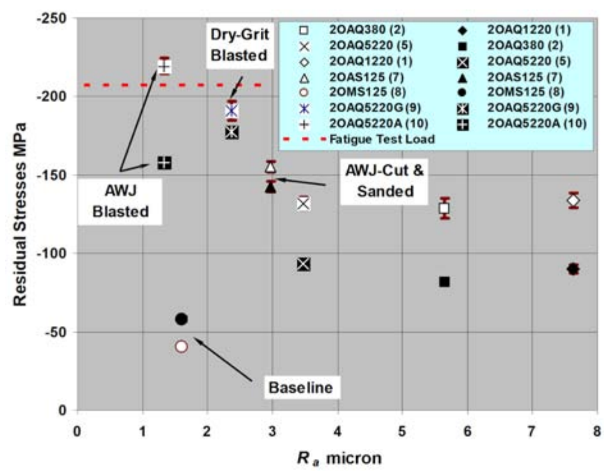
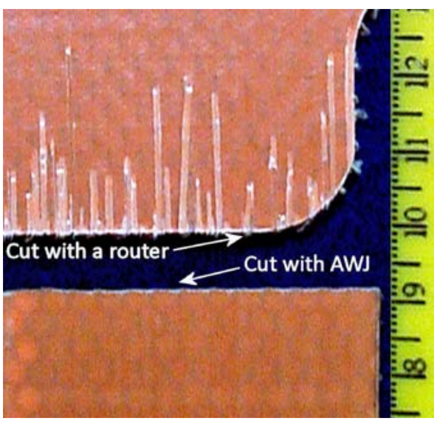


Figure 27: Compressive stresses versus R_a (Liu et al., 2009b)

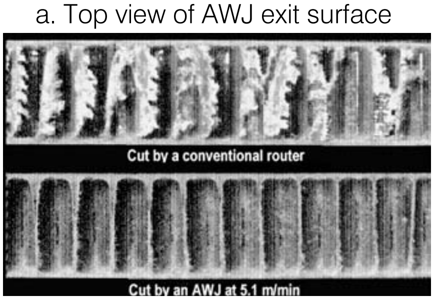
ii. *Aerospace composites*

Aircraft composites have experienced near-exponential growth in use in recent years (Slayton and Spinardi, 2015). Commercial aircraft manufactures are facing the challenges of producing more lightweight components that help airline operators meet environmental targets while coping with some severe production ramp-up rates. Because AWJ piecing damage can be mitigated by using Turbo Piercer and Mini Piercer (Section IIIe, Part 1 of the paper) on composites and laminates, and drill-head accessories can provide even more reliable drilling for delicate materials, waterjet is now considered the most efficient, consistent and affordable process for cutting composite materials. It provides a superior cut edge surface finish while imparting virtually no adverse impacts or the introduction of fiber pull out, delamination, localized part heating or mechanical stress. Furthermore, AWJ can preserve the parent material's structural integrity to a degree that is simply unmatchable by mechanical routing. Abrasive waterjetting has been applied to machine a variety of aircraft composite aero structures, including stringers (trimming), airframes, honeycomb floorboards, wing skins, fuselages, flaperons, rudders, and more (Hashish, 2013).

One example of the successful application of AWJ involved machining honeycomb composites at a low cost for use in the High-Speed Civil Transport (HSCT) aircraft under development at NASA in the 1990s (Hibbard et al., 2000; Liu, 2006). Figure 28 shows two pieces of Boeing honeycomb floorboards (with Nomex cores and fiberglass face sheets) cut with a conventional router and the AWJ (single pass at 5.1 m/min). Figure 28a reveals that there were numerous tears on the jet exit surface of the face sheet cut with the router while no tearing occurred at all on the face sheet cut with the AWJ. Severe tearing of the core materials was also evident on the edge of the floorboard cut with the router, whereas the edge of the floor board cut with the AWJ was clean with no tearing, as seen in Figure 28b.



a. Top view of AWJ exit surface



b. Side view

Figure 28: Edge quality of honeycomb cut with router and AWJ (Liu, 2013)

Extensive AWJ machining of popular aircraft composites such as carbon fiber, PEEK, G10 (fiberglass-epoxy laminate), and TBC (on turbine engines) has been conducted for various applications. Test results have also served to determine whether the cut quality and accuracy of these materials met the aircraft manufacturers' requirements (e.g., BAC 5578). In Figures 2, 10, and 18, AWJ-cut carbon fiber was used to fabricate the knee brace, model B777, and ukulele to take advantage of its superior material strength, high stiffness, and light weight. PEEK was another relatively new material that was widely used in engineering, biomedical (Figure 3), and electronic applications for its inertness and tolerance for high temperatures.

h) Field Deployment

The versatility of AWJ has also been taken advantage of in the context of field deployment. One of OMAX's Mobile JetMachining® Centers, a portable system designed for field deployment, was deployed for rapid response repair at Camp Leatherneck in Helmand Province, Afghanistan, as shown in Figure 29. [17] It provided considerable logistical flexibility, operating 24/7 to fabricate parts in-theater, often fewer than 10 miles from where they would be used. This style of in-field capability is expected to expand beyond the military, such as insitu deployment of the mobile AWJ system for reconstruction efforts following natural disasters in remote locations without access to machining facilities.

Figure 29: Repair and fabrication unit members with OMAX Mobile JetMachining Center at Camp Leatherneck, Afghanistan[17]

IV. Summary

In Part 2 of this paper, the review of the accomplishments in abrasive-waterjet technology development continued to describe a wide range of applications that further demonstrate the versatility of waterjet technology. Seven sections included applications from biomedical, milling and etching, 3D machining, near-net shaping, jewelry and musical instruments, aerospace, and field deployment. Based on both parts of the paper, the breadth of AWJ applications ranging from macro to micro scales is clearly evident. Several of these applications are unique to AWJ, as they would be considerably challenging to accomplish through the use of conventional machining.

[17] https://www.omax.com/sites/default/files/documents/600140a_-_usmc_mobile_jmc_case_study.pdf

Global Journal of Researches in Engineering (A) Volume XX Issue III Version I Year 2020

There is considerable room for AWJ to capture additional market share in the manufacturing sector as a whole. One promising case is applying AWJ as a near-net shaping tool for extremely precise machining of difficult–to-cut materials, as described in Section III.d. AWJ is capable of removing the bulk of the materials quickly, which means that near-net-shaped parts can then be finished by light trimming with proper precision tools. As such, the hybrid machining process greatly extends the operating life of precision tools and removes any concerns about embedded abrasives in the workpiece. Mitigating abrasive embedment is especially essential for fatigue-critical aerospace structures and the sterilization of orthopedics and prosthetics.

In addition to the "7M" advantage, AWJ is also a green machining tool as it uses no toxic cutting fluids and the water and garnet abrasives are recyclable (Liu, 2018). AWJ has the potential to replace conventional tools that use metalworking fluids (MWFs) during machining and grinding operations for superior cooling, reduced friction, higher workpiece surface integrity, minimized tool wear, and increased productivity increases. Health problems have been reported among workers exposed to MWFs, including incidences of respiratory, digestive and skin cancers (Malloy et al., 2007). For example, one common component in MWFs, chlorinated paraffin (CP), has prompted serious concerns among environmentalists, and the Canadian Environmental Protection Agency (CEPA) has declared all CPs toxic while the US EPA has restricted their usage in manufacturing.[18] Other forms of machining, such as chemical and plasma etching and electrochemical machining, either use toxic working fluids and/or produce hazardous waste.[19] In an attempt to reduce the use of equipment that may be harmful to the environment, AWJ has been increasingly adopted by the manufacturing community. During the 2018 ASETS Defense Workshop, for instance, a recommendation was made to adopt AWJ in Department of Defense R&D, manufacturing, and maintenance facilities for compliance (Campo, et al., 2018).

Acknowledgment

This work was supported by an internal R&D fund from OMAX Corporation. Many sample parts presented in both parts of the paper were machined directly and/or with the assistance from Associates, ChanSuey and Ruvim Mironyuk (ex-Associate), operating OMAX's Demonstration Laboratory. The MicroMAX was developed and commercialized for meso-micro machining under the support of NSF SBIR Phase 1 and 2 Grants (No. 0944239 and 1058278). The author would like to thank his colleauges Dr. Axel Henning and Mr. Ernst Schubert for reviewing the paper.

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Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 20 Issue 3 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Effects of Biomass Properties on the Performance of a Gasifier/Genset System

By Emerson Freitas Jaguaribe, Adriano Sitônio Rumão, Fernanda de Souza Silva, Vicente de Vasconcelos Claudino Filho, Wendell Venício de Araújo Galdino & Francisco Everton Tavares de Luna

Abstract- Biomass can be considered one of the most important sources of energy in the world, because it is: renewable; neutral in terms of green-house gases emissions; capable of replacing conventional fossil fuels, among other factors. On the other hand, gasification is an efficient process of turning available the chemical energy of biomass, with a relatively simple technology. In the present work a co-current open top downdraft gasifier is used, with an 8.5 kW thermal power capacity to fuel an 18 Hp Otto cycle engine coupled to an electric generator. With this apparatus, it was possible to analyze the influence of some properties of the fuel wood particles (size, density, moisture content and so on) on the efficiency of the energy conversion process.

Keywords: biomass gasifier; gasifier/genset system; electricity generation.

GJRE-A Classification: FOR Code: 850309

EFFECTSOFBIOMASSPROPERTIESONTHEPERFORMANCEOFAGASIFIERGENSETSYSTEM

Strictly as per the compliance and regulations of:

Effects of Biomass Properties on the Performance of a Gasifier/Genset System

Emerson Freitas Jaguaribe [α], Adriano Sitônio Rumão [σ], Fernanda de Souza Silva [ρ], Vicente de Vasconcelos Claudino Filho [Ѡ], Wendell Venício de Araújo Galdino [¥] & Francisco Everton Tavares de Luna[§]

Abstract- Biomass can be considered one of the most important sources of energy in the world, because it is: renewable; neutral in terms of green-house gases emissions; capable of replacing conventional fossil fuels, among other factors. On the other hand, gasification is an efficient process of turning available the chemical energy of biomass, with a relatively simple technology. In the present work a co-current open top downdraft gasifier is used, with an 8.5 kW thermal power capacity to fuel an 18 Hp Otto cycle engine coupled to an electric generator. With this apparatus, it was possible to analyze the influence of some properties of the fuel wood particles (size, density, moisture content and so on) on the efficiency of the energy conversion process. Considering the straight correlation between the gases, CO and CO_2, their production and the particle size, it was concluded that the larger the sample, the greater the CO percentage in the poor gas composition. The higher heating value of the poor gas, a direct function of the CO level, was associated with the smaller biomass density, offering the maximum efficiency of the system in generating electric power. The maximum efficiency of the system (gasifier/genset), η_{sys}, for generating electricity was 11.9 %, given that the efficiency of the combustion internal engine was just 16.87%.

Keywords: biomass gasifier; gasifier/genset system; electricity generation.

I. Introduction

At least five facts underlie the understanding that biomass is the most important source of energy in the world, [1], [2], [3], [4]. [5] [6], and they are based on the following: 1. It is a renewable fuel, [7], [8]; 2. It is neutral as regards the emission of greenhouse gases, [1], [9], [10]; 3. It is capable of replacing conventional fossil fuels, [1] to [6]; 4. It is abundant, [2], [3] and [6]; Its resources are found almost everywhere [11-12]. There are several biomass conversions, with different characteristics and results [13]. The most efficient way to make the internal chemical energy of biomass available is through the production of gas either by biochemical (fermentation) or thermo chemical (pyrolysis) processes, the latter requiring more external energy, but with faster practical results [14].

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a) *Biomass Gasifier and Gasification Process*

As well known, depending on their characteristics (method of heating, gasification agent, pressurization, transport processes, etc.) gasifiers may be classified into different types, [13], [15]. When the distinction is based on the way biomass and the gas flow move, biomass gasifiers are conceived of as fixed bed (updraft, or downdraft), fluidized bed, entrained flow, etc. The fixed bed gasifier with a fuel hopper top (also known as moving bed) is the most common [16]. It has been preferred to the closed top gasifier, such as the Imbert gasifier (throated or closed top gasifier). The reasons are: the fuel is easily fed; quick access to the instrumentation for needed control measurements; air and biomass pass uniformly downward through the four zones (drying, pyrolysis, combustion and reduction), avoiding excessive deviation from the local high average temperature; less trouble with channeling or bridging events; the top zone may be easily and conveniently adjusted [15].

Gasification agents may be air, steam, oxygen or CO_2. The fixed bed gasifier, also considered very suitable for internal combustion engines, by reason of producing low tar content, [16], [17], is appropriate for small to medium scale thermal applications [18]. Depending on the gasification agent flow direction, a gasifier may be designated as countercurrent, co-current, cross flow, etc. Generally speaking, the co-current gasifier is used in small scale power generation and the air coming from nozzles set around the reactor zone, as well as from the top (about 60 %) moves downward in the same direction as the produced gas (the poor gas). It is observed that in co-current gasifiers air input rates regulate the fuel consumption rates [19]. On the other hand, the reactor is simple to construct and generates a poor gas with low tar in its composition [20], [21].

Particle size is one of the most recurrent independent variables appearing in almost all pyrolysis or devolatilization models through a non-dimensional number [22]. However, most pyrolysis studies do not make reference to any non-dimensional number, see e.g. [23], [24], [25], [26]. Thus, considerations of the influence of the fuel dimension on the gasifier functionality, mostly come from phenomenological results, allowing to enunciate some statements such as: 1. Fine grained, or fluffy particles may produce gas flow difficulties inside the gasifier body reactor [27], with considerable pressure drops over the reduction zone; 2. Disproportional large sizes can give rise to bridging and channeling problems [4]; 3. Biomass particle size, as well as, its moisture content are important factors affecting the combustion and heat recovery, especially if combustion is incomplete [22], [24] and [28]; 4. The flame propagation speed, i.e., the rate of progress of the apparent flame zone, is dependent on the particle size, as well as on the air supply rate, and the calorific value of the solid fuel, Shin et al. [29]; 5. A reduction in the fuel particle size leads to a significant improvement in the gasification parameters, Hernandez et al. [30].

Not only should size, but also particle density be considered when the goal is to improve gasification results. In fact, it is easy to notice that density often figures in the chemical kinetics and transport phenomena correlations, where those fundamentals, as mentioned above, are necessary to help to describe the pyrolysis models [10], [30], [31] and [32]. Huff [33] demonstrated the importance of size, shape, density, moisture, and wall furnace temperature in the burning time of single pieces in fireboxes.

In reading the technical literature, we understand that the influence of the biomass particle size on the gasification process has been extensively, theoretically or experimentally, studied. However, it should be noted that most of the studies, experimental, or theoretical (models), take into account just isolated particles, [21], [22], [28], [29], [30], [31], [32], [33].

It was only around 1920 that poor (producer) gas was used to fuel engines, Shrinivasa et al. [34]. In fact, the petroleum shortage during World War II led to widespread applications of gas generation in the transportation industries of Western Europe, La Fontaine et al. [35]. As mentioned by FAO [27], spark ignition engines can be run on poor gas (producer gas) alone, and Diesel engines can be converted into full poor gas after being submitted to some modifications, or run in a dual mode. The use of poor gas on internal engines, tar and particulate contents have since been proved too great a hurdle. This fact motivatedthe IndianInstitute of Science in Bangalore, see Dasappa et al. [36], to develop biomass gasifiers capable of cleaning and cooling the poor gas, to be used in dual fuel mode (diesel/poor gas). In fact, the majority of poor gas application in engines uses the dual mode, e.g. Shrinivasa et al. [34], Dasappa et al. [36], Sridhar et al. [37], Dasappa et al. [38], Kalina [39] and Ghosh et al. [40]. Less frequent is the utilization of IC engines fueled just on poor gas: Raman et al. [41], for example, used an engine designed to run on natural gas to operate on 100 % producer gas, and Gitano [42] modified a gasoline two-stroke genset for operating on syngas (producer gas) from a biomass gasifier.

The present work discusses the global efficiency of a system formed by a co-current, downdraft fixed bed biomass gasifier, coupled to a genset, and an Otto Cycle engine to generate electricity. The biomass gasifier fuels the genset with a hundred percent poor gas. The influence of some biomass properties, such as size, density and moisture content on this overall process is analyzed.

