VAASAN AMMATTIKORKEAKOULU
VASA YRKESHÖGSKOLA
UNIVERSITY OF APPLIED SCIENCES

Oluseye Michael Johnson

FIBER OPTICS: SAFETY MEASURES ON OIL & GAS PIPELINE MONITORING IN LAGOS STATE REGION

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Johnson Oluseye Michael

VAASAN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES
Degree Program in Information Technology

ABSTRACT

Author	Oluseye Michael Johnson
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The objective of this thesis work is to research and implement the use of an optical communication system (fiber optics) as a safe and reliable monitoring system for the oil and gas pipeline industry in Lagos region of Nigeria. These optical fiber cables are laid parallel to oil and gas buried pipelines to monitor and indicate advanced warning in real time situation once leakages occur in these pipelines, thereby allowing pipeline operators to take immediate and strategic actions to resolve the problem.

This integrity and performance of oil and gas pipeline is essential to the smooth operations expected from regulatory authorities. Leakage in pipelines may be as a result of mechanical failure (cracks, corrosion, and welded joint failure) or illegal tampering (drilling, bursting, hot tapping) which could lead to spillage of the product, environmental pollution or even loss of lives, if not adequately addressed in time.

As a result of implementation of the project, the use of optical communication system (temperature point sensor) was not sustainable due to the fact that several point sensors has to be considered for monitoring the pipelines. The sensor was used to monitor abnormal temperature changes around the pipeline and thereby giving warnings, through the monitoring software in real time situation. Such monitoring software enabled me to setup important measurement parameters and observe the monitoring processes. Also, the possibility to use distributed sensor where entire cable length serves as linear sensors was considered for a future project.

Finally, knowledge acquired in this project work enhances my understanding of the use of Information technology in the field of oil and gas pipeline industry.

Keywords Fiber optics, optical fiber sensors, oil & gas pipeline monitoring

CONTENTS

LIST OF ABBREVIATIONS

bar	Pressure unit, 1 bar of pressure = 14.504 pounds/square inch
BS	British Standard code of practice
CS	Compact Series
HDPE Pipe	High-Density Polyethylene Pipe
IEC	International Electrotechnical Commission
inch	Unit of length, 1 inch is equivalent to 25.4 millimeter (mm)
IR	Infrared
ISO	International Standardization Organization
LED	Light Emitting Diode
MM Fiber	Multimode Fiber
nm	Nanometer (1 nm = 1 x 10^{-9} m); one-billionth of a meter
NGC	Nigerian Gas Company
NNPC	Nigerian National Petroleum Corporation
NPDC	Nigerian Petroleum Development Company
OPT-CS-LT15	Optris Compact Infrared Pyrometers
PRMS	Pressure Reducing & Metering Stations
SM Fiber	Single-Mode Fiber
Speed of light	Denoted as “c” (3 x 10^{8} meter per second)
µm (micron)	Micrometer (1 µm = 1 x 10^{-6} m); one-millionth of a meter

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1 INTRODUCTION

Nigeria has been an oil producing country since 1960, and also with an enormous gas reserve estimated at 190 trillion cubic feet (5 trillion cubic meter) /15/, of which only a small fraction are still used. In fact our natural gas has been flared to the atmosphere. However, the country through the "Nigerian Gas Master Plan" wants to effectively utilize and expand the gas infrastructure so as to have positive effects to the economy (commercial exploitation and management of the gas sector). So, the government started planning, some years ago to channel the natural gas to be domesticated by residential and industrial areas for use as energy sources – cooking, gas ovens, gas boilers, furnace, water heaters – as is obtained in developed countries e.g. United States of America and United Kingdom /3, 12/.

As the country projects itself for this illustrious master plan in the oil and gas industry and it has positive effects on the economic status, one must take cognizance of the effects of the expansive engineering projects involved and have an effective, reliable monitoring system. Due to the volatile nature of oil & gas pipelines in these various engineering projects, there must be an effective monitoring system which not only suits these pipelines but also advanced technologies must be applied also.

