PERFORMANCE OF POLYPROPYLENE HOMOPOLYMER (PPH) PIPES IN INDUSTRIAL CONDENSATE RECOVERY SYSTEMS

BY

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DECLARATION

I Kasaija Charles, declare that this dissertation has been composed solely by myself and has not been submitted in whole or in part to any institution for any academic award. All other authors' works that have been referenced in this Final dissertation have been duly acknowledged through citation.

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APPROVAL

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DEDICATION

I dedicate this dissertation to my parents Mr. Kasaija Charles and Mrs. Birungi Annet Kasaija in appreciation for their financial and moral support that has enabled me to attain this academic achievement. I also dedicate this dissertation to my sister Kansabe Shirley for always inspiring me as well as to Karungi Daphine for her unconditional love and care.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ARP	Acid Regeneration Plant
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CCL	Color Coating Line
CGL	Continuous Galvanizing Line
CRM	Cold Rolling Mill
FRP	Fiber Reinforced Plastic
HCl	Hydrochloric Acid
ICP	Polypropylene Impact Copolymer
ISO	International Organization for Standardization
PPH	Polypropylene Homo-polymer
PPPL	Push Pull Pickling Line
PPR	Polypropylene Random Copolymer
RWL	Rewinding Line
MS	Mild Steel
Rm	Tensile Strength
Rb	Yield Strength
ReH	Upper Yield Strength
ART	Acid Recirculation Tank

ABSTRACT

Industrial competitiveness can be achieved through sustainable manufacturing by employing a multi-dimensional approach that is capable of minimizing operational costs and production downtime. Steam remains an inexpensive source of energy for heating purposes to facilitate higher rates of chemical reactions during steel strip processing. Steam condensate contains an appreciable enthalpy that can recuperated to enhance boiler efficiency, conserve water and minimize waste heat. A condensate recovery system thus ought to be an integral part of a steam system in order to minimize the utility costs of steel plant and enable it maintain a competitive advantage. However, the reliability of the condensate recovery system to recuperate heat lies in exploitation of material properties of the piping system to match the desired system performance characteristics. This work analyzed the technical performance of PPH pipes in comparison with the conventional steel pipes when used in industrial condensate recovery system piping. Comparison was made in regard to durability, safety, maintenance cost and downtime. The results have proved that PPH pipes are more economic overtime, conserve more thermal energy, have a longer service life and their mechanical properties are enhancement with a 149.95% increase in tensile strength, 43.76% increase in compressive strength, 24.8% increase in flexural modulus and a 37.63% increase in hardness for a one-year service period. This indicates that crystalline reorientations and cross linking were dominant over oxidative degradation and chain scission. However, the impact strength greatly decreased and averaged at 3.15J/m which proves that in-service pipes become more brittle with time and therefore further studies should be done in that regard. Guidelines for installation, maintenance and support configurations for the PPH piping have been proposed. Finally, there is need for steel strip processing plants to recover all condensate while using PPH pipes, there is a dire need for further studies to ascertain the service period when oxidative degradation becomes dominant in the PPH piping.

CHAPTER ONE: INTRODUCTION

1.0 Introduction

This chapter highlights the main and specific objectives of this study. It examines the problem encountered when using steel pipes in industrial condensate recovery systems. It furthermore expounds the background of this study and provides a conceptual framework that has been applied.

1.1 Background to the Study

Waste heat is a concern in the industrial sector because of the increased energy requirements in industries and its impact on the environment. Sustainable manufacturing demands measurement of the energy intensity rather than quantifying the energy consumed by a section. Energy intensity which is the energy utilized to produce a certain product should be as minimum as possible for a certain production. A low energy intensity indirectly implies an increased efficiency (Kifleyesus, 2017) and energy conservation which is key aspect in manufacturing. Furthermore, condensate recovery is the advanced technique used to recuperate heat to improve both efficiency and effectiveness of the industry where steam is used as source of energy in a basic heating unit. (Apoorva, 2013) highlighted the mega benefits and the tangible costs an industry cuts through improvement in condensate recovery. Additionally, there is general scarcity of water in the world today and its projected that by 2030, about 700 million people will be displaced owing to scarcity of water due to both water pollution and disruption of the water cycles and therefore it is imperative that water is conserved (UNDP, 2023).

Steam is used in various industrial processes for heating purposes; for instance, in the steel manufacturing industry, steam is used in pickling lines to heat acid in order to increase the rate of reaction during the pickling process. The steam used in the pickling line is supplied at a pressure of 5 bar and it heats up acid to about 80^{0}c by transferring its enthalpy through a fluoroplastic heat exchanger submerged in the acid tanks. During heat transfer, steam loses its enthalpy to form flask steam that is discharged from the heat exchanger by the steam trap. Upstream of the steam trap, a two phase flow exists due to flash steam which consists majorly of condensate with an appreciable enthalpy of about 18% of the total enthalpy of live steam from which its produced (Sakharkar, 2018). Moreover, condensate released from the pickling line is usually contaminated with Hydrochloric acid (HCl) which is used in steel pickling due its numerous advantages over other acids. However, the main drawback of using hydrochloric acid is its high volatility under pickling conditions (Anderez, 2022), such that HCl vapors may diffuse into the condensate through the micro pores in the heat exchangers thus contaminating the condensate in addition to the inherent corrosivity of condensate due to dissolved carbon dioxide. The major source of carbon dioxide in steam is the breakdown of feed water bicarbonate and carbonate alkalinity in the boiler. The liberated Carbon dioxide (CO_2) is carried with the steam into the condensate system and it dissolves to forms carbonic acid. Even small quantities of carbonic acid can significantly lower the condensate pH and increase its corrosivity; and the corrosion rates increase with increasing temperatures. Therefore, the hot condensate that is contaminated with carbonic acid is aggressive to metal surfaces (Bloom, 1999). Even though the condensate from the pickling line has a low pH, it has a potential to be used in various ways, for instance as rinse water in the rinsing section of the pickling line, as water for adsorption in Acid Regeneration Plant (ARP) and as in a wet scrubber. This necessitates recovery of the contaminated condensate but poses a challenge of its transportation since the ordinary steel pipes are susceptible to corrosion and erosion during service.

The developments in the plastic industry have led to new emerging technologies with new plastics taking center stage as pipe construction materials for domestic and industrial applications. (Zgoul, 2008) compared the performance of cross-linked polyethylene and polypropylene random copolymer whilst steel pipes for heating purposes and concluded that both polymeric pipes are more convenient for heating purposes, corrosion resistance, and easier workability than steel pipes. Furthermore, the study revealed that plastic pipes possess low thermal conductivity and behave satisfactorily when subjected to thermal stresses for long periods of time (aging effect). Therefore, plastic pipes exhibit higher energy conservation and safety than steel pipes. Polypropylene continues to dominate a larger market share (19%) over other plastics. Among the different types of polypropylene plastics, the market share of the polypropylene homopolymer (PPH) is 65-75%, polypropylene impact copolymer (ICP) is 20-30% and polypropylene random copolymer (RCP) is 5-10%. (Maddah, 2016). The high availability of polypropylene homopolymer (PPH) makes it a potential material for different industrial applications. Consequently, this study evaluates the performance of polypropylene homopolymer (PPH) as a construction material for condensate pipes in industrial condensate systems.

1.2 Problem Statement

The inherent condensate contamination by hydrochloric acid fumes during heat transfer through heat exchangers in the steel pickling line increases the tendency of corrosion of the steel pipes that transport the condensate. This leads to persistent flash steam leakages that are costly given that the production line must be stopped to arrest such leakages thus increasing downtime above the recommended 3% of unplanned machine down time as a percentage of the scheduled run time (APQC, 2015); thus causing adverse effects on production. An appreciable length of a steel pipe or fittings must be replaced and this gives no guarantee that the weld between the new pipe or fittings with the steel pipe already in service will be leakage tight; this in turn leads to reworks. Besides that, the repaired section needs to be re-insulated thus increasing the maintenance costs. Therefore, polypropylene homopolymer (PPH) pipes are envisaged as a potential substitute to steel pipes for transportation of the acid-contaminated condensate recovery systems in the steel strip processing industry.

1.3 Objectives

1.3.1 Main Objective

To establish the technical performance of polypropylene homopolymer (PPH) as a construction material for condensate pipes in industrial condensate recovery systems of a steel plant.

1.3.2 Specific Objectives

- **i.** To determine the performance characteristics of industrial condensate recovery systems in a steel plant.
- **ii.** To establish the technical performance of polypropylene homopolymer pipes in a condensate recovery plant of a steel manufacturing plant.
- **iii.** To perform a comparative analysis of the technical performance of polypropylene homopolymer pipes and steel pipes in condensate recovery systems of a steel manufacturing plant.

1.4 Research Questions

The research questions guiding this study are:

- **i.** What influences the performance characteristics of condensate systems in a steel pickling system?

ii. How do the properties of the polypropylene homopolymer material influence its performance as a material for pipes used in condensate recovery systems of a steel manufacturing plant?

iii. How do polypropylene homopolymer pipes and steel pipes comparatively perform in condensate recovery systems of a steel manufacturing plant?

1.5 Justification of the Study

Uganda Vision 2040 acknowledges that there is a strong positive correlation between industrialization and rapid development. Establishment of economic lifeline industries which include the iron and steel industry is envisaged to be a spring board for advanced industrialization. The iron and steel industry in Uganda is in its infant stages and there is a dire need for innovations and developments to increase the energy efficiency of Uganda's steel manufacturing plants. Whereas steam remains an inexpensive source of energy for Acid heating in steel pickling, condensate recovery recuperates waste heat enhancing both energy and water conservation as well as minimizing boiler carbon dioxide emissions. An efficient condensate system lowers the steel industry's utility costs and increases production uptime. Therefore, this investigation into the performance of polypropylene homopolymer (PPH) pipes for use in condensate recovery systems envisages reducing unplanned downtime and maintenance costs, leading to a reduction in operational costs, which subsequently accelerates the return on investment.

1.6 Conceptual Framework

The conceptual framework for this study is presented in Figure 1.1. The independent variables include the condensate temperature, pressure and volumetric flow rate. The dependent variables are tensile strength, impact strength, flexural strength, burst pressure and service life; these variables are derived from the American Society of Mechanical Engineers (ASME) code for pressure piping. The moderating variables are strength of the polypropylene homopolymer (PPH) butt weld, pipe support design, percentage of flash steam, and pipeline routing.

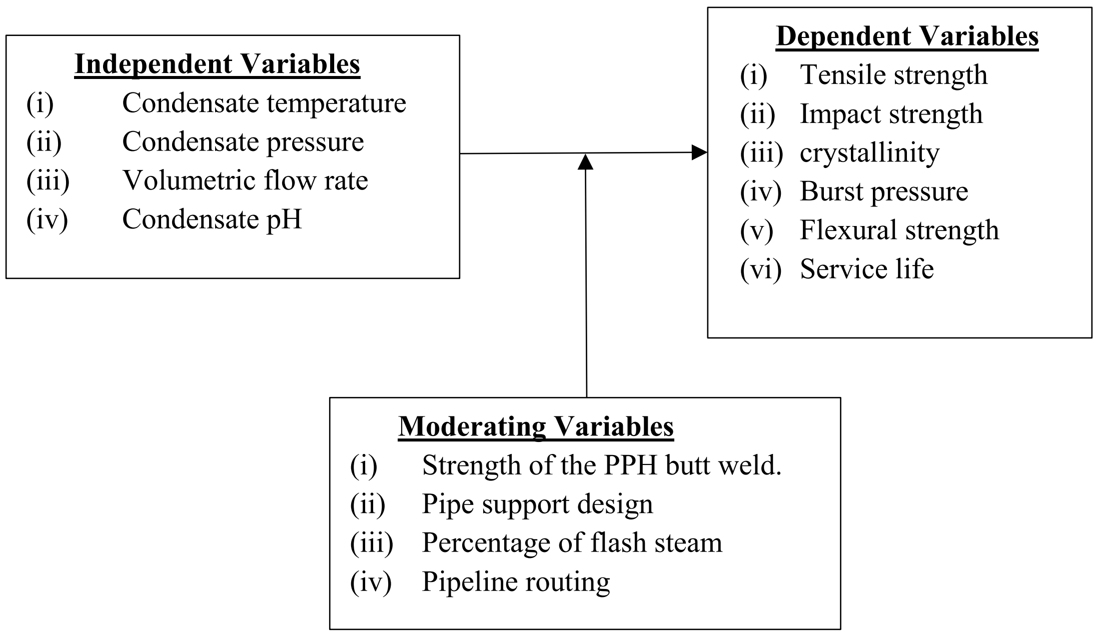


Figure 1-1. Conceptual Framework

1.7 Significance of the Study

This study aims at improving the efficiency of the condensate recovery systems by minimizing condensate leakages through the use of polypropylene homopolymer (PPH) pipes. An efficient condensate recovery system in a steel manufacturing plant reduces not only utility costs but also production downtime. A technical evaluation of the performance PPH pipes in condensate recovery systems will inform designers about their cost benefit compared to the conventional steel pipes. This will create a vast application area for the PPH pipes thus widening their market base and will trigger their manufacturers into product modification in order to gain a competitive advantage.

1.8 Scope and Limitations of the Study

This study is limited to evaluation of the technical performance of the polypropylene homopolymer and steel pipes used in the pickling line of a steel manufacturing plant while considering the typical condensate parameters in regard to the steel pickling sections. Furthermore, the investigation will only cover the performance of polypropylene homopolymer pipes as main condensate pipelines and not their corresponding inline auxiliary pipelines and valves made from polypropylene homopolymer material. Particularly, the study will analyze the performance of polypropylene homopolymer pipes available on market in regard to their potential to be used as condensate recovery pipes.

CHAPTER TWO: LITERATURE REVIEW

2.1 Steel Strip Process

The steel manufacturing plants employ various process steps to process strip steel into functions steel sheet products of various gauges, such as roofing sheets of buildings and construction steel sheets for industrial structures like warehouses and manufacturing facilities. The various processes in the steel sheet galvanizing line include: color coating, galvanizing, Rewinding, trimming, cold rolling, steel sheet pickling.

2.1.1 Color Coating Line (CCL)

Metal coil color coating is a linear process by which protective or decorative organic coatings are applied to flat metal sheet surfaces. Upon cleaning and drying the coil, its sent through a coating application station, where rollers coat one or both sides of the metal strip with a coat layer consisting of primers, intermediate coat and final finish coats. The strip then passes through an oven where the coatings are cured and exits into a water jet after which the sheet is again dried by hot air dryers to give a good surface finish to sheet. Therefore, Color coating line serves a purpose of pre-painting steel sheets before they are put into use. This process rules out the degreasing and painting process of steel sheets as compared with post-painted ones. Paint loss is less and the volatile organic compounds from the paint is efficiently treated in regenerative thermal oxiders (Kaneto, 2015).

2.1.2 Continuous Galvanizing Line (CGL)

Galvanizing is a surface protection technique that is achieved through the application of a protective zinc layer over the steel substrate to prevent it from rusting. This can be accomplished through hot dip galvanizing, electro galvanizing, and zinc spraying. Even though hot dip galvanizing causes a significant deterioration of the mechanical properties of high-strength steels (Šmak, 2021), It's the most common method of galvanizing used in steel plants. During hot dip galvanizing, steel is immersed into a bath of molten zinc. Symbiotic bonds form when zinc -aluminum alloys dissolve or diffuse into the iron substrate which endows the surface with enhanced corrosion resistance and glamor.

Continuous galvanizing lines have taken center stage in hot –dip galvanizing of steel sheets. This process line typically unwinds cold rolled coils from the rewinding line and feeds the sheet continuously through a cleaner, an annealing furnace and then into a molten zinc bath. Air "knives" blow off the excess coating from the steel sheet to control the coating thickness to the specified requirement and hot air dryers are provided cure the coating.

2.1.3 Rewinding Line (RWL)

The combined effect of high compression and tension forces reduce the strips' thickness during cold rolling in turn increases its width. Since the strip is subjected to high tensions in order to achieve flat surfaces, stresses are introduced due to changes in the crystalline structure of the metal and the coil experiences significant residual tension which is unsuitable prior to annealing. Therefore, the coil must be re-wound with lower tension in the Rewinding Line. Trimming can also be formed during rewinding where wavy edges of the sheet can be cut off such that exact widths can be achieved whenever desired.

2.1.4 Cold Rolling Mill (CRM)

Cold rolling is the reduction of the pickled strips' thickness from about 1.5-5mm to about 0.02-4mm, depending upon the desired sheet product (Rentz, 1999). Rolling is accomplished by compressing the strip between two work rolls and at the same time stretching it. This creates extensive temperatures up to 240 ^{o}C in the mill and thus requires cooling using the popular esterbased lubricants (Ogawa, 2012). These lubricants not only cool the rolls but also reduce the roll forces and moments as well as enhance the strip surface during cold rolling.

Rolling section set up can be in form of tandem mills, cluster mills, 4hi or 6hi mills. Depending upon the required gauge of the sheet, Rolling can be done continuously or reversing and the decision is based on energy economization even before installation is done. While cold rolling aims at production of flat rolled steel products e.g. roofing iron sheets, it still faces multiple quality challenges in form of irregular strip thickness and poor surface finish. However, many technologies like automatic gauge control systems have been developed to address these challenges and enable milling stations produce to global standards (Ginzburg, 1993)

2.1.5 Steel Pickling Line

The steel pickling line in a steel manufacturing plant is constituted of the pickling process, Rinsing section, condensate recovery system, and acid regeneration plant. Chemical pickling is an industrial process used to remove the surface layer of iron oxides that are formed on steel products exposed to atmospheric oxidation during hot processing (Anisoara, 2015). Pickling is accomplished through dipping the strip steel into a hot bath of 15-20% hydrochloric acid at 60-70°C so that the reactions of the steel surfaces with an acid removes the ferric oxide while maintaining a good surface finish (Rentz, 1999). Owing to the numerous advantages e.g. ability to be regenerated, enabling high higher pickling speeds (600 - 1200 fpm), and better product quality, hydrochloric acid is most popular acid used (Claudia, 2023). However, HCl is highly corrosive which increases the cost of pickling lines and it gives off choking fumes when hot (Hasler, 1997).

Heating of the acid increases the rate of a chemical reaction during the pickling process. HCl in the pickle tanks can be heated by two ways; either by direct heating with live steam or indirect heating by external heat transfer using a heat exchanger submerged in acid. Direct heating is undesirable because the condensed water reduces the acid concentration. Despite the fact that the heat exchangers used are corrosion resistant, they susceptible to leaking acid fumes to the condensate leading to contamination. (Pravin, 2016) investigated the condensate recovery from Pickling section at Jindal steel Ltd and proposed that energy conservation and enhanced overall efficiency could be achieved by using a Condensate Contamination Detection System and noted that recovered condensate could reach the feed water tanks at 66^0C

2.1.6 Acid Regeneration Plant (ARP)

The acid regeneration plant is crucial for handling and reclamation of waste acid (7-12% concentration) obtained from the pickling process. Hydrochloric acid can be recovered through vaporization by heating it to high temperatures. The recovery reaction is governed by two chemical mechanisms namely oxidation and hydrolysis of ferrous chloride that occur inside a reactor. There are two different types of reactors i.e. fluid bed roasters and spray roasters. The latter are preferred because of their simplicity, cheapness and proven commercial performance (Hasler, 1997).

During spray roasting, the waste acid is atomized at the top of the reactor and falls into the rising stream of hot gases from the burners at the bottom. Pyrohydrolysis occurs which results into the formation of HCl gas and red oxide as the by-product (Agrawal, 2014). The gas is thereafter absorbed in water to form an aqueous solution of HCl at 18-25% concentration. This regenerated acid is pumped to the pickling line and the cycle continues.

2.2 Condensate Recovery Systems

Steam is an important source of energy for industrial heating processes majorly because of its cost effectiveness. Steam from the boiler house can be distributed by either a one-pipe design or two-pipe design according to application and size of the load. A one-pipe design is suitable for low steam pressures in domestic applications while the complex industrial steam systems require utilization of a two-pipe design for steam distribution piping system. The two pipe steam heating system has a pressure line and a return to carry condensate away from the load.

2.2.1 Operational Principal of Condensate Recovery Systems

Condensate recovery is a means of waste heat recovery from steam systems. This waste heat exists as sensible heat in hot water which is few degrees below its boiling point. Recovering condensate increases the efficiency of heating systems, minimizes environmental pollution and conserves water. Significant energy savings are realized by recovering condensate which can also be used as make-up water. (Deore, 2018) reported about condensate recovery in a Diary plant and noted that heat recovered from condensate reduced the boiler fuel consumption by 20% with a further 11.58T CO_2 reduction. (Vineeth, 2013) studied condensate recovery in textile industries and noted that the efficiency of boiler increases between 2 to 6% with heat recovery.

During heating, live steam gives up its enthalpy through exchanging heat to the medium that is being heated and subsequently condense. The rate of heat transfer is dependent upon the efficiency of the heat exchanger and the thermodynamic properties of the medium being heated. The steam condensate formed is continuously discharged out of the heat exchanger by the help of steam trap which on the other hand prevents live steam leakage into the condensate pipes. Condensate piping systems are integral parts of steam distribution networks, designed to return condensed steam back to the boiler. Their installations can be configured either underground or above ground, with each configuration offering certain advantages and constraints. Underground systems are used to preserve aesthetics and minimize physical obstruction mostly in urban and institutional settings whereas above-ground condensate systems are widely employed in industrial plants, power generation facilities, and unlimited space locations (Akhtar, 2017).

Condensate pipes convey undesirable two-phase flow with flash steam of enthalpy approximately 398.09 kJ/kg covering about 95% of the total volume of pipe. Condensate water particles with a higher specific density than steam particles impinge on pipe fittings during change of flow direction because of their high inertia. This is very detrimental because it leads to erosion of pipe walls and accounts to about 75% of condensate leakages on pipe bends. Whereas flow velocity inside a condensate pipe is a contributing factor to erosion, practice has shown that the efficient flow velocity that reduces erosion is 10m/s for condensate pipes downstream of a float-type steam trap or 6 – 8m/s for other steam trap types (ARI-Armaturen GmbH, 2018)

2.2.2 Steam pressure-enthalpy relationships

One of the most important parameters characterizing steam and condensate is enthalpy, a measure of its total heat content. The relationship between steam pressure and enthalpy determines how much condensate. As pressure increases, the boiling point of water rises thus more energy is required leading to a gradual increase in sensible heat. At higher pressures, the density and energy states liquid and vapour converge hence their difference in enthalpy narrows resulting in a decline in latent heat. The rising trend in sensible heat and declining trend in latent heat explain the behavior of total enthalpy across pressure ranges and is therefore a basis for choosing an optimal steam pressure supply in heating systems. It's also vital to note that enthalpy of condensate formed from steam is directly related to the supply steam pressure and therefore the latter defines the heat content of condensate downstream of a steam trap (Micheal J moran, 2006).

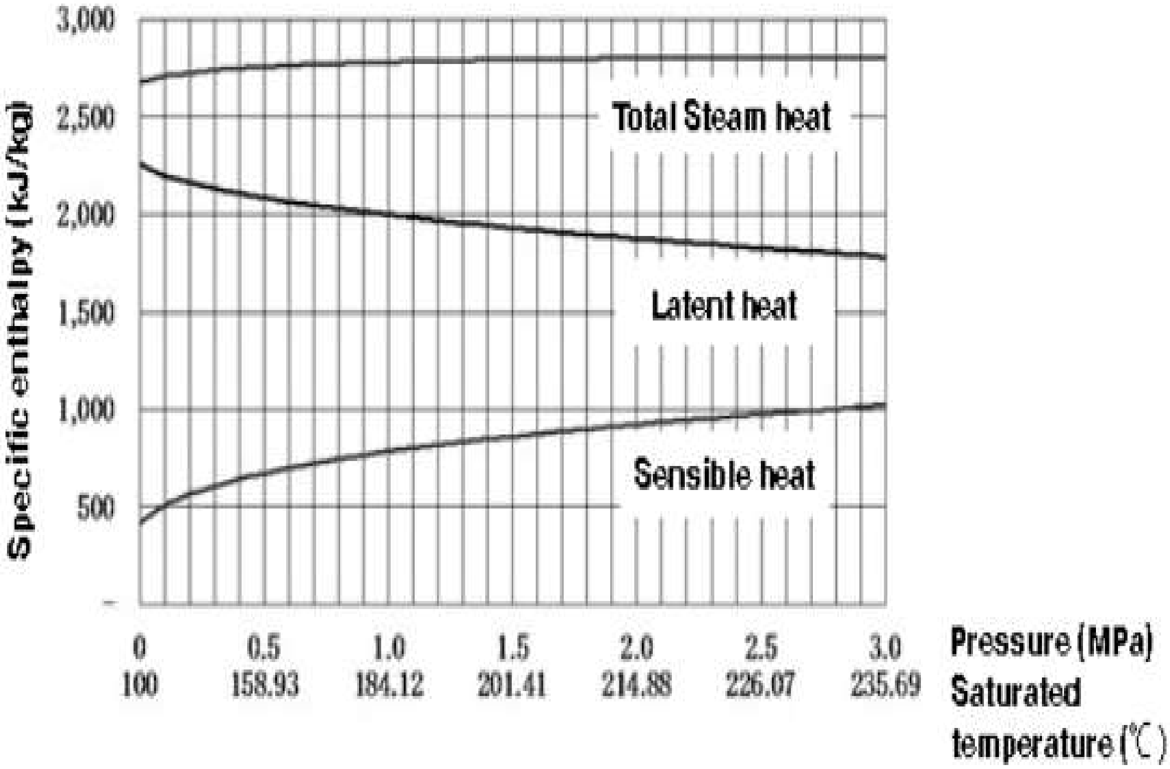


Figure 2-1. Relationship between steam enthalpy and steam Pressure.

2.2.3 Transportation of Condensate

Whereas condensate recovery is economical, proper design and maintenance of the condensate system is essential to realize those benefits. The type of steam trap and its ability to function fully will increase condensate recovery by approximately 10% (Apoorva, 2013). The design of condensate recovery system depends on the enthalpy to be maintained and volumes of condensate. Condensate is transported conventionally by copper pipes, steel pipes and stainless pipes. However, turbulent and fast-flowing wet flash steam facilitates flow-assisted corrosion that wears away the protective film for the case of stainless steel and leads to continued dissolution of the underlying metal through chemical reactions. Flow assisted corrosion is distinguishable as an erosion that is caused by mechanical processes such as abrasion (caused by particles in water), impingement (caused by water droplets in steam), and cavitation (caused by collapsing gas bubbles) (Wu, 1989).

2.2.4 Materials used in Condensate Recovery Systems

2.2.4.1 Steel

Mild steel pipe is widely used in various pipeline applications because it's cheap and has good mechanical properties. Pipe insulation has proved an ideal solution to combat heat losses, rendering mild steel pipes as a cost-effective option and conventional for condensate pipping. (Ahmad, 2022) studied the corrosion behavior of low carbon steel pipes in a condensate environment and highlighted that the rate of corrosion depends on Water and environmental parameters like temperature, salinity, dissolved oxygen content, conductivity, Total dissolved solids and pH. The high susceptibility of mild steel pipes to corrosion leads to unplanned breakdowns and raises maintenance cost.

