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PLASTIC PIPES FOR HYDROCARBON TRANSPORT AND GENERAL USE

Mavis Sika OKYERE[1][0000-0002-8015-2164]

[1]Ghana National Gas Limited Company, Department of Pipelines and Stations.
225 Osibisa Close, Airport West, Accra – Ghana.

Abstract

Traditionally, steel pipelines have been used for the construction of hydrocarbon pipelines, with the use of plastic pipes being restricted to water and sewage applications. There has been a trend to substitute traditional steel pipes with plastic pipes for constructing pipelines used in the transportation of hydrocarbons. Plastic pipes can also be used for various associated applications, including seawater cooling lines, water injection lines, drilling effluent lines, ballast lines, fire mains, potable water lines, and sewage lines. Using plastic pipes for hydrocarbon transport and terminal applications is generally driven by cost. However, the material's corrosion and chemical resistance properties give it distinct advantages over ferrous materials. This research gives information on the selection process for the acceptance and suitability of plastic pipes for the transportation of hydrocarbons and general utility applications at terminals and pump stations.

Keywords: *Plastic, Polyethylene, Glass reinforced plastics, Corrosion resistance, Chemical resistance, Flexibility.*

Introduction

Plastic pipes have revolutionised the hydrocarbon industry by offering a versatile and cost-effective alternative to traditional metal piping. These pipes are known for their corrosion resistance, flexibility, and ease of installation, making them ideal for a wide range of applications in the oil and gas sector.

Historically, steel pipe has been the primary choice for pipeline construction in transporting hydrocarbons and other high-pressure applications. Plastic pipe, on the other hand, was typically reserved for low-pressure uses such as water, sewage, and gas utilities, or as a coating for steel pipe.

In recent years, there has been a shift towards using plastic pipes instead of traditional steel pipes for building hydrocarbon pipelines (see Fig. 1). Additionally, plastic pipes have become a viable option for other related applications, including seawater cooling lines, water injection lines, drilling effluent lines, ballast lines, fire mains, potable water, and sewage systems. While plastic is a relatively new material, its quality is continually improving. The decision to use plastic pipes for hydrocarbons and terminal applications is typically based on cost, but the material's corrosion and chemical resistance properties offer unique advantages over ferrous materials.

The availability of plastic used for pipe falls into two categories, namely thermoplastic pipe and thermosetting plastic pipe.

*Corresponding author: mavis.nyarko@ghanagas.com.gh / mariiooh@yahoo.com

Thermoplastic pipe

By achieving the required temperature, these polymers can be reformed and shaped. The heating results in a softening of the material that allows a welding process to be performed [1, 2]. Example of thermoplastic is Polyethylene (PE) pipe, High-density Polyethylene (HDPE), and polyvinyl chloride (PVC).

Thermosetting plastic pipe

These are formed by heat and pressure processes and are cured by a chemical reaction, which forms part of the process. Once formed, i.e. cured, these plastic pipes cannot be re-formed or re-shaped by heating and are analogous to concrete in this respect. Pipes in this group are significantly stronger than all thermoplastics currently used for pipes. An example of a thermoset plastic pipe is a Glass Reinforced Plastic (GRP) pipe, which is usually an epoxy resin-impregnated glass fibre. Fibreglass-reinforced RTRP Pipe is the only pipe in this group that has been used for gas distribution piping systems [6-7]. The interior of the Fibre-Glass Reinforced RTRP Pipe has a smooth finish. The external surface is rough with fibres visible in the epoxy matrix. The pipes are less temperature sensitive and, depending on the epoxy resin used, have better chemical resistance than most thermoplastic pipes. Their fracture behaviour is almost entirely by weeping, so brittle breaks are most likely not to be encountered. Joining is done by epoxy adhesives, and when properly carried out, is as strong as the pipe [1].

The study provides details regarding the criteria used in selecting plastic pipes for the safe and efficient transportation of hydrocarbons and general utility purposes at terminals and pump stations.

Applications

Plastic pipes are utilised in various segments of the hydrocarbon industry:

- upstream (Exploration and Production): HDPE pipes are used for saltwater disposal lines and gas gathering systems due to their corrosion resistance and flexibility [5].

- midstream (Transportation): PE and GRE/GRP pipes transport natural gas and other hydrocarbons [5].

- downstream (Processing and Distribution): PVC and CPVC pipes are used in water supply lines and chemical transport systems [5].