II. Producing the Poor Gas

a) *Dynamics of the gasifier reactor*

At least four stages are necessary for biomass gasification: drying, pyrolysis, combustion and reduction. Being dependent on heat transfer properties, the drying process, aside from the moisture and the ash content, may also depend, as already reported, on some fuel (biomass) physical parameters, such as size, heat diffusivity, heat capacity, heat transfer coefficient, and thermal conductivity. At the beginning of the process, there is evaporation inside the fuel, production of condensable fractions with loss of water, which happens at temperatures above 100ºC. On the other hand, volatiles are released at temperatures close to 140ºC. At the same time, steam escapes from the particles, causing fuel and pores shrinkage, as well as the ending of the drying process. As the temperature increases, it is easy to detect the presence of CO_2 and CO, chiefly when cellulose is heated at 170ºC, Hill [43]. Generally speaking, pyrolysis or release of volatiles have been considered as the first stage in gas production from biomass, Di Blasi [6]. The use of thermo gravimetric analysis shows that all volatiles are released up to 500ºC, the lignin at this temperature being completely thermally degraded. Tar, the product of destructive distillation, and ash in the reactor occur at temperatures higher than 800ºC, Yoshikawa [44]. It is observed that the pyrolysis product will react at high temperatures, 700 to 1500 ºC for existent gases, chiefly for external O_2, in the combustion zone, where secondary reactions generally occur. During this process conversion of residual char is detected, presenting much slower reaction than the oxidation process, Basu [45], determining the overall gasification efficiency. Finally, as particles move into the reduction zone, they become smaller due to the consumption of the char by surface reactions. It is also in this zone that the char particles act as reducing agents for the remaining gaseous compounds, De Santanu [46], forming the poor gas, basically a mixture of H_2, CO and CO_2.

b) *The Experiment*

As mentioned earlier, this work deals with a system formed by a downdraft, co-current, open-top 8.5 thermal kW biomass gasifier and a genset, see Figure 1, to produce electricity. The gasifier reactor 0.90 m long with internal and external diameters of 0.16 m, and 0.18 m, respectively, has the annular space filled with vermiculite. The genset parts are: an original gasoline VANGUARD V-Twin, 2 cylinders, 18-hp Otto cycle, adapted to run on poor gas. and a generator from Toyama (model TG2500MX), single phase, 220 V and 60 Hz.

A resistive charge simulator with eight electric resistances is capable of testing electric powers up to 2.4 kW. An electric energy analyzer from HIOKI is used to evaluate the frequencies, current, and the electric power produced by the genset.

Gases emissions (CO, HC, NO_x and CO_2) and the lambda factor are evaluated by means of an Alphatest vehicular gas analyzer.

A thermocouple, K type, is used to evaluate the exhausted gases temperature.

c) The Biomass

Four different types of waste wood material, brought from the university campus dump and cut into uneven cubic pieces, originated the four different biomass samples, characterized by their four different edges (The first, third and fourth samples were from the species *Tabebuia heptaphylla*, and the second from *Ceasalpinia echinata*). On average, the edge and the cubic volume of the samples (1 to 4) were respectively, 13 mm (2; 197 mm^3), 16 mm (4,096 mm^3), 20 mm (8,000 mm^3) and 27 mm (19,683 mm^3). For each one of the tests, the gasifier ran with just one kind of sample.

The moisture content of each one of the four samples was determined experimentally in triplicate.

For the analysis of the biomass sample results, a proximate analysis, using the ASTM E-1131 Standard Test Method for Compositional Analysis by Thermo gravimetry was also conducted in triplicate. For these tests, 30 mg of each sample with an average diameter of 100 mm, was brought to a 100 $mL.min^{-1}$ gas flow (N_2 and synthetic air), using different temperature levels.

Figure 1: Experimental apparatus

d) The low heating value of the poor gas

As mentioned by Reed et al. [17], the gas heating value of raw producer gas containing significant condensable volatiles (tars) is difficult to measure, since the measurements are made at room temperature after the tar has been condensed. Generally speaking, in the technical literature, we find different average values. For Reed et al. [17], the lower heating value, LHV, of the producer gas, situates between 5–7 $MJ.Nm^{-3}$; Barrio et al. [47] 4.85 $MJ.Nm^{-3}$; Albertazzi et al. [48], 5 $MJ.Nm^{-3}$; Kaupp et al. [49] between 4 and 6 $MJ.Nm^{-3}$. There are, however, two publications, Yoshikawa [44] and Garcia [50], that show the plot of the LHV of the poor gas given in function of the percentage of carbon monoxide by volume of poor gas. Based on this set of scattered points, Rumão [51], using a curve fitting process, determined Eq. (1), which produced a Pearson's correlation coefficient equal to 0.9379, with a standard deviation of σ_p = 0.975 $MJ.Nm^{-3}$. The correlation, see Eq. (1), gives the LHV of the poor gas in terms of the percentage of CO by volume of poor gas, as MJ.Nm^{-3}. (Typically, in the poor gas composition, for hydrogen and carbon monoxide, it is 19± 1 % H_2 and 19± 1% CO. Therefore, in Eq. (1) the effect of H_2 was replaced by the one of CO by just altering its coefficients);

$$LHV_{poor\ gas} = -\ 0.004738.(\%CO)^2 + 0.3149.(\%CO) - 0.1057\ MJ.Nm^{-3} \quad (1)$$

e) Efficiency of the system gasifier/genset

Equation (2) was used to evaluate the efficiency of the system (gasifier/genset)

$$\eta_{sys} = \frac{p_e}{\dot{M}_b.LHV_{bio}} 100\ \% \quad (2)$$

Where

p_e is the generated electric power, W;

$\dot{M}_b$ is the evaluated mass flow used to feed the gasifier, kg/s;

LHV_{bio} is the average biomass low calorific value, J/kg, which was determined experimentally in triplicate.

f) Determining the efficiency of the internal combustion engine coupled to the genset

Since the final efficiency of the system depends on the efficiency of its elements, a series of experiments was made to determine the efficiency of the internal combustion engine coupled to the genset. The engine efficiency was evaluated using its original fuel, i.e. gasoline, choosing the better valve clearance to guarantee the maximum efficiency. After correcting the pressure rate of the engine running with poor gas, a new evaluation of the engine efficiency was determined, using Eq. (3)

$$\eta_e = \frac{P_{gen}}{P_{gas}} 100\ \% \quad (3)$$

where, P_{gen} is the power generated, W. P_{gas}, the power liberated by gasoline, whence,

$$P_{gas} = \dot{m} LHV_{gas} \quad (4)$$

$\dot{m}$ being the gasoline volumetric flow rate, m^3/s, and LHV, the lower heating value, J/kg (admitted as being 42680 kJ/kg).

g) Running the system

Figure 2: The Y shaped mixture air/gas controller

First the biomass inside the reactor is ignited with a gas torch burner. Within ten minutes, the gasifier flare is lit. The flare intensity and color start changing as well as the CO level of the poor gas. To start running the engine, the CO level must go up to 10 %. To guarantee an approximate stoichiometric mixture of air/poor gas there is an Y shape mixing apparatus, see Figure 2. A load bank resistor (power range from 0.7 kW to 2.2 kW), was used to simulate the resistive load of the generator. Having stabilized the engine, (indicated by a close value of the 60 Hz frequency, as registered by the control equipment), the electrical resistances start being loaded, and all the data (power, biomass consumption, gas composition, elapsed running time, etc.) are registered. The biomass consumption is checked by means of a digital scale, considering that at the beginning of the tests, the biomass fills the fuel hopper to its maximum level. During the operation, new quantities of weighted biomass (in kg) are used to feed the gasifier, and the elapsed time is registered. The composition of the poor gas as well as that of the exhausted gases is evaluated using a Discovery G4 vehicle gas analyzer, fromAlfatest. The whole procedure is repeated for each of the four samples of wood pieces.

III. Results and Discussion

a) The Biomass Moisture Content and Density

Table 1 shows the moisture content determined experimentally for the four biomass samples used to feed the gasifier. Table 2 presents the average density, experimentally determined, of the four wood samples. The values of the moisture content in Table 1 are all very similar, having magnitudes lower than 10.2 %. (To avoid producing lower biomass heating values, the moisture content should not be higher than 15 %, [52]).

Table 1: Moisture content of the wood samples, determined in triplicate

Sample	Essay/ Moisture Content(%)			
	1	2	3	Average (%)
1	10.992	10.442	9.042	10.159
2	8.280	10.149	9.304	9.244
3	9.868	9.793	10.670	10.110
4	8.274	9.752	9.544	9.190

In Table 2, we can see that sample 1 presents a density 19.7 % larger than that of sample 3, which in turn has the second largest density among all the samples. Samples 2 and 4 have very similar density magnitudes. It should be noted that the average density of sample 1 is considerably higher as compared with the higher densities of different tropical species, see Reys et al. [53].

Table 2: Wood pieces density, determined in triplicate

Sample	Density (kg.m-³)			
	1	2	3	Average (%)
1	1083.754	1073.243	1063.308	1073.435
2	704.696	743.469	796.531	748.238
3	814.968	863.694	908.668	862.444
4	762.917	664.674	802.483	743.358

b) Proximate analysis of the biomass

Table 3 presents the results of the proximate analysis of the four different biomasses, using the ASTM E-1131 Standard Test Method for Compositional Analysis by Thermogravimetry. It shows that all the samples present high percentage of volatile matter, facilitating the conversion and the upgrading of the fuel, Digman et al. [54]; As a result of its smallest percentage of volatile matter, sample 4 presents the highest percentage of fixed carbon (FC). Thus, consonant with its FC magnitude, its HHV is larger than those of the other samples, which show similarly smaller values. It should be remembered that fixed carbon is the solid carbon of the biomass which remains in the char after it has been submitted to the devolatilization and pyrolysis processes, as pointed out by Basu [45]. On the other hand, the smallest percentage of ash was found in sample 3. In terms of moisture we canconsider that all samples have similar contents.

Table 3: Proximate composition of the biomass

Sample	Volatile matter (%)	Fixed carbon (%)	Ash (%)	HHV (MJ/kg)	Moisture (%)
1	91.470	4.390	4.140	15.780	11.090
2	88.544	6.259	5.197	15.976	12.550
3	96.215	2.186	1.599	15.760	11.730
4	82.556	15.413	2.031	18.305	11.620

c) Temperature Distribution Inside the Reactor

Table 4 shows the temperature registered inside the reactor, in the drying, pyrolysis, combustion and reduction zones. As expected, the temperatures mount till the combustion zone, declining at the reduction zone, and depending on the biomass, the temperature changes for each of the zones in question. This behavior directly influences the percentage of CO, CO_2 and O_2 generation, see Figure 3. It shows the four types of biomass CO, CO_2 and O_2 levels, at the engine's maximum power.

Table 4: Experimental temperatures of the four samples inside the reactor zones

Zone	Temperature (ºC)			
	Sample 1	Sample 2	Sample 3	Sample 4
Drying	40.5	52.5	61.5	45.6
Pyrolysis	463.2	698.5	544.0	701.0
Combustion	954.4	1028.0	1079.0	1162.0
Reduction	860.0	844.0	952.7	1014.0

d) Behavior of the gases CO, CO_2 and O_2 of the four biomass samples, with the engine running at maximum power

In Figure 3, the CO level percentage increases as the sample volume mounts. This trend repeats for the CO_2 percentage levels all along most part of the curve. It seems that the size of the sample interrupts this tendency. On the other hand, the O_2, by reason of the CO_2 and CO gases formation, is the only curve that goes down continuously, presenting an almost fixed slope.

e) The Poor Gas LHV as regards the electric power generation

Figure 4 presents the CO, and O_2 percentage as regards their biomas s densities. The tendency lines of gases CO, and O_2 present, as expected, an inverse behavior to CO_2 lines. Comparison between the curves in Figures 3 and 4, given the fact that the formation of the gases CO and CO_2 is enhanced by the increase in temperature, indicates that the flame zone intensity is much more limited by particle density, than by particle size. This fact is supported by the data in Tables 2 and 4, which show that lower densities correspond to higher temperatures in the pyrolysis zone. In consequence, the O_2 behavior in Figure 4, is characterized byan increasing tendency, as opposed to what occurs in Figure 3.

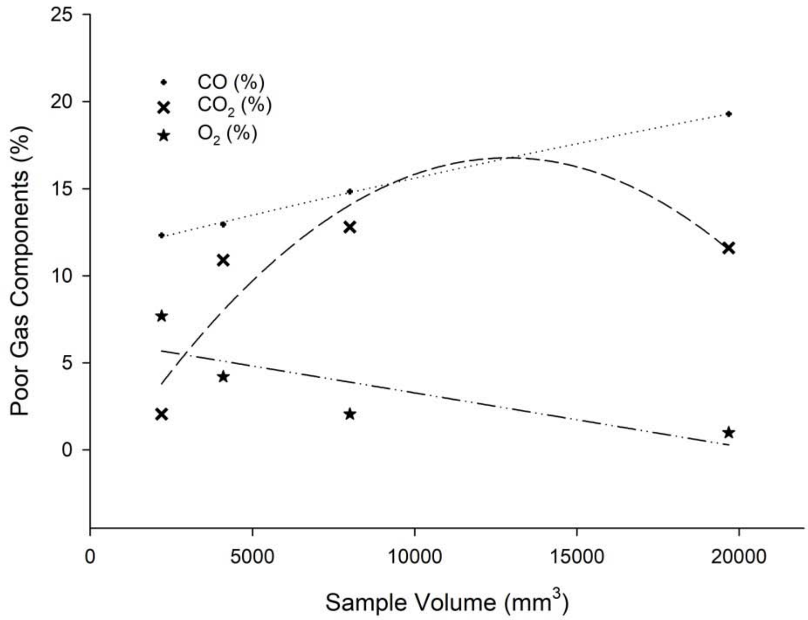

Figure 3: Percentage of CO, CO2 and O2 of the poor gas as regards as the sample size (volume)

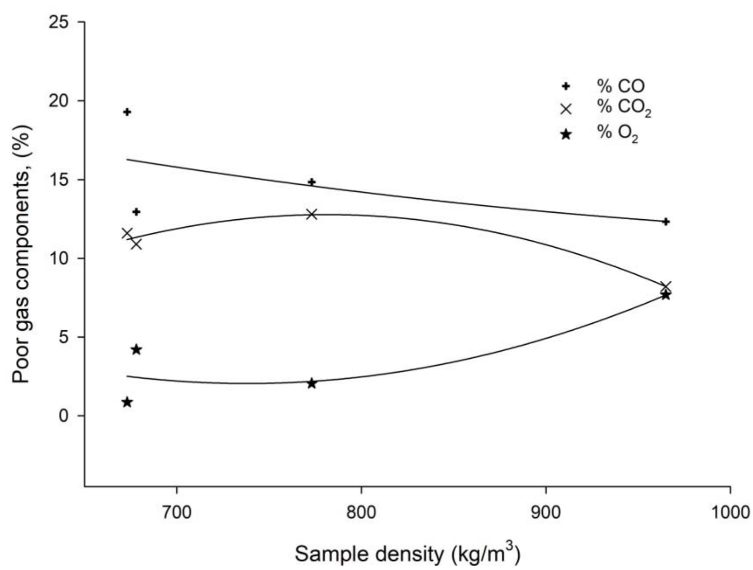

Figure 4: Percentage of CO, CO2, and O2, in terms of the biomass density

Figure 5 shows the heating value curves of the poor gas as a function of the electric power generation for the four samples. Differently from what happens with the majority of gasifiers, which use a blower to improve combustion, the enhancement of the flame inside the gasifier is mainly done by engine aspiration, acting as a driving force for gasification. As mentioned by Shin [29] the biomass size, as well as its calorific value may also influence the flame propagation speed. In Figure 5 we can see that considering the full range of variation of the electric generated power, the lowest LHV average is related to the samples having the highest average densities – 1073.435 kg.m^{-3} and 862:444 kg.m^{-3} - i.e. samples 1 and 3, respectively (see Table 2).Whereas sample 4 (ρ = 743.358 kg.m^{-3}), with the lowest average density and the largest LHV value, is the only one to show a continuous rising of the LHV. On the other hand, the second largest LHV value is produced by sample 2 (ρ = 748.238 kg.m^{-3}), which shows a rapid evolution of the generated electric power, but rapidly falls after reaching 1.7 kW. It should be noted that samples 4 and 2 present both the lowest density and volatile matter, see Table 3, while sample 4, shows the largest physical volume.