2.2.4.2 Stainless steel

The quest for a suitable material for the condensate pipes has been on for a while, (B. Chexal, 1988) suggested stainless steels type 304L, 316L, and 347L as satisfactory replacement materials. He however noted that such materials are more expensive than conventional carbon steels despite the benefits of economical installation and long service time. (Huijbregts, 1984) studied that low (<0.1 %) Cr, Cu, and Mo content can produce a remarkable increase in erosion-corrosion resistance. He developed an equation (1) that calculates the resistance of stainless steel. He based on the knowledge of the in-service pipes failures to concluded that Designers can minimize the erosion-corrosion risk by selecting steels with erosion-corrosion resistance values of at least R = 1. The chemical reaction kinetics can be greatly influenced by temperature, in awake of that, (Bignold, 1980) studied the effect of temperature and ascertained that Erosion-corrosion damage is most prevalent in the temperature range 50 to 250 ^{0}C. Furthermore, he distinguished that for a single-phase flow condition, damage occurs in the temperature range of 80 to 230 °C, whereas for two-phase, the temperatures ranges from 140 to 260°C.

$$R_{KEMA} = 0.61 + 2.43\ Cr + 1.64\ Cu + 0.3\ Mo \qquad \textbf{(1)}$$

2.2.4.3 Copper

Copper has been employed as an ideal pipe for industrial trace heating because of its low installation cost and high workability. However, condensate temperature at a low pH facilitates the coppers' decomposition into copper ions which under suitable pressure can precipitate leading to clogging. (Oliphant, 2017) reviewed the different causes of copper corrosion in plumbing systems and concluded that corrosion was dependent on the level of dissolved oxygen.

2.2.4.4 Fiber Reinforced Plastic (FRP)

FRP pipes weigh less and cannot corrode thus have a potential to outlast all the other materials used in condensate pipping. However, they are unable to withstand extreme temperatures that may emanate from live steam leakages into the condensate system rendering them as risky options (Marshall, 1998). (Kunsemiller, 1996) noted that FRP pipe has a history of failure when subjected to cyclic thermal loading and as well suggested that Underground installation should be considered for plastic condensate pipping.

2.3 Erosion-Corrosion Mechanisms in Condensate Recovery Systems

2.3.1 Mechanisms for Steel Pipe Corrosion

The fundamental causes of corrosion in carbon-steel condensate return lines are the dissolved gases particularly Carbon dioxide (CO_2) and Oxygen (O_2) which keep the pipe wall surface under a permanent state of corrosion reactions. CO_2 hydrolyses to form carbonic acid which in turn attacks iron as illustrated by the chemical equation (2). The rate of CO_2 attack is influenced by both condensate flow velocity and CO_2 concentration. At pH greater than 6, the concentration of CO_2 is approximately 2 ppm which initiates carbon dioxide recycling (Kastner, 1988). As the condensate travels downstream and passes areas of pressure drops or locations of reduced CO_2 content, the ferrous bicarbonates formed during the original attack will decompose according to the chemical equation (3).

$$Fe_{(s)} + 2\,H_2CO_{3(aq)} \rightarrow\ Fe(HCO_3)_{2(aq)} +\ H_{2(g)} \qquad \textbf{(2)}$$

$$Fe(HCO_3)_{2_{(aq)}} + 2\,H_2O_{(l)} \rightleftharpoons\ Fe(OH)_{2(s)} + 2\,CO_{2(g)} + H_2O_{(l)} \qquad \textbf{(3)}$$

The unavoidable pressure drops along pipelines allow reversible reactions and carbon dioxide recirculation proceeds readily hence higher corrosion rates. The ferrous hydroxide [$Fe(OH)_2$] formed during the CO_2 recirculation reaction can then combine with the dissolved oxygen according to equations (4-5). Depending on the reaction kinetics, the reaction in equation (4) can as well proceed as shown in equation (5). Both reactions produce rust that appears as reddish-brown hydrated hematite (Fe_2O_3) and the black hydrated magnetite (Fe_3O_4) that are the commonly observed deposits in condensate return lines. They adversely affect flow and significantly cause clogging.

$$2\,Fe(OH)_{2(s)} + \frac{1}{2}O_{2(g)} + H_2O_{(l)} \rightarrow Fe_2O_3.3H_2O_{(S)} \quad \textbf{(4)}$$

$$3\,Fe(OH)_{2(s)} + \frac{1}{2}O_{2(g)} + H_2O_{(l)} \rightarrow Fe_3O_4.4H_2O_{(S)} \quad \textbf{(5)}$$

2.3.2 Flow Assisted Corrosion

Condensate flow induces erosion-corrosion in pipes due to hydrodynamics and the corrosive nature of the medium. This leads to pipe wall thinning and normally occurs on bends that suffer locally generated high levels of turbulence as a result of change in flow direction. This failure mode is more evident in mild or carbon steel pipes operating under both single and two-phase condensate flow conditions. The rate of metal loss depends on a complex interplay of several other parameters viz; water chemistry and pipe material composition. The effect of condensate corrosivity on pipes can be reduced using filming inhibitors and neutralizing agents dosed into boiler water. (Bakalov, 2023) highlighted that morphine, cyclohexylamine and diethylaminoethanol are the most used amines in condensate water treatment. However, their use is restricted in food processing not exceeding 10-15 ppm in condensate. (Hock, 1994) investigated the use of corrosion-resistant phenolic coatings inside condensate pipe and results indicated that this coating extended the expected service life of condensate return lines by at least 10%.

2.4 Polypropylene Homopolymer

Stereoregular polypropylene is a thermoplastic with excellent chemical resistance and toughness and can be processed in a variety of ways. Injection molding, fiber extrusion and film extrusion are fabrication methods that account for nearly 90% of all polypropylene applications. It’s a white powdery or granular solid with a density of 0.90 g/cc. Polypropylene on market is in a wide array of compositions, molecular weights, and microstructures. Polypropylene types include; PPH which consists of only the propylene monomer, Random copolymer (PPR) containing 1-8% ethylene as a co-monomer and Impact copolymer which is a mixture of both PPH and PPR with about 45-65% ethylene content.

PPH exists as a semi-crystalline solid, the non-crystalline (amorphous) regions have both isotactic PP and atactic PP. However, it's vital to note that the isotactic PP in the amorphous regions is crystallizable and crystallizes slowly over time. Commercial homo-polymer polypropylene is produced using the UNIPOL technology and possesses high level of stiffness coupled with a high melting point which makes it a suitable material for different industrial applications. (Wroblewsk, 2017) studied the Influence of Operating Conditions on Changes in the Properties of Ventilation Pipes Made of Self-extinguishing Polypropylene and concluded that for the three-year in-service pipes, there was no significant deterioration of the tested features of the material.

(Poduska, 2014) experimentally determined the residual stress and other inherent properties e.g. specific enthalpy of fusion and melting point temperature of a polypropylene Vestolen P9421 grade for pipe applications and proposed a general equation describing the residual hoop stress distribution independent of pipe dimensions. The effects of 30 years of storage on the mechanical behavior and hierarchical structure of isotactic polypropylene were characterized by (Sližová, 2020) who noted that long-term storage caused a dramatic loss of ductility, accompanied by a distinct increase in the crystallinity of both the alpha and beta phases but the dynamic mechanical behavior was insignificantly influenced.

However, little is known about the mechanical behavior, chemical stability of PPH pipes when continuously exposed to steam condensate and their relation to thermal energy conservation, safety, pipping durability and the associated cost of maintenance. Therefore, the investigation into the performance of polypropylene homopolymer as a construction material for condensate pipes in industrial condensate recovery systems is thus crucial to provide a technical and economical comparative basis against the conventional steel pipes.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This study adopted an experimental research design to evaluate the performance of Polypropylene Homopolymer (PPH) pipes in industrial condensate systems. The experimental approach was chosen to enable direct observation and measurement of parameters such as temperature radiated condensate electrical conductivity etc. Mechanical Tests were conducted under controlled laboratory settings and ISO and ASTM standards were employed. Data collected was analyzed statistically to determine the significance of the findings and to support material transformations.

3.2 Research Design

This study employed the exploratory research design in which numerical data pertaining to the mechanical properties of the plastic pipes used for condensate recovery in the pickling line in the steel strip processing industry was collected; subsequently the collected data was used to describe the molecular changes that occurred in the pipe during service life as well as to predict its residual service life. Additionally, the reliability, costs of maintenance and safety of the steel condensate pipes over a period of one year was determined and compared against that of Polypropylene homopolymer (PPH) pipes.

3.3 Description of the Steam and Condensate System

The steel strip processing plant at Roofings Rolling Mills Ltd utilizes four boilers producing steam at steam pressure of 5 bar and an evaporation rate of 3500kg/hr; Table 3-1 presents the steam pressures and uses of steam at different sections of the strip processing plant. During production, the boilers in the plant are synchronized to maintain a steam pressure of 10 bar since none of the production lines needs continuous steam consumption.

The layout for steam distribution and condensate recovery in the plant is shown in Figure 3-1; and Figure 3-2 shows the condensate recovery system pipping discharging partly into a condensate tank, rinse water tanks and the outdoor scrubber system. In order to investigate its performance compared to that of the steel pipping, the PPH pipping of specifications given in Table 3-2 was fabricated and installed to replace a section of the steel pipping at the Push-Pull Pickling Line (PPPL) as shown in Figure 3-2. Samples of the PPH pipe that was installed in the PPPL were extracted after a period of one year to ascertain the rate of material deterioration. The one-year in-service period was purposively chosen on the basis of aligning with yearly production and maintenance budget expenditures with an intention to properly analyze the benefit of using PPH pipes other than Steel pipes. Furthermore, it's also a suitable period to measure lost production against the yearly standard production capacity of the production lines.

Table 3-1. Steam pressure and temperature maintained at production sections

Production Section	**Condensate Utilization**	**Steam Usage**	**Required Steam Parameters**		**Measured Values**	
			Pressure (bar)	**Temp (^{0}c)**	**Pressure (bar)**	**Temp (^{0}c)**
PPPL	Condensate recovered and used in the wet scrubber and the pickling rinse section	Heating acid in pickle tanks to 80 °C	4	135		
		Hot air Dryer	5	150		
CRM	No condensate recovery	Heating coolant to 50 ^{0}C	8	170		
		Preheating water	3	130		
CGL	Used in hot air dryers for curing the chromate layer	No Condensate recovery	3	130		
CCL	Used in hot air dryers for curing the colour coated layer	No Condensate recovery	7	160		

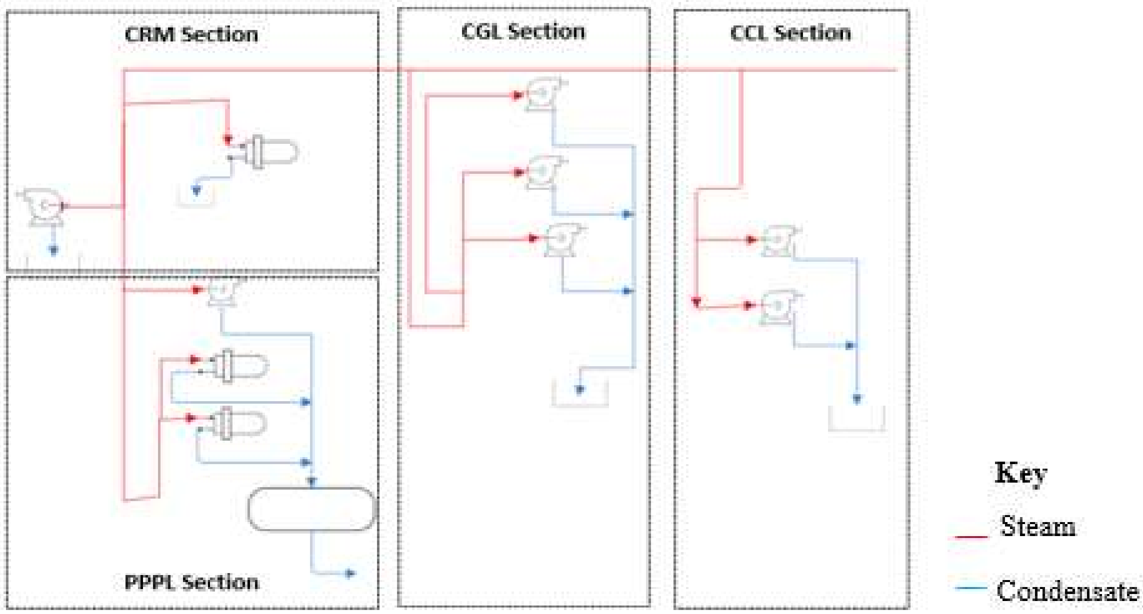


Figure 3-1. Steam and Condensate Distribution Plant Layout

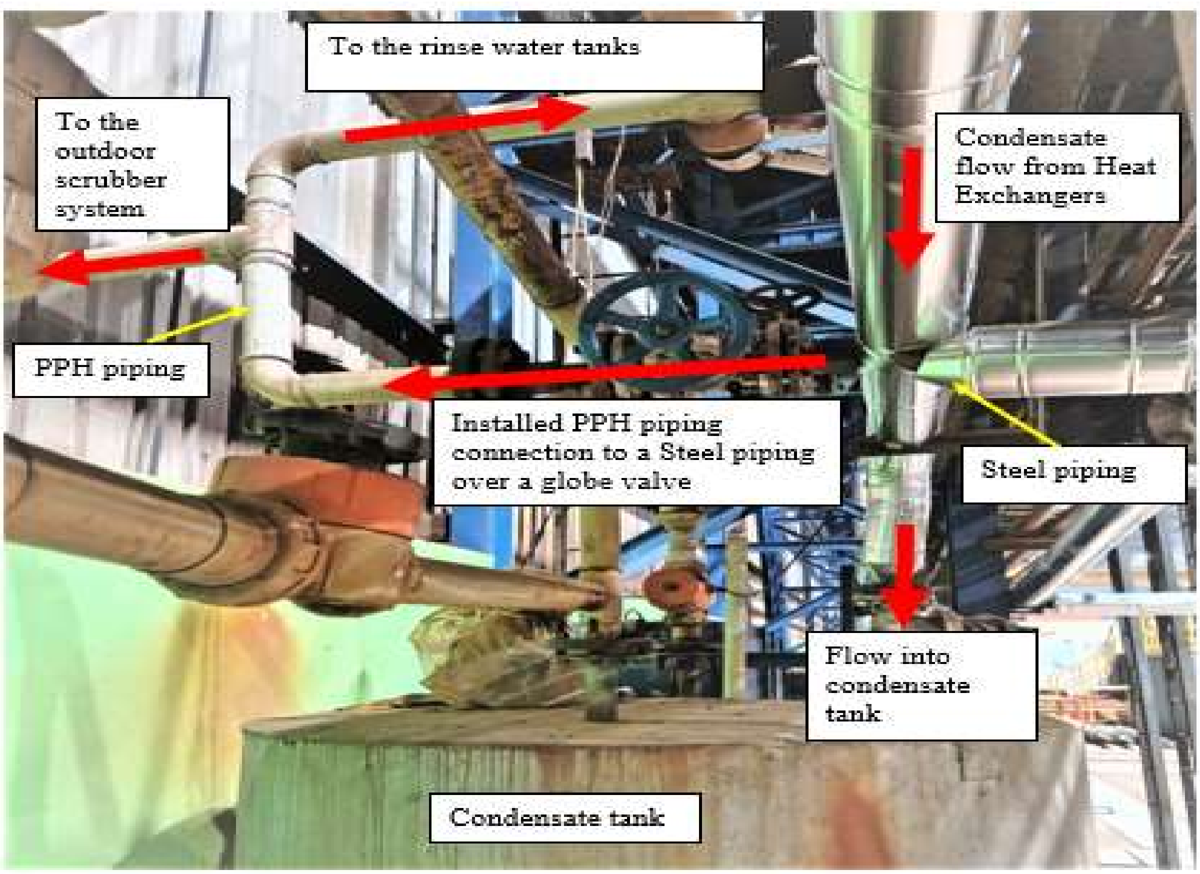


Figure 3-2. A Portion of a steel piping replaced with PPH piping

Table 3-2. Specifications of the Polypropylene Homopolymer (PPH) pipe

SN	Specification	Value
1	Outer Diameter (d)	63 mm
2	Inner Diameter (DN)	50 mm
3	Pressure Nominal (PN)	6 bar
4	Pipe wall thickness (SDR 11)	5.8mm

3.4 Determination of the Performance Characteristics of Condensate Systems

The performance characteristics of industrial condensate recovery systems in a steel strip processing plant are defined by the frequency of flash steam leakages, condensate quality, heat losses, condensate load and recovery rate. A check sheet was used to collect data for a period of ten consecutive days about the steam and condensate parameters, properties of the heated fluids, and condensate system equipment installed at different production lines. Additionally, the safety hazards were identified and recorded.

3.4.1 Flash Steam Leakages

Frequency of flash steam leakages and the amount of down time it caused in a period of two years was obtained from the Mechanical maintenance log book which is an Integrated Management System (IMS) document with a document number RRM.PH3.MTRE.R.LOG01. The condensate loss through an orifice leakage can be determined by a modified Napiers' formula as depicted in equation (6).

$$\boldsymbol{CL = 4 \,.\, P_a \,.\, D^2} \qquad \textbf{(6)}$$

Where $CL : Condensate\ Loss\ (kg/h\ )$

$P_a : Pressure\ differential\ (absolute)$

$D^2\ : Diameter\ of\ the\ orifice\ (mm)$

3.4.2 Condensate Quality

Condensate quality is defined by the level of condensate contamination which characterized by Condensate pH and electrical conductivity. The pH test was carried out according to ASTM E70 using an Edge HI2002 pH meter and electrical conductivity was carried out according to ASTM D1125: 2014 using HI-5521-02 EC meter. Both meters were manufactured by HANNA instruments.

Figure 3- 3. Conductivity meter for Testing the Condensate

Figure 3- 4. The pH meter for Testing the Condensate

3.4.3 Heat Losses

To ascertain the condensate heat losses obtained from different condensate system pipping, A digital infrared thermometer was used to measure temperature over a period of ten days along the PPH pipe and its fittings and was compared to that of a steel pipping. An effective condensate recovery system should convey condensate from the steam equipment back to the boiler or any other section that can utilize it with minimum heat losses. The piping materials' thermal conductivity and pipe wall thickness influence the heat loss at any constant ambient temperature. The rate of heat loss from uninsulated piping in a condensate system is inversely proportional to the pipe wall thickness and can be determined using equation (7).

$$\dot{Q} = \frac{2\pi k L(\Delta T)}{\ln(r_o / r_i)} \quad \textbf{(7)}$$

$\textbf{Where } \dot{Q}$: $Heat\ transfer\ rate(W)$

$\boldsymbol{k}$: $Thermal\ conductivity\ W/m°C$

$\boldsymbol{L}$: $Length\ of\ the\ pipe$

$\boldsymbol{r_o}$: $outer\ pipe\ radius$

$\boldsymbol{r_i}$: $inner\ pipe\ radius$

$\Delta\boldsymbol{T}$: $Temperature\ difference$

(a) Temperature of uninsulated steel elbow

(b) Temperature of the PPH valve

Figure 3-5. Measurement of the temperature of the Condensate System components

3.4.4 Condensate Load and Recovery Rate

The condensate recovery systems handle both the condensate start up loads as well as the running loads. At start up, steam lines are heated up to operating temperature and thus steam loses heat and condenses into saturated water at a rate influenced by ambient temperatures. The huge warm up condensate load can be calculated using the equation (8) which is a summation of equation (11-12). As the heating system tends to thermal equilibrium, the condensing rate gradually decreases due to a lower temperature difference. However, the typical condensate loads generated due to heating of a batch of a liquid or air is computed by equation 9 and 10 respectively. The condensate load due to air heating in hot air blowers is given by equation (10).

Part of the condensate flashes into steam upon exiting steam traps due to the pressure difference across a steam trap. The volume of flash steam generated is usually 300 to 1500 times greater than that of the original condensate and thus the condensate pipe size should accommodate it (ARI-Armaturen GmbH, 2018). The percentage of flash steam generated is a function of the heat content of condensate upstream of the steam trap and that in the condensate system and inversely proportional to the latent heat of vaporization in the condensate system as shown in equation (13). Equation (13) has been modified into a rule of a thumb by industrial practitioners as depicted in equation (14).

$$m_c = m_h + m_r \quad \textbf{(8)}$$

$$m_h = \frac{C_P \,.\, W_P \,.\, l \,.\, (T_S - T_{am})}{\Delta H} \quad \textbf{(9)}$$

$$m_r = \frac{0.12\pi \,.l \,.\, (T_S - T_{am}) \,.t_{su}}{\Delta H\left(\frac{1}{\lambda}\ln\left(\frac{d_1 + 2L}{d_1}\right) + \frac{2}{\alpha(d_1 + 2L)}\right)} \quad \textbf{(10)}$$

$\boldsymbol{Where\ T_s}$: $steam\ temperature\ (c)$

$\boldsymbol{L}$: $Insulation\ thickness (m)$

$\boldsymbol{l}$: $Pipe\ length (m)$

$\boldsymbol{T_{am}}$: $Ambient\ temperature\ (c)$

$\boldsymbol{\alpha}$: $Heat\ transfer\ coefficient\ (W/m^2K)$

$\boldsymbol{\lambda}$: $Thermal\ conductivity\ coeffient\ (W/mK)$

$\boldsymbol{t_{su}}$: $start\ up\ time$ (min)

$\boldsymbol{m_h}$: $condensate\ load\ from\ heating\ pipping\ (kg)$

$\boldsymbol{m_r}$: $condensate\ load\ from\ radiation\ heat\ loss\ (kg)$

$\boldsymbol{m_c}$: $Total\ condensate\ load\ (kg)$

$\boldsymbol{C_p}$: $Specific\ heat\ capacity\ (KJ/kgK)$

$\boldsymbol{W_p}$: $Pipe\ weight\ (kg/m)$

$\boldsymbol{d_1}$: $Outer\ diameter\ of\ pipe\ (m)$

$\Delta\boldsymbol{H}$: $Latent\ heat\ of\ steam\ (KJ/kg)$

$$m_c = 1000c\,.SG\,.V\,\frac{T_2 - T_1}{\Delta H\,.\,t_h} \tag{11}$$

Where $\boldsymbol{m_c}$: $Condensate\ load\ (kg)$

$\boldsymbol{c}$: $Specific\ Heat\ (KJ/kgK)$

$\boldsymbol{SG}$: $Specific\ Gravity$

$\boldsymbol{T_1}$: $Liquid\ inlet\ temperature$ (°C)

$\boldsymbol{T_2}$: $Liquid\ outlet\ temperature$ (°C)

$\boldsymbol{V}$: $Liquid\ Volume\ (m^3)$

$\boldsymbol{t_h}$: $Heating\ time\ period\ (h)$

$\Delta\boldsymbol{H}$: $Latent\ heat\ of\ steam\ (KJ/kg)$

$$m_c = \frac{60c_a\,.\,\gamma_a\,.\,Q_a\,(T_2 - T_1)}{\Delta H} \tag{12}$$

Where $\boldsymbol{m_c}$: $Condensate\ Load\ (kg/h)$

$\boldsymbol{Q_a}$: $Air\ flow\ rate\ (m^3/min)$

$\boldsymbol{T_1}$; $Air\ inlet\ temperature$ (°C)

$\boldsymbol{T_2}$: $Air\ outlet\ temperature$ (°C)

$\Delta\boldsymbol{H}$: $Latent\ heat\ of\ steam\ (KJ/kg)$

$\boldsymbol{c_a}$: $Specific\ heat\ of\ air\ (KJ/kgK)$

$\boldsymbol{\gamma_a}$: $Specific\ weight\ of\ air\ (kg/m^3)$

$$Percentage\ of\ flash\ steam = \frac{h_{f1} - h_{f2}}{h_{fg}} \times 100\% \tag{13}$$

Where $\boldsymbol{h_{f1}}$: $Heat\ content\ of\ condensate\ upstream\ of\ a\ steam\ trap$

$\boldsymbol{h_{f2}}$: $Heat\ content\ of\ condensate\ corresponding\ to\ condensate\ system\ pressure$

$\boldsymbol{h_{fg}}$: $latent\ heat\ of\ vapourisation\ corresponding\ to\ condensate\ system\ pressure$

$$Percentage\ of\ flash\ steam = \Delta T \times 0.2 \tag{14}$$

Where ΔT : $Temperature\ difference\ across\ the\ steam\ trap$

3.5 Extraction of the PPH Pipe Section for Mechanical Testing

Figure 3-6 shows the extracted PPH pipping section from which test specimen were obtained. Selection of the component and pipe fitting for analysis is guided by the purpose in the system. Therefore, the pipe elbows were chosen owing to the fact that they are very susceptible to erosion-corrosion. Additionally, samples of PPH pipping from the outdoor condensate system were also tested to ascertain the adverse effect of UV light.

Figure 3-6. PPH d63 DN50 SDR 33 pipe extracted from Service

3.6 Preparation of PPH Pipe Test Specimen for Mechanical Testing

The different mechanical tests that were performed to establish the technical performance of the homopolymer pipes used in condensate systems of steel strip processing plants included: the tensile, flexural, compression, impact and hardness tests. The characteristic features of the test pieces are each of the mechanical tests are described in this section.

3.6.1 Tensile Test Specimens

The test pieces were taken from the center of strips cut from the length of pipe. The dimensions of the test specimen are in accordance with ASTM D638–14 and a thickness of 3.2mm was maintained for all the five-test specimen as depicted in figure 3-8.

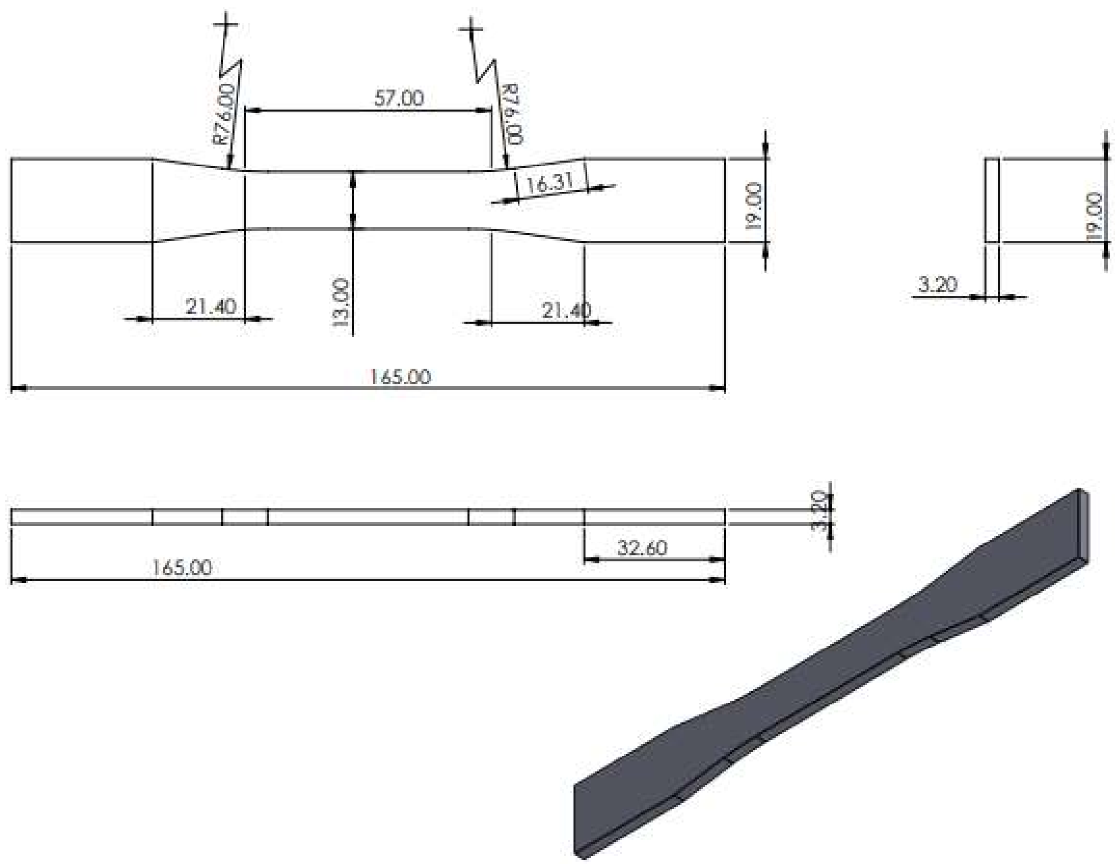


Figure 3-7. Two-Dimensions for the Tensile test specimen

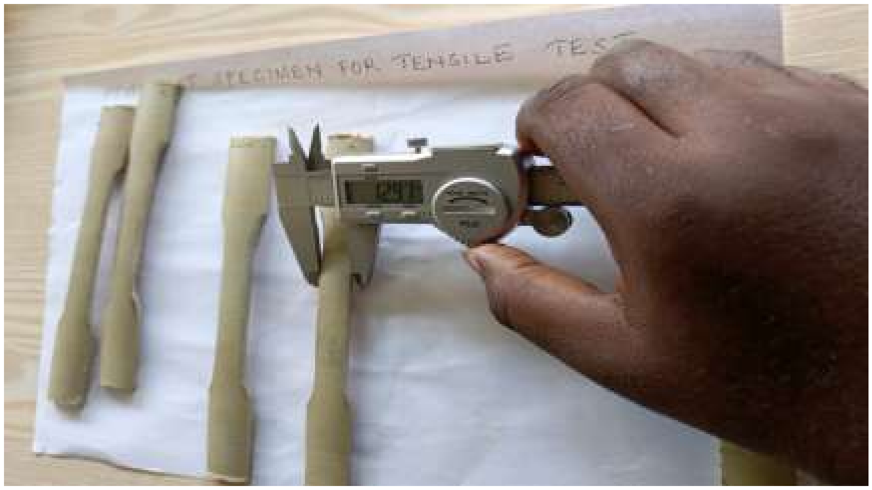


Figure 3- 8. Tensile test specimen cut out from the PPH pipe

3.6.2 Flexural Test Specimens

Five test specimens were obtained and cut to dimensions from the PPH pipes. The cross section of the test specimen was 12.7mm by 3.2 mm and were 127mm long as in accordance to ASTM D790−17. The cross-section area of the individual specimen has been calculated and presented in table 3-3. The dimensions for individual test specimen were recorded before they were subjected to a 3-point flexural test and a gauge length been the supports was 90mm.