Justification for Current Research

Despite the numerous advantages of plastic pipes, there are still challenges that need to be addressed to optimise their use in the hydrocarbon industry. Current research is focused on:

- enhancing temperature tolerance: Developing new materials or composites that can withstand higher temperatures, making plastic pipes suitable for a broader range of applications.
- improving mechanical strength: Increasing the strength of plastic pipes to handle higher pressures and more demanding environments.
- UV resistance: Enhancing the UV resistance of plastic pipes to prevent degradation and extend their lifespan in outdoor applications.
- cost-effectiveness: Reducing the cost of advanced plastic pipes to make them more competitive with traditional metal pipes.

By addressing these challenges, ongoing research aims to further improve the performance and reliability of plastic pipes, ensuring they can meet the evolving demands of the hydrocarbon industry.

Properties of Pipe Materials

Four key characteristics can be utilised to evaluate the suitability of a material for pipeline applications, which include: strength, ductility, toughness, and corrosion resistance.

Strength is typically represented graphically through a stress-strain curve for the material. Fig. 2 illustrates the stress-strain properties of commonly used pipe materials [1].

Ductility refers to a material's ability to withstand bending stresses. Materials with low ductility, such as cast iron, are prone to breaking under bending stress, while materials with high ductility, like polyethene (PE), exhibit significant resistance to bending, as demonstrated in Fig. 3.

Fig. 1. An example of a plastic gas pipe being installed [6]

Toughness indicates a material's capacity to endure impact damage and its resistance to fracture. Table 1 compares the impact resistance of various pipe materials when subjected to different excavation tools (picks) [1, 7].

Based on Fig. 2, we can visualise the relationship between strain and stress for different materials. Here's a breakdown of what the graph shows:

Steel: The stress increases significantly with strain, indicating that steel can withstand high-stress levels even with small increases in strain. This makes it a strong and ductile material.

Ductile Iron: Similar to steel, ductile iron shows a substantial increase in stress with strain, though it starts at a slightly lower stress level. It also demonstrates good strength and ductility.

Polyethylene (PE): PE shows a much lower stress response to strain compared to metals. The stress increases gradually, indicating that PE is much less stiff and more flexible.

Polyvinyl Chloride (PVC): PVC has higher stress values than PE but lower than metals. It shows a moderate increase in stress with strain, indicating it is stiffer than PE but not as strong as metals.

Glass Reinforced Plastic (GRP): GRP shows a significant increase in stress with strain, similar to metals, but starts at a higher initial stress level. This indicates that GRP is very strong and stiff.

In summary, the graph shows that metals like steel and ductile iron have high-stress responses to strain, indicating high strength and ductility. Polymers like PE and PVC have lower stress responses, indicating more flexibility and less stiffness. GRP stands out with high initial stress and significant increases, showing it is both strong and stiff.

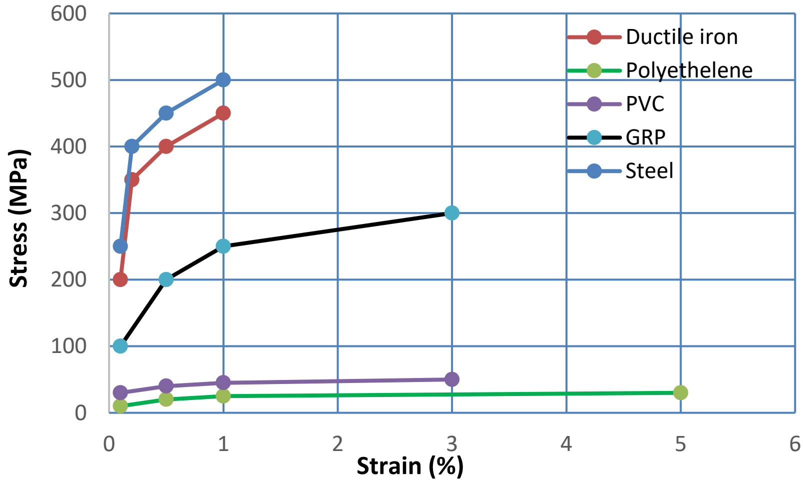

Fig. 2. Typical stress-strain relationships for different types of pipe materials [1, 3]

