

State of Art of Pipeline Distribution of Oil Products in Kenya-Threats, Challenges and Prospects

Antony Fundia Simbiri

World Bank Africa Center of Excellence,
Center for Oilfield Chemicals Research,
University of Port Harcourt, Port Harcourt, Nigeria

Ogbonna F. Joel

World Bank Africa Center of Excellence,
Center for Oilfield Chemicals Research,
University of Port Harcourt, Port Harcourt, Nigeria

Emmanuel E. Okoro

World Bank Africa Center of Excellence,
Center for Oilfield Chemicals Research,
University of Port Harcourt, Port Harcourt, Nigeria

Daniel O. Oyoo

Kenyatta University, Energy, Gas and
Petroleum Engineering Department

ABSTRACT

Finally, in 2012, Kenya hit significant commercial oil deposits that could potentially, position it among prospective world oil exporters. Unparalleled expectations from this find are arousing long dead pipedreams of economic bonanza and overnight transformation among all stakeholders. However, to avail this resource to the markets, for the expected fiscal changes to occur, it has to be transported. This paper, therefore, seeks to microscopically review the current status of the pipeline transport of oil products in Kenya in the last decade. A summarized outlook of pipeline oil distribution globally is availed, especially in well-developed oil jurisdictions. This is sequenced with a comprehensive history of oil pipeline transport in the country. The flow mechanism of white and black oil products in pipelines is then briefly addressed in view of the waxy Turkana oil. A sneak preview of the legal landscape on oil pipeline transport in Kenya is likewise highlighted. The current content and context of pipelines, flow of white and black oil products in pipelines, and new pipeline infrastructure are then discussed with Kenya Pipeline Company Limited as the central denominator. Additionally, assertions on the upcoming new crude oil pipeline are evaluated. Finally, it exposes the prospects and challenges in the pipeline transport of oil products and sums up with viable recommendations for its long-term progress.

Keywords: Pipeline transportation, spillage, vandalism, pressure drop, white products, wax appearance temperature, smart drones, AGI: Above Ground Installations, AGO: Automotive Gas Oil, API: American Petroleum Institute, BOOT: Build, Own, Operate, and

Transfer Agreement, DPK: Dual Purpose Kerosene, ERW: Electric-Resistance-Welded, JCC: Joint Coordinating Commission, KPC: Kenya Pipeline Company, LAPSSET: Lamu-Port-South Sudan-Ethiopia Transport, MPS: Motor Premium Spirit, NbCr: Niobium Chromium, NDT: Non-Destructive Testing, PPTS: Pipeline Performance Tracking System, RTP: Reinforced Thermoplastic Pipes, SCADA: Supervisory Control and Data Acquisition, VCI: Vapour-Phase Corrosion inhibitors, VOC: Volatile Organic Compounds, WAT: Wax Appearance Temperature

INTRODUCTION

Energy is the lifeblood of any modern economy. In many industrialized nations, the veins and arteries of this lifeblood are oil and gas product pipelines. Oil and gas pipelines include pipelines that move crude oil and natural gas as well as those that transport petroleum products, (Shaikh et.al., 2017). In Kenya, petroleum products usually transported in a pipeline include automotive diesel, kerosene, super and regular petrol amongst others, (Gicharu 2017). Each of these oil products touch many segments of the society. And now, new crude oil has been added into the mix. Therefore, understanding the dynamics of oil pipeline transport in Kenya from the market to the consumer plays a crucial role in the overall progress of the nation.

This paper, therefore, seeks to assemble all the data and congregate every information on the status of oil pipeline transport in Kenya in the last decade. Academic research, scholarly investigations and published studies in the oil pipeline industry in Kenya remain extremely rare. Being a vital industry in the country, the authors sought to establish the history and present dynamics of this oil sub-sector. Therefore, an assessment of the content and context of oil pipeline transport in Kenya is presented below. The data referenced in this review is from secondary sources. Systematic methodology was deployed as searches in Google Scholar, Scopus, Elsevier and offline libraries were used, by using “oil pipeline transport in Kenya” as the subject.

Pipeline Distribution of Oil Products in the World

According to the *Global Energy Monitor*, by December 2020, 2,381 oil and gas pipelines were operational in 162 countries. Their total length is approximately over 1.18 million km, enough to go around the Earth 30 times. The USA leads with 240,711 km of petroleum products pipeline. Next is Russia with 163, 872 km, and the third is Canada which has 100,000 km of pipelines. In the US for instance, roughly two-thirds of the petroleum shipped in the nation is via oil pipelines. A total of over 14 billion barrels of petroleum per year is delivered to different destinations. These pipelines exist throughout the country and vary by the goods they supply, the content makeup of the pipes, and the size of the pipes. Even though some of these pipelines are above the ground, a majority of them are buried underground.

The oil pipeline network of the USA alone is estimated to be more than ten times larger than that in Europe, (Pipeline, 2005). Meanwhile, in Europe, only 20% of the crude oil is imported through pipelines: namely Druzhba (the longest pipeline in the world – 4000 km from Russian oilfields) and Norpipe. Oil pipelines from other nations are currently of less importance for the energy supply in the European Union¹. In view of the ongoing conflict between Russia and Ukraine (March 2022), pipelines from other nations have suddenly become crucial. For

¹ COM (2008) 782, Brussels 13.11.2008 SEC (2008) 2869

instance, negotiations of increasing the flow of African oil and gas through Algeria (Figure 1) to Europe have commenced, (Wang, 2022). The EU internal pipeline network is uniquely made up of limited connections between the western European pipeline network and the Eastern infrastructures, with the Ingolstand – Kralupy-Litinow (IKL) pipeline of 349 km and a capacity of 10Mtons per year being the only link between the two zones². Currently, the world is connected by more than 3.5 million kilometers of pipelines. This is expected to increase by 12.2% by 2022, with Asia constructing the most kilometers³ while North America will lead in investments.

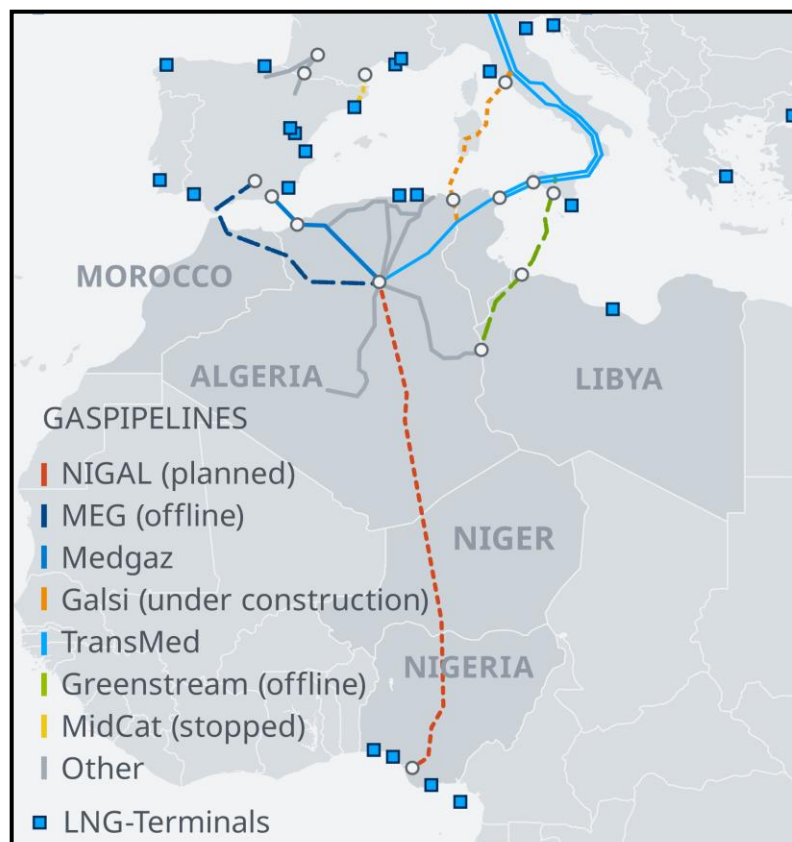


Figure 1. Pipeline Network Africa – Europe.

(Source: ENI/GIE/World LNG Map 2006)

Pipeline Distribution of Oil Products in Kenya

The distribution of oil products in Kenya and beyond is a vital economic activity. This is because, the entire East and Central Africa (Eastern Democratic Republic of Congo, Rwanda, North Tanzania, Uganda, South Sudan, etc.) depend on these products from and through Kenya, (Mikwa 2014). It is managed and administered by the Kenya Pipeline Company Limited. Efficiency in the distribution of these oil products is vital in ensuring that the right volumes of the products reach their destinations, in a sustainable manner and at the right price, (Muthini et.al 2016). Various grades of crude oil or several refined products can be transported through the same pipeline in different batches. This is the mode used by the Kenya Pipeline Company.

² Oil Infrastructures COM (2008) 782, Brussels 13.11.2008 SEC (2008) 2869

³ Global Crude Oil Pipeline Industry Outlook to 2022, by GlobalData and Upstream Analytics

The current pipeline system in Kenya spans 1,792km running from Mombasa through Nairobi to Nakuru, Kisumu and Eldoret, (Figure 2). In 1978, the first 450km 14" diameter pipeline was completed from Mombasa to Nairobi. Additionally, another 446 km 8/6-inch diameter from Nairobi to Western was completed and in 1994, it was commissioned. A parallel 14" pipeline (with three booster pumps, four mainline pumps, and product transfer facilities) valued at \$122 million was completed and commissioned from Nairobi to Eldoret in 2011 to accommodate a new flow rate, from the old 44,280 bpd up to 79,292 bpd.

In 2015, another 121 km 10" diameter parallel pipeline was commissioned from Sinendet to Kisumu. In June 2018, KPC commissioned a new, 20-inch Mombasa – Nairobi multiproduct petroleum pipeline (Line 5) to replace the old 14" pipeline together with 96 core fiber cable for the complete length of the pipeline. Unlike the old line which was commissioned in 1978 and had a capacity of 125,000 barrels per day, the new one has a capacity of 287,000 barrels per day. At a total cost of \$500 million⁴, the construction was undertaken by a Lebanese firm Zakhem International⁵ and used the same 450km wayleave as the old pipeline. By 2023, the expected new flow rate of the new pipeline is 382,420 bpd, rising to 523,320 bpd by 2044. One unique feature with Kenya's oil pipeline market, is that, it is mainly driven by the transportation of white oil products, with a huge chunk of it being imported oil products.