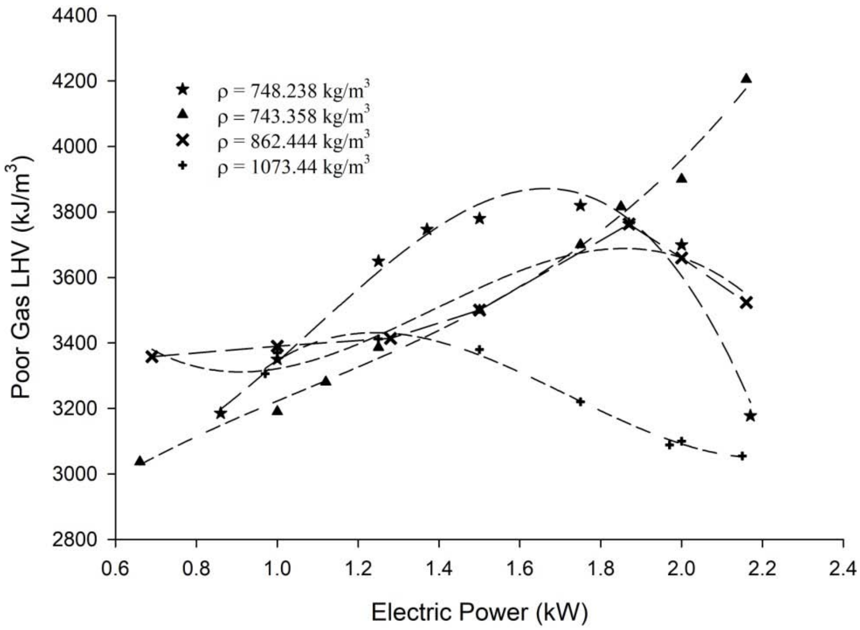

Figure 5: Poor gas lower heating value in function of the generated electric power, considering the four biomass samples

f) Biomass Specific Consumption

Figure 6 presents the biomass specific consumption in terms of the electric generated power, for the four different sizes of biomass. We see that, in general, the specific consumption of the biomass decreases with the increase of the generated power level, the lowest consumption being achieved by sample 4 type (considering the whole range of electric power generated), and sample 3 coming next (their densities are respectively 743.358 kg.m^{-3} and 862.444 kg.m^{-3}). For the electric power ranging from 0.9 kW to 2.2 kW, the consumption raised on average, 2.5 kg/kWh, when the gasifier was fueled with sample 1 type (ρ = 1073.435 kg.m^{-3}). When the system is running with sample 4 biomass type, (ρ = 743.358 kg.m^{-3}) the consumption is the smallest, as compared with the other biomass types.

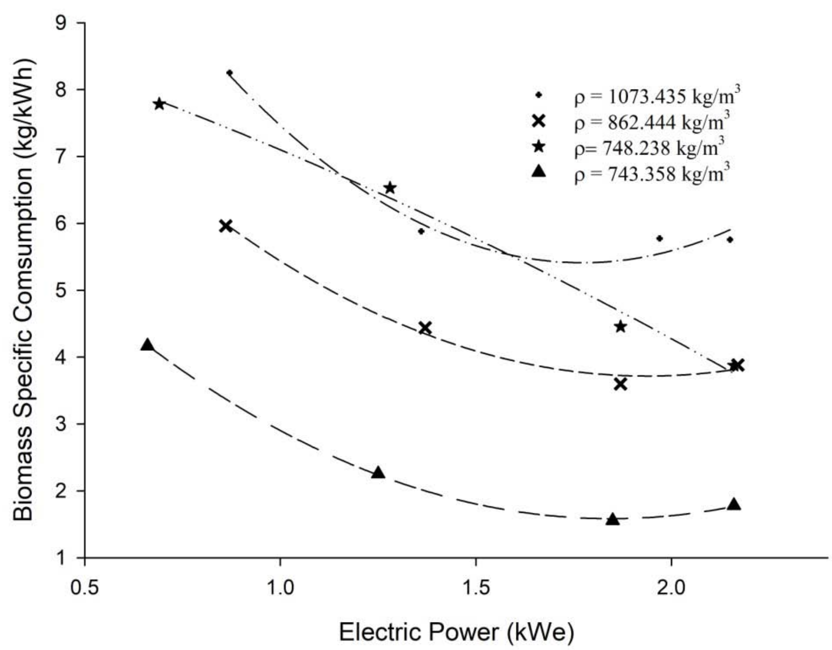

Figure 6: Biomass specific consumption

g) Efficiency of the system Gasifier/ Otto Cycle engine/Generator

Figure 7 presents the plot for the system (gasifier/genset) efficiency, see Eq. (2), in terms of the generated electric power. It shows that from the smallest power up to 1.8 kW, no matter the sample, the efficiency of the system tends to increase. From this point on, in three of the cases, the curves show a slight decrease as the electric power increases. The highest efficiency (11.99 %) results from the use of sample 4 biomass (ρ = 743.358 kg.m^{-3}), when the electric power reached 1.85 kW. In this connection, Tinaut et al. [55] using a one-dimensional stationary model of biomass gasification to study the effect of the biomass particle size on the gasification process in a downdraft fixed bed gasifier, showed that the maximum efficiency was achieved with a smaller particle size. In their case, the model was validated experimentally in a small-scale gasifier by comparing the experimental temperature fields, biomass burning rates with predicted results. However, the biomass density was not taken into consideration. In another model developed by Thunman et al. [24], concerning solid fuel conversion in a grate furnace using a fixed bed fuel bed, they concluded that particle density has small influence on the conversion rate, but noted that the particle size influenced the combustion behavior. In our case, however, small density has shown to have a beneficial influence on the various aspects of the gasifier, i.e. on its behavior and on the electricity production system, see Figure 6.

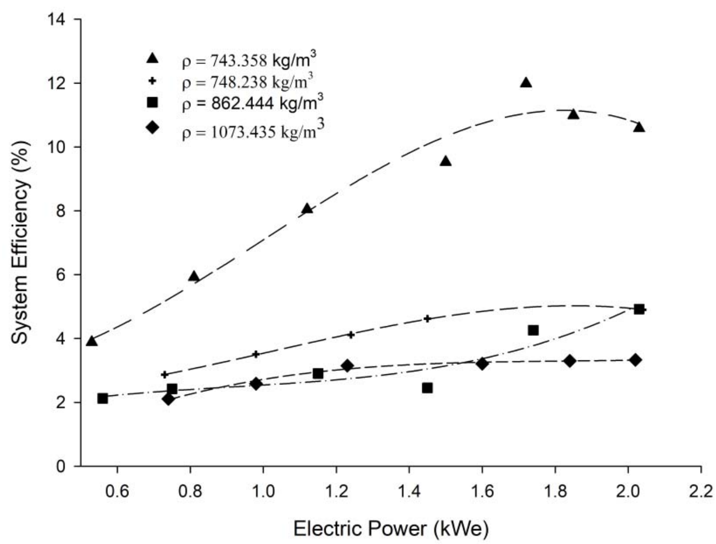

Figure 7: System (Gasifier/Genset) Efficiency vs Electric power, considering the use of the different samples

h) The Genset Efficiency Under Maximum Power Generation

The use of Eq. (3), gave as result η_e = 16.87%, to generate 2 kW electric power. And as we have seen, the maximum efficiency of the system (gasifier/genset), η_{sys}, for generating electricity was 11.9 %, which may be considered low. If the efficiency of the genset, η_{gens}, running on its maximum power is of 13.5 %, i.e. 80 %, of the power determined when run on gasoline, it becomes evident, from Eq. (3), that the gasifier efficiency, η_g, is, in fact, 88.1 %,

$$\eta_g = \frac{\eta sys}{\eta gens} \qquad (5)$$

IV. Conclusions

The dissimilar curves in Figures 3 and 4, are an indication that we cannot analyze gasification performance referring just to biomass size, as Hernández et al. [30] did. Therefore, because of an existing correlation between biomass size and density, we can conclude, see Figure 3, that the larger the sample, the greater the CO percentage. Concerning the CO_2 formation, it seems that there is a sample size limit (associated with a determined density value), when its production decreases caused by flammable shortage.

The most remarkable fact registered in the several tests concerning sample 4 (ρ = 743.358 kg.m^{-3}) is that it allows the maximum temperature of the reactor combustion zone. Analyzing its average figures of moisture content, density, and higher heating value, and comparing them with those of other samples, it is clear that sample 4 reunites the suitable property values to guarantee the adequate conditions for generating electricity, with the smallest biomass consumption. In other words, it shows the best effective energy efficiency among all the samples. It is also possible to conclude that the smaller the density, the slower the specific consumption, see Figure 6. Consequently, lower density helps the gases residence time raise, enabling a more efficient gasification, as indicated by the decreased concentration in O_2, see Figure 4. According to Billaud et al. [56], CO_2 formation occurs from combustion reactions and is directly bound up with the amount of O_2. As a consequence of higher temperatures, there is an elevation in carbon monoxide concentration, a flammable gas, cf. Yin et al. [57]. It should be mentioned that similar results were obtained by Feng et al. [25], in studying a catalytic steam gasification of biomass. The only divergence is the behavior of CO_2, which decreased in a certain portion of the curve, due to the increase of the volume sample, as well as of its density. On the other hand, it should be noted that, given the HHV function of the CO level, the higher heating value of the poor gas made sample 4 biomass (ρ = 743.358 $kg.m^{-3}$), the only one capable of offering the system maximum efficiency in generating electric power.

Considering both the maximum efficiency of the system, and the efficiency of the engine running with poor gas, we can conclude that the gasifier efficiency with maximum power is about 88.1 %, undoubtedly, a standout figure, Ptasinsky [58].

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance with Ethical Standards:

The authors declare that they have no conflict of interest.

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Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 20 Issue 3 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Design of Radiator for Internal Combustion Engine with Tubes in Distribution of Sierpinski and Fins with Fractal Convolution

By Luis Eduardo Llano Sánchez, Darío Domínguez, Martha Cecilia Melo & Carolina Gonzalez Rodríguez

Universidad Militar Nueva Granada

Abstract- Introduction: Fractal geometries have demonstrated their efficiency in nature, for that reason a fractal geometry will be implemented to improve the transfer in a heat exchanger. This paper presents the design of the radiator for an internal combustion engine, where the location of the tubes through which the fluid passes are given by the distribution of Sierpinski and the perforations of the fins were made with fractal convolution. The outlet temperature respect to inlet temperature is studied and analyzed through a CFD software. This document shows theory fundamental used to design the radiator, with the implemented methodology, its results and conclusions.

Keywords: fractal convolution; sierpinski distribution; fins design; radiators.

GJRE-A Classification: FOR Code: 299902

Design of Radiator for Internal Combustion Engine with Tubes in Distribution of Sierpinski and Fins with Fractal Convolution

Luis Eduardo Llano Sánchez [α], Darío Domínguez [σ], Martha Cecilia Melo [ρ] & Carolina Gonzalez Rodríguez [Ѡ]

Abstract- Introduction: Fractal geometries have demonstrated their efficiency in nature, for that reason a fractal geometry will be implemented to improve the transfer in a heat exchanger. This paper presents the design of the radiator for an internal combustion engine, where the location of the tubes through which the fluid passes are given by the distribution of Sierpinski and the perforations of the fins were made with fractal convolution. The outlet temperature respect to inlet temperature is studied and analyzed through a CFD software. This document shows theory fundamental used to design the radiator, with the implemented methodology, its results and conclusions.

Objective: Verify that a radiator with fractal design improves heat transfer in comparison with a commercial radiator.

Methodology: For this study, the design of the radiator in matlab was made, then the CAD design and the corresponding simulations in Ansys were performed. The numerical analysis was carried out. Finally, for the case of the common radiator, the data was adjusted to the Newtonian cooling function and for the radiator with fractal design it was performed as a function of Mittag-Leffler.

Results: The designed radiator cooling temperature curve falls faster than the commercial radiator curve, which is an indication that the radiator with fractal geometry improves heat transfer in the exchanger.

Conclusion: The Mittag-Leffler function best approximates the temperature curve of the Fractal Radiator. To estimate a fractal object under the condition of thermal conductivity, when making the estimation it is suggested that it must relate to the Fourier equation of fractional type in fractal medium.

Keywords: fractal convolution; sierpinski distribution; fins design; radiators.

I. Introduction

Since their appearance in 1975, fractals have been used in many areas related to engineering applications and have proven useful for increasing performance while using less volume. It has been shown that the self-likeness of fractal patterns could be used to create an effective distribution system over geometric surfaces.

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Originally, they emerged as geometric shapes that are repeated in an iterated manner at different scales and that are self-similar. In the first decade of its development its geometric properties and its possible connections with other disciplines were obtained. Subsequently from the work of Nigmatullin [1], it began to incursion with connections of the area with fractional or fractional calculation, and from this, in the 21st century the possible applications to the various engineering. This work is part of the fractal theory to heat transfer, through simulated constructions by computer, which are feasible to build, on fins whose surface is fractal.

The essential characteristics of fractals is the irregularity of surfaces that can be repeated at different scales, this allows to improve heat transfer, for instance the surfaces of the fins under Euclidean geometries have been used in a classical way [2], [3]. One of the applications of surface engineering with fins is the radiator. By attaching the metal sheet to the water pipes at a defined temperature, the area of the convection surface increases and thus increases the heat transfer rate [4], if this is changed from geometry to fractal geometry, the transfer efficiency should be markedly improved.

Due to the increasing use of methods to improve the design of the heat exchanger in the industry, Compact heat exchangers have been developed which ones have a high proportion of heat transfer surface to heat exchanger volume, considering the fractal capacity to increase heat transfer. These are divided into fin tubes and fins plates [5] [6], which allow a high heat transfer coefficient in the high turbulence flow as that offered by a laminar flow in a flat tube situation [7].

This project investigated a tube heat exchanger based on the use of the Sierpinski fractal pattern where the spaces are not square but circular, and those are given by an operation fractal operation called convolution. Using computer modeling software, this indicated that with fractal iteration, an increase in heat transfer is achieved. Another research interest involving fractals in engineering has been the effects of fractal on surface diffusion rates.

In reference to radiators, they can use any type of compact exchangers, for the purpose of controlling the engine temperature when the engine is too high [8]. Based on the different models of cooling systems manufactured in [9], [10], [11], it decided to analyze the behavior of the design of the radiator with convolution fractal distribution fins, because in heat transfer fractal designs have shown better results than common geometries [12], [13].

The following simulations presented was made through CFD software since it allows us to study trends and properties [14].

II. Methodology

This project methodology is divided in four parts: fin calculus, fractal distributions, CAD and simulation.

a) Radiator Design

A radiator has four parts: inlet tank, outlet tank control cap and diaper (figure 1). The principal parameters are the diaper dimensions [15] which includes fins and tubes, these last parameters are those that will be considered to implement the fractal geometry.

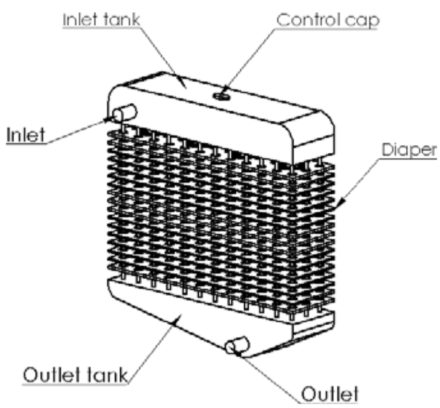


Fig. 1: Parts of a radiator

Tubes design: The chosen parameters to realize the tube design were: Cross section (1), total internal perimeter (2), and hydraulic diameter (3).

$$A_{tube} = N_t \left[t_{hi} \cdot (t_{wi} - t_{hi}) + \frac{\pi}{4} t_{hi}^2 \right] \qquad (1)$$

$$P_{tube} = N_t \left[\pi \cdot t_{hi} + 2 \cdot (t_{wi} - t_{hi}) \right] \qquad (2)$$

$$D_{htube} = \frac{4 \cdot A_{tube}}{P_{tube}} \qquad (3)$$

Where N_t is the radiator tubes number, t_{hi} is height of the tube, t_{wi} is the internal width of the tube.

Fin design: To design the heat transfer area on the side of the tube Aefect, tube and the area Ac, these can be expressed as:

$$A_{efect,tube} = N_t \left[2 \cdot (t_{wi} - t_{hi}) - \pi \cdot t_{hi} \right] \qquad (4)$$

$$A_c = (N_t \cdot t_{ho} + N_c \cdot c_h) \cdot L_t \qquad (5)$$

b) Design using the Sierpinski distribution

Considering the values obtained of (4) and (5), it was necessary to find an efficient distribution, for this reason it was decided to use the Sierpinski distribution to locate the tubes.

To determine the location of the centers of the holes, we considered the dimensions of the fin, because the fin has a rectangular form, this one was divided into four squares, and in each one we applied the Sierpinski distribution. Finally, we made a Matlab program which calculates the center and the location of the holes, the result of the algorithm is illustrated in figure 2.

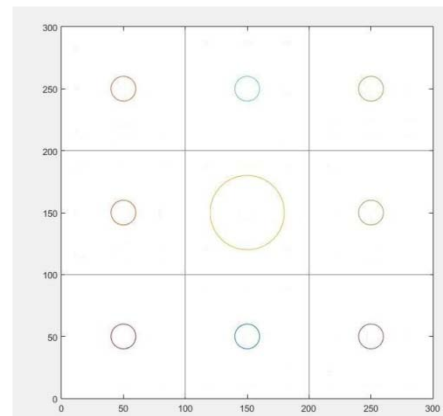


Fig. 2: Result obtained from Matlab

c) Fractal Convolution

In 2015, Cotton, McLeman y Pinchock proposed process to combine two fractals [16], one into each other and they explored the combined effect on fractal dimension. This project explores that effect over a radiator and its effect calculated through a simulation. The construction follows the parameters exposed in [16], except that apart from the Sierpinski we build a new fractal (figure 3) and the result of the convolution between Sierpinski and the fractal designed will be determinate the radiator perforations.