As the world of Information Technology becomes more advanced, the use of optical communication (fiber optics) and its suitability to oil & gas pipeline monitoring system has become a possibility.

The integrity and performance of oil and gas pipeline is essential to the smooth operations expected from regulatory authorities. The pipeline safety, as it concerns regulatory authorities, is the safety mechanism on pipelines so as to protect the public, environment and even pipeline workers from any form of loss. Such safety mechanism is the use of fiber optics as a safe way to monitor these highly flammable fluids inside the pipelines. However, due to advanced optical communication systems employed in new technologies in fiber optics, I propose in my thesis work the use of fiber optic sensors (optoelectronic device) which run along these pipelines (outside and close to the pipelines), thereby giving an advanced warning in real time situation and allowing pipeline operators to take immediate and strategic actions so as to prevent loss of lives and properties.

Thus, this thesis project, will study the workings and suitability of optical communications (fiber optics) to be used in these pipelines, understand these pipelines integrity itself and demonstrate in a test environment the parameter(s) critical to these monitoring systems.

2 BACKGROUND OF THE PROJECT

There has been quite a lot of pipeline construction ongoing especially in the Lagos region, which is an area of the size of 999.6 km^2 and has estimated population of 21 million, making it the largest city in Africa – due to its economic and commercial hub of the country /23/. There has been enormous encouragement by the government for indigenous companies as a result of the country's local content maximization plan, one of which is Jami Energy Limited. In the course of the operations of oil or gas in their pipeline, while in use, no monitoring for the pipeline was made in the event of spillage or tampering, which unfortunately had resulted in loss of lives, properties and pollution to the environment. Some of pipelines are aging and replacements must be carried out /14/. A critical analysis on fiber optic cables, which will be laid along these pipelines as a safety measure to monitor them, will be considered.

As a result of the interest by the Federal Republic of Nigeria for a means of pipeline surveillance mechanism and its encouragement in the local content maximization plan in the areas of engineering, Jami Energy Limited, being a wholly indigenous engineering company stands out to be part of this noble engineering feats in not only to partake in engineering processes but also to contribute its own quota to the overall developmental goals in the country.

2.1 Jami Energy Limited

Jami Energy Limited, is situated at 201, Ikorodu Road, Obanikoro, Lagos State, Nigeria. It was established in 2006, and is an indigenous engineering company, which is a fully integrated Engineering, Procurement and Construction company with considerable experience on construction works, coupled with an excellent team of experienced personnel that are able to provide effective project management and a splendid history on engineering projects, such as mechanical, civil/construction, electrical, oil and gas pipelines engineering fields and various procurement services.

The following quality services are undertaken:

Engineering

- Process analysis
- Feasibility studies
- Front end and detailed engineering design
- Industrial and project management
- Plants expansions and relocation
- Plant inspection and valuation

Technical construction

- Fabrication and installation of industrial and domestic gas distribution pipelines and networks – welding of carbon steel, stainless steel, PE pipes
- Fabrication and installation of gas process pipelines – main, distributed and internal pipelines
- Pipelines treatment and cladding with fiberglass, polyurethane
- Fabrication and installation of gas processing plants
- Fabrication and installation of horizontal and vertical storage tanks, mixers, blending kettles etc
- Maintenance and cleaning of tanks and pipelines, sandblasting and spray Painting
- Cathodic protection of pipelines
- Structural steel works
- Fabrication and installation of water treatment plants
- Provision of water distribution system
- Installation waste water and treatment facilities
- Supply and installation of chemical efficient decontamination plants.
- Plant inspection and valuation

Procurement services

- Engineering related materials procurement

The company has handled various engineering projects. Standard engineering equipments and tools were used in the course of their various projects.

3 FIBER OPTICS DESIGN

This chapter deals with fiber optics and its significance in this project.

