ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical, Chemical and Materials Engineering

Mechanical Design and Manufacturing Engineering Program

Design of Vacuum Bath Components and Optimization of Cooling Parameter's in Pipe Factory: A Case of Amhara Pipe Factory, Bahir Dar, Ethiopia

By

Asmare Tenaw Wondimineh

Advisor: Dr. Kassu Jilcha (Asst. Professor)

Co-Advisor: Mr. Mulugeta Hagos (MSc)

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Approved by aboard of examiners':

	Signature	Date
Chair, Department Graduate committee		
Mr. Abdulmelik Husen	__________	_________
Advisor	Signature	Date
Dr.Kassu Jilcha (PhD)	____________	_________
Internal Examiner	Signature	Date
Dr. Guteta Kabeta (PhD)	___________	_________
External Examiner	Signature	Date
Dr. Asmamaw Tegegne (PhD)	___________	_________

Candidate Declaration

I hereby declare that the work which is being presented in this thesis entitled **"Design of Vacuum Bath Components and Optimization of Cooling Parameter's in Pipe Factory"** in partial fulfilment of the requirements for the award of the degree of masters of science in Manufacturing Engineering is an authentic record of my own work carried out November 2017 to September 2018 under the supervision of Dr. Kassu Jilcha and Mulugeta Hagos (MSc) Program of Mechanical Design and Manufacturing Engineering, Adama science and Technology University, Ethiopia. The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

Asmare Tenaw Wondimineh ______________ ____________

Candidate signature date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with our approval:

Dr. Kassu Jilcha (Asst.professor) ____________ _____________

Advisor signature date

Mr. Mulugeta Hagos (MSc.) ______________ _____________

Co-advisor signature date

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ABSTRACT

Water spray cooling system is one of the most common manufacturing process in the field of industry to maintain required product. The main purpose of this study is to optimize the cooling parameters of high density polyethylene pipe during manufacturing in order to minimize the defect of scraps in Amhara pipe factory. The study is based on different objectives, that is, to analyze & design of water bath components, to determine the effect of cooling parameters on response values of each run experiment, to determine and analyze most affecting cooling parameters in order to get minimum ovality, deforming and surface roughness and to estimate the relative contributions of each control factors on the measured response. The methods for this study are data collection, selection of materials, size determination, design of components and modeling, sample size selection and optimization techniques. The finding shows that optimum combination of control factor for deforming Feed rate 60.9 rpm, water flow20.42l/min and haul off 0.22, for ovality feed rate 60.9 rpm, water flow 18.56 l/min and haul off 0.68m/min, for surface roughness Feed rate 60.9 rpm, water flow 25.51 l/min and haul off 0.22m/min. It is recommend that defect or scrap product could be optimized by Taguchi doe. The researcher recommended that it is a good way of implement an optimum condition of cooling parameters in the field of water spray cooling process before wound off the pipes.

Key words: water bath, Taguchi, orthogonal array, optimization of cooling parameters

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Abbreviations and Acronyms

ANOVA	Analysis of variance
APF	Amhara pipe factory
DOE	Design of experiments
DOF	Degree of freedom
FES	Flash evaporation system
FR	Feed rate
GA	Genetic algorithm
HDPE	High density polyethylene
HOS	Haul off speed
ISO	International systems of organization
N.B	Nota bane (remember)
OD	Outside diameter
PC	Per pice
PLC	Private limited company
PN	Nominal pressure
S/N	Signal to noise ratio
SDR	Standard diametral ratio
SS	Sum of square
UHV	Ultra high vacuum
UPVC	UN plasticize polyvinyl chloride
WT	Wall thickness
Δ	Delta
SST	Total sum of squared deviations
SSd	Sums of the squares of the deviations

CHAPTER ONE

INTRODUCTION

1.1 Back ground

There are few number of pipe factory in Ethiopia having a problem of spray cooling system, spray patterns, volumetric capacity of cooling bath, optimization of cooling parameter way of efficiency and effectiveness, manufacturing process and technological problems. Most plastic sheet and pipe factories are manufacturing two broad categories of products such that pipes and plastic sheets. Under the category of pipes the factory manufactures UPVC pipes, HDPE pipes, casing/screen pipes and flexible hoses. In the other category, it manufactures Geomebrane sheets and greenhouse film/sheet. APF is situated at the gate of Bahiredar city which is 560 km from Addis Ababa [APF,2016]. The factory produces high quality plastic made products such as UPVC, HDPE, Geomebrain sheet, flexible hose and green house film. It uses extruding system of operation. The main beneficiaries of APF products are Amhara regional state rural and agricultural bureau, Amhara water construction agency, investors, farmers, contractors etc. A factory is awarded with ISO 9001:2008 quality management system certificates. In the factory either the vacuum cooling capacity or design of water spray system technique, the pipe could be cool enough so that it maintains its circularity before it exits the cooling bath. Various methods of cooling are utilized to remove the residual heat out of the HDPE pipe especially in line six. Depending upon the pipe size, the system might use either total immersion or spray cooling. Spray cooling is usually applied to large diameter pipe where total immersion would be inconvenient. Smaller diameter pipe is usually immersed in a water cooling bath. Cooling water temperatures are typically in the optimum range of 428° to 464°F (220° to 240°C). The total length of the cooling baths must be adequate to cool the pipe below 482°F (250°C) in order to withstand subsequent handling operations [Fazaeli et al. 2012 ; APF,2016].

Water Spray cooling System: it contains two sets water pumps, which are connected with storage water bath of the calibration tank. The water out lets of two water pumps are connected with filter system & then divide into two ways to enter into water distribution ring of the calibration tank, and then connected with four water tubes to make the water spray out from spray nozzles which has been installed at the four water tubes. Automatic water control system, the water outlet of water pump is installed with magnetic valve for water drainage and another magnetic valve for water charging is installed under the calibration tank, which are controlled by water level controller. If the water level in water bath is over the upper position water level controller showed, then the magnetic valve for water drainage is open. In the same way, if the water level in water bath is reaching up to the down position of water level controller showed. However, adjusting pressure can result in dramatic changes to the spray angle and drop size. With precision spray control, flow rate from a single nozzle can be varied without changing pressure. Spray angle and drop size remain unchanged and uniform application of coatings is ensured [Fazaeli et al. 2012].

Spray nozzles: are precision components designed to yield very specific performance under very specific conditions. Just because a nozzle is spraying doesn't mean that the spray system performance is optimal. Many factors can impact the results of the spraying system. To achieve long-term, efficient, optimal performance and keep operating costs as low as possible, we need to consider the Spray system in its entirety and develop a plan for evaluating, monitoring and maintaining it. If we don't already have a spray system optimization program in place, we could be wasting significant amounts of chemicals, water, energy and time and risking process and product quality without even knowing it [Cavalheiro et al. 2013].

Vacuum Cooling System: A basic vacuum system integrates with the following components temperature control, housing, water pump motor, spray tube, spray, roller, frame supporter, single screw, roller, filters& wheel [APF, 2016].In the design of water spray system by increasing diameter of spray, increasing number of spray, it is possible to decrease number of vacuum cooling bath, time, improve quality of products etc.in the factory. The design technique will must be carefully performed because, in the factory there are two vacuum cooling bath, water spray with in minimum diameter , spray gap 16cm,number of spray is 32 in one bath total 4*32cm. There for to optimize vacuum bath components redesign and optimize the cooling parameters was essential such as ovality, surface roughness and deforming or bending.

Optimization: an act, process, or methodology of making something (such as a design, system, or decision) as fully perfect, functional, or effective as possible; specifically the mathematical procedures (such as finding the maximum of a function) involved in this study. It is defined as the process of finding the conditions that give the minimum or maximum value of a function, where the function represents the effort required or the desired benefit [Parkinson et al. 1993]. In Amhara pipe factory there was the occurrence of pipe defects during manufacturing process because of cooling system.

1.2 Statement of the Problem

In Amhara pipe factory, a machine which produces HDPE have two vacuum cooling bath that was used for cooling purpose. When the expert needs to produce other new products and change of raw material, this results in large amount of defects, this defects could be ovality of pipe, deforming of pipe or surface roughness of pipe. The defect of pipes could reduce income or economic aspect of the factory. The employee would wait until it finish the process because of cooling system even if there were defects. This process is time consuming, poor quality of products, it also create large amount of scrap. In the existing HDPE manufacturing process number of vacuum cooling bath is two with in the length of 6m, high water spray gap, efficiency and effectiveness of spray is low &water pump capacity is low. The two vacuum bath assist entrance to end process they tried to on haul off speed, surface roughness and feed rate which result in scrap.

All the above problem would occur due to length of cooling bath, spray gap, optimization problem of feed rate, water flow and haul-off speed, spray pattern & operation. In the factory four HDPE producing machine available at APF at least about 5.5m pipes would be changed to scrap .This is estimated to be 8899 birr (cost/m=1618.02) birr loss in cash in every defects of episode the cost per meter value of the factory is depend on the customers ordered. To solve this problem design of vacuum bath components and optimization cooling parameters would reduce scrap and economic loss due to scrap.

1.3 Basic Research questions

- How to analyses & design water bath components?
- How to analyses & optimize control factor such as feed rate, water flow and haul-off?
- How to determine the effect of cooling parameter's on response values of each run experiment?
- What are the most affecting cooling parameter's on ovality, deforming and surface roughness?
- How to estimate the relative contribution of control factor on the measured response?

1.4 Objectives

1.4.1General Objective of the study

The general objective of this research is design of vacuum bath components and optimization of, cooling process parameter in order to reducing pipe defects and increase productivity of the pipe factory.

1.4.2 Specific objective of the study

The Specific objectives of this study are as follows:

- To analyze & design water bath components
- To analyze & optimize control factors such as feed rate, water flow and haul-off speed.
- To determine the effect of cooling parameters on response values of each run experiment.
- To determine and analyze most affecting cooling parameters in order to get minimum ovality, deforming and surface roughness.
- To estimate the relative contributions of each control factors on the measured response.

1.5 Scope of the study

There are few number of pipe factory in Ethiopia having a problem of spray cooling system, spray patterns, volumetric capacity of cooling bath, optimization of cooling parameter way of efficiency and effectiveness, manufacturing process and technological problems. Trying to solve all the above problem will accelerate the growth manufacturing sector in general and the pipe factors in particular .But due to shortage of time and budget constraint the scope of this research deals with design of components and optimization of control factors & minimization of cooling bath, showing the analysis of design, assembly of design part into cooling bath in the case of reducing the pipe defects and economic lost. Moreover, the experiment used in the factory were deformation test, surface roughness test and ovality test of pipes in the study area.

1.6 Limitation of the study

There were some limitations presented in working this research; such as there was no internet availability for some months to searching necessary data, lack of resources related to this research. In general when this paper was studying the following limitations are faced:

Inability to get sufficient documented data in a short time, limitation of design text book, lack of well experienced man power in the pipe factory to get detail information, motivation of the company manager to support me is low in different criteria to get data. Even if there are limitation during research work I have faced some of them by referring different websites and internet access, by referring related research journals and articles.

1.7 Significance of the study

The significance of this study is believed to increased product quality in Amhara pipe factory, minimize delivery time, and hence used to reduce defects or scraps. In addition to this, it would important to create awareness about cooling technique. Furthermore the significance of this research is to show how to optimize control factor and water spray cooling system.

1.8 Organization of the study

The next chapter of the research is organized as follows: Chapter two provides discussion related with theoretical and empirical literature review on the subject matter. The third chapter discussed about the research methodology and material selection which includes description the study area and methods of the study such as sources of data, and techniques for data collection, study design, methods of optimization and software for analysis. The fourth chapter analysis of detail design of components and optimization of cooling parameters .The fifth chapter deals with results and discussion resulted from the analyzed data. The last chapter consists of summary of findings, conclusions, recommendations and future work of the study.

CHAPTER TWO

LITERATURE REVIEW

In this section of the study back ground of water spray and vacuum bath, characteristics of design and optimization of water spray system and vacuum bath, theory of design and optimization of water spray system and vacuum cooling bath, factors affecting the design and optimization of water spray system and vacuum cooling bath, types of spray patterns, empirical research and research gap study will be discussed in detail.

2.1 Back ground of Water Spray System and Vacuum Cooling Bath

Conducting the literature review is done prior to undertaking the research. This is critically provide as much information as needed on the technologies available and methodologies used by other research counter parts around the world on the topic. This sub title provides characteristics, theories, factors, optimization method, contribution of the project and the literature reviews (empirical research) on topics related to the Design and optimization of water spray cooling system, and vacuum cooling bath parameter's in pipe factory.

Water remains the predominant cooling suppression medium world-wide. By adapting its method of application, water can even be used to extinguish or control cooling in situations where it would not normally be considered suitable. A water spray system is connected to the supply through an automatically or manually actuated flow control valve. Water is then piped to specially designed nozzles which distribute it over the protected area. Automatic valves are actuated by a detection device installed in the protected area [Fazaeli et al. 2012].

In most of the world different plastic and pipe factories could manufacture different in size, length, diameter, thickness and best scrap minimization techniques. But most of them could not show best feed rate, haul off /on, best investigation of design optimization of water spray system for a combined vacuum cooling bath .In addition to this they did not show best performance of the vacuum cooling bath in the plastic sheets and pipe factories.

2.2 Characteristics of Design and Optimization of Water Spray System and Vacuum Cooling Bath

2.2.1 Characteristics of Design and Optimization of Vacuum Cooling Bath

In the design and optimization of vacuum cooling bath lower temperature water flowing into the pipe and plastic sheets. This means that the evaporative condition can be easily obtained. The water under the evaporative condition absorbs the latent heat and will be cooled. In this section, the water cooling characteristics are depends on volume (capacity) of vacuum bath, length height, width of bath etc. There are different types of vacuum bath in pipe factories especially in plastic sheets and HDPE pipes. In the factory amount of water, 6m of length of cooling bath, temperature control, wheel, frame support, filter, roller , screw, water pump motor, water spray, spray tube are in housing. In this characteristic volume of enclosed bath, flow rate of heat exchanger in water spray, filled water and air volume, evaporating area, flow rate in to pipes will be consider. On the other hand optimization is also one character of vacuum bath. Most data's will collect from Amhara pipe factory for thesis project etc. [APF, 2016].

2.2.2 Characteristics of Design and Optimization of Water Spray System

Basic water spray system characteristics are precision components designed to yield very specific performance under specific conditions. To design and optimization of water spray system determine the best nozzle type or diffusor for the application, the following reference characters are the performance that each nozzle type is designed to deliver [Shull, 2012].

A) Hollow Cone (Whirl chamber-Type): general spray characteristics available in awide range of capacities and drop sizes. Provides a good interface between air and drop surfaces. Spray angle for this type of spray pattern is in b/n 40-165°.

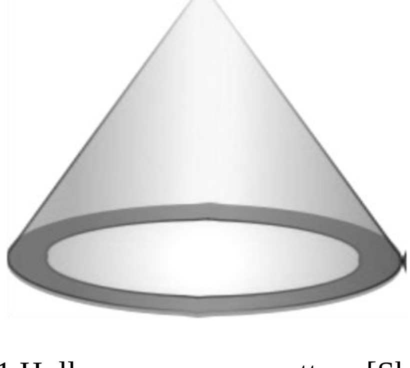


Figure 2.1 Hollow cone spray pattern [Shull, 2012]

B) Hollow Cone (Deflected-Type): general spray characteristics utilizes a deflector cap to form an “umbrella” shaped hollow cone pattern. Spray angle for this type of spray pattern is in b/n 100-180°.

C) Hollow Cone (Spiral-Type): general spray characteristics provides a hollow cone pattern with drops that are slightly coarser than those in other hollow cone sprays. Spray angle for this type of spray pattern is in b/n 50-180°.

D) Full cone: general spray characteristics utilizes an internal vane to provide a uniform, round, full spray pattern with medium-to-large sized drops. Spray angle for this type of spray pattern is in b/n 15-125°.

Figure 2.2 Full cone spray pattern [Shull, 2012]

E) Full Cone (Spiral-Type):general spray characteristics provides relatively coarse drops in a full cone pattern with minimal flow obstruction. Spray angle for this type of spray pattern is in b/n 50-170°.

F) Flat Spray (Tapered): general spray characteristics a tapered-edge flat spray pattern nozzle is usually installed on a header to provide uniform coverage over the entire swath as a result of overlapping distributions. Spray angle for this type of spray pattern is in b/n 15-110°.

G) Flat (Even): general spray characteristics Provides even distribution throughout the entire flat spray pattern. Produces medium-sized drops. Ideal where high and uniform spray impact is required. Spray angle for this type of spray pattern is in b/n 25- 65°.

H) Flat Spray (Deflected-Type): general spray characteristics produces a relatively even flat spray pattern of medium-sized drops. The spray pattern is formed by liquid flowing over the deflector surface from a round orifice. Spray angle for this type of spray pattern is in b/n 15-150°.

Figure 2.3 Flat fan spray pattern [Shull, 2012]

I) Solid Stream : general spray characteristic's solid stream nozzles provide the highest impact per unit area. Spray angle zero degree.

J) Atomizing (Hydraulic, Fine Mist): general spray characteristics a hydraulic, finely atomized, low capacity spray in a hollow cone pattern. Spray angle for this type of spray pattern is in b/n 35-165°.

K) Air Atomizing and Air Assisted: general spray characteristics atomization produced by a combination of air and liquid pressures. Air assisted nozzles feature internal impingement atomization to assist fine drop formation. It is cone and flat spray patterns.

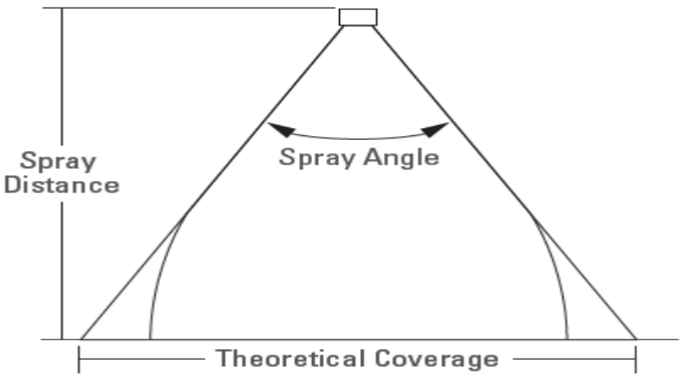


Figure 2.4 Orientation of water spray angle [Shull, 2012]

2.3 Theory of Design and Optimization of Water Spray System and Vacuum Cooling Bath

In the design and optimization of water spray system and vacuum cooling tank it is possible to reduce defects of scrap in plastics sheet and pipe factories, it is also used to reduce delivery time production. In general there are many benefits of an optimized water spray system some of this are [Shull, 2012].

It is used to improved product /process quality and it had low, consistent operating costs.

It is used to minimal defects or scrap and minimal environmental impact.

In addition to this it is used for trouble free operation non-un scheduled down time.

Needs to improve the water spray systems are as follows: It had the advantage of reducing water resources and economically cost effective.

It is used to reduce scrap due to spray system performance and increase throughout put by reducing time for pipe and plastic production.

Furthermore it reduce spray system maintenance time and extend production runs before spray system maintenance is required .The basic principle of vacuum cooling consists in removing of the latent (evaporating) heat of a solvent (usually water), which implies a fast decrease of the cooled liquid temperature. To keep the evaporation process running, continual reducing of the total pressure in the equipment must be applied. The general cooling vacuum is a device for cooling water in industrial condensers or pipe and plastic sheets. The present cooling vacuum have defects with noises, low performance structures and environmental problems. This paper focuses on a new water cooling system using design and optimization of water spray & cooling bath in an enclosed vacuum housing and a water pump system. Several researchers were carried out to improve high vacuum pressure and water cooling characteristics. The water pump performance was tested with various water temperatures. Based on the vacuum pressure of the water pump motor, the water cooling characteristics is optimized and increase effect of cooling system in the pipe factory.

2.4 Factors Affecting the Design and Optimization of Water Spray System and Vacuum Cooling Bath

In the design and optimization of water spray system &vacuum cooling bath there are so many factor [Ashgriz, 2011]. Factors affecting the water spray system are:

The spray pattern types, flow rate/application rate, the Spray angle, spray coverage require and properties of liquid to be sprayed, specific gravity, viscosity, temperature, and surface tension, drop size, velocity, impact required, spray system operation continues or intermittent, process condition constant or variable and finally the types of material to be design.

2.5 Optimization Method

Optimization methods alone or integrated with other methods provide very effective techniques in finding the best process parameters values leading to least, ovality, surface roughness and other defect. While in the other hand, it increase the output quality by the contribution percentage [Ibrahim et al. 2011; Muhammad et al. 2011]. Design of experiment (DOE) using Taguchi method was used in this study to optimize the (SN Ratio) [Druta, 2003].Optimization of cooling processes is one of the most widely investigated cooling parameters and the experimental results are then transformed into a signal to noise ratio problems in cooling. The objective functions in the cooling problems are: (1) minimization of time of cooling, (2) maximization of production rate, (3) maximization of profit rate and (4) continual improvement of output quality in product and processes include modeling of input-output and in process parameters relationship and determination of optimal wounding conditions. A weighted combination of these objectives may be taken, or the problem can be solved as a multi-objective optimization problem. In the cooling optimization problem, there are constraints on ovality, surface roughness, bending or deforming etc. [Shyam and Karna, 2012]. Basically in manufacturing process the optimizing of cooling parameters (cooling speed, feed rate, scrap, haul-off speed etc.) is necessary to minimize the surface finish of working material, HDPE pipe, water temperature etc. Among different optimization techniques well known methods method are:-Taguchi method, Artificial neural networking (ANN), and Genetic algorithm (GA).

2.5.1 Taguchi Method

Design of experiment (DOE) is one of a scientific method of conducting experiments, which enable the experimenter to draw valid inferences on the unknown parameters based on the data collected through experiments. The use of the DOE makes behaviors of the researcher purposeful and organized, and appreciably facilitates and an increase in the productivity of the work and also in the reliability of the results obtained. The techniques for laying out experiments when multiple factors are involved, has been known for a long time and is popularly known as the factorial design of experiments. This technique helps the researcher to determine the possible combinations of factors and to identify the best combination for desired results. DOE provides a powerful means to achieve breakthrough improvements in product quality and process efficiency. DOE involves a well-planned set of experimental runs, in which all parameters of interest are varied over a specified range, which are based on the preliminary experiments and systematic data results. In performing a designed experiment, changes are made to the input variables and the corresponding changes in the output variables are observed. The input variables are called factors and the output variables are called response. Factors may be either qualitative or quantitative [Technical Manual, 2009; Shyam and Karna, 2012].In industry, designed experiments can be used to systematically investigate the process or product variables that influence product quality. When the process conditions and product components that influence product quality identified, direct improvement maintained to enhance a product's manufacturability, reliability, quality, and field performance. Since resources are limited, it is very important to get the most information from each experiment work. Well-designed experiments can produce significantly more information and often require fewer runs than haphazard or unplanned experiments. In addition, a well-designed experiment will evaluate the effects that have identified as important. Designed experiments are often carried out in four phases: planning, screening, optimization, and verification.

(A)Planning: Careful planning can avoid problems that can occur during the execution of the experimental plan. The preparation required before beginning experimentation based on problem. Steps need during planning are: Define the problem, Define the objective, Develop an experimental plan that will provide meaningful information and lastly make sure the process and measurement systems are in control [Rama and Rao, 2012].

(B)Screening: in many process development and manufacturing applications, potentially influential variables are numerous. Screening reduces the number of variables by identifying the key variables that affect product quality [Rama and Rao, 2012]. This reduction allows focusing process improvement efforts on the really important variables, or the vital few. Screening may also suggest the best or optimal settings for these factors, and indicate whether or not curvature exists in the responses.

(C)Optimization: after identified the important variables or 'vital few' by screening, it is necessary to determine the best or optimal values for the experimental factors. Optimal factor values depend on the process objective that either to maximize process yield or reduce product variability [Rama and Rao, 2012].

(D)Verification: Verification involves performing a follow-up experiment at the predicted "best" processing conditions to confirm the optimization results.

Essentially, traditional experimental design procedures are too complicated and not easy to use. A large number of experimental works have to be carried out when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments [Rama and Rao, 2012]. The Taguchi Method, transformed from traditional experimental design methods, was developed by Dr. Taguchi Genichi in 1949. Professional statisticians have welcomed the goals and improvements brought about by Taguchi methods, particularly by Taguchi's development of designs for studying variation. After World War II, the Japanese manufacturers were struggling to survive with very limited resources. If it were not for the advancements of Taguchi the country might not have stayed afloat let alone flourish as it has. Taguchi revolutionized the manufacturing process in Japan through cost savings. He understood, like many other engineers, that all manufacturing processes are affected by outside influences, noise. However, Taguchi realized methods of identifying those noise sources, which have the greatest effects on product variability. His ideas have been adopted by successful manufacturers around the globe because of their results in creating superior production processes at much lower costs. He wanted to reduce the number of experiments and effectively examine problems in the research and development of communication systems. Such a unique experimental design method could be used to improve the process and product design by combining orthogonal arrays with simple function computation.

Taguchi method uses parameter design to improve the quality by defining the target functions aiming at the quality required for improvement, identify the factors and levels in the target functions, and apply orthogonal arrays to determine the allocation of experimental factors and the number of times so that fewer experiments are needed to acquire the same information obtained in full-factorial experiments. As a result, little experimental data needs to be analyzed to effectively improve product quality. Orthogonal Arrays and S/N Ratios are the major tools used in the Taguchi Method and emphasized the consideration of quality in product and process design. In other words, the emphasis was on reducing the variability of product performance by utilizing ANOVA to understand the effects of various significant factors in tolerance design and further setting the tolerance of different significant factors based on the costs of the significant factors to acquire the best quality and most robust design. Utilizing engineering knowledge to plan the experiments, the Taguchi Method focuses on finding a solution to achieve the objectives. The experimental results of Taguchi's experimental design method have the following advantages: high reproducibility, easy identification of the experimental variables, a reduced number of experiments, and easily understood analyses. The Taguchi Method therefore has been utilized for improving the industry and optimizing parameter design [Ostertagová, 2013; Shyam and Karna, 2012]. As a result, the Taguchi method has become a powerful tool in the design of experiment methods. During experimental work, production of part affected either from external means or internal factors. Those factors made variation on the output result of product. In Taguchi experimental procedure, main factor influencing at the product/process are:

1. Control factor: are one of design factor that are to be set at optimum level to improve quality and reduce sensitivity to noise. When optimizing of factor with different cooling parameters (feed rate, water flow and haul-off etc.), the level of each parameters can be change up to maintain optimized result at the product. This parameter is called control factor [Ostertagová, 2013].

2. Noise factors: factor that represent the noise that is expected in production or in actual use of the products are factor whose values are hard to control during normal process or use condition [Ostertagová, 2013].

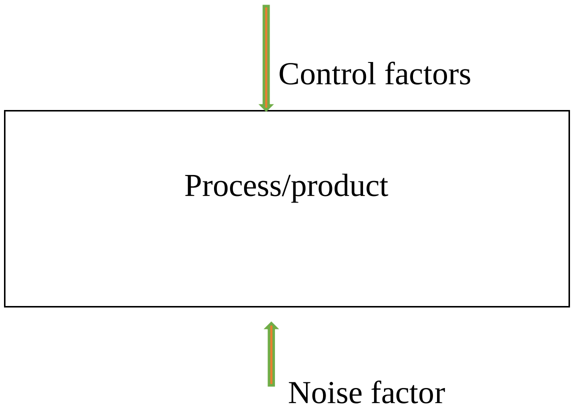
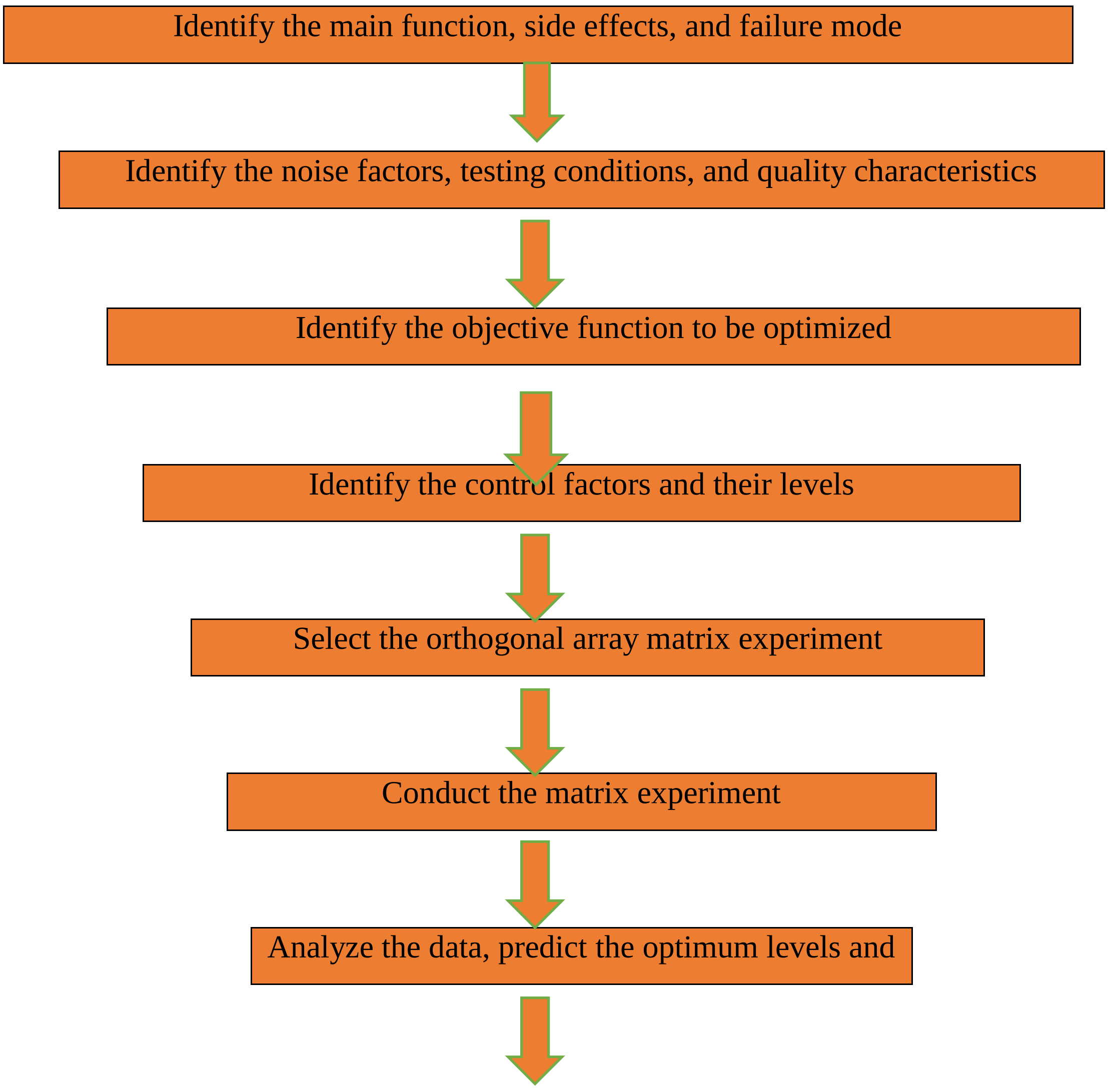


Figure 2.5 Taguchi process [Ostertagová, 2013]



Perform the verification experiment and plan the future action

Figure 2.6 Steps in Taguchi method of optimization [Ostertagová, 2013]

2.5.2 Analysis of variance (ANOVA)

ANOVA is a statistical method used for determining individual interactions of all control factors with degree of Difference or similarity between two or more groups of data. In the analysis, important parameters are identified and the percentage distributions of each control factor were calculated to measure the corresponding effects on the quality characteristics. The performed experimental plan was evaluated at a confidence level of 95% [Alagarsamy and Raveendran, 2016; Adem, 2012].Analysis of variance (ANOVA) is a statistical procedure concerned with comparing means of several samples. It can be thought of as an extension of the F-test for two independent samples to more than two groups. This technique is very useful in revealing important information particularly in interpreting experimental outcomes and in determining the influence of some factors on other processing parameters. When performing an ANOVA procedure the following assumptions are required [Ostertagová, 2013].