One interesting project that has been in the pipeline for quite some time now is the Kenya-Uganda Oil Pipeline (KUOP), visualized by the Kenyan and Ugandan governments. This pipeline is expected to be developed through a public-private partnership under a 20-year build, own, operate, and transfer agreement (BOOT) and managed by a joint coordinating commission (JCC) with each of the governments owning 24.55% share, while private investors will own a 51% stake. While the estimated cost of the pipeline is \$302 million, with an estimated length of 352 km, the expected capacity is 168m³ per hour with an annual capacity of 1.2 million m³. The new pipeline is expected to commence in Eldoret in Kenya interconnect with the existing 14" diameter pipeline (Line 4), cross to Uganda through Malaba on the border, and end in Kampala with a spur line branching off to Jinja in Uganda. This pipeline has the objective of delivering white petroleum products from Kenya to Uganda and vice-versa.

In the future, the line is expected to extend to Kigali in Rwanda and Bujumbura in Burundi. A common user depot in the East of Kampala with a terminal capacity of 72,000m³ will be added to the pipeline. Besides the terminal, two other tanks with a capacity of 32,500m³ for MPS products will be added, two tanks with a capacity of 5,654m³ for DPK products, two tanks with a capacity of 10,544m³ Jet products and two tanks with 22,570m³ capacity for AGO products, and four interface tanks with a capacity of 904m³. This pipeline network is based on the general principle of "inter-modal compliment" where pipelines are used for long-distance hauls while road and rail cover short and medium-distance hauls.

⁴ Pipeline Network, KPC Website, accessed June 2018

⁵ Kenya awards Mombasa-Nairobi oil pipeline contract to Lebanese firm, Reuters, 2 July 2014.

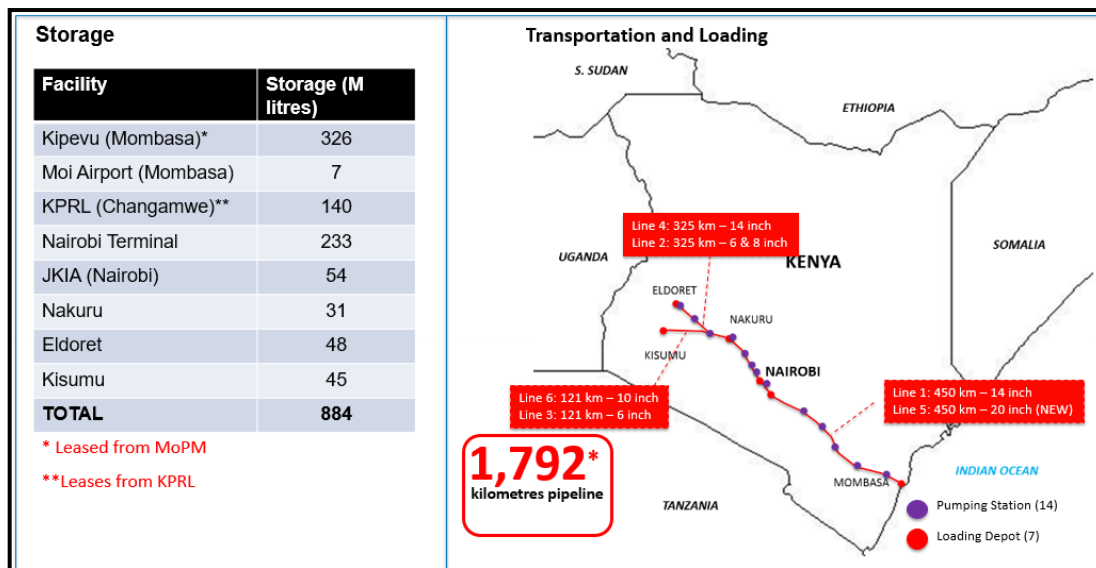


Figure 2. Current pipeline infrastructure in Kenya.

(Source: Kenya Pipeline Website,2022)

Another major pipeline project, that would have cemented Kenya's position as a regional pipeline logistical hub, is the 1,145 km East African Crude Oil Pipeline (EACOP). However, it failed to take off as previously planned. Initially planned to evacuate crude oil from both Uganda and Kenya, the pipeline's budget was \$3.5 billion, to be funded by Chinese National Offshore Oil Company (CNOOC) and France's Total. However, due to several lingering issues including security concerns⁶, pipeline cost, duration of land compensation in Kenya (approximately two years for land clearance), rugged terrain, availability (full construction of Lamu Port and its facilities is behind schedule), shortest schedule, South East waves in Lamu port of up to 3.5 meters off Lamu during monsoon season, anticipated annual average export shut down due to wind estimated at 4.5%, ecological fragile systems (coral reefs, unique mangrove trees, and fish breeding grounds), incompatible dredging schedule (at an approximate cost of \$800 - \$1bn) of Lamu port with the Ugandan crude oil pipeline project schedule, and cultural sensitivity of Lamu (Lamu has UNESCO recognized sites) raised by Uganda over the pipeline's Kabaale-Lokichar-Lamu (Kenya) route, catalyzed its change of mind. This resulted in the Ugandan government opting for the Kabaale-Tanga (Tanzania) route. And thus, the birth of what will be the world's longest heated pipeline, (Figure 3).

⁶ Alon Mwesigwa, The Observer, Uganda News, 18th April, 2016, <https://observer.ug/news-headlines/43729-oil-route-uganda-chooses-tanzania?>

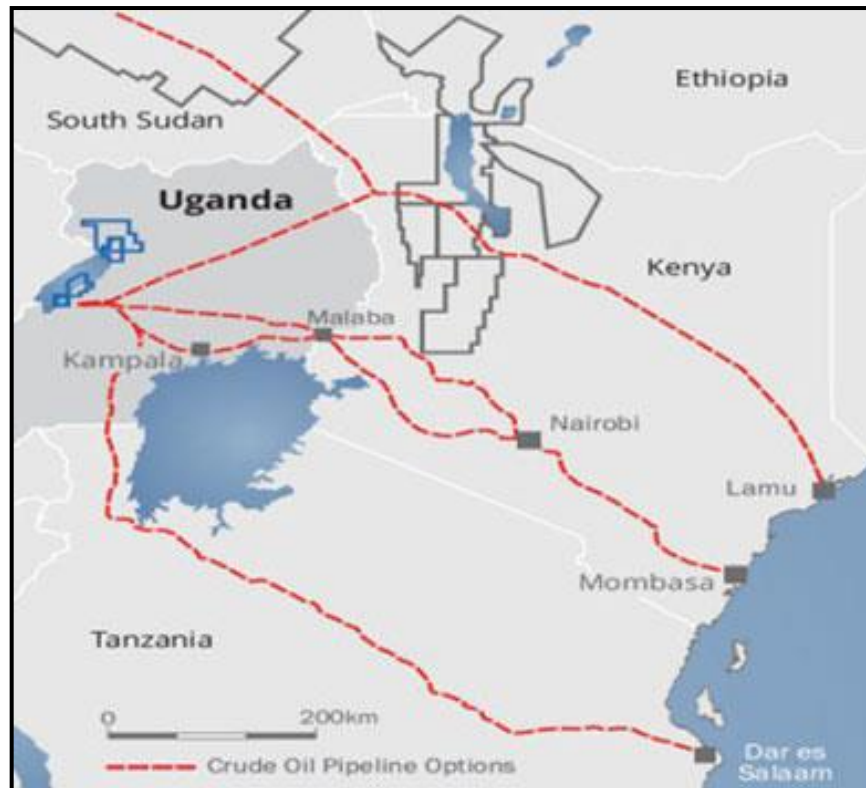


Figure 3. Oil Pipeline Route Options for The East African Crude Oil Pipeline (EACOP).
(Source: Commissioner for Petroleum Exploration and Production, Government of Uganda, 2016).

Flowability of Oil Products in Pipelines

The flow of oil in pipelines is governed by liquid flow principles. Changes in the terrain, the liquid properties of the fluid in the pipe, scale formation, electrochemical changes along the metal-fluid interface, friction losses in the pipe, etc. are but some of the parameters that invariably influence the overall flowability of oil in the pipe. Generally, the average velocity of oil in pipelines is 3-8 miles per hour, and it depends on the pressure, viscosity, pipe diameter, and terrain topography. One of the most challenging aspects of oil transport through pipelines is the maintenance of pressure throughout the pipeline so that the oil can keep flowing. Over the years, an array of methods has been assembled, to characterize this pressure influence.

Among these methods, is Benjamin Miller's method, (McAllister 2009), as shown in equation (1) below. In an attempt to understand the mode of pressure drop in the new 20" Mombasa – Nairobi multiproduct petroleum pipeline (Line 5), it is demonstrated that Benjamin Miller's method is valid for the petroleum oil products pipeline, as it observes the least value within the same flow rate range for calculated parameters, (Wambua et.al 2019).

$$Q = (0.1692) [(D^5P)/(S_g)]^{0.5} [\log(D^3S_gP)/(\mu^2) + 4.35] \dots\dots\dots(1)$$

Where: Q = flow rate (bbl/hr)

P = pressure loss (psi/mile)

D = internal diameter of pipe (inches),

S_g = specific gravity

μ = viscosity (centipoise)

Likewise, the design of oil pipelines, is a function of several parameters. Precise prediction of pressure drops, liquid holdup, and flow pattern is crucial for the design of oil pipelines. Presently, there are several commercial software that simulates multiphase flow in pipelines. And the latest simulators don't only consider pressure and temperature alone but viscosity as well. Viscosity remains a vital component in the overall efficient flow of oil in the pipeline. The maximum values of viscosity to the optimal flow of crude oil range between 250 and 400 cSt at 37.8°C, (Munoz et.al 2016).