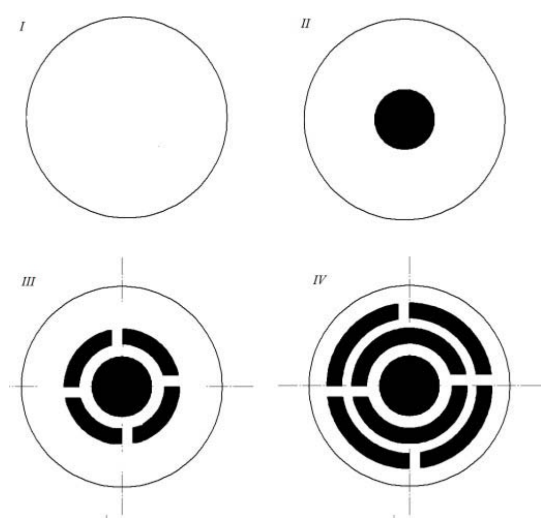


Fig. 3: Fractal figure construction

The contribution in this project was the use of these ideas to simulate the behavior of the radiator. The figure 4 shows the result of the fractal convolution that was made, and the fractal dimension was calculated through HarFa v5.3.33 software [19], its result was illustrated in the figure 5.

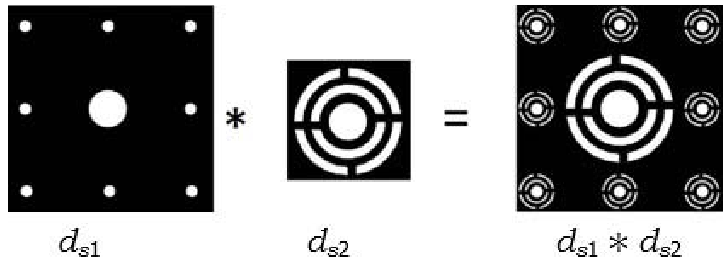


Fig. 4: Fractal convolution

Where, $ds1$ corresponds to the tubes distributions dimension, $ds2$ to the fractal figure designed dimension and DF is the product of the convolution between those fractals.

To calculate the fractal dimension, we used Harfa software and the operator form proposed by Cotton, McLeman and Pinchock, and these are:

$$ds1 = 1.8927$$

$$ds2 = 0.7392$$

$$DF = ds1 * ds2 = 1.3991 \qquad (6)$$

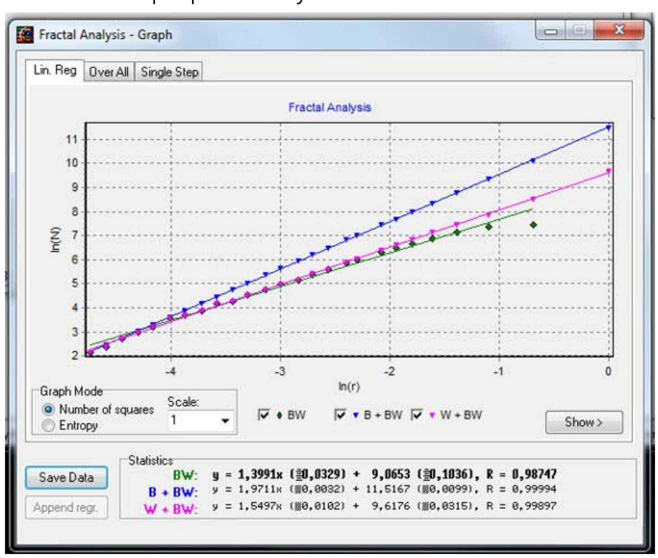


Fig. 5: Harfa Results

d) Simulation

CAD: This model was made through a 3D software. With the values previously found, the measurements of the drill bits are determined for the diameters of the holes and tubes passing through them, which corresponds to 1⁄8 "for the small hols and 3⁄8" for the central holes. The figure 6 shows the result of the convolution implemented in a fin design.

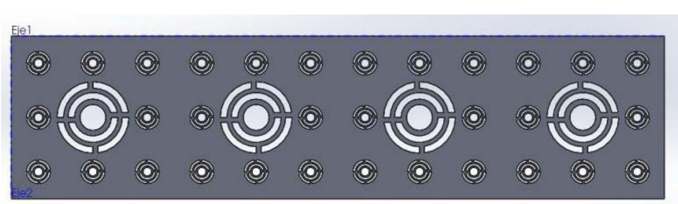


Fig. 6: Fin design in CAD

Meshing: Because the geometry radiator had 36 tubes and more that 500 perforations, it was necessary to use a mesh with the right size to analyze in CFD study and skewness coefficient that was less than 0.86 to be compatible with Fluent. Table 1 shows the mesh parameters implemented.

Table 1: Mesh Characteristics

Size Function	curvature
Size	3.3208 e-2 mm
nodes	3409535
number of elements	2835588

Parameters of CFD simulation: The computational model was set to a laminar model, with temperature and flow parameters shown in Table 2. The initial values of velocity and pressure was setting with SIMPLEC algorithm.

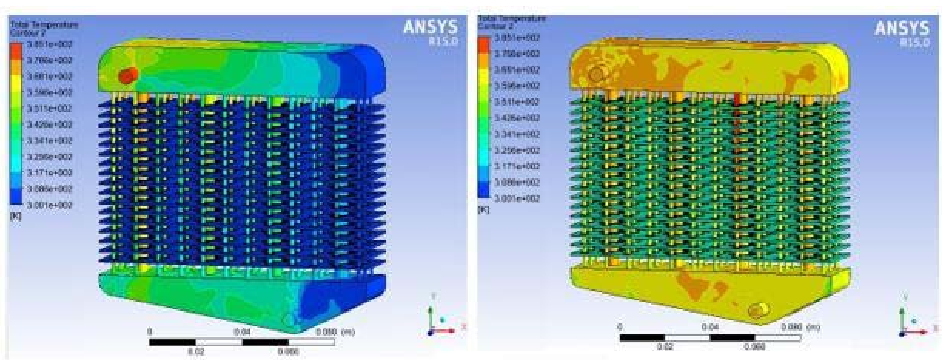
Table 2: Simulation Parameters

Convection (forced)	80 *W/K.m*^{2}
Fluid inlet temperature	385 K
Ambient temperature	300 K
Initial mass flow	0.1 Kg/s

III. Results

a) CFD

Simulation was performed in Ansys, it was made in order to analyze the temperature in the radiator in a time of 30 seconds. Figure 7 shows the difference between temperature at time t=1s and final temperature at time t=30s.



a). t=1s b). t=30s

Fig. 7: Radiator temperature

The obtained results show a reduction of 7K with regard to the initial temperature of the fluid. Considering that the analysis of the figure 8 is the temperature analyzed at the radiator outlet, where *T* (0)*Outlet* = 300*K* is the ambient temperature.

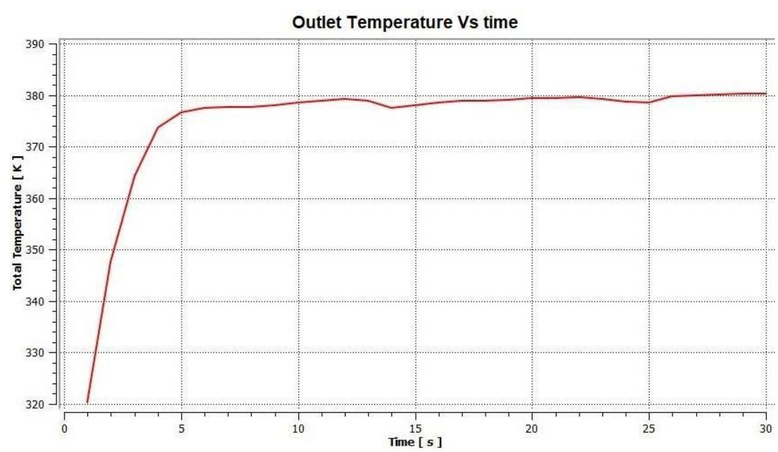


Fig. 8: Ansys results

b) Data processing

The data processing in this radiator has the purpose to find the function that fits better to fractal design. The first step consists in taking a temperature model and adjusting to a Mitag- Leffler function. To realize it, it was necessary to analyze the temperature decreasing, taking as reference the fluid initial temperature at the inlet radiator as T (0)inlet= 385K.

Figure 9 shows the change of temperature at the outlet of the radiator.

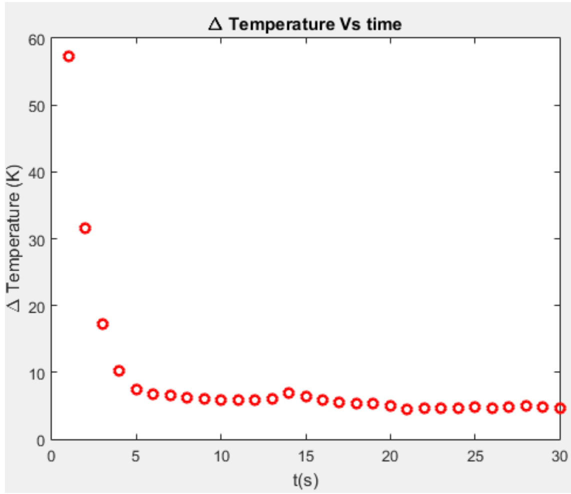


Fig. 9: Temperature drop at the radiator outlet

With the obtained data from figure 9, it proceeded to looking for Newton temperature classic model as the form:

$$\frac{dT}{dt} = K(T - Tm) \tag{7}$$

When estimating the model purchased with (7) we find that:

$$T(t) = 6 + 70e^{-0.47t} \tag{8}$$

When the adjustment analysis of the regression is performed, we find that:

$$R^2 = 0.8456$$

Square root of the middle square = 9.87 Con valor p = 9, 09X10^{-18}

Figure 10 illustrates the classical model (red line) and the points plot the data obtained from the simulation.

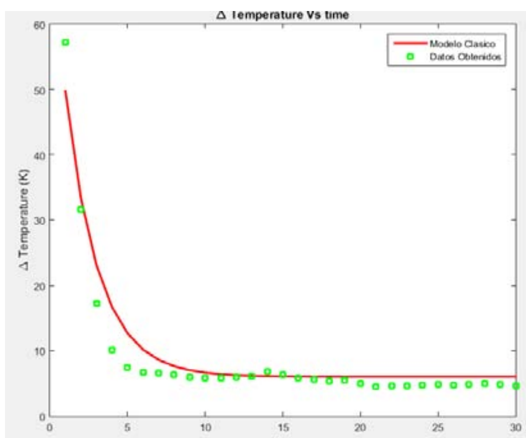


Fig. 10: Estimated classic model and simulation data

This is a lumped system, which temperature varies with the time, but remains unformed around the system at any time. The temperature of a lumped body of arbitrary shape with a mass m, volume V , surface area A_S, density ρ and specific heat C_P, initially at a temperature Ti, that is exposed to convection at a time t = 0 at a medium temperature $T\infty$, with a heat transfer coefficient h is expressed as:

$$\frac{T(t) - T_\infty}{Ti - T\infty} = e^{-bt} \tag{9}$$

Where,

$$b = \frac{h \cdot A_s}{\rho \cdot V \cdot C_p} = \frac{h}{\rho \cdot L_c \cdot C_p} \tag{10}$$

For the design of this radiator, the parameters of table III were considered.

Table 3: System Characteristics

h	$80\ W/\ (K.m^2)$
C_p	$4{,}1813\ J/\ (Kg.\ K)$
V	$0{,}000137\ m^3$
ρ	$2700\ Kg/m^3$
A_s	$0{,}003732\ m^2$

Because the fractal form used is a fractal one and before the estimation by means of the calculation of Mittag- Leffler, definitions will be proposed that seek to link the parameters with the fractal dimensions, as follows:

Definition 1: We will call fractal dimension of convection (dF_C) to: Being the natural logarithm of the coefficient of heat transfer coefficient h and the natural logarithm of the product of $\rho \cdot L_C \cdot C_p$. This definition can be expressed as:

$$a_F = \frac{ln(h)}{ln(\rho \cdot L_c \cdot C_p) + D_F} \qquad (11)$$

Where D_F is the fractal dimension of the convolution made in (6)

Replacing the equation 10 with Tabla 3 data, we obtained the value of $dF = 0,4084$

Calculate the α value: However, since the construction is fractal it is suggested to adjust the classical model to a Mitag- Leffler function with a value of α

To find the value of α, it was taken as a reference the value of dF found in (11), and considering some observations given by Tatom [18] with some modifications appropriate to the project:

$$\alpha = \frac{1}{2} \cdot \left(\frac{1}{2 - d_F} \right) \qquad (12)$$

Which value of $\alpha = 0,31$.

If Mitag-Leffler function with a value of $\alpha = 0.3$ is presented in the form of a Fox H-function, we get:

$$E_\alpha(z) = H^{1,1}_{1,2}\left[-z \left| \begin{matrix} (0,1) & \\ (0,1) & (0,\alpha) \end{matrix} \right. \right] \qquad (13)$$

As Haubold, Mathai and Saxena [17] indicates, when we performed the adjusting analysis with $\alpha = 0.3$, we find that: R^2decreases to 0.23, the square root of the average square decreases to 5.17 and $p = 4,59X10^{-5}$, as shown in figure 11.

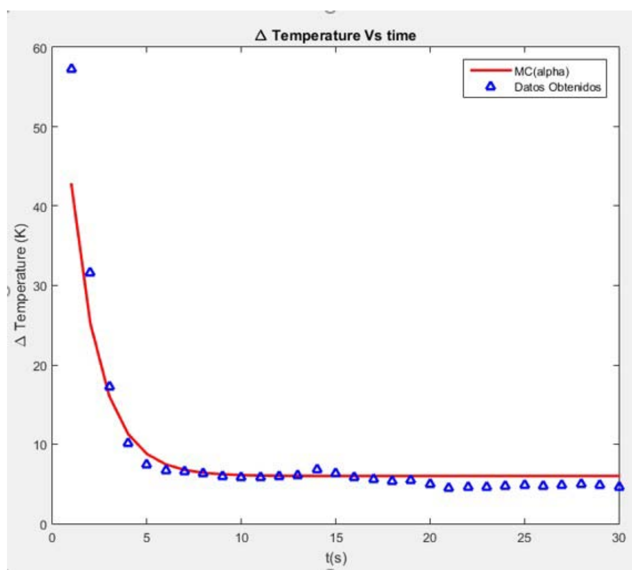


Fig. 11: Mittag-Leffler Function with α = 0.3

The linearity is lost, but the adjustment is improved, which is in accordance with the fractal model, in a fractal geometry. When calculating the classic model obtained in term of the Fox H-function, we obtain:

$$T(t) = 6 + 70 \cdot H^{1,0}_{0,1}\left[Z|_{(0,1)} \right] \; para \; Z = -0,47t \qquad (14)$$

While Mitag-Leffler adjustment is:

$$T(t) = 7 + 70 \cdot H^{1,1}_{1,2}\left[-Z|^{(0,1)}_{(0,1),(0,\alpha)} \right] \; para \; Z = 0,47t \; \alpha = 0,3 \qquad (15)$$

The improvement of the adjustment suggests that there must be a connection between the value α = 0.3 and the fractal dimension of the proposed design convolution ds1* ds2 = 1.3991.

When making the adjustment, it resembles the theoretical calculation of [18]. However, the values proposed by Zhao should be changed by the values of the model adjusted for this case of the radiator, in the following way: $\mu^2\omega$ is the thermal conductivity of the fractal material designed using the Sierpinski distribution, $\rho\omega$ its density, $c\omega$ specific heat, for the authors these values must be changed by their natural logarithm and the corresponding ω of the fractional order of the equation must be changed to the value α of this model.

IV. Conclusions

The simulation has shown that the fin surface in heat transfer and fractal shape and the yield of the fractal fins improve heat transfer or flow by improving fin efficiency.

The fundamental hypothesis on which the authors of the project are based is that since the fractals are self-similar objects and work at any scale, it is feasible to apply them at any scale of the engineering.

The Mittag-Leffler model with $\alpha = 0, 3$, fits much better than Newton's classic model because it changes from a distribution of a Euclidean geometry to a fractal geometry, in the design of fins in a radiator and the distribution of tubes.

To estimate a fractal object under the condition of thermal conductivity, when making the estimation it is suggested that it must relate to the Fourier equation of fractional type in fractal medium as we saw in [18]

This simulation further suggests that the reconstruction of the fins not in the form of the classical geometric euclidea but fractal and with operations of convolution between fractals markedly improves the behavior of heat transfer. It is further suggested to explain these phenomena with the possible connection with fractional calculation, which allows innovation within heat transfer and its associated engineering, we will therefore say that we have a promising future through these ideas.

Acknowledgment

To the vice-rectory of research of the Universidad Militar Nueva Granada, and to the project INV-ING 2612.