A. The observations are independent of one another
B. The observations in each group come from a normal distribution
C. The population variances in each group are the same (homoscedasticity)

The basic property of ANOVA is that the total sums of the squares (total variation) is equal to the sum of the SSd (sums of the squares of the deviations) of all the condition parameters and the error. In order to investigate which parameters significantly affected the performance characteristics, ANOVA was accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean of the S/N ratio, into contributions by each of the process parameters and the error. The percentage contribution p by each of the process parameter in the total sum of squared deviations SST is a ratio of the sum or squared deviations SSddue to each process parameter to the total sum of squared deviations SST [Noor, 2014].

2.6 Empirical Research

In this part optimization of water spray and vacuum cooling bath parameter status reduction of scrap of HDPE plastic pipe will be discussed based on the previous research findings.

Steddum, (1971) was the first to study water sprays in vacuum conditions. He used a large vacuum chamber in which water was sprayed at an ambient pressure. The pressurization method for the nozzle consisted of a pressurized gas cylinder forcing water through the nozzle. A plate was placed inside the chamber at a distance two to six feet from the spray. The plate was used to determine if the droplets had frozen. If they bounced off the plate, they were assumed frozen, if they stuck to the plate and led to ice accumulation on the plate, the droplets were assumed to have been liquid. He did not measure droplet size, but did reason that there existed a range of droplet sizes in a given spray, and that smaller droplets would freeze faster. No attempt at resolving the heat transfer of the impacting droplets was made.

Grissom, (1979), Bachalo, (1985) and Rizza, (1979) studied spray cooling in vacuum conditions. Using a "careful trial and error" method, they found the maximum heat flux for a given set of conditions that related to the design of the shuttle flash evaporator system .There have been no publications revealing the exact design process for the Shuttle fes. The publication by Grissom appears to be the only one that makes public at least some of the process. Grissom studied spray cooling at a system pressure of, which is slightly above water's triple point. Above the triple point of water, water can exist as a liquid. Below the triple point, water can exist at equilibrium in only two phases: solid (ice) and water vapor. His limited data can therefore not be used to evaluate the failure mechanisms of freezing caused by very low system pressures on the order of 0.01 Torr or lower. A. Rizza studied a water spray in vacuum at the triple point, but not below the triple point. He found that splash and stick droplet dynamics did not apply near the triple point, since partial solidification (freezing) of the droplets affected the impact.

Yanosy, (1985) who earlier worked for Hamilton Standard on the design team of the FES, developed a relationship to predict heat transfer for spray cooling in a vacuum. He only considered system pressures above the triple point pressure of water, which is the nominal operating condition of the FES. Thus, any freezing or failure modes of the FES were not a part of his MSC dissertation.

Golliher and Yao, (2013) the past research has not truly investigated the operational mode well below the triple point to understand the mechanism of heat transfer in this range. This understanding is needed to decide whether it is possible to actually operate normally in this range. If so, then recovery formal failure mode would be possible. It is also possible that operation in this range may allow water to be used as a working fluid for cooling electronics. There are other issues to consider for this application, but basic knowledge of the spray cooling in a vacuum would be part of the answer. A conference presentation of the early results of this research is available. A water spray system must be designed so that it can supply the desired quantity of water to the pipes at sufficient pressure. The design involves specifying the sizes of different elements of the spray and spray tube and checking the adequacy the system.

Malpas, (1992) Speed and efficiency are two features of vacuum cooling, which are unsurpassed by any conventional cooling method, especially when cooling boxed or palletized products. Cooling time, in the order of 30 min ensures that tight delivery schedules and strict cooling requirements for the safety and quality of foods can be met.

Noble, (1985) any product which has free water and whose structure will not be damaged by the removal of such water can be vacuum cooled. The speed and effectiveness of vacuum cooling are mainly related to the ratio between its evaporation surface area and the mass of foods. Vacuum cooling has been satisfactorily used to remove field heat of horticultural products in the United States since the proven to be an effective method for precooling certain types of fresh vegetables such as lettuce and mushroom.

Longmore, (1983) However, if there is a low ratio between the surface area and the mass, or an effective barrier to water loss from the produce surface, vacuum cooling may be very slow. Produces such as tomatoes, apples and pepper, which have a relatively thick wax cuticle, are not suitable for vacuum cooling .

Pescod, (1979) carried out one study using plastic pipes in indirect evaporative cooling unit with small prostution. He expected less heat transfer will be placed between plate and air because of low thermal conductivity of plastic. Though, it found that efficiencies of wet surface had given higher efficiencies of heat exchanger; which proved that wet surface gives higher efficiencies than dry surface.

Golliher and Yao, (2013) the studied system can be used for cooling any case in which there is indirect contact with the water cooled by the system. They investigated the direct contact of the vacuum and the food being cooled, in the present study, the water is cooled in the evaporative cooling system when circulating water passes through the ejector obstruction; this cooled water may be used for indirect cooling of a solid or liquid food, such as milk and coffee among others, in a jacketed bath.

2.6.1 Production of High Density Polyethylene Pipes

The high density Polyethylene pipe production is carried out in eight distinct stages, right from raw materials to finished pipe of required dimensions. In this topic the main concentration is to show where cooling problem is occur.

(1)Mixing Unit: This unit comprises of hot and cold chambers. The raw materials are thoroughly mixed in the hot chamber first and are automatically transferred to the Cold chamber. The output of the Cold chamber is a homogenous mixture of the raw materials in proper proportion.

(2)Helical Spring Conveyor Unit: The output of mixing unit is conveyed to Extruder unit through a helical spring conveyor enclosed in a flexible HDPE pipe.

(3)Extruder unit: A threaded feeder thrusts the mixture into a die set with a concentric mandrel and sleeve of required size to extrude the pipe. The mandrel and sleeve heaters impart the required temperature, thus giving uniform temperature distribution in the pipe cross-section.

(4)Vacuum Pass: The extruded pipe is made to pass through a vacuum unit. This facilitates the extruded pipe to sustain the dimensions without any wrinkling and improves cleanliness and hardness of the pipe surface.

(5)Cooling Pass: In this unit water is used for spray cooling to ensure the pipe quality and high speed stable extruding. In this stage there is formation of defects of plastic pipe.

(6) haul-off Unit: The chain drive with an endless wooden gripper belt is used to provide traction to pull the extruded pipe.

(7). Planetary Cutter Unit: A motor-driven circular saw cutter enables high-speed cutting operation of the pipes. A chamfer tool is also incorporated along with the cutter.

(8)Belling Unit: This unit performs the bulging operation on one end of the cut pipes to facilitate joining of pipes.

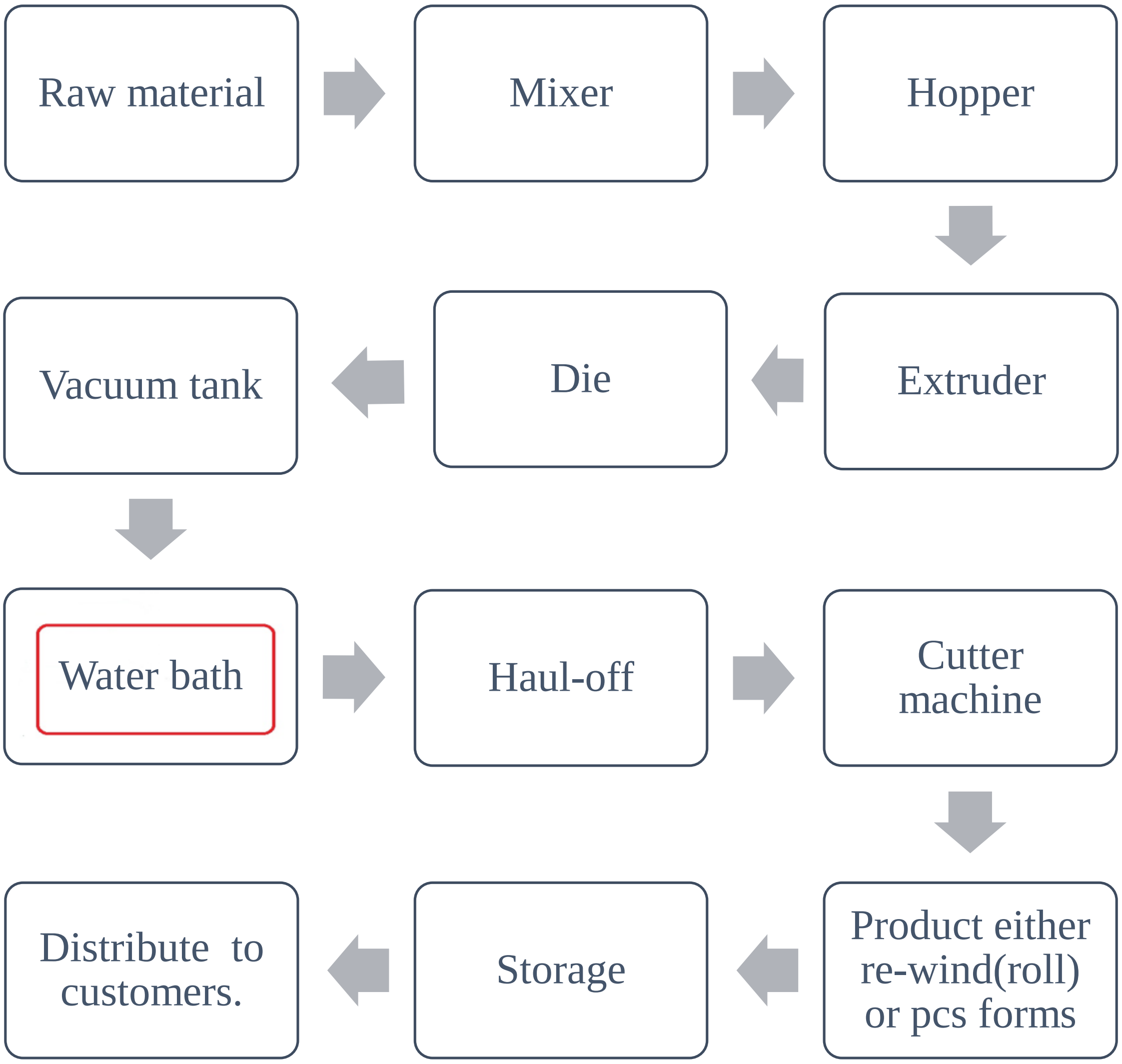


Figure 2.7 Conceptual over all process (survey observation, 2018)

2.6.2 Critiques on the Previous Studies

Review of the above past studies about the optimization and design of water spray and vacuum cooling bath of HDPE pipe scrap reduction showed that some of them were used extruder optimization of process parameter to analyze the impact which did not shows causality but only shows relationship. Additionally, even those who use the impact model their findings were inconclusive finding and most of studies focus only the income side of effect and few of them used few indicator of economic reduction. And hence; the researcher is interested to investigate the extent of design and optimization of water spray system and vacuum bath to partial fill the existing literature gap. Additionally, there is institutional and location difference across these countries and hence, the impact had difference from one plastic pipe factory to other plastic pipe factory. Hence, the researcher is initiated to analyze the design and optimization of water spray system and vacuum bath in Amhara pipe factory.

2.7 Research Gap

Malpas, (1992) ,Golliher and Yao, (2013), Noble, (1985),(Fazaeli et al. 2012) have studied speed and indirect evaporative cooling are most controlling cooling parameters in plastic pipe factory. The previous research finding was limited to the water spray cooling system so as to minimize the defect of HDPE plastic pipe but unable to give attention to improve the efficiency and effectiveness of the water spray cooling system, and some of researchers reported optimization technique only. They did show how to optimize water spray cooling capacity and minimize the defect of HDPE plastic pipe together. Moreover, in the study area the research were conducted about optimization of extruder process parameter and they ignore the optimization of water cooling parameters. (Muhammad et al. 2011),Optimization methods alone or integrated with other methods provide very effective techniques in finding the best process parameters values leading to least scrap ,ovality , distortion and other defect. While in the other hand, it increase the output quality by the contribution percentage. For this study, High-density Polyethylene would create bettor cost minimization. Due to the problem of cooling plastic pipes, optimization technique has to be implement in order to reduce defects and give higher shape retention. Here, Taguchi method will be implement to estimate the best parameter injection that suites strength characteristics. Design of experiment (DOE) using Taguchi method was used in this study to optimize the injection parameters and the experimental results are then transformed into a signal to noise ratio (S/N Ratio). Effective extrusion process requires that the machine and tool operating in well conditions. This requires control over the process parameters such as temperature, pressure, machine speed, and the relative speeds of the auxiliary. As these manufacturing processes involve steady state conditions, any action that can stabilize any parameter or condition is beneficial to the process. Cycle time reduction has been also done successfully by considering proper selection of process parameters. These parameters have significant effects on microstructure, extrude quality, material flow behavior and strength of the extrude. So these parameters need to be analyzed and according to this modeled the extrude product. Proper selections of all the process parameter put direct impact on the quality and productivity of the plastic product so by considering all these factors some important process parameters like Melting temperature, Extrusion pressure, Winding speed and Extruder speed are selected and for conducting the experiments some set of definite values of all the process parameters [Shyam and Karna, 2012]. Cognizing this fact, the researcher is interested to investigate design of water bath components and optimization of cooling process parameters in Amhara plastic pipe factory in order to minimize the defect of the plastic pipes.

CHAPER THREE

MATERIALS AND METHODS

The aim of this section is to present the material and method that would be used to collect information, for showing the methodology of the study that follows. Method of data collection selection of material size determination (design), optimization and data analysis.

3.1 Materials

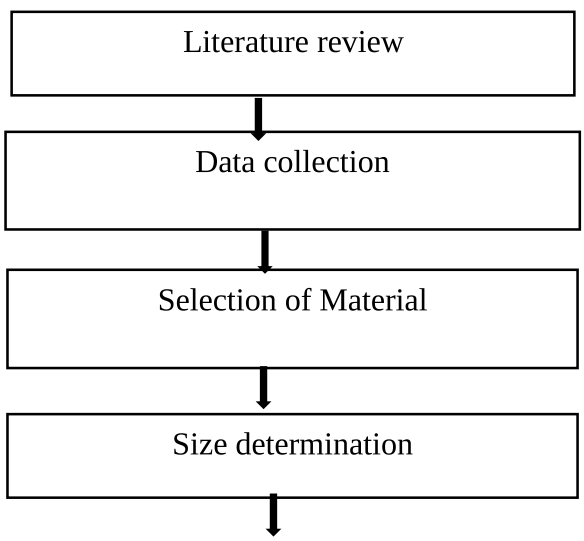
The materials requirement for this study are as follows.

Table 3.1 Material requirement

Equipment name	Number
Micrometer	1
Varner caliper	2
Deep gage	1
Hydrostatic pressure tester	1
Surface roughness tester	1
Meter	1
CAD software	1
Solid work software and ansys software	2
Control factors (feed rate, water flow and haul-off),	3

3.2 Methods

To carry out the study, the following methods have been followed.



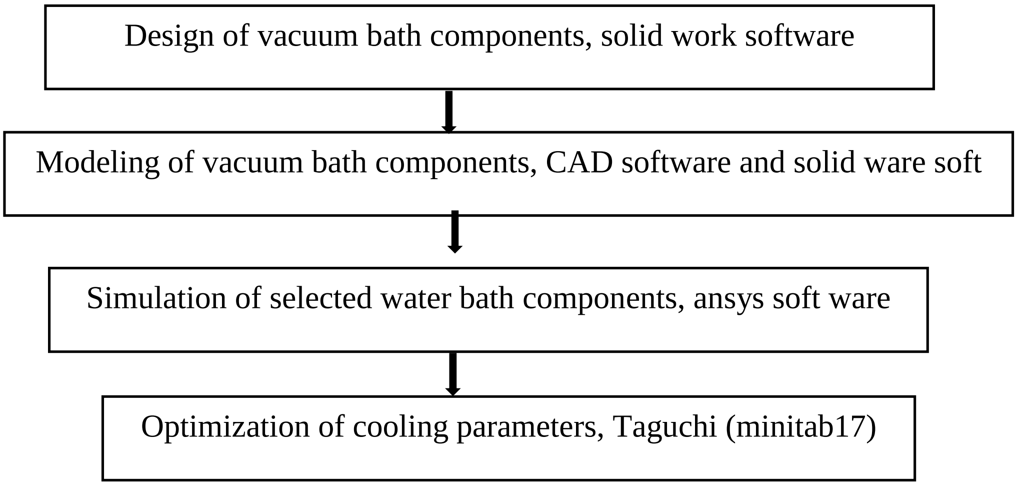


Figure 3.1 Flow char diagram

Methodology of this work includes the stages described below:

1. **Literature review: literature** related to this topic were gathered from journals publish articles, websites, books manuals etc. reviewed thoroughly.
2. **Data collection:** data related the water bath component, its model technical specification, dimensions and types of spray systemetc.were collected from manufactures manual and direct measurement.
3. **Design of vacuum bath component:** after thoroughly revising the previous works; best and competitive to be manufacture mechanism will be designed. Design of water bath component of kinematics, Kinetics and maximum load applied with its simulation by solid work and ansys.
4. **Selection of material:** the proper material for each part will be selected on the basis of types of load and areas of application.
5. **Size determination: once** the types loads the proper materials are identified, the various stresses (such as: ultimate, yield, etc.) can be taken from standard design hand book. Considering a proper factor of safety (fs), the allowable (safe) stress and then the size of each element of water bath (vacuum bath) component can be determined.
6. **Modeling of water bath components:** after designing each parts of vacuum bath components; each part also modeled by using CAD and solid work software. For simplicity to simulate the selected design of components will be done using ansys software.
7. **Simulation of selected vacuum bath components**: after modeling the designed of load obtaining parts can simulate by ansys software.

8. **Optimization of cooling parameters:** Optimization of cooling processes is one of the most widely investigated cooling parameters and the experimental results are then transformed into a signal to noise ratio problems in cooling. In this method there are eight steps, the following figure shows steps of optimization.

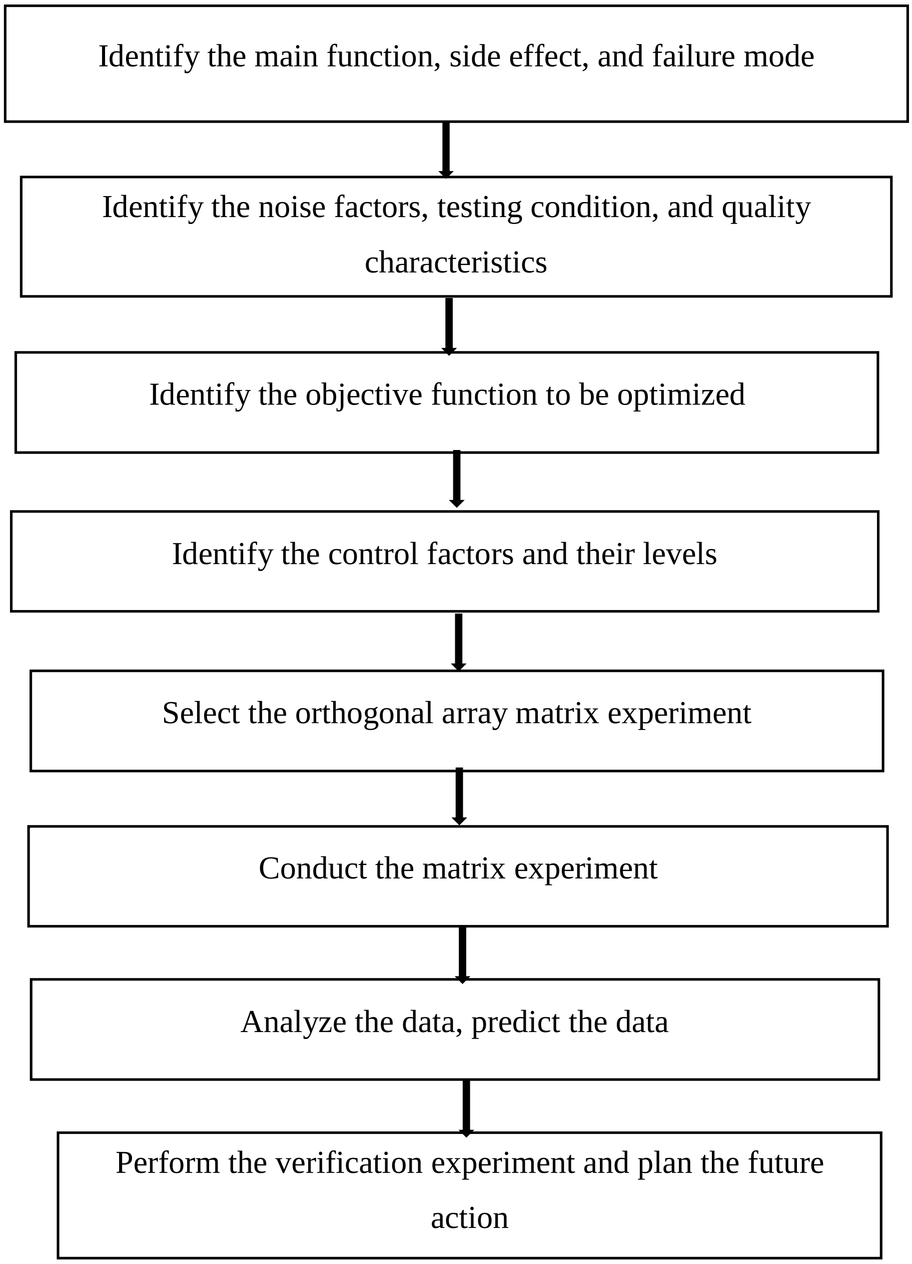


Figure 3.2 Steps in Taguchi method of optimization

3.3 Sample size selection

In the design and optimization of vacuum bath components the parts to be designed are housing, water spray, spray tube, frame support, roller, roller support, bolt and nut.

Table 3.2 Specifications of components' [APF, 2016]

S.no	Name of components	Dimensions			Materials
		Length	Diameter		
			OD	ID	
1.	Vacuum bath	5.8*0.55*0.58m			Stainless steel
2.	Spray tube	5.8 m for one water bath	27mm	25mm	Cast iron
3.	Water spray		Inlet 7.5mm Out let 3mm	5mm 2.4mm	Plastic rubber
4.	Frame support	5.8*0.55*0.58m			Stainless steel
5.	Roller	190mm of contact	8mm		Carbon steel
6.	Roller support	200mm	25mm width		Cast iron
7.	Bolt	219.2mm	5.9mm	5.77mm	Carbon steel
8.	Nut	3mm	5.9mm		Carbon steel

3.4 Selection of Cooling Parameter's and Their Levels

In this study, cooling process parameters like haul off speed, cooling time(feed rate) and water flow of the cooling were selected as control factor and each of them are conducted with three levels as shown in figure below. Since in this study there are three process parameters (haul-off speed, feed rate and water flow) each of them with three levels, the total degree of freedom is seven. Once the degrees of freedom are evaluated, the appropriate orthogonal array is selected to serve the specific purpose.

Table 3.3 Cooling parameters and their levels for two month observations [APF, 2016]

Symbol	Cooling parameters	Level 1	Level 2	Level 3
A	Feed rate (rpm)	60.9	69.2	84.1
B	Water flow(l/min)	18.56	20.42	25.51
C	Haul-off speed(m/min)	0.22	0.53	0.68

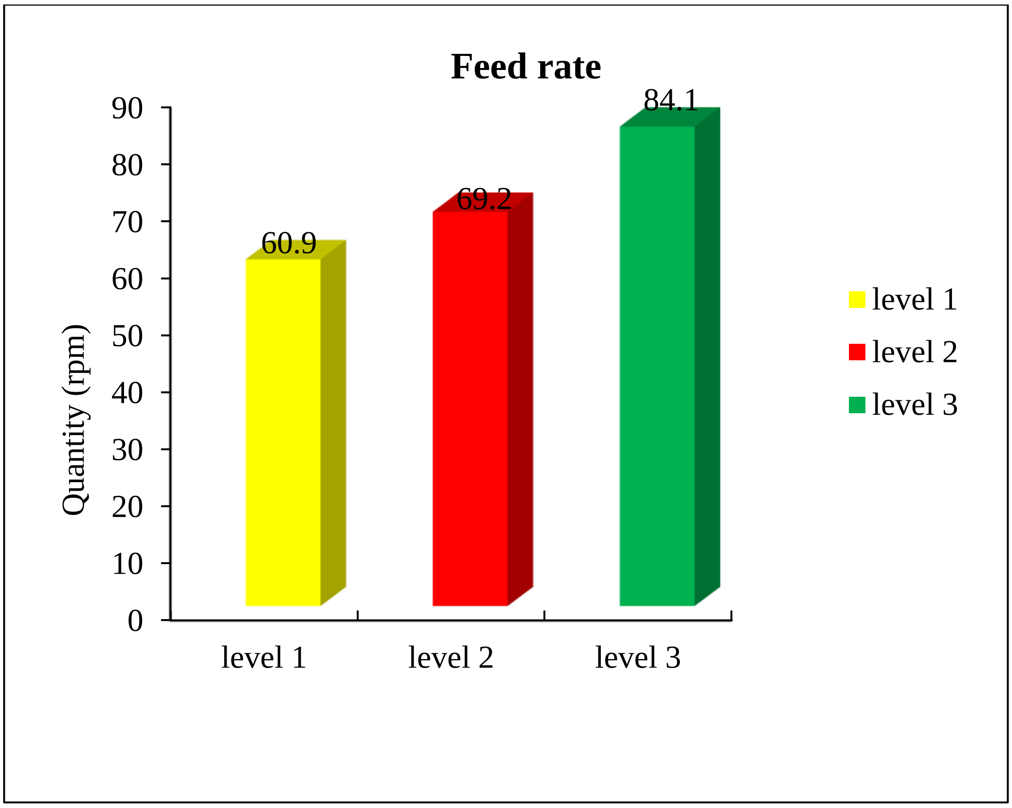


Figure 3.3 Factor level of feed rate

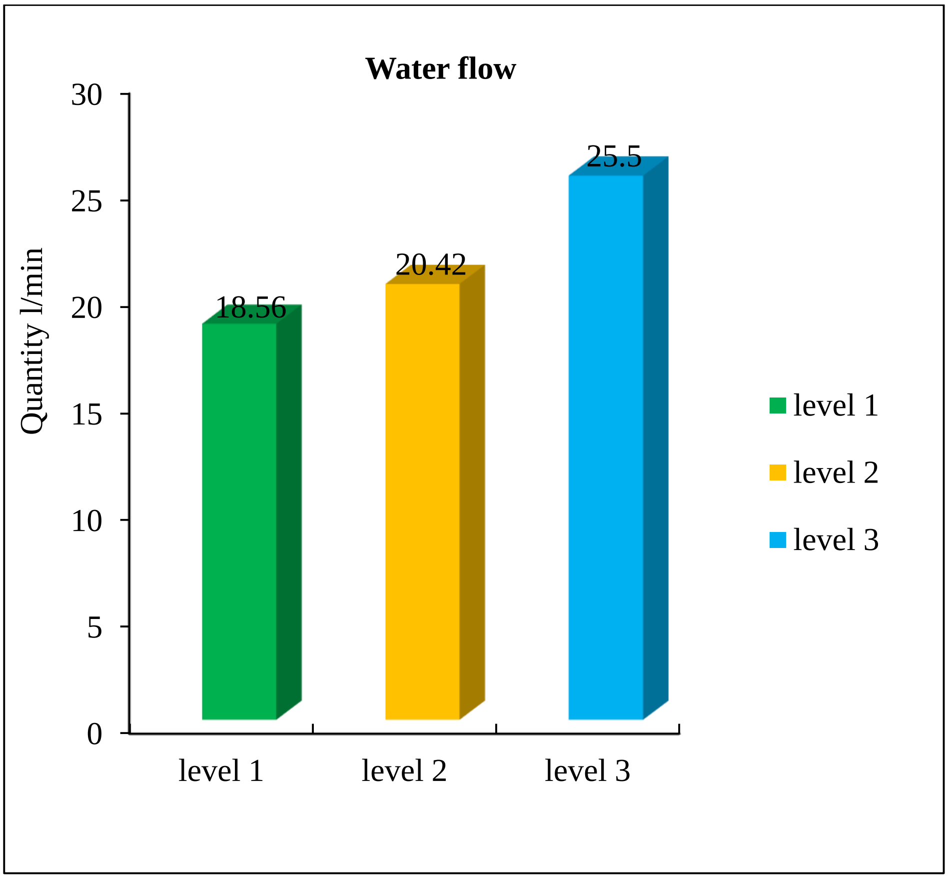


Figure 3.4 Factor level of water flow

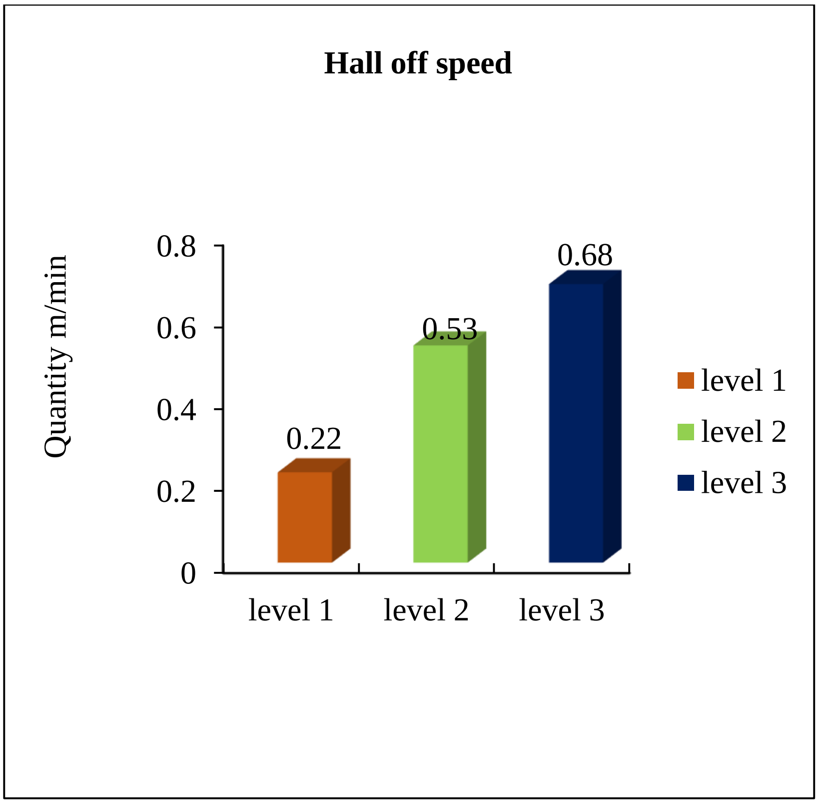
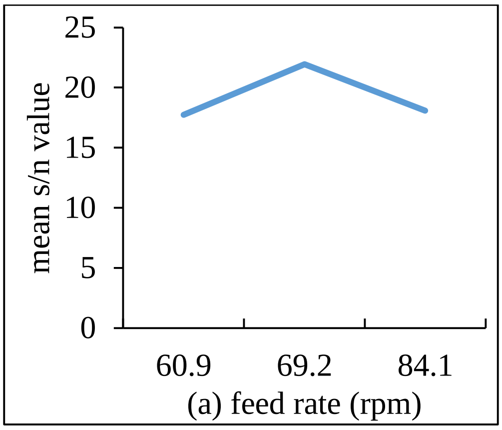
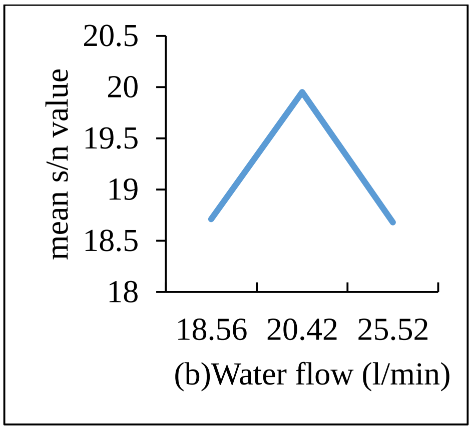