For a waxy crude like Turkana oil, an array of methods is available on how to reduce the viscosity. Some of these include

- (a) **Magnetic and pulsed electric fields:** This method temporarily aggregates paraffin and asphaltene suspended particles inside the crude oil into short chains along the field, (Homayuni et.al 2011). This aggregation then changes the rheological properties of the oil which turns into viscosity reduction. The disadvantage is that this reduction lasts only for a few hours, thus necessitating re-application of the electric field, (Tao et, al 2014). Additionally, this technique possesses the inherent risk of a dielectric breakdown that may occur due to the water content inside the oil or accidental discharge sparks. The magnetic field on the hand, (Du et.al 2011), doesn't have the risk of accidental discharge spark, so it is considered safer of the two options.
- (b) **Core annular flow:** this is a water-oil two-phase flow technique. It works by surrounding the crude oil and lubricating the pipeline wall with water, which acts as a lubricant that absorbs the shear stress existing between the oil and the pipeline wall because the less viscous phase migrates to the high shear region near the pipeline wall, (Bensakhira et.al 2004). Therefore, the water flows as the annulus while the crude oil flows as the core. Usually, a ratio of between 10% and 30% of water is enough to improve the crude oil transportation in the pipelines. And so apart from the water for water flooding needed for production of Turkana oil, this method requires voluminous amounts of water to sustain this flowability.
- (c) **Chemical additives:** This technique works on the basis that these additives can be stretched out into long chains because of their elastic properties, thus forming films inside the oil matrix, which act as shock absorbers that damp and minimize small eddies that are the cause of drag in a turbulent flow. This in turn reduces the turbulence in the pipeline and increases the flow rate. Surfactants can also be deployed singularly, (Kumar et.al 2017) and use the mechanism of interfacial tension reduction. Moreover, the application of alkaline based surfactants would be viable given the slightly acidic nature of Turkana crude, (Peres et.al 2021). However, a mixture of surfactant and polymers initiates more efficient drag reduction than that of additives alone, (Matras et.al 2008). Examples of these drag-reducing additives include polyethylene oxides and different vapor-phase corrosion inhibitors (VCI) – (VCI-A, VCI-B, VCI-C, VCI-D, and VCI-E). No indication has been shown about the possibility of the operators of LLCOP using this method.
- (d) **Heating:** preheating of the crude oil and subsequent heating of the pipeline is required to reduce heavy oil viscosity and improve heavy oil flowability, (Hart 2014). However, heated pipelines are expensive ventures, with high capital inlays, operational costs, technical considerations of the pipeline expansion, pipeline internal corrosion, heat loss estimations, number of pumping and heating stations, and the entire length of the pipe must be heated, (Saniere et.al 2004). Apparently, this is the method the consortium

operating the LLCOP have settled for, just like the 1,145 km East African Crude Oil Pipeline (EACOP).

- (e) **Dilution:** these include the use of light crude oil as a diluent, (Hasan et. al 2010), use of alcohol, (Gateau e.al 2004), naptha (Myers et.al 2000), condensate (Shigemoto et.al 2006), kerosene (Santos et.al 2014), oil-in-water emulsions (Hardy et.al 1988, Zaki 1997, Yaghi et.al 2002), heavy crude oil-light crude oil mixtures. Apparently, the addition of kerosene to crude oil improves the flowability of oil more than the addition of water, the addition of flow improver, and preheating of the oil, (Ghanman et.al 2006). However, in scenarios where waxy crude has been emulsified, the restart of such pipelines becomes problematic, and the lengthening of the pipeline only amplifies the influence of the emulsification, (Sun et.al 2016). Thus, the possibility of wax precipitation in crude oil emulsion and the properties of the formed emulsion gel must be incorporated during multiphase pipeline shutdown.

Restart and shutdown of pipelines is usually done at the pump stations. Pump stations adjust pipeline pressure, pump the oil product in the pipeline, monitor flow, increase the through-put of the pipelines, contain safety equipment and serve as launching pads for pipeline pigs. Alongside the simulation of pump capacities, is the crucial aspect of economic pipe-diameter calculations. Cost factors that incorporate functions of pipe diameter for carbon steel pipe and correction factors, is an approach used widely in the industry. Base cost factor (K/SUB fi) for fittings or base cost factor (X) for pipe can be multiplied by a ratio of escalation indexes and the old value replaced by the corrected value. This enables any future changes in costs to be incorporated, (Talwar, 1984). Most of these oil pipelines almost exclusively utilize steel pipe but with external coating and cathodic protection to minimize external corrosion whilst internal corrosion is managed using additives.

Some of the common modern pipeline manufacturing technics, (Kiefner et.al 2001) include furnace lap-welding process, furnace butt welding process, electric-resistance-welding process, electric flash welding process, seamless pipe process, straight seam submerged-arc-welding technic, and double submerged-arc method. Some of the steel grades (distinguished by the amount of carbon content) used in oil and gas pipeline manufacture include: mild/low-grade carbon steel contains less than 0.3% carbon by weight, medium-grade carbon steel that contains 0.3% to 0.59% carbon by weight, high-grade carbon steel contains 0.6% to 0.99% carbon by weight and ultra-high grade carbon steel contains 1.0% to 2.0% carbon by weight. To enhance corrosion inhibition during their lifetimes, pipelines undergo hydro-testing to determine their fitness.

Generally, oil and gas pipelines have the following internationally recognized codes: ASME B31.4 for pipeline transportation systems for liquid hydrocarbons and other liquids, ASME B31.8 for gas transmission and distribution systems, ISO-13623 for petroleum and natural gas industries, and DNV-F-101 for the offshore standard for submarine pipeline systems. Most of the pipes deployed on the old pipeline (450km 14" diameter Mombasa to Nairobi) were made through the electric-resistance-welded (ERW) method using carbon steel grade API 5L X52 specifications. Along the entire stretch of the pipeline, it has a nominal wall thickness of 6.35mm, while at pump discharges, the nominal wall thickness ranges from 12.7 mm to 6.35 mm. KPC claims, the entire 450 km was coated with coal tar enamel as the major source of

corrosion protection and impressed current as an additional means of cathodic protection.

LEGISLATION

Introduction

The pipeline distribution of oil products in Kenya is regulated by several legal instruments. As part of the energy policies laid out in the Sessional Paper Number 4 of 2004 and the Kenya Vision 2030, the sector has a rather robust legal ecosystem. The Kenya Vision 2030, for instance, is a long-term development blueprint for the nation. It aims to set up, “A globally competitive and prosperous country with a high quality of life by 2030.”

Vision 2030 identifies flagship projects to be done within specific timelines, then listed below is a summary of energy (oil and gas distribution sub-sector) specific projects to be undertaken by 2013:

- Enhanced oil supply: Installation of four booster pump stations to double the capacity of the Mombasa – Nairobi oil pipeline from 440m³/hr to 880m³/hr in Konza, Makindu, Manyani, and Samburu. By 2021, this had been achieved.
- Extension of the national oil pipeline from Nairobi to Eldoret (Line 4) using the same leeway as to the old pipeline. It will be 340km in length. By 2021, this had been achieved.
- Joint Ventures: The government will partner with the government of Uganda and Tamoil East Africa limited in a joint venture company for the extension of 352km oil pipeline from Eldoret to Kampala (the Eldoret-Kampala-Kigali Refined Petroleum Products Pipeline-EKKRPP). By 2021, this had not been achieved.
- Construction of 6,000-tonne common user Liquid Petroleum Gas (LPG) import handling facility in Mombasa through Public-Private Partnership. By 2021, this had been achieved.
- Construction of a 2,000-tonne common user LPG handling facility in Nairobi. By 2021, this had not been achieved

Policy Making Institutions in the Distribution of Oil Products

Ministry of Petroleum and Mining:

The Ministry of Petroleum and Mining is responsible for overall policy coordination and development of the oil and gas sector in Kenya. It's responsible for setting policy upon receipt of advice from the EPRA and the Energy Tribunal.

The functions of the Authority (about the oil and gas subsector) as provided in Section 10 of the Energy Act 2019 include:

- Regulate -
- Importation, refining, exportation, transportation, storage, and sale of petroleum and petroleum products except for *crude oil*; (italics highlighting – author's).

Therefore, the control and coordination of a new crude oil pipeline in Kenya will need the amendment of the current KPC's mandate or the formation of an entirely new corporate entity.

KENYA PIPELINE COMPANY (KPC) LTD

Pipeline Distribution of White Oil Products

KPC, with a vision of being “Africa’s premier world-class oil and gas company”, is 100% equity-owned by the Government of Kenya. This state entity, owns, control and manages a multi-product pipeline network and facilities for transportation, storage, and distribution of refined oil products across/throughout Kenya. KPC ‘s total storage/depot facilities are located at Kipevu, Moi Airport, Jomo Kenyatta International Airport, Nairobi Terminal, Nakuru, Eldoret, and Kisumu. White oil products in Kenya are mainly transported through the pipeline, with a marginal portion finding their way through road oil tankers. Table 3.1 below highlights where these transported white oils are stored around the country and their capacities.

Table 4.1 - KPC Depots in Kenya

No.	Depot	Total Capacity
1	Nairobi terminal	100,580
2	Jomo Kenyatta international airport	54,141
3	Moi airport Mombasa	7,349
4	Kipevu oil storage facility	326,233
5	Nakuru depot	30,553
6	Eldoret depot	48,089
7	Kisumu depot	45,288
	Grand Total	612,233

(Source: KPC, 2015)

According to the Congressional Research Service, (2014), transporting oil and gas by pipeline is generally cheaper than transporting it by rail or truck. The average cost of transporting oil and gas by truck per barrel is about \$20, \$10 - \$15 a barrel for rail, and \$5 per barrel for the pipeline, which is also confirmed by the research firm Strata. These alternatives, however, come with their advantages; rail is faster than pipeline at transporting oil and gas over long mileages. For instance, comparatively, where rail can transport oil from a remote field for a period of five to seven days, oil hauled over the same distance through a pipeline would take about forty days, (Batheja, 2014). Despite the high initial expenditure of setting up an oil pipeline, they are a worthwhile investment. Moreover, they need less human capital than rail or truck and are more efficient over a large distance.