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Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 20 Issue 3 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Transient Thermal Analysis of the Turbine Blade

By M. Yashwanth Kumar, Shaik Himam Saheb
& M. Venkata Ramana Reddy

Abstract- Turbine blade is the individual component which makes up the turbine section of a gas turbine or steam turbine. The blades are extracting power from the high temperature, high pressure gas makes by the combustor. The turbine blades are often the limiting component of gas turbines. In general, all solid and non-solid models will deform when certain amount of thermal or structural loads applied within the environmental condition. With specific end goal to discover the progressions of the item or segment analysis software is utilized. In this paper the model is designed concerning all the accessible constraints utilizing like Catia in which all the individual parts are created in part module and assemble each other in assemble module. Later the product record is changed over to "stp" file format (standard exchange of product file) and imported to Ansys workbench to find deformation and analytic value with respect to the model or product definitions. Ansys software finds the precise or estimated solutions.

Keywords: design, analysis, meshing, turbine blades.

GJRE-A Classification: FOR Code: 850506

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Transient Thermal Analysis of the Turbine Blade

M. Yashwanth Kumar [α], Shaik Himam Saheb [σ] & M. Venkata Ramana Reddy [ρ]

Abstract- Turbine blade is the individual component which makes up the turbine section of a gas turbine or steam turbine. The blades are extracting power from the high temperature, high pressure gas makes by the combustor. The turbine blades are often the limiting component of gas turbines. In general, all solid and non-solid models will deform when certain amount of thermal or structural loads applied within the environmental condition. With specific end goal to discover the progressions of the item or segment analysis software is utilized. In this paper the model is designed concerning all the accessible constraints utilizing like Catia in which all the individual parts are created in part module and assemble each other in assemble module. Later the product record is changed over to "stp" file format (standard exchange of product file) and imported to Ansys workbench to find deformation and analytic value with respect to the model or product definitions. Ansys software finds the precise or estimated solutions.

Keywords: design, analysis, meshing, turbine blades.

I. Introduction

A turbine blade is the part which makes up the turbine segment of a gas turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are usually the restricting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and barrier coatings Blade fatigue is a major source of failure in steam turbines and gas turbines. Fatigue is caused by the stress induced by vibration and resonance within the operating range of machinery. To protect blades from these high dynamic stresses, friction dampers are used. Blades of wind turbines and water turbines are designed to operate in different conditions, which typically involve lower rotational speeds and temperatures. Gas turbine engine, a single turbine segment is comprised of a plate or center point that holds numerous turbine sharp blades. Turbine section is connected to a compressor section via a shaft (or "spool"), and that compressor section can either biaxial or centrifugal .The temperature is then greatly increased by combustion of fuel inside the combustor, which sits between the compressor stages and the turbine stages. The high-temperature and high-pressure exhaust gases then pass through the turbine stages. The stages separate energy from this stream, bringing down the pressure and temperature of the air. This process is very similar to how an axial compressor works, only in reverse. The number of turbine stages varies in different types of engines, with high-bypass-ratio engines tending to have the most turbine stages. The number of turbine stages can have a great effect on how the turbine blades are designed for each stage. Many gas turbine engines are twin-spool designs. Other gas turbines use three spools, adding an intermediate pressure spool between the high- and low- pressure spool. The high-pressure turbine is exposed to the hottest, highest-pressure air, and the low-pressure turbine is subjected to cooler, lower-pressure air. The difference in conditions leads to the design of high-pressure and low-pressure turbine blades that are significantly different in material and cooling choices even though the aerodynamic and thermodynamic principles are the same. Under these severe operating conditions inside the gas and steam turbines, the blades face high temperature, high stresses, and potentially high vibrations. Steam turbine blades are critical components in power plants which convert the linear motion of high- temperature and high-pressure steam flowing down a pressure gradient into a rotary motion of the turbine shaft. The present paper deals with the thermal stresses that arise due to temperature gradient within the blade material. The analysis is carried out under steady state conditions using Ansys software. The study has been conducted with three different materials stainless steel, Titanium alloy, Aluminium alloy.

II. Literature Review

In today's economic climate, cost pressure is a pervasive problem. One way to reduce costs is to carry out repair of single components within assemblies. In some applications, the regeneration can save up to 70 % of the costs compared to the replacement with remanufactured components. Due to the high potential in cost saving, most companies try to keep their knowledge in repair processes for themselves. Much effort is put into the improvement of processes in the maintenance, repair, and overhaul (MRO) of engines. An engine consists of approximately 30,000 components. Their repair takes a significant volume of the engine business with an increasing trend. Furthermore, Rupp indicates that the material costs add up to 50 % in the maintenance costs of engines. The repair or

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regeneration of components such as castings, seal fins/labyrinth, and notches is mostly carried out manually. Engine components of particular interest regarding the regeneration process are compressor, and turbine blades and vanes due to their high value. Most available references regarding the regeneration of those components concern the material deposit. Information on the recon touring is even harder to find .Nevertheless; this final shape cutting of a work piece is a crucial step regarding the later workpiece quality. Engine blades are an example for workpieces that have high requirements in accuracy and quality combined with a complex shape and difficult material conditions. The usual procedure for recon touring is characterized by a lot of manual working steps. This includes, e. g., manual grinding in the area of interfering contour. Achieving the final contour and a suitable surface topography is the most important aim. In order to limit the variety of occurring damages, Carter classifies these into basic groups. He describes and lists common failure mechanisms occurring at engine blades. Damage types are

Micro structural changes: due to high variations in temperature

Oxidation: due to chemical reactions of the workpiece material with the ambient air

Cracks: through high tensile stresses caused by thermal fatigue

Abrasion: through sand or small particles

Deformation: due to the impact of foreign objects or creep

Entire breakages: through foreign objects or thermo mechanical cracks or creep.

Any damage can be reduced to at least one of the three main causes: thermal influence, mechanical influence, or chemical influence. This paper in the following gives a literature review about regeneration processes related to the aviation industry. Moreover, it collects and generalizes detailed information on the machining point of view. The scientific basics extracted from the references can be transferred to other mechanical engineering sectors.

III. Modelling of Slap and Slider for Friction Surface

For Designing and analyzing an engineer must be familiar with the cause, which the manufacturing and thermal analysis done on the materials. Slap and slider are designed individually and assembled in order to obtain the final shape of the turbine blade. The slap and slider of the blade are designed as per the design standards using CATIA software as shown below:

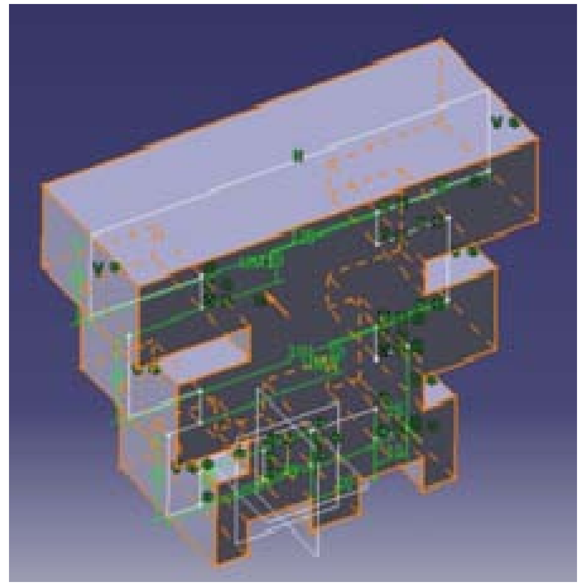


Fig. 1: Pad Tool for Base Locker

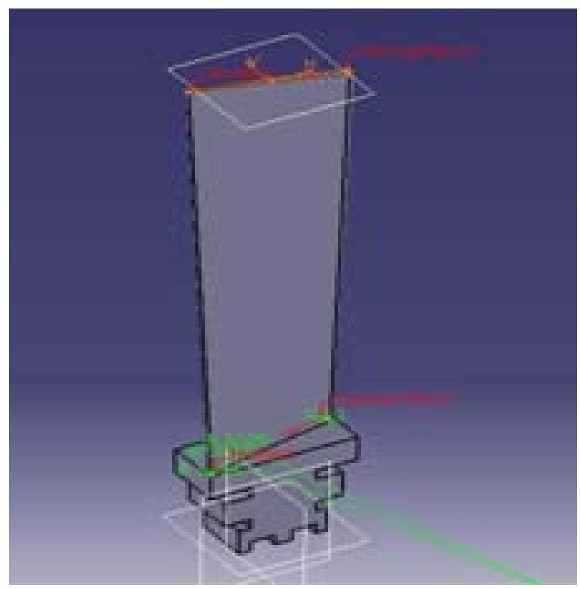


Fig. 2: Final Shape of Steam Turbine Blade

IV. Thermal Analysis of Turbine Blade

For thermal analysis of the turbine blade, ANSYS software is used. The blade is then analyzed sequentially with thermal analysis preceding structural analysis. The model is discretised using noded plane element & structural solid element. The thermal analysis is done by applying the temperature load of 80 °c on the front flat face of the model as shown in figure. Pertain the radiation load on the inward faces of the display, as laid out in fig. The inward faces are presented to air. The ambient temperature is 22 °c. The model is meshed and the boundary conditions applied for the thermal analysis. The model is meshed, boundary condition are applied for the analysis.

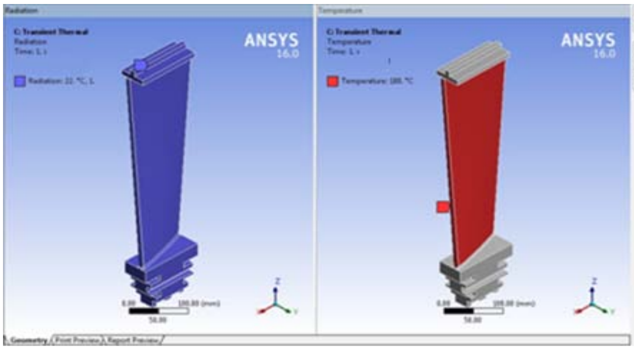


Fig. 3: Temperature and Radiation the Steady-State Thermal

After the thermal boundary conditions are applied, it is now important to analyze the behavior of the model with respect to the boundary conditions applied. The analysis that is carried out for different materials is shown in following figures

For Stainless Steel

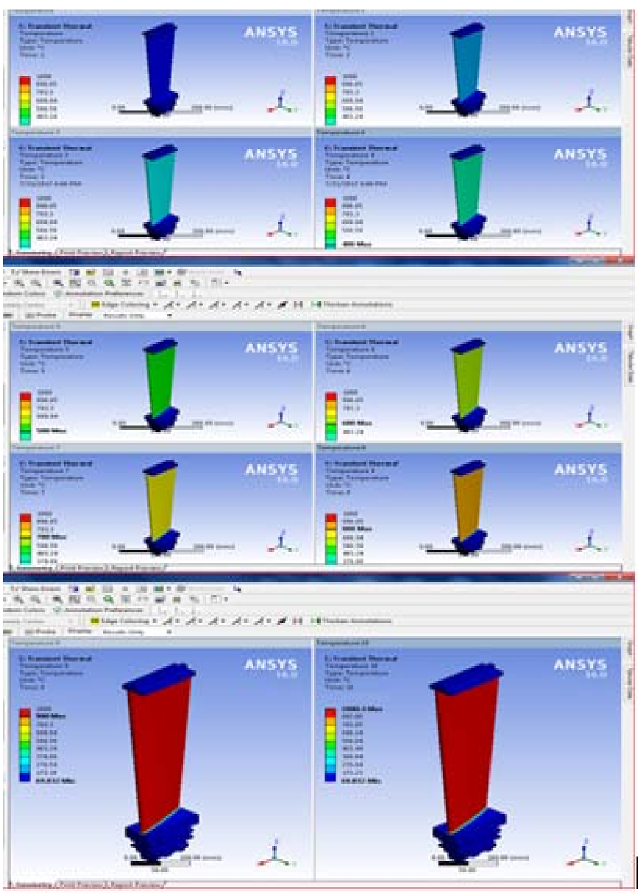


Fig. 4(a): Total Temperature Thunderbolt is added under Solution Node

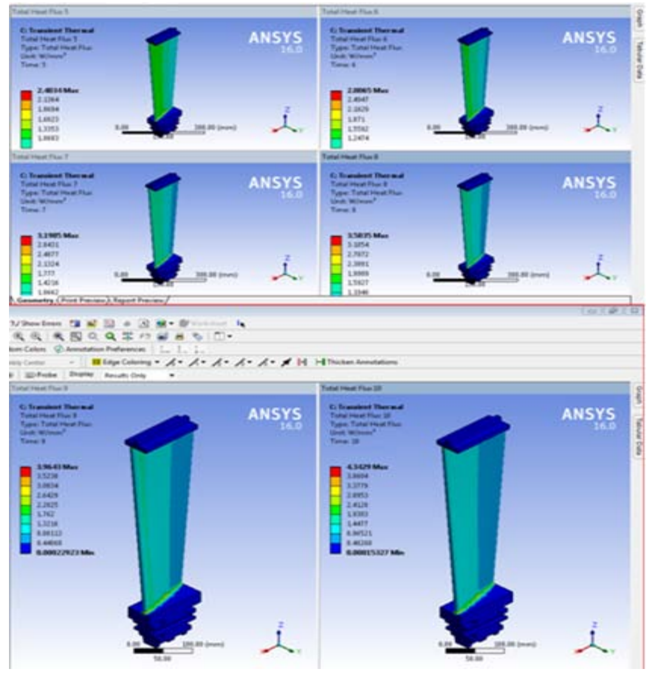


Fig. 4(b): Total Heat Flux Thunderbolts is added under Solution

For Titanium Alloy

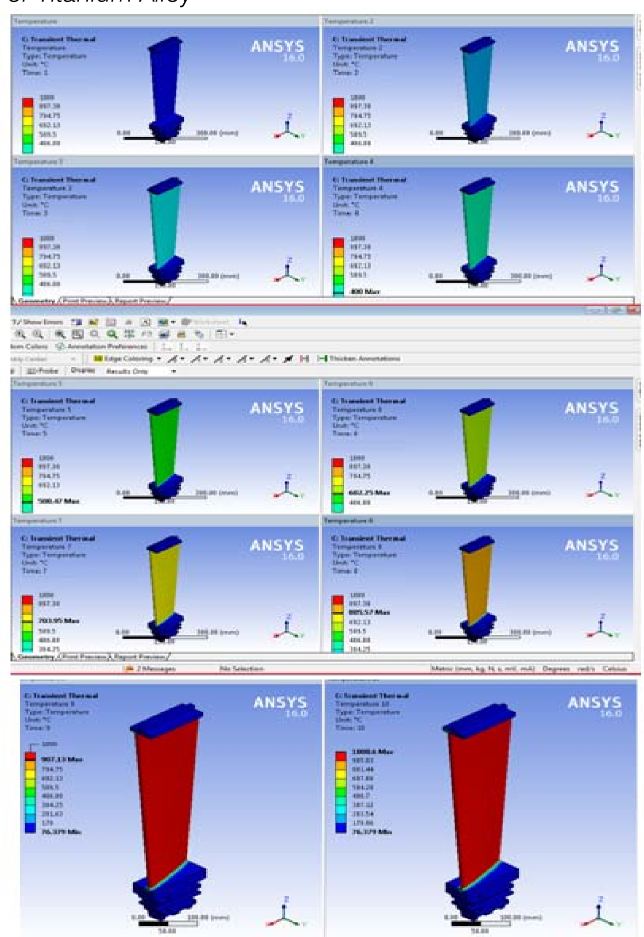


Fig. 5(a): Total Temperature Thunderbolt is added under Solution Node

Global Journal of Researches in Engineering (A) Volume XX Issue III Version I Year 2020