Figure 3.5 Factor level of haul of speed

In order to find the find out the effects of different parameters and as well as their levels, mean S/N ratio has been calculated. The mean S/N ratio calculated by, averaging the S/N ratios for each level of the cooling parameters. In this study, an attempt is made to investigate the design and optimization of water spray system, vacuum cooling bath cooling parameters in Amhara pipe factory. The Taguchi method uses S/N ratio to analysis the variations of the experimental design. Since in this study the aim is to obtain minimum ovality, deforming or bending and surface roughness, lower-the-better performance characteristic is chosen. The mean s/n ratio of surface roughness of HDPE pipes as shown the following fig graphically.





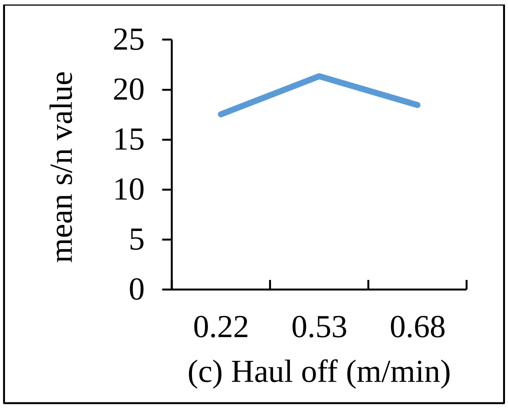


Figure 3.6 Mean s/n ratio surface roughness (a) feed rate, (b) water flow (c) and haul of *speed*

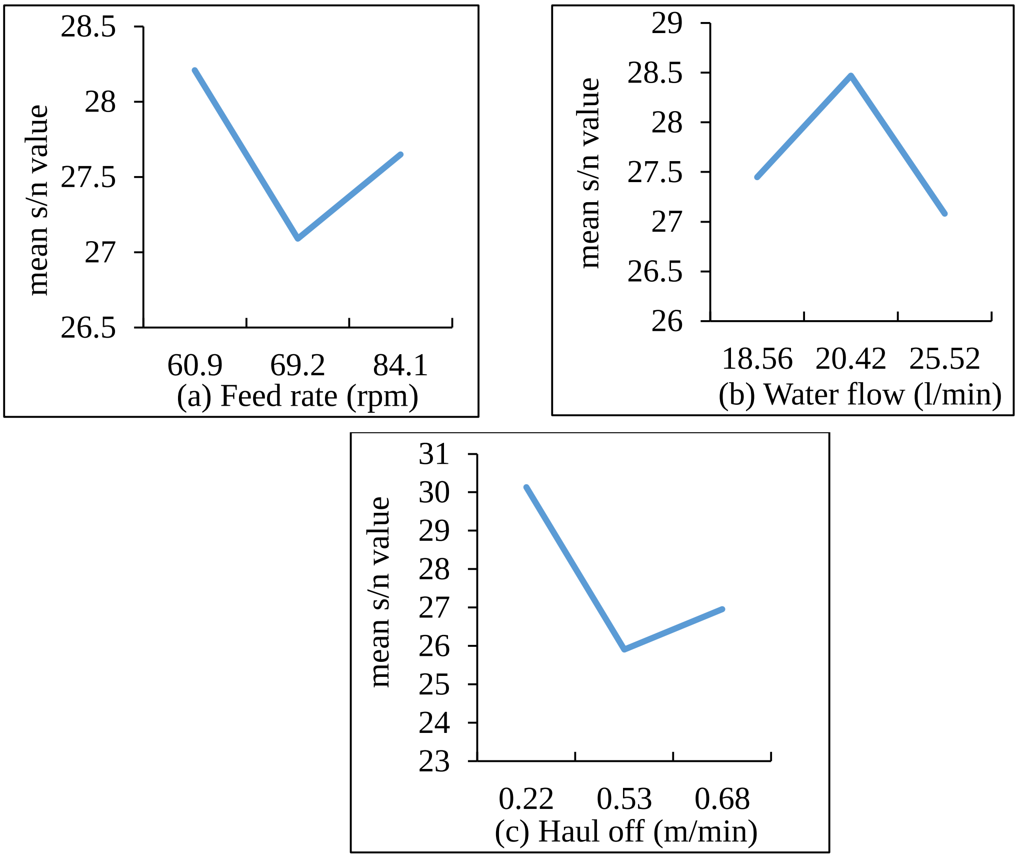
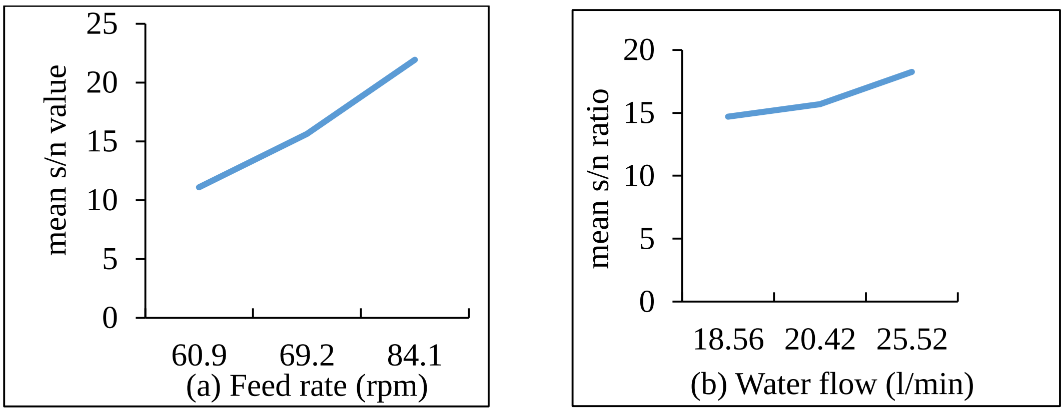


Figure 3.7 Mean s/n ratio of deformation or bending (a) feed rate, (b) water flow (c), and haul of speed



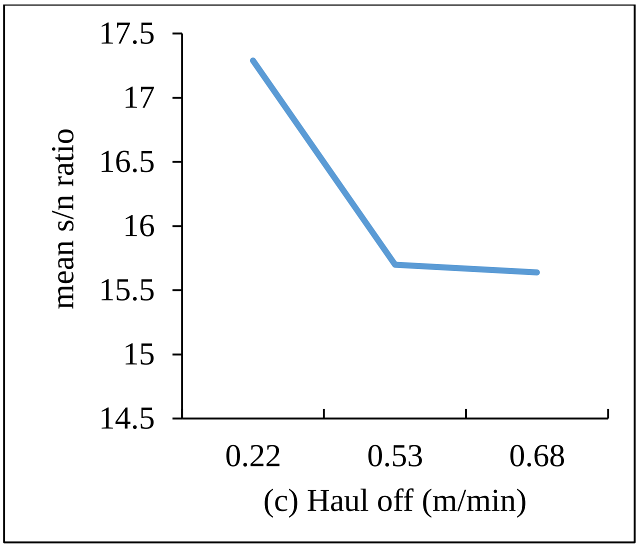


Figure 3.8 Mean s/n ratio of ovality (a) feed rate, (b) water flow (c), and haul of speed

To summarize the above figure 3.6 when feed rate, water flow and haul of speed increase the mean s/n value of surface roughness evenly increase and decrease. In figure 3.7 when the feed rate and water flow increase bending of mean s/n value decrease and increase, while haul of speed increase mean s/n value decrease and increase.in figure 3.8 of mean s/n value of ovality is decrease while haul speed increase. Further increasing of feed and water flow the mean s/n value of the ovality shown above also increase.

3.5 Selection of Orthogonal Array

In the Taguchi method, orthogonal array can provide an effective experimental performance with a minimum number of experimental trials. The configuration of orthogonal arrays is determined with respect to total degrees of freedom of the targeted function [Adem T., 2012]. In order to select an appropriate orthogonal array for experiments, the total degrees of freedom need to be calculated. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. Total degree of freedom computed by summation of all values which gain from subtracting one from each level and adding overall degree of freedom. For example if there are six two-level process parameter, then the total degree of freedom be seven. Since in this study there are three process parameters (haul-off speed, feed rate and water flow) each of them with three levels, the total degree of freedom is seven. Once the degrees of freedom are evaluated, the appropriate orthogonal array is selected to serve the specific purpose. To select appropriate orthogonal array, there are two basic conditions. First the number of runs in orthogonal design greater than or equal to total degrees of freedom and second condition is the selected orthogonal array should be able to accommodate the factor level combination in the experiment. Therefore, the appropriate orthogonal array in this study is *L*9 OA. The cooling parameters were assigned to each column and nine combinations of cooling parameters were formed as shown below.

Table 3.4 Orthogonal array of Taguchi L9

Experiment no.	Cooling parameter level		
	A	B	C
1.	60.9	18.56	0.22
2.	60.9	20.42	0.53
3.	60.9	25.51	0.68
4.	69.2	18.56	0.53
5.	69.2	20.42	0.68
6.	69.2	25.51	0.22
7.	84.1	18.56	0.68
8.	84.1	20.42	0.22
9.	84.1	25.51	0.53

After successfully selecting the level of cooling parameters (haul-off speed, feed rate, and water flow) as shown in Table 3.3 and arranging cooling parameters on selected orthogonal array as shown in Table 3.4, the experimental work on direct cooling of HDPE pipe will proceed. When the required cooling speed is decided, water spray cooling system is covers outer surfaces of the pipes. The selected diameter (D) of pipes for optimization in cooling depend on customer requirement. Under this type of pipes, the factory can manufacture outside diameters (OD) 16mm to 315 mm with different nominal pressures conforming to the ES-ISO standards. The factory has four lines/ machines such that two machines can manufacture outside diameters 16mm to 110 mm and the other two machines has capacity of producing diameters 75 mm to 315mm. the machines have different coiling capacity with respect to diameters. Diameters from 16mm-110mm can be coiled from 50-500 meters per a roll according to each machines' capacity as well as customer's requirement .Diameters from 125mm-315mm are manufactured by 5-12 meters length per piece (pc) according to customer's requirement.

The optimization procedure starts by following steps in selected Taguchi orthogonal array as listed in Table 4.13 at each experimental run of optimization the spray system, the quality department immediately induced the length measuring based on customer requirement or need; ovality (internal and external) measuring based on the standard by considering the tolerance value; Wall thickness measuring (perpendicular & diagonal) based on the standard by considering the minimum and maximum value; Weight per meter this is one of the basic measuring unit because of the selling cost is determine by its weight per meter. After completing cooling process in each of experimental steps, the ovality of HDPE pipes, surface roughness and bending or deforming can measured by using different types of tester such as inspection tester, ovality tester and finally laboratory test for HDPE pipe performed by quality department. Optimizing the cooling parameter could minimize the defect of HDPE pipe by some certain amounts.

CHAPTER FOUR

Design of Components and Optimization of Cooling Parameters

Detail design is the part of a design process which completes the embodiment of technical products with final instructions about the shapes, forms, dimensions and surface properties of all individual components, the definitive selection of materials, and a final scrutiny of the cooling methods, operating procedures and optimized components. In the design analysis the following components of water spray cooling and vacuum bath will be designed for best and safe operation. The components of water spray cooling and vacuum bath made up of the following components:-these are housing (vacuum bath),temperature control (not design) ,water pump motor (not design), water spray, spray tube, frame support, roller, roller support, cover plate, bolt and nut. The above components are modeled by solid works 2013.

Table 4.1Specifications of equipment's [APF, 2016]

Equipment type		Outer diameter	Inside diameter	Length
Water spray	inlet	7.5mm	5mm	-
	outlet	3mm	2.4mm	-
Spray tube		27mm	25mm	5.8 m for one water bath
Frame support				5.8*0.55*0.58m
Roller support		26mm	25mm	20cm
Vacuum Cooling bath				5.8*0.55*0.58m

N.B .in addition to the above specification the following data are used for design and optimization of water spray system and vacuum bath.

Amhara pipe plastic factory of line (Line-6) has two water baths and two vacuum tanks, so total number of spray for this line is 96*4 of total 384 pcs.The capacity of Water pump motor is 5.5-7.5 kilo watt, temperature control 220-240 ℃, Amount of water required in one bath is 3.5m^3/hr, for both (two water bath) and (two vacuum tanks). Remember the process is continuous; therefore, we calculate the total required in 24hrs for both. Voltage 380v, and current 6A. Capacity of vacuum water, water bath, sprays tube, and spray in terms of volume are:-Vacuum tank: shape cylindrical, dimensions Length 5.8m, Outer diameter 0.6m (r = 0.3m), volume is $\pi r^2 L$ which have value of 1.639m^3 ·The Water bath shape is rectangular, dimensions Length 5.8m, width 0.58m, and height 0.55m, volume of water bath is L*H*W amount of $1.85m^3$ .Spray tube shape is cylindrical, dimensions are Length 2.7m, outer diameter 0.027m (r = 0.0135), volume of spray tube is $\pi r^2 L$ and having capacity of $3.319137*10^{-3}m^3$.Spray Dimension are: - Length 46.2mm , outlet diameter 2.4mm 0.0024m(r = 0.0012m), volume of spray is $\pi r^2 L$ in amount of $2.08898*10^{-3}m^3$.

Time required for cooling: it depends on its OD and PN but the total length from die to cutter machine is 30m, so this is cooling length. The distance between die & cutter machine is the cooling time. Therefore, the minimum time required to cool: minimum 30min and the maximum 1:30 (one & half hour).Remember: OD & PN increase directly the cooling time also increase. Therefore, more cooling time required for high OD product produced. HDPE lost in only in line six: in eleven (11) months 34,231.81kg was loss, in terms of cost is 2,225,067.65 birr (Ethiopian birr).

4.1 Design of Vacuum Bath (Housing)

A housing is just one of the components of a mechanism, as the shell is an integral part of a tortoise's skeleton. Without this part the mechanism doesn't exist. This is the difference between a housing and a guard; the latter is just to isolate the mechanism from the surroundings. The housing is almost always the biggest part of a mechanism. It is usually made as a closed box, so that the rest of the parts are mounted inside it. In this respect, the housing also serves as a guard. The housing is most often (not always) the fixed part of a mechanism that serves to attach it to some foundation or substructure or to another unit.

Material for housing are intricately shaped, they are mostly cast, and usually only the surfaces that fit to other components are machined. One of the most widespread materials is stainless steel. It has good cast ability and machinability, increased (as compared with construction steels) corrosion resistance, and good wear resistance. Good damping capacity enables it to reduce the noise and vibrations created in the working mechanism [Timoshenko, 2003].

Design specification are:-Height of vacuum bath (housing) 0.58m, Width of vacuum bath 0.55m, Length of the vacuum bath 5m, Thickness of vacuum bath 1.5mm and Amount of water required is $1.3m^3/_{hr}$. Materials used for vacuum cooling bath is 303 stainless steel & rubber with σu =601 Mpa and σy =241 Mpa due to the following reasons [Budynas, 2006]. The selection of material is depend on great corrosion resistance, good weld ability, Temperature resistance, commonly used for fasteners, machine parts, high strength and good machinability. Stainless steel should be chosen (depending on the wall thickness) to achieve the needed strength. The Brinell hardness, HB, and the modulus of elasticity E, can be approximately determined as follows:-

$$\text{HB}= 0.43 * \sigma u + 100 = 358.43\text{Mpa}$$

$$\text{E}= \frac{\mathbf{9.5*10^4*\sigma u}}{\text{HB}} = 159.291\text{Gpa}$$

The allowable stress σ_{all} is the maximum stress to which a component is designed and it is much less than the ultimate stress of the material and stress by load.

Take f.s =2

$$\sigma a_{ll} = \frac{\sigma y}{\text{f.s}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1.1)}$$

$$\sigma a_{ll} = 120.5\text{Mpa}$$

$$\sigma t = \frac{\sigma \text{all}}{\text{f.s}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1.2)}$$

σt=60.25Mpa,σt= permissible tensile stress for vacuum material, Let μ=coefficient of friction b/n frame support &vacuum bath, L =length of vacuum bath and The force exerted by each vacuum bath can be calculated as

$$\text{F} = \text{l} * \text{w} * \sigma t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1.3)}$$

F=5*0.55*60.25=1657KN

Let p be the pressure of the vacuum bath due to force, uniform pressure distribution over the surface could be formulated as shown below.

$$\text{P} = \frac{\text{force}}{\text{projected area}}$$

$$= \text{l} * \text{w} * \sigma t/\text{l} * \text{w} * \frac{1}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1.4)}$$

$$\text{P}=30.13\text{N/mm}^2$$

∴Frictional force between vacuum bath and frame (bath) support

$$\text{F} = \mu * \text{pressure} * \text{area} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1.5)}$$

$$= 0.25 * 30.13 * \frac{\pi}{4}\left(26\text{mm}^2 - 25\text{mm}^2\right) = 384.157\text{N}$$

The torque that can be transmitted by each vacuum bath or water spraying tube

$$\text{T} = \text{F} * \text{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1.6)}$$

$$= 1657\text{KN} * 5\text{m} = 8285\text{KNm}$$

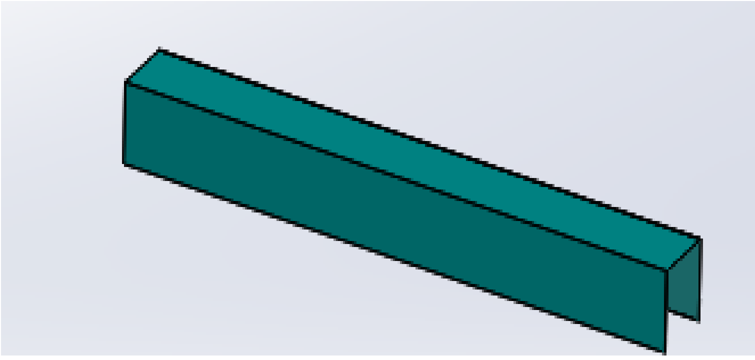


Figure 4.1 Solid model of vacuum bath

4.2 Design of Spray Tube

The design of a spray tube involves determination of inside diameter of the tube and its wall thickness as discussed below.

1. Inside diameter of the spray tube, the inside diameter of the tube depends up on the quantity of water to be sprayed. Design Specification of spray tube is outside diameter 27mm inside dia. 25mm, V=velocity of water flow in per minutes, Q= quantity of water carried per hour is 3.5 $\frac{m^3}{hr}$ this value is total of four spray tube. We know that the quantity of water flowing per minutes,

$$Q=area*velocity= \frac{\pi * D^2}{4} * V \text{ .... } (1.7)$$

$$Q= 3.14*0.027*0.027*v/4=\frac{3.5}{60*4}$$

$$V=25.51m/min$$

$$D = \sqrt{\frac{4}{\pi} * \frac{Q}{V}} \text{.. } (1.8)$$

$$D = \sqrt{\frac{4}{\pi} * \frac{0.0146}{25.51}} = 27mm$$

2. Wall thickness of the tube; after deciding up on inside diameter of the spray tube, the thickness of wall (t) in order to with stand the internal water pressure (p) may be obtained by using thin cylindrical formula. The thin cylindrical formula may be applied when

❖ the stress across the section of the tube is uniform

❖ the internal diameter of spray tube (D) is more than twenty times its wall thickness i.e. $D/t \geq 20$ and

❖ the allowable stress (σll) is more than six times the pressure inside the tube i.e. $\sigma ll/p \geq 6$

According to thin cylindrical formula, wall thickness of tube t

$$t = \frac{P*D}{2\ \sigma ll} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (1.9)$$

$$t = \frac{20.083*27mm}{2*120.5} \quad = 2.25mm$$

A little consideration will show that the thickness of wall as obtained by above relation is too small. Therefore for the design of tubes, a certain constant is added to the above relation .now the relation can be written as

$$t = \frac{P*D}{2\ \sigma t} \ + c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2.0)$$

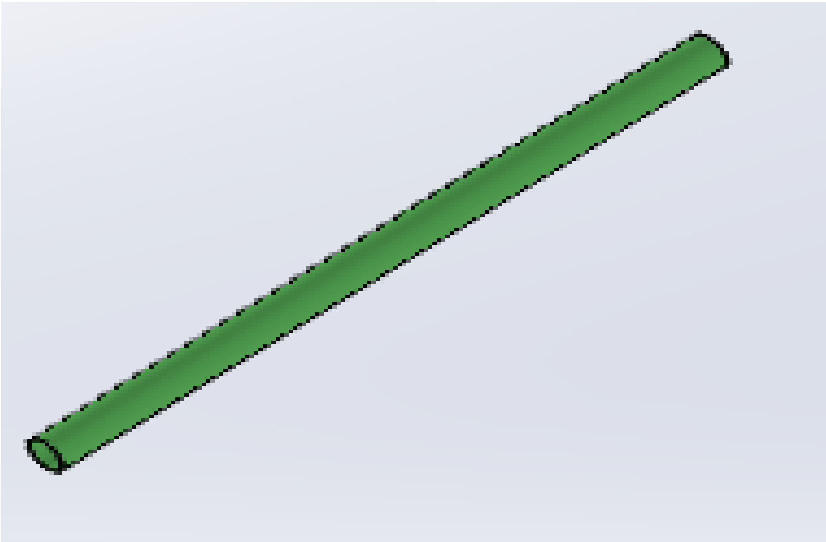


Figure 4.2 Solid model of spray tube

4.3 Design of Water Spray

These design procedures are provide for the general guidance of the water spray system and spray tube designers [Technical Manual, 2009]. They contain broad outlines of the types of considerations, which enter into the design of water spray systems and spray tube. The following these procedures will result in satisfactory system design for this project.

1. Determine equipment dimensions and water density requirement

2. Establish individual design areas and total design area.

3. Determine individual and total design area water demand.

4. Determine water supply conditions and probable available pressure for each design area.

5. Determine number and type of nozzles required to give adequate coverage and water delivery (by trial and error).In selecting a nozzle arrangement to give suitable coverage, the designer has a choice of a number of coverage angles and a number of capacities. It will be necessary to select a proper arrangement to provide adequate density and coverage.

Table 4.2 Theoretical spray coverage at various distances in (cm) from nozzle orifice [Shull, 2012]

Spray angle	5cm	10cm	20cm	30cm	40cm	50cm	60cm	70cm	80cm	100cm
5°	0.4	0.9	1.8	2.6	3.5	4.4	5.2	6.1	7.0	8.7
10°	0.9	1.8	3.5	5.3	7.0	8.8	10.5	12.3	14.0	17.5
15°	1.3	2.6	5.3	7.9	10.5	13.2	15.8	18.4	21.1	26.3
20°	1.8	3.5	7.1	10.6	14.1	117.6	21.2	24.7	28.2	35.3
25°	2.2	4.4	8.9	13.3	17.7	22.2	26.6	31.0	35.5	44.3
30°	2.7	5.4	10.7	16.1	21.4	26.8	32.2	37.5	42.9	53.6
35°	3.2	6.3	12.6	18.9	25.2	31.5	37.8	44.1	50.5	63.1
40°	3.6	7.3	14.6	21.8	29.1	36.4	43.7	51.0	58.2	72.8
45°	4.1	8.3	16.6	24.9	33.1	41.4	49.7	58.0	66.3	82.8
50°	4.7	9.3	18.7	28.0	37.3	46.6	56.0	65.3	74.6	93.3
55°	5.2	10.4	20.8	31.2	41.7	52.1	62.5	72.9	83.3	104
60°	5.8	11.6	23.1	34.6	46.2	57.7	69.3	80.8	92.4	115
65°	6.4	12.7	25.5	38.2	51.0	63.7	76.5	89.2	102	127
70°	7.0	14.0	28.0	42.0	56.0	70.0	84.0	98.0	112	140
75°	7.7	15.4	30.7	46.0	61.4	76.7	92.1	107	123	153
80°	8.4	16.8	33.6	50.4	67.1	83.9	101	118	134	168
85°	9.2	18.3	36.7	55.0	73.3	91.6	110	128	147	183
90°	10.0	20.0	40.0	60.0	80.0	100	120	140	160	200
95°	10.9	21.8	43.7	65.5	87.3	109	131	153	175	218
100°	11.9	23.8	47.7	71.5	95.3	119	143	167	191	238
110°	14.3	28.6	57.1	85.7	114	143	171	200	229	286
120°	17.3	34.6	69.3	104	139	173	208	243	-	-
130°	21.5	42.9	85.8	129	172	215	257	-	-	-
140°	27.5	55.0	110	165	220	275	-	-	-	-
150°	37.3	74.6	149	224	229	-	-	-	-	-
160°	56.7	113	227	-	-	-	-	-	-	-
170°	114	229	-	-	-	-	-	-	-	-

In the Water spray design for a horizontal spray tube:-Make a detail survey of the spray and its surroundings .i.e. diameter, length, height of ends, located and dimensions of any irregularities which may impede distribution of water such as ladders, man holes, piping cooling and the like. NB, location and material of supporting structure for spray tube. Determine contents of spray tube and establishment water density requirements for cooling system. Specification of spray tube are Spray tube diameter outer dia. 27mm, inner dia. 25mm,Spray tube end height=h=D/4=6.7mm,Spray tube shell length 5m ,Density, requiredρw 1000kg/m^3,Thickness t is 2mm.