Several studies radiate around the risks of pipelines to human health and safety. Hyped accidents like the Makueni leakage, the 2010 natural gas pipeline rupture in San Bruno California which killed eight people, and many others push the public to perceive pipelines with perilous suspicion. However, a comparative study between pipeline safety and rail and truck reveals that pipeline transport is the safest method of hauling oil and gas. In the USA for instance, fatalities in truck transport of oil stood at 10.2, rail was 2.4 and pipelines was 1.7 fatalities to operators, personnel, and the general public. Analogous data in the oil industry in Kenya are scarce. However, Kenneth Green, an expert on crude-oil transportation at the Fraser Institute observed, “on an apple-to-apple basis”, pipelines have fewer accidents and cause less harm to human health than do railcars moving comparable amounts of oil and gas, (Moliniski, 2015).

Challenges facing the distribution of oil products through Kenya Pipeline Company Limited have been investigated, (Shigadi et. al 2016, Gicharu et.al 2017, Kipkirui et.al 2019). Pilferage on the distribution of oil products, the influence of fuel supply on the management of petroleum products, and the efficiency in the transport and distribution of these products so that the right volumes are delivered at the right price and in a sustainable manner were the main parameters highlighted in these studies. They demonstrate that the right informational technology should be deployed, the necessary human capacity engaged, adequate security, and higher pipeline capacity enhanced to improve pipeline service delivery. However, storage capacity and depot, (Figure 4) infrastructure (loading capacity) proved challenging. Therefore, the need to reduce the red carpet involved in truck clearance and enhance quality control measures at depots and tank farms is emphasized. Furthermore, research on infrastructure improvement needs to be done to ease the business environment of pipeline operations.

Still, on the business ecosystem necessary for pipeline operations, procurement of materials for the pipeline operator remains on shaky ground. In studying the determinants of how sustainable procurement practices in the oil and gas sector can be implemented in Kenya for example, in KPC, resource capacity, legal and regulatory framework, supplier participation, and management commitment stand out as significant variables, (Murungi et.al 2019). These significantly and positively influence the implementation of sustainable procurement in the oil and gas industry.



Figure 4. A KPC depot.
(Source: KPC, 2015)

Interestingly, EPRA, before the National Assembly Energy committee stated that the road transport of petroleum products from the port of Mombasa to Nairobi is cheaper by between \$15 to \$20 per cubic meter in comparison with using the newly built pipeline whose construction cost was \$475 million. Additionally, this regulator, through its director-general, claimed that transporting oil products through the pipeline from Mombasa to Kampala in

Uganda was \$89 per cubic meter while the road transport cost stands at \$75 per cubic meter⁷. These claims by EPRA, however, didn't have any reference to any comparative analysis of the risks of oil road transport, the overheads of maintaining pump stations along the pipeline, or any other such variables. Additionally, during this seating, EPRA didn't infer any previous engineering feasibility study conducted by KPC before the construction of this pipeline and whether EPRA was involved or consulted. With such nefarious collaboration by the regulator, as highlighted in Table 3.2, KPC's Vision 2025 as of 2021, remains a dry pipedream.

Table 4.2: Vision 2025 2nd Medium Term Plan Project

Item No	Project Name	Time Frame	Achieved /Not Achieved
1	Replacement of The Mombasa-Nairobi Pipeline	2013-2016	Achieved
2	Construction of Additional Tanks in Nairobi	2013-2016	Not Achieved
3	Eldoret-Kampala-Kigali Refined Petroleum Products Pipeline	2014-2016	Not Achieved
4	Construction of Additional Loading Arms in Eldoret	2013-2015	Not Achieved
5	Construction of a Parallel Pipeline from Sinendet to Kisumu	2013-2015	Not Achieved
6	LPG Storage & Bottling Facilities in Nairobi	2012-2016	Not Achieved

(Source: KPC Website, 2022)

Despite all the noted challenges in the operations of Kenya Pipeline Company including inflation of its invoices and alleged grand malpractices⁸, the government of Kenya has initiated the construction of a new pipeline to transport the Lokichar crude from Turkana to Lamu, on the coast of Kenya. If the inherent challenges facing KPC will be addressed before it's given the role of running this new pipeline is not yet clear. The other alternative would be to establish a completely new entity to run the new Lokichar – Lamu Crude Oil Pipeline.

Lokichar - Lamu Crude Oil Pipeline (LLCOP)

To monetize Kenya's new crude oil resources (estimated at 1.5 billion barrels of proven and probable oil reserves and daily estimated production of around 100,00 barrels per day), an 892-kilometer pipeline and supporting infrastructure must be built from Turkana (Lokichar) to Lamu, thus the birth of LLCOP. Originally planned to be funded jointly by a consortium of the Kenyan and Uganda governments and international oil companies, the pipeline will now have to be funded solely by the Kenyan government and the upstream investors (Tullow Oil Company, Africa Oil, and Total) after the Uganda government opted for the Tanzanian route, thus the high unit capital and operating costs.

The crude oil pipeline Pre-Front End Engineering Design (FEED) studies were completed in 2015 and a Joint Development Agreement (JDA) was signed in 2017 between the Government of Kenya and upstream investors (Tullow Oil Company, Africa Oil and Total). The Front-End Engineering Designs (FEED) by the British Wood Group and the Environmental and Social Impact Assessment (ESIA) studies by Golder and Associates were completed in 2019. In the 2020/2021 budget, the Kenyan government allocated the State department for petroleum \$7.7 million, an addition to the \$6.3 million the department had set aside for the research, feasibility

⁷ Business Daily, 21st August, 2019

⁸ Kenya Pipeline Company (KPC) Board Chairman John Ngumi on Thursday told a Nairobi court how the procurement of the Sh1.7 billion Kisumu oil jetty was flawed, Nairobi, Kenya, 20th June, 2020.

studies, project preparation, and design of the Lokichar-Lamu oil pipeline.

The Lokichar-Lamu Crude Oil Pipeline (LLCOP) involves the construction of 892 km of the pipeline (Figure 5). It will traverse six counties (Turkana, Samburu, Isiolo, Meru, Garissa, and Lamu) within the LAPSSET corridor. According to the initial designs, this requires the excavation of two-meter-deep trenches along the proposed route to lay pipes of 40-50 centimeters in diameter. Furthermore, a total of 16 Above Ground Installations (AGIs) which include pump stations, pressure reduction points, and generators will be installed. However, because of the waxy nature of the oil, trace heating will be done through a long line trace system (to 80°C). As per the official timelines, the pipeline should be completed in the second half of 2023 and not June 2022, as earlier planned⁹.

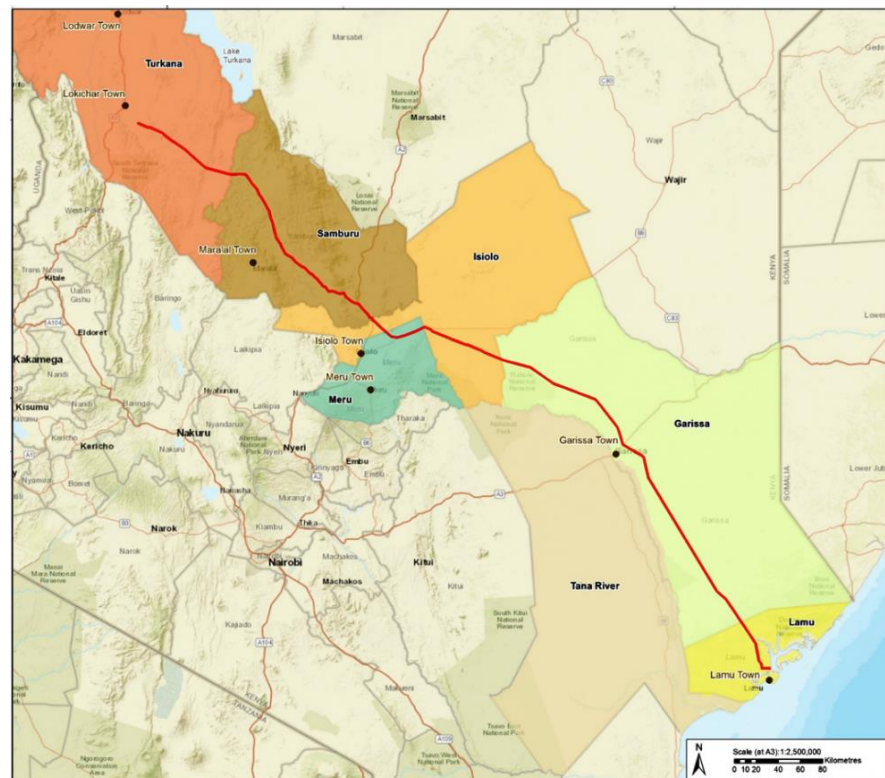


Figure 5. LLCOP route in Kenya.
(Source: LAPPSET, 2014)

Having said so, the design of this heated pipeline is complicated, (Guevara et.al, 1998) since it involves numerous factors, {e.g., expansion of the pipelines, high costs (Chang et.al 1999), several pumping/heating stations, frictional pipe pressure loss, heat losses, viscosity changes (Figure 6)} etc. that must be factored before it is completed. Another additional factor would be, the increased corrosion rate of the internal pipe not only due to the temperature but also due to the slightly acidic nature of Turkana crude, (Peres et.al 2021).

Recently, the initial design had sized an 18" pipe, but was resized to 20", (Africa Oil Corp, 2021). It is not clear why the resizing took place, however in most such cases, it emanates from initial

⁹ Business Daily, 13th May, 2020

underestimation of the play or new drilling technologies would have opened the potential to access more oil that was previously thought inaccessible thus allow for more flow rates and consequently increased production.

Admittedly, heat treatment in oil pipelines could induce changes in the colloidal structure of the crude oils and worsen their rheological properties, (Evdokimov et.al, 2002). In characterizing the dead crude oil from Ngamia (Lokichar) region in Turkana County, it was demonstrated that the Ngamia oil is weakly acidic with low moisture content % (0.70 ± 0.17) and is free from high heavy metal ion concentrations, (Peres et. al 2018). Moreover, the Ngamia crude is sweet and has a waxy nature¹⁰. In view of the above, analyzing the impact that heat tracing will have on the slightly acidic crude in the pipeline is vital to model the lifespan of the pipeline. Additionally, the type of ant-corrosive additives deployed must be compatible with the effect of heating and acidic nature of the crude. On the contrary, this will pose a challenge to its economical haulage and impact on the maintenance regime of the pipeline.

