جامعة الأمير محمد بن فهد
PRINCE MOHAMMAD BIN FAHD UNIVERSITY

College of Engineering

Department of Mechanical Engineering

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Senior Design Project Report

Design and Development of an experimental prototype to investigate the flow dynamics in impinging jets encountered in well drilling application

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

Team Members

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Abstract

Impinging jets have been extensively investigated because of their wide industrial applications, ranging from turbine blade cooling, to well drilling and cooling of electronic devices, etc. Despite their geometric simplicity, the flow physics of impinging jets is complex. The flow dynamics of a jet impinging on a rotating disk has received less attention than with stationary disk despite its relevance to cooling processes in many industrial applications, such as the cooling of bearings, gas turbines disks, and alternators of wind generators.

An impinging jet is usually decomposed into three regions: the free jet, the impinging region and the outer wall-jet region. The physical composition of impinging jets depends upon a number of parameters, such as Reynolds number, orifice shape, orifice-to-plate distance and inflow turbulence. Each region of an impinging jet features different turbulence dynamics and requires an in-depth flow physics analysis using advanced experimental techniques.

Based on such a background, the project will be looking into the fluid flow visualization while in a drilling well operation that is taking place. Additionally, these processes will be made sure to be simulated and tested in laboratory environment for the sake of awareness and demonstration.

Acknowledgement

First of all, we would like to express our appreciation to our advisor Dr. Mohammad El-Hassan for his continued support in our project and his sincere encouragement. Also, we express our sincere thanks to our professors in the faculty of Engineering for their expertise and guidance. We would like to extend our thanks and appreciation to Dr. Faramarz Djavanroodi, chair of the Mechanical Engineering Department at PMU, for his continuous encouragement and to believe in us and our abilities to carry out such a project that clearly tests us and challenges us to hone and use our gained knowledge through the year. Lastly, we thank our parents for the unceasing encouragement, support, and attention as because of their moral support we are able to stand tall at such a position.

List of Acronyms

P	**Pressure**
$\dot{m}$	**Mass Flow Rate**
V	**Velocity**
A	**Cross Sectional Area**
V	**Volume**
Re	**Reynolds Number**
H	**Height**
P	**Density**
M	**Mass**
Ma	**Mach Number**
$\dot{Q}$	**Volume Flow Rate**
D	**Diameter**
μ	**Dynamic Viscosity**

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Chapter # 1: Introduction

1.1 Project Definition

As our project is aiming in developing and designing an impinging jet unit/mechanism on a rotating disc, which actually will be biased towards the drilling well operations. However, considering that impinging jets are widely used in many different industrial sectors where there is a need to cool down components and to wash out contamination, these jets, due to their extremely high velocity and turbulence can also effectively play a vital role in heat transfer based on the needs and for such an achievement the desired Reynold's Number must be achieve in order to get desired results and characteristics.

1.2 Project Objectives

The main objective of this project is to design and build an experimental prototype to investigate the flow dynamics in impinging jets encountered in well drilling application. The primary objective of our study is to deepen the knowledge of the turbulent boundary layer that develops on a rotating disk through detailed experimental measurements. The present project has two main objectives:

(i) To design and build an experimental setup that consist of a jet nozzle, a rotating disk and a water tank with optical access to investigate the flow dynamics.

(ii) To select and fabricate a drill bit in order to simulate the well drilling operating conditions in a laboratory environment.

(iii) To source different components for jet flow visualization and wall shear stress measurements.

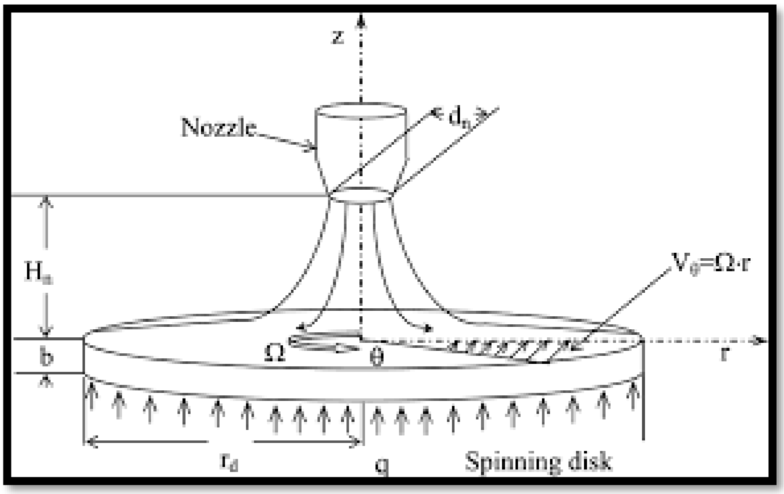

Figure # 1: Impingement on a Rotating Disc

1.3 Project Specifications

Since our team will be devising a flow visualizing of an impinging jet on a rotating disc rather than a stationary one, the jet will depend heavily on the Reynold's Number and flow exit velocity. The bit design and everything will be selected accordingly.

In order to give a sense of idea regarding the specifications of our prototype, the considerations are highly on the Reynold's Number being produced by the jet which will be ranging within the limit of 500-10000. Additionally, the pump and the orifice design will be based on the losses within the piping systems as it should have as minimal perturbation possible in order to make it work effectively and efficiently.

1.4 Project Applications

According to the design and the sophistication our project involves, it is quite usual that it will have most of its viable uses in the industrial sector at a wide range. Based on the theories and hypotheses applications in the industrial region can be:

- Cooling the drilling bit while in an operation.
- Washes away effectively the debris while in the drilling operation because of high turbulence in the flow.
- Rocket Launcher cooling.
- Gas Turbine Cooling.
- High-Density electrical equipment cooling as it requires a higher heat transfer.

Chapter # 2: Literature Review

2.1 Project Background

The impinging jet is of great importance in many engineering-relevant problems, such as the cooling, heating, and drying processes. Accordingly, a computational prediction of heat and fluid flow associated with flow impingement has long been a challenging task in turbulence. The difficulty is that the turbulence structures are not solely determined by the mean shear, but also by the stagnation and streamline curvatures that play important roles as they impose extra rates of strain. In the present study, we consider a more complicated case in which the flow is being impinged onto a rotating disk. The moving wall causes a skew of the boundary layer, and the disk rotation asserts a centrifugal force to the fluid particle attached to the wall [1].