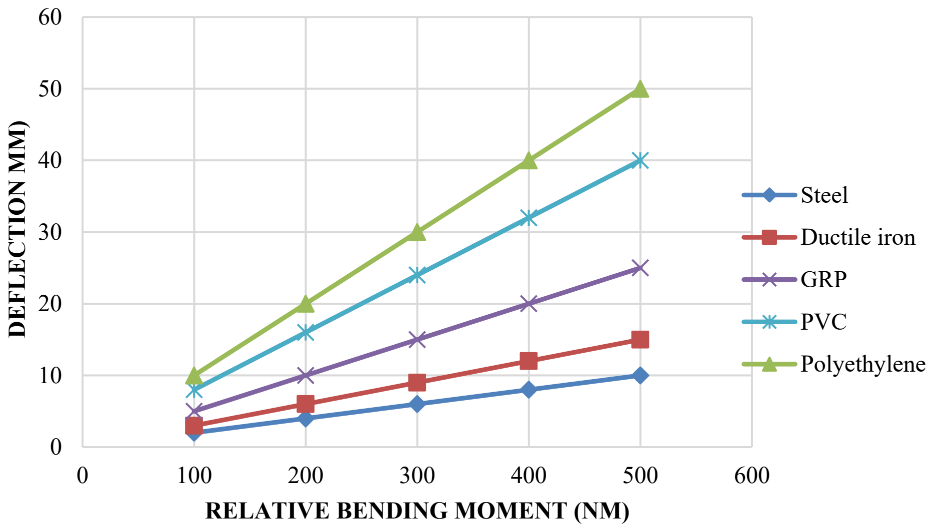

Fig. 3. Bending properties for 2-meter lengths of different pipe materials [1, 3]

Fig. 3. is a graph that demonstrates how different materials react to varying bending moments, showing their relative flexibility and strength. Each material exhibits a different slope, indicating how much it deflects under specific bending moments.

- Steel: Minimal deflection, indicating high stiffness and strength.
- Ductile Iron: Moderate deflection, more flexible than steel.
- Polyethylene (PE): Significant deflection, showing high flexibility.
- Polyvinyl Chloride (PVC): Moderate to high deflection.
- Glass-Fiber Reinforced Plastic (GRP): Moderate deflection, combining strength and flexibility.

Table 1. Impact resistance of various pipe materials

Pipe Material	Impact Resistance	Excavation Tool	Observations
HDPE	High	Pick	Minimal damage, high flexibility
PVC	Moderate	Pick	Some cracking, moderate brittleness
GRE/GRP	High	Pick	Minimal damage, high strength
PE	Moderate	Pick	Some deformation, moderate flexibility
PEX	High	Pick	Minimal damage, high flexibility
PP	Moderate	Pick	Some cracking, moderate brittleness

Observations

- **HDPE**: Exhibits high impact resistance due to its flexibility and toughness, making it less prone to damage from picks.
- **PVC**: Moderate impact resistance; can crack under high impact due to its brittleness.
- **GRE/GRP**: High impact resistance; strong and durable, with minimal damage observed.
- **PE**: Moderate impact resistance; flexible but can deform under impact.
- **PEX**: High impact resistance; flexible and tough, similar to HDPE.
- **PP**: Moderate impact resistance; can crack under high impact due to its brittleness.

Properties of Plastic Pipes

General Properties

The change from the use of traditional materials such as iron or steel to plastic for gas distribution piping systems, other hydrocarbons, and general use, is due to the following advantages and properties.

Resistance to corrosion both internally and externally

As plastic is not susceptible to corrosion in the same way as steel, it does not require internal or external coating to protect it from the environment or corrosive elements. Similarly, plastic pipes do not require the capital and operational costs of a cathodic protection (CP) system [1].

Thermally insulated steel pipe requires a very high integrity of coating to protect it from the ingress of water. If water does enter the coating and penetrate the insulation, it is complicated to remove. The presence of water inside the pipeline coating makes it difficult to protect steel pipes, as CP systems are ineffective in such a situation. Water-penetrating dry insulation (foam type) around a plastic pipe, such as GRP, will not result in any deterioration of the carrier pipe material.

No joints

Plastic pipe requires much simpler jointing and non-destructive testing (NDT) than that of an equivalent steel pipe. The grade and wall thickness of the plastic pipe required will be as per the manufacturer's standard grade and wall thickness specifications.

As plastics have a relatively low melting point, any heat resulting from an incident would quickly render the exposed plastic pipe inoperable, although fire-resistant plastics are available. The restricted temperature range of plastic pipe makes it unsuitable for pipelines where hot or excessively low temperatures are expected, either internally or externally. This makes some plastics unsuitable for some above-ground hydrocarbon applications or as above-ground fire water mains, where fire would result in failure and leakage [1].

Reasonable strength and ductility in fracture

Plastics are generally softer than steel and have less wear resistance and inherent toughness, which means that plastic pipes will not withstand aggressive pigging operations. If wax deposits are expected to be present in an oil, other methods of wax removal will have to be considered. It should be noted that the smooth surface of plastic pipes would resist the build-up of wax deposits (although no figures are available to verify or quantify the resistance properties of any of the plastics).

The weight of a plastic pipe is approximately 25% of an equivalent steel pipe.