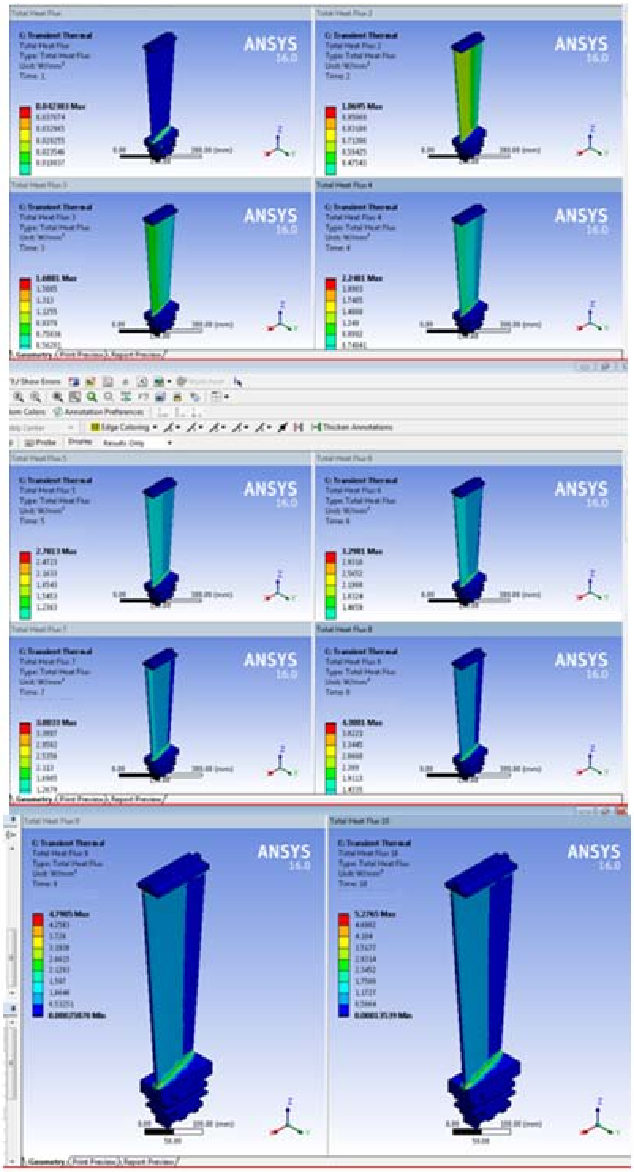
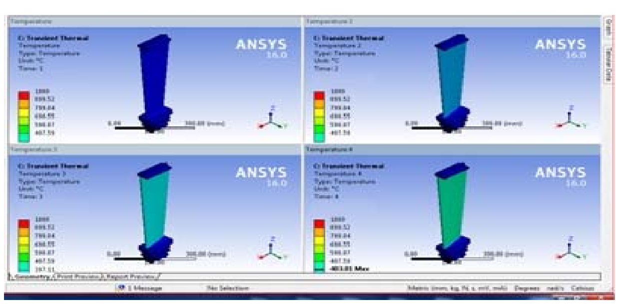


Fig. 5(b): Total Heat Flux Thunderbolt is Added Under Solution

For Aluminum Alloy



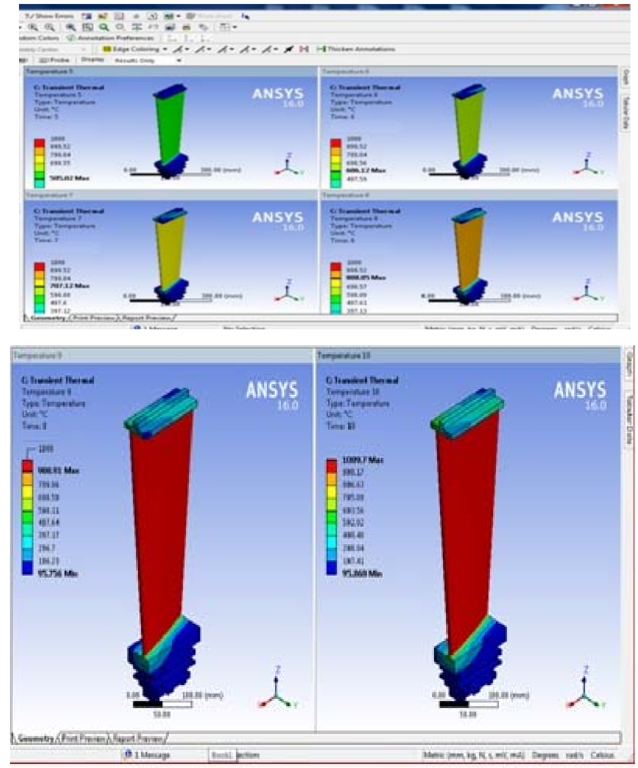
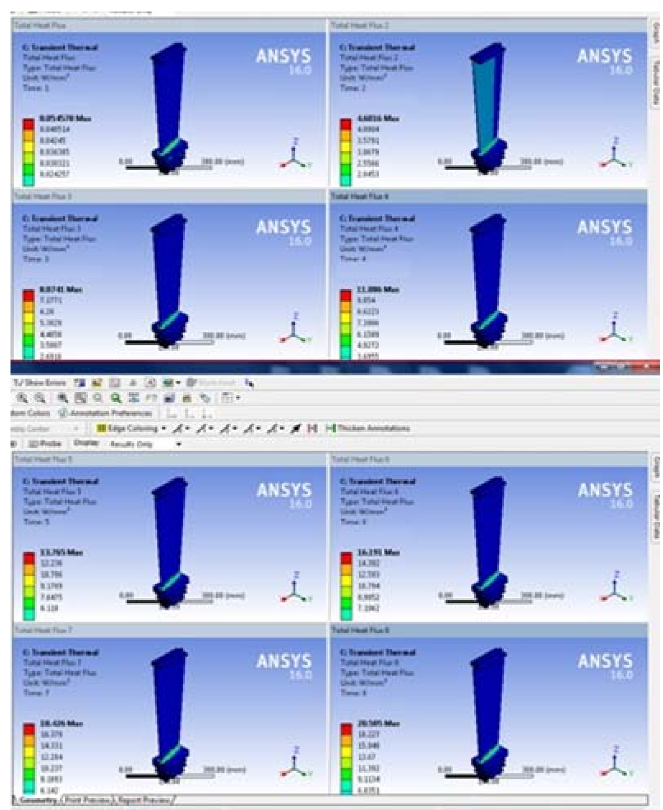


Fig. 6(a): Total Temperature Thunderbolts Is Added Under Solution Node



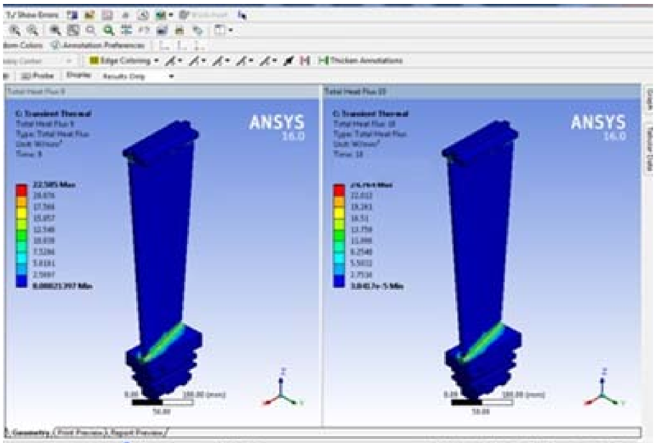


Fig. 6(b): Total Heat Flux Thunderbolt Is Added Under Solution

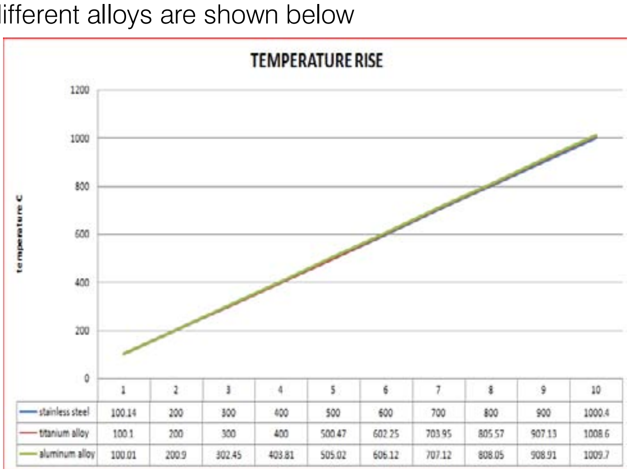
V. Result and Discussion

After the conduction of the thermal analysis on turbine blade is done using Ansys software. The results that are obtained with the rise in Temperature and Heat Flux by Temperature rise from 100 to 1000°C for different alloys is mentioned in the following table below:

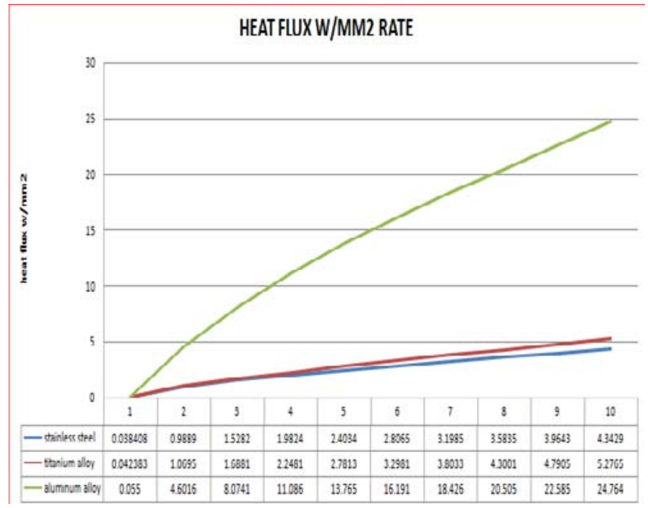
Table 1: Temperatures and Heat Flux by Temperature Rise from 100 To1000°C

S.No	Heat Flux W/Mm2			Temperature C		
	Stainless Steel	Titanium Alloy	Aluminum Alloy	Stainless Steel	Titanium Alloy	Aluminum Alloy
1	0.038408	0.042383	0.055	100.14	100.1	100.01
2	0.9889	1.0695	4.6016	200	200	200.9
3	1.5282	1.6881	8.0741	300	300	302.45
4	1.9824	2.2481	11.086	400	400	403.81
5	2.4034	2.7813	13.765	500	500.47	505.02
6	2.8065	3.2981	16.191	600	602.25	606.12
7	3.1985	3.8033	18.426	700	703.95	707.12
8	3.5835	4.3001	20.505	800	805.57	808.05
9	3.9643	4.7905	22.585	900	907.13	908.91
10	4.3429	5.2765	24.764	1000.4	1008.6	1009.7

The graphical representation for rise in Temperature and Heat Flux from 100°C to 1000°C for different alloys are shown below



Graph 1: Heat Flux W/Mm2



Graph 2: Temperature C

From the above graphs, it is found that temperature has significant effect of the thermal stresses induced in the Turbine Blade of different alloys. Moreover the temperature is high for Aluminium alloy and the heat flux is also high.

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Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 20 Issue 3 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Implementation of Lean Six Sigma Approaches in Construction Operations

By Naji S Abdelwanis, Faisal El Feitouri & Monaem Elmnifi
Benghazi University

Abstract- Lean Six Sigma (LSS) methodology is often successfully used to optimize processes, reducing defects and wastes in manufacturing processes, when applied in construction, improving its quality while reducing cost. Even though LSS has been widely used in construction processes all over the industries, it is rarely used in Libyan construction industry. Libyan constructions experience with material shortages, late material delivery, and lack of experienced design and project management, unstable process, and ineffective communications, inadequate planning and scheduling which results in along cycle time of the process. The purpose of this paper is to implement lean six sigma techniques as a sophisticated tool in Libyan Construction projects. Value stream mapping (VSM) is considered as a special type of flow chart that uses to depict and improve the flow of process steps and information from origin to delivery to the customer.

Keywords: lean six sigma (LSS), value stream mapping (VSM), DMAIC, construction.

GJRE-A Classification: FOR Code: 091399

IMPLEMENTATIONOFLEANSIXSIGMAAPPROACHESINCONSTRUCTIONOPERATIONS

Strictly as per the compliance and regulations of:

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Naji S Abdelwanis [α], Faisal El Feitouri [σ] & Monaem Elmnifi [ρ]

Abstract- Lean Six Sigma (LSS) methodology is often successfully used to optimize processes, reducing defects and wastes in manufacturing processes, when applied in construction, improving its quality while reducing cost. Even though LSS has been widely used in construction processes all over the industries, it is rarely used in Libyan construction industry. Libyan constructions experience with material shortages, late material delivery, and lack of experienced design and project management, unstable process, and ineffective communications, inadequate planning and scheduling which results in along cycle time of the process. The purpose of this paper is to implement lean six sigma techniques as a sophisticated tool in Libyan Construction projects. Value stream mapping (VSM) is considered as a special type of flow chart that uses to depict and improve the flow of process steps and information from origin to delivery to the customer.

Keywords: lean six sigma (LSS), value stream mapping (VSM), DMAIC, construction.

I. Introduction

The Libyan construction industry has confronted many challenges over the past decades. More specifically, there have been some issues related to the availability of funds required to projects completion as well as technical problems during execution phases. Therefore, it is hard to stay in today's competitive market because the world of construction is changing and developing rapidly. However, the construction industry consumes huge quantities of resources and produces a plenty of waste (Banawi, M. Bilec, 2014). In fact, there are several types of waste (Muda) which are considered as activities that customers are not interested in paying for (pascal, 2014). In other words, waste can be any human activity that consumes resources, but does not add value to the product or service (Womack &Daniel, 2003). According to (Shingo, 1984), Waste can be specifically classified into 7 types of waste, and they can be summarized as follows: Over-Production waste is known as overuse of resources. For example, in production line, activities may be achieved too far ahead of the timetable that has already customized to perform these activities Extra Process is also a term that indicates to placing more into the product or operation that won't be valued by customers Inventory is also called as work-in-process which is presently unneeded or in surplus of requirements. The next waste is Transportation which is any materials or information that does not move efficiently among several processes at work. Waste of Waiting is any delay that is caused by idle materials, workers and information among the operations that are not concurrent. Motion is any movement of employee or equipment that is not necessary and does not add any value to products. Additionally, Waste of Correction Defects is reworking or rectifying the mistakes. The Correction will cause extra cost and waste time. Finally, Waste of Human Under Utilizing is not to benefit from the full capabilities of talent people. In brief, Waste is anything that does not add value to the product or services, and it takes time, consumes resources or occupies space. However, Sudhakar and Vishnuvardhan (2017) show that the measurements of the activity productivity are based on the ratio of the output and input for some construction works within an activity through the schedule, and it help plan an activity more accurately.

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II. Waste in Construction Projects

As mentioned earlier, Waste in the construction field, on the other hand, has been kept in consideration as the subject of many researches recently, and researchers apply many ways to reduce or eliminate the waste in the construction area (Hosseini; Wong & Zavichi, 2015). However, project managers seem that they conceptualize the Waste as physical waste. But from the lean perspective, which is an action strategy with the main objective of bringing down waste (Banawiand Melissa, 2014). There are a variety of hidden wastes can be noticed on the projects such as activities that do not add value to the process (Hosseini; Wong & Zavichi, 2015). In other words, the vast majority of construction managers agree that the construction projects confront various of wastes such as surpass, delays, and errors (Al-Aomar, 2012). Consequently, most of construction projects rarely complete on time, as will be mentioned later. The next terms explained more about some concepts in this regard.

III. Lean Approach

Lean is a systematic procedure to eliminate different types of waste (Amitha, Shanmugapriya, 2016).

Lean can also end the waste formed through the altering in progressed activities within project. Lean is also the series of tools that is utilized to eliminate the aforementioned sorts of waste. Moreover, lean is an integrated system of essential tools that can be utilized to reduce or eliminate different types of waste, and thus it is considered an effective tool to saving the cost resulted from delays in construction projects, for instance.

IV. Lean Construction

Back to almost twentieth century, an automobile manufacturing firm was called Toyota from Japan suffered several major issues like high costs, poor level of quality and high cost of raw material. However, in the late of 1940s, a Japanese engineer named Ohno released the spark of the Toyota Production System (TPS) that is identified as Lean Production (Abdelhamid, 2005). Additionally, Japanese were able to figure out that the mass production wouldn't be valid in Japan for some reasons which were the torn economy, the small local market and the competitiveness with the foreign market (Pascal, 2015). Nevertheless, lean approaches have been successfully applied widely, it has also been adopted in construction field, which are the International Group of Lean Construction (IGLC) and the Lean Construction Institute (LCI) (Abdelhamid, 2005).

V. Value Stream Mapping (VSM)

The paper applies value stream mapping (VSM), which is a Lean technique that constructs a process flow diagram of activities and information. The VSM utilizes a systematic method, and it covers all the tasks and activities which bring the project to completion, it also shows all steps needed to the operation, to show accurately any ineffectiveness that may appear in the map (Banawi, M.Bilec, 2014). However, the VSM included the following elements:

Activities steps – The VSM describes each of the process steps in the value stream, either value added or non-value added.

Information flow – The VSM depicts any backup information, schedule and specifications.

Cycle time (CT) – It shows one cycle time required to complete one activity, or it can be one step in a process.

Work in process (WIP) – It is any intermediate time which is not included in the predecessor activity nor the successor activity in the schedule.