2.2 Previous Work

As our project needs ideas and some consideration of the approach to the problems. Our team got involved in a mini-research work to deal with the previously done work, projects and research related to impinging jets. Of course, we had to aim towards the findings and implications with respect to rotating discs of an impingement of fluid. For that, we needed to do an extensive amount of study based on the Reynolds Number to be achieved. Furthermore, the projects done in the past carry a lot of intel which we can use to our benefit as discussed below.

First of all, he free-surface flow formed by a circular jet impinging on a rotating disk is analyzed theoretically. The study explores the effects of rotation and inertia on the thin-film flow. Both boundary-layer height and film thickness are found to diminish with rotation speed. A maximum film thickness develops in the supercritical region, which reflects the competition between the convective and centrifugal effects. Unlike the flow on a stationary disk, an increase in the wall shear stress along the radial direction is predicted, at a rate that strengthens with rotating speed. Our results corroborate well existing measurements. The location and height of the hydraulic jump are determined subject to the value of the thickness at the edge of the disk, which is established first for a stationary disk based on the capillary length, and then for a rotating disk using existing analyses and measurements in spin coating. The case of a stationary is revisited in an effort to predict the location and height of the jump uniquely. The formulated value of the height at the edge of the disk seems to give excellent results for a jet at moderately high flow rate (or low viscosity) where the jump structure is well identifiable in reality [2].

Secondly, an experimental study of the flow interaction and heat transfer between a single impinging jet and a rotating disk is presented. Tests were conducted over a range of jet flowrates, impingement radii, and disk rotational speeds with various combinations of three jet and three disk sizes. Flow visualization using smoke addition to the jet flow reveals the presence of a flow regime transition, which is correlated in terms of the rotationally induced disk pumping flow acting as a crossflow influence on the jet. Higher rotational speeds, larger impingement radii, and smaller jet flowrates favor a rotationally-dominated flow interaction, whereas the opposite trends favor an impingement-dominated interaction. Heat transfer rates are essentially independent of jet flowrate in the rotationally-dominated regime, but increase strongly with increasing flowrate in the impingement-dominated regime [3].

These previously done work has provided a sense of direction in order for our project to take a significant shape and progress. Because, what many people have done with regards to rotating discs impinging, there has been more focus towards the impinging jet on a stationary disc which really seems fine enough. However, if gone in-depth of the flow studies when the discs are rotating, there is a completely new different picture and flow visualization.

2.3 Comparative Work

For our team and the project, we are responsible to hold up our reputation as mechanical engineers in our institute and successfully pass out by achieving of the most important milestone of the whole degree plan, the senior year project. And, for that we have to ensure that the project we are pursuing as a team can be compared with the projects or some research work done in the past.

To begin with, a research conducted by one of the faculty members from the Croatian University of Zagreb, put forth the idea of cooling of a rotating disc and the effect that a jet impinging on a rotating disk has on the cooling process of the disk is measured experimentally. The laminar and turbulent local heat transfer coefficients are obtained for a wide range of rotational and jet Reynolds numbers. Correlation formulas are proposed for both flow conditions, and respective differences in heat transfer mechanisms are discussed. It is shown that the jet promotion of turbulence causes laminar heat transfer coefficients to increase strongly but exerts no such pronounced influence on turbulent heat transfer. The correlation formula for laminar heat transfer is compared with existing experimental data, and satisfactory agreement is obtained [4].

Also, Results are presented from an experimental study conducted to determine the average convective heat transfer coefficient for the side of a rotating disc, with an approximately uniform surface temperature, cooled by a single liquid jet of oil impinging normal to the surface. Tests were conducted over a range of jet flow rates, jet temperatures, jet radial positions, and disc angular velocities with various combinations of three jet nozzle and disc diameters. Correlations are presented that relate the average Nusselt number to rotational Reynolds number, jet Reynolds number, Prandtl number, and dimensionless jet radial position [5].

Since most of these projects were and are highly focused on the heat transfer and cooling aspect of a disc (whether stationary or rotating disc), an impingement jet actually serves as a coolant. However, while keeping such a basic concept with us as a constant parameter of consideration, our team actually will be visualizing the fluid flow while the jet is impinged on a rotating disc. Because, there are new studies and theories to learn and investigate. Based on such a concern, parameters such as orifice diameter, pump flow consistency, pressure losses in the piping system and the most important parameter of them all, Reynold’s Number are kept on the priority for the successful demonstration of our project.

Chapter # 3: System Design

3.1 Design Constraints and Design Methodology

3.1.1: Geometrical Constraints:

Since our project is completely based on the fact that it will be used for the flow visualization and laboratory purposes, we had to make some drastic design constraints which included a drilling bit in a scaled-down size, along with a pump that should be free from any kind perturbations as there will be a need to obtain a proper Reynolds Number in flow output which would be turbulent enough. Moreover, orifice diameter and the nozzle specifications also needed some proper kind of selection or fabrication may also be needed in a worst-case scenario.

3.1.2: Sustainability:

In order to make our prototype sustainable enough for the laboratory-controlled environment. Most components were selected on the basis of withstanding high heat, high pressure and abrasive punishment from the fluid flow at extremely high velocity. Since, we are aiming towards enhancement of drilling operations, we have also made sure that the components are corrosion resistant as fluid of many different properties could be used for the sake of testing and analyses to observe behavioral changes in flow dynamics. Moreover, preventive maintenance was kept at a number one priority because it can lead to some catastrophic failure of the whole system or may even lead to unsafe operation giving undesired results or observatory results when required.

3.1.3: Environmental Concern:

In terms of environmental aspect, it is safe to claim that our prototype can do no such harm to the environment as most components being used will be completely safe. If the question comes of disposing a specific component, there are many industrial methods by which it can be disposed off properly and be reused again. However, to power up our system we would for sure require an electric source but there are no emissions bound to be produced by our system which makes it environmentally friendly. Additionally, being a lab-based prototype flow visualization setup, we are confident that it could pass through the required decibels allowed within lab conditions, hence, making it free from any noise pollution.

3.1.4: Social Impact:

Any project that is for the well fare of the industry that will surely benefit the society of it. Since, the project will always be aimed towards the betterment of operational efficiency, effectivity or cost saving without compromising on the quality of the outcome, claims can be made with pure intention that it would open an opportunity for investors to step in the field to sponsor such projects which can reach the prosperous stages of development. These investments will provide a very clear social impact proving the ideas and the skillful youth which are striving to contribute in achieving one of the objectives of Vision 2030 which is to increase the public's investment funds so the people of Saudi Arabia can get benefit and the needs that any prosperous and developed country would need to survive and compete.