Some forms of plastics are susceptible to ultraviolet (UV) and chemical degradation. However, the correct choice of plastic would provide pipes with UV and chemical stability to suit a particular application.

1. Ease of construction with semi-skilled labour
2. Low material cost

The Cost of Plastic Pipes

The cost advantages generally drive the suitability and use of the plastic pipe, although the corrosion and chemical resistance properties of the material give distinct advantages over ferrous materials. This is especially applicable where harmful chemicals are present in the ground, or the fluid being transported contains corrosive elements.

The cost savings associated with the use of plastic pipes are not from the cost of the pipe. The cost of a coated high-pressure steel pipe per meter is comparable to the cost per meter of a suitable plastic pipe such as GRP.

The cost savings associated with the use of plastic pipes, such as GRP, come from the savings associated with the transportation and handling of a lighter material and savings in construction costs. Relative savings of plastic than that of steel are accumulated from:

- Cheaper bulk transportation due to the loads being lighter than steel pipes;
- No requirement to provide and operate a cathodic protection (CP) system;
- No requirement to provide a test of a corrosion-resistant coating;
- Simple jointing procedures and low level of jointing skill;
- No requirement for involved NDT procedures of field joints;
- No requirement for heavy lifting equipment and welding plant during the construction process.
- The availability of some plastic pipes as continuous lengths reduces jointing costs and requires only narrow trench excavation.

Other Plastic Pipes Available

Manufacturers of plastic pipes have numerous plastics available that have been used for pipework, namely:

- ABS (thermoplastic -40°C to 70°C) food and beverage processing, refrigeration plant, chemical production;
- PVC (thermoplastic 0°C to 100°C) chemical process plant;
- Polypropylene (thermoplastic 0°C to 100°C) chemical and pharmaceutical industry;
- Vulcathene (ambient temperature) for chemical waste applications;
- PVDF (thermoplastic -40°C to 140°C) chemical and pharmaceutical industry.
- Polyethylene.

It should be noted that the above plastics are not normally used for the transportation of hydrocarbons by pipeline, and tend to be restricted to water and chemical plant applications.

However, it should be noted that the temperature, pressure ranges, and available sizes may result in suitable products being available in the future.

For this reason, checks should always be made with manufacturers to ascertain the available products on the market.

Polyethylene Pipes

Polyethylene is a 'polymer' material. The term polymer is derived from the Greek meaning 'many parts' and is used to describe materials having very long chemical chains made up of repeating units.

Polyethylene is made from linked molecules of ethylene, which is obtained from the processing of oil and natural gas [7]. However, the grades of polyethene required for gas distribution pipes require significant modification of the basic structure to obtain the long-term mechanical properties required for a safe gas distribution system [2, 5].

In general terms, the tremendous growth in recent years for plastics at the expense of metals in pipeline applications has resulted from the toughness of plastics, the material's strength combined with flexibility, offering the means for highly cost-competitive installed pipe systems. The combination of corrosion resistance and the simplicity of jointing has been instrumental in the widespread adoption of plastics, which is currently estimated to be around 2 million tonnes annually in Western Europe alone. Among the materials under consideration, polyethene (PE) pipe exhibits the lowest ultimate tensile strength, as illustrated in Fig. 2. However, it stands out for its flexibility and significant elongation at the point of failure. While it is not susceptible to galvanic corrosion, it does possess time-dependent strength characteristics. Despite these characteristics potentially leading to a failure in gas containment over time, historical data from the USA and Britain suggests that its lifespan significantly exceeds the anticipated design minimum of 50 years [19].

Advancements in polyethene (PE) pipe technology has led to the creation of materials that can function at pressures of 10 barg, incorporating robust safety factors . Future innovations, such as PE-XL, are expected to further enhance the range of operational pressures. Due to its corrosion resistance, PE can be seamlessly joined using automated fusion systems, offering numerous operational benefits. As a result, PE is the preferred material for the majority of gas companies. Nevertheless, it is important to note that while PE 80 is rated for operation up to 5 barg and PE 100 up to 10 barg, these pressure ratings may not be suitable for all locations. Consideration of safety and risk factors is essential [18, 19].

Properties of Polyethylene

1. Very flexible

Polyethylene pipe exhibits the lowest ultimate tensile strength among the materials under consideration; however, it stands out for its exceptional flexibility and significant elongation before failure.

2. It possesses a high degree of ductility
3. The material demonstrates strong resistance to bending.
4. No corrosion problems

Polyethylene is not susceptible to galvanic corrosion, although it does exhibit time-dependent strength characteristics.