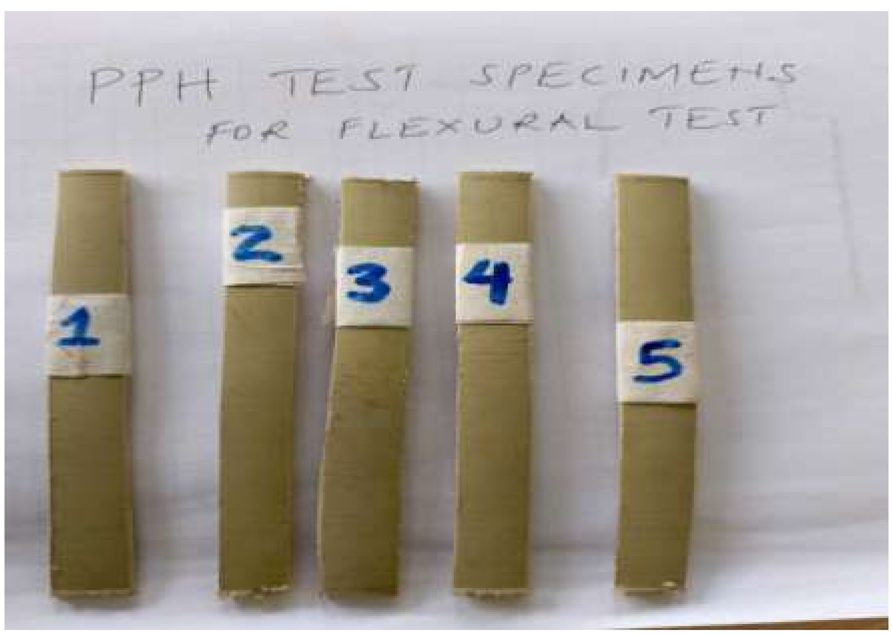


Figure 3-9. Test specimen for flexural test.

Table 3-3. Individual test specimen cross-sectional area

S/N	Gauge Length (mm)	(W*t)	Area (mm^2)
PPH 01	90.0	12.7*3.0	38.10
PPH 02	90.0	12.45*3.07	38.22
PPH 03	90.0	12.45*3.07	38.22
PPH 04	90.0	12.45*3.04	37.85
PPH 05	90.0	13.08*2.97	38.85

3.6.3 Izod Impact Test Specimens

The impact test was carried out on a Pendulum impact tester according to ASTM D256 − 23 A set consisting of five specimens were tested. The specimens were cut longitudinally from the PPH pipe with dimensions in mm as shown figure 3-10.

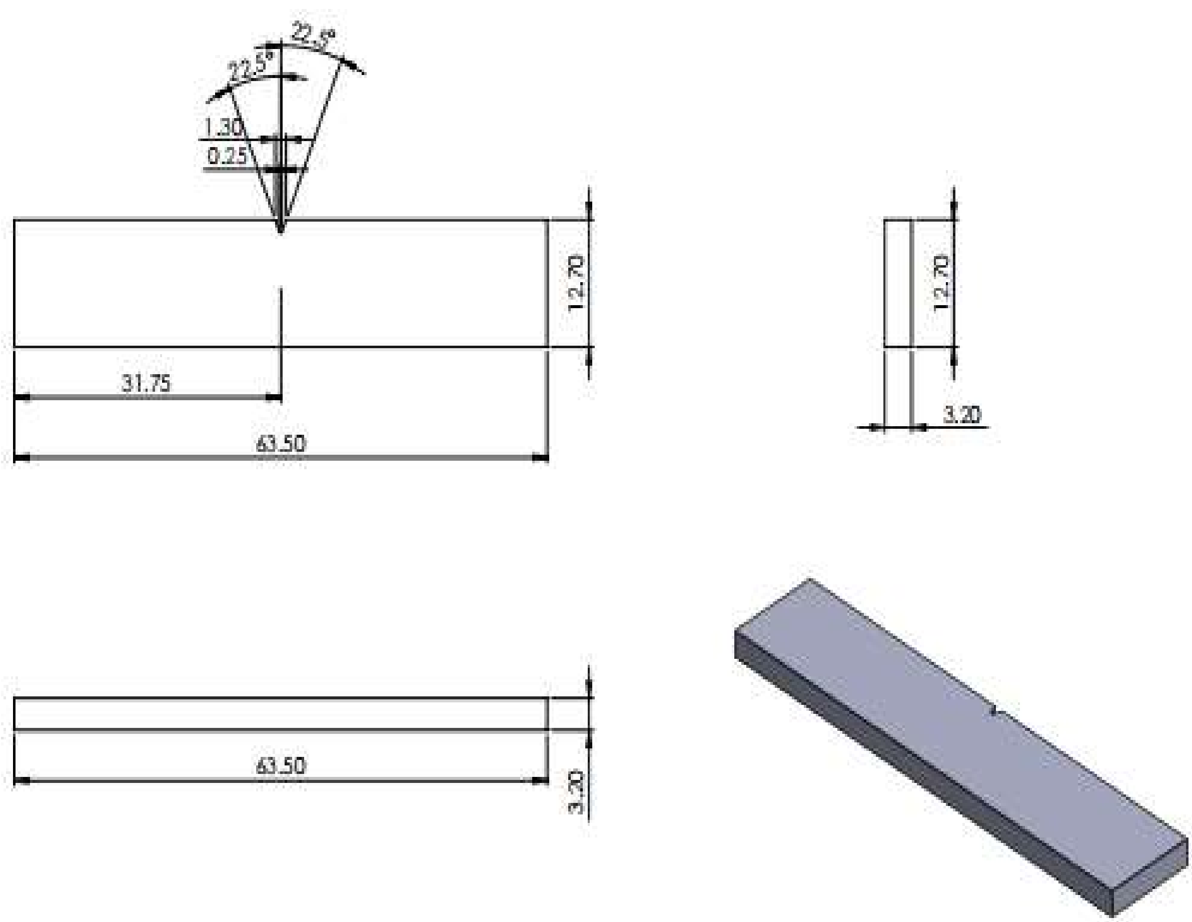


Figure 3-10. Dimensions of the test specimen for the impact test

3.6.4 Compression Test Specimens

The test specimen had a cross section of 12.7 mm by 3.2mm and were 12.7mm long as in accordance to ASTM D695−23. They were cut from the pipe, placed between the platens of the universal tensile machine and compressed using a crosshead speed of 5mm/min until they were deformed.

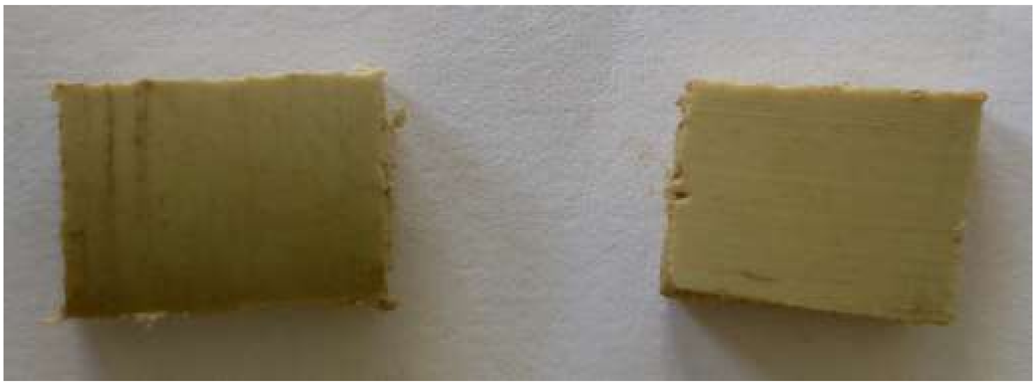


Figure 3-11. Test specimen for compression Test

3.6.5 Hardness Test Specimens

The test specimens were cut from the circumference of the pipe and the hardness test was carried out from the inner surface of pipe that was exposed to high temperatures, the cross section was 25mm by 5.8mm and were 25mm long in accordance to ASTM D785 – 23.

Figure 3-12. Test Specimen for Hardness Test

3.7 Description of Equipment and Tools

The equipment and tools used for the tensile, flexural, compression, impact and hardness tests in this study are described in this section.

3.7.1 Universal Tensile Testing

The tensile and compression tests were carried out using an STD 606W Microcomputer controlled Electro-Hydraulic Servo Universal Tensile Machine. The essence of carrying out a tensile test was measure the strength of the pipe during thermal expansion whereas the compression test was to measure the maximum compressive strength in case the PPH pipe are installed underground. The distance between the grips was 115mm and the test speed was maintained at 100mm/min for all the five tensile specimens.

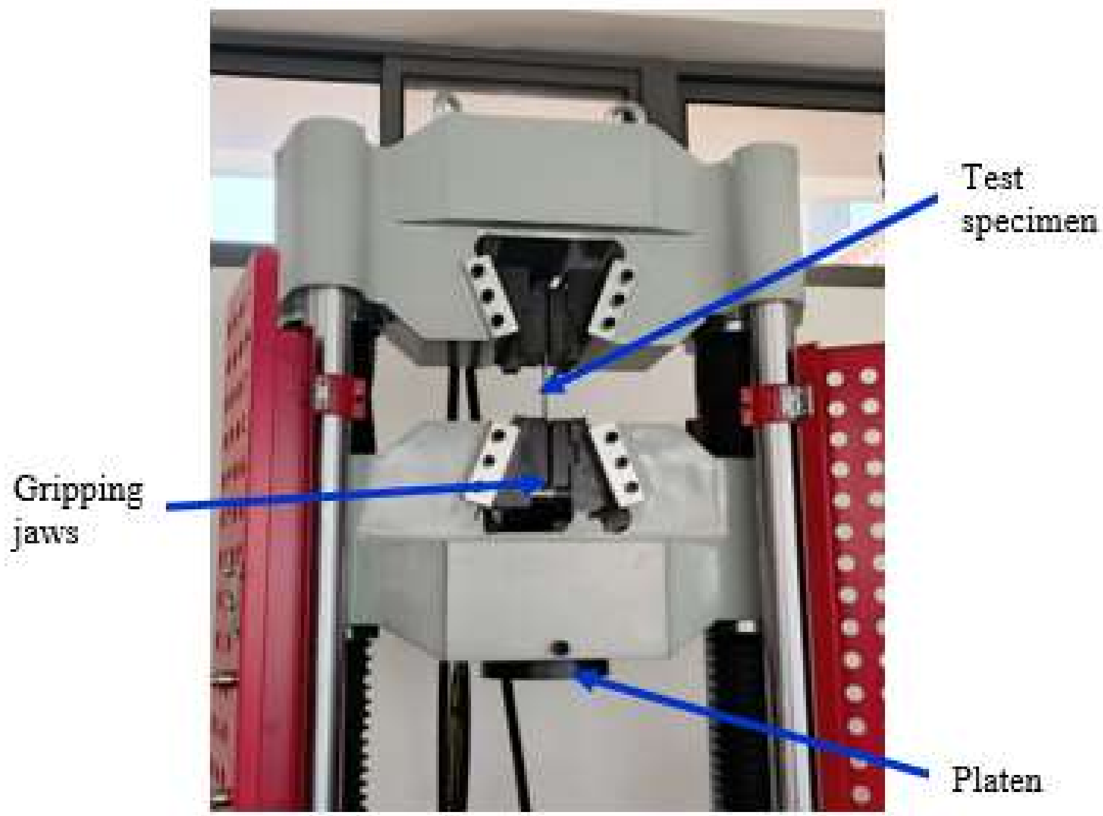


Figure 3-13. The Universal Tensile Machine

3.7.2 Rockwell Hardness Tester

The hardness tests were carried out using a Digital Hardness Tester Model JMHR-150ZS. The importance of this test is to measure the resistance of the pipe to flow assisted erosion. The machine was calibrated using a copper block and half inch indenter was employed as in accordance to ASTM D785 – 23. The machine engaged a 60kgf on the indenter against the test specimen and the hardness values were read out using the R-Scale.

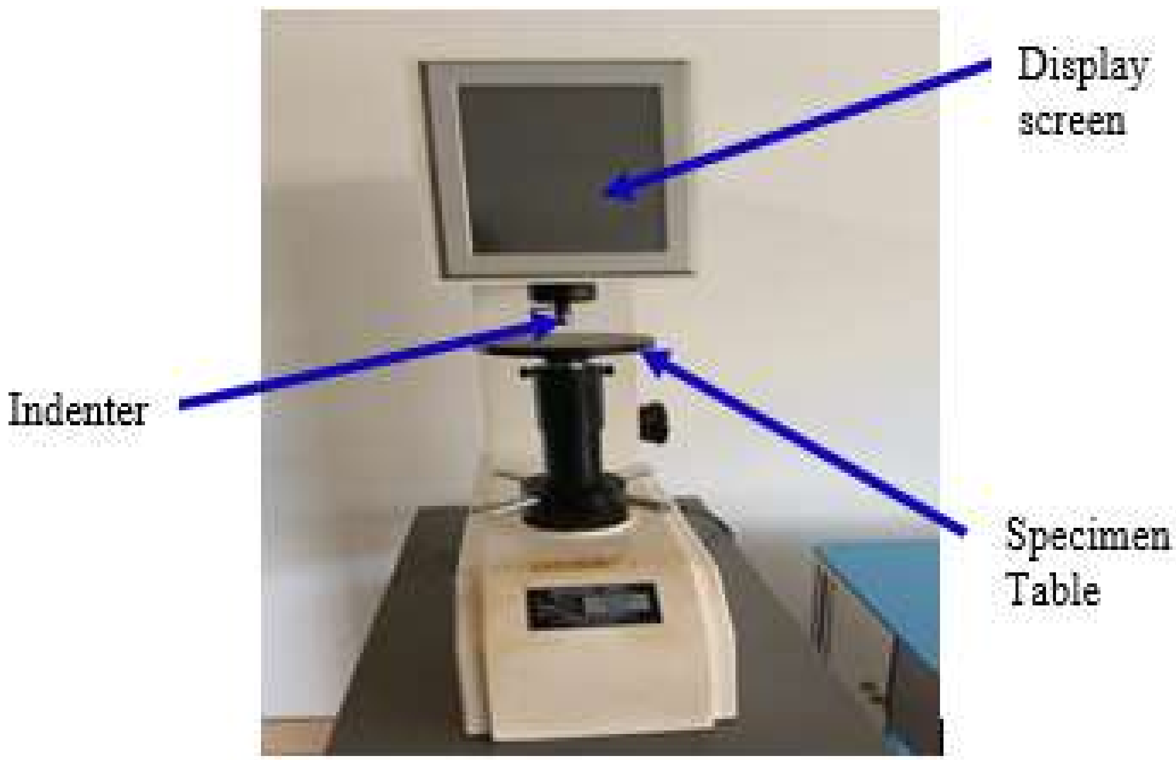


Figure 3-14. Digital Rockwell Tester

3.7.3 Flexural Testing Machine

The 3-point flexural test was carried out on a GT-MS-10KN at a span of 90mm using a crosshead speed of 10mm/min. The importance of this test was to ascertain the maximum bending strength of pipe in an event that it sags. The machine had a total bend depth of 55mm upon which it would automatically unload and the maximum flexural strength would be reflected on the HMI. The machine software allowed for a variety of plots which include Stress versus Strain, Force Vs Time as well as Force versus Elongation.

Figure 3-15. Flexure Testing Machine

3.7.4 The Notched-bar Impact Tester TE15

The impact testing equipment was used to study the resistance of the material to crack propagation. It consisted of a main unit, an instrumentation unit and a power supply. The main unit consists of a pendulum supported in a rigid frame by low-friction bearings coupled by an encoder to measure the angular position of the swinging pendulum. To perform a test, the pendulum is raised to the start position where it is held by an electromagnet and then released to strike the specimen clamped at the bottom base. The instrumentation unit measures and displays the pendulums' angular position before and after the impact as well as the energy absorbed by the impact in Joules.

Figure 3- 16. Notched-bar Impact tester TE 15

3.8 Determination of the Technical Performance of PPH Condensate Pipes

The technical performance of polypropylene homopolymer condensate pipes used in the outdoor condensate recovery systems of the steel processing plant was obtained by carrying out mechanical tests on test specimen extracted from the out-of-service PPH pipes after one year of operation. The technical performance of the PPH pipe was evaluated in regard to its maintainability, reliability and safety. Safety as a performance characteristic of a condensate system relates to both safe operation and underlying engineering controls based on system design and exploitation of material properties.

3.8.1 Procedure of Tensile Tests Undertaken

The specimen was placed in the grips of the testing machine while taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine. The distance between the ends of the gripping surfaces was adjusted to 115mm before tightening the grips evenly and firmly to the degree necessary to prevent slippage of the specimen during the test. Precaution is taken to ensure that the machine guards were tightly closed was taken as well as the safe distance from the machine was maintained. The start button was pressed that powered the machine and the test machine program prompted to have the specimen dimensions entered. Using the HMI, input the width and thickness dimensions of the specimen and click on run. The inbuilt extensometer records the extension produced and a stress strain graph is automatically displayed on the HMI from which all tensile properties were readout.

3.8.2 Procedure of Flexural Tests Undertaken

The distance between the support spans was adjusted to 90mm and the specimen was placed with its width lying across the fixtures. Centering of the specimen on the supports was achieved by ensuring that the long axis of the specimen was perpendicular to the loading nose and supports. The loading nose was made to be close to, but not in contact with the specimen with the help of a pendant before the machine was run. Using the HMI, the width and thickness of the specimen were input and the load of 10KN was applied at a set crosshead rate of 10mm/min. Upon starting the machine, the inbuilt deflectometer in the test machine automatically measures the motion of the loading nose relative to the supports until a maximum point of 55mm depth up to which the crosshead retrieves. The Load-deflection curves are automatically generated and used to determine the flexural strength and flexural modulus of elasticity.

3.8.3 Procedure of Impact Tests Undertaken

The specimen width in one location adjacent to the notch centered about the anticipated fracture plane as well as the depth of material remaining in the specimen under the notch was measured and recorded. The specimen was placed to be approximately vertical between the anvils and positioned precisely so that it is rigid but not too tightly clamped in the vise. special attention was paid to ensure that the impacted end of the specimen (the notched width) is the end projecting above the vise. The safety glass guard for the machine was closed and the release button pressed to let the pendulum strike the specimen. The indicated breaking energy of the specimen, the pendulum swing angle before and after striking denoted α and β respectively were all recorded. The net breaking energy value was divided by the measured width of the particular specimen to obtain the impact resistance under the notch in J/m. On the other hand, the impact strength (kJ/m^2) can be obtained by dividing the net breaking energy value by the measured width and depth under the notch of the particular specimen.

3.8.4 Procedure of Compression Tests Undertaken

The measured width, length and thickness values of the specimen at several points were input into the test machine program using the HMI. The test machine program automatically calculates and records the minimum value of the cross-sectional area of the specimen. The specimen was placed between the surfaces of the compression platens taking care to align the center line of its long axis with the center line of the plunger platen and to ensure that the ends of the specimen are parallel with the surface of the compression platens. The crosshead plunger platen of the testing machine was adjusted until it just contacts the top parallel surface of the specimen and its speed was set at 5mm/min.

The button is pressed to power the hydraulic system of the testing machine in order to provide a compressive force against the specimen. A safe distance from the machine was maintained when its powered. The failure stress and compressive strength of the specimen is displayed on the Stress-Strain curves generated by the test machine program on the HMI.

3.8.5 Procedure of Hardness Tests Undertaken

The R scale with a 12.7 mm indenter and 60-kg major load was used. The spring constant or correlation factor of the machine was determined as follows; A soft copper block, of sufficient thickness and with plane parallel surfaces was placed on the anvil in the normal testing position. The sample and anvil were raised by the capstan screw to the 12.7 mm indenter until the small pointer is at the starting dot and the large pointer reads zero on the black scale. The major load was applied by tripping the load release lever. The dial gage then indicated the vertical distance of indentation plus the spring of the machine. This operation was repeated several times without moving the block, but resetting the dial to zero after each test while under minor load, until the deflection of the dial gage became constant. The specimen was placed on the anvil which was raised until the specimen just touched the indenter. The minor load (10kgf) was applied and later a switch was activated to apply a full load (60kgf) and waited for the dwell time which was about four seconds. The major load was removed, returning to the minor load only and read the displayed hardness value on the HMI. The test was repeated 3-5 times on different locations and the average is the most correct hardness value of the specimen.

3.9 Comparative Analysis of Performance of Steel and PPH Condensate Pipes

A comparative analysis of the technical performance of polypropylene homopolymer and steel condensate pipes in a condensate recovery plant of a steel plant was done by evaluating the tradeoffs of using PPH pipes other than steel pipes. This evaluation was in regards to installation costs, maintenance costs, service life, safety and the reliability.

3.9.1 Comparison of Costs of Steel and PPH Condensate Pipe fittings

The costs related to the use of a particular material was determined from the company's business application software (SAP). This established the purchase valuation prices for tools, pipe fittings and consumables used during maintenance. These prices were used to determine maintenance costs incurred whereas the labor costs were determined from employees monthly pay slips.

3.9.2 Comparison of Service Life of Steel and PPH Condensate Pipes

The comparison between the service life of the steel pipping and PPH piping was established using a fatigue analysis simulation as well as experimentally determining the change in the mechanical properties with time. The fatigue analysis simulation was carried out using SolidWorks software and 1000 cycles were used.

3.9.3 Comparison of Safety Aspects of Steel and PPH Condensate

The data pertaining the near misses, burns were obtained from the accident registers and line safety boards. Checklists were used to obtain data concerning the safety hazards and risks during maintenance associated with both pipping. Furthermore, line operators, technicians and engineers were interviewed in order to obtain the safety issues they face while using the PPH pipping whilst Steel pipping.

3.9.4 Comparison of Downtime of Steel and PPH Condensate

The company maintenance log book was used to obtain the amount of downtime and mean time to failure from which the reliability for both the PPH and steel piping was compared.

3.10 Data Quality Control

The calibration of the equipment to be used was done per equipment manufacturer specifications. The tests procedures and test specimen dimensions conformed to International Organization for Standardization (ISO) and American Society for Testing and Materials (ASTM). The tensile test was carried out according to ASTM D638−14. The determination of flexural properties was carried out in accordance to ASTM D790−17. The impact test was carried out according to ASTM D256−23. The hardness test was carried out according to ASTM D785−23.

3.11 Data Analysis

Data was analyzed by descriptive analysis with the aid of Microsoft Excel. A 3D frequency distribution bar chart was used to show the frequency of failure of condensate systems at different production sections. A 2D bar chart was used to present cost variations for different pipe fittings. Pie charts were used to show the maintenance costs incurred in using a particular piping material. SolidWorks flow was used as a simulation software to ascertain the service life of the PPH pipe.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents and discusses the results obtained from the experimental tests conducted. The presentations have been aligned according to the specific objectives. The results have been validated against the standards and scientific explanations have been made to explain the deviations.

4.1 Performance Characteristics of Condensate Systems

The condensate system consists of equipment such as steam traps, flash tanks and pumps connected to each other by pipe lines along with valves and instruments are mounted for monitoring of systems' parameters. The key performance indicators for condensate systems are high reliability and uptime through minimum flash steam leakages, low condensate contamination, high energy conservation and a greater condensate recovery rate.

4.1.1 Minimum Flash Steam Leakages

The frequency of failure of the inline equipment and condensate leakages on different production lines with in a period of one year is presented in Figure 4-1. Equipment failure constitutes failure of steam traps, heat exchangers, pumps and valves. CRM had the highest frequency of equipment failure of which were majorly valves. This is attributed to presence of suspended scum particles in the condensate that settle on valve seats and prevent full valve closure. PPPL had persistent condensate leakages with a frequency with at least three leakages per month. Additionally, two globe valves experienced valve gland leakages due to corrosion of the valve stems. Condensate contamination and higher HCl ppm in air around the pickle tanks as a result of minor fume leakages from the acid tanks sealing gaskets is responsible increased corrosion of the condensate pipes and valves, respectively. Only condensate pump failure occurred at CCL as a result of a worn-out bearing. For all the production lines, at least three technicians were required to restore the system performance within three hours of shut down; however, the high down time at CRM arises from the oily work environment that hinders welding of pipes in position which necessitates pipes to be removed and welded remotely for safety reasons. High reliability and uptime of a condensate system can be achieved through less maintenance downtime when there is a low number of flash steam leakages within a larger period of production time. The mean time between failures of any condensate system component is a crucial aspect and contributes to the overall reliability of the condensate system.