3.1.5: Economic:

According to the Kingdom's Vision 2030 objective to improve the GDP and the overall cost-effectiveness in several different projects, quite prominently in the field of oil and gas, these technological advancements can play a very supporting role for the future and well-being prosperity of our country. Since, we as a group and many other technical personnel are thriving to work hard and devise solutions to improve the quality of operations and save cost, we think our project could be a very unique initiative towards the contribution of improved and cost-effective drilling operations. Because, approximate fare for one day of operation at a typical drilling site in Kingdom can escalate to as much 200,000 U.S. Dollars, little but prominent advancements can play a very root cause for the cost savings.

3.1.6: Safety:

Safety is always kept as number one priority for us, since we will be dealing high pressure, high temperature and also fluid with a very high velocity. As well as, the rotating drilling bit which is powered via belt pulley system will be under extreme operation. So, we have ensured that our prototype all the essential safety standards and preventions that requires a safe operation, testing, observation and analyses.

3.1.7: Ethics:

Ethically, we are bound to select a topic and a unique idea which will benefit the Kingdom and its people. Although no project or prototype or even a research cannot be conducted by a mere idea of an individual, it takes some background information, some knowledge, some exposure to the relevant topic of interest and future recommendations of previously done work. So, instead of just following an idea of our own, we are also taking some motivation, some ideas and knowledge from the work done globally relevant to our topic. This gives us more confidence and a proper insight of how we will be able to work our thing in a way we have intended it to.

3.2 Engineering Design Standards

Since our project contains components that are readily available in the market, as far as the engineering standards are concerned, they are dependent on the manufacturers producing such components. However, below is the list of components with their grade/ standards enlisted.

Components	***Engineering Standards***	***Details***
Cylinder	Acrylic (ASTM D4802)	Bore: 10.7 cm, Length: 50 cm
Hollow Shaft	Stainless Steel (SS304)	Bore: 1.95 cm, Length: 80 cm
Drill Bit	Photopolymer	Bore: 2 cm, Diameter: 9.3 cm
Pulleys	Carbon Steel (ASTM A29)	Bore: 1.4 cm, Diameter: 10 cm

Table # 1: Engineering Standards

3.3 Theory and Theoretical Calculations

In order to properly carry out successful calculations of our system design, some theoretical aspect has been taken into consideration to come up the necessary requirement with which our system could work and produce outcomes such as power, torque of drilling bit, etc. Following calculation carried out in the bottom would surely be necessary in order to help identify the specifications and working requirements for our prototype.

3.3.1 Torque:

For Torque calculations; (250 RPM as Maximum)

$$T = \frac{hp \times 5252}{N}$$

$$T = \frac{0.496178 \times 5252}{250}$$

$$T = 14.127\ N.m$$

Considering Minimum RPM of 50;

$$T = \frac{hp \ \times 5252}{N}$$

$$T = \frac{0.496178 \ \times 5252}{50}$$

$$T = 52.11 \ N.m$$

3.3.2 Volume Flow Rate:

Assuming our Re is ranging between 500-10000,

$$Re = \frac{\frac{4\dot{m}}{\pi D}}{\mu}$$

If, Re = 10000,

$$Re = \frac{\frac{4\dot{m}}{\pi(0.005)}}{0.891 \times 10^{-3}}$$

$$\dot{m} = 0.0.3498 \ kg/s$$

$$\dot{m}(for\ the\ eight\ outlet\ jets) = 0.2798 \ kg/s$$

$$Q = \frac{\dot{m}}{\rho}$$

$$Q = \frac{0.2\dot{7}98}{1000}$$

$$Q = 0.0002798 \frac{m^3}{s}$$

$$Q \cong 17 \ L/min.$$

3.4.3 Pump Work

$$P_{in} = \rho gh = atmospheric\ pressure$$

$$Maximum\ Pump\ of\ Work\ \left(W_{pump}\right) = \dot{m}gh$$

$$W_{pump} = (0.2798)(9.81)(20)$$

$$W_{pump} = 54.8967 \ kW$$

Since we are dealing with the changes in pressure only, the change in heat will be zero.

$$q_{net} = \Delta u = zero$$

However, to determine the work of pump to the stem;

$$W_{pump} = \dot{m}gz_2 + \dot{E}_{mechanical\ losses}$$

$\dot{E}_{mechanical\ losses}$ *will be zero since piping friction losses and in hoses*

$$W_{pump} = (0.2798)(9.81)(0.5)$$

$$W_{pump} = 1.4669\ kW$$

3.4.4 Required Pump Pressure

$$\Delta P = P_{out} - P_{in} = \frac{W\_pump}{\dot{v}}$$

$$\Delta P = \frac{1.46169}{0.0002798}$$

$$\Delta P = 5224.05\ Pa$$

3.4 Product Subsystems and selection of Components

3.4.1 Base

Since we are designing and manufacturing a prototype for lab testing purposes solely for the sake of fluid flow visualization in the water impinging jets of a drilling bit, the whole system should be mounted on a base that can withstand a considerable amount of load and can secure motors and other moveable components effectively.

3.4.2 Dampers

Since we will be mounting some heavy motors along with all the system components including pulleys, stands and a steel pipe with a drilling bit one of it's ends. It is prone to have vibrations that can disturb the overall performance of our system and visualization of impinged fluid. So, we have placed dampers to absorb the persisting vibrations effectively to avoid system operation disturbance and hinderance.

3.4.3 Motor

We have selected a motor that will be powering the drilling by means of a belt and pulley mechanism. Since, we are using belt mechanism, we are bound to have minor slippage losses which we can consider as negligible as it will be functioning in a newer state. Therefore, the motor will be mounted in a vertical position.

3.4.4 Water Pump

We have selected a centrifugal type water pump which will be pump water from a reservoir in order to successfully simulate fluid flow and can maintain a proper flow rate. Although we would be facing some head loss in the fluid flow, it is possible that such an anomaly could cause perturbations while achieving the Reynolds' Number we desire.

3.4.5 Drilling Bit

Drilling bit is the main component of interest as we are focusing to improve the drilling operations being carried globally, especially in the region of Eastern Province, KSA. Typical drilling bits contain an orifice that impinges the fluid used to exit at an elevated pressure and flow rate which is mostly in turbulent conditions. The similar kind of drilling bit will be used but when the fluid we would be using is water.