5. With a life expectancy exceeding fifty (50) years, the time-dependent strength properties may eventually lead to gas containment failure. Nevertheless, historical data from the United States and the United Kingdom suggest that its lifespan significantly surpasses the anticipated design minimum of 50 years.

6. Polyethylene is favoured by most gas companies due to its corrosion resistance, ease of joining through automatic fusion systems, and various operational benefits. However, it is important to note that while PE 80 can function at pressures up to 5 barg and PE 100 at 10 barg, these pressure ratings may not be suitable for all locations. Safety and risk considerations must be considered.

7. The material is characterized by its low ultimate tensile strength and exhibits time-dependent strength properties.

Pressure and Temperature Ranges

The most common example of a thermoplastic used for hydrocarbons is a polyethene (PE) pipe. The operational temperature of PE is limited to between 0°C and 20°C, which if exceeded significantly reduces the working pressure (see Table 2. below).

PE has been used successfully for the past twenty years by gas and water distribution companies, for the transportation of gas up to pressures of 2barg and water up to 16 barg [19-20]. High-density PE (HDPE) has also been successfully used for gas pressures up to 16 barg [10, 14, 21].

PE 80 is capable of functioning at pressures of up to 5 barg, while PE 100 can operate at pressures reaching 10 barg [20].

Grades and Diameters Available

The choice of PE pipe relies on the Standard Dimensional Ratio (SDR), defined as the nominal outside diameter divided by the minimum wall thickness and the material grade (PE80, PE100, etc. depending on the manufacturer) as shown in Table 2-3. For example, PE80 is a high or medium-density PE (HDPE or MDPE) used for gas and water applications, PE100 is a high-performance PE (HPPE), PE-XL is also used for hot water applications, gas distribution, hot water supply, piping to radiators and underfloor heating [1, 10].

Table 2. PE pipe classification for water application [5, 11, 17, 19-20]

Temperature (°C)	**PE 80 – MDPE SDR 17.6/17**	**PE80 – MDPE SDR 11**	**PE 100 SDR 11**	**Life (Years)**
20	6.0	10.0	16.0	50
25	5.6	9.3	14.8	50
30	5.2	8.7	13.9	50
35	4.8	8.0	12.8	50
40	4.4	7.4	11.8	50
50	3.4	5.6	10.9	25
60	3.4	5.6	9.8	10

Key Points:

Polyethylene (PE) pipes are classified based on their material grade and Standard Dimension Ratio (SDR), which affects their pressure rating and application suitability. Here's a summary of the classifications for water applications:

1. PE 80 – MDPE (Medium Density Polyethylene)
    - SDR 17.6/17: Suitable for lower-pressure applications.
    - SDR 11: Suitable for higher-pressure applications.
2. PE 100 (High-Density Polyethylene)
    - SDR 11: Suitable for high-pressure applications and offers long-term strength and performance.

The lifespan of PE pipes can vary based on the operating temperature and pressure. Generally, PE pipes can last up to 50 years or more under optimal conditions

Further restrictions may apply, for example, ISO Standards restrict gas pressure of PE100 SDR11 at 10 barg, although no guidelines are available for oil applications [19-20].

It should be noted; that the maximum operating pressure may be limited by a particular client or the regulations of a specific country. Excessive ambient temperatures (in the ground) would therefore prohibit the use of PE pipe, as would hot wellhead conditions, heater installations and a large reduction in gas pressure (resulting in a low temperature). The pressure and temperature restrictions restrict the suitability of PE to hydrocarbon applications.,

The classification of Polyethylene (PE) pipes for gas distribution has evolved, reflecting improvements in material properties and performance standards. Here's a comparison of the previous and current ISO classifications:

Table 3. PE classification for gas distribution [1, 18]

	Previous classification	Current ISO classification
1st generation	PE 50	MRS 63
2nd generation	PE 63	MRS 80
3rd generation	PE 80	MRS 100

Key Points:

- 1st Generation (PE 50 to MRS 63): The initial classification, PE 50, has been updated to MRS 63, indicating a minimum required strength (MRS) of 6.3 MPa.
- 2nd Generation (PE 63 to MRS 80): The second generation, PE 63, has been reclassified to MRS 80, with an MRS of 8.0 MPa, reflecting improved material strength.
- 3rd Generation (PE 80 to MRS 100): The third generation, PE 80, is now classified as MRS 100, with an MRS of 10.0 MPa, representing the highest strength in this classification series.

These classifications ensure that PE pipes used in gas distribution meet stringent performance standards, providing safety and reliability in their applications.