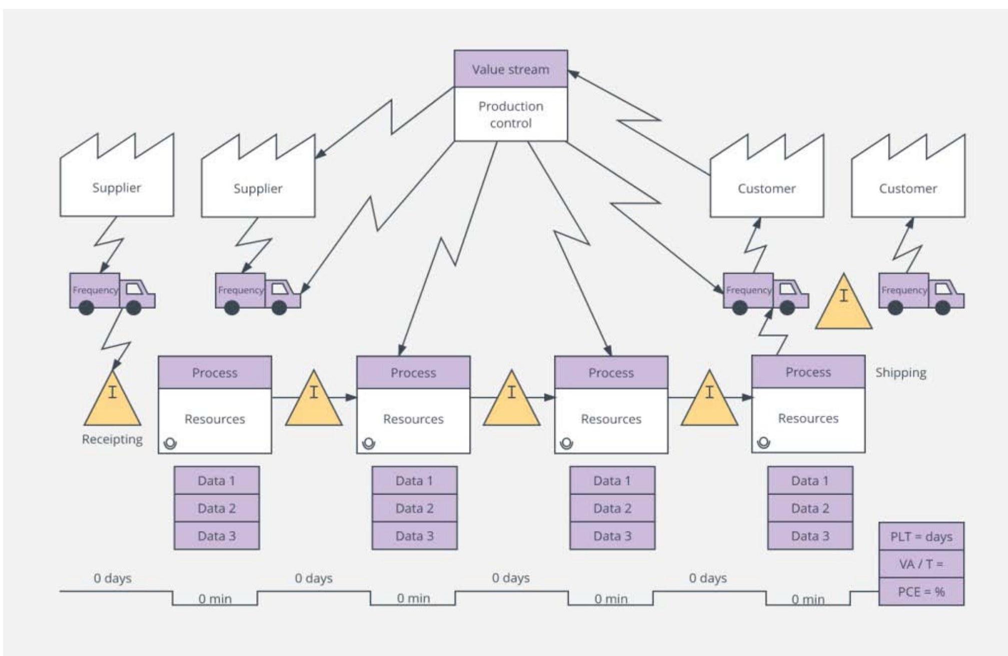

Figure 1: Example of VSM

VI. Lean six Sigma (LSS)

Six sigma is a quality improvement method that aims at optimizing operations while eliminating defects and costs. Six sigma is a quality improvement method that aims to optimize operations while eliminating defects and costs. Six Sigma approach can be relevant to all fields and industries including construction because it searches to improve quality and eliminate variation between upstream and downstream of the process, and errors (Al-Aomar, 2012). This technique focuses on finding out and eliminating process performance variability, and also utilizing several statistical methods to obtain rate of defects close to zero. Six sigma is also a mass improvement method used to help businesses achieve a high level of success. The Six Sigma system focuses on customer requirements, data, statistical analysis and ongoing improvement (Banawi, M. Bilec, 2014). They also state that Sigma indicates to the amount of discrepancy or variance that happening in the process, it equals in statistics to 3.4 defects per millions of opportunities (DPMO). A Fishbone is an optimal tool analysis that can be considered in order to figure out the causes and effects of the variation in the project schedule, as following:

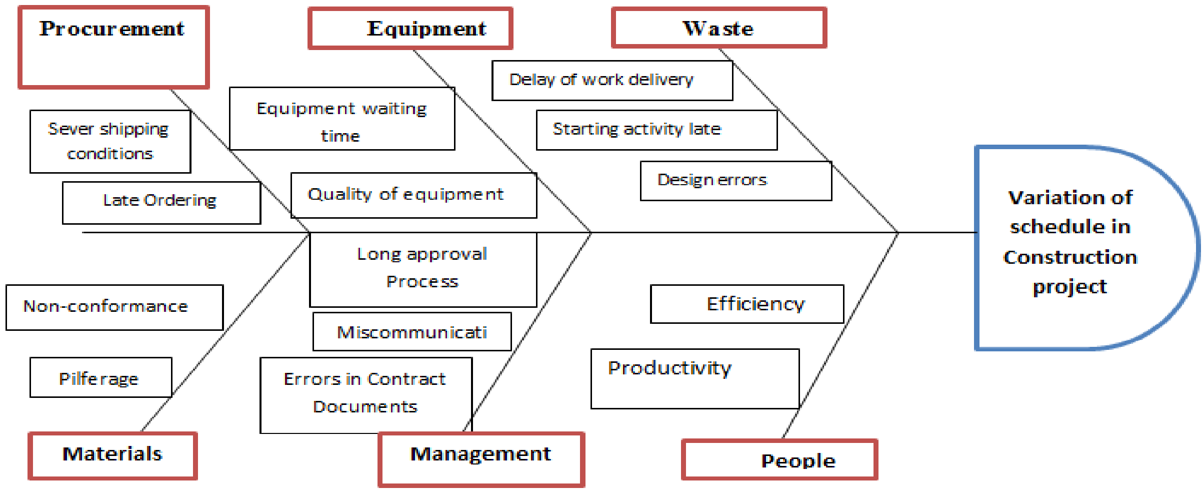

Figure 2: Shows the Fishbone diagram

DMAIC is a Six Sigma five-steps improvement paradigm: Define, measure, analyze, improve, control. Specifically, it is a number of ways and tools that can be utilized in each of the five phases. DMAIC can also be arranged into 5 steps as following (Sriram, Revathi, 2016):

DEFINE - To defines customer needs, and any requirements that don't meet these needs are considered as defects. At any time, schedule of project, the activities should be defined with the start and end milestones.

MEASURE - To determine and collect proper data related to the defects and the process to be developed. Specifically, to find out and collect the data regarding the delay in the project.

ANALYZE - To study the data that are collected from the last steps and analyze it in order to figure out the root causes of the defects, or delays.

IMPROVE - To Improve the process by reducing or eliminating the defects. It is also to identify the inputs that cause the variation in the outputs and improve them. It can be to reduce the time that caused the delay gradually.

CONTROL - It just makes sure that the previous procedure is effective, by reviewing the operation as a whole. It is to review the total time allocated to the activity.

VII. Methodology

The objective of this paper was to help reduce or eliminate the waste resulted from different processes by applying and improving a certain lean six sigma techniques. (VSM) is implemented in an infrastructure construction project at Al-Abyar City.

In order to attain this goal, some objectives were specified as:

- Reviewing the detailed time schedule of the above-mentioned project to figure out the delays among the project activities, and extracting the time that caused the waste of waiting. This is in turn considered to use a certain tool which is (VSM), as a technique used in addressing the delay in this project.
- Constructing a fish-bone model to display and analyze different types of waste of delay resulted on the project activities.
- Considering the Lean Six Sigma as an approach that can be applied by using a unique tool which is DAMIC method, as defined above.

VIII. Implementation of the VSM

VSM was applied to the processes of the water distribution project at Al-Abyar city. In this case, the process is consists of four activities which starts with project elaboration, bills of quantities elaboration, review by the client and ends with comment amendments. Each process has its constrain time in which it should be completed within. However, even though one process has been completed within the scheduled completion dates, the others have fallen behind schedule. It should be noted that due to time constrain and the lack of updated information of many construction projects in the Benghazi area the research project was implemented in a small section of a water distribution project in Al- Abyarcity.

The following table shows the estimated duration time, starting and finishing days at each activity as well as actual and delay time:

Table 1: Water distribution project activities

S. No.	Activity Name	Original duration	Starting and finishing days Start	Finish	Actual work	Delay
1	Project elaboration	27	17/8/2009	28/9/2009	11	0
2	Bills of quantities elaboration	7	20/6/2010	28/6/2009	8	150
3	Review by the client	4	20/6/2010	23/6/2010	3	147
4	Comments amendments	7	26/6/2010	23/7/2010	27	149

Based on lean philosophy any activities that do NOT change the form, fit, or function of the part and activities the customer does not want to pay for are classified Non-Value added activities (Waste), (Womack and Daniel, 2003, Banawi and Bilec 2014). In this project the original duration time in is classified as value added process which was accurately estimated by experts while the rest are classified as non-value added time. The following table presents the current status of the project activities:

Table 3: Current state mapping of water distribution activities

Time classification	Duration(days)	Percentage of time
Total value added time	45	9%
Total non- value-added time	439	91%
Total processing time	484	100%

As shown in the table above the total value added time represents just about 9% from the total time of the water distribution project, while the non-value-added activities represent about 91% of the total time. This waste was due the following activities:

1. Long approval process due to unjustified bureaucracy.
2. Non-payment of outstanding invoices on time.
3. The continuous changing of design concepts, which negatively affects the beginning and finishing of the implementation of the activities among the time schedule.
4. Neglect and lack of carful follow-up of the project schedule.
5. The late beginnings of the activities within the project due to series of long administrative procedures.

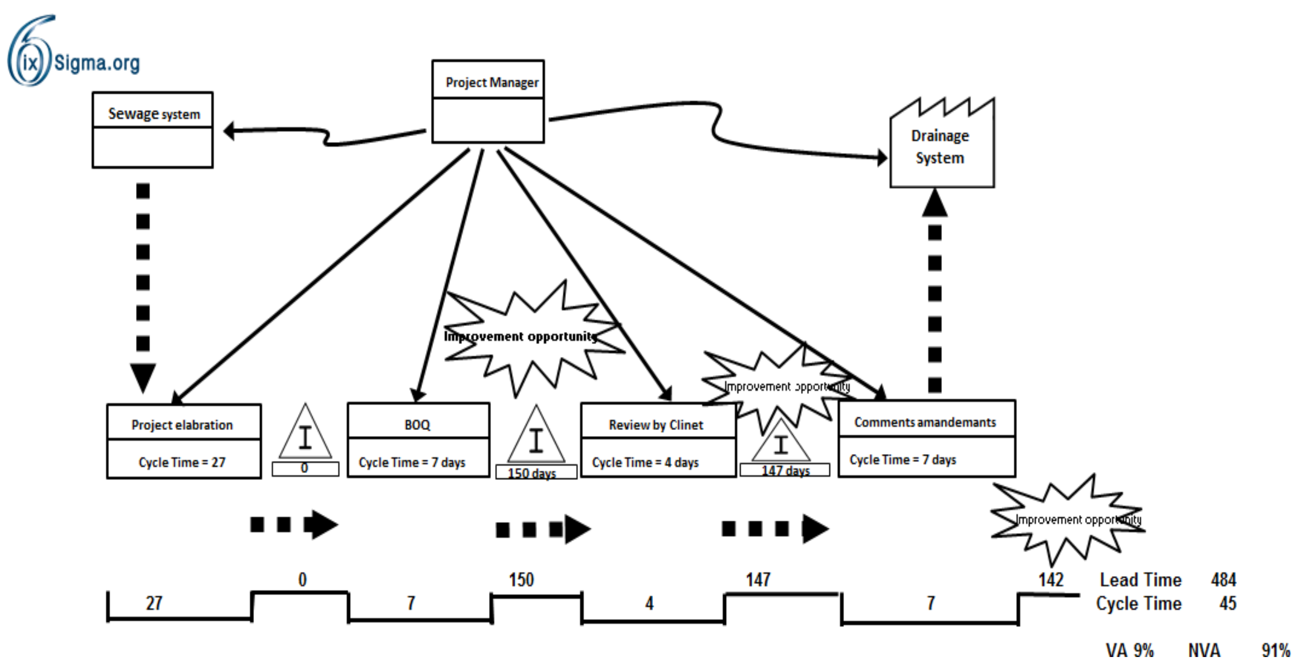

Figure 3: Value stream map (VSM) of the water distribution process.

Value Stream efficiency can be calculated by the following equation:

$$VSE = \text{Value add/Process Lead Time} = 45/484 = 0.09 \times 100 = 9\% \quad (1)$$

IX. Suggested Future State Mapping

Some suggested steps for future state mapping should be considered in order to improve overall project efficiency. These steps can be implemented as following:

1. In the first future plan Process Lead Time (PLT) of the BOQ, Review by client and comments amendments processes was decreased from 484 days to 184 days. Based on the calculation of this suggested step the VSE was improved from 9% to 24%, while the waste was reduced from 91% to76%.
2. In the second future plan PLT of the same three processes was decreased from 184 days to 75 days. Consequently, the VSE was improved from 24% to 60%, while the waste was reduced from 76% to 40%.
3. In the third future plan the PLT of the same three processes was decreased from 75 days to 60 days. Consequently, the VSE was improved from 60% to 75%, while the waste was reduced from 40% to25%.

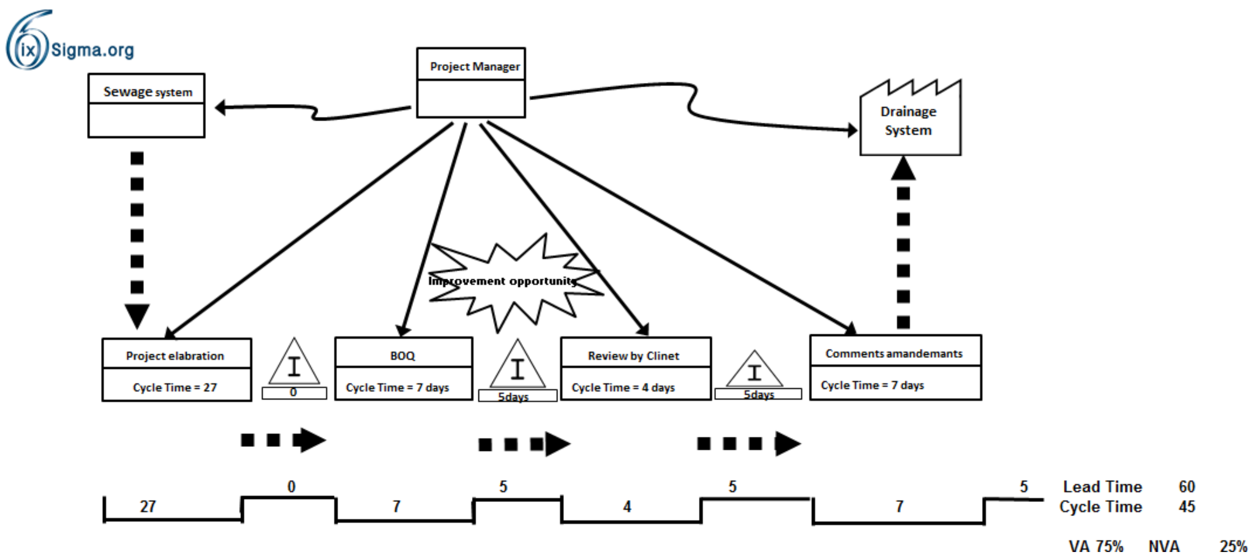

Figure 4: Future state mapping of the water distribution process

Table 3: Future state mapping of water distribution activities

Time classification	Duration(days)	Percentage of time
Total value added time	45	75%
Total non- value-added time	15	25%
Total processing time	60	100%

X. Conclusion and Recommendations

In real world construction process is a complex system that involves many interrelated tasks performed by different contractors. In order to overcome such this problem, complex construction project is treated as a collection of small projects. In this research paper, a small part of water distribution system was evaluated to find the major causes of waste that leaded to increase the PLT which made the project to fail behind the schedule. Lean Six sigma methodology was implemented the performance in construction operations by finding the main cause of variation and thus lean techniques were used to eliminate the waste which increased the VSE up to 75%. The VSE of any construction project could be improved by clearly identified the process bottleneck that leads to increase the PLT. It is recommended to implement Lean six sigma approaches in construction capital projects to improve overall the performance of construction operations in Libya.

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Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 20 Issue 3 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Burning Municipal Solid Waste to Generate Electric Power, a Study in Al-Marj, Libya

By Monaem Elmnifi, Naji Abdelwanis & Otman Imrayed
Benghazi University

Abstract- Incineration is used to reduce the effect of harmful environmental and health problems resultant from waste dumping into unsuitable landfills. The aim of this paper is to use incineration method to produce electrical energy from waste treatment. It is a new technology that destructs the solid waste by controlled burning at high temperatures. Different applications of incineration techniques have been evaluated in order to treat waste in El-Marj city. Based on daily waste weight for every person random samples are collected from different zones in the city for about 8 years. The thermodynamic model calculations of proposed plant show that one ton of waste can produce one MW of electricity.

Keywords: incineration; waste; electrical energy; environment.

GJRE-A Classification: FOR Code: 839804

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Burning Municipal Solid Waste to Generate Electric Power, a Study in Al-Marj, Libya

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Abstract- Incineration is used to reduce the effect of harmful environmental and health problems resultant from waste dumping into unsuitable landfills. The aim of this paper is to use incineration method to produce electrical energy from waste treatment. It is a new technology that destructs the solid waste by controlled burning at high temperatures. Different applications of incineration techniques have been evaluated in order to treat waste in El-Marj city. Based on daily waste weight for every person random samples are collected from different zones in the city for about 8 years. The thermodynamic model calculations of proposed plant show that one ton of waste can produce one MW of electricity.

Keywords: incineration; waste; electrical energy; environment.

I. Introduction

Thermal and non-thermal techniques are most common and popular method for municipal solid waste (MSW) treatment to produce energy. These technologies are widely used to reduce the environmental impacts caused by inadequate waste management [1]. Incineration and all other high temperature treatments are classified as waste thermal treatment. The basic idea of thermal process is to use heat resulting from burning waste to generate energy, while the non-thermal process is to generate energy without direct burning of waste or any burning resource [2].

As a result of continues improvement of thermal technologies, there are about 600 plants using incineration processes has been established recently to produce energy [3].

Incineration is considered as one of the common thermal methods, that is widely used as a treatment technique for MSW. One of main advantages of incineration is to reduce the quantity and volume of the waste. In incineration treatment process unprepared row materials are usually used [4]. Organics from the waste are collected and burnt at high temperatures. The incineration technique is an active technique that directly control of burning mixed waste in the presence of air at temperature range of 600- 850C° [1, 6].