3.4.6 Cylinder

In order to keep a safety enclosure around the impinging operation where the drill bit will be revolving at a high angular speed and ejecting water from its jets at a very high pressure, a transparent cylinder will be used, most probably of light weight polycarbonate glass which is impact resistant and better than any glass or plastic grade.

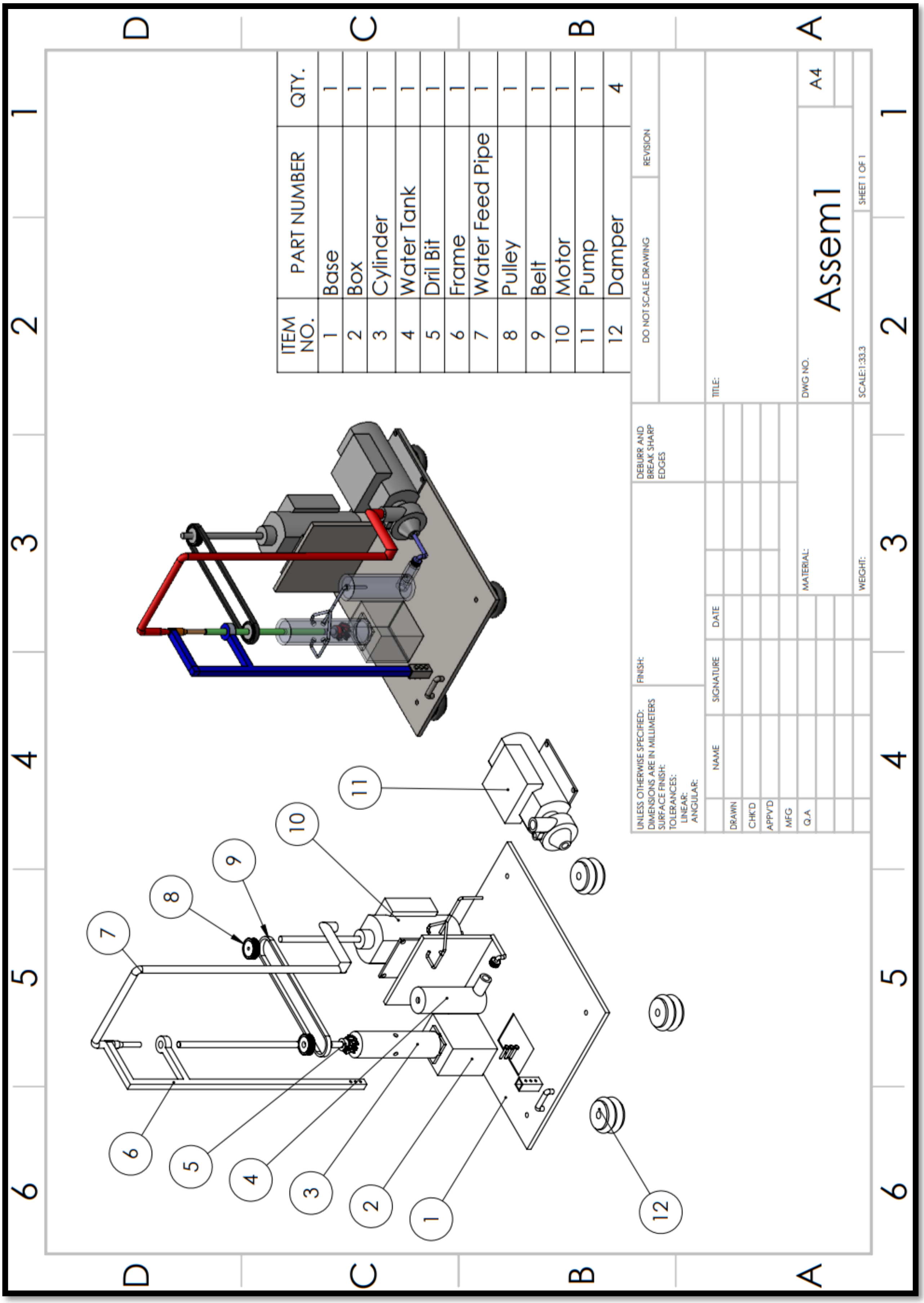

Figure # 2: Prototype CAD Model

3.5 Manufacturing and Assembling (Implementation)

As engineering students attending the final year project, time always can get too limited if we some delays are encountered while the assembling and manufacturing of the prototype. So, in order to be free from hassles and dilemmas, we have been gathering and purchasing the required components which would be assembled and bolted down with each other in a timely fashion however, it will all be carried out at a third party fabrication workshop where availability of tools are in reach as well as we can also have some assistance from some of the skilled technical personnel in order for us to achieve the required and desired product. As there is a pulley belt mechanism which would be operating the drilling bit, it would need a careful installation as well as alignment to prevent any operational mishaps.

Chapter 4: System Testing and Analysis

4.1 Experimental Setup, Sensors and data acquisition system

4.1.1: Humidifier

In order to obtain the data from out Stirling Engine system, we first had to go step by step calculating and measuring all the important parameters necessary to define our system's performance. For that, we first measured the output flywheel's angular speed in revolutions per minute (rpm) using a tachometer. The setup was conducted in manner that a small strip of paper was attached to the flat face of the flywheel and the laser was directed towards it in order to properly read revolutions. However, our system managed to run at 800 rpm when in peak heat. Since our system is small scale, the amount of rpm produced at maximum potential was quite satisfactory.

Moreover, the tachometer has following specifications;

Specifications:

- Non-Contact Measurement: 50 to 9999RPM ± (0.03% + 2)
- Measuring Distance: 50 mm to 250 mm
- Auto Power Off: 30 seconds
- MAX/MIN/AVG Function: Yes
- m/min, m/sec, ft/min, ft/sec, in/min unit selection: Yes
- Data Hold: Yes
- Display Back Light: Yes
- Low Batter Indication: Yes
- Power Supply 4x1.5 AAA Batteries (Excluded)
- Package Size: 19 x 11 x 16 cm/ 7.6 x 4.4 x 2.4 in.
- Package Weight: 288g / 9.6 oz.