Jointing of PE Pipe

The jointing of PE is a very simple process, being undertaken with either mechanical couplings (e.g. flanges) or as an electrofusion process. The electrofusion process can be undertaken with couplings or as a butt-welding process. For low-pressure water applications, push-fit joints are used.

Butt fusion jointing is undertaken by heating the ends of the two pipes being joined and then pressing them together to form a welded joint. The electrofusion couplings are supplied with heating elements fitted, to which the pipes are inserted. As the jointing processes are undertaken using purpose-built rigs with automated timing mechanisms, the jointing process requires a low level of operator skill.

The joints require no additional NDT other than the testing with the completed pipeline.

Standard Fittings

Sizes up to 250mm (10”) diameter can be supplied in continuous 250-meter lengths, which reduces the trenching and jointing requirements. The availability of continuous pipe makes it suitable for pipeline rehabilitation, where it can be inserted into existing pipe, reducing excavation costs.

Metal valves are used in PE pipework systems, the transition pieces being standard [22].

The pipe lengths are easily shaped to fit the profile of the excavation. Standard fittings and pipe bends are available to aid the construction process. Transition pieces can be supplied between plastic pipes, steel pipes, and steel valves. In addition to the electrofusion couplings, there are standard fittings available in the PE pipework systems to suit all applications. The available standard items are elbows, branch fittings, tees, size transition pieces, flange, screwed transition pieces, and end caps [1, 18-20].

Construction and Pressure Testing of PE Pipelines

Because of the Visco elastic nature of PE, the pipe material tends to creep during pressure testing, resulting in a noticeable pressure decay.

Guidelines for the pressure testing of polyethene are available, where the allowable pressure decay from creep is calculated and compared to the measured pressure loss in the pipeline [23].

An example of guidelines for construction and testing is the Manual for Polyethylene Pipe Systems for Water Supply Applications, with similar examples for gas pipelines given in British Gas Specifications and Institute of Gas Engineers (IGE) Recommendations [1, 18].

It should be noted that information on pressure testing requirements is readily available from the pipe manufacturers, to suit a particular application. Normally plastic pipes are only tested for no more than two hours, although this period may be extended or increased, depending on the local legislation, proximity, risk assessment, and engineering judgment [19-20, 23].

Limitations of PE Pipe

In addition to any temperature limitations, PE is susceptible to "leaching" or permeation, where the porosity within the PE allows chemicals to pass through the pipe wall into the surrounding ground [4]. This limitation is overcome by using a composite pipe material, which has an impervious layer of aluminium built into it.

These composite pipes are used in the water industry to protect chemicals entering the pipe from the contaminated ground. Similarly, for locations such as petrol stations, it is used to stop the oil seeping into the ground.

Uses of PE Pipe

The use of PE pipe is normally limited to:

- The transportation of non-sour gas distribution at ambient temperature and low pressures (less than 16 barg typical).
- Situations where extremes of temperature are not expected.
- The transportation of low-pressure oil, only if non-leaching composite pipe is used. E.g. Petrol stations.
- Water and general utility applications e.g. Pump stations and terminals.

Polyvinyl Chloride (PVC)

PVC plastics have the highest density of any currently used thermoplastic pipe (density of PVC 1.35-1.40).

Certain families of organic solvents, including ketones and aromatic hydrocarbons, can attack them [7]. Because of its affordability, resistance to chemicals, and longevity, PVC pipes are utilised extensively for various purposes. In addition to some industrial uses, they are a common option for irrigation, sewage, and water supply systems. PVC pipes are a great option for both above-ground and underground piping systems because they are robust, simple to install, and impervious to corrosion and deterioration [7, 23].

Uses of PVC Plastics

1. Construction: Pipes, window frames, and siding.
2. Healthcare: Medical tubing, blood bags, and IV containers.
3. Electronics: Insulation for wires and cables.
4. Consumer Goods: Flooring, clothing, and toys.

Limitations of PVC Plastics

1. Temperature Sensitivity: Not suitable for high-temperature applications.
2. Environmental Concerns: Production and disposal can release harmful chemicals.
3. Brittleness: This can become brittle over time, especially in cold conditions.

Grades and Diameters Available

1. Rigid PVC (uPVC): Used for pipes and construction materials.
2. Flexible PVC: Used for hoses, cables, and medical products.
3. CPVC (Chlorinated PVC): More heat-resistant, used in hot water systems.

Diameter

PVC pipes are available in a wide range of diameters, typically from 16mm to 630mm for various applications

Jointing Methods

1. Solvent Cementing: Common for smaller diameter pipes.
2. Heat Fusion: Used for larger diameter pipes.
3. Mechanical Joints: Such as flanges and threaded joints for easy disassembly.