3.1 Historical Perspective of Optical Communications

The basic concept of fiber optics is the use of light which is the medium for transmitting information or messages from one point to another. Using such light as a means to transit or communicate information or messages dates back to antiquity. Those periods in time used signal fires, fire beacons, smoke signals, reflecting mirrors, signal lamps or maritime lights far back in the early days to convey specific information over long distances, up to around 10 km.

However, poor visibilities in the atmosphere or wind affect negatively the overall objective in communication. In the eighteenth century, in order to communicate over greater distance, the uses of intermediate relay station in the form of "repeaters or regenerators" through a mechanical means was further suggested by Claude Chappe in 1792. Coded messages through "optical telegraph" were made possible between Paris and Lille in France, by transmitting mechanically between the two cities about 200km apart, in July 1794. Though, a repeater about 100km distance was used as intermediate relay stations. The opto-mechanical communication systems were still slow in those periods, its relative data transmission rate (bit rate); denoted as B was less than 1bit per second ($B < 1$ b/s) /1/.

Also, the invention of electricity or electrical energy by means of movement of electrons in copper wires helped to convey information from one point to another in the 1830s, through the use of telegraph and telephone by communicating over greater distances. Also in 1948, the use of microwave communication systems using electromagnetic waves to achieve over 100 Mb/s in bit rate with the help of repeaters' spacing and operating at a carrier frequency of 4 GHz, made the use of optics relatively lesser in use for communication /1/.

The invention of laser in the 1950s, paved the way for modern optical communication or light in the 1960s by Prof. Charles Kao and George Hockman, by making use of glass medium which pass through a fiber (waveguide) as a means to cover and protect the light from escaping or loss as it transmit along a given path. However, high losses occurred through the movement of the light wave due to impurities in the glass and the quality of fiber in use at that time /8/.

Great efforts were made globally in the 1970s and 1980s through research to reduce significantly the losses in the fiber optics communication systems, and rapid achievements were made, such as greater transmission distance of over 10,000 km, optical frequencies increased in its enormous bandwidth by a factor of 10,000 times over high-frequency microwave transmission, its bit rate was over 10 Gb/s. Hence, the latest advanced technologies and researches of optical fiber communication, enabled it to carry gigabits of information at the speed of light /1/.

3.2 Why the Use of Fiber Optics in Oil and Gas Pipeline

The gains of using fiber optics to monitor the oil and gas pipeline in such given areas are quite many and pose greater advantages compare with other communication systems. The basic concept of optical communications system is the transmission of signals through fiber optics in any given distance so as to monitor specific conditions and indicate warnings if breached.

The reasons for choosing fiber optics over other communication systems such as twisted pair cables, coaxial cables or copper based cabling are as follows: /1, 4, 11/

- **Greater transmission capacities over long distance**
  The transmission of its signal strength along the fiber is by far much more beneficial, achieving a distance of 200 km without the use of regeneration along the cable, compared to other communication systems.
- **Non-conductivity (non electrical)**

This unique property makes fiber optics stand out as only light waves (signals) are transmitted along the fiber. Since oil and gas are highly flammable when a leak is detected in the pipeline or comes in contact with electrical waves, the use of copper or metallic based communication systems cannot be used as a monitor due to their conductivity nature.

- **Non interference with electromagnetic**

  The interference from EMI (Electromagnetic Interference), such as power lines or RFI (Radio Frequency interference) does not disturb the workability of fiber optics, due to its dielectric nature (no metallic composition).

- **Signal security**

  The detection of the signal transmission along the fiber is practically zero, unlike metallic based communication systems; this is due to the dielectric nature of the fiber optics.

- **Long durability lifespan and reliable**

  The lifespan of fiber optics exceeds over 40 years, and its reliability is second to none due to technological advancement over the period.

- **Large bandwidth**

  The bandwidth of fiber optics is very large, which enables it to carry more information compared to copper based communication systems and also low attenuation properties.

- **Low cost**

  With recent technological advances and rise in the demand for the use of fiber optics and its accessories, its costs have come down, making it relatively affordable compared to copper cables and with greater advantage in bulk purchase especially when its length runs in several kilometers.