Figure # 3: Tachometer

4.1.2: **Infrared Thermometer**:

Since our system works on the principles of thermodynamic and temperature difference, there was a need to determine how much heat input was given by the source, which in our case is an LPG powered stove, and in order to observe and see the temperature difference, we used an infrared thermometer which was an essential instrument to detect temperature without any physical contact on the system components.

In order to analyse the temperatures in different parts like the heating cylinder, cooling cylinder and the burner. The system was operated for several minutes to reach maximum performance conditions where the output is stable, reasonable and favourable. After that, the infrared thermometer was directed towards the component and held for several seconds to obtain a stable temperature reading.

Additionally, the infrared thermometer used had the following specificatons;

Specifications:

- Temperature range：-50 ~ 380℃ (-58~716℉)
- Accuracy：±1.5% or ±1.5℃
- Repeatability：±1% or ±1℃
- Distance Spot Ratio：12:1
- Emissivity：0.95 preset
- Resolution：0.1℃/℉
- Response Time：500ms
- Wavelength：8-14μm
- ℃/℉ Selection
- Data Hold function
- Laser Target Pointer selection
- Backlight ON/OFF selection
- Auto Power Shut Off
- Power supply：2 x 1.5V AAA battery
- Weight：115.1g（Including battery）
- Dimension：144.5 x 38 x 93 mm

Figure # 4: IR Thermometer

Testing Parameters	
Tachometer	**To obtain the output angular speed (rpm)**
IR Thermometer	**To obtain the operating temperatures**

Table # 2: Testing Parameters

4.2 Results, Analysis and Discussion

Data obtained from performing the setups in order to get our system performance figures, following tables have been compiled which shows us the temperatures, angular speeds and also the flow visualization by the means of Computational Fluid Dynamics Software.
CFD analysis is used in order to describe the flow dynamics in the complex geometry of the drill bit. Therefore, flow separation, recirculation regions and interaction between different jets can be investigated.