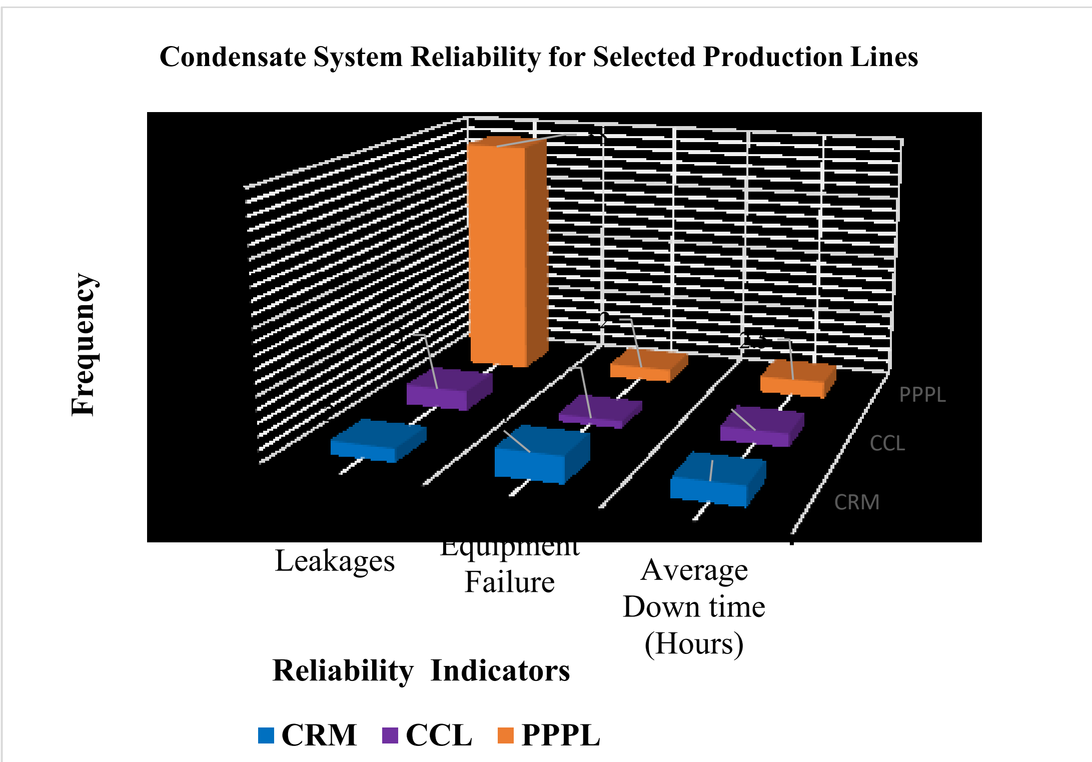


Figure 4-1. Condensate system reliability for the selected production lines

4.1.2 Condensate Contamination Levels

Electrical conductivity and pH of the condensate are presented in Figure 4-2 and Figure 4-3 respectively. The Electrical Conductivity of CCL is expectedly high because of diffusion of ions from volatile organic compounds that are present in coating paint and primers. These volatile organic compounds as a result of evaporation of organic solvents that make up the coating mixture dissolve into condensate and raises its conductivity. About 85% of the coatings used are organic solvent based and have solvent contents ranging from 0 to 80% V. They are liquid formulations of polyesters, acrylics, alkyds resins dissolved in typical organic solvents like Xylene, Toluene, Methyl Ethyl Ketone (EPA, 2024). The Electrical conductivity of CRM condensate is slightly higher than that of PPPL due to condensate contamination from the scum particles that are present in the condensate as suspended particles. In addition, the CRM condensate was oily which indicates of contamination by mill coolant (Quaker oil) which is a typical soluble oil. To understand the underlying factors for the low conductivity of the PPPL condensate, pH tests were carried out to ascertain the presence of hydrogen ions and the results are shown in Figure 4-5.

The low pH at PPPL is attributed to acid contamination during steam heating via heat exchangers in the pickle tanks. The PPPL process section contains two Acid Recirculation Tanks (ART). ART1 contains HCl at 8-12% and ART 2 contains 14-16% Acid concentration. During pickling HCl evaporates at specific rates under specific conditions of temperature and acid concentration. The HCl vapor pressure accumulates in the tanks during heat up and at a HCl concentration of 18%, the percentage volume of HCl in vapor is about 1.13% under one standard atmosphere at acid temperature of 80 ^{0}C (Hasler, 1997). The partial pressures of both HCl and water over aqueous solutions of HCl obtained from tables (Perry, 1997) were used to compute the percentage volume of both HCl and water in Vapor as depicted in Table 4-1. The high-volume percentage of HCl in vapor which vapor inherently contaminates the condensate is responsible for corrosion of the steel condensate pipes. This has led to persistent condensate leakages and thus undermining the reliability of the condensate system.

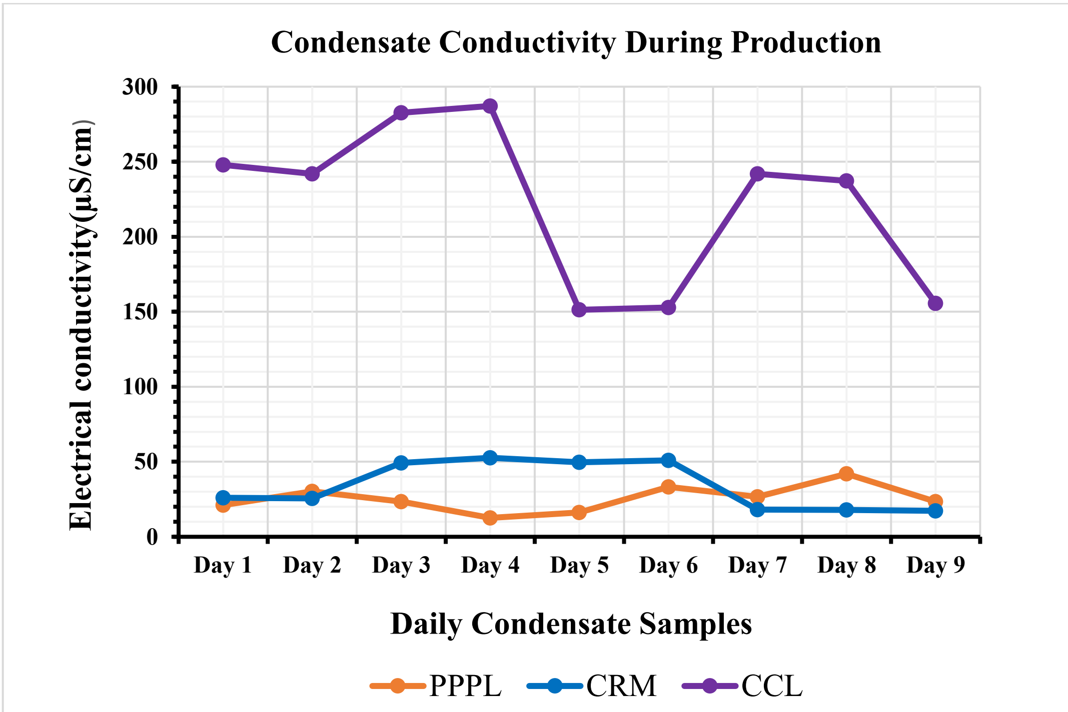


Figure 4-2. Condensate Conductivity during Production

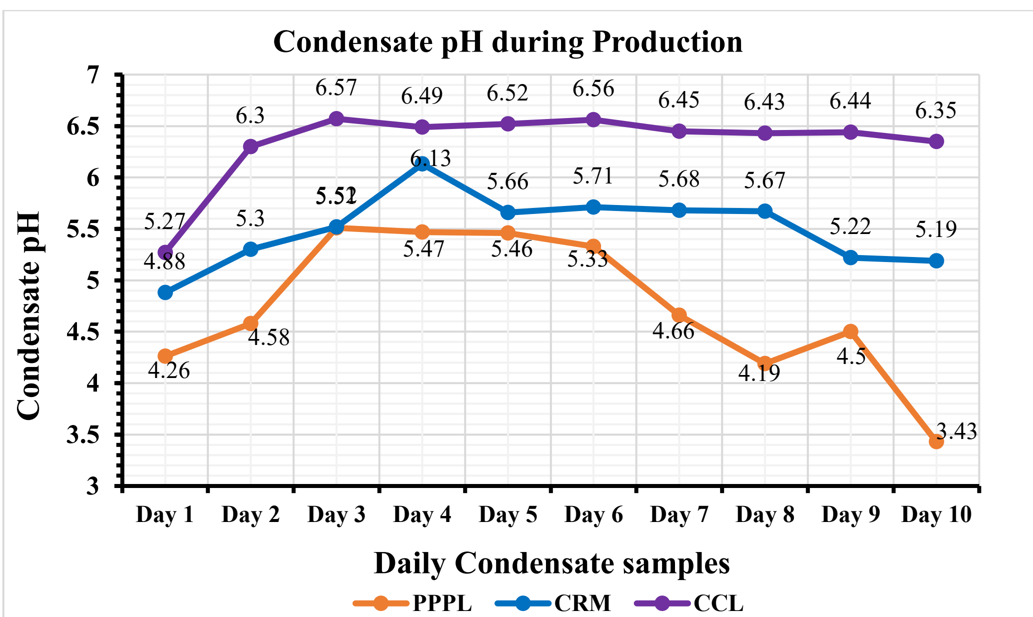


Figure 4-3. Typical Condensate pH for different lines during Production

Table 4-1. Composition of HCl vapor at 80 ^{0}C under one standard atmosphere

Acid Concentration	Vol % HCl in vapor	Vol % Water in Vapor
8%	$\frac{0.39}{760} \times 100 = 0.05\ \%$	$\frac{323}{760} \times 100 = 42.50\ \%$
12%	$\frac{1.34}{760} \times 100 = 0.18\ \%$	$\frac{292}{760} \times 100 = 38.42\ \%$
14%	$\frac{2.50}{760} \times 100 = 0.33\ \%$	$\frac{273}{760} \times 100 = 35.92\ \%$
18%	$\frac{8.6}{760} \times 100 = 1.13\ \%$	$\frac{248}{760} \times 100 = 32.63\ \%$

4.1.3 Uninsulated Pipe Heat Losses

Figure 4-4 shows the average temperatures emitted from the different pipe sections of both steel and PPH piping recorded over a period of five days. Generally, the uninsulated PPH piping reduces heat loss by 37.92% compared to the un insulated steel piping. However, PPH piping conserves the least heat at the elbows which is 32.12% of heat radiated by steel elbows. Steel Tee joints radiated 76.44% more heat than that of the PPH-make. Temperature measurements along the pipes' length revealed that steel pipes radiated 54.71% more heat than PPH pipes. The low heat loss from the PPH pipping can be attributed to low thermal conductivity of the material. Minimum heat losses are desirable not only to enhance energy conservation but also promote system safety. The heat losses were as a result of radiation loses as well as leakages from condensate pipes. The existing condensate pipelines at all production lines were insulated with Rockwool except at PPPL where the pipe insulation was strapped off for easy leakage tracing which leads to significant radiations losses.

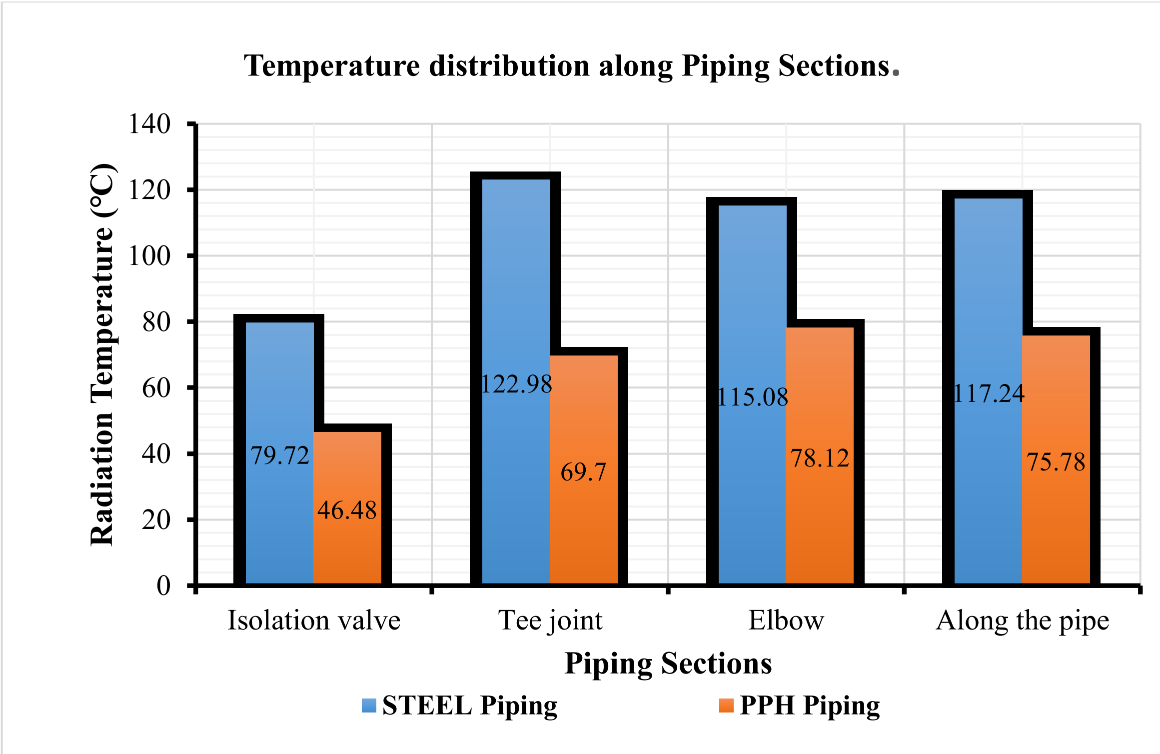


Figure 4-4. Temperatures radiated at pipe fittings for different pipe materials.

The rate of heat loss greatly depends on the thickness of the pipe wall and is governed by equation (13) which depicts that the thicker the pipe wall the less the heat radiated. Considering the maximum recorded temperature of about 78 ^{0}C emitted at the PPH elbow and by employing equation (13) it can be noted that for a 6m length of a d63 PPH pipe would lose heat to a maximum of 1189.38 W which is very minimal and therefore these pipes require no insulation in service unlike the steel pipes that have high thermal conductivity.

$$\dot{Q} = \frac{2\pi\ X\ 0.22\ X\ 6\ X\ 32}{\ln(32.5\ /\ 26)} = 1189\ W$$

The equivalent uninsulated steel pipes would lose a significant amount of heat which will in turn increase on the utility costs. The heat lost by one full length (6m) of an Uninsulated Steel pipe is approximates to that lost by about 20 PPH pipes and thus the narrative of leaving steel pipes uninsulated in order to easily identify condensate leakage is a costly adventure.

$$\dot{Q} = \frac{2\pi\ X\ 50\ \ X\ 6\ X\ 3}{\ln(30.1\ /\ 24)} = \ 24{,}969\ W$$

4.1.4 Condensate Recovery Rate

The condensate recovery systems are designed to handle both the condensate warm-up loads and running loads. The warm-up loads are generated from a 75mm thick insulated 200mm main steam supply pipeline made of EN 10216-2 P235GH non alloyed carbon during line start up. The rate of condensate generation from steam lines at different production sections during both warm up and running were calculated using Equation (6) which is a sum of Equation (7-8) and the results are presented in Table 4-2. Unlike CRM that used steam to heat coolant and water, PPPL used steam to heat hydrochloric acid that is highly corrosive. The running loads produced from each production line as a result of heating liquids were calculated from the operation parameters using equation (9) and the results are presented in Table 4-3. The running loads produced from each production line as a result of heating air by hot air dryers was calculated from the operation parameters using Equation 10 and the results are presented in Table 4-4. The overall condensate loads produced by each production line per hour is a summation of the condensate loads due to start up loads, heating of liquids and air during operation and are shown in Figure 4-5. Even though PPPL had the highest condensate load per hour, its condensate recovery rate was less than expected due to multiple leakages on the condensate pipes. From Equation 14, and using the typical operating pressure of 4 bars at PPPL, a single 2 mm orifice on a pipe leads to 32 kg/hr condensate loss.

Table 4-2. Warm-up Condensate Loads produced by each production line.

Operation Parameters	PPPL	CRM	CCL	CGL
Ts (°C)	141	162	155	134
P_{max}	5	8	7	3
L (m)	0.075	0.075	0.075	0.075
l (m)	84	162	162	174
T_{am} (°C)	25	25	25	25
ΔH (KJ/kg)	2105	2197	2085	2120
t_{su} (min)	30	10	3	5
m_h (kg)	100.512	192.663	185.688	184.104
m_r (kg)	77.532	48.019	23.342	14.702
m_c (kg/hr)	178.044	240.682	209.031	198.806

Table 4-3. Condensate Loads due to steam heating of different process liquids

Operation Parameters	PPPL		CRM	
	ART 1	ART 2	Mill coolant	Water
c (KJ/kgK)	2.8	3.7	3.5	4.18
SG	1.2	1.036	1.04	1
T_1 (°C)	40	40	45	25
T_2 (°C)	80	80	60	35
V (m^3)	20	20	45	2
t_h (hr)	0.5	0.5	1	0.5
ΔH (KJ/kg)	2108	2108	2047	2047
m_c (kg/hr)	2550.28	2909.45	1200.29	81.68

Table 4-4. Condensate Loads due to steam heating Air

Operation Parameters	PPPL	CCL		CGL
		Dryer 1	Dryer 2	
Q_α (m^3/min)	8500	180	180	180
T_1 (°C)	25	25	25	25
T_2 (°C)	60	90	90	80
ΔH (KJ/kg)	2108	2085	2085	2120
c_α (KJ/kgK)	1.005	1.005	1.005	1.005
γ_α (kg/m^3)	1.184	1.184	1.184	1.184
m_c (kg/hr)	10176.2	407.695	407.695	331.077

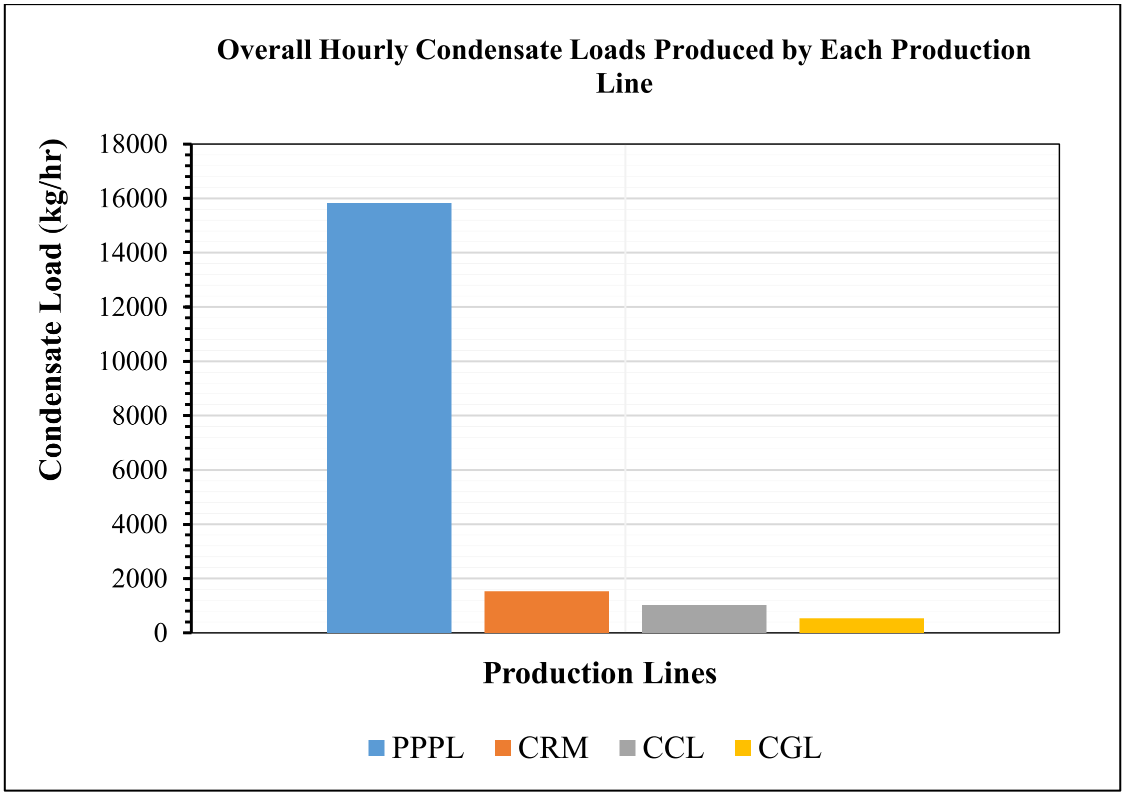


Figure 4-5. Hourly Condensate Loads

4.2 Technical Performance of Polypropylene Homopolymer as Condensate pipe

The test results were used to analyze the effect of the operating conditions on mechanical properties that directly relate to the crystalline structure transformation of the PPH pipes. The data obtained from mechanical tests were generated from inbuilt software in the testing machines and presented in form of numerical values and graphs; this data was used for prediction of the service life of the PPH pipes which would inform the designers of condensate systems of steel processing plants about the key technical considerations for installation and maintenance of these systems.

4.2.1 Extracted PPH pipe Tensile properties

Tensile strength (Rm) indicates the pipe's ability to withstand hoop stresses when pressurized without rupture. Yield strength (Rb) is another tensile property that depicts the pipe materials' resistance to deformation under stress. The thermal expansions and contractions create mechanical stresses with in the in-service pipes and therefore the pipe material should sustain them. Five test specimen of dimensions presented in Table 4-5 were subjected to tensile tests as in accordance to ASTM D638 using a test speed of 100mm/min and the results are presented in the Table 4-6. All tensile properties of pipe increased by a factor greater than two and this can be attributed to crystallinity transformations due thermal annealing as a result of longtime exposure to high temperatures.

PPH pipes experience stress relaxation of the polymer material as it under goes through thermal ageing. chain scission is predominant at this early stage and enables crosslinking as polymer chains break down and entangle thus not only forming new chemical bonds but also increase rigidity and stiffness. Additionally, elevated temperatures can transform the amorphous regions of the material into a more orderly crystalline structure hence a significant increase in tensile strength and elastic modulus.

Table 4-5. PPH Tensile test specimen dimensions

Sample No	Shape	Size(mm)	Area (mm^2)	Le(mm)
1	Sheet (width * thickness)	12.55*3.49	43.8	100
2	Sheet (width * thickness)	12.6*3.20	40.32	100
3	Sheet (width * thickness)	12.38*3.08	38.13	100
4	Sheet (width * thickness)	13.44*3.20	43.01	100
5	Sheet (width * thickness)	10.90*2.90	31.61	100

Table 4-6. PPH Tensile Test Results

Sample No	Rm (MPa)	Rb (MPa)	ReH (MPa)	Ae (%)	E(MPa)
1	172	172	169	1.1	13208
2	189	158	186	4.6	2882
3	57	22.8	56.5	8	6134
4	52	13.3	51.4	4.2	5467
5	64.1	21.7	45.7	7.9	1233
Mean		77.56	101.72		5784
Standard Deviation		80	69		4595

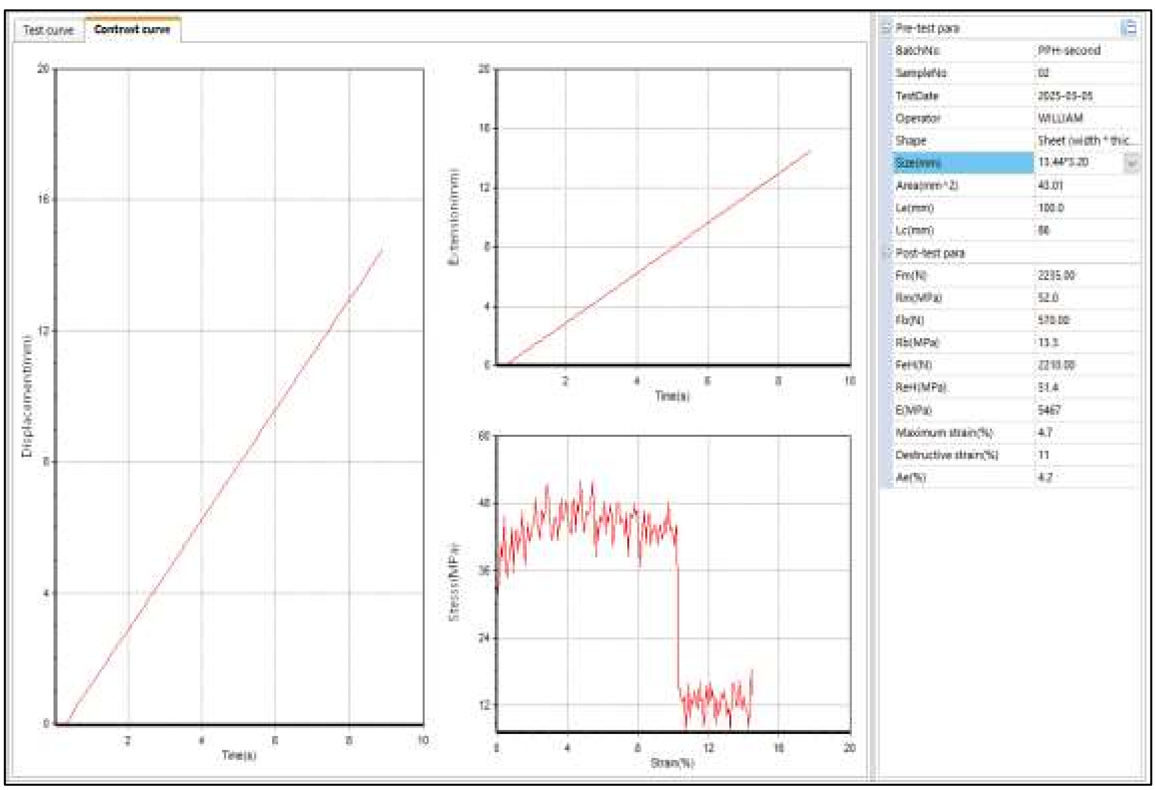


Figure 4-6. Tensile results for test specimen PPH-04

4.2.2 Extracted PPH pipe Flexural properties

The materials flexural modulus is a measure of its stiffness and depicts its ability to resist bending during service. The gravitational force due to mass of the flowing condensate exerts upon the pipe length a bending force which adversely subjects the piping system to undesirable stresses. Therefore, there ought to be a shrewd technical judgement upon the pipe wall thickness and an optimal flexural strength that should withstand bending given the temperature and specific gravity of the medium being conveyed. The test results presented in Table 4-7 indicated a 19.79% increase in flexural modulus compared to that of a virgin material vindicating that the pipe becomes stiffer during service. However, the negative sign on the values indicate that the test specimen was bending in the counter direction of y-axis. Even though, the pipe initially experiences buckling, the polymer structural transformation makes its stiffness to increase with time and therefore higher forces will be required to produce a slight bend in pipes as depicted in Figure 4-7. Long term exposure to elevated temperatures increases polymer chain mobility which enhances crystallinity due to molecular reorientation. This improves load distribution under bending forces thus increasing the flexural strength as vindicated by the sample results in Figure 4-8.

Table 4-7. PPH Flexural Test Results

Sample No.	Width (mm)	Thickness (mm)	Maximum Flexural Strength (MPa)	Flexural Modulus of Elasticity (MPa)
1	12.450	3.040	-21.288	-1517.667
2	13.080	2.970	-24.671	-1479.960
3	12.700	3.000	-29.537	-1628.478
4	12.450	3.070	-25.951	-1494.005
5	12.450	3.070	-31.592	-1666.309
Maximum	13.080	3.070	-21.288	-1479.960
Minimum	12.450	2.970	-31.592	-1666.309
Mean	12.626	3.030	-26.608	-1557.284
Standard Deviation(δ)			4.061	84.298

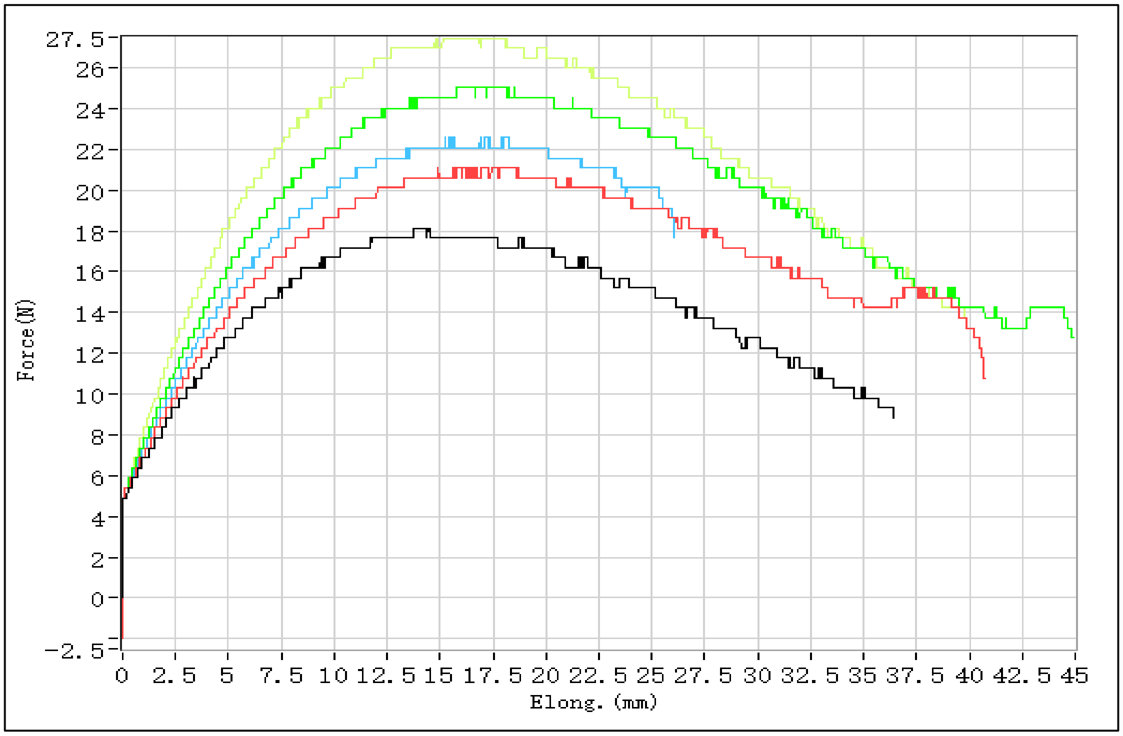


Figure 4 -7. Force Vs Elongation graph for specimens subjected to flexural test.