Construction and Testing

- Construction: PVC pipes are extruded and can be reinforced with other materials for added strength.
- Testing: Includes pressure testing, impact testing, and chemical resistance testing to ensure durability and performance

Glass Reinforced Plastic Pipe

Reinforced plastics present an additional avenue for innovation in pipe systems. By incorporating a secondary material, such as glass or carbon fibre, the physical properties of these plastics can be significantly enhanced. Research has shown that with sufficient reinforcement, polyethene can endure internal pressures exceeding 400 barg before rupture, which is tenfold the capacity of unreinforced variants. While mechanical jointing may serve as an initial solution, advancements in jointing technology are essential to fully exploit these promising opportunities. Furthermore, utilizing polymer fibres for reinforcement could enable the development of a heat-fused system. The combination of corrosion resistance and the ability to withstand high pressures makes reinforced plastics particularly advantageous for offshore applications, where substantial cost savings could be achieved compared to traditional steel and more intricate composite materials [5, 11, 15-16].

Pressure and Temperature Ranges

An example of a thermoset plastic used for the transportation of hydrocarbons is an epoxy resin with fibreglass reinforcement, known as glass-reinforced plastic (GRP). The operational temperature of GRP is between 0°C and 75°C [1, 8-9].

As with all plastics, GRP is unsuitable for oil or gas pipelines where hot fluid or excessively low temperatures are expected. The allowable operational temperature of GRP does allow some heating of the fluid. For example, the use of a water bath heater at the inlet of the pipeline should not result in an excessive temperature in the pipeline, although local hot spots associated with trace heating would be unacceptable.

GRP has been used in the United States of America and Eastern European countries for crude oil pipelines at pressures up to 25 barg [8]. It has not been an acceptable pipe for hydrocarbon pipelines in the United Kingdom to date.

Grades and Diameters Available

GRP is available in two forms, chopped strand mat construction and filament wound pipe. The chopped mat pipe is susceptible to transient shock loads and is normally restricted to water and sewage applications.

The filament wound pipe is available in 6-to-10-meter lengths (depending on the manufacturer) from 100mm (4”) diameter upwards [15]. The grade of pipe required will be as per the manufacturer's standard specifications, which are normally based on standard wall thickness and material stiffness as in Table 4.

Table 4. GRP pipe classification for water application [11, 15-16]

Pressure and wall thickness limitations of GRP pipe (Water applications)			
250mm (10”) diameter		Stiffness (N/mm^2)	
	5000	10000	15000
Pressure (barg)		Wall thickness (mm)	
24	-	-	8
20	-	-	7
16	7	7	8
10	6	7	7
6	5	6	6

Jointing of GRP

Because the plastic is a thermoset, it cannot be welded to the adjoining pipe section. Therefore, the pipes are mechanically joined to form a pipeline, either as a flanged joint, push-fit coupling, or resin-sealed joint.

Push-fit couplings are normally used for sewage and low-pressure water applications. As leakage from hydrocarbon pipes is not acceptable, mechanical joints are supplemented by the application of a jointing compound kit. The compound jointing kit seals the inside of the mechanical joint with an epoxy glue compound and/or fully encapsulates the joint, making it leak-proof.

The jointing of GRP requires a low level of construction skill when compared to the welding requirements associated with steel pipeline construction.

Standard Fittings

In addition to the standard pipe joints, standard fittings are available in GRP pipework systems to suit all applications. The standard items are elbows, branch fittings, tees, size transition pieces, and end caps.

Metal valves are used in GRP pipework systems.

Construction and Pressure Testing of GRP Pipelines

GRP pipe is brittle and tends to crack under compressive loads. For this reason, the material estimates should allow for 5 to 10% to consider breakages that will be encountered during transportation, on-site handling, and the construction process.

As with PE pipe, the integrity testing (strength test) of a constructed pipeline only requires a short test, normally a few hours. As the material is brittle it does not tend to suffer from creep in the same way as a PE pipe does.

Limitations of GRP Pipe

In addition to any temperature limitations, the material's brittleness makes it susceptible to third-party interference. This is especially important where vehicle access is expected, where it will require steel sleeve or concrete protection. Temperature limitation is overcome by the use of insulation, regular monitoring, or regulation of the temperature.

GRP can be supplied with a high level of fire resistance.

Uses of GRP

The use of GRP pipe is normally limited to:

- The transportation of oil at a temperature not exceeding 75°C at pressures less than 25 barg i.e. Buried oil well flowlines;

- Non-hydrocarbon applications, such as cooling and injection lines, up to 25 barg and 75°C;
- Pipeline routes where third-party interference is not expected to be a problem, i.e., Oil fields with restricted access.