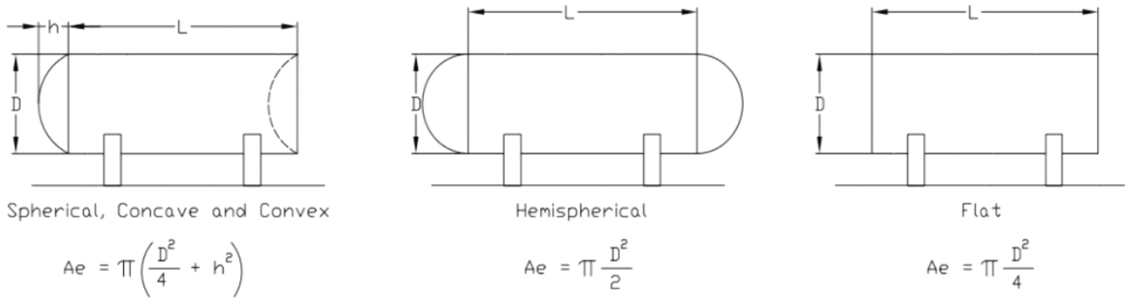


Figure 4.3 Design area of horizontal spray tube

1. Find the area of the cylindrical shell (A_S)

$$A_S = \pi DL\text{…………………………….. (2.1)}$$

$$=3.14*27*5m=423900mm^2$$

2. Find the water required for the shell (Q_S), water required is the shell area times the required density.

$$Q_S = A_S * \rho w\text{………………………… (2.2)}$$

$$=423900mm^2 *1000kg/m^3 =423.9\ kg/m$$

3. Find the area of the ends (A_e)

Use the proper formula for the spray tube ends .If both ends are not the same, use the appropriate formula for ends neglecting the presence of spray tube fittings. In case of this research one end is the same for hemispherical and other ends flat

$$A_e = \pi\frac{D^2}{2}\text{ ………………………… (2.3)}$$

$$=3.14*(27)*27/2=1,144.53mm^2$$

4. Find the water required for the ends (Q_e)

$$Q_{e1} = A_{e1} * \rho w\text{ …………………… (2.4)}$$

$$Q_{e2} = A_{e2} * \rho w \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

$$Q_{e1} = 1144.53*1000= 1.14453kg/m$$

$$Q_{e2} = \pi \frac{D^2}{4} * \rho w \ldots\ldots\ldots\ldots\ldots (2.6)$$

$$Q_{e2} =3.14*27*27/4*1000= 0.572265kg/m$$

5. Determine the total amount water required (Q_{tot})

The total amount of water required is the sum of the water for the shell, both ends, in Amhara pipe factory the number of spray tube for one vacuum bath is 4, there for the total number of spray tube is eight. The total amount of water required is

$$Q_{tot} = 4 * Q_S * Q_{e1} * Q_{e2} \ldots\ldots\ldots\ldots\ldots\ldots (2.7)$$

$$= 4*423.9*1.14453*0.572265=1,110.54kg/m$$

6. Assume water spray pressure:-based up on the known water supply conditions/or assumed

7. Pump conditions and supply piping conditions, calculate the pressure available to spray tube.

8. Find water required from each water spray (Q_{ws}) for each design area divide the water requirement by the number of water spray discharging in to the design area.

$$Q_{ws=}\frac{Qarea}{\text{number of spray}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.8)$$

$$\frac{3.5}{16} = 0.21875 \frac{m^3}{hr}$$

9. Select the proper water spray capacity: consult k tables and determine the pressure which will give the required flow for the nozzle selected.

10. Adjust the design: hydraulically calculate the piping system to produce the required water spray flow .for each individual design area required, water demand must be discharged in to the design area. Discharge from each water spray is must be as uniform as possible.

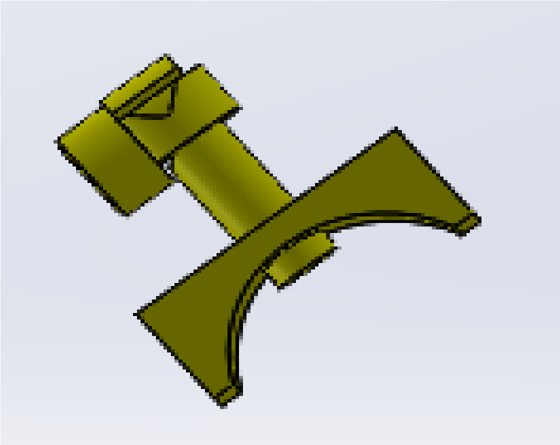


Figure 4.4 Solid model of water spray

4.4 Spray Performance Considerations

(i) Capacity: water spray varies with spraying pressure. In general, the relationship between flow rate and pressure is as follows. Cooling water without dissolved minerals as phosphers, sulpher,iron etc.in flow temperature (T1) is max.15℃,out flow temperature (T2) is T1+5℃,in flow pressure min 25 bar and hardness 5-8°dH

$$\frac{\mathbf{Q1}}{\mathbf{Q2}} = \frac{(\mathbf{P1})^{\mathbf{n}}}{(\mathbf{P2})^{\mathbf{n}}} \quad \text{.................................... (2.9)}$$

Where, Q=flow rate ($\frac{m^3}{hr}$), P=water pressure (bar), n=exponent applying to the specific spray type

$\frac{\mathbf{0.08125}}{\mathbf{0.21875}} = \frac{(\mathbf{20})^{\mathbf{0.5}}}{(\mathbf{p2})^{\mathbf{0.5}}}$, 0.08125 is minimum water inlet of cooling system of one spray

$P2 = 144.97 \text{ bar}$

Table 4.3 Capacity factors for specific spray type [Shull, 2012]

Spray type	Exponent (n)
Hollow cone spray (all)	0.50
Full cone spray (vanelless)	0.50
Flat spray nozzles (all)	0.50
Spiral nozzle(all)	0.50
Full cone spray (standard)	0.46
Full cone spray(square spray)	0.46
Full cone spray(oval spray)	0.46
Full cone spray(large capacity)	0.46
Full cone spray (wide spray)	0.44
Full cone spray (square spray)	0.44

(ii) Specific gravity: specific gravity is the ratio of the mass of a given volume of water to be sprayed to mass of the same volume of water. In spraying, the main effect for specific gravity liquid other than water is on the capacity of spray nozzle. Since the values are based on spraying water, conversion factor or formula can be applied to determine the spray capacity.

$$\text{capacity of liquid being sprayed} = \text{capacity of water} * \frac{1}{\sqrt{\text{specificgravity}}} \text{.............. (3.0)}$$

This formula is used for the case of other than water is to spray in the system.

(iii) Impact: impact, or the impingement of a spray on to the target surface, can be expressed in several different ways. The most useful impact values with regard to spray performance is the impact per square inch (cm). Basically this, values depends on the spray pattern distribution and spray angle. To obtain impact using the following formula;

$$I = K * Q * \sqrt{P} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where, I =total theoretical spray impact, Q_r =flow rate, K =constant, P= water pressure being sprayed

Table 4.4 k factor for spray design [Shull, 2012]

I	lbs.(f)	kg(f)	Newton's	Newton's
K	0.526	0.24	0.24	0.24
Q	gpm	l/m	l/m	l/m
P	psi	Kg/cm^2	bar	Mpa

For this design of water spray we can calculate the theoretical water spray impact as shown below.

$$I = 0.24 * 0.21875 * \sqrt{20} = 0.235 \text{ kg(f)}$$

Table 4.5 Calculation of weight per meter of HDPE pipe for PN 6 [APF, 2016]

OD (mm)	Thickness mm		Weight /meter (kg/m)			Price (birr/m)		
	Min.	Max.	Min.	Max.	Ave.	Min.	Max.	Ave.
110	4.2	4.8	1.34	1.521	1.43	80.35	91.23	85.74
125	4.8	5.4	1.74	1.945	1.84	104.33	116.62	110.5
140	5.4	6.1	2.18	2.46	2.32	130.71	147.50	139.11
160	6.2	7.0	2.88	3.225	3.05	172.685	193.37	183.03
180	6.9	7.7	3.61	3.995	3.8	216.456	239.54	227.998
200	7.7	8.6	4.46	4.957	4.71	267.42	297.22	282.32
225	8.6	9.6	5.61	6.227	5.92	336.37	373.37	354.87
250	9.6	10.7	6.95	7.71	7.33	416.72	462.29	439.51
280	10.7	12.1	8.67	13.5	9.14	519.85	809.46	664.65
315	12.1	13.5	11.0	12.257	11.65	659.56	734.93	697.24

N.B Calculation of selling cost for the factory of each outer diameter and pn6 $= \frac{\text{weight}}{\text{meter}} * 59.96 \text{ birr/kg}$

Table 4.6 Calculation of weight per meter of HDPE pipe for PN20 [APF, 2016]

OD (mm)	Thickness(mm)		Weight /meter (kg/m)			Price (birr/m)		
	Min.	Max.	Min.	Max.	Ave.	Min.	Max.	Ave.
110	12.3	13.7	3.63	3.978	3.8	217.54	238.40	227.97
125	14	15.6	4.68	5.139	4.91	280.47	307.98	294.23
140	15.7	17.4	5.88	6.424	6.15	352.39	384.99	368.69
160	17.9	19.8	7.66	8.359	8.01	459.06	500.95	480.007
180	20.1	22.3	9.67	10.59	10.13	579.52	634.65	607.089
200	22.4	24.8	11.98	13.084	12.53	717.96	784.12	751.04
225	25.2	27.9	15.16	16.559	15.6	908.54	992.38	950.46
250	27.9	30.8	18.65	20.33	19.49	117.69	1218.377	668.03
280	31.3	34.6	23.43	25.568	24.5	1404.16	1533.057	1468.61
315	35.2	38.9	29.66	32.342	31.00	1777.52	1938.24	1857.88

N.B Calculation of selling cost for the factory of each outer diameter and pn20 $= \frac{\text{weight}}{\text{meter}} * 59.932\ \text{birr/kg}$

Table 4.7 Calculation of weight per meter of HDPE pipe for PN 12.5 [APF, 2016]

OD (mm)	Thickness(mm)		Weight /meter (kg/m)			Price (birr/m)		
	Min.	Max.	Min.	Max.	Ave.	Min.	Max.	Ave.
110	8.1	9.1	2.50	2.765	2.63	150	165.9	157.95
125	9.2	10.3	3.20	3.56	3.38	192	213.6	202.8
140	10.3	11.5	4.03	4.45	4.24	241.8	267	254.4
160	11.8	13.1	5.27	5.80	5.53	316.2	348	332.1
180	13.3	14.8	6.68	7.36	7.02	400.8	441.6	421.2
200	14.7	16.3	8.20	9.02	8.61	492	541.2	516.6
225	16.6	18.4	10.41	11.45	10.93	624.6	687	655.8
250	18.4	20.4	12.84	14.10	13.47	770.4	846	808.2
280	20.6	22.8	16.08	17.66	16.87	964.8	1059.6	1012.2
315	23.2	25.7	20.39	22.389	21.39	1223.4	1343.34	1283.37

N.B Calculation of selling cost for the factory of each outer diameter and pn12.5 $= \frac{\text{weight}}{\text{meter}} * 60\ \text{birr/kg}$

Table 4.8 Calculation of weight per meter of HDPE pipe for PN 16 [APF, 2016]

OD (mm)	Thickness(mm)		Weight /meter (kg/m)			Price (birr/m)		
	Min.	Max.	Min.	Max.	Ave.	Min.	Max.	Ave.
110	10.0	11.1	3.01	3.306	3.16	180.6	198.36	189.48
125	11.4	12.7	3.91	4.295	4.10	234.6	257.7	246.15
140	12.7	14.1	4.87	5.346	5.11	292.2	320.76	306.48
160	14.6	16.2	6.39	7.015	6.70	383.4	420.9	402.15
180	16.4	18.2	8.07	8.867	8.47	532.02	532.02	508.11
200	18.2	20.2	9.96	10.937	10.45	597.6	656.22	626.91
225	20.5	22.7	12.63	13.828	13.23	757.8	828.68	793.74
1250	22.7	25.1	15.54	16.999	16.27	932.4	1019.94	976.17
280	25.1	28.4	19.47	21.32	20.39	1168.2	1279.2	1223.7
315	28.6	31.6	24.67	26.967	25.82	1480.2	1618.02	1549.11

N.B Calculation of selling cost for the factory of each outer diameter and pn16 $= \frac{\text{weight}}{\text{meter}} * 60 \text{ birr/kg}$

Table 4.9 Calculation of weight per meter of HDPE pipe for PN 10 [APF, 2016]

OD (mm)	Thickness (mm)		Weight /meter (kg/m)			Price (birr/m)		
	Min.	Max.	Min.	Max.	Ave.	Min.	Max.	Ave.
110	6.6	7.4	2.05	2.286	2.17	123	137.16	130.08
125	7.4	8.3	2.62	2.917	2.77	157.2	175.02	166.11
140	8.3	9.3	3.30	3.66	3.48	198	219.6	208.8
160	9.5	10.6	4.31	4.769	4.54	258.6	286.14	272.37
180	10.7	11.9	5.46	6.024	5.74	327.6	361.44	344.52
200	11.9	13.2	6.74	7.425	7.08	404.4	445.5	424.95
225	13.4	14.9	8.53	9.427	8.98	511.8	565.62	538.71
250	14.8	16.4	10.48	11.536	11.01	628.8	692.16	660.48
280	16.3	18.7	13.17	14.50	13.83	790.2	870	830.1
315	18.7	20.7	16.68	18.34	17.51	1000.8	1100.4	1050.6

N.B Calculation of selling cost for the factory of each outer diameter and pn10 $= \frac{\text{weight}}{\text{meter}} * 60 \text{ birr/kg}$

E.g. of weight per meter calculation for HDPE pipe outer diameter of pipe 315mm, nominal pressure10 bar= 1N/mm^2.

Weight /meter: - Minimum 16.68kg/m, Maximum. 18.34kg/m

$$\text{Average} = \frac{\text{minimum+maximum}}{2} = 17.51\text{kg/m}$$

Price calculation of HDPE pipe:- minimum price $= \frac{\text{weight}}{\text{meter}} * 60\ \text{birr/kg}$

$$= 16.68 * 60 = 1000.8\ \text{birr/m}$$

$$\text{Maximum price} = \frac{\text{weight}}{\text{meter}} * 60\ \text{birr/kg}$$
$$= 18.34 * 60 = 1100.4\ \text{birr/m}$$

$$\text{Average price} = \frac{1000.8\ \text{birr} + 1100.4\ \text{birr}}{2} = 1050.883\ \text{birr/m}$$

For this value of HDPE pipes the length of vacuum bath is 6m,therefore 6*1100.4which have the amount of 6602.4 birr/m maximum value for this length and 6*1050.883 in an amount of 6305.298 birr /m average value for the same length. Most of the time Amhara pipe factory is produced PN value of 6, 10, 12.5, 16, and 20 in the sheet and plastic pipe manufacturing factory.

E.g. Effective cooling length of HDPE pipe can be calculated as follows:

(L)=WT*M*F/D*10

Where L =effective cooling length, WT= minimum wall thickness, M=output, F=cooling factor 7mh/kg, for nominal pressure 10 bar= 1N/mm^2, Wall thickness 6.6mm

Output =500kg/hr. this value expectations for OD =160mm you can see appendix table

L=6.6*500*7/160*10=1443,750mm from this value it can cool up to this amount of length of plastic pipe .whereas above to cool this length the output and diameter of pipe is changed depending on customers order.

4.5 Design of Roller Structure

Some types of roller structure have cages of composite materials, which are more sensitive to high temperature and certain oil additives. When using such structures, the corresponding information of the manufacturer should be studied thoroughly. Rings and rolling elements of roller support are usually made of low-alloy, high-carbon steel that reaches a hardness of 59-63 HRC after hardening and low temperature tempering. Tempering temperature is about 220-240° C, and most of the residual stresses due to quenching remain in the steel, which becomes brittle.Therefore,roller structures must not be subjected to impact during installation; this may release part of the stresses and change the geometry of the raceways. Generally, machines like to be treated nicely and gently. Mounting and dismounting of roller structure should be performed using special devices or temperature deformation (usually cooling in water with controlled temperature). It is clear that the heating temperature must not exceed 240°C [Timoshenko, 2003].

The load capacity of a roller structure depends not only on its geometry, but also on the quality of the metal and heat treatment, on the accuracy of machining and surface conditions, on technological subtleties, lubrication, and so on. That is why the formulas for contact stresses given in the following text are intended for understanding purposes only. The load capacity of RBs should be calculated in accordance with the recommendations and data of the manufacturers given in the catalogs. Let's examine the contact stresses by the simplest example of a cylindrical roller structure. Specification are: - R= load this the same as load of pipe in 315mm OD, =21.39*5*10= 1069.5N, E= modulus of elasticity 206*10^5 (Mpa), L= length of contact line (mm)= 16mm, The diameter of the roller=8mm,r_e = Equivalent radius of curvature, The radius inner race way is let as assume 30mm, The most loaded roller is pressed between two rings with force F could be calculated as follows

$$F = \frac{5*R}{z} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where z= number rolling elements= 6 in pipe factory,$F = 891.25N$

The maximum magnitude of this stress σ_H may be determined using Hertz's formula

$$\sigma_H = 0.418\sqrt{\frac{F*E}{r_e*L}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

$$r_e = \frac{ri*r}{ri+r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

$$r_e = \frac{30*8}{30+8} = 6.32mm$$

$\therefore\ \sigma_H = 0.418\sqrt{\frac{891.25*2.06*10^5}{6.32*16}} = 563Mpa$ The width of the contact area is calculated as follows

$$b_c = 3.04\sqrt{\frac{F*r_e}{L*E}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

$$b_c = 3.04\sqrt{\frac{891.25*6.32}{16*2.06*10^5}} = 0.126mm$$

It is known for a fact that sometimes the fatigue cracks originate at a depth. The most shear stress (for roller structure) is located at a depth of $0.4b_c$ and its magnitude is

$$\tau_{max} = 0.304 * \sigma_H \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

$$\tau_{max} = 0.304 * 563Mpa = 171.15Mpa$$

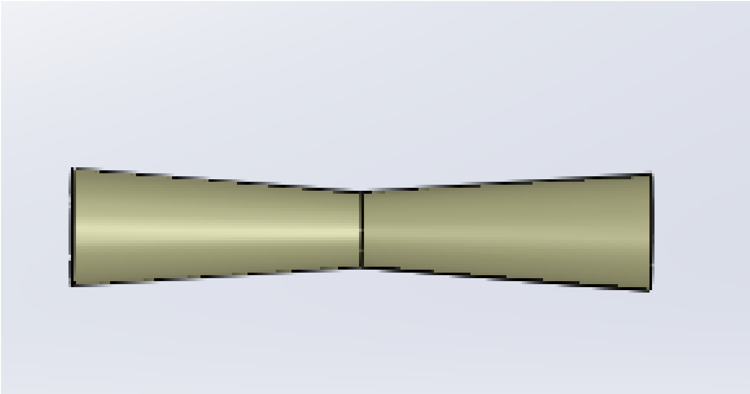


Figure 4.5 Solid model of roller structure

4.6 Design of Cover Plate (Roller Support)

Design Specification the material selected for cover plate of the pipe rolling is grey cast iron of FG200. grey cast iron is used for automotive components such as cylinder block, brake drum, clutch plate, cylinder and cylindrical head, gears and gear housing of gear box, covers etc. due to this reason , we select grey cast iron of gradeFG200 (s_{yt} = 2oo Mpa and hardness 160- 220HB). It is cheap, can be give complex shape, posse's high compressive strength. The length of the cover plate is 200mm,Width of the cover plate is 25mm,The thickness of the cover plate (t_1) and it determined as follow; Let us consider the semi cover plate as shown in the fig. the internal pleasure in the die tries to bend the pipe while the bolts try to retain it in its position. But the center pressure of these two loads does not concede. Hence the cover plate is subjected to bending stress. Where X is the center of pressure for roller and pipe loaded, Y is the center of internal pressure we know that the bending moment at A-A, M [Budynas, 2006].

$$M=\frac{\text{total hdpe pipe load}}{2}\text{(ox-oy)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

Load of HDPE pipe=pressure of HDPE pipe*area, therefore for PN 20 and outer diameter of 315mm, with thickness of 3.5mm is

$$= 2\text{N/mm}^2 * (\frac{\pi}{4}(315^2 - 311.5^2) = 3444.36\text{N}$$

$$M= \frac{W}{2}(0.318D_p\text{- } 0.212D_P)$$

$$M=0.053W*D_p = 0.53*3444.36*1$$

$$M = 1825.51 \text{ N-mm}$$

Outside diameter of the cover plate $D_o = D_p + 3d_1$

D_o = 1+ 3*8= D_o = 25mm

Width of the plate w, W = D_O - $2d_1$

$W = 25 - 2(8) = 9mm,$

Therefore section modules, Z

$$Z = \frac{1}{6}(t_{1^2})\ w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.8)$$

We know that bending (tensile stress) for grey cast iron 200Mpa

$$\sigma_t = \frac{M}{Z} = 200$$

$$Z = \frac{M}{200} \quad mm^{-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

$$Z = \frac{1825.51}{200}$$

$$Z = 9.1mm^{-1}$$

Therefore, from the above equation

$$t_1 = \sqrt{\frac{Z*6}{W}}$$

$$t_1 = \sqrt{\frac{9.1*6}{9}} = 6.1mm$$

Therefore thickness of the cover platet_1, is 6.1mm and the cover plate opening depth =outer diameter of roller + some allowance clearance 26 + 5 = 31mm, Note that: fore width of the cover plate so it is less, we take the 25mm.

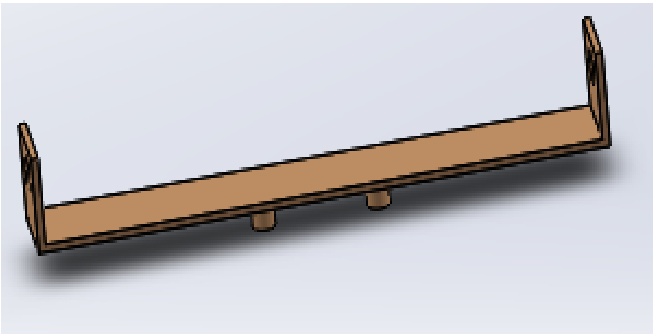


Figure 4.6 Solid model roller support

4.7 Design of Bolt and Nut

Material selection for bolts and nuts are chosen of material grade is dependent on the duty of the line. Using incorrect bolting could have serious Consequences. For example, normal alloy steel bolting (B7) on a low temperature service is not suitable as the bolting will be susceptible to brittle fracture. Stainless steel bolting has limitations at high pressure due to the relatively low strength of the stainless steel [Khurmi and Gupta, 2005]. We select materials for bolt and nut is carbon steel due to the following reasons: - Carbon steels in general are easy to work with exhibiting excellent machinability and weld ability. Though as the carbon content increases, the ease of manufacture decreases. The added carbon changes the behavior of the material at high temperature and therefore needing a more refined process. When a bolt and nut is made of medium carbon steel, the effective height of nut is made equal to the nominal diameter of bolt. The desirable properties of bolt materials are follows:-

i. It should have sufficient strength to with stand stress due to external load and applied torque.

ii.It should poses high wear resistance, it should have good machinability.

iii. Bolts are made from plain carbon steel such as 30c8, 40c8, 45c8 and alloy steel like 40cr1. But we select 45c8 medium carbon steel (ultimate tensile strength , s_{yt} = 630 Mpa, hardenability 229HB yield strength y_t=380 Mpa). The bolts are case hardened by nitrating process. Design specification of bolt and nut are from table (coarse series) text book of machine design. Pitch, p 1mm, nominal diameter bolt and nut, d 7mm, pitch diameter for both bolt and nut, d_p 6.35mm, core diameter for bolt, $\mathrm{d_c}$ 5.77mm, core diameter for nut, d_c 5.9mm,depth of thread of bolt 0.613mm,Stress area 28.9mm^2,Diameter of the hole = 8mm, Head of the bolt is3mm.

From the material properties: Tensile strength of bolt material, σ_t = 630Mpa, Ultimate tensile strength of nut material, Su_t = 190Mpa. There is relative motion between bolt and nut and wear is inevitable. The material for the nut should be soft and conformable to that of bolt. The wear is always restricted to softer surface. Therefore, if at all component is to be replaced, it should be the nut that is less cost compared with bolt. Bronze is ideal material for nut. The material for the nut is tin, bronze and phosphorus bronze ($\mathrm{su_{t=190Mpa}}$)

Where, d= nominal diameter, $\mathrm{d_c}$ = Core diameter of the bolt, n=number of bolts, σ_t = Tensile strength of the bolt material = 630 Mpa, P =applied (load) force vacuum bath = Stress area*pressure=869.89N. Let as assume, the nominal diameter of the bolt is 7mm, we find that the corresponding core diameter of the bolt is 5.77mm.

$$\mathrm{P} = \frac{\pi}{4}\mathrm{d_{c^2}}\,\sigma_t\,\mathrm{n} = 869.89\mathrm{N}$$

$$\text{From this equation, } \mathrm{n} = \frac{\mathrm{p}}{\frac{\pi}{4}\mathrm{d_{c^2}}\sigma_t} = \frac{869.89}{\frac{\pi}{4}*5.77^2*630} \ldots\ldots\ldots\ldots\ldots\ldots \text{(4.0)}$$

n= 1 but, we need n=4 bolts, We know that for a leak proof joint, the circumferential pitch of the bolts should lie between $20\sqrt{\mathrm{d_1}}$ to $30\sqrt{\mathrm{d_1}}$, Maximum circumferential pitch of the bolt =$30\sqrt{\mathrm{d_1}}$ =84.85mm and minimum circumferential pitch of the bolt = $20\sqrt{\mathrm{d_1}}$ =56.56 mm. Since the circumferential pitch of the bolts obtained above is within 56.56mm and 84.85mm. The size of the bolt chosen is satisfactory.

- ✓ The length of the thread at the end of the bolt is 10mm.
- ✓ The total length of the bolt is, L = 2 times of the thickness of the cover plate +the clearance of cover (roller support) b/n roller +length of roller support + the length of the head L = 2*6.1 +4+200 + 3= 219.2mm.

Therefore, size of the bolt is M7, design dimensions of screw threads, bolts and nuts according to IS: 4218 (part iii) 1976 (reaffirmed 1996) [Khurmi and Gupta, 2005].

For nut: - the permissible bearing pressure between bolt and bronze nut is 10N/mm^2. The number of threads required to support load is, z

$$Z = \frac{4W}{\pi S_{b(d^2 - d_c^2)}} \qquad \text{............................ (4.1)}$$

Where: z= number of threads; d= nominal diameter of the bolt, d_c = Core diameter of the bolt,

$$Z = \frac{4*869.89}{\pi*10(7^2 - 5.77^2)} = 6$$

The axial length of nut (H) is given by:-

$$H = Z*P \qquad \text{..................................... (4.2)}$$

Where: P= pitch of the thread, H= 6* 2= 12 mm,

The transverse shear stress at the root of the threads in the nut is given by, τ_n

$$\tau_n = \frac{W}{\pi dtz} \qquad \text{..................................... (4.3)}$$

$$\tau_n = \frac{869.89}{\pi*7*2*6} = 3.3\text{Mpa}$$

Factor of safety, f_s $\quad f_s = \frac{0.5su_t}{\tau_n}$ .... (4.4)

$$f_s = \frac{190*0.5}{3.3} = 28$$

Since, the high factor of safety results in unnecessary risk of failure. Therefore the values of factor of safety based on ultimate strength of 190Mpa from value of safety factor is 6 for soft material and alloys. The dimensions of the nut are shown below. The outer diameter of the nut is assumed to be twice of the nominal diameter of the thread. (i.e.14mm).The circumferential pitch of the studs cannot be measured and marked on the cylinder cover. The center of the holes are usually marked by angular distribution of the pitch into 'n' number of equal parts.

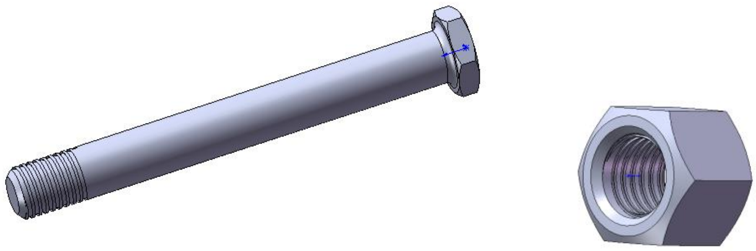


Figure 4.7 Solid model of bolt and nut

4.8 Design of Support Frame

In the design of water spray and vacuum bath the bottom part is support frame. It will depend on the size of vacuum bath with some clearance. Support frame made up of stainless, support frame have 6 legs. The dimension of the support frame (housing support) will be 5.8m*0.55m*0.58m it has similar dimension of vacuum bath. Load acting on the support frame can be gained=load of vacuum bath + load of HDPE pipe +load of spray tube. Load of vacuum bath is1657kN, Permissible compressive stress of stainless steel (σ_c) = 160 N/mm^2

Compressive area of base= $5 * 0.58 = 2.9\text{m}^2 = 2900000\text{mm}^2$, the load acting on the vacuum bath =load of water spray +load of spray tube +load of hdpe pipe

$$\text{Load of water spray} = \frac{\pi}{4}(\text{do}^2 - \text{di}^2) * \text{Pressure} \ldots\ldots\ldots\ldots\ldots (4.5)$$

$$\sigma\text{t} = \frac{\sigma\text{all}}{\text{factor of safety}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.6)$$

Where, σt =tensile stress of water spray, σ_{ll} =Ultimate tensile stress of water spray material= 34N/mm^2, $\sigma\text{t} = \frac{34}{5} = 6.8\text{N/mm}^2$; there fore Load of water spray= $\frac{\pi}{4}(7.5^2 - 3^2) * 6.8/6 = 42.058\text{N}$

Total $=$ no. of spray in one vacuum bath $* 42.058 = 16 * 4 * 42.058 = 2691.712\text{N}$

Load of HDPE pipe=pressure of HDPE pipe*area…………………… (4.7)

For pn 20 and outer diameter of 315mm, with thickness of 3.5mm is= $2\text{N/mm}^2 * (\frac{\pi}{4}(315^2 - 311.5^2) = 3444.36\text{N}$

$$\text{Load of spray tube} = \text{pressure of spray tube} * \text{area} \ldots\ldots\ldots\ldots\ldots (4.8)$$

$$\frac{\sigma\text{ll}}{\text{pressure}} \geq 6 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.9)$$

Pressure= $\frac{120.5\text{N}}{\text{mm}^2} \div 6 = 20.083\ \text{N/mm}^2$

Load of spray tube= $\frac{\pi}{4}(27^2 - 25^2) * 20.083 = 6558.3\text{N}$, therefore Total load of spray tube $= 4 * 6558.3 = 26233.218\text{N}$

The total load acting on support frame can be calculated using the following formula.

=Load of vacuum bath + load of hdpe pipe +load of spray tube+ load of water spray

$= 1657\text{KN} + 3444.36\text{N}+26233.218\text{N} + 2691.712\text{N} = 1689.369\text{KN}$

Load acting the support frame (housing support) =1689.369KN . Checking for compressive strength σ_c = 0.1012N/mm^2. The induced compressive stress is less than permissible valve. Hence the design is safe.