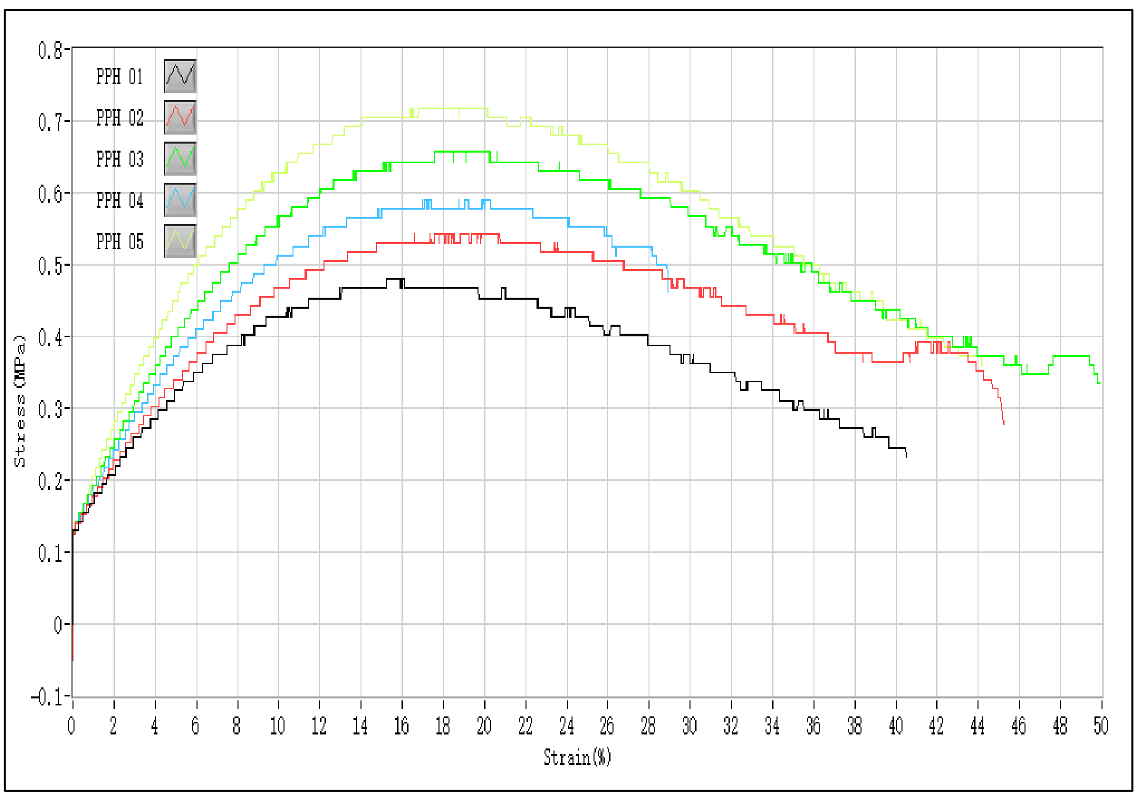


Figure 4-8. Stress – strain graph for specimens subjected to flexural strength

4.2.3 Extracted PPH pipe Impact Properties

An impact test measures the energy absorbed by a material during fracture and is indicative of the materials' toughness hence its ability to withstand instantaneous shocks. During service, these shocks present as high-force impact loads resulting from both hydraulic and thermal water hammers that greatly undermine the safety of condensate systems. An Izod impact test was carried out on five samples according to ASTM 256 using a notched bar impact tester TE 15. The energy absorbed at fracture was a computation of the total energy required to fracture the specimen divided by the specimen width and results have been presented in Table 4-8. It follows that the test specimens exhibited very low energy absorbed at fracture averaged at 3.15 J/m and indicates that the pipe is prone to brittle failure. The drastic decrease in the impact strength compared to that of the virgin pipe can be attributed to increase in crystallinity due to long term thermal exposure.

Table 4-8. Energy Absorbed at Fracture

S/N	Specimen Width (mm)	α	B	Energy Absorbed (J/m)
1	12.7	68	67	3.15
2	12.7	69	68	3.15
3	12.6	64	63	3.17
4	12.8	65	64	3.13
5	12.6	66	65	3.17
Average	**12.68**	**66**	**65**	**3.15**

4.2.4 Extracted PPH pipe Compression Strength

The compression test measures the ability of the pipe to withstand compressive forces. These forces are emancipated from the crushing loads due to concrete or soil for the case of buried pipes in underground condensate piping systems. Five specimens were tested according to ASTM D695-23 using a test speed 5mm/min and the results have been presented in table 4-9.

The tested specimen therefore exhibited an average of compressive strength of 64.44MPa with a sample standard deviation of 5.1 which strength is 43.84% more than that of the virgin pipe. The increase in the compression strength can be attributed elevated in-service temperatures that transforms the material to an orderly arranged crystalline structure which increases the polymer density hence the pipe becomes more rigid.

Table 4-9. PPH Compression test results

Size(mm)	Area(mm^2)	Le(mm)	Failure Stress (MPa)	Strength (MPa)
12.7*3.2	40.64	12.7	53.4	71.1
12.7*3.2	40.64	12.7	44.8	61.6
12.7*3.2	40.64	12.7	20.8	68.7
12.7*3.2	40.64	12.7	44.9	61.1
12.7*3.2	40.64	12.7	10.9	59.7

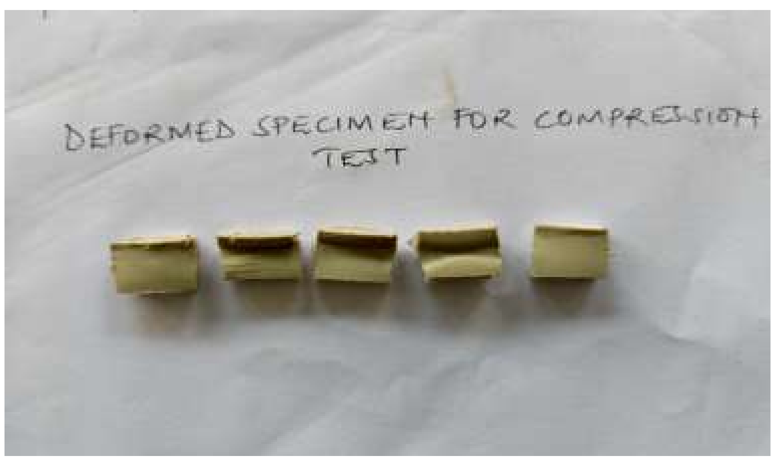


Figure 4- 9. Deformed specimen after a compression test

4.2.5 Extracted PPH pipe Hardness Test Results

Hardness is surface property of a material that indicates its resistance to indentation or scratches. The results presented in Table 4-10 show an increase of 37.63% in hardness to an average of R126.62 from specified R92 by the manufacturer (Georg fischer) and this due to crosslinking of the polymer molecules. When exposed to elevated temperatures, PPH undergoes both chain scission as well as crossing linking. These two mechanisms are responsible for thermal degradation of the polymer however depending upon the exposure time, reactive species e.g. oxygen and the reaction kinetics, one mechanism dominates over the other. Crosslinking not only binds together polymer strands but also reconnects the broken chains due to chain scission. This in turn creates a more compact and dense molecular structure thus increasing polymer density and crystallinity at an expense of molecular mobility hence increase in hardness. The localized swellings as depicted in Figure 4-11 are due to increased water absorption into the polymer structure as a result of the combined effect of high flash steam temperature and impact pressure. Even though this happens, there was no observable signs of wearing off and erosion of the PPH elbow surfaces unlike the steel elbows that are susceptible to erosion-corrosion.

Table 4-10. Rockwell hardness values for the inner surface of the PPH pipe

		HARDNESS VALUES				
No.	**TYPE**	**SAMPLE A**	**SAMPLE B**	**SAMPLE C**	**SAMPLE D**	**SAMPLE E**
1	HRR	126.60	119.50	117.70	127.60	121.10
2	HRR	129.10	123.50	120.70	126.90	123.10
3	HRR	127.80	129.10	127.40	125.40	123.40
4	HRR	129.60	130.00	130.00	129.20	125.90
5	HRR	129.60	129.40	129.80	129.30	130.00
AVERAGE		**128.53**	**126.30**	**125.11**	**127.66**	**125.50**

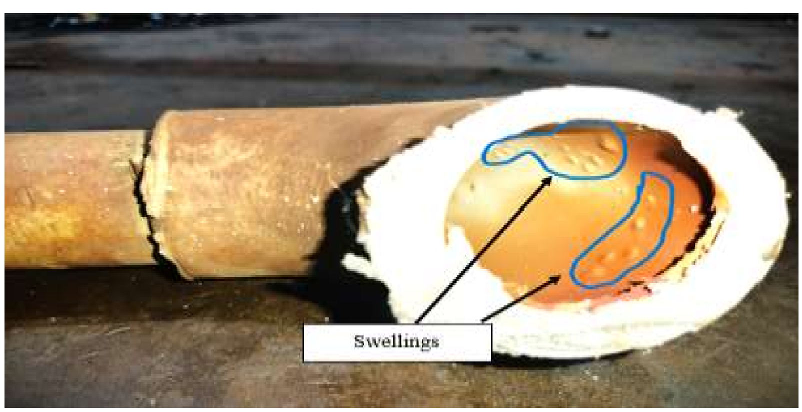


Figure 4-10. Swellings on the inner surface of the elbow

4.3 Performance Comparative analysis of PPH and Steel pipes

Cost cutting is a vital aspect in industrial economics and awards a competitive advantage between manufacturing plants. Exploitation of material properties to be able to widen their areas of application thus is an outstanding strategy to minimize maintenance costs as well as other hidden costs associated with using a particular material. A computation of the overall cost incurred in using a particular material over a given period of time is imperative and quantifies its contribution to the production costs. Striking a balance between the optimal mechanical properties and performance requirements of a condensate system will in turn lead to improved system efficiency. The comparative analysis covers not only the technical performance to ascertain durability but also the costs associated with using a selected material in regards to labor, cost of pipes and their fittings, employee safety, installation and maintenance costs. Cost analysis is a quantitative basis for decision making and influences the choice of material for condensate piping.

4.3.1 Comparative analysis of the material properties of PPH and steel pipes

Material properties are the underlying characteristic features that guide the selection of a particular pipe material that can enhance the performance of the condensate systems in steel plants. They should as well leverage with the specified design parameters. The Steel and PPH material property values as specified by manufacturer are presented in Table 4-11. Despite of the good mechanical properties of steel that has over time made it a desirable material for condensate pipes, its high thermal conductivity demands that pipes be insulated and its poor resistance to corrosion makes it a costly for maintenance.

Table 4-11. Comparison of the Technical parameters of PPH and Steel materials

MATERIAL PROPERTY	Unit	PPH	STEEL
Density	kg/m3	900	7850
Tensile strength (at yield)	MPa	31.03	250-350
Tensile strength (at break)	MPa	38.61	400-550
Modulus of elasticity	GPa	1.30	200-210
Compressive strength	MPa	44.82	600-900
Flexural modulus	GPa	1.25	200-210
Izod impact (at 23C)	J/m	603.18	267-534
Hardness	Shore D	70	80-90
Melting point	^{0}C	160	1400-1500
Corrosion resistance		Excellent	Poor
Thermal Conductivi3ty	W/m. K	0.22	40-60

4.3.2 Mechanical properties of virgin and out-of-service PPH pipes

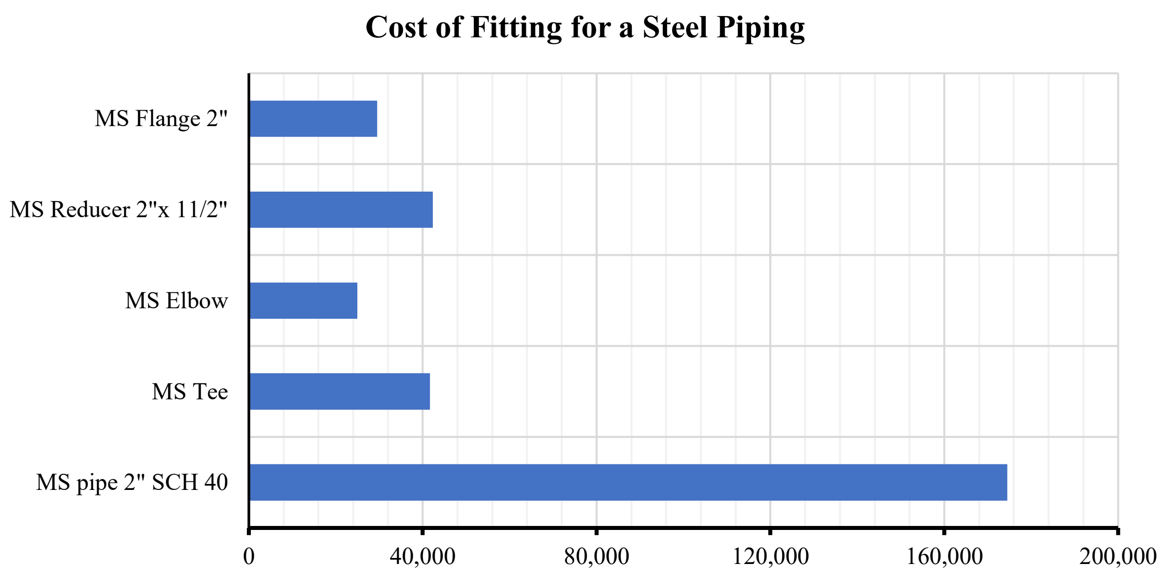
A comparison between the mechanical property values of the virgin pipes and out of service PPH pipes was made. The out of service pipe had one-year service period transporting condensate with 10% flash steam with an average pH of 4.74. Results presented in Table 4-12 showed that generally the mechanical properties of the out of service pipes were enhanced during service. The continuous exposure of PPH pipes to high-temperature condensate and flash steam enhanced their mechanical properties during a one-year service period; however, there was a drastic decrease in impact strength of the pipe. This can be attributed to thermal annealing which influenced the molecular reorientation, increased crystallinity and crosslinking mechanisms which have dominated over oxidative degradation and chain scission.

Table 4-12. Effects of long-time thermal exposure on the mechanical properties of PPH

MATERIAL PROPERTY	Unit	Virgin PPH pipe	Out of Service PPH pipe
Tensile strength (at yield)	MPa	31.03	77.56
Tensile strength (at break)	MPa	38.61	101.72
Tensile Modulus of elasticity	GPa	1.30	4.595
Compressive strength	MPa	44.82	64.44
Flexural modulus	GPa	1.25	1.56
Rockwell Hardness	R scale	92	126.62

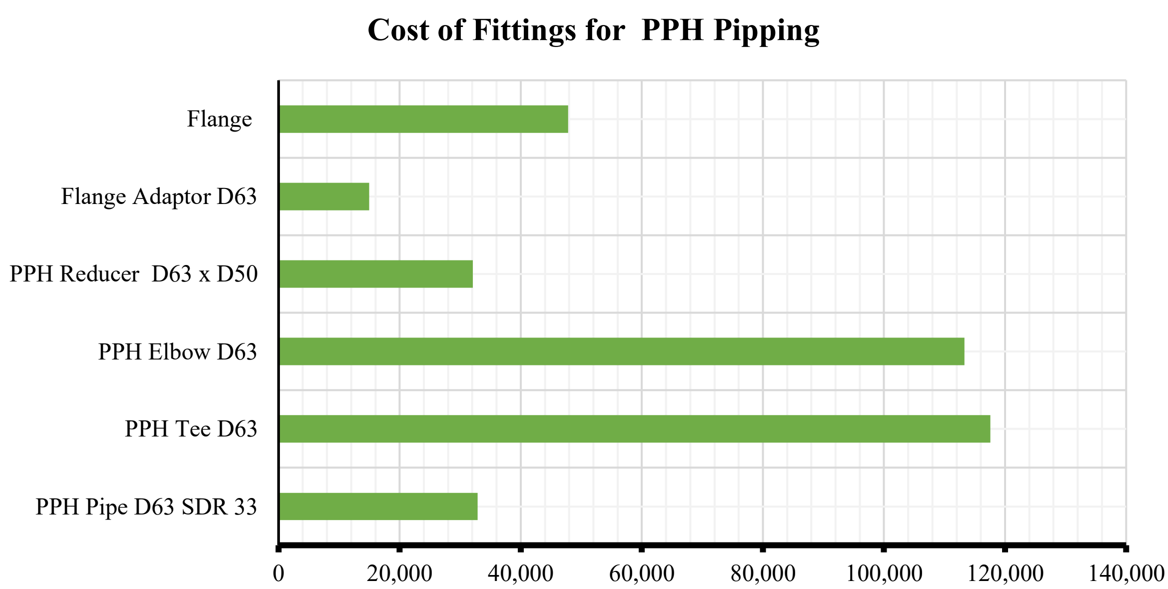
4.3.3 Comparison between Fittings Purchase Expenditures

Pipping is a major component that makes up a condensate system and its therefore a vital aspect to consider during design and installation. The cost of the pipes and their fittings largely depend on their construction material however, other forces (Porter forces) in the economy influence the price of the pipping components. The choice of the pipe material to be used contributes greatly onto the overall installation costs and should be critically evaluated in order to achieve a quick return on investment or result into a short payback period of an installed condensate system. The Figure 4-11 shows the variations in prices for different steel pipe fittings. Unlike steel pipes, PPH pipes are commercially unavailable in the Ugandan market and therefore a safety stock should be maintained. However, since they are corrosion resistant and offer a better performance, their inventory level can be minimum compared to that of steel-make. Figure 4-12 shows that elbows cost much cheaper than the rest of steel pipe fittings and yet they are frequently replaced during maintenance owing to erosion corrosion thus they can significantly increase the maintenance costs. The Reducer and tee fittings considerably have the same prices however the consumption of the Reducers was much higher than that of the Tee fittings. The flanges were the least replaced and never faced any significant damages in service. Generally, the initial installation cost of PPH pipping is more than that of steel pipping. The PPH tee and elbows are more expensive than other fittings and this may be attributed to the use of sophisticated technology for their intricate shape manufacture. Whereas it's an attractive option to minimize the overall installation cost, a detailed analysis of the hidden costs associated with the use of both piping has been made and presented in Table 4-13.



	MS pipe 2" SCH 40	MS Tee	MS Elbow	MS Reducer 2"x 11/2"	MS Flange 2"
Ugx	174,518.64	41,666.67	24,928.81	42,307.69	29,550.45

Figure 4-11. Unit cost of different fittings for a Steel piping



	PPH Pipe D63 SDR 33	PPH Tee D63	PPH Elbow D63	PPH Reducer D63 x D50	Flange Adaptor D63	Flange
Ugx	32,890.11	117,577.86	113,267.28	32,096.18	14,982.62	47,849.71

Figure 4-12. Unit cost of different fittings for a PPH piping

4.3.4 Pipeline fabrication and maintenance cost expenditure comparison

Maintenance aims at restoring the performance of the system in an event of a breakdown or system deterioration. Fabrication and maintenance cost expenditures comprises of resources spent on purchase of specialized equipment, consumables, power consumption and competence training. Table 4-14 presents the company valuation price for the tools and consumables used in fabrication of steel as well as PPH pipping. The initial investment in tools and equipment used in pipping fabrication is a fixed cost and is informed by the choice of the pipping material. Even though the maintenance of these equipment may seem negligible, the consumables used can put up a significant cost that can drain the maintenance budget. Consumables accounted for about 18% of the maintenance requirements for a steel piping, 13% of which is due to insulation wool replacement as depicted in Figure 4-13. Unless controlled, cutting discs and weld electrodes can significantly form part of consumables more so during reworks. Even though the aluminum sheets within which the insulation wool is held tightly against the pipe walls remain unaffected upon condensate leakage, blind rivets are needed to fasten the sheets back after maintenance.

Table 4-13. Steel fittings yearly consumption

Steel fittings	**Yearly Consumption (Pieces)**	**SAP evaluation Price (UGX)**	**Cost (UGX)**
MS Elbow	18	24,928.81	448,719
MS Flange 2"	3	29,550.45	88,651
MS Reducer 2"x 11/2"	8	42,307.69	338,462
MS Pipe 2" SCH 40	9	174,518.64	1,570,668
MS Tee	5	41,666.67	208,333
Total Cost			**2,654,833**

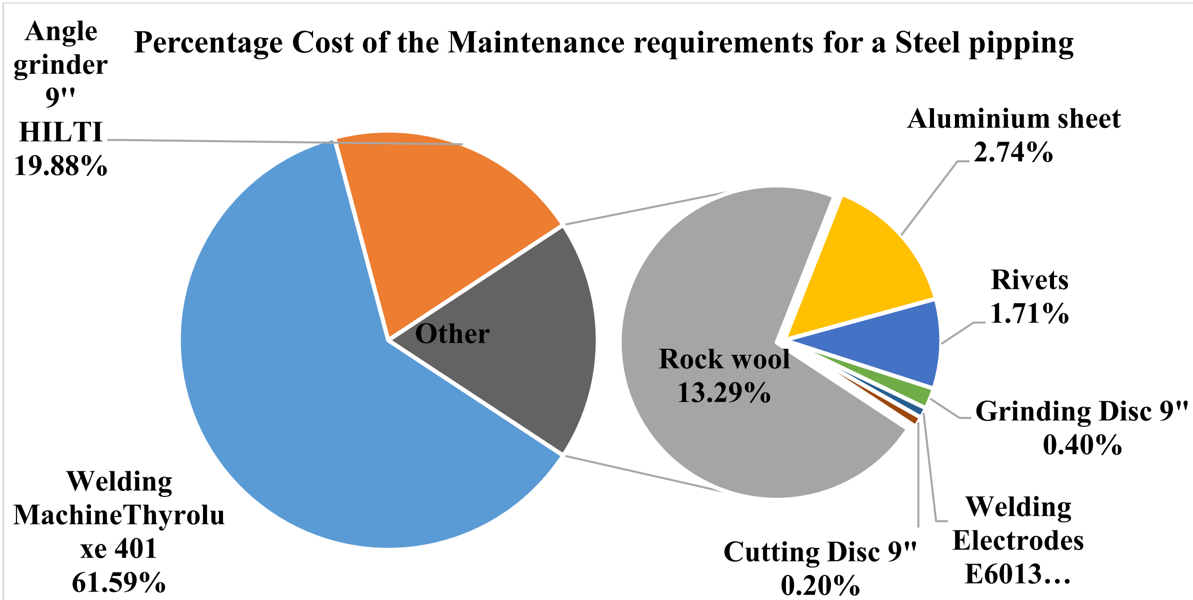


Figure 4-13. Percentage Cost of Requirements for Steel Piping Maintenance

Maintaining a steel piping is condensate system is burdensome due to corrosion erosion of steel pipes which leads to pipe wall thinning (see Figure 4-14) and initiates tiny orifices resulting into persistent condensate leakages. The susceptibility of steel to corrosion-erosion undermines their service life and drains the maintenance budget in turn increasing the production cost. Table 4-13 shows the quantity of fittings and cost incurred by the company for a period of one year for maintenance of the steel piping. The yearly maintenance expenditure excludes the labor costs and the cost due to lost production time. Since the average down time due to condensate leakage is three hours and the production cycle time for the PPPL line is thirty minutes, the economic loss due to maintenance of steel piping is equivalent to the profits that would be realized after six production cycles.

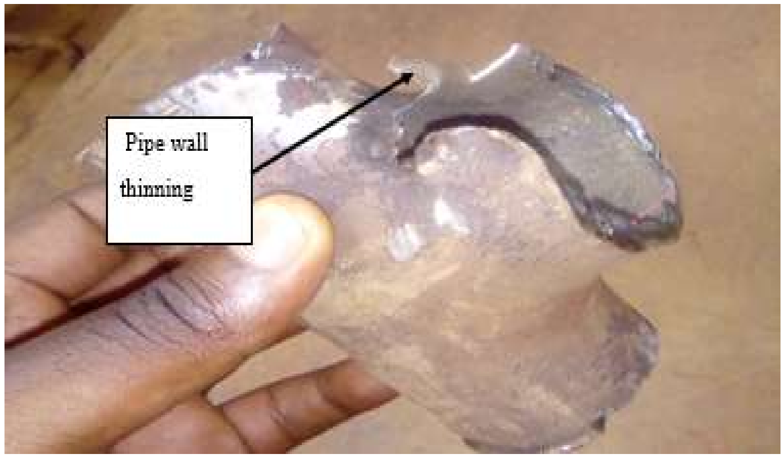


Figure 4-14. MS-tee wall thinning due to corrosion-erosion

Table 4-14 provides maintenance requirements for the PPH and steel piping which indicates that the PPH requires less consumables that are at the same time cheap and account for 2% of the maintenance requirements. Technically, a butt weld was preferred than socket fusion during joining of pipes because the latter introduces an additional weld that increases the chances of condensate leakage. Effective regulation of the fusion temperatures could rule out the need to do additional welding using filler wires and thus cutting down on the cost of consumables. In comparison with the steel piping, it can be concluded that the PPH piping is cost effective and is a better option for condensate systems. Figure 4-15 shows the percentage cost for different maintenance requirements for a PPH piping. Unlike steel piping that is rigid and thus proves cumbersome correcting misalignments at flanges during pipeline fabrication, the flexible and light weight PPH piping can accommodate a misalignment of up to 3mm at flanges which can be corrected by tightening of fasteners. This makes installation and maintenance of PPH piping much easier and reduces downtime. However, the high thermal expansion coefficient and flexibility of the PPH pipes necessitates that they are properly supported to prevent slagging as well as allow room for expansion.