The waxy nature of crude oil is defined by two critical chemical parameters namely its pour point and its cloud point, (Petrowiki, 2016) also called the wax appearance temperature (WAT). WAT is the critical temperature at which wax nuclei form (G. A. Mansoori, H. Lindsey Barnes and Glen M. Webster, 2003), it is highly specific to each crude and is a function of:

- Paraffin concentration
- Cooling rate during measurement
- Water/oil ratio
- Oil composition
- Pressure
- Molecular mass of paraffin molecules
- Occurrence of nucleating materials e.g., asphaltenes, corrosion products, formation fines, etc.
- Shear environment

¹⁰ See Gaffney Cline, Continent Resource Estimates, 2014, p. 3; and Prospectus, Africa Oil, 2015, p. 54

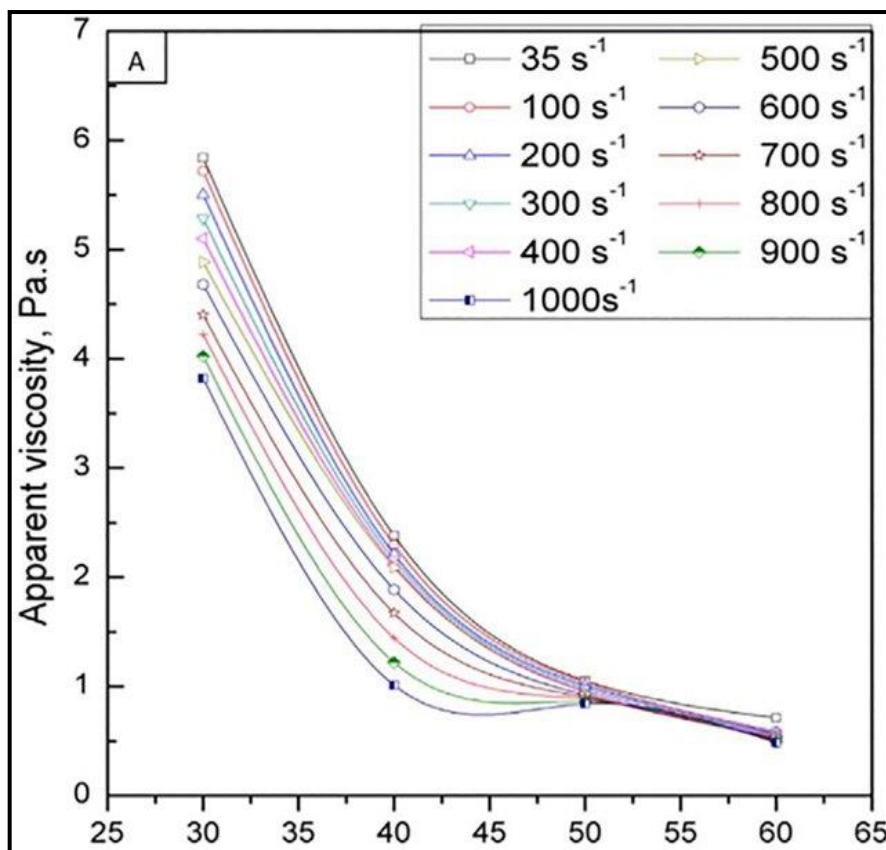


Figure 6. Viscosity response of heavy oil in the heat treatment temperature range of 30-60°C
(Source: Kumar et.al 2017)

The wax can be either a clean waxy crude: crude oil in which there exists only hydrocarbons and wax as its only heavy organic constituents or regular waxy crude: which is widespread in the world and the major complex systems problems related to the production, processing, and transportation of these medium-gravity fluids is not just crystallization of their wax content at low temperatures, but also the depositions which don't disappear upon heating and will not be completely removed by pigging. They're not clean, and additionally contain asphaltenes, resin, etc. Drawn below (Figure 7) are some of the possible methods of improving the flow of Ngamia crude oil in the upcoming Lokichar-Lamu pipeline.

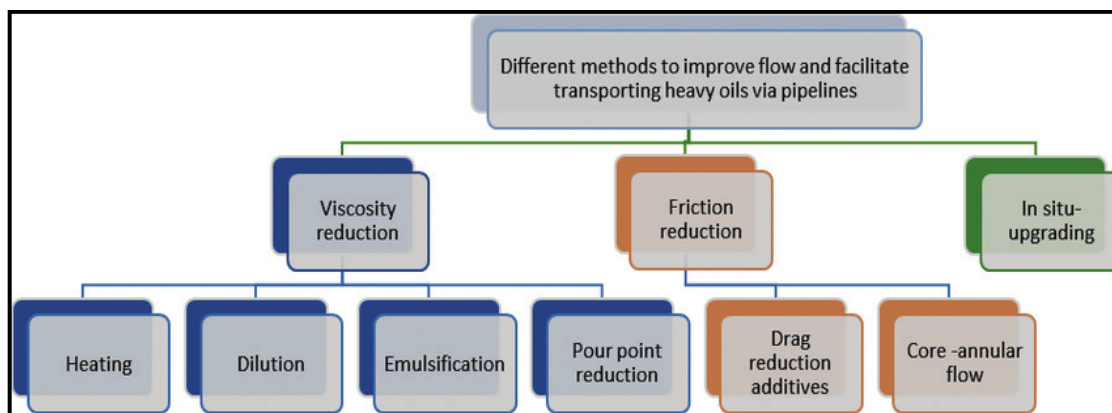


Figure 7. Possible Methods of Improving Heavy Crude Flow in Pipelines.
(Source: Researchgate.net, 2019)

ARISING ISSUES

Leaky Maintenance

Despite its unsophisticated level, the oil pipeline network in Kenya has already experienced several oil related incidents. In 2015, KPC's pipeline ruptured, spilling oil into the Thange River, contaminating, drinking water in Thange village, Makueni county, South East Kenya, 187 kilometers East of Nairobi. Over 800 school children were among those affected apart from the villagers and their drinking water¹¹. In September 2020, KPC chose to undertake spot repairs of an oil spillage along with the Samburu Area in Kwale county, which was attributed to a "drastic pressure drops" on a section of the pipeline. As earlier indicated, most of the pipes deployed on the old pipeline were manufactured by the electric-resistance-welded (ERW) method using carbon steel grade API 5L X52 specifications.

The oil spill preparedness and response in Kenya has been studied, (Muthike, 2018). This researcher notes that Kenya is among the signatories of the OPRC Convention and has adopted national systems for implementation of the provisions of the convention. His study shows that Kenya has tried to fully execute the provisions of this convention. An oil spill authority on oil spill preparedness has been set up. Internationally standardized instruments and machines have been put in place and personnel from oil firms have likewise been trained in their applications.

Furthermore, the scholar claims, that the nation has a draft national oil spill response contingency plan and draft dispersant use policy. However, the research revealed that in case a large spill was to happen, these training and exercises would not be able to handle it and specific regulations on oil spill preparedness and response still miss.

The current main sources of waste generation from the downstream oil and gas sub-sector include:

- (a) Petroleum retail outlets
- (b) KPC depots
- (c) Port of Mombasa
- (d) KPRL
- (e) Industries that use fuel oil

The causes of waste generation from the upstream and midstream are yet to be identified and quantified. A comparative analysis of oil pipeline failures in oil and gas industries in the Niger Delta reveal that the main causes of failure are: corrosion, ageing, mechanical failure – welding defects, pressure surge problems, stress, wall thickness, etc (Achebe et.al 2012).

Environment

Even though pipeline transportation of oil products is considered safer and cheaper than ground transportation of tankers and rail, pipeline failures do happen. Consequently, they detrimentally maim the environment. In order to lay pipelines underground, extensive acres of trees and vegetation have to be cleared, thus rich ecosystems are brutally adjusted, decreasing habitats for animals' species and rare plants. Certainly, environmental risk is not limited to the construction process alone but even during the operation of the pipelines. Pipelines need

¹¹ Andrew Ross, Anadolu Agency, 6th November, 2015

compressor stations that pose significant health hazards. They are sources of air pollution with a combination of pollutants emitted such as volatile organic compounds (VOCs), nitrogen oxides (NO_x), formaldehyde, and greenhouse gases. These gases in turn affect the nervous system, cause lung damage, and impact the respiratory system of the area residents and employees of the compressor stations. Moreover, the noise levels of these compressors can reach 100 decibels. Such a level, accelerates loss of hearing because, according to the Centre for Disease Control and Prevention (CDC), listening to sounds at or above 85 decibels over an extended period damages eardrum. Additionally, compressor stations consume colossal amounts of energy for their operations. KPC, for instance, is the largest consumer of electricity in Kenya¹². And this is just for the refined white oil products alone, meaning for the waxy Turkana crude oil, the power bill for the 16 AGIs will be astronomical in order to overcome the shear and frictional forces along the pipeline.

The Lokichar-Lamu crude oil pipeline is among the most environmentally challenging projects for the Kenyan government. It will traverse through two protected areas, six conservancies, two key biodiversity areas (KBA), three main rivers, and vital areas for wildlife and marine and coastal ecosystems¹³. How this impact on the environment will be minimized is a theme for future research.

Safety

Pipelines can also accidentally release crude oil or natural gas due to third-party damage (this is damage done by people or contractors not associated with the pipeline operator), operator error, corrosion, control systems' failure, mechanical failure, and natural forces such as floods and earthquakes. Additionally, these pipeline occurrences can result in fatalities or injuries. For instance, for Kaduna Refinery and Petro-chemical company in Nigeria, it is showed that insufficient pipeline networks are major challenges, (Obasanjo 2013). For years now, this refinery has been a depilated state. On the other hand, in the Akwa Ibom State of Nigeria, it is revealed that outdated, rusty, and poorly maintained oil pipelines often led to oil spills during transportation of the product, (Akpan 2014). This therefore, implies that, regular and proper maintenance of oil pipelines is essential for smooth and proper pipeline operations.

Additionally, keen care is needed in order to remove the deposition of scale, gas hydrates, asphaltene and naphthene which may plug the pipeline, which in turn may result in heavy losses to both the parties not only in monetary terms but also in terms of leakage due to pipeline bursting, (Vincent 1984). Summarily, the adoption of proper maintenance systems for oil pipelines needs to be proactive and not reactive. In Tanzania, for Instance, a gas pipeline leak detection system by the Tanzanian Petroleum Development Corporation in their natural gas distribution pipeline as a safety measure confirmed reduction of losses, (Lukonge et.al 2019). It is imperative therefore that effective and standard measures be integrated in the HSE policies of entities like KPC.