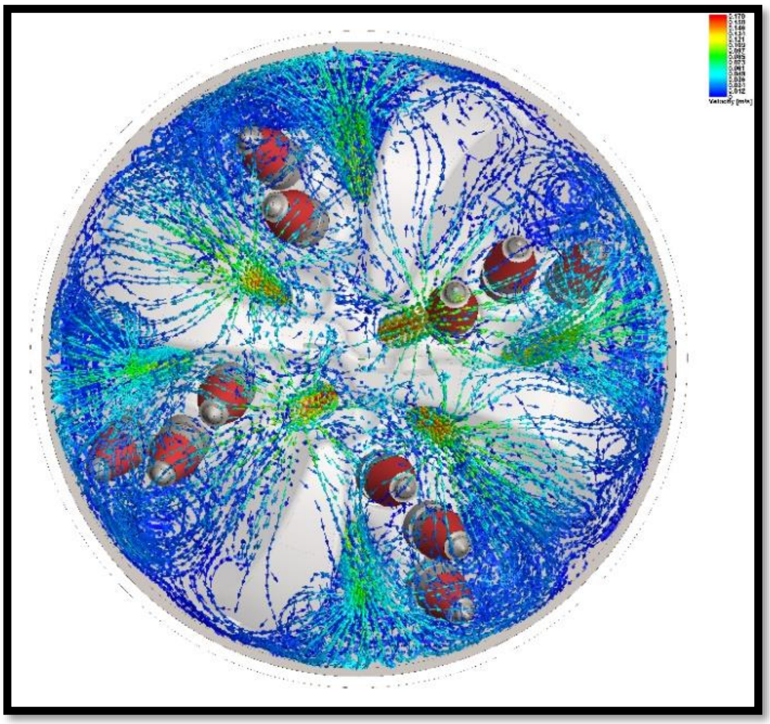

Figure # 5: Bottom View of Drilling Bit Flow Visualization

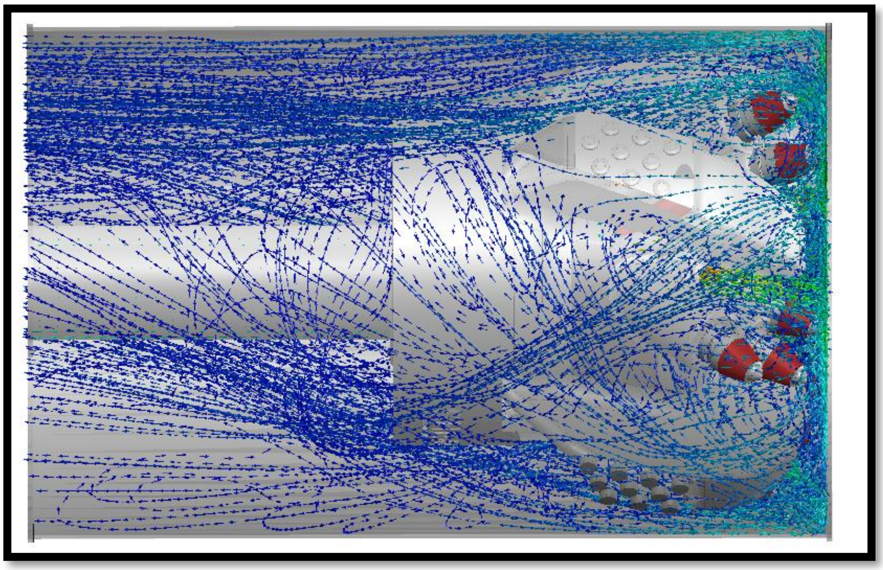

Figure # 6: Side View of Drilling Bit Flow Visualization

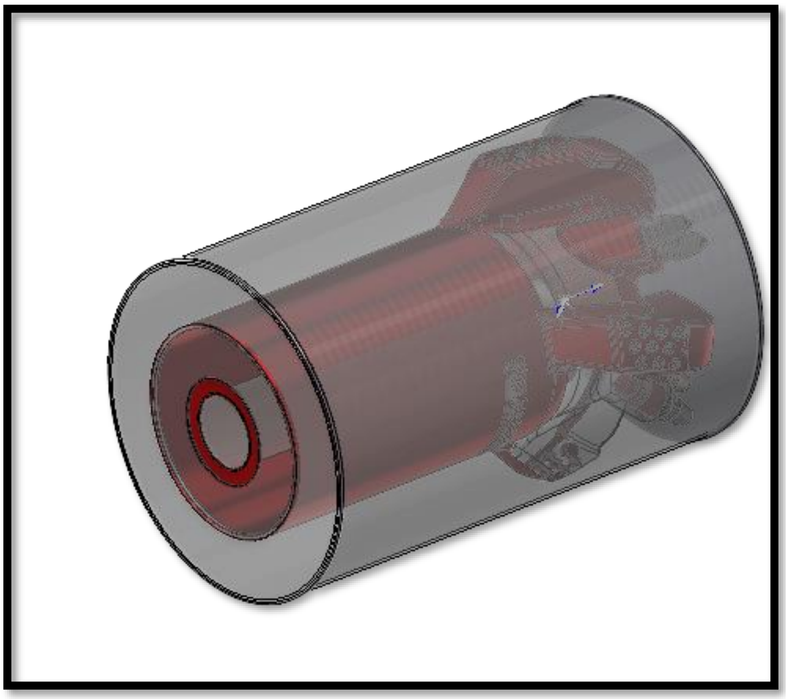

Figure # 7: CAD Model of Prototype Drilling Bit

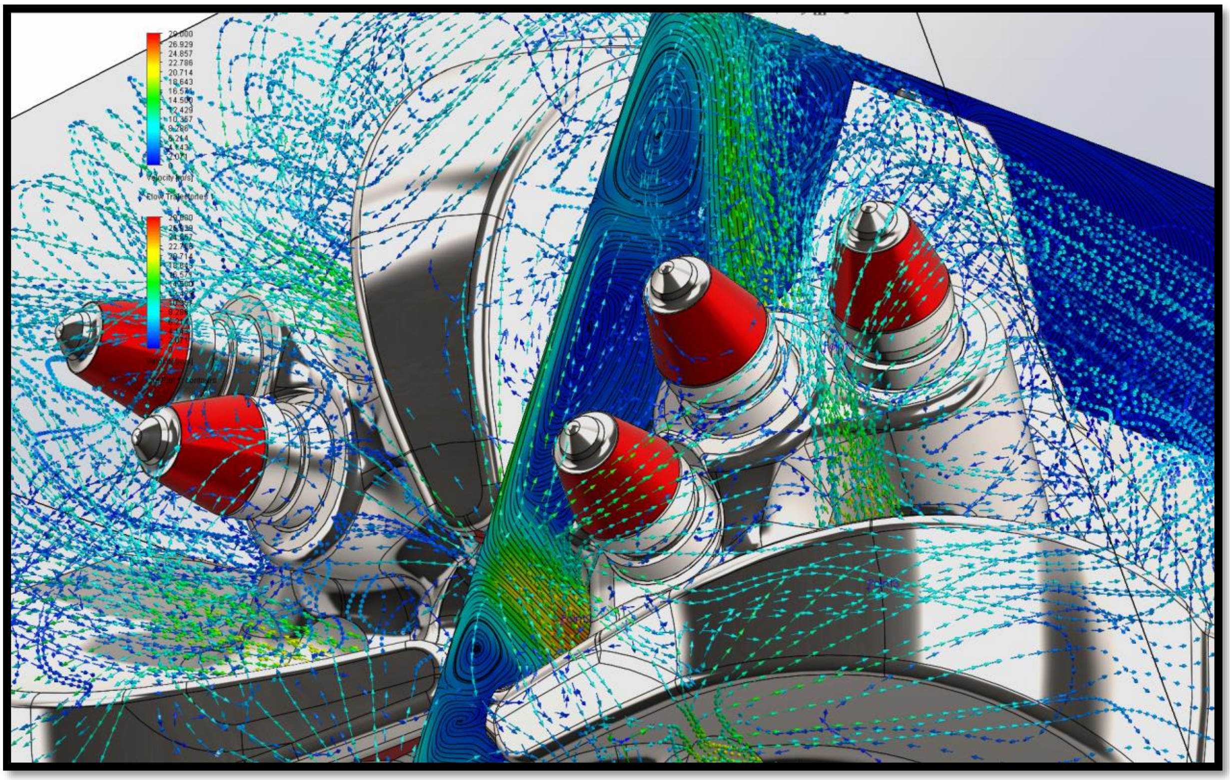

Figure # 8: CFD Model of Prototype Drilling Bit in Operation

Figures above were obtained from CFD results after selecting a mesh of 12 million hexahedral cell, Near wall refinement and Adiabatic walls with an overall computational time of 72-96 hours/case.

Additionally, the angular speed recorded when motor was operated at 4.8 Hz should be 288 rpm but due to losses during power transmission via belt and the resistance of the fluid movement enclosing the drill with acrylic glass gave us a reading of 252 rpm.

Similarly, the temperature was recorded for drill bit at no operation conditions i.e. 0 rpm to be about 36.8^{O}C with the water temperature to be around 28^{O}C. Then when operated at 288 rpm, the water temperature was risen to be about 31.8^{O}C.

Chapter 5: Project Management

5.1 Project Plan

The project comprises of various tasks that are assigned to each group member in an equal manner, to ensure fairness between the members. Each member was given a specific task that needed to be completed within a certain amount of time.

The times and dates listed in the Gantt Chart were followed to ensure consistency and quality of the work done by the group members.

Table 3 displays the number of tasks done alongside with the number of days it took for that specific task to be completed.

<table>
<tr><th>S. No.</th><th colspan="2">Tasks</th><th>Start</th><th>End</th><th>Duration</th></tr>
<tr><td>1</td><td colspan="2">Ch. 1: Introduction</td><td>23.01.2019</td><td>27.01.2019</td><td>4 days</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Ch. 2: Literature Review</td><td>Project Background</td><td rowspan="3">30.01.209</td><td rowspan="3">03.02.2019</td><td rowspan="3">4 days</td></tr>
<tr><td>Previous Work</td></tr>
<tr><td>Comparative Study</td></tr>
<tr><td rowspan="5">3</td><td rowspan="5">Ch. 3: System Design</td><td>Design Constraints & Methodology</td><td rowspan="5">08.02.2019</td><td rowspan="5">19.02.2019</td><td rowspan="5">9 days</td></tr>
<tr><td>Engineering Design Standards</td></tr>
<tr><td>Theory & Theoretical Calculations</td></tr>
<tr><td>Product Subsystems & Component Selection</td></tr>
<tr><td>Manufacturing & Assembly</td></tr>
</table>

4	Ch. 4: System Testing & Analysis	Experimental Setup, Sensors & Data	10.03.2019	29.03.2019	19 days
		Results, Analysis & Discussion			
5	Ch. 5: Project Management	Contribution of Team Members	06.04.2019	09.04.2019	3 days
		Project Execution Monitoring			
		Challenges & Decision Making			
		Project Bill of Materials & Budget			
6	Ch. 6: Project Analysis	Impact of Engineering Solution	05.04.2019	08.04.2019	3 days
		Contemporary Issues Addressed			
7	Ch. 7: Conclusion & Recommendation	Conclusion	07.04.2019	09.04.2014	2 days
		Future Recommendation			
8	Design of Prototype		08.02.2019	11.02.2019	3 days
9	Parts Purchased		11.02.2019	27.03.2019	46 days
10	Manufacturing		20.03.2019	27.03.2019	7 days
11	Testing		28.03.2019	04.04.2019	7 days

Table # 3: Tasks and their Duration

Table 4 identifies the team members responsible for their respected tasks.