Table 4-14.Valuation price for maintenance requirements of specific piping materials

Pipping Material	Maintenance Requirements		UOM	SAP Valuation Price (Ugx)
STEEL	Tools and Machines	Welding Machine Thyroluxe 401	EA	2,520,000.00
		Angle grinder 9" HILTI	EA	813,479
	Consumables	Welding Electrodes E6013	KG	8,128.67
		Cutting Disc 9"	PC	8,100.00
		Grinding Disc 9"	PC	16,200.00
		Rock wool	ROL	543,628.61
		Aluminium sheet	PC	112,000.00
		Rivets	EA	70,000.00
PPH	Tools and Machines	Heating plate 1500W for Butt welding	EA	2,205,000.00
		Hacksaw	EA	31,682.15
		Heat gun HL 500	EA	296,610.20
		Pencil grinder GGS 300L 8mm 300W	EA	623,125.39
	Consumables	Abrasive stone conical 2"	PC	27,968
		PPH filler wire 4mm	KG	32,287.13
		Anglelines 50x50x3mm	PC	62,923.73

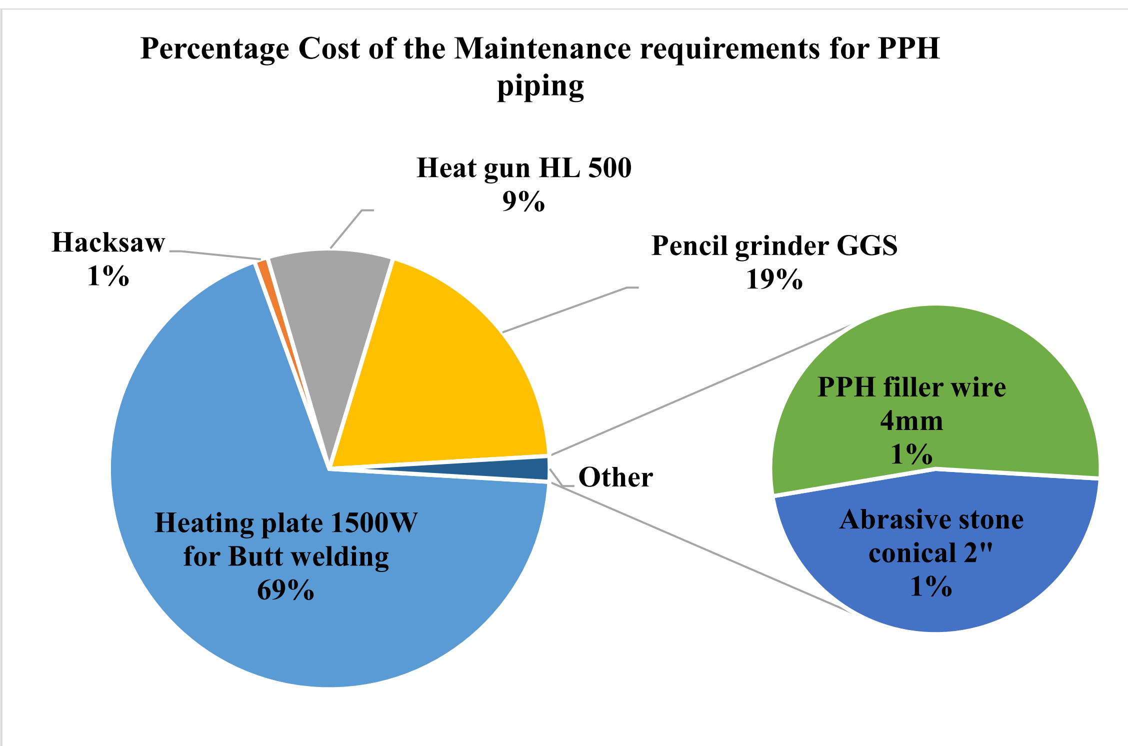


Figure 4-15. Percentage Cost of Requirements for a PPH piping Maintenance

4.3.5 Comparison between service life of PPH and Steel pipes

The simulation results relieved that a span of 2.5m between the point pipe supports was optimal and would give a bending displacement of 6.997mm as shown is Figure 4-16. However, using continuous V-supports is more economical and a length of 1.2m would optimally minimize bending displacement to as low as 5.8mm as shown in the Figure 4-17. The simulation results further revealed that continuous V-supports are ideal and produce less bending displacements compared to point supports. However, it was noted that the pipes' von mises stresses and strain insignificantly change with the length of the v-support. The PPH piping should never be supported near its ends because it will definitely give way off the support due to thermal expansion and large bending displacements. Table 4-15 shows the maximum von mises stresses, strain and bending displacements encountered by PPH pipe carrying condensate and flash steam at 110 ^{0}C at 1 bar pressure for each case when supported by V or point supports.

The service life of the pipe supported by point supports 2.5m apart was estimated using a fatigue simulation. The results revealed that there would be a damage percentage of 0.0058 which is far less than 1 hence the pipe will require many cycles for it to fail. Assuming a thousand cycles occur during operation every day due to pulsation and impact loads as a result of impingement of accelerated condensate stream onto the inner pipe surfaces, the service can be calculated through dividing the minimum total life by estimated cycles encountered daily. From figure 4-18, the minimum total life of the pipe is 1,712,000 cycles and therefore the PPH pipe is expected to serve for more than 4.5 years unlike the steel pipes that corrodes a few months after installation.

Table 4-15. Displacement produced by different pipe supports.

Pipe support type	Support length(m)	Max. von Mises stress (N/m²)	Max Strain	Max. Displacement (mm)
Point support	1.5m apart	1.943×10^{7}	6.065×10^{-3}	28.091
	2.5m apart	8.105×10^{6}	5.736×10^{-4}	6.991
	4.5m apart	1.331×10^{8}	2.878×10^{-3}	427.859
Continuous V-support	0.8m	1.654×10^{7}	6.719×10^{-3}	8.029
	1m	1.627×10^{7}	6.671×10^{-3}	6.921
	1.2m	1.660×10^{7}	6.711×10^{-3}	5.800

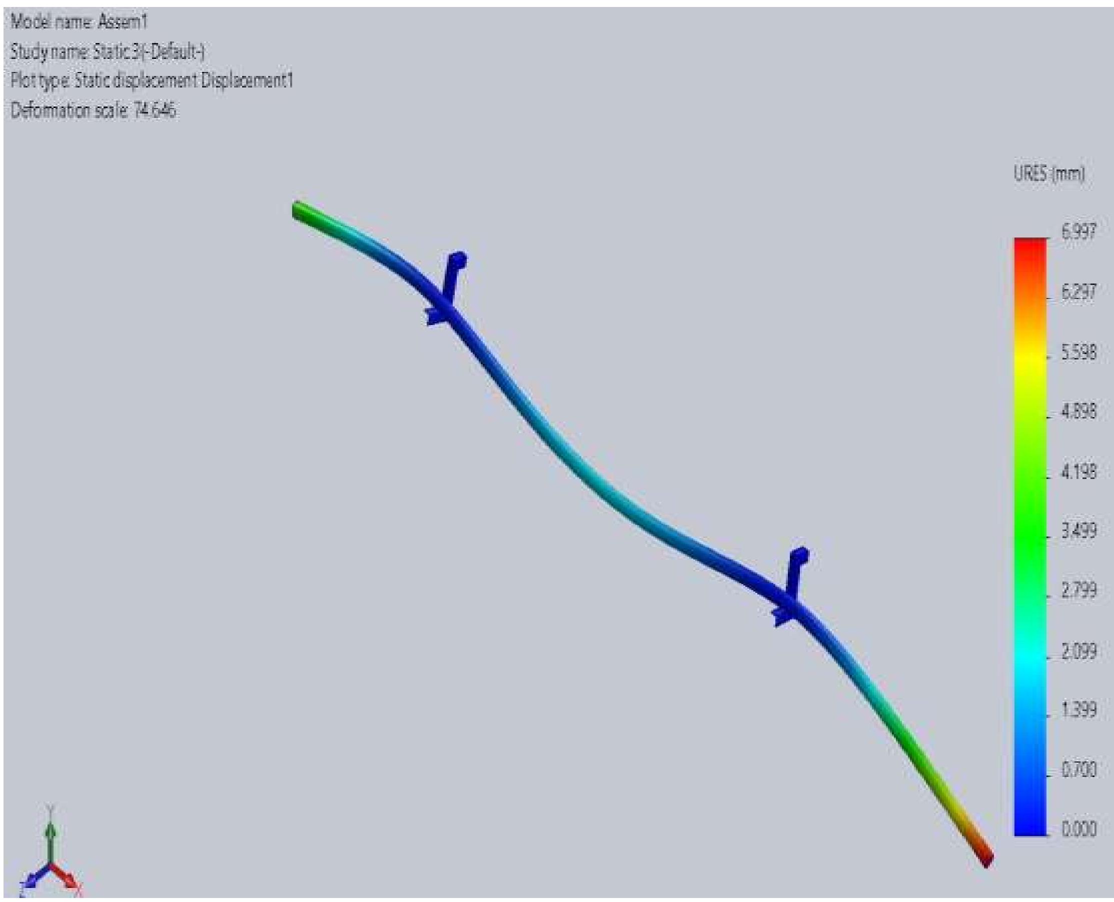


Figure 4-16. Point support simulation results.

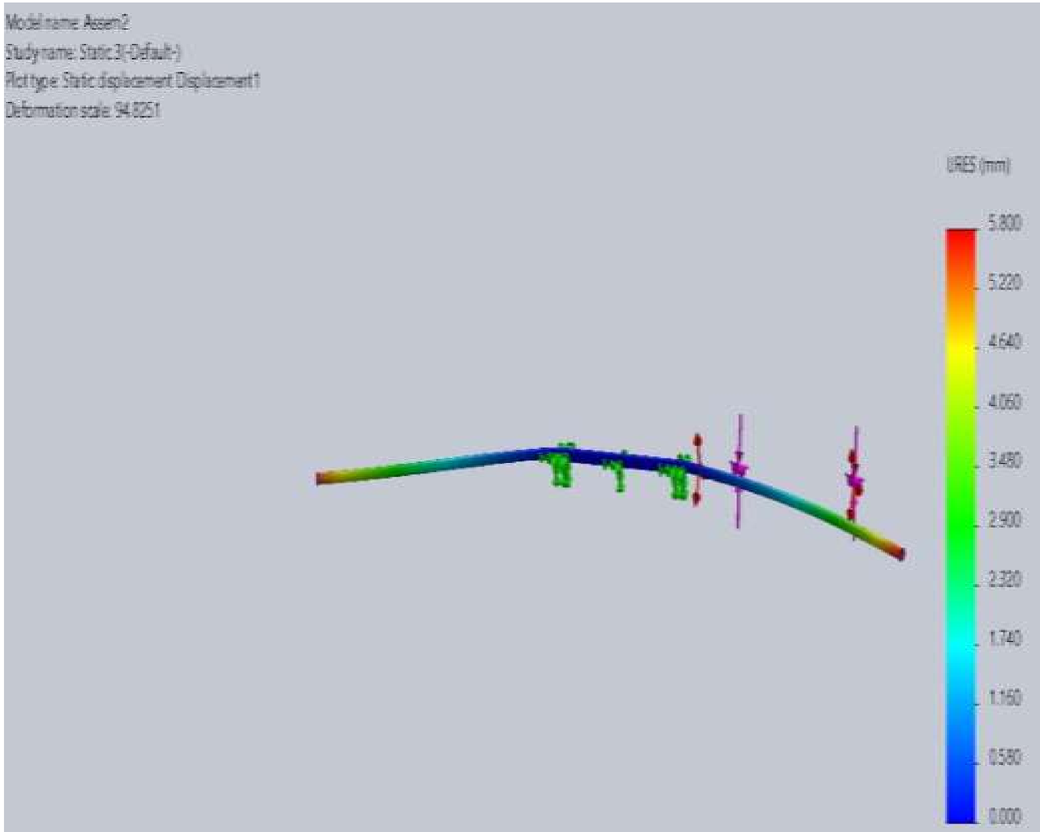


Figure 4-17. V-support simulation results

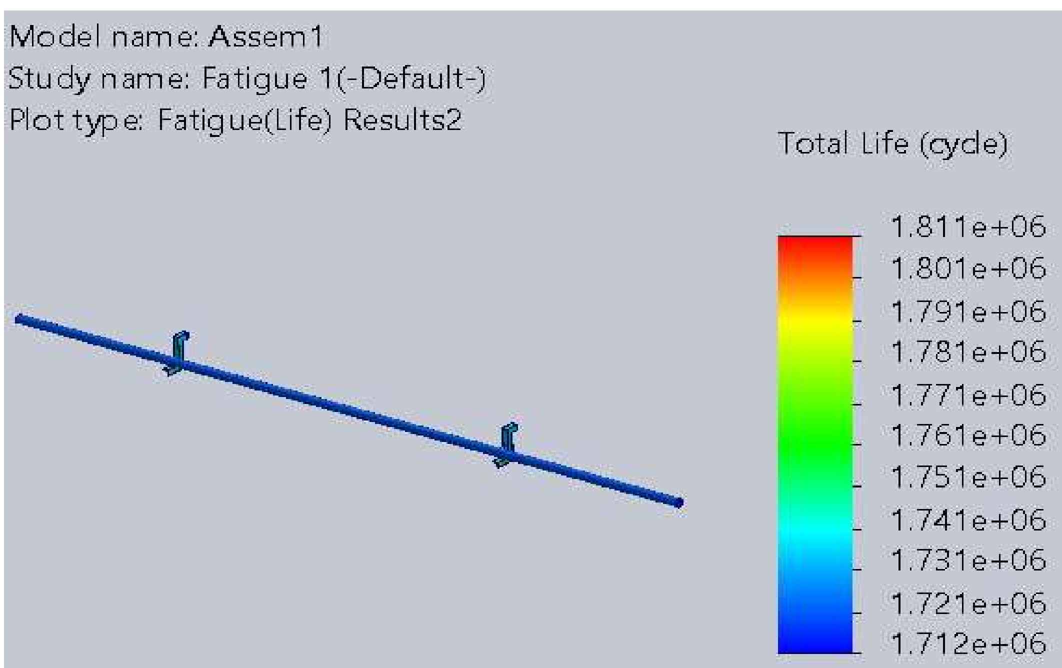


Figure 4-18. Fatigue Simulation Results

4.3.6 Labor and Safety Cost Comparisons

Both technicians and operators were orally interviewed about their safety while using PPH piping systems compared to steel pipping. 40% of the technicians revealed that the condensate piping ran through confined spaces which poses a challenge of taking them out of service because of their heavy weights for the case of steel pipes. Meanwhile, 60% of the operators felt safe because of a low risk of burns while interacting with a PPH pipping. Some operators however claimed that the expansion of pipes during service made them feel unsafe and always raises their gut feelings about a probable pipe burst. A skilled workforce should be capable of using inexpensive tests to determine the brittleness of the PPH pipeline after some service time. This analysis is a basis for regulating fusion temperatures and pressures during maintenance to prevent pipeline leakages. Therefore, skilled manpower is required for the PPH pipeline fabrications and their remuneration is almost twice that of steel fabricators because of the technicalities to do with pipe thermal expansion, fusion temperatures and pressures. In modern industries, safety of workers and machinery is key and a priority during production and maintenance. Steam as well as pressurized vessels are occupational hazards and where registered by the company with a risk rank of “Medium”. To minimize the occurrence of steam burns, the company incurs an appreciable cost to provide PPEs to the employees during operation and maintenance of the steel condensate piping.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study evaluated the performance of Polypropylene Homopolymer pipes in industrial condensate recovery systems of a steel strip processing plant. The pipes' operating environment was analyzed and technical performance as well as the cost benefit of using PPH pipes in comparison to the conventional steel pipes was done for a one-year service period.

The results have proved that PPH pipes are more economic overtime, conserve more thermal energy, have a longer service life estimated at 4.5 years and their mechanical properties are enhancement with a 149.95% increase in tensile strength, 43.76% increase in compressive strength, 24.8% increase in flexural modulus and a 37.63% increase in hardness during a one-year service period. This indicates that crystalline reorientations were dominant over oxidative degradation. However, the impact strength of the PPH pipe drastically decreased which demands attention to pipe sizing for a given condensate system to prevent brittle fracture as a result of water hammers. Although PPH piping has a high initial installation costs, lower consumables, fewer reworks, high reliability and longer service life led to not only significant maintenance savings but also reduced production down time. PPH's chemical resistance made it particularly suitable for acidic environments such as pickling lines, where hydrochloric acid fumes degrade steel pipes rapidly.

Condensate systems are intended to return or recover flash steam back to the boiler or further utilize the sensible heat present in the condensate for a variety of purposes e.g. condensate is used as rinsing water in steel pickling. In strip processing, generally steam is used for heating purposes either via a heat exchanger or direct heating using steam ejectors. During heating saturated dry steam gives up its latent heat and condenses. Accumulation of condensate in the heat exchangers not only leads to stalling a condition that reduces heating efficiency but also poses a risk of water hammers thus should be continuously discharged through a steam trap.

5.2 Recommendations

Given the evaluation of the performance of PPH pipes in the industrial condensate system after a one-year service period undertaken in this study, the following recommendations are made:

There is need for steel strip processing plants to recover all condensate and install detectors to monitor condensate contamination in their recovery systems.

There is need to study more about the optimal support configurations for PPH piping in a condensate systems to avoid pipe sagging and joint stress.

There is need for further studies to ascertain the service period when oxidative degradation becomes dominant in the PPH piping.

There is need to carry out studies to understand the best configuration that can be used to compound the two pipes into one for leverage.

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APPENDICES

Appendix A: Date of installation of the PPH condensate pipe line

Date: 13th/06/2023

Man power present	
Ekot (B)	
Okiima (B)	
Emma (A)	
Olowo (G)	

Delay		
Nature of day	Today	Cumulative

Major items consumed	

Items to be indented

Pending jobs:

Dear ~~[illegible]~~ Team, - Lubricate and tighten any fasteners for Pinch roll 2, 3

- Inspect for any leakages on the Rinse water tanks.
- Inspect all the seal cooling for the horizontal pumps in ARP.
- Do proper House Keeping on the exit shear, clean the equipment & the valve stands.

Appendix B: Description of Procedure for PPH condensate pipe line fabrication.

	ROOFINGS ROLLING MILLS LTD PHASE 3 MECHANICAL MAINTENANCE LOG BOOK	Doc. No : RRM. PH3.MTE.R.LOG01 Issue Date : 16 July 2021 Rev. No : 00 Rev Date : 07 July 2021 ISO 9001:2015 clause 8.1, ISO 14001:2015 clause 8.1, ISO 45001:2018 clause 7.5

Shift Incharge: KASATSA CHARLES Shift: 9

Sr.No.	Unit	Equipment	Job Description	Manpower	Duration	Remark
1.	PPH	[illegible] Condensate Line Modification	- Joining [illegible] pipes from the condensate tank to the Scrubber. - Laying the pipe line on the pipe tray	[illegible]	8hrs	Done.

Shift Incharge Signature [illegible]

Section Incharge Signature

Appendix C: Condensate system modification file

ROOFINGS ROLLING MILLS LTD.
PLANT - 3
MECHANICAL MAINTENANCE
PROCESS ENHANCEMENT/MODIFICATION FILE

DOCUMENT NO : RRM.PH3.MTE.R.MEM.PEF06

ISO 9001: 2015, ISO 14001:2015, ISO 45001: 2018

REV DATE	12/5/2023
REV NO.	02
ISSUE DATE	15/5/2023

Section: PPPL

EQUIPMENT: CONDENSATE LINE

DATE	EQUIPMENT	OBSERVATION/PROBLEM	MODIFICATION	REMARKS
18/07/23	Condensate Line	- The Automatic valve on the Dryer line closing due to increase in condensate temperature beyond the set point in WRT, The sheet thus not being dried properly - Too much condensate over flowing to the sump	Channeling the Condensate line to the Scrubber thus Condensate is being distributed to WRT tanks and the scrubber.	optimal temperature achieved and maintained

PREPARED BY: MAINTENANCE ENGINEER

VERIFIED BY: H.O.D

APPROVED BY: PLANT MANAGER

Appendix D: The name plate for the universal tensile machine

Appendix E: The name plate for the machine used for a 3-point flexural test

Appendix F: The name plate for the machine used for the hardness test

Appendix G: The PPH flexural test results

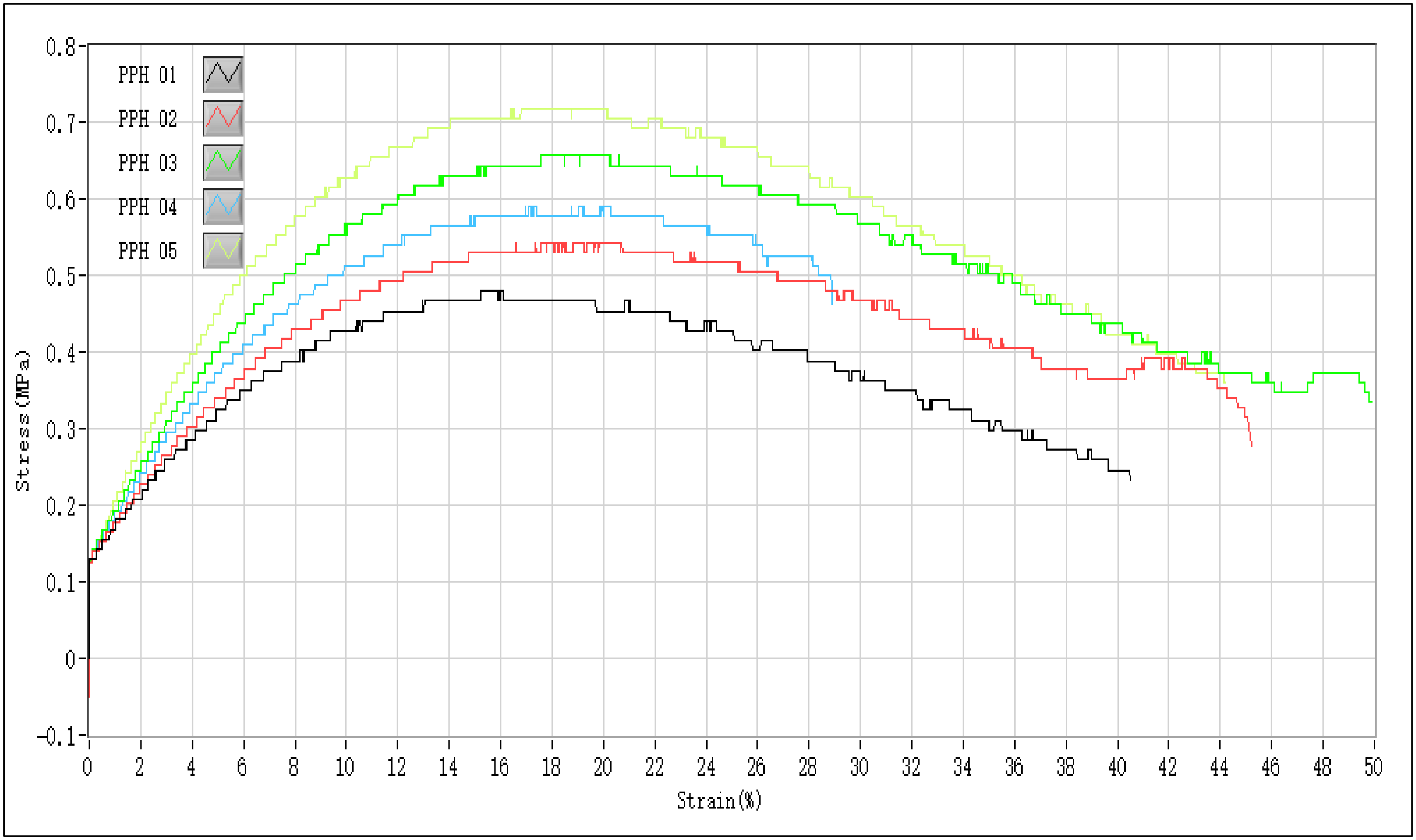
UIRI-MMSDC
MATERIALS & NDT LABORATORY

TEST BATCH NUMBER:	PPH	CLIENT'S NAME	KASAIJA CHARLES
TEST END DATE:	17TH FEB 2025	MATERIAL NAME	POLYPROPYLENE HOMOPOLYMER
TEST PERSONNEL	BAKWATANA G. WILLIAM	AMBIENT TEMPERATURE	25 ^{0}C
TEST SERIAL NUMBER	GAUGE LENGTH (mm)	AREA (mm²)	(W*t)
PPH 01	90.0	38.10	12.7*3.0
PPH 02	90.0	38.22	12.45*3.07
PPH 03	90.0	38.22	12.45*3.07
PPH 04	90.0	37.85	12.45*3.04
PPH 05	90.0	38.85	13.080*2.97

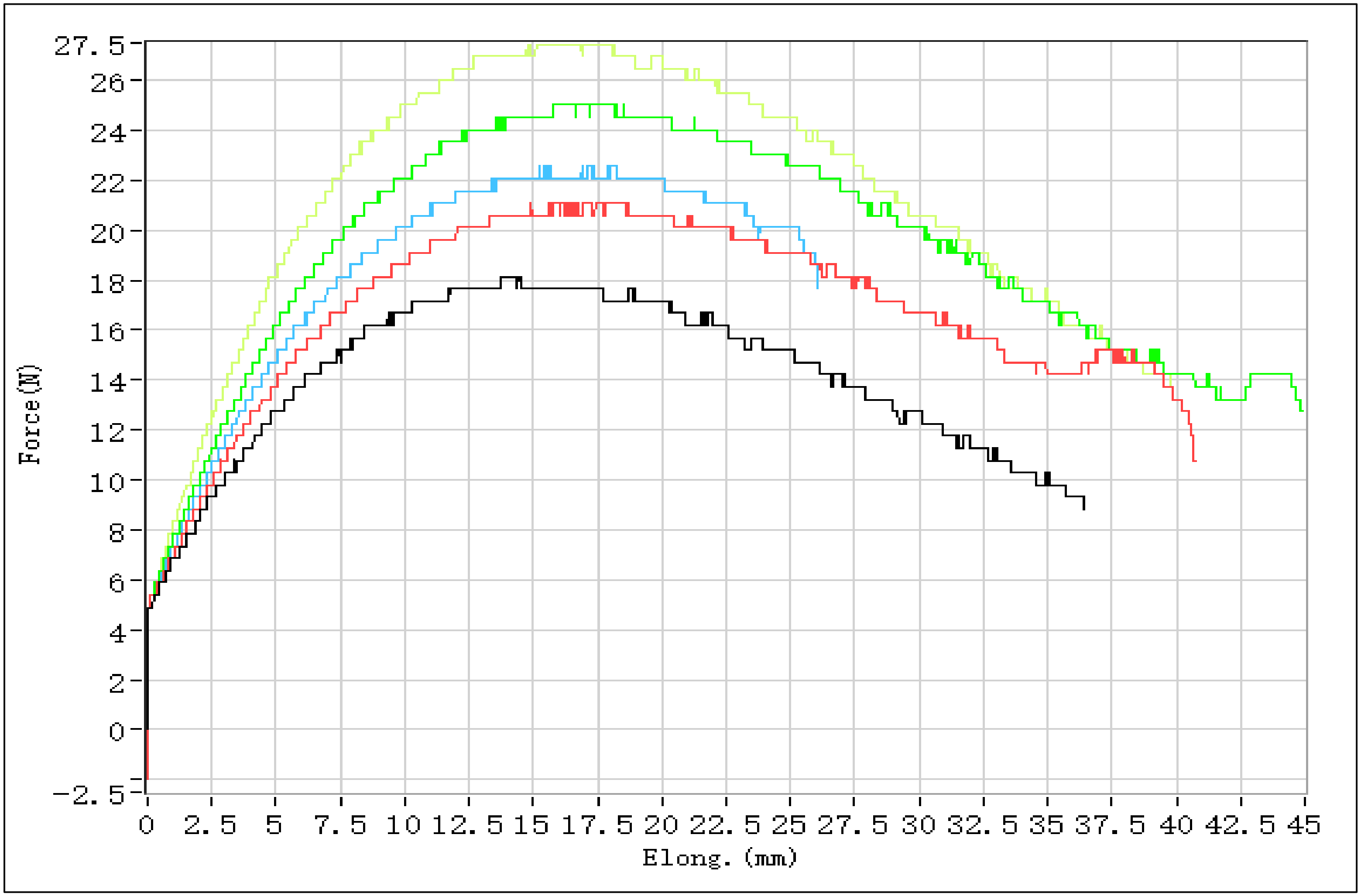
TABLE OF RESULTS

No.	Force @ Peak (N)	Maximum Flexural Strength (MPa)	Flexural Modulus of Elasticity (MPa)	Width (mm)	Thickness (mm)
1	18.143	-21.288	-1517.667	12.450	3.040
2	21.085	-24.671	-1479.960	13.080	2.970
3	25.008	-29.537	-1628.478	12.700	3.000
4	22.556	-25.951	-1494.005	12.450	3.070
5	27.460	-31.592	-1666.309	12.450	3.070
Maximum	27.460	-21.288	-1479.960	13.080	3.070
Minimum	18.143	-31.592	-1666.309	12.450	2.970
Mean	22.850	-26.608	-1557.284	12.626	3.030

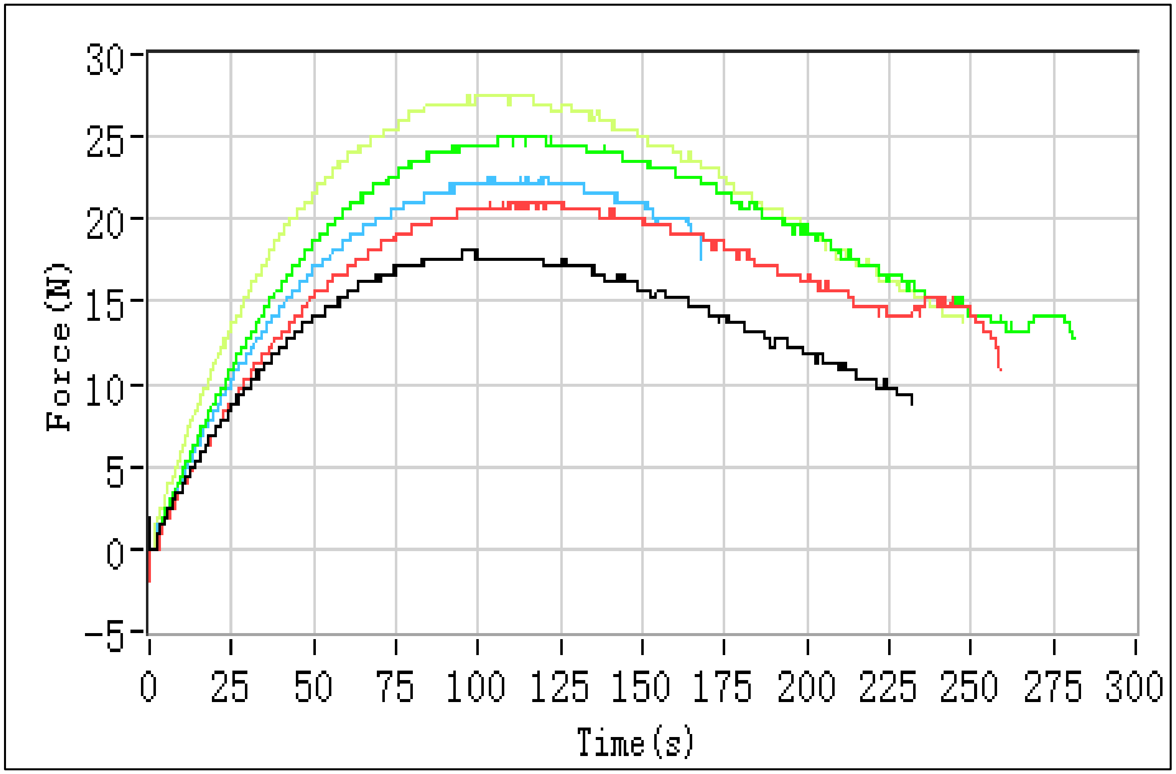
Appendix H: The PPH flexural test Stress – Strain plot.