Fibre-Glass Reinforced RTRP Pipe

Reinforced thermosetting resin pressure piping (RTRP), commonly referred to as fibreglass-reinforced plastic (FRP) piping systems, is a composite material consisting of glass fibre reinforcements, thermosetting plastic resins, and various additives [8]. The durability of RTRP is attributed to the fibreglass reinforcement, while its corrosion resistance is a result of the resin component. An example of its application is the RTP pipe utilized by Saudi Aramco for oil flow lines (see Fig. 4).

Uses Of RTRP

- Used for gas distribution piping
- The interior has a smooth finish
- External surface is rough with fibres visible in the epoxy matrix
- Pipes are less temperature-sensitive
- Better chemical resistance than most thermoplastic pipes

Types of Reinforced Thermosetting Resin Pressure Piping (RTRP)

Glass Types

- E-Glass (Electrical Glass): Used for the structural layer due to its high strength.
- C-Glass (Chemical Glass): Ideal for the initial corrosion barrier surface because of its chemical resistance.
- ECR-Glass: Similar to E-Glass but without boron trioxide and fluorine, offering better chemical and thermal resistance.

Resin Systems

- Polyester Resin (Isophthalic): Used in GRP (Glass Reinforced Polyester Piping Systems) for a service temperature range of 50°C to 75°C.
- Epoxy Resin: Used in GRE (Glass Reinforced Epoxy Piping Systems).
- Vinylester Resin: Used in GRV (Glass Reinforced Vinylester Piping Systems) for a service temperature range of 75°C to 100°C [15 -16].

Additives

Fillers, catalysts, accelerators, inhibitors, aggregates, and pigments enhance specific properties.
For example, antimony trioxide improves flame retardance.

RTRP is also commonly referred to as FRP piping. Due to its durability and corrosion resistance, it finds applications in chemical plants, oil and gas facilities, and water/sewage systems.

Fig. 4. Reinforced Thermoplastic Pipe (RTP) being laid on a Saudi Aramco project [24]

Uses of Plastic Pipes

Plastic pipes provide a cheap alternative to steel line pipes, the cost savings coming from the transportation and construction costs, not from the cost of the pipe.

For buried oil pipelines operating at pressures up to 25 barg and temperatures below 75°C, GRP provides a suitable alternative to steel pipelines [1,13].

PE provides a suitable alternative to steel pipelines for buried sweet gas pipelines operating at pressures up to 16 barg and ambient temperature.

Plastic pipe also provides a cost-effective solution to offshore and onshore facilities engineering, for items such as fire hydrant ring mains, seawater cooling lines, water injection lines, drilling effluent lines, ballast lines, potable water, sewage, and underground cable conduits [1].

Conclusions

From the study on plastic pipes for hydrocarbon and general several conclusions can be drawn.

Regarding *corrosion resistance* the plastic pipes, such as HDPE, PVC, and GRE/GRP, exhibit excellent corrosion resistance, making them ideal for harsh environments in the hydrocarbon industry [14, 21].

Regarding *Flexibility and Durability* HDPE and PEX pipes are highly flexible and durable, which reduces the risk of damage during installation and operation.

Regarding *Chemical Resistance* the PVC, CPVC, and PP pipes offer superior chemical resistance, making them suitable for transporting a wide range of fluids, including corrosive chemicals [9].

For *Cost-Effectiveness* the Plastic pipes are generally more cost-effective than traditional metal pipes, both in terms of initial installation and long-term maintenance.

On Temperature and Pressure Limitations they have limitations in high-temperature and high-pressure applications. GRE/GRP pipes are an exception, offering better performance in these conditions.

On *Impact Resistance* the HDPE and PEX pipes demonstrate high impact resistance, making them less prone to damage from excavation tools and other mechanical impacts.

Ongoing research is essential to address the limitations of plastic pipes, such as enhancing their temperature tolerance, mechanical strength, and UV resistance. The use of plastic pipes contributes to sustainability efforts by reducing the need for frequent replacements and minimizing environmental impact through lower energy consumption during production and transportation.

Recommendations for Future Research

Material Innovation: Development of new composite materials that combine the best properties of different plastics to enhance overall performance.

Enhanced Testing: Conduct extensive real-world testing to ensure the reliability and durability of plastic pipes under various conditions [12].

Cost Reduction: Focus on reducing the production costs of advanced plastic pipes to make them more competitive with traditional materials.

By addressing these areas, the hydrocarbon industry can further optimise the use of plastic pipes, ensuring they meet the evolving demands and contribute to more sustainable and efficient operations.

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