Load acting on legs= $\frac{\text{load acting on upper part housing support}}{6}$ because the frame support has 6 legs.

$$\frac{1689.369\text{KN}}{6} = 281.56\text{KN}$$

$$\sigma_{c=} \quad \frac{\text{load acting on legs}}{\text{A}}$$

$$w = \frac{\text{F}}{\sigma_{c*L}} \text{ ……………………………………………….. (5.0)}$$

Where F=load acting on legs, L= length of the legs, w=width of legs

$$\text{L} = \frac{\text{F}}{\sigma_{c*W}}$$

W=20mm, L=480mm, for support frame Length = 5.8m, width = 0.58m, and height = 0.55m, volume of support structure = L*H*W = 5.8*0.55*0.58 = 1.85m^3

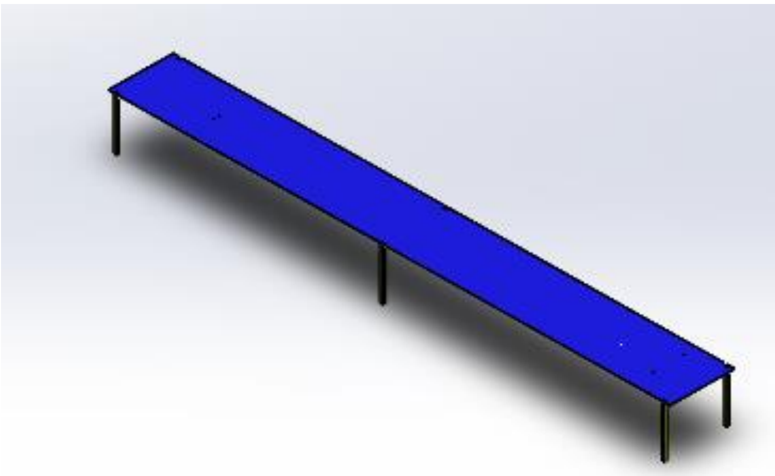


Figure 4.8 Support frame

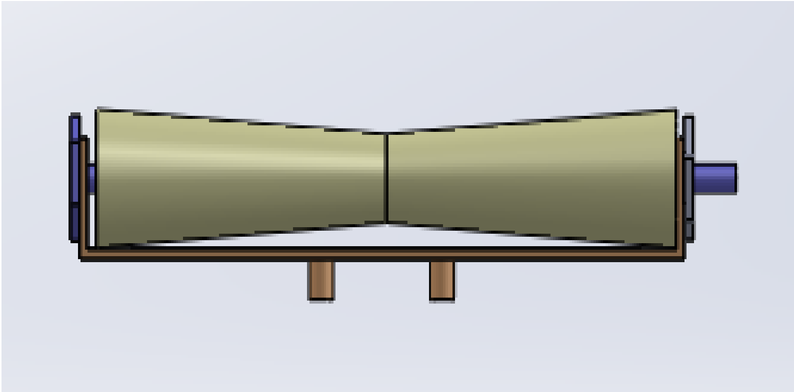


Figure 4.9 Assembly of roller support, roller, bolt and nut

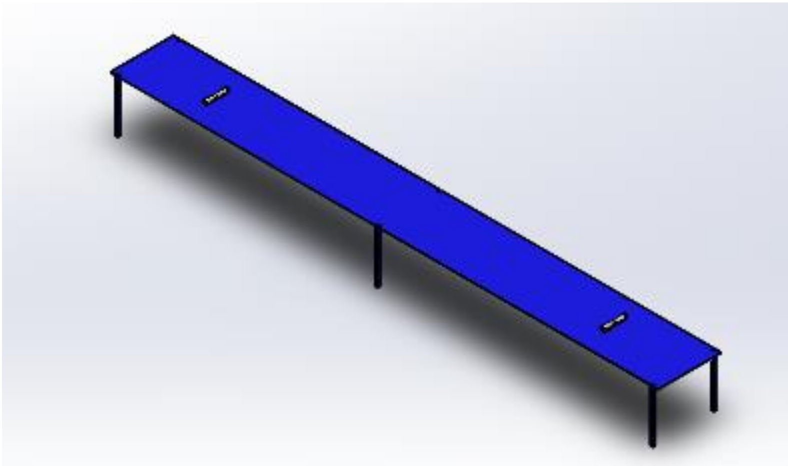


Figure 4.10 Assembly of frame support, roller support, roller, bolt and nut

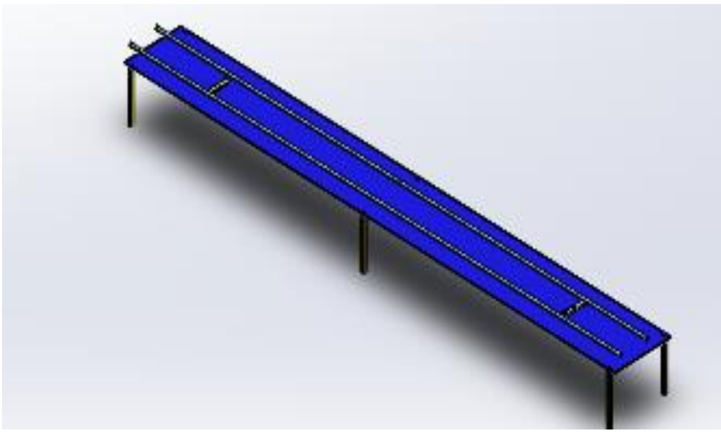


Figure 4.11 Assembly of frame support, roller support, spray tube with bolt and nut

Table 4.10 Names of components dimensions for solid work drawing and ansys simulation

S.no	Name of components	Dimensions			Materials
		Length	Diameter		
			OD	ID	
1.	Vacuum bath	5.8*0.55*0.58m			Stainless steel
2.	Spray tube	5.8 m for one water bath	27mm	25mm	Cast iron
3.	Water spray		Inlet 7.5mm	5mm	Plastic rubber
			Out let 3mm	2.4mm	
4.	Frame support	5.8*0.55*0.58m			Stainless steel
5.	Roller	190mm of contact	8mm		Carbon steel
6.	Roller support	200mm	25mm width		Cast iron
7.	Bolt	219.2mm	5.9mm	5.77mm	Carbon steel
8.	Nut	3mm	5.9mm		Carbon steel

4.9 Stress Calculations by Theoretical Method

Calculating stress and deformation by theoretical calculation. In the design and optimization of water spray tube and vacuum bath involves thin cylinder type of water spray. For thin cylinder such as gun, pipes, hydraulic press and hydraulic cylinder the wall thickness is relatively medium. So stress variation across the thickness is also significant. The stresses present in thin water spray tube which are circumferential, radial, and longitudinal. In this procedure calculate the hoop stress and deformation [Khurmi and Gupta, 2005].

Calculating Parameters, σ_Θ= Circumferential Stress, σr= Radial Stress, σ_z= Axial Stress

4.9.1 Water Spray Tube

Stress Calculation for water spray tube, thick cylinder condition, for thick cylinders such as guns, pipes to hydraulic presses, high pressure hydraulic pipes the wall thickness is relatively large and the stress variation across the thickness is also significant.

Where; - ro = Outer radius of cylindrical shell = 13.5 mm, ri = Inner radius of cylindrical shell = 12.5, pi = Intensity of internal pressure = 20.083Mpa,

σr = Radial stress.

$$\sigma r = \frac{p_i r_i^2 \,(1-\frac{r_o^2}{r_i^2})}{r_o^2 - r_i^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(.5.1)}$$

σr= -20.83 N/mm^2

Circumferential Stress (σ_Θ)

$$\sigma_\Theta = \frac{p_i r_i^2 \,(1+\frac{r_o^2}{r_i^2})}{r_o^2 - r_i^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.2)}$$

σ_Θ = 37.30 N/mm^2

Axial stress (σ_z)

$$\sigma_z = \frac{p_i r_i^2}{r_o^2 - r_i^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.3)}$$

σ_z = 120.69 N/mm^2

Equivalent Stress (Von Mises Stresses) (σ_{eq})

$$\sigma_{eq} = \sqrt{[\sigma_\Theta{}^2 + \sigma_r{}^2 - \sigma_\Theta * \sigma_r \;]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.4)}$$

σ_{eq} = 46.175 N/mm^2

Failure criteria

$$\frac{1}{2}[(\sigma_\Theta - \sigma_r)^2 - (\sigma_r - \sigma_z)^2 - (\sigma_z - \sigma_\Theta)^2] \leq \sigma_y{}^2$$

-11.739.06 $\leq$ 58081 $N/mm^{2,}$ According to failure criteria above design is Safe.

4.9.2 Deformation of Water Spray Tube

In case of thin water spray having inner radius (r_i) and outer radius (r_o), Let the water spray is subjected to internal pressure (p_i). The value of Poisson's ratio and modulus of elasticity or Young's modulus (*E*) for steel material is 0.25 to 0.33 and 200 to 220 respectively used in engineering practice. Calculate the deformation for water spray$_\Theta$= Circumferential deformation water spray tube, δ_r= Radial Deformation, ϵ_Θ= Circumferential Strain, E = Modulus of Elasticity

$$\epsilon_\Theta = \frac{\sigma_\theta - v\sigma_r}{E} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.5)}$$

ϵ_Θ = 20.86* 10^{-2}

Circumferential Deformation (δ_Θ)

$$\delta_\Theta = \epsilon_\Theta \, 2\Pi \, r_o \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.6)}$$

δ_Θ= 1.7685mm

Radial Deformation (δ_r)

$$\delta_r = \in_\Theta * r_o \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (5.7)$$

$$\delta_r = 2.8161mm$$

Deformation (δ) $\delta = \delta_\Theta + \delta_r$, δ=4.586mm

4.9.3Assembly Drawing

4.9.3.1 Methods of Assembly

I. First put frame support at the bottom ,and then insert the sub assembly drawing of roller support with roller ,bolt and nut .the roller support and the frame support is connected through welding.

II. Set the spray tube on the frame support in four different position. The spray tube and frame support is connected by welding.

III. Insert the vacuum housing into the above of frame support or water bath

IV. The roller is also place or set on the roller support.

Then the roller, cover plate (roller support) are connected by bolts

VI. After that bolts are tied by nuts. Finally we the desired shape water spray system and vacuum cooling bath.

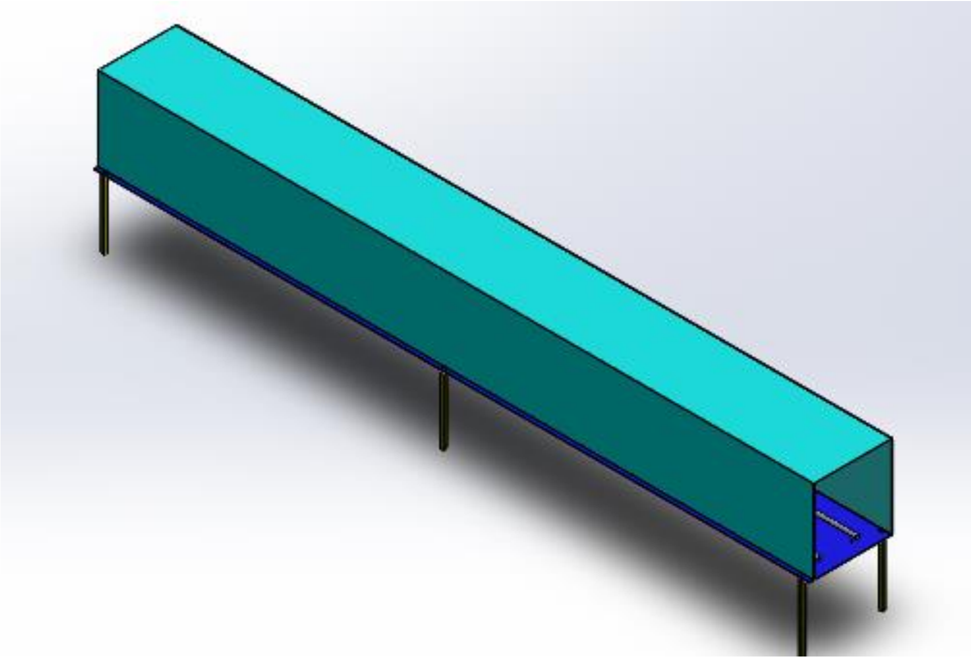


Figure 4.12 Final Assembly of Solid Model Drawing

4.9.4 Analysis of the System

In numerical analysis ansys software is a powerful technique used for different metal deformation problems including strain energy. In this study, ansys software has been used to analysis total deformation, static structural von- mises stress, elastic strain of bench work obtained during simulation process. In this study ansys software had the following basic steps to obtain the required result. These are: static structure, mesh generation, fixed support, load and finally solution (deformation, equivalent von-misses stress, strain, maximum shear stress). It is very important to avoid failure of components of vacuum bath. The simulation analysis of vacuum bath components could gave better and reliable results.

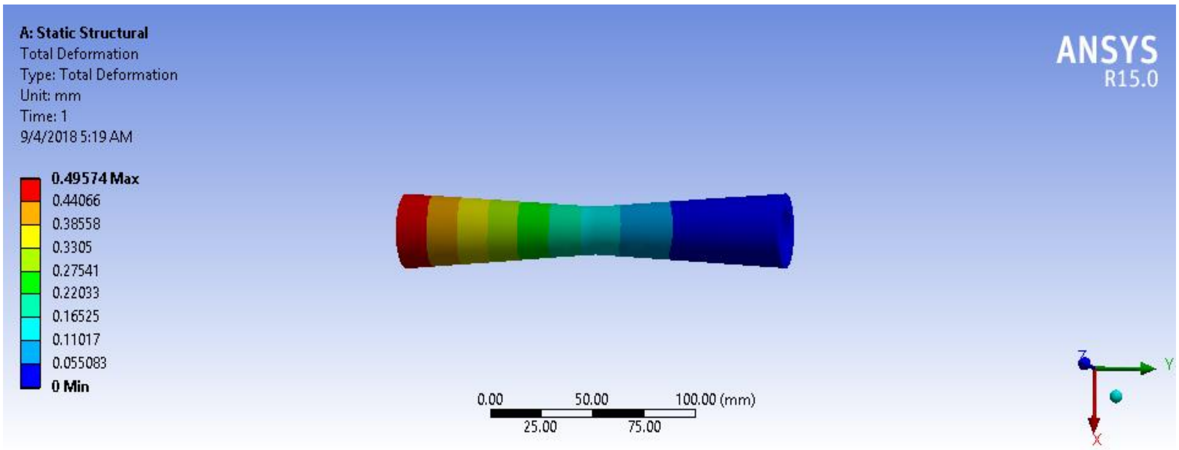


Figure 4.13 Block diagram of simulation of roller in total deformation

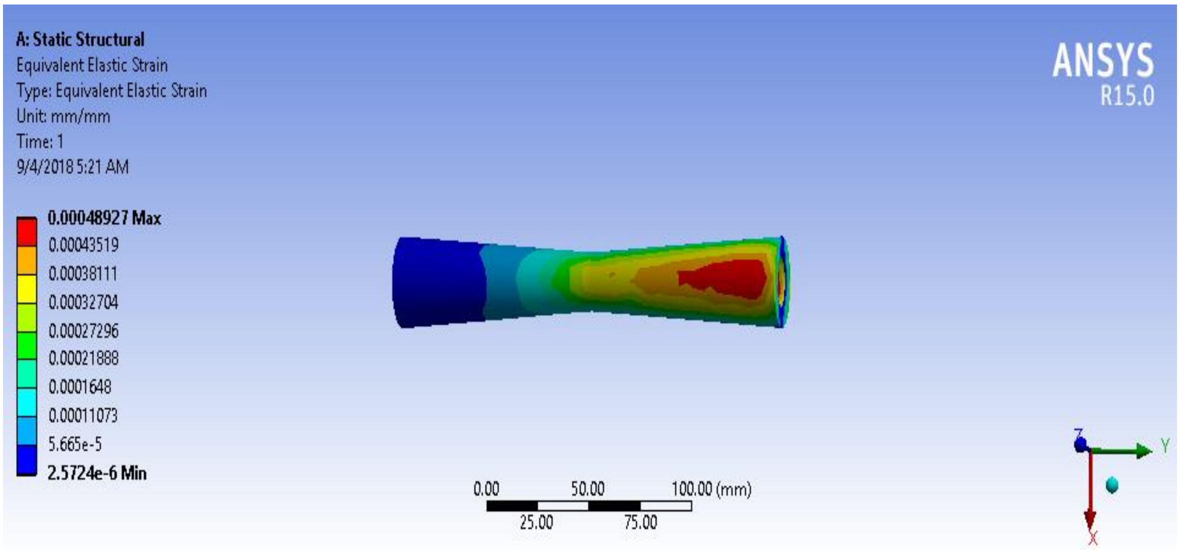


Figure 4.14 Block diagram of simulation of roller equivalent elastic strain

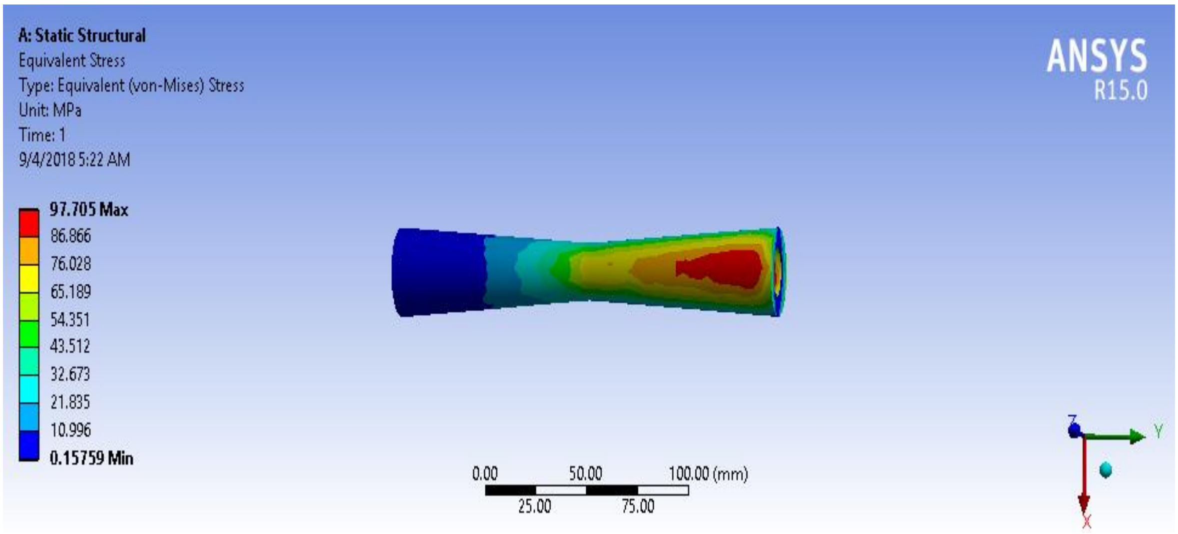


Figure 4.15 Block diagram of simulation of roller equivalent von miss stress

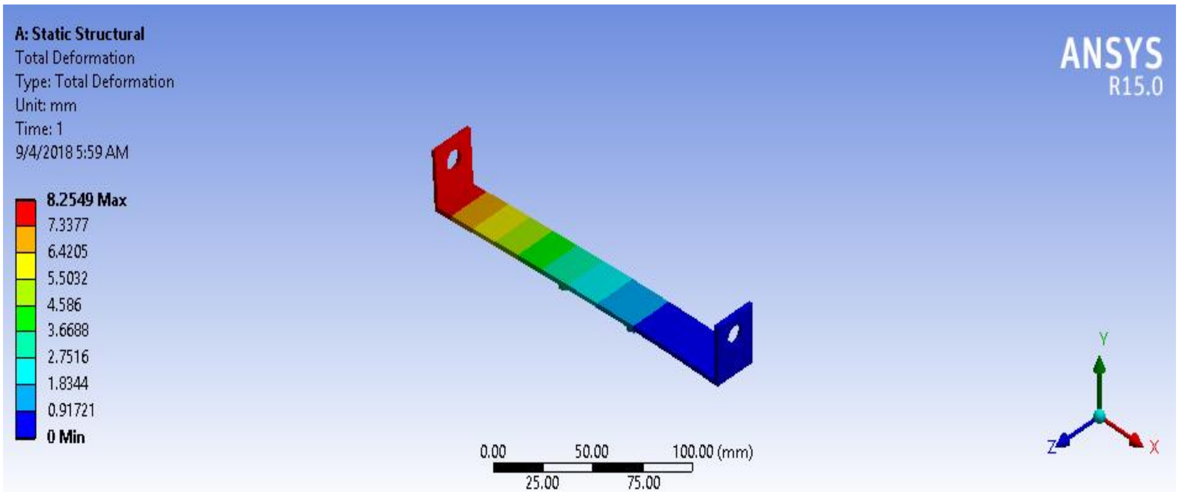


Figure 4.16 Block diagram of simulation of roller support in total deformation

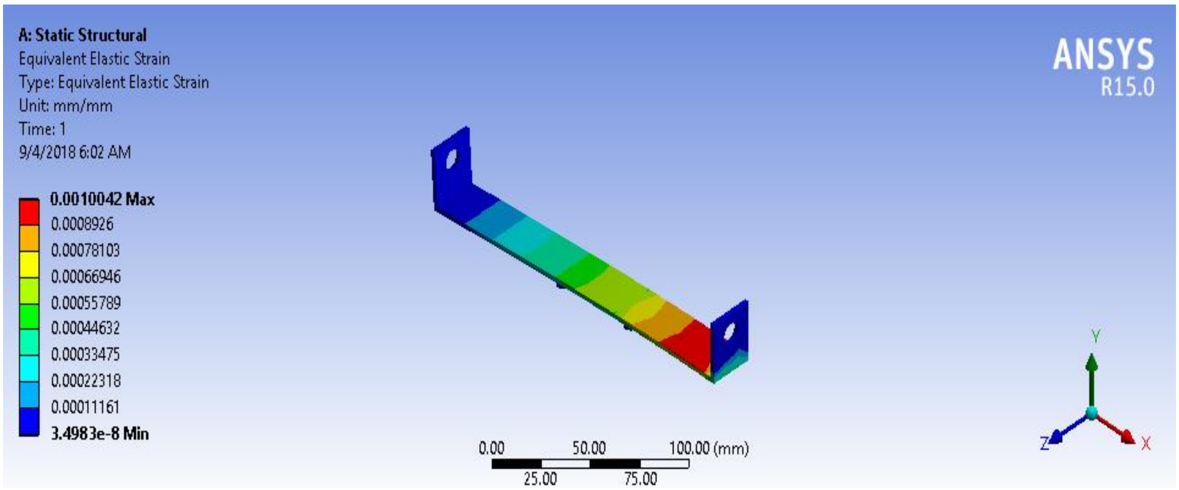


Figure 4.17 Block diagram of simulation of roller support equivalent elastic strain

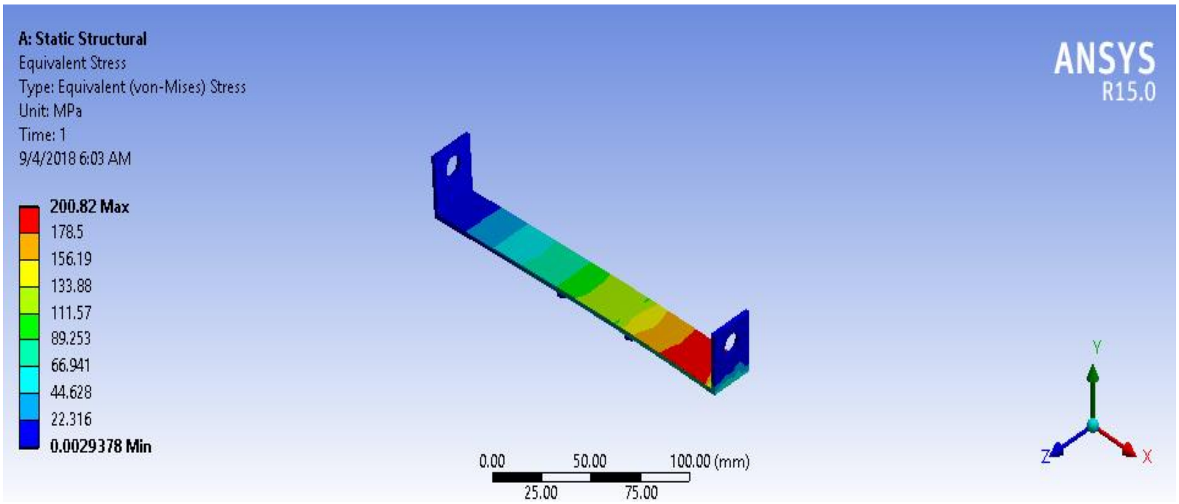


Figure 4.18 Block diagram of simulation of roller support equivalent von-miss stress