Kenya Maritime Authority, confirms that between 1988 and 2013, Mombasa County alone experienced five oil spills. Even though this state entity is responsible for damages incurred due

¹² Kajilwa, Graham (2017-12-18). "Why Bamburi cement put off mega plans for alternative solar energy". The Standard. Retrieved 2017-12-18.

¹³ Rapid Risk Assessment of the Lokichar-Lamu Crude Oil Pipeline, pg 6

to oil spills, this should be a solely state mandate of the National Environment Management Authority¹⁴. Apart from spills, pipeline rupture and vandalism remain a sticky issue in oil product pipeline transportation partly due to environmental justice issues, (Emmanuel et.al, 2021). In Nigeria, for instance, this is acknowledged in the Federal Government's Fourth Plan (1981 – 1985) as a major threat to the efficiency of pipeline operations¹⁵.

In Kenya, similar ranking is missing and if its available, it is inaccessible. However, categorizing, recording and ranking such incidents will enhance the firm's perception and reputation in view of the increasing environmental scrutiny from different corners in the industry.

Industry Standards

Reliability and efficiency are some of the major factors to consider in pipeline transportation of oil products, (Xiao et.al, 2018). In the USA, API has set industry practices that guide pipeline reliability and safety operations. For instance, a) Pipeline operators can use a pipeline performance tracking system, controlled and coordinated by API. In this system, operators can submit data on potential and actual pipeline incidents. The aim here would be to track long-term safety patterns. This same system can be executed in Kenya with an independent auditor monitoring the system, for purposes of accountability. Moreover, KPC can apply integrity technology and modeling to identify potential pipeline cracking, institute repairs, gather and use data to establish preventive measures for pipeline cracking. And improve their effectiveness and efficiency by using in-line inspection devices, that travel within pipelines and collect data on potential imperfections in pipe walls.

Moreover, modern Supervisory Control and Data Acquisition (SCADA) systems that return real-time information about the rate of flow, flash point, the pressure, the speed, specific gravity, density, etc. can be adopted by KPC. With such measures, incidents of diversion of adulterated fuel worth millions of dollars¹⁶ and procurement of fictitious hydrant valves with firms¹⁷ that have no abode at the registrar of companies, will be history. Incidentally, the wax formation along the pipeline must also be contained.

Above all, the transportation of Turkana crude oil from Lokichar to Lamu via the pipeline should not be restricted to heating the pipeline but rather explore the various methods of transporting waxy or heavy crude for cost reduction. Conclusively, by ascertaining the paraffinic content of this crude, the ease of choosing the best method of sustaining the flow of the crude can be achieved and the issue of sub-optimal usage of the pipeline erased.

Security

The safe securing of pipelines remains a major issue for most operators. Even though most of the pipelines lie below the ground surface, some sections are usually above the ground. Providing security for these sections remains challenging, especially if the section is in a remote area. In countries like Nigeria, Mexico, Brazil, groups of local militia/criminal cartels may locate these isolated areas, break or blow them to steal crude oil. For instance, in 2016, the Niger Delta

¹⁴ Kenya Maritime Authority, Website

¹⁵ Nigeria. Fourth National Development Plan, 1981-1985. Annu Rev Popul Law. 1987; 14:293-6. PMID: 12346675

¹⁶ The Nairobi Law Monthly, Special Report, 9th October, 2018 – Kenya Pipeline Grand Corruption.

¹⁷ The East African, 27th December, 2016 – Kenya Pipeline Company Leaks \$10m in Procurement Scams.

Avengers militants blew up the Nembe 1, 2, and 3 trunk lines in Bayelsa and Rivers states, which is owned by the Aiteo group, and siphoned off the crude oil, (Nsikan et.al 2019). In this region, pipeline vandalism remains a burning issue to pipeline oil transport. Other times, a spur can invalidate everything in the pipeline, necessitating flushing and refilling of the pipeline. If the pipe was very deep in the soil, then this becomes a very expensive overhead. Different research in the Niger Delta region, however, reveals the existence of a significant and positive relationship between poor management, poor governance, legal and environmental degradation, (Umar et.al 2017) while demonstrating no significant relationship between poverty, unemployment and vandalism, very much contrary to many previous studies.

In Kenya, insider stealing remains a challenge. A typical case of pipeline insecurity is highlighted by the Mlolongo theft¹⁸. This oil siphoning went on undetected for several months. Intriguingly enough, it is the fourth such reported case in under two years, revealing the possibility of large-scale losses of the oil products in its 1,792-kilometer network nationwide (a similar diversion was discovered on the Sinendet – Kisumu line at Kibos and a similar one at Koru area in Kisumu County)¹⁹. As KPC later accused the security provider of its new 20" oil products' pipeline, it couldn't answer invasive queries on the effectiveness of its multiple layers of surveillance on the pipeline, including a helicopter and numerous rugged 4 x 4 vehicles.

Furthermore, the Energy and Petroleum Regulatory Authority notified KPC for omitting critical leak detection systems from its new multi-billion pipeline despite existing in the approved plans. Apparently, in 2018, insurers refused to pay when KPC²⁰ claimed that 7.2 million liters of oil products had been lost through spillage. On investigation, traces of spillage could not be found, leading to industry insiders terming it an audacious white lie. Like Nigeria, which lost \$3.5 billion of revenue to crude oil theft (or about 200,000 barrels of oil per day, which is 100,000 more barrels than what Kenya expects to be producing once the Turkana oil comes online!) in 2021 alone, (about 10% of the country's foreign reserves), (xxxxx). Kenyan oil thieves are evicting scarce foreign investors in droves, much to the detriment of the current government's big four agenda, with manufacturing, being one of four pillars.

Similarly, given the proximity of Lamu to the Somali border, high levels of security assurance and presence will need to be given not just to the company personnel, given the numerous armed cattle robbers, frequent terrorist attacks by Al-Shabab, and threats from the likes of Mombasa Republican Council, whose aim is secession of the Coast Province, but to the pipeline and its infrastructure themselves including the critical 16 AGI's.

Terrain

The Lokichar -Lamu crude oil pipeline will cover 892 kilometers. Most of its journey is through tough and severe terrain. Elements of weather like searing desert temperatures, delicate ecosystems, sudden sandstorms, Rift valley terrain (faults and fissures), volcanic rocky soil and dramatic changes in elevation (from 6m at Lamu to 2300m above sea level at Chemerongit

¹⁸ Edwin Okoth, 19th July, 2020, Daily Nation – Kenya: Mlolongo Pipeline Oil Theft “Sparked KPC Legal Battle with Security Firm

¹⁹ Edwin Okoth, 26th June, 2019, Business Daily – Two Arrested Over New Kenya Pipeline Fuel Theft.

²⁰ John Kamau, 22nd November, 2018, Daily Nation – Riddle of Shs1bn ‘Split’ fuel at Kenya Pipeline that you might have to pay

hills), and logistical issues of transporting equipment to the worksite, pose a series of challenges that this project must encounter and solve. The risk of seismic waves in the Rift valley tertiary region (where some of the LLCOP must cross to the western part of Kenya) is high. Flooding, landslides, soil erosion is another risk that must be contained, (Lamu is relatively flat with an elevation of approximately 6m above sea level – suitable for pipeline construction but very prone to onshore and offshore flooding, while Lokichar is relatively flat (700-800m) above sea-level but surrounded by small hills including Loichangamatak, Kamorok, and Chemerongit, with a series of interconnected streams draining into Turkwel river).

Sinkholes, or natural channeling pose challenges to LLCOP. Recently, a large fault stretching several miles appeared on the floor of Rift valley, even though it was in the south-western part, it is still part of the tertiary Basin, (Diaz 2018). Extensive periodic sensitivity analysis of all the pipeline wayleaves should be part and parcel of the monthly operations of KPC. Admittedly, how the pressure drop across the 892-kilometer terrain will be handled to reduce the pump power and consequently the power bill, is a research objective that can aid in automating pump and booster station operations. According to Wambua et.al (2019), the Shell-MIT method is a suitable candidate for validation of pressure drop of heavy crude oil pipelines like the LLCOP but the elevation change must be cautiously monitored.

Geopolitical Issues

Pipeline construction involves the repossession of land for right-of-way construction. This pipeline will cross several counties within Kenya, all with peculiar and unique land issues. Land in Kenya is an emotive issue. Unlike in the USA, where eminent domain is used to allow states or federal government bodies to exercise their power to take private property from residents or citizens for public use and development, in Kenya, the case is different. The National Land Commission is the only entity in the nation that has the mandate of acquiring land on behalf of the government for national projects for creation of wayleaves. And it must compensate citizens for any acquired land. The average time for land compensation of acquired land for public projects is two years. Since the onset of this project, two years have already elapsed. However, serious problems of compensation of acquired land in the several counties that the \$5billion Lokichar-Lamu pipeline will traverse remain.

Timely, proper and equitable compensation is a challenge that the National Land Commission is yet to overcome. It is yet to fully execute the compensation, thus delaying the full implementation of the pipeline. Furthermore, the recent decision by the Ugandan government to opt for the Kabaale – Tanga route for its oil exports from the Lake Albert basin seems to have thrown into limbo the entire Lokichar-Lamu oil pipeline.

Initially, considered a joint project between Kenya and Uganda, now Kenya has to single-handedly work out a new funding package. Even though Toyota Tshusho is rumored to have made a bid for its construction, the final execution of the pipeline construction remains a pipe dream for the time being. A simple lesson for Kenya could be drawn from the 1,768km long Baku-Tbilisi-Ceyhan underground pipeline which BP and its partners built through Azerbaijan, Georgia, and Turkey, through sober social analysis, intense political lobbying, mutual partnership-building, calm diplomacy, and sheer grit patience in attaining sufficient levels of regional collaboration.