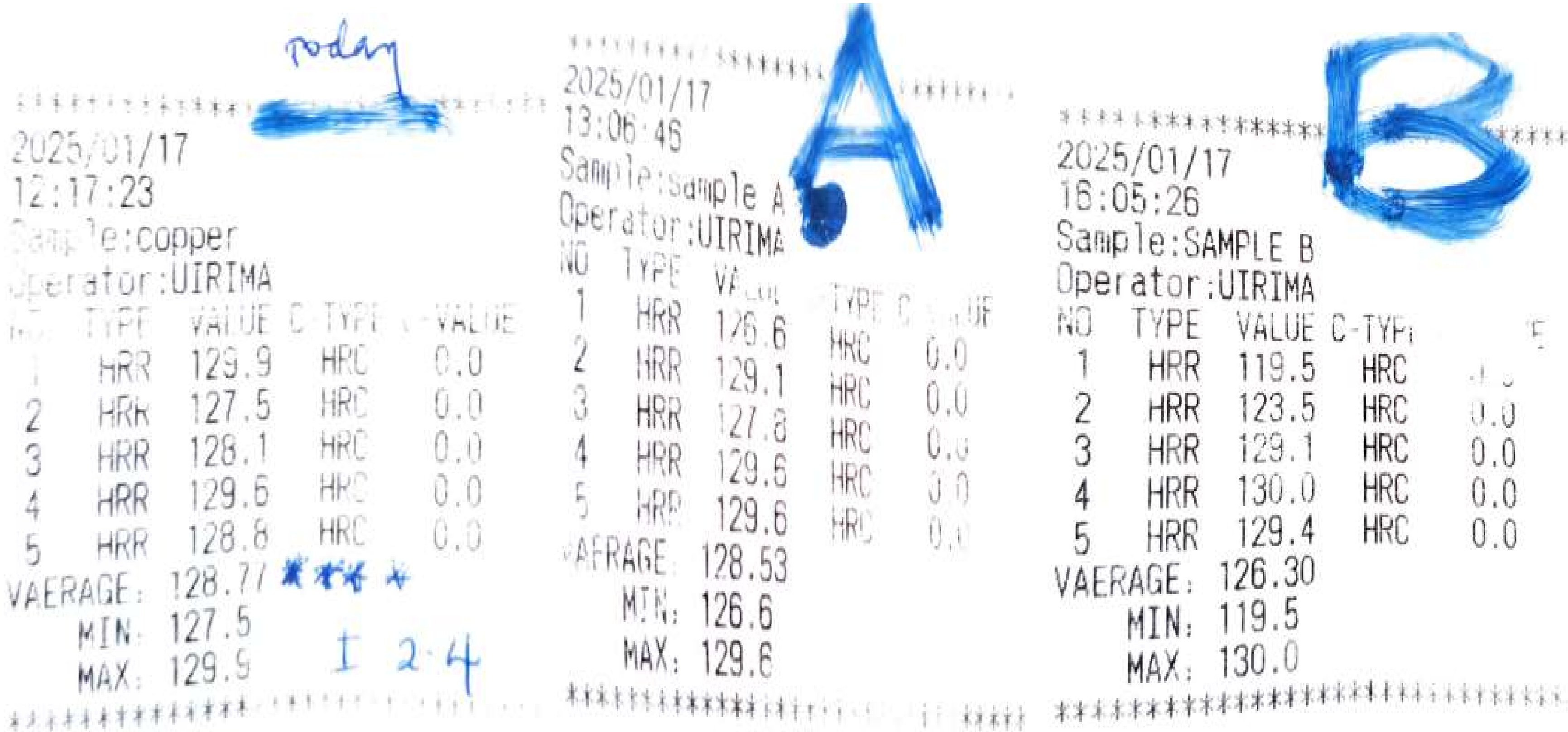
Appendix I: The PPH flexural test Force-elongation plot.



Appendix J: The PPH flexural test Force –Time plot.



Appendix K: The PPH Hardness test results.



2025/01/17
12:17:23
Sample:copper
Operator:UIRIMA

NO	TYPE	VALUE	C-TYPE	C-VALUE
1	HRR	129.9	HRC	0.0
2	HRR	127.5	HRC	0.0
3	HRR	128.1	HRC	0.0
4	HRR	129.6	HRC	0.0
5	HRR	128.8	HRC	0.0

VAERAGE: 128.77
MIN: 127.5
MAX: 129.9

2025/01/17
13:06:46
Sample:sample A
Operator:UIRIMA

NO	TYPE	VALUE	C-TYPE	C-VALUE
1	HRR	126.6	HRC	0.0
2	HRR	129.1	HRC	0.0
3	HRR	127.8	HRC	0.0
4	HRR	129.6	HRC	0.0
5	HRR	129.6	HRC	0.0

VAERAGE: 128.53
MIN: 126.6
MAX: 129.6

2025/01/17
16:05:26
Sample:SAMPLE B
Operator:UIRIMA

NO	TYPE	VALUE	C-TYPE	C-VALUE
1	HRR	119.5	HRC	[illegible]
2	HRR	123.5	HRC	0.0
3	HRR	129.1	HRC	0.0
4	HRR	130.0	HRC	0.0
5	HRR	129.4	HRC	0.0

VAERAGE: 126.30
MIN: 119.5
MAX: 130.0

C

****

2025/01/17

16:14:40

Sample:SAMPLE C

Operator:UIRIMA

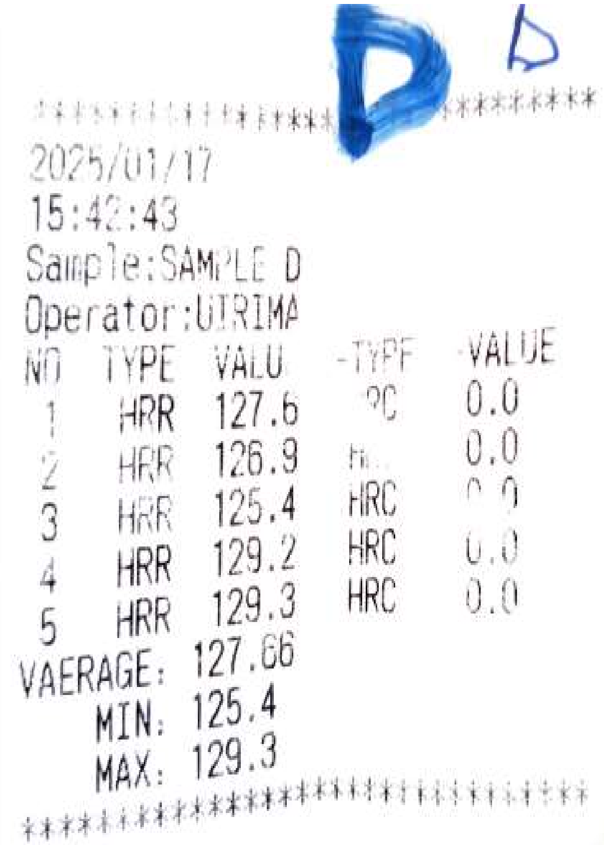
NO	TYPE	VALUE	C-TYPE	C-VALUE
1	HRR	117.7	HRC	0.0
2	HRR	[illegible]	HRC	[illegible]
3	HRR	127.4	HRC	0.0
4	HRR	130.0	HRC	0.0
5	HRR	129.8	HRC	0.0

VAERAGE: 125.1[illegible]

MIN: 117.7

MAX: 130.0

****



D D

****

2025/01/17

15:42:43

Sample:SAMPLE D

Operator:UIRIMA

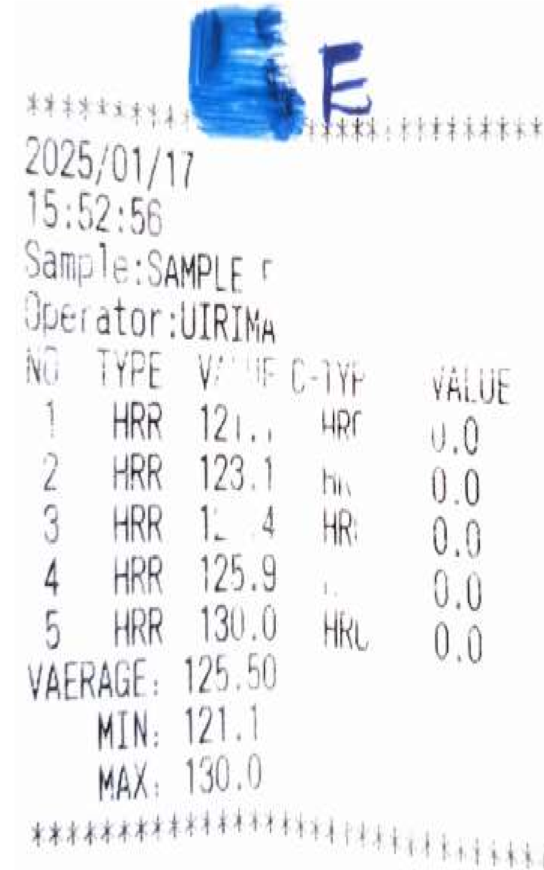
NO	TYPE	VALUE	C-TYPE	C-VALUE
1	HRR	127.6	HRC	0.0
2	HRR	126.9	HRC	0.0
3	HRR	125.4	HRC	0.0
4	HRR	129.2	HRC	0.0
5	HRR	129.3	HRC	0.0

VAERAGE: 127.66

MIN: 125.4

MAX: 129.3

****



E E

****

2025/01/17

15:52:56

Sample:SAMPLE E

Operator:UIRIMA

NO	TYPE	VALUE	C-TYPE	C-VALUE
1	HRR	121.[illegible]	HRC	0.0
2	HRR	123.1	HRC	0.0
3	HRR	1[illegible].4	HRC	0.0
4	HRR	125.9	HRC	0.0
5	HRR	130.0	HRC	0.0

VAERAGE: 125.50

MIN: 121.1

MAX: 130.0

****

Appendix L: The PPH impact test results.

Appendix M: PPH Tensile test Specifications.

BatchNo	SampleNo	TestDate	Operator	Shape	Size(mm)	Area(mm^2)	Le(mm)
PPH	01	2025-02-13	WILLIAM	Sheet (width * thickness)	12.55*3.49	43.80	100.0
PPH	02	2025-02-13	WILLIAM	Sheet (width * thickness)	12.6*3.20	40.32	100.0
PPH	03	2025-02-13	WILLIAM	Sheet (width * thickness)	12.38*3.08	38.13	100.0
PPH-second	04	2025-03-05	WILLIAM	Sheet (width * thickness)	13.44*3.20	43.01	100.0
PPH-second	05	2025-03-05	WILLIAM	Sheet (width * thickness)	10.90*2.90	31.61	100.0

Appendix N: PPH Tensile test results

Lc(mm)	Fm(N)	Rm(MPa)	Fb(N)	Rb(MPa)	FeH(N)	ReH(MPa)	E(MPa)
92	7525.00	172	7525.00	172	7410.00	169	13208
105	7620.00	189	6370.00	158	7485.00	186	2882
124	2175.00	57.0	870.00	22.8	2155.00	56.5	6134
86	2235.00	52.0	570.00	13.3	2210.00	51.4	5467
90	2025.00	64.1	685.00	21.7	1445.00	45.7	1233

Maximum strain(%)	Destructive strain(%)	Ae(%)
5.0	5.0	1.1
5.4	16	4.6
8.1	10	8.0
4.7	11	4.2
9.4	14	7.9

Appendix O: PPH Compression test results

BatchNo	SampleNo	TestDate	Operator	Shape
PPH	02	2025-02-18	BAKWATANA WILLIAM	Rectangle (length * width)
PPH	03	2025-02-18	BAKWATANA WILLIAM	Rectangle (length * width)
PPH	04	2025-02-18	BAKWATANA WILLIAM	Rectangle (length * width)
PPH	05	2025-02-18	BAKWATANA WILLIAM	Rectangle (length * width)
PPH	01	2025-02-18	BAKWATANA WILLIAM	Rectangle (length * width)

Size(mm)	Area(mm^2)	Le(mm)	Fm(N)	Strength(MPa)
12.7*3.2	40.64	12.7	2890.00	71.1
12.7*3.2	40.64	12.7	2505.00	61.6
12.7*3.2	40.64	12.7	2790.00	68.7
12.7*3.2	40.64	12.7	2485.00	61.1
12.7*3.2	40.64	12.7	2425.00	59.7

Fb(N)	Failure stress(MPa)	FeH(N)	ReH(MPa)	E(MPa)
2170.00	53.4	2660.00	65.5	4145
1820.00	44.8	2230.00	54.9	1606
845.00	20.8	1695.00	41.7	5783
1825.00	44.9	2340.00	57.6	1630
445.00	10.9	1885.00	46.4	2638

Maximum strain(%)	Destructive strain(%)	Ae(%)
11	17	5.8
9.4	30	8.3
14	31	3.5
15	39	12
14	24	8.8

Appendix P: Partial Pressures of HCl over aqueous Solutions of HCl

TABLE 2-10 Partial Pressures of HCl over Aqueous Solutions of HCl*

$\log_{10} p\text{mm} = A - B/T$, ($T$ in K), which, however, agrees only approximately with the table. The table is more nearly correct. mmHg, °C

% HCl	A	B	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	60°	70°	80°	90°	100°	110°
2	11.8037	4736			0.0000117	0.000023	0.000044	0.000084	0.000151	0.000275	0.00047	0.00083	0.00140	0.00380	0.0100	0.0245	0.058	0.132	0.280
4	11.6400	4471	0.000018	0.000036	.000069	.000131	.00024	.00044	.00077	.00134	.0023	.00385	.0064	.0165	.0405	.095	.21	.46	.93
6	11.2144	4202	.000066	.000125	.000234	.000425	.00076	.00131	.00225	.0038	.0062	.0102	.0163	.040	.094	.206	.44	.92	1.78
8	11.0406	4042	.000118	.000323	.000583	.00104	.00178	.0031	.00515	.0085	.0136	.022	.0344	.081	.183	.39	.82	1.64	3.10
10	10.9311	3908	.00042	.00075	.00134	.00232	.00395	.0067	.0111	.0178	.0282	.045	.069	.157	.35	.73	1.48	2.9	5.4
12	10.7900	3765	.00099	.00175	.00305	.0052	.0088	.0145	.0234	.037	.058	.091	.136	.305	.66	1.34	2.65	5.1	9.3
14	10.6954	3636	.0024	.00415	.0071	.0118	.0196	.0316	.050	.078	.121	.185	.275	.60	1.25	2.50	4.8	9.0	16.0
16	10.6261	3516	.0056	.0095	.016	.0265	.0428	.0685	.106	.163	.247	.375	.55	1.17	2.40	4.66	8.8	16.1	28
18	10.4957	3376	.0135	.0225	.037	.060	.095	.148	.228	.345	.515	.77	1.11	2.3	4.55	8.6	15.7	28	48
20	10.3833	3245	.0316	.052	.084	.132	.205	.32	.48	.72	1.06	1.55	2.21	4.4	8.5	15.6	28.1	49	83
22	10.3172	3125	.0734	.119	.187	.294	.45	.68	1.02	1.50	2.18	3.14	4.42	8.6	16.3	29.3	52	90	146
24	10.2185	2995	.175	.277	.43	.66	1.00	1.49	2.17	3.14	4.5	6.4	8.9	16.9	31.0	54.5	94	157	253
26	10.1303	2870	.41	.64	.98	1.47	2.17	3.20	4.56	6.50	9.2	12.7	17.5	32.5	58.5	100	169	276	436
28	10.0115	2732	1.0	1.52	2.27	3.36	4.90	7.05	9.90	13.8	19.1	26.4	35.7	64	112	188	309	493	760
30	9.8763	2593	2.4	3.57	5.23	7.60	10.6	15.1	21.0	28.6	39.4	53	71	124	208	340	542	845	
32	9.7523	2457	5.7	8.3	11.8	16.8	23.5	32.5	44.5	60.0	81	107	141	238	390	623	970		
34	9.6061	2316	13.1	18.8	26.4	36.8	50.5	68.5	92	122	161	211	273	450	720				
36	9.5262	2229	29.0	41.0	56.4	78	105.5	142	188	246	322	416	535	860					
38	9.4670	2094	63.0	87.0	117	158	210	277	360	465	598	758	955						
40	9.2156	1939	130	176	233	307	399	515	627	830									
42	8.9925	1800	253	332	430	560	709	900											
44	8.8621	1681	510	655	840														
46			940																

*Accuracy, ca. 2 percent for solutions of 15 to 30 percent HCl between 0 and 100°; for solutions of > 30 percent HCl the accuracy is ca. 5 percent at the lower temperatures and ca. 15 percent at the higher temperatures. Below 15 percent HCl, the accuracy is ca. 5 percent at the lower temperatures and higher strengths to ca. 15 to 20 percent at the lower strengths and perhaps 15 to 20 percent at the higher temperatures and lower strengths.

Appendix Q: Partial Pressures of water over aqueous Solutions of HCl

TABLE 2-9 Partial Pressures of Water over Aqueous Solutions of HCl*

$\log_{10} p\text{mm} = A - B/T$, ($T$ in K), which, however, agrees only approximately with the table. The table is more nearly correct.

Partial pressure of H_2O, mmHg, °C

% HCl	A	B	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	60°	70°	80°	90°	100°	110°
6	8.99156	2282	4.18	6.04	8.45	11.7	15.9	21.8	29.1	39.4	50.6	66.2	86.0	139	220	333	492	715	
10	8.99864	2295	3.84	5.52	7.70	10.7	14.6	20.0	26.8	35.5	47.0	61.5	80.0	130	204	310	463	677	960
14	8.97075	2300	3.39	4.91	6.95	9.65	13.1	18.0	24.1	31.9	42.1	55.3	72.0	116	185	273	425	625	892
18	8.98014	2323	2.87	4.21	5.92	8.26	11.3	15.4	20.6	27.5	36.4	47.9	62.5	102	162	248	374	550	783
20	8.97877	2334	2.62	3.83	5.40	7.50	10.3	14.1	19.0	25.1	33.3	43.6	57.0	93.5	150	230	345	510	729
22	9.02708	2363	2.33	3.40	4.82	6.75	9.30	12.6	17.1	22.8	30.2	39.8	52.0	85.6	138	211	317	467	670
24	8.96022	2356	2.05	3.04	4.31	6.03	8.30	11.4	15.4	20.4	27.1	35.7	46.7	77.0	124	194	290	426	611
26	9.01511	2390	1.76	2.60	3.71	5.21	7.21	9.95	13.5	18.0	24.0	31.7	41.5	69.0	112	173	261	387	555
28	8.97611	2395	1.50	2.24	3.21	4.54	6.32	8.75	11.8	15.8	21.1	27.9	36.5	60.7	99.0	154	234	349	499
30	9.00117	2422	1.26	1.90	2.73	3.88	5.41	7.52	10.2	13.7	18.4	24.3	32.0	53.5	87.5	136	207	310	444
32	9.03317	2453	1.04	1.57	2.27	3.25	4.55	6.37	8.70	11.7	15.7	21.0	27.7	46.5	76.5	120	184	275	396
34	9.07143	2487	0.85	1.29	1.87	2.70	3.81	5.35	7.32	9.95	13.5	18.1	24.0	40.5	66.5	104	161	243	355
36	9.11815	2526	0.68	1.03	1.50	2.19	3.10	4.41	6.08	8.33	11.4	15.4	20.4	34.8	57.0	90.0	140	212	311
38	9.20783	2579	0.53	0.81	1.20	1.75	2.51	3.60	5.03	6.92	9.52	13.0	17.4	29.6	49.1	77.5	120	182	266
40	9.33923	2647	0.41	0.63	0.94	1.37	2.00	2.88	4.09	5.68	7.85	10.7	14.5	25.0	42.1	67.3	105	158	230
42	9.44953	2709	0.31	0.48	0.72	1.06	1.56	2.30	3.28	4.60	6.45	8.90	12.1	21.2	35.8	57.2	89.2	135	195

*Accuracy, ca. 2 percent for solutions of 15 to 30 percent HCl between 0 and 100°; for solutions of > 30 percent HCl the accuracy is ca. 5 percent at the lower temperatures and ca. 15 percent at the higher temperatures. Below 15 percent HCl, the accuracy is ca. 5 percent at the lower temperatures and higher strengths to ca. 15 to 20 percent at the lower strengths and perhaps 15 to 20 percent at the higher temperatures and lower strengths.