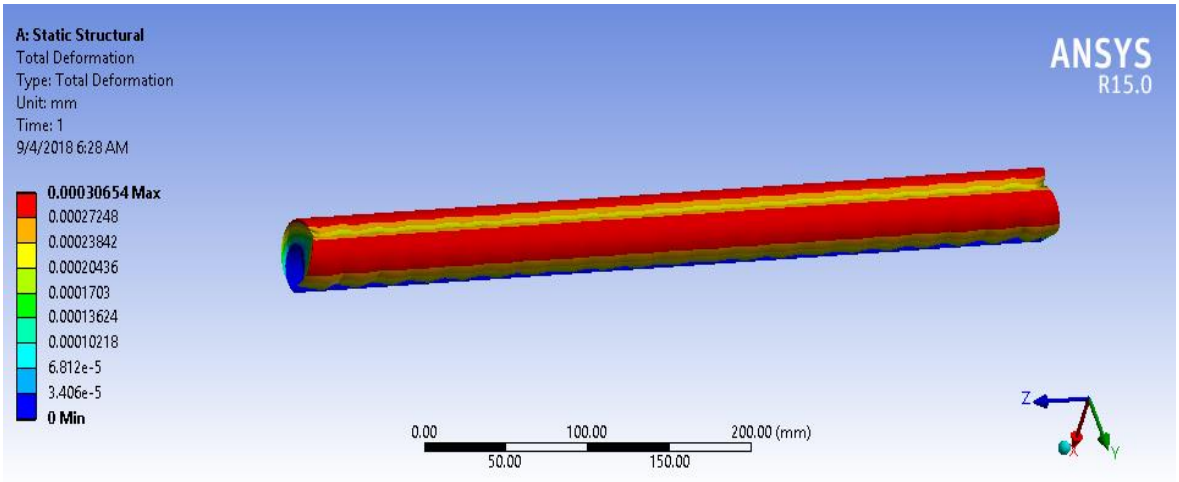


Figure 4.19 Block diagram of simulation of spray tube in total deformation

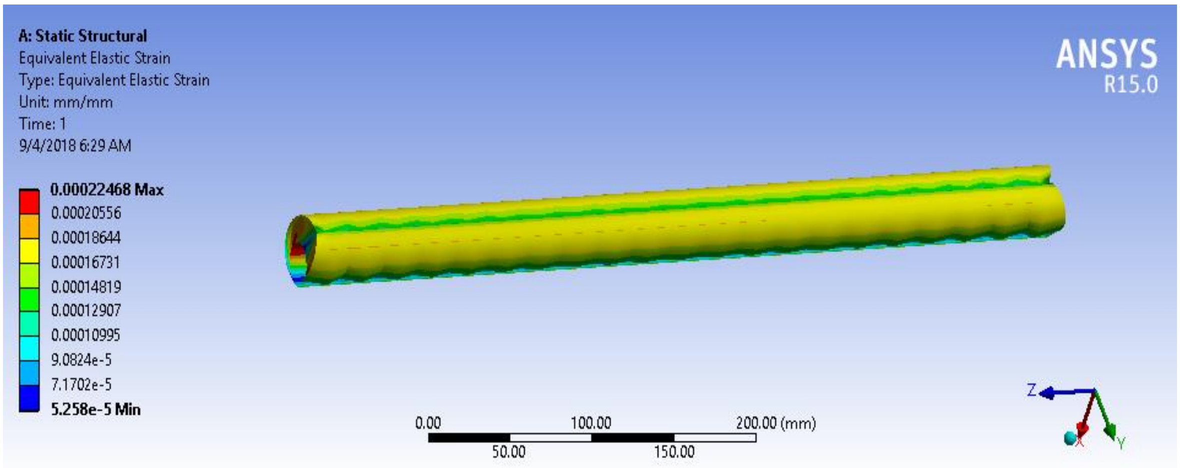


Figure 4.20 Block diagram of simulation of spray tube equivalent elastic strain

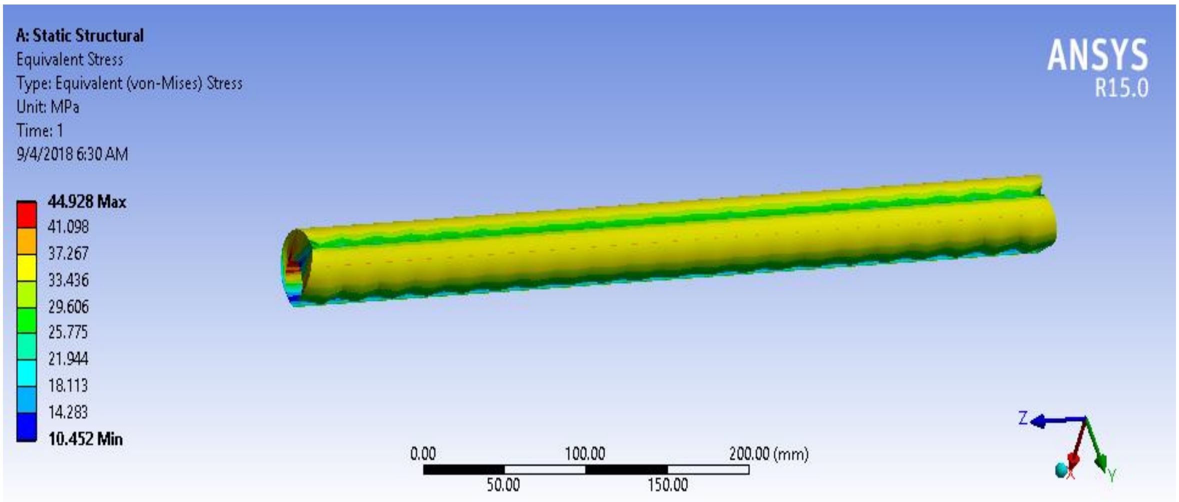


Figure 4.21 Block diagram of simulation of spray tube equivalent von-miss stress

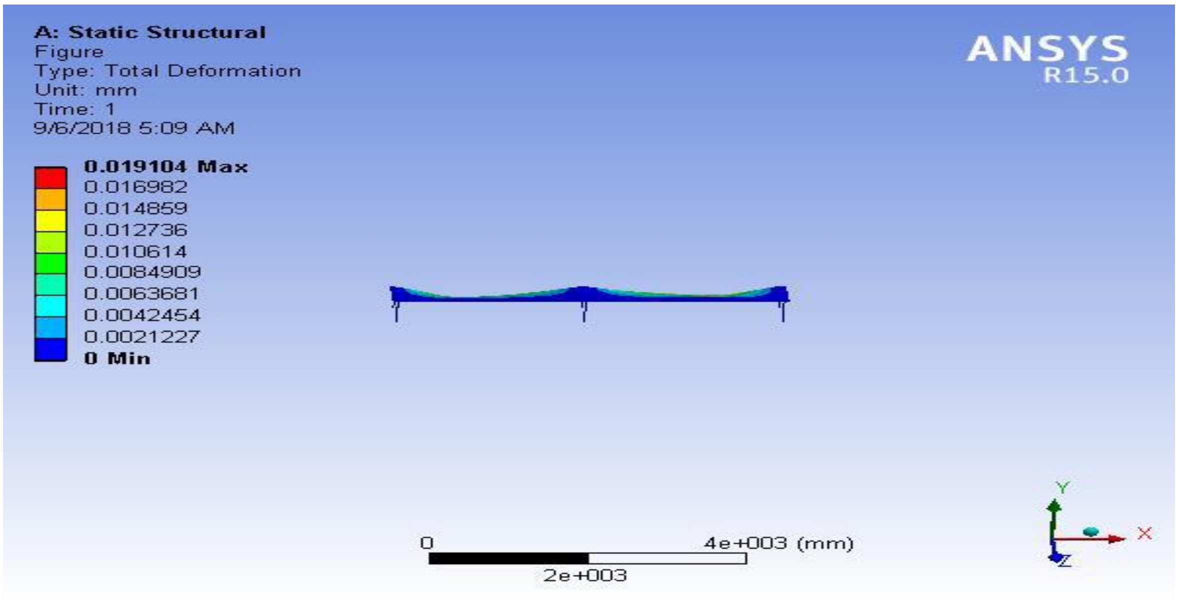


Figure 4.22 Block diagram of simulation of frame support in total deformation

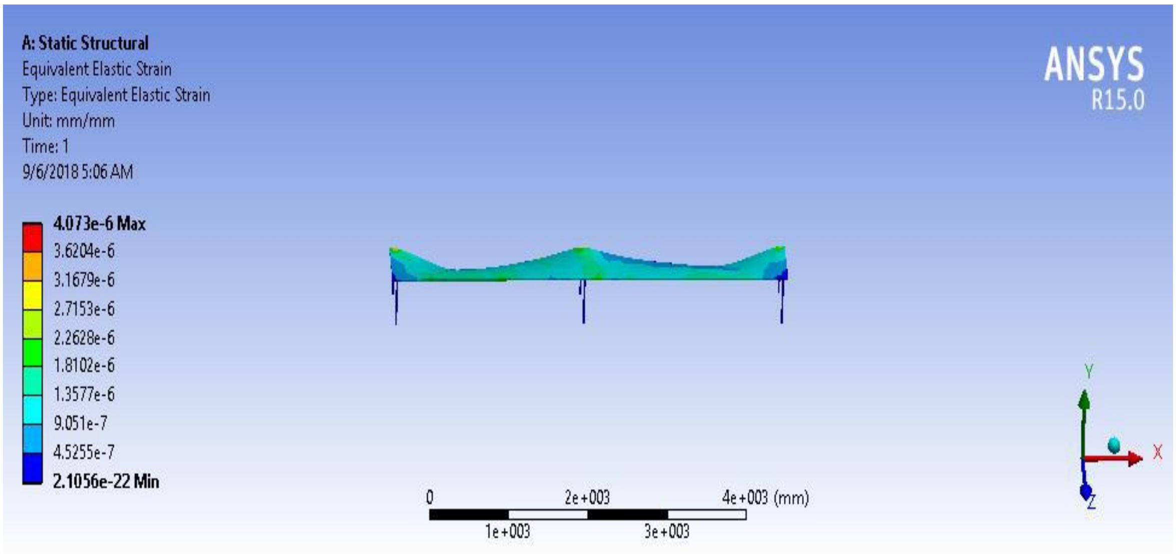


Figure 4.23 Block diagram of simulation of frame support equivalent elastic strain

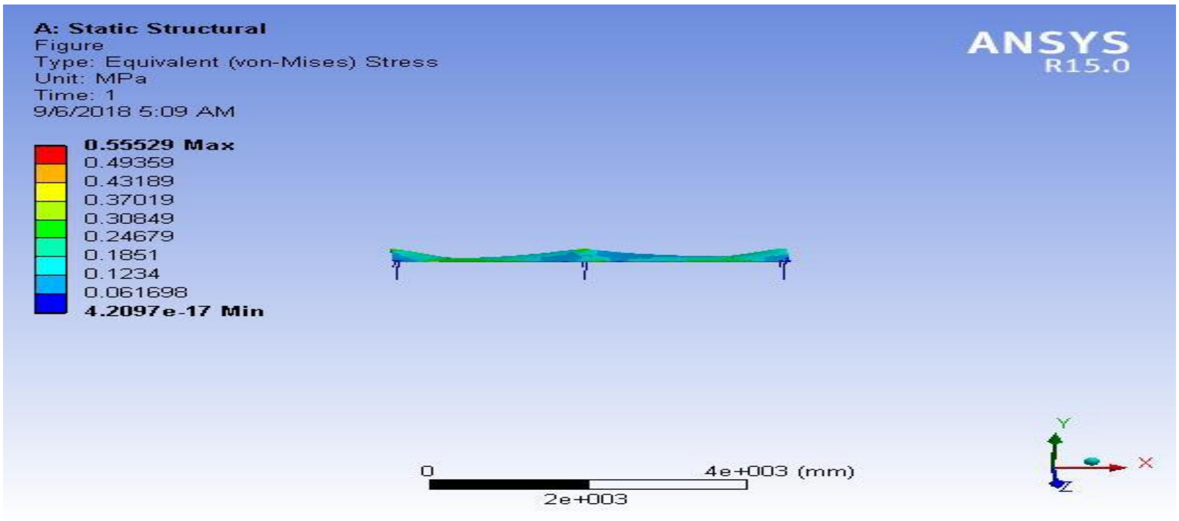


Figure 4.24 Block diagram of simulation of frame support equivalent von-miss stress

These figure shows results in different components of the design water spray and vacuum cooling bath as compared to theoretical. All the above figure of the results of analytical and numerical analysis are discussed in chapter five. From this it is possible to compare the total deformation, equivalent von-miss stress, and equivalent strain of the system when the load is applied.

4.9.5 Optimization of Cooling Process Parameters

The common failure or defect which are normally occurring in plastic cooling process are due to three main causes during part and change of, material selection, and processing [APF, 2016]. In many cases, the failures occur during the processing and these failures cause some defects that can found in cooling part. The following are the most common types of defects or scraps found in the cooling process during manufacturing of high density polyethylene pipes ovality problem, Surface roughness/scratch problem and bending or deforming problem. In the cooling process the defect are become during the production due to poor understanding of the processing method, use of inadequate or vacuum bath, lack of trained staff water bath break down, and inappropriate working environments.

Types of test: - Physical inspection; surface roughness or smoothness, uniform material flow based on feed rate and haul-off, and appearance/color etc. Measuring on process: -Length measuring based on customer requirement or need ovality (internal and external) measuring based on the standard by considering the tolerance value. Wall thickness measuring (perpendicular & diagonal) based on the standard by considering the minimum and maximum value. Weight per meter: - this is one of the basic measuring unit because of the selling cost is determine by its weight per meter. Laboratory test for HDPE pipe:-

- ❖ Hydrostatic pressure test- if the product has an Ovality problem, it is impossible to run the hydrostatic test because of the test is done ‘water-in-air’. Due to the presence of a leakage problem.
- ❖ Tensile strength: - if the product has a surface problem, the test result shows below the standard value.

4.9.5.1Need of the Optimization of the Cooling Process Parameters

Plastic pipe cooling process is the most widely pipe manufacturing process use in APF. In the cooling process as discuss above the various defects are frequently occurs and hampers the productivity. If we need to enhance the production rate, it is very essential to optimize the cooling process parameters and improve the productivity; following are the reason to optimize the process parameters ;Decrease customer complains ,Decrease rework cost , increase factory profit , increase employee benefits like, bones, rank, and other incentives and finally to optimize cooling time.

4.9.5.2 Experimental Setup and Procedure of Optimization

Design of Experiment (DOE) is one of interesting method to improve product design or improve process performance in experimental investigation used to reduce cycle time required to develop new product or processes. Design of experiment is a test or series of test that the input or independent variable (parameter) of a process is change so that observation and identifying corresponding changes in the output response can be verify. The result of the process is analyzed to find the optimum value or parameters that have a most significant effect to the process. One of approach from design of experiment Taguchi and analysis of variance (ANOVA) methods were used to analyses the experimental data to find out effect and contribution of independent variable (parameters) in the output response.

4.9.6 Taguchi Method

Taguchi Method is one of the simplest and effective approaches for parameter design and experimental planning developed by a Japanese engineer Dr. Genichi Taguchi. Taguchi method is not only reducing number of experimental design technique, but also a beneficial technique for high quality system design [Adem T., 2012]. The Taguchi technique includes the following steps:- Selection and evaluation of quality characteristics (responses) and process parameters or independent variable, identification of number of levels for the process parameters and possible interactions between the process parameters, Selected appropriate orthogonal array for process parameters, run experiments based on the arrangement of the orthogonal array, analyze the experimental results using the S/N ratio and Anova, finally selection of the optimal levels of process parameters and investigating the optimal process parameters through the confirmation experiment.

4.9.6.1 Signal-To-Noise (S/N) Ratio Characteristics

Taguchi method uses *S/N* ratio to measure the variations of experimental design. In this the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value i.e. standard deviation (S.D.) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D. Generally there are three categories of quality characteristics in the analysis of the S/N ratio, i.e. the lower the better, the higher the better, and the nominal the better. The formula used for calculating S/N ratio is given as shown in equation below.

Smaller the better: It is used where the smaller value is desired.

$$S/N = -10 \log \frac{1}{n} \sum_{i=1}^{n} yi^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.8)}$$

Where y = the measured value in a run/row or observed response value and n = number of replications or the number of measurements in a trial/row, in this study, n=1

Nominal the best: It is used where the nominal or target value and variation about that value is minimum.

$$S/N = -10 \log \frac{\mu^2}{\sigma^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.9)}$$

Where σ = mean and μ= variance

Higher the better: It is used where the larger value is desired.

$$S/N = -10 \log \frac{1}{n} \sum_{i=1}^{n} \frac{1}{yi^2} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6.0)}$$

In the present work, the aim is to minimize a given responses i.e. ovality, scrap and surface roughness by optimizing parameters. From these point of view, the selected signal to noise ratio is smaller the better and which mathematical calculated by using equation (5.8).

CHAPTER FIVE

RESULT AND DISCUSSION

5.1 Analysis Result of the Design

In the study of this research it could possible to calculate the dimension of water spray, spray tube, roller, roller support, and frame support components. In this research the Static Structural Analysis is carried out the above mentioned part. These parts are particularly selected; because of load applied during cooling process. The calculated values for above component are in terms of equivalent von-miss Stress, equivalent strain, and deformation. In this study it could conclude that all components of the designed parts are under the safe limit. It is very important to avoid failure of the components for the designed purpose. The above calculation is made manually and comparing ansys software to get better and reliable results. In addition to thus designing and simulation of the parts. Ansys software is used to analysis numerical values and the results are shown below.

Table 5.1 Simulation result of roller

Type	Total deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress	Load applied
minimum	0. mm	2.5724e-006 mm/mm	0.15759 MPa	0
maximum	0.49574 mm	0.00048927 mm/mm	97.705 MPa	891.25 N

Table 5.2 Simulation result of roller support

Type	Total deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress	Load applied
minimum	0. mm	3.4983e-008 mm/mm	0.0029378 MPa	0
maximum	8.2549 mm	0.0010042mm/mm	200.82 MPa	3444.36N

Table 5.3 Simulation result of spray tube

Type	Total deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress	pressure
minimum	0. mm	5.258e-005 mm/mm	10.452MPa	0
maximum	0.00030654 mm	0.00022468 mm/mm	44.928 MPa	20.083 MPa

Table 5.4 Simulation result of frame support

Type	Total deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress	
minimum	0. mm	2.1056e-022 mm/mm	4.2097e-017 MPa	0
maximum	0.019104 mm	4.073e-006 mm/mm	0.55529 MPa	1689.369KN

From the above simulation result of total deformation, equivalent elastic strain, and equivalent elastic von-miss stress at different load applied we compared to the theoretical results the design is safe. Hence designing and optimizing the water spray system and vacuum bath is the one of the best mechanism to minimize scraps of plastic pipes.

5.2 Analysis Result of the Signal-To-Noise (S/N) Ratio

In this study, an attempt is made to investigate the design and optimization of water spray system, vacuum cooling bath cooling parameters in Amhara pipe factory. The Taguchi method uses S/N ratio to analysis the variations of the experimental design. As defined in Signal-to-Noise (S/N) ratio characteristics, there are three categories of performance characteristics, i.e., the lower-the-better, nominal the-better and the higher-the-better. Since in this study the aim is to obtain minimum ovality, deforming or bending and surface roughness, lower-the-better performance characteristic is chosen. The equation of "smaller is the better" (Eq. (5.8) was selected for the calculation of S/N ratio. The experimental values of each response and calculation of S/N ratio in column of run formatted in Table 5.5, 5.6, and 5.7.

Table 5.5 S/N ratios of experimental results for bending or deforming

Exp. No.	Feed rate (rpm)	Water flow (L/min)	Haul-off (m/min)	Deforming (%)	S/N ratio
1	60.9	18.56	0.22	0.0322	29.8429
2	60.9	20.42	0.53	0.0374	28.5426
3	60.9	25.51	0.68	0.0478	26.4114
4	69.2	18.56	0.53	0.0592	24.5536
5	69.2	20.42	0.68	0.0472	26.5212
6	69.2	25.51	0.22	0.0309	30.2008
7	84.1	18.56	0.68	0.0400	27.9588
8	84.1	20.42	0.22	0.0304	30.3425
9	84.1	25.51	0.53	0.0586	24.6240

Table 5.6 S/N ratios of experimental results for ovality

Exp. No.	Feed rate (rpm)	Water flow (L/min)	Haul-off (m/min)	Ovality (mm)	S/N ratio
1	60.9	18.56	0.22	3.20	-10.1030
2	60.9	20.42	0.53	3.60	-11.1261
3	60.9	25.51	0.68	4.00	-12.0412
4	69.2	18.56	0.53	4.50	-13.0643
5	69.2	20.42	0.68	5.00	-13.9794
6	69.2	25.51	0.22	9.80	-19.8245
7	84.1	18.56	0.68	11.10	-20.9065
8	84.1	20.42	0.22	12.50	-21.9382
9	84.1	25.51	0.53	14.00	-22.9226

Table 5.7 S/N ratios of experimental results for surface roughness

Exp. No.	Feed rate(rpm)	Water flow (L/min)	Haul-off (m/min)	Surface roughness (μm)	S/N ratio
1	60.9	18.56	0.22	5.0094	-13.9957
2	60.9	20.42	0.53	12.6690	-22.0548
3	60.9	25.51	0.68	6.2560	-15.9259

4	69.2	18.56	0.53	14.8970	-23.4620
5	69.2	20.42	0.68	10.9239	-20.7675
6	69.2	25.51	0.22	11.9779	-21.5676
7	84.1	18.56	0.68	8.5816	-18.6714
8	84.1	20.42	0.22	7.1053	-17.0316
9	84.1	25.51	0.53	8.4539	-18.5411

In order to find out the effects of different parameters and as well as their levels, mean S/N ratio has been calculated. The mean S/N ratio calculated by, averaging the S/N ratios for each level of the cooling parameters as shown in Table (5.8, 5.9, and 5.10). Which mean that for "R" response with a level of "i", mean S/N ratio be dividing total sum of S/N ratio at a given level "i" into total number of level that given at equation 6.1 and 6.2.

Total s/n ratio, $\eta i = \sum_{j=1}^{n} S/N_j$ ………………………… (6.1)

Where; i= nomenclature of level, = number for i's level

Mean S/N ratio, $m = \frac{\eta i}{n}$ ……………………………… (6.2)

Where; n is total number of level, Since the selected character of S/N Ratio of each responses used in this paper is the smaller is the better, the smaller the delta value (Δ) of a parameter is the better from other. In order to distinguish the rank of each cooling parameters on a given response, delta value (Δ) value is calculated by subtracting minimum value of mean S/N ratio from maximum value of mean S/N ratio as shown in equation 6.3.

Delta (Δ) = (mean S/N) max - (mean S/N) min …………………… (6.3)

The optimum conditions on this approach obtained by sorting the delta in an order of significantly affecting the process.

Table 5.8 Mean S/N ratio of Deforming or Bending

Level	feed rate	water flow	haul-off
1	28.27	27.45	30.13
2	27.09	28.47	25.91
3	27.65	27.08	26.96

Delta (Δ)	1.17	1.38	4.22
Rank	3	2	1

Table 5.9 Mean S/N ratio of ovality

Level	feed rate	water flow	haul-off
1	-11.09	-14.69	-17.29
2	-15.62	-15.68	-15.70
3	-21.92	-18.26	-15.64
Delta (Δ)	10.83	3.57	1.65
Rank	1	2	3

Table 5.10 Mean S/N ratio of Surface roughness

Level	feed rate	water flow	haul-off
1	-17.73	-18.71	-17.53
2	-21.93	-19.95	-21.35
3	-18.08	-18.68	-18.45
Delta (Δ)	4.61	1.27	3.82
Rank	1	3	2

From Table 5.8 it is clear show that haul off speed is the most influencing factor on the deformation or bending of plastic pipe followed by water flow and feed rate. Table 5.9 Mean S/N ratio of ovality show that feed rate is more influencing parameter at when related to water flow and haul off speed. In the similar manner surface roughness table show that feed rate is major affecting factor at the surface roughness of work piece and water flow is least influencing parameter.

5.3 Analysis of Variance (Anova)

The purpose of ANOVA was to determine effect of individual parameters which significantly affected the performance characteristics with the help of percentage contribution of individual parameters**.** In this study, Minitab 17 software ANOVA module used to investigate the effect of parameters and further analyzed by main effect plot on each responses. In each Table (5.11, 5.12, and 5.13) of Anova result for a given responses the following formulas are used: in order to find percentage contribution, it is necessary of calculating degree of freedom, sum of square, mean square and P-value of each cooling parameters. When formulating, procedure maintained by Minitab 17 software it follows the equations at 6.4, 6.5, 6.6, 6.7, and 6.8.

Degree of freedom (DOF) = level of parameter-1………………… (6.4)

$$\text{Sum of square (SS)} = \sum_{i=1}^{n}(yi - \text{mean of y})^2 \quad \ldots\ldots\ldots\ldots\ldots \text{(6.5)}$$

Mean square is calculated easily dividing sum of square in to DOF, which means

$$\text{Mean square (MS)} = \frac{\text{SS}}{\text{DOF}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(6.6)}$$

%C = (sum of square of individual factor) ÷(total sum of square)………… (6.7)

Where; %C is Percentage contribution

$$\text{F} = \frac{\text{MS effect}}{\text{MS error}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(6.8)}$$

Where F is the ratio between the mean of squares effect and the mean of squares error.

F-test is used to see the significance of each factor (or interaction) on the response variable or Signal-to-noise ratio. In order to obtain the most significant variables, was used which considers influent those variables that present F ≥ 2.0, are the most significant variables in the process.

Statistically, there is a tool called the P - test to see which process parameters have significant effect on the quality characteristic. Usually, when P-values less than 0.05 are considered to have a statistically significant contribution to the performance measures. This analysis was carried out for significance level of α=0.05 i.e. for a confidence level of 95%.

Table 5.11 Anova result for bending or deforming

Cooling parameter	DOF	Sum of Square	Mean Square	p-value	F-value	Contribution (%)
Feed rate	2	0.000067	0.000033	0.814	0.34	6.65

Water flow	2	0.000089	0.000045	0.758	0.47	8.84
Haul-off	2	0.000660	0.000330	0.041	3.45	65.54
Error	2	0.000191	0.0000955			
Total	8	0.001007				

Table 5.12 Anova result for ovality

Cooling parameter	DOF	Sum of Square	Mean Square	p-value	F -value	Contribution (%)
Feed rate	2	125.04	62.521	0.003	59.23	85.23
Water flow	2	14.58	7.288	0.731	6.90	9.9
Haul-off	2	4.969	2.484	0.902	2.3	3.39
Error	2	2.111	1.0555			
Total	8	146.70				

Table 5.13 Anova result for surface roughness

Cooling parameter	DOF	sum of Square	Mean Square	p-value	F-value	Contribution (%)
Feed rate	2	42.09	21.045	0.132	3.21	49.12
Water flow	2	2.690	1.345	0.909	0.20	3.14
Haul-off	2	27.81	13.904	0.308	2.12	32.46
Error	2	13.09	6.545			
Total	8	85.68				

Table 5.11 shows Anova results for bending or deforming. It is observed that, haul-off speed (65.54%) is the most significant cooling condition followed by water flow (8.84%) and feed rate (6.65%) which have least effect in controlling the bending or deforming of pipes. However all of the parameters are not statistically significant. From the analysis of the Table 5.12 shows that P-value for all of cooling parameters (feed rate, water flow and) greater than 0.05. It means that feed rate (85.23%) is the most significant cooling condition on ovality of plastic pipe manufacturing. But water flow (9.9%) has least effect followed by haul-off speed (3.39%) which have no effect on plastic pipe manufacturing cooling condition respectively. Therefore haul off speed has statically significant. Anova result for surface roughness at mention in Table 5.13 show that feed rate is most significant parameter with a contribution of (49.12%), haul-off speed has a contribution of (32.46%) and water flow with no

contribution of (3.14%) at the surface roughness of work piece. Since for the percentage contribution of water flow value (3.14%) is less than 0.05 so that it is statically significant on surface roughness.

5.4 Main Effect Plots

The data in this study was further analyzed by using main effect plot, which determine the optimal design conditions to obtain the maximum or minimum value of responses. Since at this work main objective is to reduce the effect of cooling parameters on deforming, surface roughness (good surface finish) and ovality, factor which give minimum response has been selected as optimum value. In order to analysis cooling condition, Minitab 17 software package is used, which is plotted by evaluating mean of response at each level of parameters. In the plots it show the variation of individual response with the cooling parameters (feed rate, water flow and haul-off speed) separately. At the time of plotting Minitab 17 display horizontal-axis as process parameters at three level and vertical-axis as the response value.

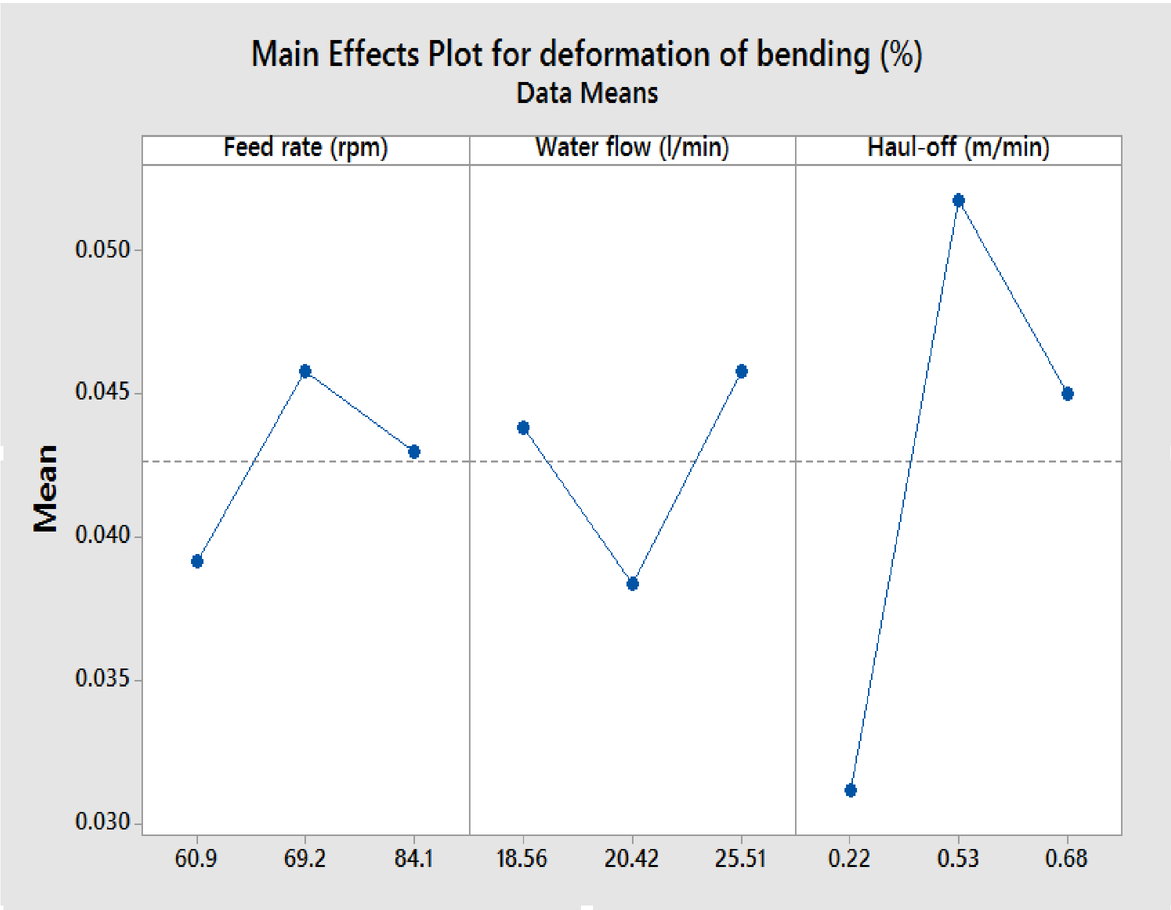


Figure 5.1 Main effect plot deformation or bending

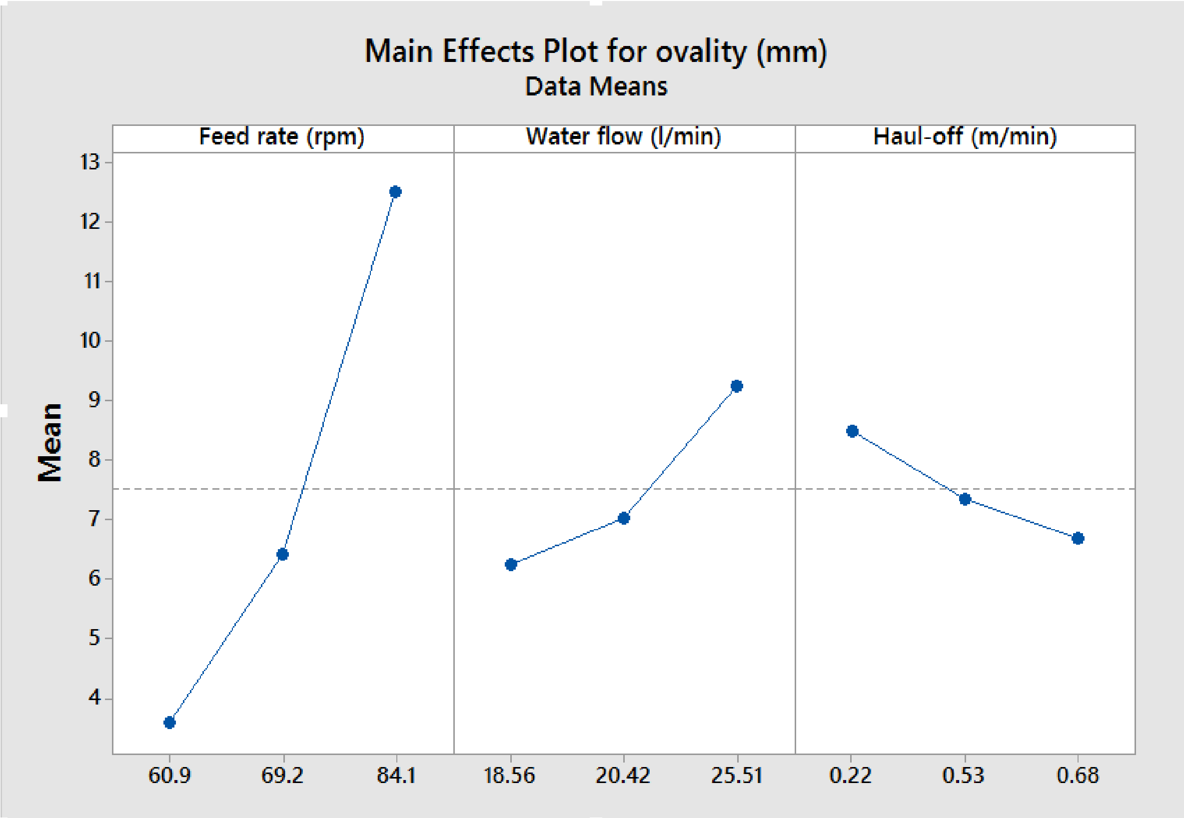


Figure 5.2 Main effect plot for ovality

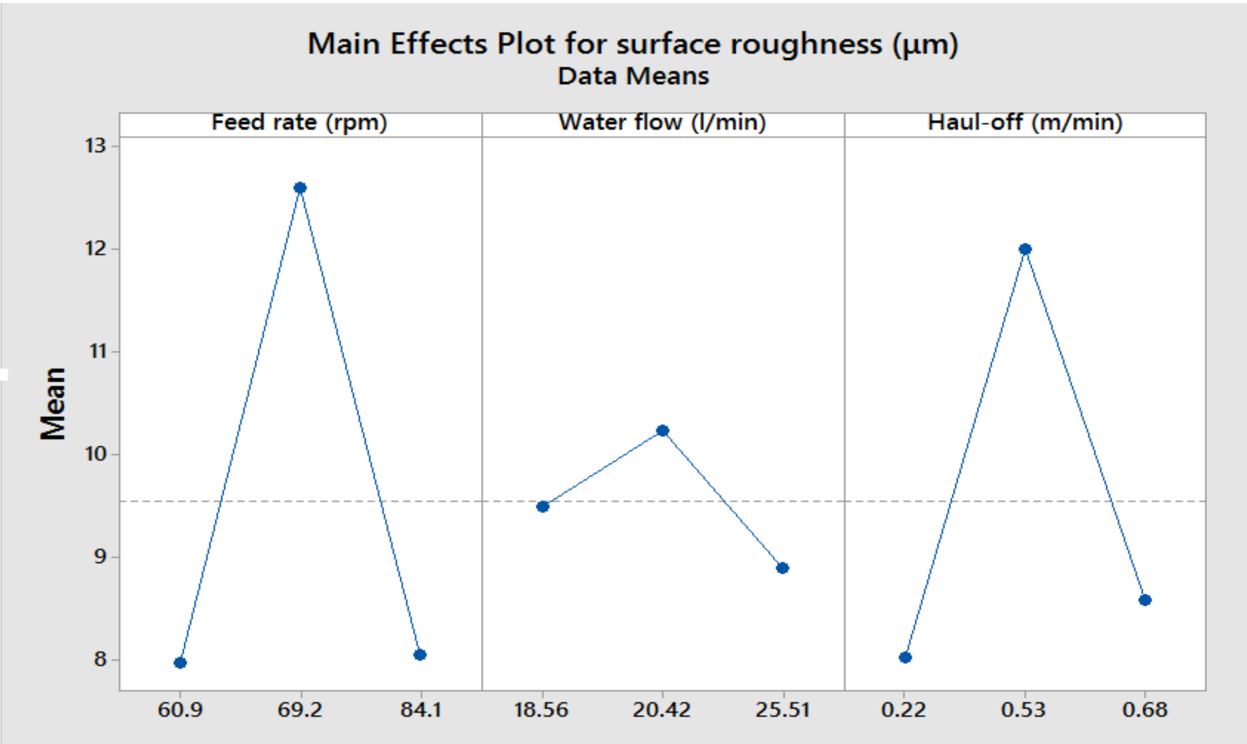


Figure 5.3 Main effect plot for surface roughness

From figure 5.1 shows that with the increase in feed rate and haul off speed there is un-evenly (increase and decrease) of deformation or bending of plastic pipes. On the other hand, when the water flow increases there is un-evenly (decrease and increase) of deformation or bending of plastic pipes. The main effect plot for shows the optimal design condition for obtaining low deformation is archived at feed rate 60.9 rpm (level-1), water flow 20.42 l/min (level-2), and haul-off speed (hos) of 0.22 m/min (level-1). The main effect plot for ovality at figure 5.2 show with the increase of feed rate and water flow there is also increase of ovality of plastic pipe. However, with the increase of haul-off speed there decrease in ovality of plastic pipes. Therefore, at the level of feed rate 60.9 rpm (level-1), water flow 18.56 l/min (level-1), and haul-off speed 0.68 m/min (level-3) maintain low ovality of plastic pipe manufacturing compare to other levels. The main effect plot for surface roughness at figure5.3 shows that within the increase of all cooling parameter (feed rate, water flow and haul off speed) there is un-evenly (increase and decrease) surface roughness .Therefore the main effect plot of plastic pipe manufacturing surface roughness analysis is that the minimum surface roughness obtained at feed rate 60.9(level-1), water flow 25.51 l/min (level-3) and haul-off speed 0.22m/min (level-1).