RECOMMENDATIONS

This paper has thus explored the state of art of pipeline distribution of oil products in Kenya. And it has shown that this industry has the potential to drastically change the economic ecosystem of Kenya. It therefore recommends the following measures:

- (a) Apply new technology: Technology can help in leakage detection (Sharma et.al-2014, Salam et.al -2014) within a pipeline setup through pressure analysis and even in cleaning the pipelines. Therefore, the future of oil product pipeline transport in Kenya lies in the application of new technologies, in daily pipeline operations, maintenance, and innovation of construction materials. New operational software, intelligent pipeline management systems, fiber vibration intrusion warning systems, leak detection systems, artificial intelligence, data analytics, multi-factor intelligent pipeline modeling and advanced intelligent algorithms, internet of things (IoT), machine learning, use of smart drones (that combine infrared thermography and 3-D characterization) for NDT/NDE inspections, adopt new NbCr designed pipes with desired ferrite/acicular ferrite microstructure with excellent strength, weldability and toughness, (Siciliano et.al, 2007), alternatively, use reinforced thermoplastic pipes (RTP),(Achebe et.al 2012), adapt multi-layer flow for the waxy crude oil (also known as lubricated pipelining, Sarmadi et.al 2019), implement the use of solar panels for the 16 AGI's for LLCOP and all other pipeline trunk lines, explore the use of surfactants/polymers in the Turkana crude oil's journey from Lokichar to Lamu (Kumar et.al 2017), or even water as annular fluid, (Wylde et.al 2012), etc, will optimize the use of pipelines inefficient transport of oil product distribution.
- (b) Adopt new economic models: Given the increasing world (including the East and Central Africa) energy needs (especially oil products), pipeline transport will continue to play a crucial role in respective economies. State players alone will not fill this gap. Just like in public transport, due to the huge capital outlay required for pipeline investment, the private sector should be involved in investing in a new pipeline network. Economic Instruments like Build-Rent-Transfer (BRT), Build-Own-Operate (BOO), Build-Operate-Transfer (BOT), Build-Own-Operate-Transfer (BOOT), Build-Lease-Transfer (BLT), Rehabilitate-Lease-Transfer (RLT), and Rehabilitate-Operate-Transfer (ROT) should be deployed by the government in new pipeline transport of oil products. Investment in new pipeline infrastructure, largely managed and operated with smart technologies, in a race to become the automatic regional logistical hub of oil and gas products, given the gas reserves recently discovered in Tanzania, the new oil discoveries in Uganda, the existing oil production in South Sudan plus its frequent disputes of export with its former colonial master – Sudan and the second-largest market in Africa – Ethiopia in terms of population, must be considered and pursued. With the added advantage that Kenya already has a robust and developed market infrastructure, being a step ahead of the crowd will only be possible if more investments are made, both private and public.
- (c) Enforce industry standards: KPC should adopt an industry practice widely used in the USA, of Pipeline Performance Tracking System (PPTS). This is an absolutely free-will and comprehensive reporting system that collects data on spills and pipelines infrastructure. It has a standard template for recording incidents, carefully crafted to assess the implications for operations and the impacts of incidents, while prioritizing risk mitigation strategies. It also has a page for onshore and offshore mileage, mileage by diameter, mileage by date of construction plus other related features. Affiliated to

this, is the adoption of community policing where the pipelines cross. By engaging local security personnel, in places where the pipeline is over the land, the community will be empowered to participate in the protection of public property in their domain, thus fast-tracking the report of leakages, spills, vandalism, and any other related incidents on the oil installations.

- (d) Eradicate grand corruption: The politics, economics, and mathematics of theft in KPC point in one direction: effective judicious dispensation of justice. As one of the state entities entrusted with operating the oil pipeline network, KPC has one of the worst track records in public funds' spillage²¹. Numerous court cases involving KPC still drag in Kenyan courts at a very viscous velocity. Speedy sentencing of public looters will deter corruption, encourage foreign investment and transform lives through safe and efficient delivery of quality oil products from the market to the customer, as claimed in KPC's mission. Unfortunately, the speed of wheels of justice in Kenya can sometimes be painstakingly slow, for instance, when KPC paid heavily dense legal fees to the tune of \$1.5 million²² to four top law firms in Kenya to represent it in a court case where a Lebanese contractor was demanding for payment of approximately \$40 million for operational delays in the building of the \$500 million Mombasa-Nairobi pipeline (Line 5). And in January 2021, in yet another legal case²³, KPC lost a bid to recover approximately \$156,000 from a contractor, who according to KPC, failed to complete the clearance of bushes and rehabilitation of the right-of-way along the Mombasa-Nairobi and Nairobi-Eldoret pipeline routes even though the contractor had been paid. How he was paid before completing the task is hard to unravel. It is not clear if KPC possess such procedural instruments like work completion certificate in their daily procurement operations.

CONCLUSION

This paper reviewed the state of the art of oil pipeline transport in Kenya. It is clear that the current KPC network is plagued with diverse challenges, both aged, current, and potential future ones. This paper focused on both white and black oil product distribution and shows possible technical, social, and economic solutions. These solutions need to be researched in more detail and be optimized. The pipeline model of oil product distribution in Kenya should be allowed to play its main role as the primary transport mode of these products within the country with the rest of the other modes of transport like rail and road serving as secondary feeder transport modes. A comparative analysis evaluating the benefits and disadvantages of reforming the entire distribution system is therefore necessary. This paper also highlights that the approach of investing in modern-day technology to counteract human frailties can succeed.

It, therefore, concludes that if Kenya desires to effectively and efficiently distribute oil products, in a manner similar to the United States and other world leaders in oil product pipeline distribution, then it can do so by simply sticking to the law.

²¹ The East African, 27TH December, 2016 – Kenya Pipeline Company Leaks \$10m in Procurement Scams.

²² Edwin Mutai, Kenya Pipeline on the spot over Shs165m legal fees, Business Daily, 13TH September, 2021

²³ Joseph Wangui, KPC Fails to recover Shs17m paid for bush clearance, Business Daily, 11TH January, 2021

ACKNOWLEDGEMENT

The authors acknowledge the World Bank Africa Centre of Excellence for Oilfield Chemicals Research, University of Port Harcourt, Nigeria for their support in carrying out this research. The authors acknowledge the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) for financial support during research.

References

- A B Lukonge, X. Cao (2019). IOP Conf. Ser.: Earth Environ. Sci. 342 012019
- Africa Oil Corporation (2021). Africa Oil Provides an Update for Project Oil Kenya Including a Higher Plateau Production Rate and an Independent Resources Evaluation. Suite 2000. 885 West Georgia Street Vancouver, B.C Canada V6C 3E8. Ph. 604-689-7842
- Ahmed Tukur Umar, Moh'd Shahwahid Hajj Othman (2017). Causes and Consequences of Crude Oil Pipeline Vandalism in the Niger Delta Region of Nigeria: A Confirmatory Factor Analysis Approach. *Cogent Economics & Finance* (2017), 5: 1353199. <https://doi.org/10.1080/23322039.2017.1353199>
- Akpan, P. (2014). Oil Exploration and Security Challenges in the Niger-Delta Region: A Case of Akwa Ibom State, Nigeria. *IOSR Journal of Research & Method in Education (IOSRJME)*, 4(2), 41–48
- Basma M. Yaghi & Ali Al-Bemani (2002). Heavy Crude Oil Viscosity Reduction for Pipeline Transportation, *Energy Sources*, 24:2, 93-102, DOI: 10.1080/00908310252774417
- Batheja, A (2014). Rail Transport of Crude Oil Increases as Pipeline Falls Short. *The New York Times*. (4). Retrieved from: https://www.nytimes.com/2014/04/13/us/rail-transport-of-crude-oil-increases-as-pipeline-falls-short.html?_r=0;
- Bensakhria A, Peysson Y and Antonini G (2004). *Oil & Gas Science & Technology* (59) 523
- Beth Gasheri Murungi, Anaya W Senelwa (2019). Determinants of Implementation of Sustainable Procurement Practices in Oil and Gas Sector in Kenya. (A Case of Kenya Pipeline). *International Journal of Recent Research in Commerce Economics and Management (IJRRCEM)* Vol. 6, Issue 4, pp: (185-191), (10-12), Available at: www.paperpublications.org. ISSN 2349-7807
- C.H. Achebe, U.C. Nneke, O.E. Anisiji (2012). Analysis of Oil Pipeline Failures in the Oil and Gas Industries in the Niger Delta Area of Nigeria. *Proceeding of The International MultiConference of Engineers and Computer Scientist 2012 Vol II. IMECS 2012*, (3), Hong Kong.
- Chang C, Nguyen QD, Ronningsen HP (1999). Isothermal start-up of pipeline transporting waxy crude oil. *J Non-Newton Fluid Mech* 87:127–154
- Chris M. Wambua, Ogbonna F. Joel, Sunday S. Ikiensikimama, Daniel O. Oyoo (2019). Validation of Calculated Pressure Drop Using Experimental Data with Standard Methods of an Existing Software. *Journal of Engineering Research and Reports*. 9(3):1-10. Article No. JERR.53705. ISSN: 2582-2926
- Congressional Research Service (2014). U.S. Rail Transportation of Crude Oil: Background and Issues for Congress. Retrieved from: <https://fas.org/sgp/crs/misc/R43390.pdf>;
- Emanuel, R. E., Caretta, M. A., Rivers, III, L., & Vasudevan, P (2021). Natural gas gathering and transmission pipelines and social vulnerability in the United States. *GeoHealth*, 5, e2021GH000442. <https://doi.org/10.1029/2021GH000442>
- Evdokimov, I.N., Eliseev, D.Yu., and Eliseev, N.Yu. (2002). Negative viscosity anomaly in liquid petroleum after heat treatment. *Chemistry and Technology of fuels and oils*, 38, 3, 171-177