S. No.	Task	Assigned Members
1	Introduction	Abdullah & Jassim
2	Literature Review	Adham and Ibrahim
3	System Design	Abdullah, Jassim & Barrak
4	Testing and Analysis	Jassim & Abdullah
5	Project Management	Ibrahim
6	Project Analysis	Adham
7	Conclusion and Recommendation	Barrak
8	Design	Abdullah & Adham
9	Parts Purchased	Jassim, Barrak & Ibrahim
10	Manufacturing	Abdullah and Adham
11	Testing	Abdullah, Jassim & Adham

Table # 4: Assigned Members for Each Task

5.2 Contribution of Team Members

Each member's contribution and their willingness to work was discussed in our first meeting as a team, and the tasks were divided and agreed upon by each member.

Table # 5 shows how much work each group member contributed, as a rough percentage.

S. No.	Tasks		Assigned Member	Contribution
1	Ch. 1: Introduction		Abdullah and Jassim	100%
2	Ch. 2: Literature Review	Project Background	Barrak	33%
		Previous Work	Adham	33%
		Comparative Study	Ibrahim	34%
3	Ch. 3: System Design	Design Constraints & Methodology	Barrak	20%

		Engineering Design Standards	Jassim	20%
		Theory & Theoretical Calculations	Abdullah	20%
		Product Subsystems & Component Selection	Ibrahim	20%
		Manufacturing & Assembly	Adham	20%
4	Ch. 4: System Testing & Analysis	Experimental Setup, Sensors & Data	Everyone	40%
		Results, Analysis & Discussion	Abdullah	60%
5	Ch. 5: Project Management	Contribution of Team Members	Abdullah, Jassim & Adham	100%
		Project Execution Monitoring		
		Challenges & Decision Making		
		Project Bill of Materials & Budget		
6	Ch. 6: Project Analysis	Impact of Engineering Solution	Ibrahim & Barrak	100%
		Contemporary Issues Addressed		
7	Ch. 7: Conclusion & Recommendation	Conclusion	Barrak	100%
		Future Recommendation		

8	Design of Prototype	Abdullah	50%
		Jassim	50%
9	Parts Purchased	Ibrahim	20%
		Adham	30%
		Abdullah	30%
		Jassim	20%
10	Manufacturing	Abdullah	60%
		Barrak	40%
11	Testing	Everyone	100%

Table # 5: Contribution of Tasks

5.3 Project Execution Monitoring

To ensure the continuous progress of the project, regular meetings between the group members, to discuss the next step, and between the group members and the advisor, to take approval for said step, needed to be done on a regular basis. In addition to these meeting, we were asked to hand in progress reports and perform a presentation to explain what we have done in the project till the date of the presentation. All the dates are listed in table 6 below

Activities and/or Events	Time and Date
Assessment Class	Once a week
Meeting with the group members	Weekly
Meeting with the Advisor	Bi-Weekly
Midterm Presentation	21.03.2019
Finishing Final Prototype	04.04.2019
Test of the System	06.04.2019
Final Submission of Report	17.04.2019
Final Presentation	18.04.2019

Table # 6: Dates of Activities and Events

5.4 Challenges and Decision Making

While working in developing our project to its final stages, we incurred some problems which effected the progress of our project and acted as a hurdle to overcome. However, after successions of different suggestions and review, they were eventually rectified. The problems we faced were some of the following:

5.4.1: Equipment and Device Problems

- **Pump**
  We had to make sure that for our system, we should manage a pump that does not have any perturbations because we need to maintain a proper Reynold's Number and also a flow turbulent enough to ensure proper achievement of the theory we have based on our objective on.

- **Acrylic Cylinder**
  Since we are after simulation of flow, we had to make sure that the acrylic cylinder we choose is safe enough to visualize the flow, also, can provide a safe operation without any leakage of fluid during operation and is able to withstand high amount of pressure and stresses.

5.4.2: Testing & Safety Issues

Since our project aims to demonstrate the flow visualization in the drilling well operations, we also made sure to properly take care of the impingement phenomena to ensure that we are abiding by the objectives and theory which supports our system. However, there were safety concerns related to experimental testing in which the drive belts were exposed without any shield in case of any mishap could snap and injure the person near to it. Also, since our acrylic cylinder does not enclose it the drilling unit all the way to the top, we had to make sure there is ample flow rate to avoid spillage and also successfully work after our objective that we want to achieve. Moreover, when measuring the rpm of drill bit it was extremely difficult to get a proper and reasonable reading due to hinderance in recording rpm as the sticker was on the drill bit shaft and was submerged in the drilling fluid containing cylinder.

5.4.3: Design Problems

The most basic and prominent design problems we had were with the selection of proper pump to transfer the drilling fluid through the bit and circulate it back to the reservoir. Moreover, the pump we agreed on using was centrifugal type which ensures proper water flow and is also very prominent in decreasing any variation in flow rate and pressure changes. Also, we had to have a driving system in order to operate the drilling bit and the drilling operation for which we had to undergo through several amount of research that completely takes care of vibration dampening during operation along with proper power transmission.

5.5 Project Bill of Materials & Budget

The table below illustrates the parts we purchased and the amount given to the third party for manufacturing some of the intricate parts for us. It includes the total amount spent in our project in Saudi Riyals (SAR).

Table 7 shows the amount of money paid for each part in Saudi Riyals (SAR).