The result of Minitab 17 for S/N ratio revealed that: the bending were minimum at feed rate, water flow and haul off speed 60.9 rpm, 20.42l/min and 0.22m/min respectively.

These combinations does not exist in the OA list. Therefore confirmation experiment is required. The experimental confirmation test is the final step in verifying the results drawn based on Taguchi's design approach.

Table 5.14 Confirmation experiment result of bending

Ex.no	Feed rate	Water flow	Haul-off	Deforming (%)	S/N
1	60.9	20.42	0.22	**0.0467**	**26.614**

Table 5.15 Confirmation experiment result of ovality

Ex.no	Feed rate	Water flow	Haul-off	ovality	S/N
1	60.9	18.56	0.68	**3.4**	**-10.63**

Table 5.16 Confirmation experiment result of surface roughness

Ex.no	Feed rate	Water flow	Haul-off	Surface roughness	S/N
1	60.9	25.51	0.22	**8.446**	**-18.533**

Table 5.17 Optimum combination of control factor

Ex.no.	Response	Optimum combination of control factor
1	Deforming	Feed rate **60.9** rpm,water flow **20.42**l/min and haul off **0.22**
2	Ovality	Feed rate **60.9** rpm, water flow **18.56** l/min and haul off **0.68** m/min
3	Surface roughness	Feed rate **60.9** rpm, water flow **25.51** l/min and haul off **0.22** m/min

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

On the design and optimization water spray system and vacuum cooling bath of the study being made in the company, the following conclusions are made.

Water spray cooling is one of the most common manufacturing process in the field of industry to maintain required product. At the time of water spray cooling there is a well-known challenges either at the work part or defect that to be used during manufacturing process. Due to this problem, the quality of product decrease and increase in rework cost. In order to overcome those difficult, optimization of parameters is necessary in direct water spray cooling process. This study has focused on the application of the Taguchi design of experiment and Anova analysis methods for the finding optimized process parameters in direct water spray cooling process of HDPE pipe in different diameter. For cooling process of HDPE plastic pipe water spray system and spray tube have major contribution to overcome the defect problem. Required Taguchi orthogonal array was selected with various level of cooling parameters (haul-off speed, feed rate and water flow). At each experimental work, steps in Taguchi orthogonal array follows to analysis the effect of parameters on the responses (ovality, bending or deforming, and surface roughness). Data collection is performed at the time of manufacturing operation and after cooling process. After each data collection, both Taguchi method and Anova are used to investigate optimal design condition and percentage contribution of selected factor in order to maintain minimum responses. The optimum value obtained after water spray cooling process are:

A. The optimum cooling conditions obtained from Taguchi method for optimizing deformation or bending during cooling of HDPE pipes in manufacturing condition are at feed rate 60.9 rpm, water flow 20.42l/min and haul-off speed (hos) 0.22m/min as compare to other levels and with percentage contribution of 6.65%, 8.84%, and 65.54% respectively.

B. From main effect plot of ovality it show that low ovality of plastic pipe manufacturing was obtained at the level of feed rate 60.9 rpm, water flow 18.56 l/min, and haul off speed 0.68m/min as compare to other levels and with the percentage contribution of 85.23%, 9.9%, and 3.39% respectively. From this cooling parameters haul off speed has statically significant.

C. Analysis of Variances (Anova) for surface roughness indicate that, feed rate is most significant parameter with a contribution of (49.12%), haul-off speed with a contribution(32.46%),and water flow has a contribution of (3.14%) which has statically significant in the surface roughness of plastic pipe manufacturing factory with optimum condition level of feed rate 60.9 rpm (level-1), water flow 25.51 l/min (level-3) and haul off speed 0.22m/min (level-1).

D. From confirmation experiment of the optimum condition of deforming are the final step in verifying the results drawn based on Taguchi's design approach the results are: feed rate 60.9 rpm, water flow 20.42l/min and haul-off speed (hos) 0.22m/min, deforming value 0.0467% and s/n 26.614.

E. From confirmation experiment of the optimum condition of ovality are the final step in verifying the results drawn based on Taguchi's design approach the results are: the level of feed rate 60.9 rpm, water flow 18.56 l/min, and haul off speed 0.68m/min, ovality 3.4mm and s/n -10.63.

F. From confirmation experiment of the optimum condition of surface roughness are the final step in verifying the results drawn based on Taguchi's design approach the results are: with optimum condition level of feed rate 60.9 rpm (level-1), water flow 25.51 l/min (level-3) and haul off speed 0.22m/min (level-1), surface roughness 8.446 (μm) and s/n -18.533.

6.2 Recommendation

Based on the findings of this study, the following recommendations are made: Since water spray cooling process is one of most important manufacturing process in the area of plastic pipe industry, power cooling, food beverage, and medical equipment in order to maintain the products at desired requirement. It is necessary things to obtain over all process flow with regard to good production of plastic pipes at minimum cost and time. For these reason optimization of cooling parameters are main issue for qualitative work in plastic pipe factory. From these point of view, it is recommended a good way of implement an optimum condition of cooling parameters in the field of water spray cooling process before wound off the pipes. It also recommend that a better way of being more familiar with a Taguchi design of experiment and Anova analysis particularly in optimizing the cooling parameters with a minimum experimental rework cost and to attract the market shareholders/customers from other competitive factories. In addition to this it is recommend that defect or scrap product could be optimized by Taguchi doe.

6.3 Future Work

From different aspects, into the optimization of cooling parameter's for pipe cooling system application the possibility of finding the appropriate optimum condition for pipe defects depends on the precise knowledge of the confirmation and predicted value of the reducing the defects. The following recommendations for future work can be noted:

- → Finding of different optimization method and treatment processes for the better reduction of plastic pipe scrap.
- → Characterization can be done by using different types of neutral networking or genetic algorism to improve defect of plastic pipe.
- → In this research, the mechanical experimental property characterization is done using only the hydraulic and quality testing machine. However the experimental testing should be done using appropriate universal testing machine that strain gauge was installed on it in order to attain a precise results.
- → From the optimization property of control parameter's study based on, different parameter's water inlet temperature, pressure, cooling time etc. is necessary to optimize the rest control parameters of plastic pipe.

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APPENDIX

Appendix Table: 1 output values of pipes for SDR 26

S.NO	O.D(mm)	SDR26	Weight(kg/m)	Output(kg/h)	Speed(m/min)
1	160	6.20	3.129	500	2.66
2	180	6.90	3.961	530	2.23
3	200	7.70	4.846	560	1.92
4	225	8.60	6.079	590	1.62
5	250	9.60	7.555	620	1.37
6	280	10.70	9.445	650	1.15
7	315	12.10	12.003	680	0.94
8	355	13.60	15.188	710	0.78
9	400	15.30	19.219	740	0.64
10	450	17.20	24.216	770	0.53

Source ;(field observation survey, 2018)

Appendix Table: 2 output values of pipes for SDR 17

S.NO	O.D(mm)	SDR17	Weight(kg/m)	Output(kg/h)
1	160	9.5	4.676	500
2	180	10.7	5.935	530
3	200	11.9	7.298	560
4	225	13.4	9.267	590
5	250	14.8	11.371	620
6	280	16.6	14.551	650
7	315	18.7	18.432	680
8	355	21.1	23.447	710
9	400	23.7	29.673	740
10	450	26.70	37.606	770

Appendix Table: 3 output value of pipes for SDR11

S.NO	O.D(mm)	SDR11	Weight(kg/m)	Output(kg/h)
1	160	14.60	6.901	500
2	180	16.40	8.882	530

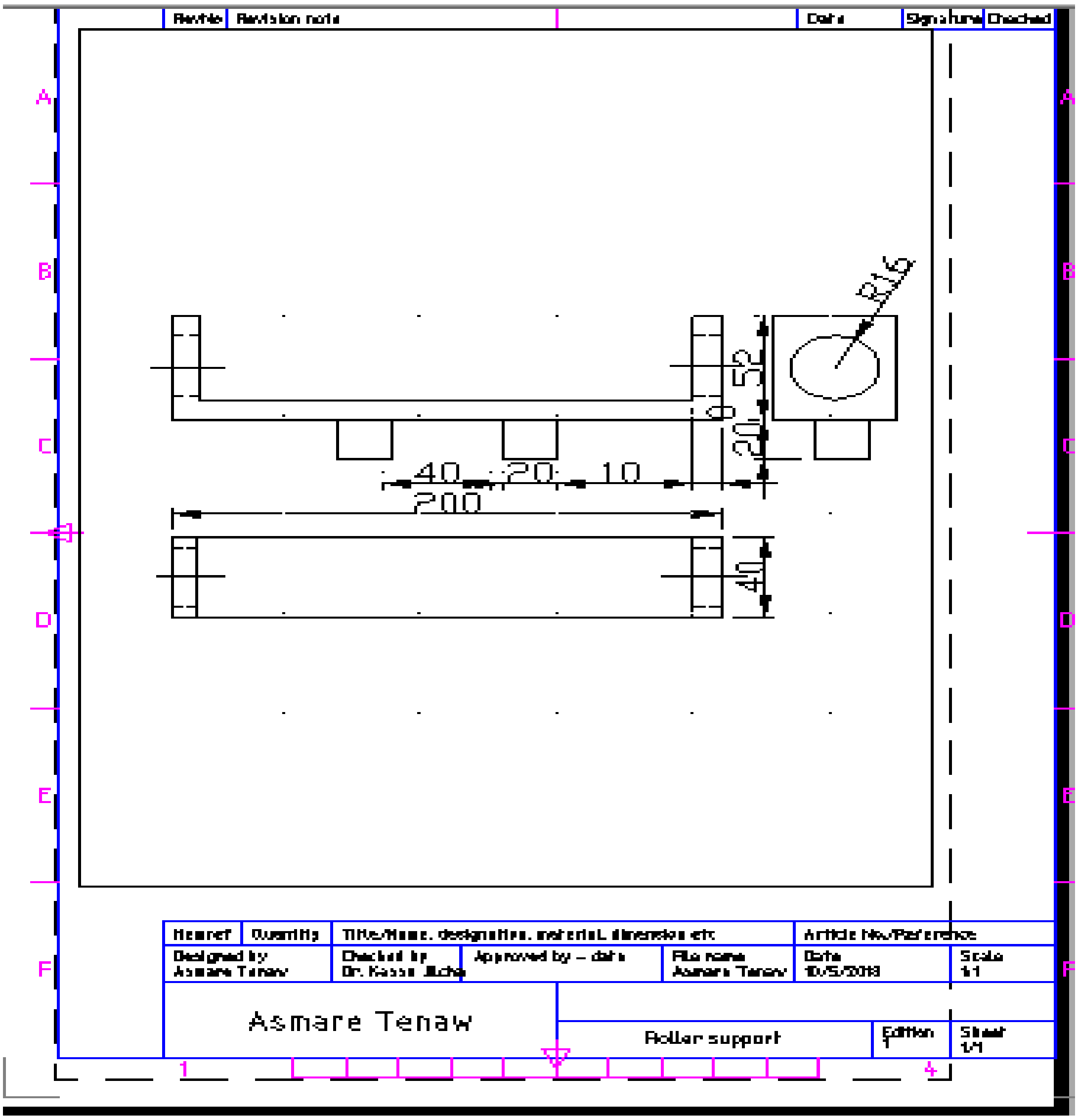
3	200	18.20	10.965	560
4	225	20.50	13.879	590
5	250	22.70	17.104	620
6	280	25.40	21.425	650
7	315	28.60	27.163	680
8	355	32.20	34.462	710
9	400	36.30	43.765	740
10	450	40.90	55.459	770

(Field observation survey, 2018)

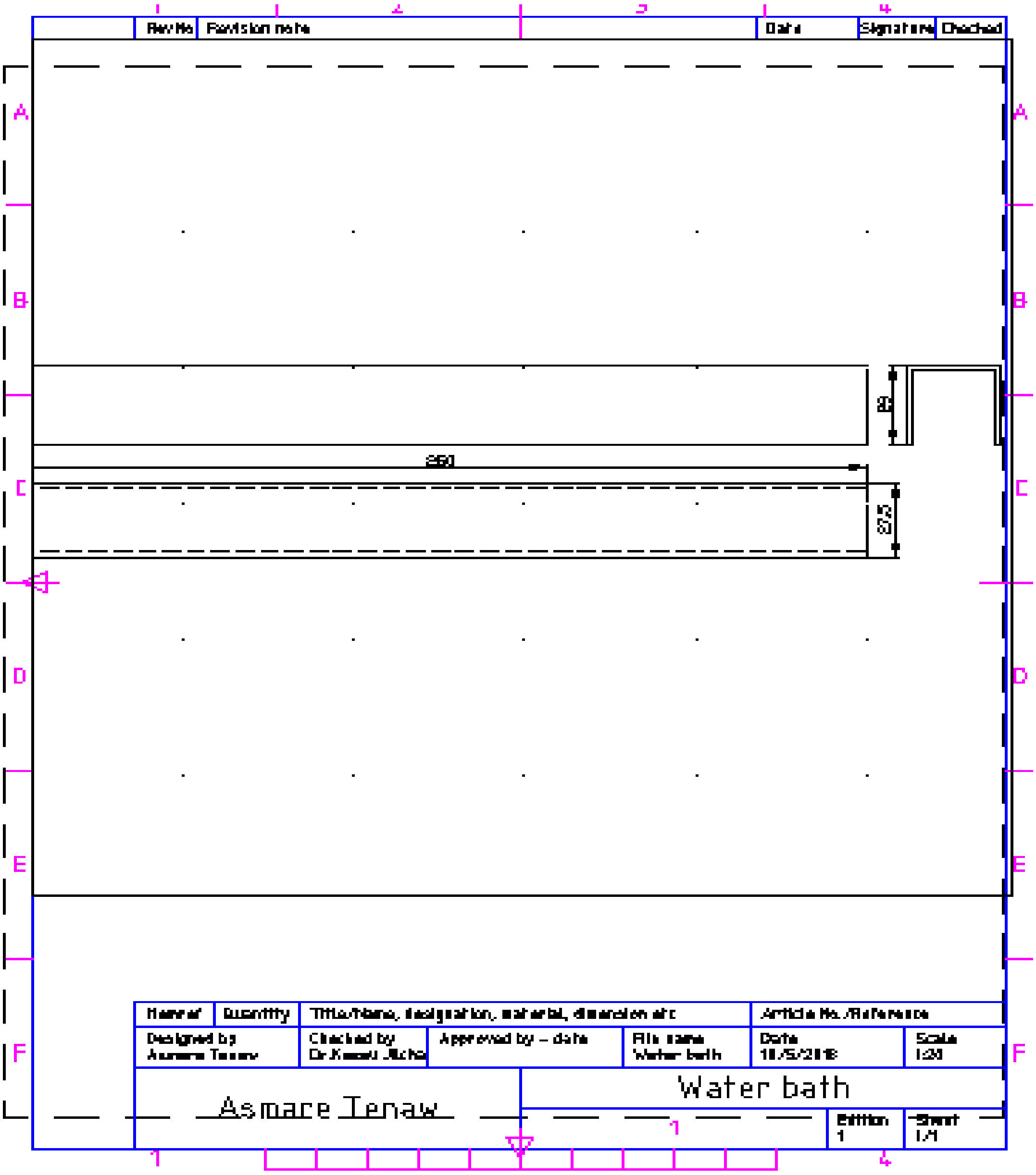
Appendix Table: 4 specification of pipe dimensions according to standard DIN 8074

SDR	OD[mm]	WT [mm]	Ovality [mm]	Line speed- [m/min]	Cooling factor [mh/k]	Vacuum Bath[m]	Spray Bath[m]	Output [kg/hr]
26	160	6.2	3.2	4.00	7.00	9.00	12	718
17	160	9.5	3.2	2.43	7.00	9.00	18	650
11	160	14.6	3.2	1.07	7.00	9.00	18	423
9	160	17.9	3.2	0.73	7.00	9.00	18	345
7.4	160	21.9	3.2	0.50	7.00	9.00	18	282
26	180	6.9	3.6	3.57	7.00	9.00	12	800
17	180	10.7	3.6	1.92	7.00	9.00	18	648
11	180	16.4	3.6	0.84	7.00	9.00	18	424
9	180	20.1	3.6	0.58	7.00	9.00	18	344
7.4	180	24.6	3.6	0.40	7.00	9.00	18	282
26	200	7.7	4.00	2.88	7.00	9.00	12	800
17	200	11.9	4.00	1.55	7.00	9.00	18	648
11	200	18.2	4.00	0.69	7.00	9.00	18	423
9	200	22.4	4.00	0.46	7.00	9.00	18	344
7.4	200	27.4	4.00	0.32	7.00	9.00	18	282
26	225	8.6	4.50	2.29	7.00	9.00	12	800
17	225	13.4	4.50	1.22	7.00	9.00	18	652
11	225	20.5	4.50	0.54	7.00	9.00	18	425
9	225	25.2	4.50	0.37	7.00	9.00	18	346
7.4	225	30.8	4.50	0.25	7.00	9.00	18	282

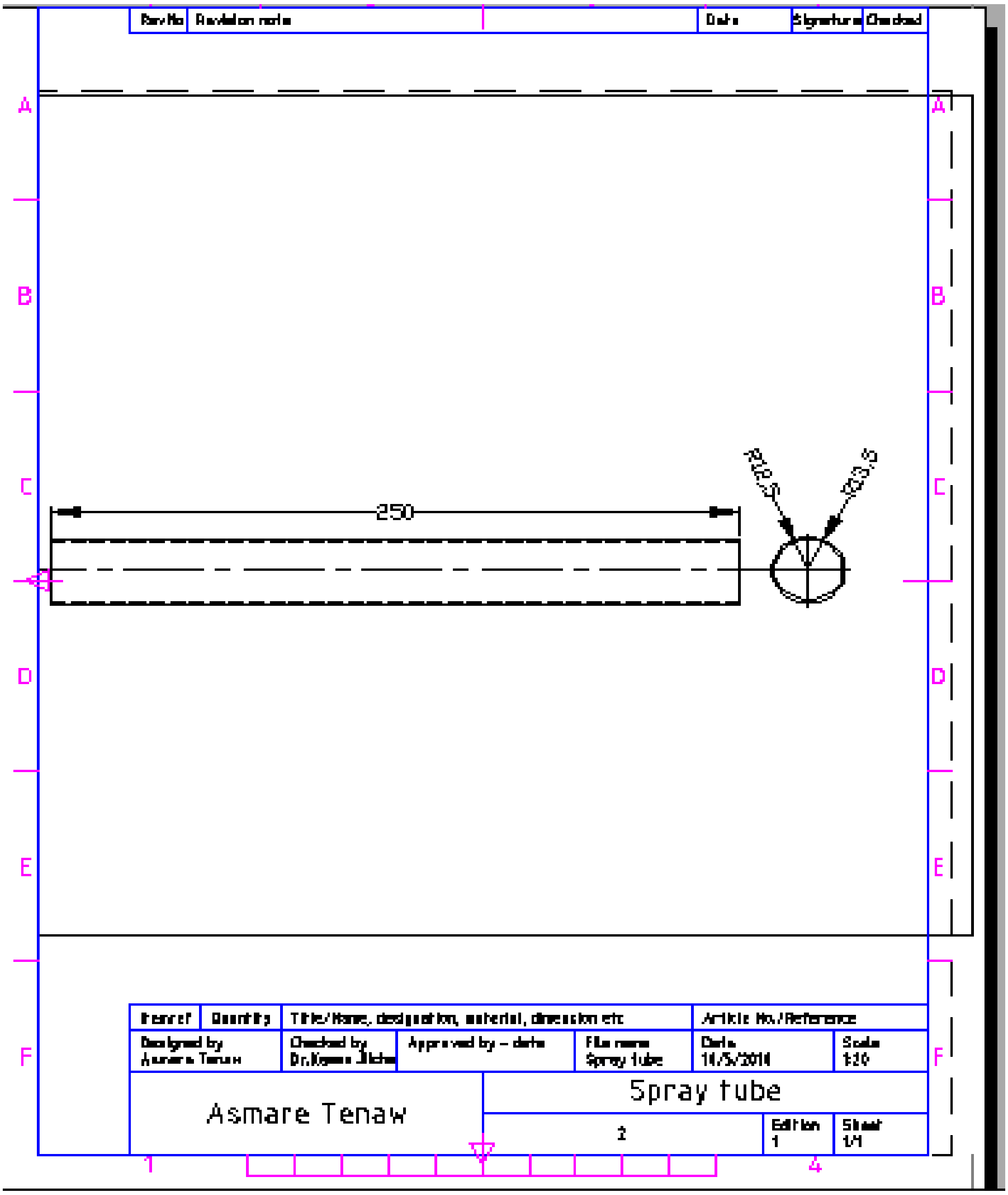
26	250	9.6	5.00	1.85	7.00	9.00	12	800
17	250	14.8	5.00	1.00	7.00	9.00	18	651
11	250	22.7	5.00	0.44	7.00	9.00	18	425
9	250	27.9	5.00	0.30	7.00	9.00	18	345
7.4	250	34.2	5.00	0.21	7.00	9.00	18	282
26	280	10.7	9.8	1.48	7.00	9.00	12	800
17	280	16.6	9.8	0.80	7.00	9.00	18	650
11	280	25.4	9.8	0.35	7.00	9.00	18	425
9	280	31.3	9.8	0.24	7.00	9.00	18	345
7.4	280	38.3	9.8	0.16	7.00	9.00	18	282
26	315	12.1	11.10	1.17	7.00	9.00	12	800
17	315	18.7	11.10	0.63	7.00	9.00	18	649
11	315	28.6	11.10	0.28	7.00	9.00	18	425
9	315	35.2	11.10	0.19	7.00	9.00	18	345
7.4	315	43.1	11.10	0.13	7.00	9.00	18	282



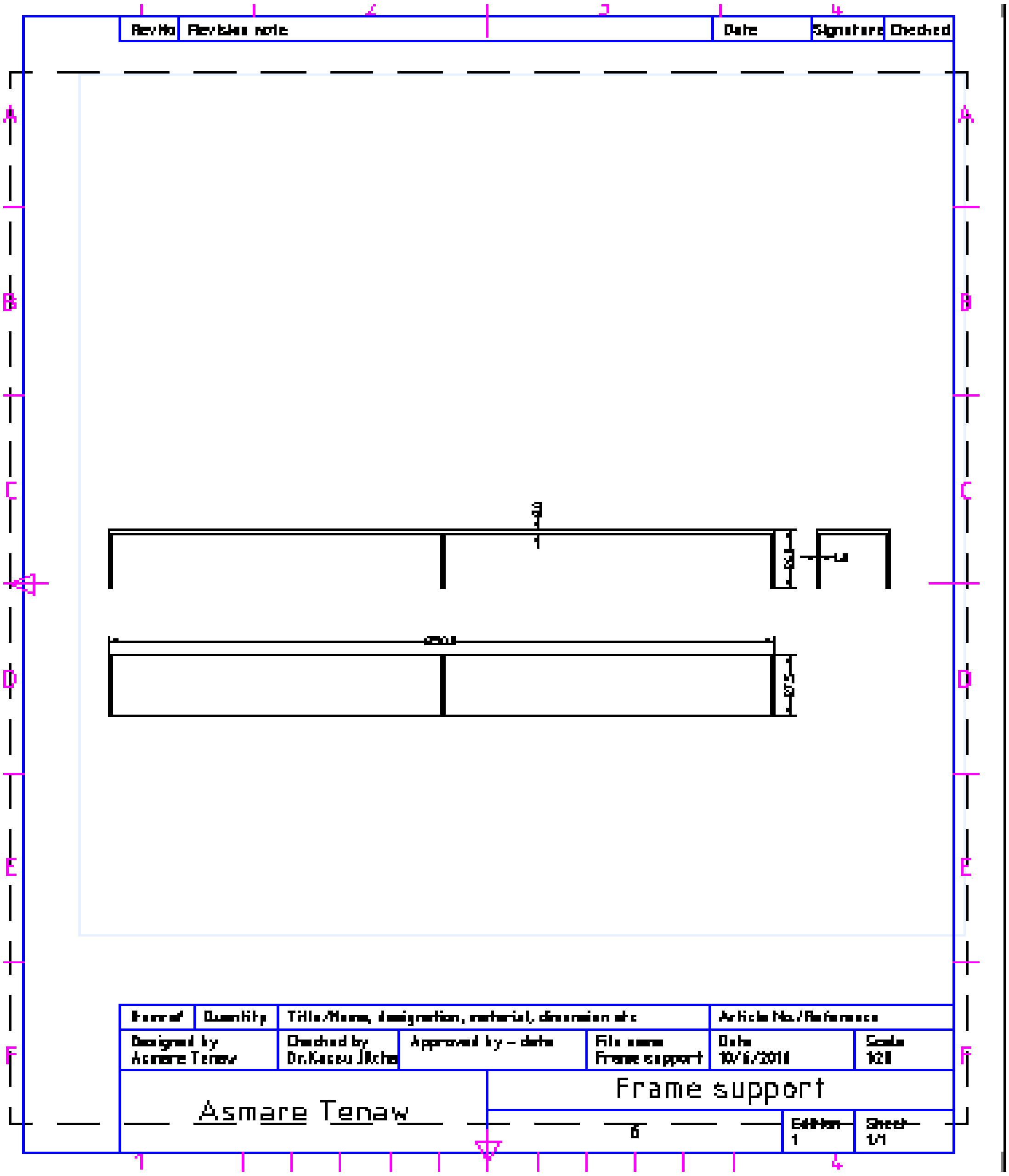
Appendix Figure: 1 Two dimensional sketch of roller support