In addition to incineration, there are two waste thermal techniques which known as advanced thermal treatment (ATT) used in waste industry as gasification, pyrolysis. Pyrolysis can be classified as a process without the use of oxygen. It requires external heat to maintain the desirable temperature, while gasification is considered to be between pyrolysis and combustion with control of oxygen. [5]

Compare to the other two thermal methods, incineration requires less area and less waste volume and quantity which can be considered to be more appropriate for Libyan waste management than the others.

Even though several ways are widely used to treat waste in the World, Libyan waste management has not applied any of the basic techniques at any waste treatment level. In this paper, Pfaffenauincineration treatments model has been studied to apply it in El-Marj city. The results show that the rate of waste in the city (kg/capita/ day) has been increased from 0.68 in 2006 to 1.08 in 2015. In addition, based on the thermodynamic equation our calculations show that one MW can be generated from one ton MSW. This paper is divided as following, types of thermal of waste treatment, data collections, model, results and conclusions.

II. Methods of Thermal Waste Treatment

The major difference between the three thermal technologies incineration, pyrolysis and gasification is shown in table 1. Temperature, pressure, atmosphere, stoichiometric ratio and products from the process are used as the base of comparisons between the three methods [6].

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Table 1: Typical reaction conditions and products from pyrolysis, gasification and incineration Processes adapted from [6]

	Pyrolysis	Gasification	Combustion
Temperature (°C)	250 - 700	500 – 1600	800 – 1450
Pressure (bar)	1	1 – 145	1
Atmosphere	Inert/nitrogen	Gasification agent: O2, H20	Air
Stoichiometric ratio	0	<1	>1
Products from the Process			
Gas phase:	H2, CO, hydrocarbons, H2O,N2	H2,CH4, CO, CO2, H2O, N2	CO2, H2O, O2, N2
Solid phase:	Ash, coke	Slag, ash	Ash, slag
Liquid phase:	Pyrolysis oil and water		

III. El-Marj Mswi Municipal Solid Waste Input Data

MSW data are collected from EL-Marj city during the period of (2006 – 2015).In 2001, the percentage of MSW per capita was about 0.915 kg / day, while in 2006 the proportion of the individual production of MSW was 0.98 kg per day. [9] The Municipal Solid Waste (MSW) generation in the Middle East and North Africa is estimated about 0.16 to 5.7 kg /person/day, with an average of 1.1 kg/capita/day [10]. Based on the prvious researches and our calculations the rate of 0.68-1.08 is used in this study. The technical data for MSWI potential for EL-Marj is shown in table2.

The average of waste can be calculated as following equation.

$$Theavaerageofwaste\,{}^{kg}/_{capita} = \frac{totalamountofwasteperonefamily}{numberoffamilymembers}$$

In this research, the average number of a family is assumed to be 7.

Table 2: Technical data for MSWI potential of EL-MARJ

Year	Citizens	Waste indicators [kg/capita/ day]	Waste quantity [Kg/year]	Waste quantity [ton/year]	The cumulative amount of waste
2006	55340	0.68	37.7	13505	13505
2007	62234	0.98	60.6	22228.5	35733.5
2008	71674	0.99	70.95	25896.75	61630.25
2009	80467	1.00	80.46	29367.9	90998.15
2010	89654	1.015	90.10	32886.5	123884.65
2011	98675	1.028	101.43	37021.9	160906.5
2012	107765	1.041	112.18	40945.7	201852.2
2013	116897	1.054	123.2	44969	246821.2
2014	125987	1.067	134.43	49067	295888.2
2015	135119	1.08	145.93	53264	349152.2

IV. Physical Model

Pfaffenau combustion plant is implemented in this research, data and schematic diagram are shown in the following table 3 and fig.1 respectively.

Table 3: General data of the fluidized bed reactor of the waste incineration plant Pfaffenau

Fluidized bed reactor Pfaffenau	
Start-up	1994
Start-up after overhaul	31.12.2000
Firing technology	Fluidized bed reactor
Waste throughput	26000t
Average calorific value of the waste	5000 - 30000 kJ kg-1
Thermal output	8 MW
Operating hours (test operation)	7300

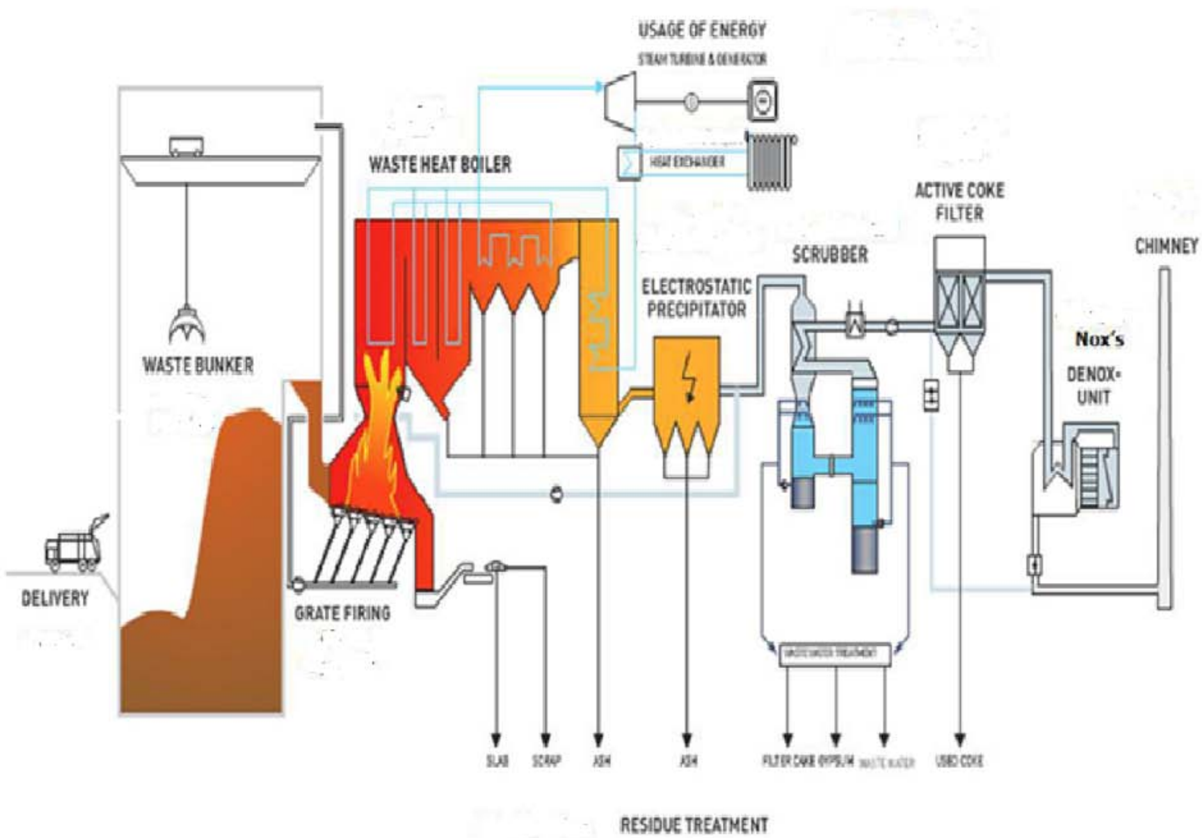


Figure 1: Shows the general structure of the power station of waste incineration

According Pfaffenau model the general construction of the station is consisting of the following units:

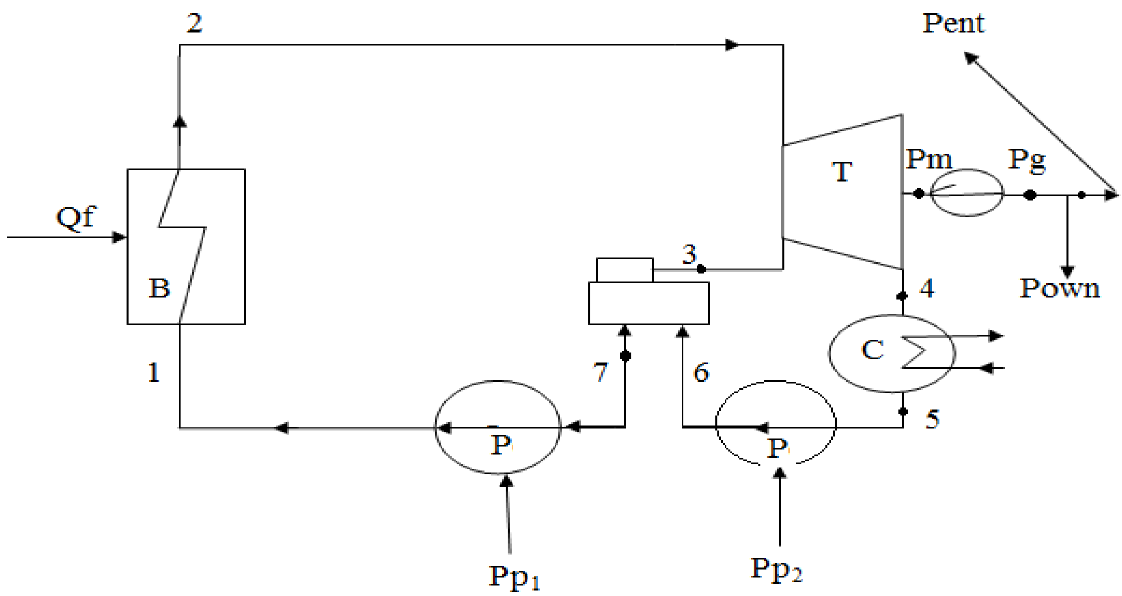
1. Waste bunker
2. Firing system: fluidized bed reactor
3. Waste heat boiler
4. Flue-gas cleaning devices consisting of: Electrostatic precipitator, three-stage wet scrubber,
5. Catalyst for NOX removal and dioxin destruction
6. Multistage waste water treatment plant
7. Steam turbine, generator and heat decoupling system.

This model was constructed in 2000 and it operated since 2001. In the first stage of waste incineration process, the MSW are delivered to waste banker then, moves to the pre-combustion process where metal and glasses are removed. Gas and slug or ashes are produced during the combustion stage. Flue gas is cleaned by using different filters. The clean gas is emitted through chimney in the last stage of the process. Thermal conversation of waste to energy is now very much applied technology for waste management system due to the generation of heat and energy from the waste stream. [6, 8]

V. Mathematical Model and Data Analysis

The mathematical model is the model that describes the accounts of the system when changing conditions of operation based on form physical in the, model is as follows: The Fig. 2 shows Diagram of the most essential component of the station.

The calculation of the generated potential energy from MSW incineration is obtained from thermodynamic equations mentioned below and fixed thermodynamic conditions in table 4 [11].



B=Boiler , T= turbine , C= Condenser ,P= pump

Fig. 2: Schematic of Power Plant

The thermodynamic equation are

$$P_m = m_2 \times (h_2 - h_1) \quad (1)$$

mechanical power from turbine (P_m)

$$P_g = \eta_g \times P_m \quad (2)$$

gross electric energy (P_g)

$$P_{net} = P_g - P_{own} \quad (3)$$

net electric energy (P_{net})

whine:

m = mass flow rate of steam (kg / s)

η_g = electric generator efficiency (%)

P_{own} = needs of electricity of power plant (6%.Pg)

h_2 = enthalpy input to turbine *(kJ / kg)*

$$Q_f = m_f \times c_v \quad (4)$$

The amount of heat supplied by fuel (Q_f)

$m_f = massofwaste\ (kg/s)\ , c_v = calorificvolumeofwaste\ (kJ/kg)$

$$Q_s = m_2 \times (h_2 - h_1) \quad (5)$$

The amount of steam supplied by boiler (Qs)

$$m_s = massofsteam\ (kg/s)$$

$h_2 = enthalpysteamatpoint\ 2\ , h_2 = f\ (P_2\ , T_2)$

$h_1 = Enthalpysteamatpoint\ 1$

$$\eta_o = (P_g - P_p / Q_f) \tag{6}$$

Overall Efficiency of The Plant (η_o)
needs of electricity of power pump (P_p)

$$\eta_{th} = \frac{P_{net}}{Q_s} \times 100 \tag{7}$$

η_{tb} Thermal efficiency (%)

$$S.f.C = \frac{(3600 \times m_f)}{Pnet} P_{net} \tag{8}$$

$$S.S.C = \frac{3600 \times m_s}{P_{net}} \tag{9}$$

S.f.C specific fuel consumption (kg_f / kW h)

S.S.C specific steam consumption (kg_s / kW h)

By conducting the calculations on the station and at temperatures ranging from 400 to 600 the change in output power ranging from 20 to 40 MW. Our calculations based on the upper equations show that the best efficiency can the plant reached is 28% at a temperature of 600 C° with lowest rate of fuel consumption. These results are show in table 5, table 6, table 7.

Table 4: Given thermodynamic data, P_{net} = 20 - 40 MW

Point	Condition	Given data
1	Compressed water	P = 95 bar T= 45 C°
2	Superheated steam	P = 90 bar ,T =400 to 600 C°
3	Wet steam expansion from 2	P = 6 bar , η_G = 97% η_B = 75%
4	Wet steam expansion from 3	P = 0.06 bar , X = 0.88
5	Saturated liquids	P = 0.06 bar
6	Compressed water	P = 6.5 bar
7	Saturated liquids	P = 6 bar
8	Water	P = 1 bar , T = 20 C°
9	Compressed water	P = 2 bar
10	Compressed water	P = 1.5 bar , T = 30C°

Table 5: Shows the results of the study at a temperature of 400 C°

P_{net}, MW	M_f, kg/s	η_{th}	η_o%	s.f.c, kg_f/kwh	S.S.C Kg_s/kwh	Mcw
20	3.2	27	20	0.58	5.4	1878
25	4.05	27	20	0.58	5.3	2347
30	4.8	27	20	0.58	5.3	2738
35	5.5	27	20	0.58	5.3	3207
40	6.2	27	20	0.58	5.3	3598

Table 6: Shows the results of the study at a temperature of 500 C^o

P_{net}, MW	Mf, kg/s	η_{th}	η_o, %	s.f.c, kg/kwh	S.S.C Kgs/kwh	Mcw
20	2.6	25	25	0.46	3.8	1353
25	3.2	25	25	0.46	3.8	1664
30	3.9	25	25	0.46	3.8	2026
35	4.3	25	25	0.46	3.8	2388
40	4.9	25	25	0.46	3.8	2214

Table 7: Shows the results of the study at a temperature of 600 C°

P_{net}, MW	M_f, kg/s	η_{th}	η_o, %	s.f.c, kg_f/ kwh	S.S.C kg_s/ kwh	Mcw
20	2.3	38	28	0.4	3.1	1118
25	2.8	38	28	0.4	3.1	1344
30	3.4	38	28	0.4	3.1	1666
35	4.1	38	28	0.4	3.1	1988
40	4.8	38	28	0.4	3.1	2214

VI. Results and Analysis

Based on the fixed values taken from the table 4 the electrical energy produced from 20-40 MW were calculated during the changes of temperature degrees from 400 to 600 C°. From equation (1) the mechanical energy was calculated (P_m) and by using equation (2) we calculated (p_g) gross energy and from it we got the total efficiency energy (p_{net}). From the thermal capacity of waste (CV) which amounts from 5000-30000 kJ/kg, where we had assumed it to be (30000), the thermal energy of waste (Q_f) was calculated from equation (4) and with using table steam on the temperature degrees from 400-600C° the Enthalpy steam ($h_1 - h_2$) was found and from it the thermal energy of steam (Qs) was calculated. Through the previous equations, the thermal efficiency was calculated (η_{th}) with the reparation in equation (7) and the total efficiency (ηo) from equation (6). Also the rate of consumption of fuel and gas (S.f.c), (S.S.c) from equation (8,9) and through it we obtain the results that are provided in the tables (5) (6) (7) that show each study on its own included with the change of temperature degrees from 400,500,600C° respectively.

After holding these accounts on bikes mentioned the heat was taking the temperature of 800C° and 1200 C° and found that there is an increase in the overall efficiency of the plant with a lack of consumer waste mass.

VII. Conclusions

In this paper we have calculated the daily amount of solid waste for each person, so it can be used to generate the thermal or electrical energy by burning it in the bed furnace and thus gaining heat with temperature above 850c°. We have applied thermodynamic equations to calculate the daily amount of solid waste for each person, so it can be used to generate the thermal or electrical energy by burning it in the bed furnace and thus gaining heat with temperature above 850c°. We have applied thermodynamic equations to calculate the rate of produced energy from 20Mw to 40Mw with change in temperature from 400c° to 600c° and to achieve results for the rate of fuel consumption, total efficiency and thermal efficiency. From these results it has been shown that the most efficient and least consumed fuel is at temperature of 600c°.

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Appealing Decisions

Unless specified in the notification, the Editorial Board's decision on publication of the paper is final and cannot be appealed before making the major change in the manuscript.

Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

Declaration of funding sources

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Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

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Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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ISSN 9755861