Appendix R: SAP record for 2-inch pipe consumption

Reservation List Inventory Management

Reservation Item Adopt

Plant	Reservation	Mvt Type Text	I...	R...	Reqmts date	MvT	D/C	Material	Material Description	Reqmnt q...	Diff. q...	Unit	RCa	Acct assgt	Bat...	Cost Ctr
2300	1000024364	GI for order	4		25.03.2019	261	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	5	5	EA	F	000010000070		
2300	1000024364	GI for order	15		25.03.2019	261	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	1	1	EA	F	000010000070		
2300	1000055296	GI for cost center	1		19.05.2019	201	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	1	0	EA	K	0000200037		200037
2300	1000059184	GI for order	1		29.05.2019	261	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	1	0	EA	F	000010000257		
2300	1000059184	GI for order	15		29.05.2019	261	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	1	1	EA	F	000010000257		
2300	1000060471	GI for order	1		04.06.2019	261	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	3	3	EA	F	000010000263		
2300	1000061160	GI for cost center	1		05.06.2019	201	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	1	0	EA	K	0000200339		200339
2300	1000071339	GI for order	1		01.07.2019	261	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	1	0.500	EA	F	000010000292		
2300	1000071343	GI for order	1		01.07.2019	261	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	1	1	EA	F	000010000293		
2300	1000140673	GI for order	9		16.01.2020	261	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	1	1	EA	F	000010000835		
2300	1000207921	GI for order	5		07.08.2020	261	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	5	0	EA	F	000010001754		
2300	1000249986	GI for order	3		27.11.2020	261	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	1	1	EA	F	000010002256		
2300	1000329484	GI for order	2		22.06.2021	261	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	3	0	EA	F	000010003155		
2300	1000554495	GI for cost center	1		01.02.2023	201	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	1	0	EA	K	0000200325		200325
2300	1000571362	GI for cost center	2		15.03.2023	201	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	2	2	EA	K	0000200337		200337
2300	1000576508	GI for order	10		29.03.2023	261	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	3	0	EA	F	000010005887		
2300	1000581261	GI for cost center	1		11.04.2023	201	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	1	0	EA	K	0000200337		200337
2300	1000653255	GI for cost center	3		27.09.2023	201	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	5	0	EA	K	0000200325		200325
2300	1000719799	GI for cost center	2		29.02.2024	201	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	10	0	EA	K	0000200039		200039
2300	1000726976	GI for cost center	6		16.03.2024	201	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	3	0	EA	K	0000200325		200325
2300	1000761260	GI for cost center	1		05.06.2024	201	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	10	10	EA	K	0000200337		200337
2300	1000792489	GI for cost center	10		10.08.2024	201	H	40008450	MS SEAMLESS PIPE 2"NBX6 MTR, SCH 40	10	0	EA	K	0000200617		200617

Appendix S: SAP record for 2-inch flange consumption

Reservation List Inventory Management

Reservation Item Adopt

Plant	Reservation	Mvt Type Text	Itm	R...	Reqmts date	MvT	D/C	Material	Description	Reqmnt q...	Diff. q...	Unit	RCa	Acct assgt	Bat...	Cost Ctr
2300	1000061160	GI for cost center	2		05.06.2019	201	H	40003597	MS FLANGE 2"	2	0	PC	K	0000200339		200339
2300	1000071343	GI for order	6		01.07.2019	261	H	40003597	MS FLANGE 2"	1	0	PC	F	000010000293		
2300	1000093144	GI for order	2		30.08.2019	261	H	40003597	MS FLANGE 2"	1	0	PC	F	000010000458		
2300	1000207921	GI for order	7		07.08.2020	261	H	40003597	MS FLANGE 2"	5	5	PC	F	000010001754		
2300	1000207921	GI for order	16		07.08.2020	261	H	40003597	MS FLANGE 2"	1	1	PC	F	000010001754		
2300	1000249986	GI for order	4		27.11.2020	261	H	40003597	MS FLANGE 2"	4	0	PC	F	000010002256		
2300	1000329484	GI for order	1		22.06.2021	261	H	40003597	MS FLANGE 2"	10	0	PC	F	000010003155		
2300	1000393845	GI for order	2		04.12.2021	261	H	40003597	MS FLANGE 2"	1	0	PC	F	000010004050		
2300	1000424272	GI for cost center	3		21.02.2022	201	H	40003597	MS FLANGE 2"	1	1	PC	K	0000200325		200325
2300	1000424341	GI for order	3		23.02.2022	261	H	40003597	MS FLANGE 2"	3	0	PC	F	000010004324		
2300	1000554495	GI for cost center	5		01.02.2023	201	H	40003597	MS FLANGE 2"	1	0	PC	K	0000200325		200325
2300	1000576508	GI for order	3		29.03.2023	261	H	40003597	MS FLANGE 2"	5	5	PC	F	000010005887		
2300	1000646096	GI for cost center	8		11.09.2023	201	H	40003597	MS FLANGE 2"	2	0	PC	K	0000200325		200325
2300	1000704084	GI for cost center	7		25.01.2024	201	H	40003597	MS FLANGE 2"	4	4	PC	K	0000200325		200325
2300	1000704173	GI for order	1		27.01.2024	261	H	40003597	MS FLANGE 2"	2	0	PC	F	000010006956		
2300	1000710074	GI for cost center	1		07.02.2024	201	H	40003597	MS FLANGE 2"	2	2	PC	K	0000200337		200337
2300	1000733499	GI for cost center	1		01.04.2024	201	H	40003597	MS FLANGE 2"	6	0	PC	K	0000200327		200327
2300	1000733522	GI for cost center	1		02.04.2024	201	H	40003597	MS FLANGE 2"	2	2	PC	K	0000200039		200039
2300	1000751840	GI for cost center	1		15.05.2024	201	H	40003597	MS FLANGE 2"	1	0	PC	K	0000200338		200338
2300	1000761260	GI for cost center	2		05.06.2024	201	H	40003597	MS FLANGE 2"	10	0	PC	K	0000200337		200337
2300	1000773374	GI for cost center	1		01.07.2024	201	H	40003597	MS FLANGE 2"	10	0	PC	K	0000200337		200337
2300	1000815527	GI for cost center	1		30.09.2024	201	H	40003597	MS FLANGE 2"	2	0	PC	K	0000200037		200037
2300	1000817398	GI for cost center	1		04.10.2024	201	H	40003597	MS FLANGE 2"	2	2	PC	K	0000200037		200037
2300	1000825858	GI for cost center	6		25.10.2024	201	H	40003597	MS FLANGE 2"	2	2	PC	K	0000200325		200325
2300	1000839868	GI for cost center	1		25.11.2024	201	H	40003597	MS FLANGE 2"	2	2	PC	K	0000200337		200337
2300	1000856576	GI for order	15		06.01.2025	261	H	40003597	MS FLANGE 2"	8	0	PC	F	000010008141		
2300	1000870130	GI for cost center	1		05.02.2025	201	H	40003597	MS FLANGE 2"	8	8	PC	K	0000200337		200337

Appendix T: SAP record for Reducers consumption

Reservation List Inventory Management

Reservation Item Adopt

Plant	Reservation	Mvt Type Text	I...	R...	Reqmts date	MvT	D/C	Material	Material Description	Reqmnt q...	Diff. q...	Unit	RCa	Acct assgt	Bat...	Cost Ctr
2300	1000059184	GI for order	6		29.05.2019	261	H	40003640	MS REDUCER 2"X11/2"	2	2	PC	F	000010000257		
2300	1000638365	GI for cost center	2		25.08.2023	201	H	40003640	MS REDUCER 2"X11/2"	1	0	PC	K	0000200325		200325
2300	1000704084	GI for cost center	8		25.01.2024	201	H	40003640	MS REDUCER 2"X11/2"	2	2	PC	K	0000200325		200325
2300	1000735421	GI for cost center	2		05.04.2024	201	H	40003640	MS REDUCER 2"X11/2"	1	1	PC	K	0000200325		200325
2300	1000735437	GI for cost center	2		05.04.2024	201	H	40003640	MS REDUCER 2"X11/2"	2	0	PC	K	0000200325		200325
2300	1000825858	GI for cost center	2		25.10.2024	201	H	40003640	MS REDUCER 2"X11/2"	2	0	PC	K	0000200325		200325
2300	1000834576	GI for cost center	1		14.11.2024	201	H	40003640	MS REDUCER 2"X11/2"	2	0	PC	K	0000200618		200618
2300	1000850837	GI for cost center	1		20.12.2024	201	H	40003640	MS REDUCER 2"X11/2"	2	0	PC	K	0000200609		200609
2300	1000851067	GI for cost center	2		21.12.2024	201	H	40003640	MS REDUCER 2"X11/2"	1	0	PC	K	0000200618		200618
2300	1000870254	GI for cost center	1		05.02.2025	201	H	40003640	MS REDUCER 2"X11/2"	2	0	PC	K	0000200327		200327
2300	1000870309	GI for cost center	1		05.02.2025	201	H	40003640	MS REDUCER 2"X11/2"	1	0	PC	K	0000200327		200327

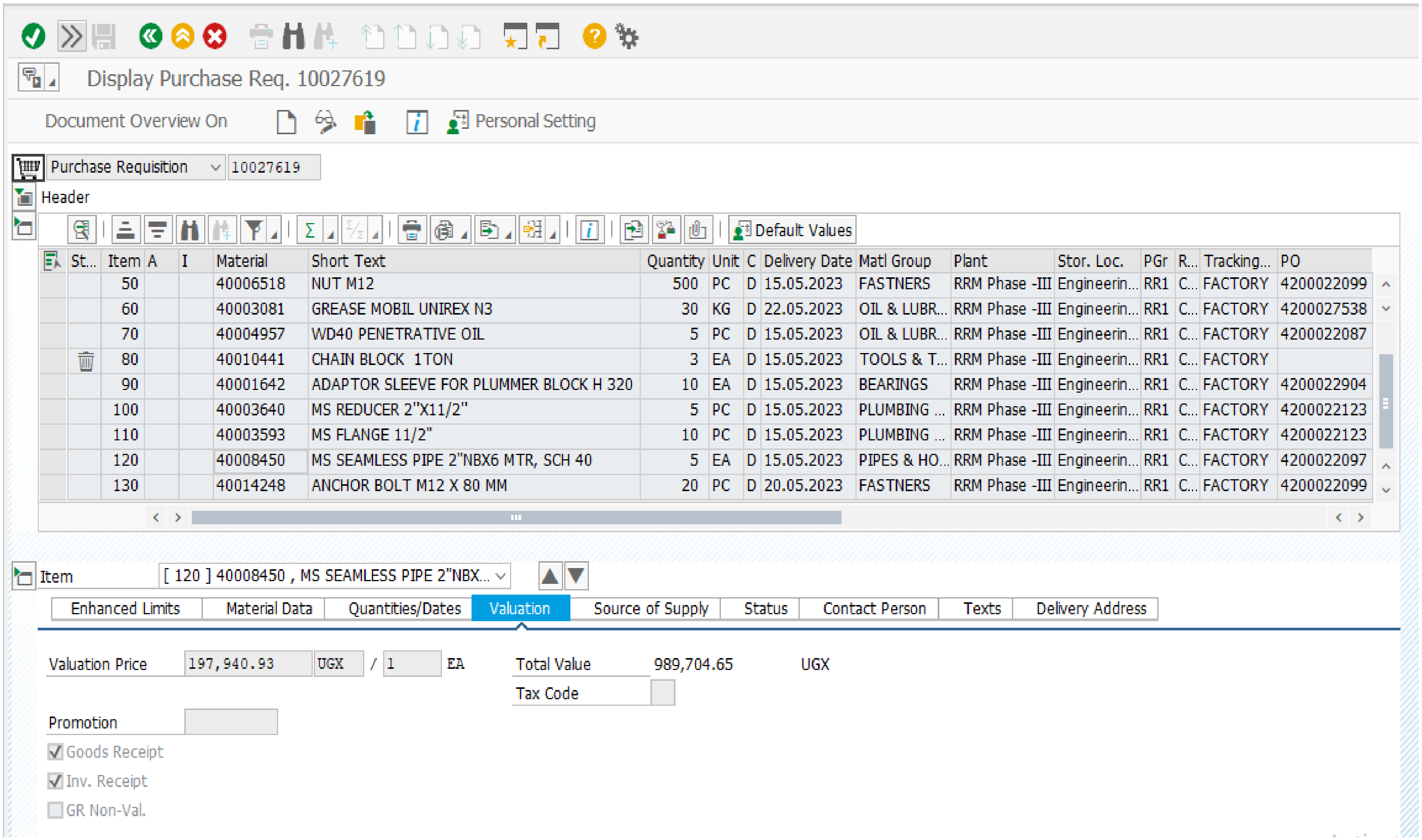
Appendix U: SAP record for 2-inch Tee consumption

Reservation List Inventory Management

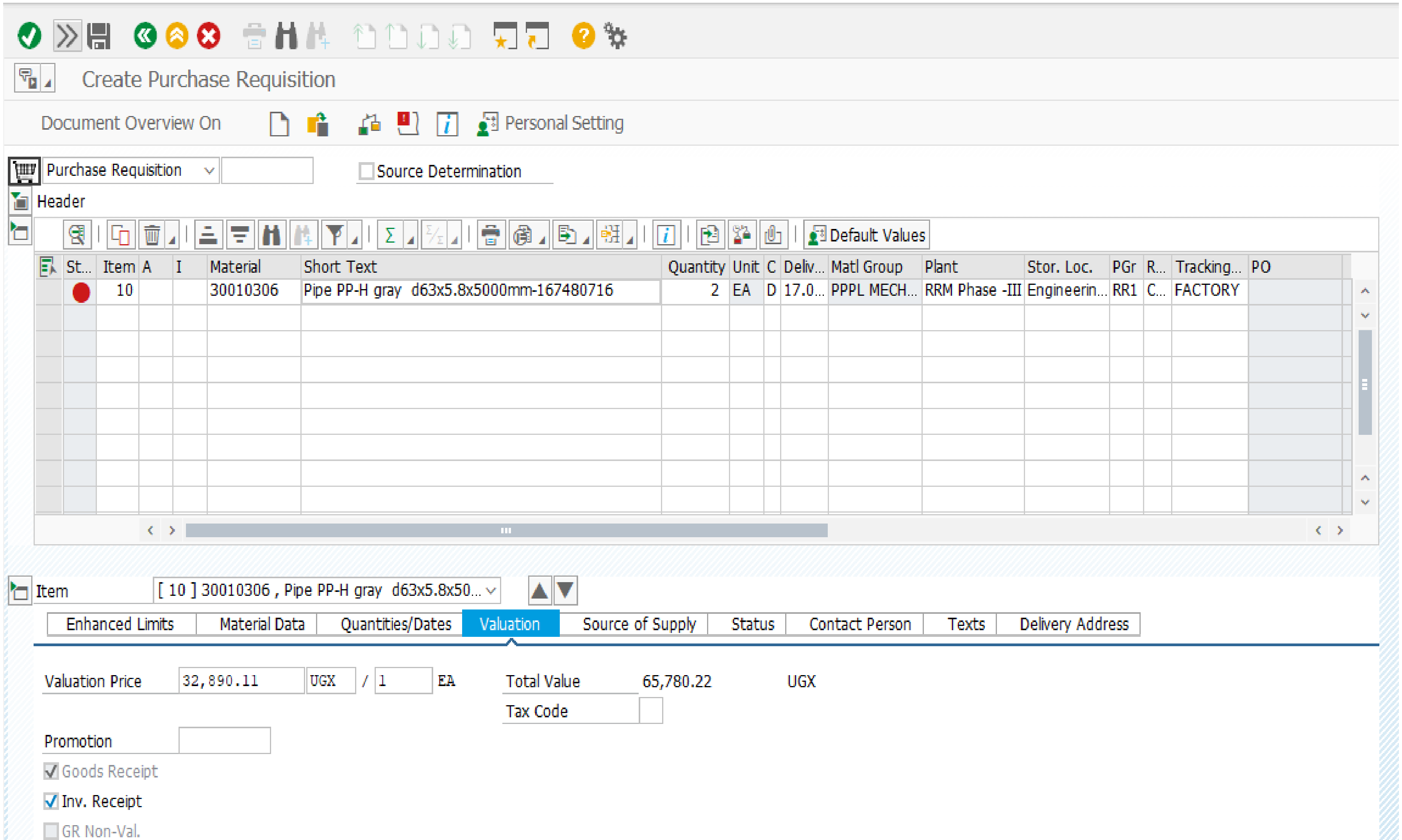
Reservation Item Adopt

Plant	Reservation	Mvt Type Text	I...	R...	Reqmts date	MvT	D/C	Material	Description	Reqmnt q...	Diff. q...	Unit	RCa	Acct assgt	Bat...	Cost Ctr
2300	1000091722	GI for order	12		28.08.2019	261	H	40003681	MS TEE 2"	2	2	PC	F	000030020417		
2300	1000424272	GI for cost center	4		21.02.2022	201	H	40003681	MS TEE 2"	1	1	PC	K	0000200325		200325
2300	1000424341	GI for order	4		23.02.2022	261	H	40003681	MS TEE 2"	1	0	PC	F	000010004324		
2300	1000502334	GI for cost center	1		13.09.2022	201	H	40003681	MS TEE 2"	1	0	PC	K	0000200331		200331
2300	1000534509	GI for cost center	1		07.12.2022	201	H	40003681	MS TEE 2"	2	0	PC	K	0000200034		200034
2300	1000554495	GI for cost center	2		01.02.2023	201	H	40003681	MS TEE 2"	1	0	PC	K	0000200325		200325
2300	1000663048	GI for cost center	5		20.10.2023	201	H	40003681	MS TEE 2"	4	0	PC	K	0000200602		200602
2300	1000735421	GI for cost center	1		05.04.2024	201	H	40003681	MS TEE 2"	1	1	PC	K	0000200325		200325
2300	1000735437	GI for cost center	3		05.04.2024	201	H	40003681	MS TEE 2"	2	0	PC	K	0000200325		200325
2300	1000761260	GI for cost center	3		05.06.2024	201	H	40003681	MS TEE 2"	4	0	PC	K	0000200337		200337
2300	1000870130	GI for cost center	2		05.02.2025	201	H	40003681	MS TEE 2"	4	4	PC	K	0000200337		200337
2300	1000870251	GI for cost center	2		05.02.2025	201	H	40003681	MS TEE 2"	1	0	PC	K	0000200331		200331

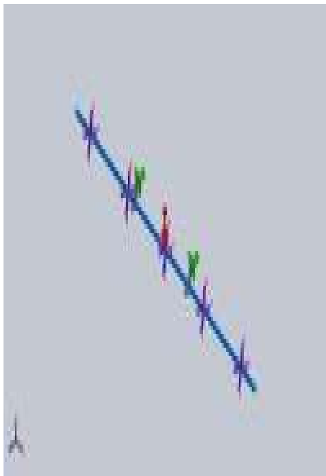
Appendix V: Valuation price for MS seamless pipe 2"



Appendix W: Valuation price for PPH Pipe d63



Appendix X: Pipe and support material properties used in the Flexural Stress simulations

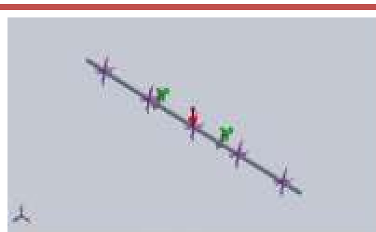
Model Reference	Properties		Components
	Name:	**PPH progef**	SolidBody 1(Boss-Extrude1)(pipe simulation-1)
	Model type:	Linear Elastic Isotropic	
	Default failure criterion:	Unknown	
	Yield strength:	3.103e+07 N/m^2	
	Tensile strength:	3.861e+07 N/m^2	
	Compressive strength:	4.482e+07 N/m^2	
	Elastic modulus:	1.29966e+09 N/m^2	
	Poisson's ratio:	0.43	
	Mass density:	899.6 kg/m^3	
	Thermal expansion coefficient:	9e-05 /Kelvin	
Curve Data:N/A			
	Name:	**Plain Carbon Steel**	SolidBody 1(Sweep1)(point support-1), SolidBody 1(Sweep1)(point support-2)
	Model type:	Linear Elastic Isotropic	
	Default failure criterion:	Unknown	
	Yield strength:	2.20594e+08 N/m^2	
	Tensile strength:	3.99826e+08 N/m^2	
	Elastic modulus:	2.1e+11 N/m^2	
	Poisson's ratio:	0.28	
	Mass density:	7,800 kg/m^3	
	Shear modulus:	7.9e+10 N/m^2	
	Thermal expansion coefficient:	1.3e-05 /Kelvin	
Curve Data:N/A			

Appendix Y: Pipe and Support Loads & Fixtures used in the Flexural Stress Simulations

Fixture name	Fixture Image	Fixture Details
Fixed-1		Entities: **2 face(s)** Type: Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	0.00853157	59.039	-1.05429	59.0484
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details
Force-1		**Entities:** **1 face(s)** **Type:** Apply normal force **Value:** 20 N
Gravity-1		**Reference:** **Top Plane** **Values:** 0 0 -9.81 **Units:** m/s^2
Pressure-1		**Entities:** **1 face(s)** **Type:** Normal to selected face **Value:** 101,325 **Units:** N/m^2 **Phase Angle:** 0 **Units:** deg
Temperature-1		**Entities:** **1 face(s)** **Temperatur e:** 110 Celsius

Appendix Z: Pipe and support Mesh information used in the Flexural Stress simulations

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	27.7705 mm
Minimum element size	9.25674 mm
Mesh Quality	High
Remesh failed parts independently	Off
Reuse mesh for identical parts in an assembly (Blended curvature-based mesher only)	Off

Total Nodes	26567
Total Elements	13127
Maximum Aspect Ratio	24.063
% of elements with Aspect Ratio < 3	30.9
Percentage of elements with Aspect Ratio > 10	1.56
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:04
Computer name:	

Appendix AA: Check sheet

COMPANY	Roofing Rolling Mills		OPERATOR/TECHNICIAN	Tinayeshwa Tom									
SECTION	PPPL		DOJ	6/05/2021									
Condensate system Performance Characteristics													
Parameter	**Parameter Feature/ Parameter Description**	**Parameter Range**	**acknowledge**	**Measured Value/ Chosen Parameter Feature**									
				Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**	**Day 8**	**Day 9**	**Day 10**
Condensate Equipments	Type of stream trap	Mechanical	✓										
		Thermostatic	✓										
		Thermodynamic											
	Type of Condensate pump	Mechanical											
		Electric centrifugal pump	✓										
	Type of isolation valves	Gate valve											
		Ball valve											
		Piston valve											
		Globe valve	✓										
	Type of check valves	Swing check valve											
		Lift check valve											
		Disc check valve	✓										
	Type of flow meter	Orifice plate											
		Vortex											
		Electromagnetic	✓										
	Type of heat exchanger	Shell and tube											
		Plate											
		Coil	✓										
	Type of Pressure gauge	Bourdon tube	✓										
		Digital	✓										
Steam usage	Heated liquid	Acid	✓										
		Water											
		Coolant											
		Oil											
	Heating Air	Atmospheric Air	✓										
		Exhaust fumes											
	Direct heating	Water											
		Tanks / vats											
Steam parameters	Temperature	130 - 150 °C	✓	143°C	145°C	147°C	144°C	146°C	147°C	143°C	147°C	146°C	145°C
		151 -180 °C											
	Pressure	3 - 5 Bar	✓	4.5	4.5	4.8	4.5	4.5	4.9	4.5	4.9	4.9	4.5
	→ Supply pipe length → 84m 214 - 228	6 - 10 Bar											
Condensate recovery	Condensate recovered		✓										
	Condensate dumped to sewers												
Condensate recovery rate													
Heat up period	< 20 mins												
	20-30 mins		30 mins										
	> 30 mins												
	Initial liquid temp	Room temp											
		25 - 30°C											

		31 - 40°C	40°C										
Heated liquid properties	Final liquid temp	50 - 80°C	80°C										
		81 - 95°C											
	Volume of the liquid	< 30 m³	20 m³										
		30-70 m³											
		71-100 m³											
Heated Air properties	Inlet temp	Room temp											
		25 - 30°C	25°C										
	Outlet temp	50 - 80°C	62°C										
		81 - 110°C											
		110 - 150°C											
	Air flow rate	<20 m³											
		21 - 50 m³	8500 m³										
Energy Efficiency													
Condensate pipe parameters	Insulation material type	Rockwool	✓										
		Calcium silicate											
		Fiber glass											
	Pipe material	Steel											
		PPH											
		Both PPH & Steel	✓										
	Pipe length	< 50m											
		50 - 100m C14 - C28	63m										
		100 - 150m											
	Temperature radiated (Uninsulated steel fittings)	Elbow	117.8	117.6	117.3	122.1	109.6						
		Tee	124.1	126.7	123.5	123.6	117.6						
		Along the pipe Length	113.3	120.4	121.[illegible]	114.6	118.8						
		Isolation Valve	80.2	57.4	80.8	86.1	92.1						
	Temperature radiated (Uninsulated PPH fittings)	Elbow	76.6	76.9	76.9	80.3	79.9						
		Tee	74.3	69.2	70.	68	66.9						
		Along the pipe Length	77.3	76.8	74.4	75.3	75.1						
		Isolation Valve	46.6	45.7	42.7	53.3	47.1						
	Pipe size	1 inch											
		1.5 inch	✓										
		2 inch											
Reliability and Uptime													
Condesate system failure modes	Condensate leakage frequency	Once in 4 months											
		Once in a months											
		3 times a months	✓										
	Equipment failure frequency	Once in a year											
		Once in 6 months	✓										
		Once in 3 months											
	Maximum line down time	< 2 hours											
		2-4 hours	3hrs										
		> 4hours											

Condensate system safety	Work at height	< 7m	✓										
		7-12m											
	Frequency of burns	Monthly											
		Quarterly											
		Half yearly											
		Yearly	✓										
Condensate quality													
Condensate properties	Physical appearance	Clear and colourless	✓										
		Suspended particles											
	Chemical properties	Itchy on skin and eyes	✓										
		Electrical conductivity (µS/cm)		21.05	30.32	23.40	12.61	16.28	33.22	26.67	41.93	23.24	306.1
		pH		4.26	4.58	5.51	5.47	5.46	5.33	4.66	4.19	4.50	3.43
		Chocking smell	✓										

Appendix AB: Research Introductory Letters

KYAMBOGO UNIVERSITY
P. O. BOX 1, KYAMBOGO – KAMPALA, UGANDA
TEL: 041-287341, FAX: 041-220464
www.Kyambogo.ac.ug

Department of Mechanical and Production Engineering

19th JUNE 2024

THE EXECUTIVE DIRECTOR,
UGANDA INDUSTRIAL RESEARCH INSTITUTE,
P.O.BOX 7086,
KAMPALA.
UGANDA.

RE: INTRODUCTION LETTER FOR MR. KASAIJA CHARLES TO CONDUCT MSC RESEARCH EXPERIMENTS AT UIRI.

Dear Prof. Charles Kwesiga,

This is to introduce to you the above named student with Registration number **23/U/GMEM/0703/PE** pursuing a Master of Science Degree in Advanced Manufacturing Systems Engineering, Department of Mechanical and Production Engineering, Kyambogo University.

He intends to carry out research on "**Performance of Polypropylene Homopolyer (PPH) Pipes in Industrial Condensate Recovery Systems**", in partial fulfillment of the requirements for the award of a Master of Science Degree in Advanced Manufacturing Systems Engineering.

The purpose of this letter therefore is to request you to help him carry out laboratory tests and experiments concerning the research samples in your institution and get the findings related to the research area.

Any assistance rendered to him will be highly appreciated.
Thank you

Yours sincerely,

Maureen Nalubowa Ssempijja (PhD)
Head of Department Mechanical and Production Engineering
Email: maureenssempijja@kyu.ac.ug

HEAD OF DEPARTMENT MECHANICAL AND PRODUCTION ENGINEERING
KYAMBOGO UNIVERSITY
19 JUN 2024
P. O. BOX 1, KYAMBOGO

KYAMBOGO UNIVERSITY
P. O. BOX 1 KYAMBOGO
Tel: 041 - 4286792 Fax: 256-41-220464
Website :www.kyu.ac.ug Email: drgt@kyu.ac.ug
Directorate of Research and Graduate Training
Office of the Director

APPENDIX 8: INTRODUCTORY LETTER

Date: June 19, 2024

The Executive Director,
Uganda Industrial Research Institute
P.O Box 7086
Kampala-Uganda

Dear Sir/Madam,

RE: KASAIJA CHARLES

This is to Introduce to you the above-named student **Reg No: 23/U/GMEM/0703/PE** pursuing Master of Science in Advanced Manufacturing Systems, Department of Mechanical and Production Engineering, Kyambogo University.

He intends to carry out research on **"Performance of Polypropylene Homopolyer (PPH) pipes in Industrial Condensate Recovery Systems"** In Partial Fulfillment of the Requirements of the award of Master of Science in Advanced Manufacturing Systems of Kyambogo University

The purpose of this letter therefore is to request you to introduce the student to relevant offices as well support with any necessary assistance and guidance.

Any assistance rendered to him will be highly appreciated.

Yours sincerely,

Prof. Bosco Bua
AG. DIRECTOR

KYAMBOGO UNIVERSITY
19 JUN 2024
DIRECTOR
DIRECTORATE OF RESEARCH AND GRADUATE TRAINING

Appendix AC: Acceptance Letter

Engineering – Please handle
[signature]
6th Jan, 2025

C/o KASAIJA CHARLES
KYAMBOGO UNIVERSITY
P.O. BOX1, KYAMBOGO
KAMPALA, UGANDA
10TH OCTOBER,2024

THE EXECUTIVE DIRECTOR
UGANDA INDUSTRIAL RESEARCH INSTITUTE
P.O. BOX 7086
KAMPALA, UGANDA

UGANDA INDUSTRIAL RESEARCH INSTITUTE
OFFICE OF THE EXECUTIVE DIRECTOR
UIRI 03 JAN 25
RECEIVED
P. O. BOX 7086, KAMPALA

Dear sir,

RE: PERMISSION TO CONDUCT MSc RESEARCH EXTERIMENTS

I kindly submit to you a request to permit me to have my laboratory tests and experiment carried out at UIRI.

My research topic is "Performance of Polypropylene Homopolyer pipes in industrial condensate Recovery systems" and I intend to carryout physical tests on plastic samples to ascertain the rate of Thermal degradation.

Please attached introductory letter from the university and I am looking forward to your positive response.

Yours faithfully

[signature]

KASAIJA CHARLES
0778327412/0750334967
Kasaijacharles3@gmail.com

UGANDA INDUSTRIAL RESEARCH INSTITUTE
OFFICE OF THE EXECUTIVE DIRECTOR
UIRI 14 OCT 2024
RECEIVED
P. O. BOX 7086, KAMPALA

Appendix AD: Plagiarism Clearance Certificate

turnitin

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This receipt acknowledges that Turnitin received your paper. Below you will find the receipt information regarding your submission.

The first page of your submissions is displayed below.

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Assignment title:	Thesis 2
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File size:	34.19M
Page count:	127
Word count:	17,912
Character count:	98,745
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19/11/2025

PERFORMANCE OF POLYPROPYLENE HOMOPOLYMER (PPH) PIPES IN INDUSTRIAL CONDENSATE RECOVERY SYSTEMS

BY

KASAIJA CHARLES

A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTERS OF SCIENCE IN ADVANCED MANUFACTURING SYSTEMS ENGINEERING OF KYAMBOGO UNIVERSITY

OCTOBER 2025