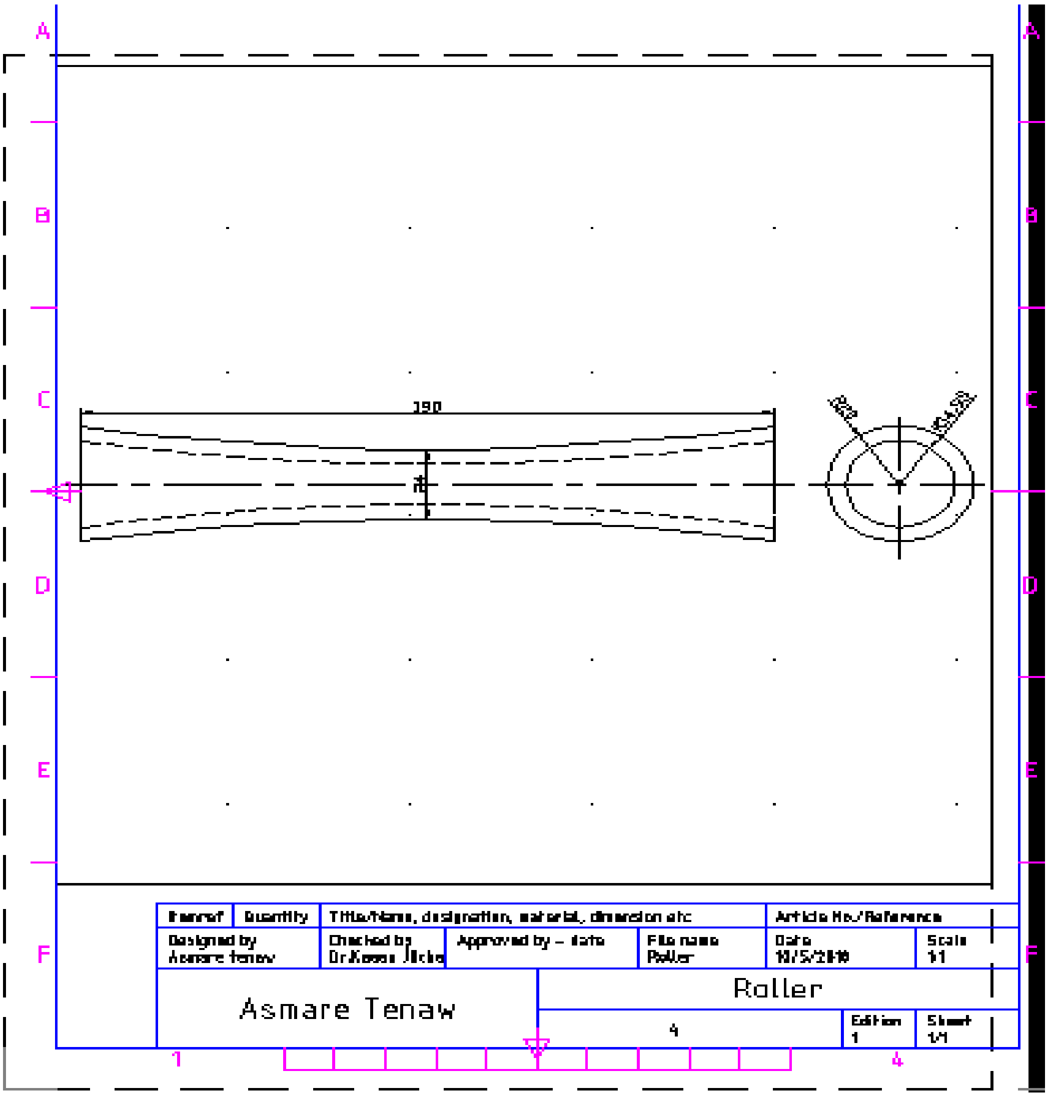
Appendix Figure: 2 Two dimensional sketch of water bath



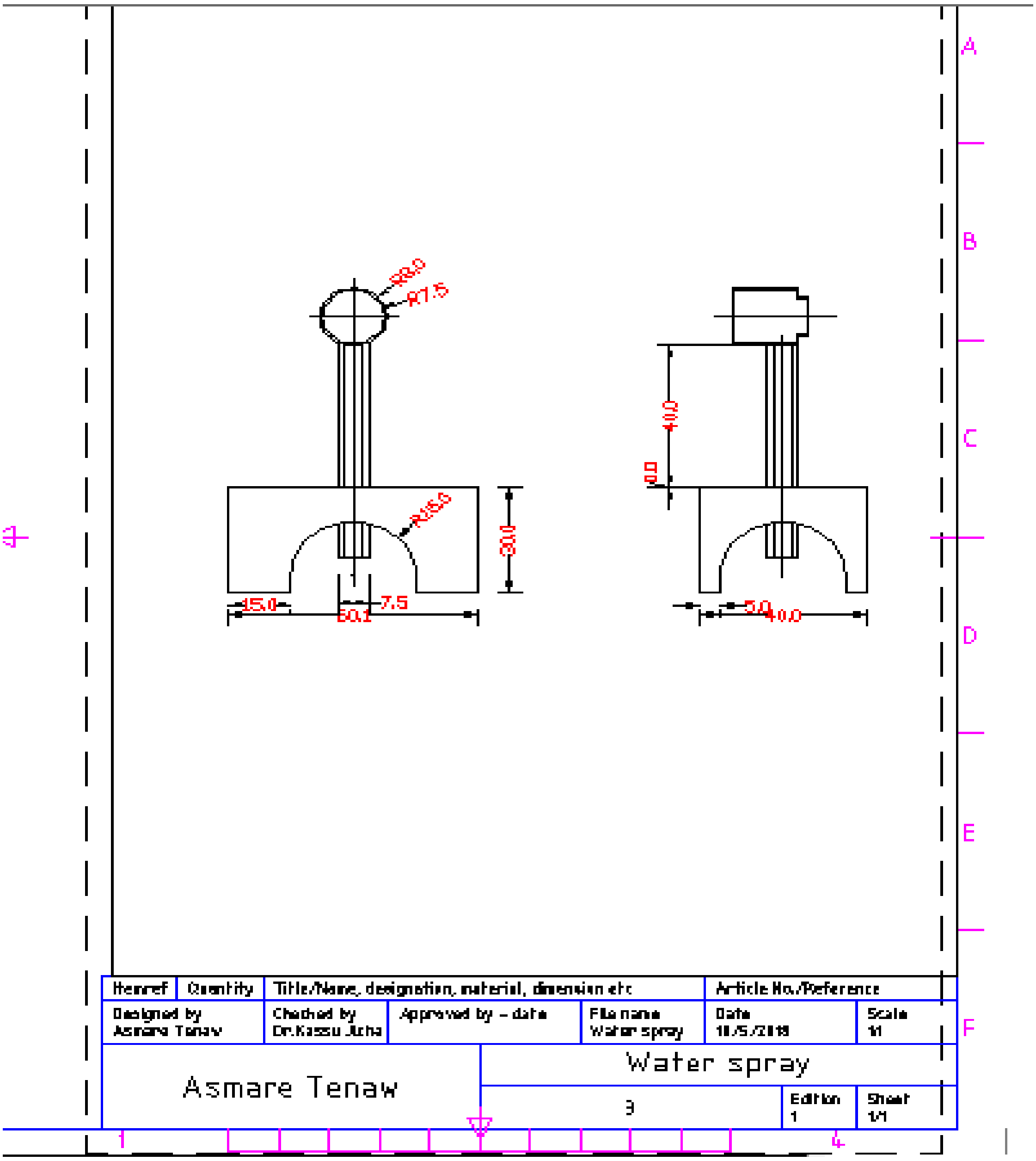
Appendix Figure: 3 Two dimensional sketch of spray tube



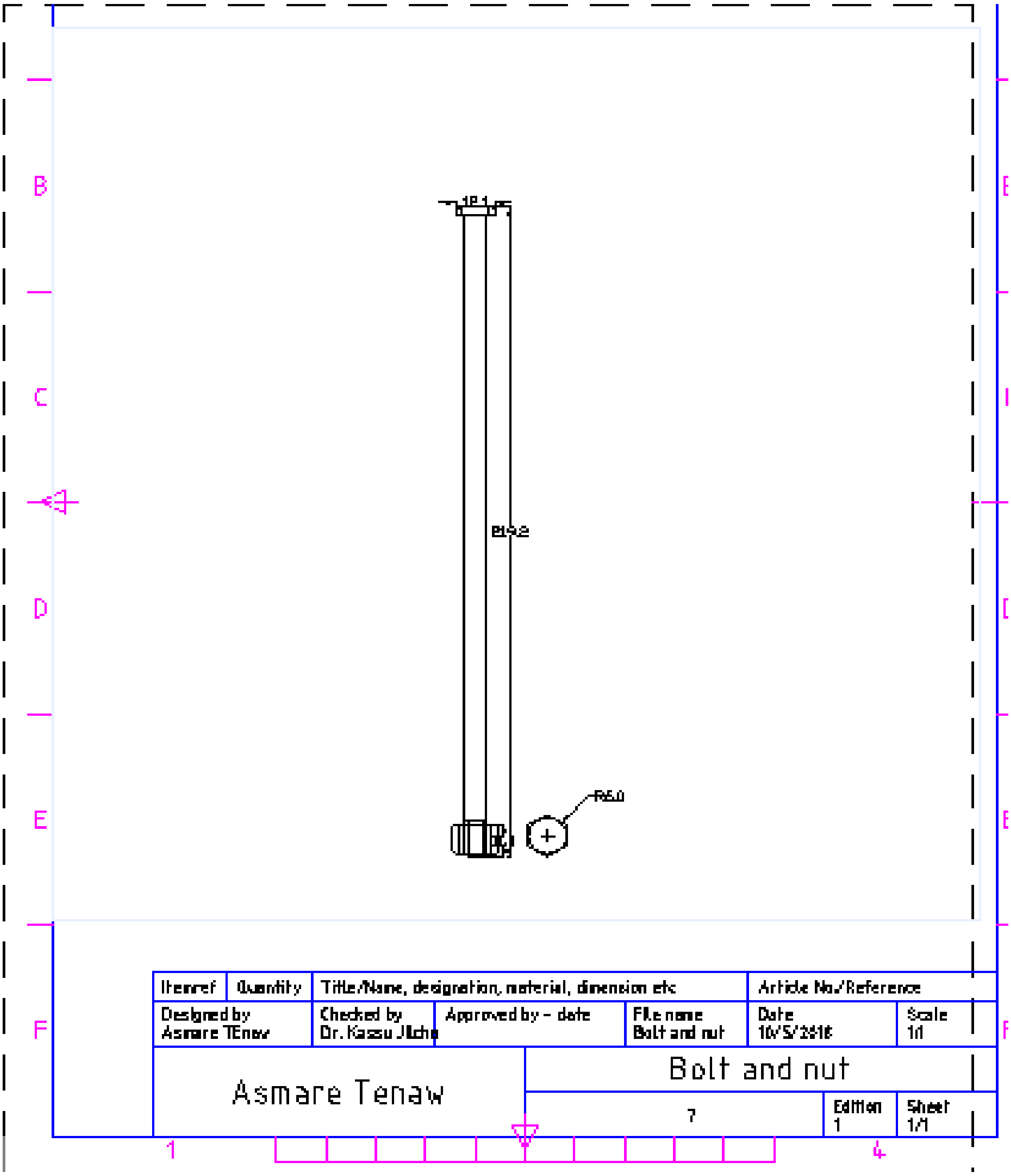
Appendix Figure: 4 Two dimensional sketch of frame support



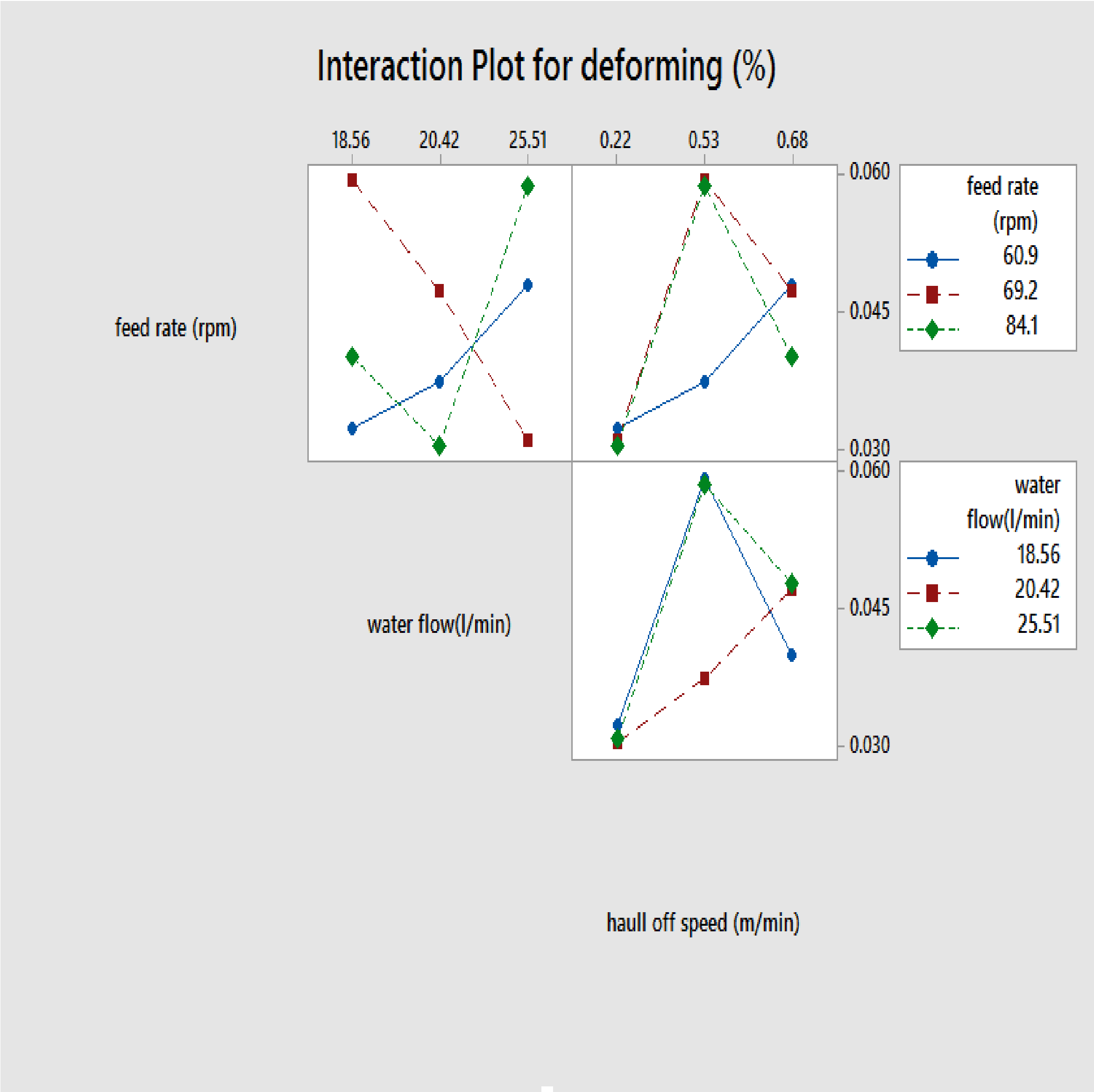
Appendix Figure: 5 Two dimensional sketch of roller support



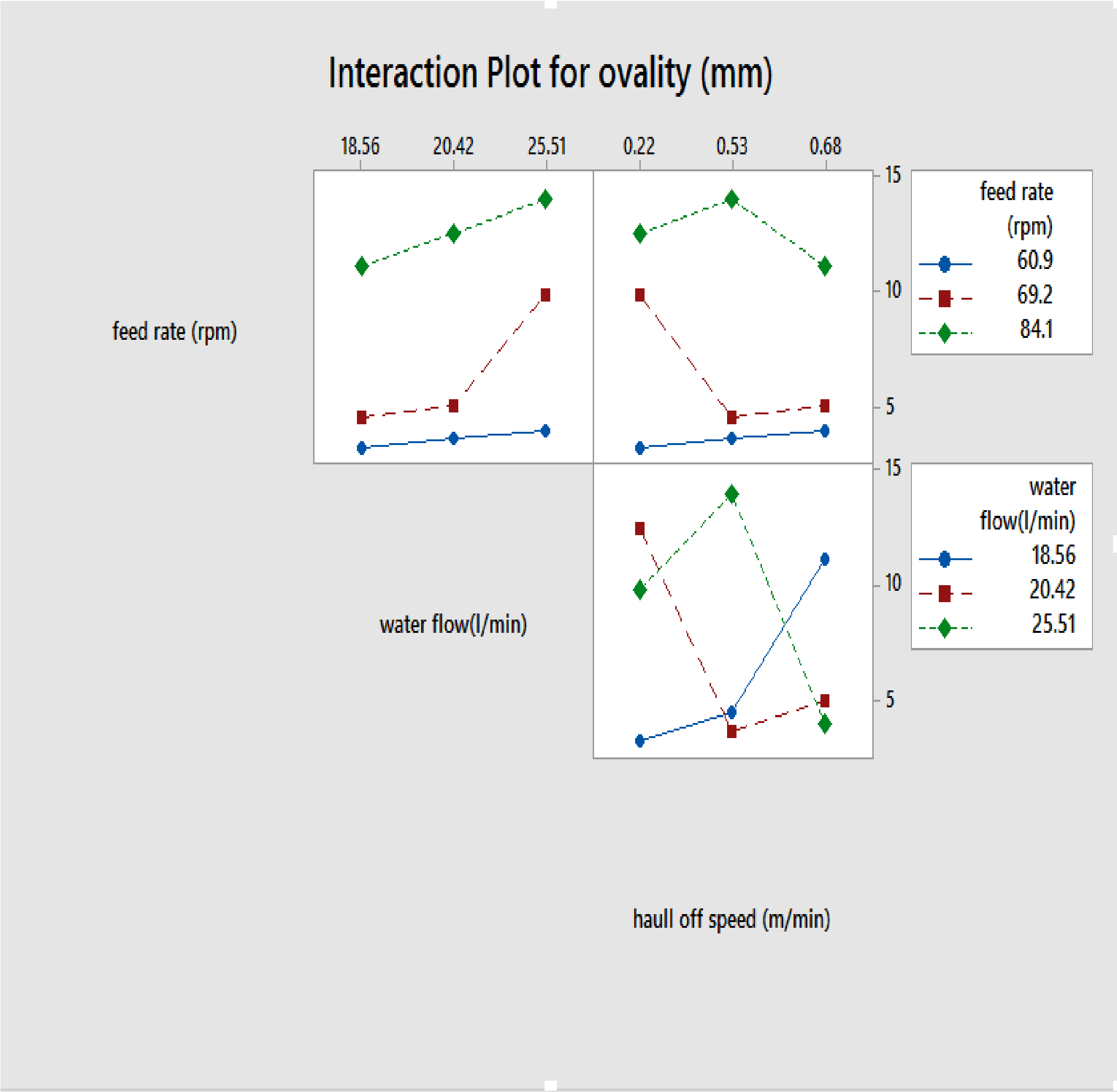
Appendix Figure: 6 Two dimensional sketch of water spray



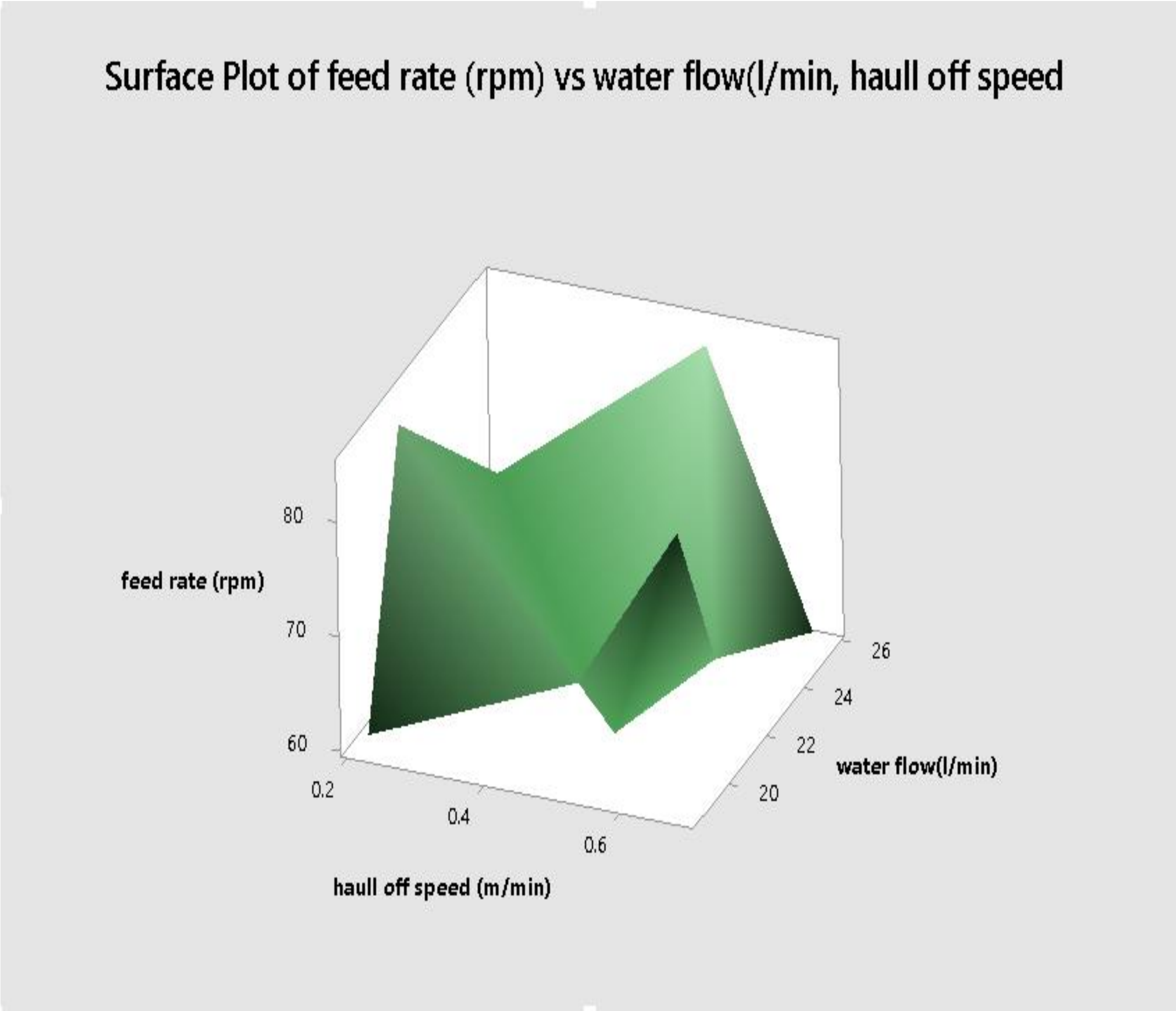
Appendix Figure: 7 Two dimensional sketch of roller support



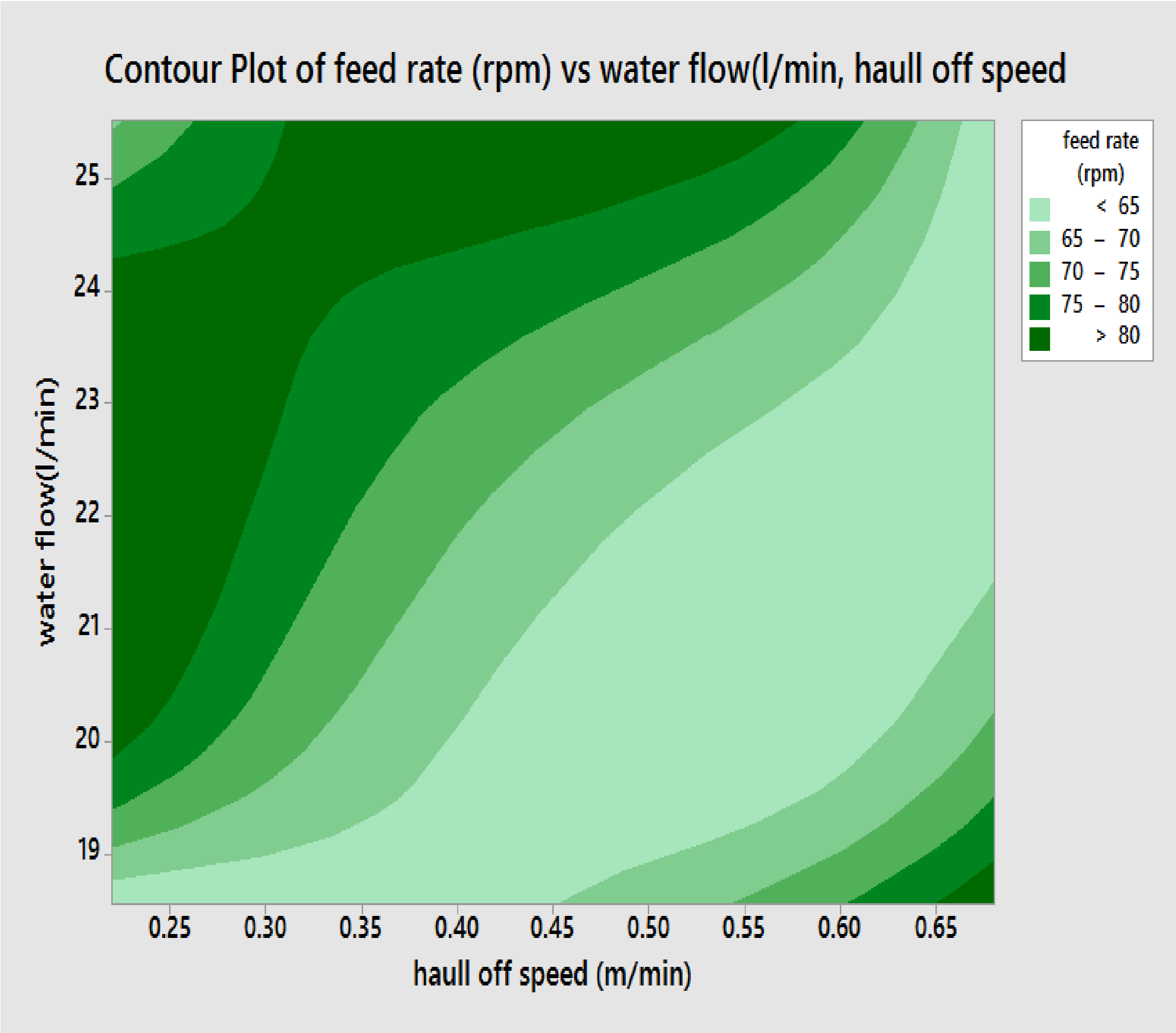
Appendix Figure: 8 Interaction plot of deformation



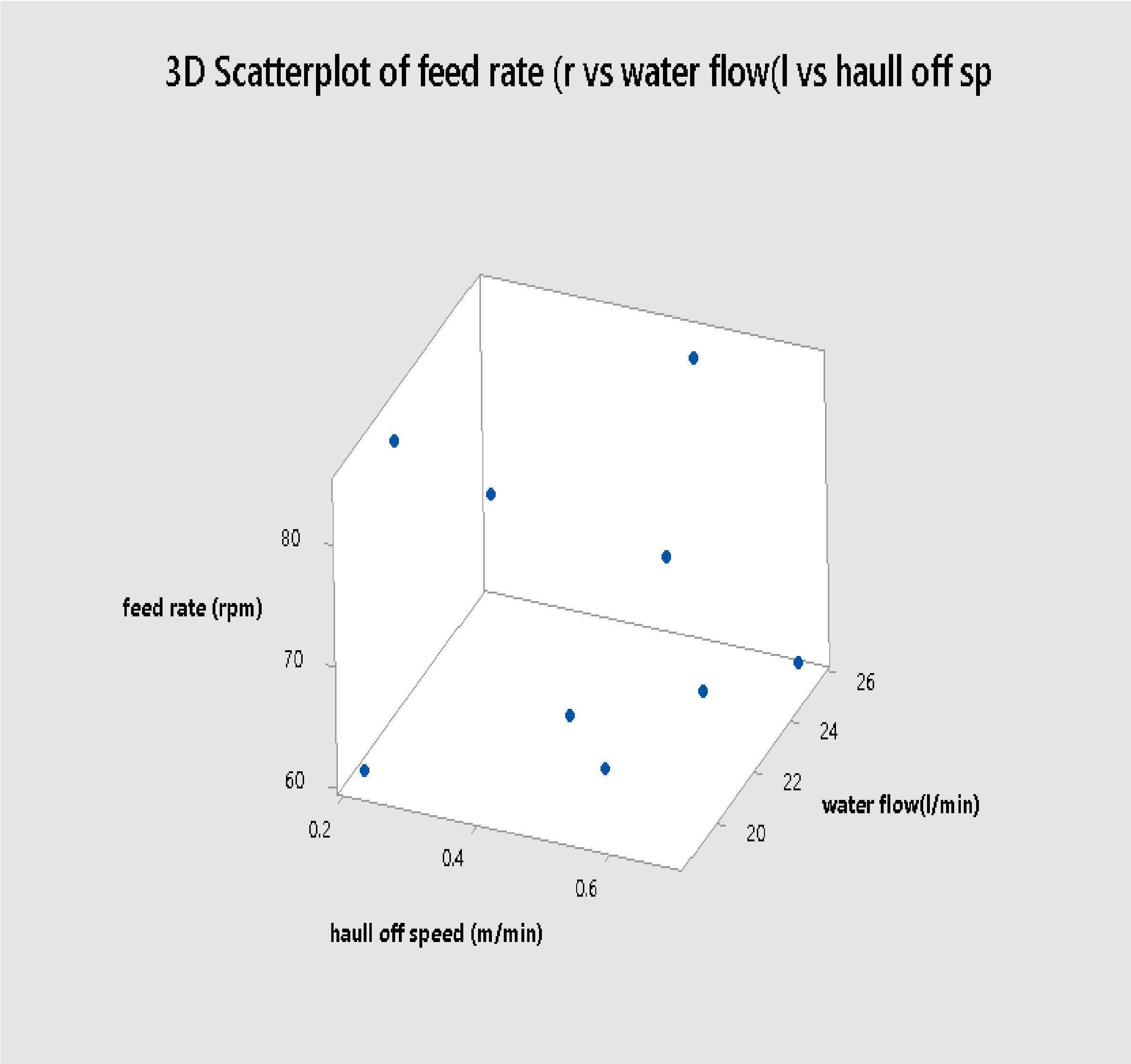
Appendix Figure: 9 Interaction plot of ovality



Appendix Figure: 10 Surface plot of the optimized parameters



Appendix Figure: 11 Counter plot of optimized parameters



Appendix Figure: 12 Scatter plot of optimized parameters