- F. Homayuni, A. Hamidi A. Vatani, A.A Shaygani and R. Faraji Dana. (2011). Viscosity Reduction of Heavy and Extra Heavy Crude Oils by Pulsed Electric Field. *Petroleum Science and Technology*, 29:2052–2060. Copyright © Taylor & Francis Group, LLC ISSN: 1091-6466 print/1532-2459 online. DOI: 10.1080/10916461003699143
- Fulvio Siciliano, Douglas G. Stalheim, J. Malcolm Gray (2008). Modern High Strength Steels for Oil and Gas Transmission Pipelines”. January 2008. DOI:10.1115/IPC2008-64292
- G. A. Mansoori, H. Lindsey Barnes and Glen M. Webster, 2003
- Gateau P, Henaut I, Barre L and Argillier J F (2004). *Oil & Gas Science & Technology* (59) 503.
- Germano Mwabu (2018). Kenya’s Oil Governance Regime: Challenges and Policies. CRPD Working Paper No. 71 (12). Centre for Research on Peace and Development (CRPD) KU Leuven Parkstraat 45, Box 3602, 3000 Leuven, Belgium Phone: +32 16 32 32 50; Fax: +32 16 32 30 88; <http://www.kuleuven.be/crpd>
- Gicharu, N. P. (2017). Factors Influencing Supply of Petroleum Products in Kenya: A Case of Kenya Pipeline Company Eldoret Depot, Uasin Gishu County, Kenya. Unpublished Master of Arts in Project Planning and Management Thesis: University of Nairobi.
- Guangyu Suna, Jinjun Zhanga, Chenbo Maa, Xinyi Wang, (2016). Start-up Flow Behavior of Pipelines Transporting Waxy Crude Oil Emulsion. *Journal of Petroleum Science and Engineering*. www.elsevier.com/locate/petrol. <http://dx.doi.org/10.1016/j.petrol.2016.10.007>
- Guevara, E., Gonzalez, J. and Nuñez, G (1998). Highly viscous oil transportation methods in the Venezuela oil industry. *Proceedings of the 15th World Petroleum Congress*, John Wiley and Sons, London, 495-501.
- Hardy, W. A., S. P. Sit, and A. Stockwell. (1988). Field Trials of Transoil Technology for Emulsion Pipelining of Bitumen. Fourth UNITAR/UNDP Conference on Heavy Crude Tar Sands, Vol. 5, Paper No. 222, UNITAR/UNDP: Edmonton, Alberta
- Herman Wang (2022). As Europe Seeks Alternatives to Russian Gas, Algeria Has Pipeline Capacity to Spare. *LNG/Natural Gas* (1).
- IMF Guide on Resource Revenue Transparency available at:
<https://www.imf.org/external/np/pp/2007/eng/051507g.pdf> accessed 20 December 2020
- John F. Kiefner and Cheryl J. Trench (2001). Oil Pipeline Characteristics and Risk Factors: Illustrations from The Decade of Construction,” Report, (12). © American Petroleum Institute.
- John Kihara Chege (2012). Challenges of Strategy Implementation for Firms in the Petroleum Industry in Kenya. Unpublished thesis, Master of Business Administration, School of Business, University of Nairobi.
- José A. D. Muñoz, Jorge Ancheyta, and Luis C. Castañeda (2016). Required Viscosity Values to Assure Proper Transportation of Crude Oil by Pipeline. *Energy Fuels*. DOI: 10.1021/acs.energy.fuels.6b01908. (09).
- Kenya Vision 2030 (2020). The Popular Version”, pg 6, available at:
<http://vision2030.go.ke/inc/uploads/2018/05/Vision-2030-Popular-Version.pdf>
- Kumar, S., Mahto, V (2017). Emulsification of Indian heavy crude oil using a novel surfactant for pipeline transportation. *Petrol. Sci.* 14 (2), 372e382. <https://doi.org/10.1007/s12182-017-0153-6>.
- LCDA. (2016). Brief on LAPSSSET Corridor Project. LCDA. https://en.wikipedia.org/wiki/Lamu_Port_and_Lamu-Southern_Sudan-Ethiopia_Transport_Corridor
- Lucia Perez Diaz (2018). Africa is Splitting in Two - Here is Why. Fluid Dynamics Research Group, Royal Holloway, University of London.

Mamdouh T. Ghannam, Nabil Esmail (2006). Flow Enhancement of Medium-Viscosity Crude Oil. *Petroleum Science and Technology*, 24:985–999. Copyright © Taylor & Francis Group, LLC. ISSN: 1091-6466 print/1532-2459 online. DOI: 10.1081/LFT-200048166

Matras Z, Malcher T and Gzyl-Malcher B (2008). *Thin Solid Films* (516) 8848

McAllister EW. Pipeline rules of thumb handbook: A manual of quick, Accurate Solutions to Everyday Pipeline Engineering Problem. Burlington, Ma: Gulf professional Publ; 2009

Mikwa, O. (2014). Determinants of Choice of Transportation Mode for White Petroleum by Oil Marketing Companies in Kenya. *IOSR Journal of Business and Management*, 16(2), 135–148

Ministry of Energy and Mineral Development (2008). The Republic of Uganda, National Oil and Gas Policy for Uganda.

Muthike, Stellamaris Ndeve (2018). Assessment of Kenya's capacity to effectively prepare for and respond to oil spill incidents. *World Maritime University Dissertations*. 680. https://commons.wmu.se/all_dissertations/680

Muthini, J. N., S, P. N. G., Guyo, W., & Shale, N. I. (2016). Role of Government Health and Safety Regulations on Petroleum Supply Chain Management. *IOSR Journal of Business and Management*, 06(12), 29–36.

Myers R D, MacLeod J B, Ghosh M and Chakrabarty T 2000 US Patent Application 6096192

Nsikan, J., Ekeins-Wilson, M., Anyandike, T., & Ortencia, M. (2019). Supply Chain Disruption in Nigeria Oil and Gas Sector: Some Mitigation Strategies. *International Journal of Scientific and Research Publications (IJSRP)*, 9(2), 86-91.

Obasanjo, O. T. (2013). Comparative Analysis of the Modes of Transportation of Petroleum Products Out of Kaduna Refinery and Petro-Chemical Company. Unpublished Master Degree Thesis: Ahmadu Bello University.

Obuola Odhiambo Phelix, (2017). Strategy Formulation and Performance of Selected Firms in Oil and Gas Industry in Kenya” Unpublished Master of Business Administration Degree, Kenyatta University, 2020.

Otieno Judith Peres, Daniel Oyoo Okanga, Robert Bichanga (2018). Characterization of Dead Crude Oil from Ngamia Region, Turkana County, Kenya. *Global Scientific Journals*, Vol. 6, Issue 12, Online ISSN 2320-9186. www.globalscientificjournal.com

Oxford Institute for Energy Studies (2014). Kenya: An African oil upstart in transition”, October 2014. Copyright Oxford Institute for Energy Studies (Registered Charity, No. 286084). ISBN 978-1-78467-011-5

Peter Ndegwa Gicharu, Yona Sakaja Mang'usho (). Factors Influencing Supply of Petroleum Products in Kenya; A Case of Kenya Pipeline Company, Eldoret Depot, Kenya. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)*. ISSN (Print) 2313-4410, ISSN (Online) 2313-4402. © Global Society of Scientific Research and Researchers. <http://asrjetsjournal.org/>

Pipeline (2005) Pipeline 101 (<http://www.pipeline101.com>)

Ravindra Kumar, Shirsendu Banerjee, Ajay Mandal and Tarun Kumar Naiya, Flow improvement of heavy crude oil through pipelines using surfactant extracted from soapnuts, *Journal of Petroleum Science and Engineering*, <http://dx.doi.org/10.1016/j.petrol.2017.02.010>

Salam, A. E. U., Tola, M., Selintung, M., & Maricar, F. (2014). On-Line Monitoring System of Water Leakage Detection in Pipe Networks with Artificial Intelligence. *ARPN Journal of Engineering and Applied Sciences*, 9(10), 1817–1822.

Sanière A, Henaut I and Argillier J F (2004). *Oil & Gas Science & Technology* (59) 455

- Santos R G, Loh W, Bannwart A C and Trevisan O V (2014). Brazilian Journal of Chemical Engineering (31) 571
- Sarmadi, P. and Frigaard, I.A. (2019). Stable core-annular flows in inaccessible domains via a triple-layer configuration. Chem. Eng. Sci. X, 3, 100028.
- Shadi W. Hasan, Mamdouh T. Ghannam, Nabil Esmail (2010). Heavy crude oil viscosity reduction and rheology for pipeline transportation. Fuel 89 (1095 – 1100). www.Elsevier.com/locate/fuel
- Shaikh, F., Ji, Q., Shaikh, P.H., Mirjat, N.H., Uqaili, M.A (2017). Forecasting China's Natural Gas Demand-Based on Optimized Nonlinear Grey Models. Energy 140, 941-951
- Sharma, S. L., Qavi, A., & Kumari, K. (2014). Oil Pipelines/Water Pipeline Crawling Robot for Leakage Detection/Cleaning of Pipes. Global Journal of Researches in Engineering: Robotics & Nano-Tech, 14(1), 31–38.
- Shigadi Miriam Wawuda, Faith Mungai (2016). Factors Affecting Distribution of Oil Products in Kenya: A Case Study of Kenya Pipeline. International Journal of Supply Chain Management. ISSN xxxx-xxxx (Paper) ISSN xxxx-xxxx (Online) Vol.1, Issue 1 No.1, pp 34-48, www.iprjb.org
- Shigemoto N, Al-Maamari R S, Jibril B Y and Hirayama A 2006 Energy & Fuels (20) 2504
- Suraw, N. I., & Kariuki, S. N (2018). Economic Factors and Financial Performance of the Petroleum Firms in Kenya. Vol. 5, ISS. 4, pp 695 – 705 (10). The Strategic Journal of Business & Change Management. ISSN 2312-9492(Online) 2414-8970(Print). www.strategicjournals.com, ©Strategic Journals
- Tao R and Tang H 2014 Fuel (118) 69
- Turkana County- United Nations Joint Programme 2015-2018, (Executive Office, Turkana County Government, Lodwar, Turkana UN Resident Coordinator Office, Nairobi, Kenya), pg 4, available at: <https://info.undp.org/docs/pdc/Documents/KEN/ProDoc%20Turkana-UN%20Joint%20Programme%20final%205th%20%20March%202015-binder%20%282%29.pdf> accessed 20 February 2020
- Vincent-Genod J (1984). Fundamentals of Pipeline Engineering.
- Wylde J J, Leinweber D, Low D, Botthof G, Oliveira A P, Royle C, Kayser C (2012). Heavy Oil Transportation: Advances in Water Continuous Emulsion Methods. In: Proceedings of the world heavy oil congress, Aberdeen.
- Xiao Q, Li J, Sun J, Feng H, Jin S (2018). Natural-gas pipeline leak location using variational mode decomposition analysis and cross-time–frequency spectrum. Measurement. 2018; 124:163-172.