Materials	**Cost (SAR)**
Centrifugal Pump	870
AC Motor	800
Speed Controller	750
Stainless Steel Shaft	500
3 Ball Bearings	50 each
2 Pulleys	85
Acrylic Cylinder	200
Water Tank	110
Belt	25
Steel Base	920
Swivel Connection	120
Water Injectors	50
Flowmeter	150
Hoses	50
Check Valve	40
Total Sum	**4820**

Table # 7: Bill of Materials

Chapter 6: Project Analysis

6.1 Life-Long Learning

Since we were working as a team in the progress of our project, we had one aim completely firm in our minds and that was to achieve all the goals we had set in the beginning of project. Of course, in order to achieve that, we were prone to use and utilize some software and hardware by using our time in a very efficient manner and also to manage all of these things, we had to setup and prescribe a pre-planned schedule which really gave us a boost in every aspect we worked on and we would like to share some of that experience.

6.1.1: Software Skills:

When designing our prototype, we first referred to some websites online and then test out the constraints on Solid-Works Simulation. We designed and simulated the necessary components for our project to guarantee suitable procedure concurring to our needs of materials that are sufficient enough to withstand our system so that it can run efficiently. It all went extremely well by the group's contribution and support since each member was able to solve an obstacle more rapidly depending on the way they thought. Correspondingly, we utilized Microsoft Excel to exhibit the charts and graphs displaying our experimentation data. In addition, we had to make use of Computational Fluid Dynamics where we could properly simulate the flow of drilling fluids on conditions where we can improve drilling performance under the borehole.

6.1.2: Hardware Skills:

To conduct a performance test of our system, we had to interact with some of the facilities provided in our Laboratories which included a Tachometer and an IR Thermometer. Having sufficient background knowledge on using an IR Thermometer and a Tachometer we were able to successfully without additional help. This hardware equipment helped to obtain the experimental data that was necessary to demonstrate the performance of our system as a whole.

6.1.3: Time Management:

Since we had about 3 months of total time to be given to the project, we really needed to manage time in an efficient manner in order to be ahead of time for predicted problems and hurdles we thought we would face. Although, we were still falling short of that as days were passing by, our team really worked on it in every spare time they had available in order to accomplish a heap of milestone that was set for us.

6.1.4: <u>Project Management</u>:

To carry out the whole schedule of developing our project, we needed a plan to execute and follow it step by step. By conducting weekly meetings with our team mates, we were able to assign tasks based on the time one is comfortable and available. This mutual communication and understanding led to a properly managed progress flow related to our project which we are proud of.

6.2 Impact of Engineering Solutions

6.2.1: <u>Society</u>:

Any project that is for the well fare of the industry that will surely benefit the society of it. Since, the project will always be aimed towards the betterment of operational efficiency, effectivity or cost saving without compromising on the quality of the outcome, claims can be made with pure intention that it would open an opportunity for investors to step in the field to sponsor such projects which can reach the prosperous stages of development. These investments will provide a very clear social impact proving the ideas and the skillful youth which are striving to contribute in achieving one of the objectives of Vision 2030 which is to increase the public's investment funds so the people of Saudi Arabia can get benefit and the needs that any prosperous and developed country would need to survive and compete.

6.2.2: <u>Economy</u>:

According to the Kingdom's Vision 2030 objective to improve the GDP and the overall cost-effectiveness in several different projects, quite prominently in the field of oil and gas, these technological advancements can play a very supporting role for the future and well-being prosperity of our country. Since, we as a group and many other technical personnel are thriving to work hard and devise solutions to improve the quality of operations and save cost, we think our project could be a very unique initiative towards the contribution of improved and cost-effective drilling operations. Because, approximate fare for one day of operation at a typical drilling site in Kingdom can escalate to as much 200,000 U.S. Dollars, little but prominent advancements can play a very root cause for the cost savings.

Looking in terms of fluid dynamics of impinging jet flow visualization and flow control in order to achieve an improved drilling operation. It is quite logical by looking into the efficiency aspect of drilling. If the well is being drilled with a smooth flow, even though complications in the carrying out the operation arise, it can save some cost in the long run. As one of the very recent paper published elaborated of a new technique to carry out drilling but in different environments which will contain a conventional rotary drilling bit along with high pressure fluid jets. Because according to the researchers, when such a system will work in harmony, jet pressure and cutting conditions can be managed based on the hard formations being encountered which will save the operation from any kind of catastrophic failures and halts. Since this system is still under development by the name of "Thermodrill", it will serve as a hybrid technology in drilling field.

6.2.3: Environment:

If we consider our prototype of how it will benefit on an environmental basis, to give an insight in terms of indirect perspective. It would decrease the cost of fuel used and eventually lower the pollutants beings produced by the powering up the whole unit when in a drilling operation. Furthermore, it would serve as a very basic solution in order to decrease bit balling which effectively improves drilling efficiency when down below the borehole subsequently lower the power consumption and fuel burnt. These aspects were considered when we decided to design an impingement system for drilling bits as it will improve number associated parameters.

6.3 Contemporary Issues Addressed

Since our prototype or project is still in a condition where many things can go wrong or may even be a hazard in terms of safety perspective, we ensured that proper precautionary measures were taken in order to properly operate our mechanism without causing harm to the environment and operators. Also, some optimization may be required in order to properly function our mechanism without any pump perturbations and that can resolve quite a number of problems which will be optimization based if all things are considered where we have to make sure that a specific range of Reynold's Number is maintained for a flow to be turbulent enough to avoid bit balling and improving the drilling operations.

Chapter 7: Conclusion & Future Recommendations

7.1 Conclusion

To sum up, we have managed to achieve our project and the prototype within the time frame specified to us as a group. Moreover, this led to the conclusion of determining and successfully proving our theory related to the impinging jets efficiency and how it can reduce bit balling phenomena to improve borehole rate of penetration by successfully visualizing the flow studies in cases where the turbulence and Reynold's number are kept almost managed at a desired level. It also gives us an insight on how to utilize software and hardware that would groom us and enhance our skills to be able to put in the line of duty of our professional fields in the future.

7.2 Future Recommendations

Since, our mechanism and system has been carried out to such a level of determination while designing, building and manufacturing so studies can be performed on it, there are some optimization issues that would need some attention in order to further improve the overall prototype which would be having better pump, power transmission units using gears instead of belts to reduce losses and also sensors at the jets that would maintain and detect the pressure or velocity deviation and could manage to compensate for parameters that would generally improve the overall performance of our system. Although, our group has achieved a remarkable milestone in which pure thermofluidic studies are being applied, we still think there can be room made for any necessary improvements as required.

8. References

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