- **Low error rate**

  Low error rate makes fiber optics idle for use in communication systems.

- **Light weight and flexible nature**

Fiber optics is quite light in weight and smaller compared to coaxial or copper cables, and also its unique flexibility, such as handling while working in the field, poses greater advantage over copper cables.

3.3 Fundamental of Fiber Optics

The basic composition of optical fiber, as illustrated in Figure 1, can be divided into three main parts: the first main part is the core; this is made up of glass (silica) through which light travels along a defined path. The second main part is cladding, which is also made up of glass but serves as a surrounding layer around the core to keep the light path within the core only. This occurs as a result of a process known as total internal reflection of the light between the core and cladding.

The third main part is specifically for protective covering purposes, consisting of plastic coating, buffer jacket, strength members and polyurethane outer jacket. Figure 1 shows the composition of fiber optic.

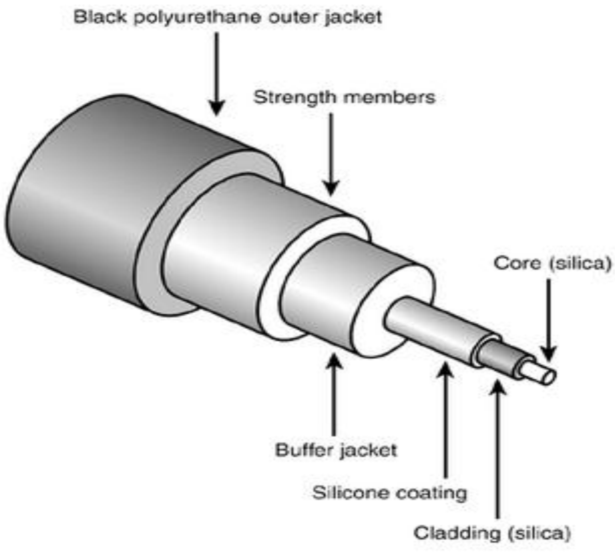

Figure 1. Composition of fiber optics /6/

There are two basic types of fiber optics: single-mode (SM) and multimode (MM), the classification is based by the way the light travels through the fiber and dimension of their respective core of the fiber.

3.3.1 Single-mode (SM) Fiber

The single-mode fiber is typically characterized by the dimension size of its core, usually in the range between 8 µm to 12 µm and cladding of 125 µm. The single-mode fiber shown in Figure 2.

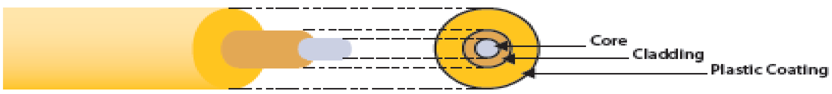

Figure 2. Composition of single-mode fiber /10/

Due to its small dimension size compared to multi-mode fiber, the light pulse or signal travelling along the core is only one ray or mode of propagation; that is one path for the light signal (information) travelling along the core of the fiber (as shown in Figure 3).

This is an advantage compared to the multimode fiber, such a situation is called the modal or intermodal dispersion, which does not hinder the light signal (information) being carried along the fiber. This enables higher bandwidth applications. Also, the single-mode fiber can carry a light signal of more than 40 Gbps over greater distances where repeater spacing must be maximized. To enhance its carrying capacity, multiple light signals of varying different wavelength can be transmitted into a fiber, which is known as wavelength division multiplexing.

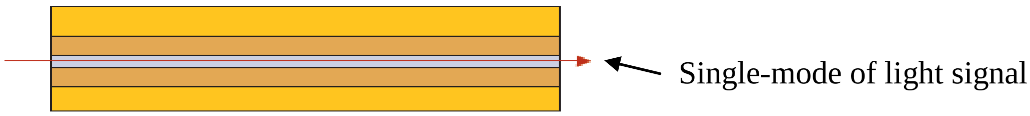

Figure 3. Single path of light travelling in single-mode fiber /10/

However, the intermodal or chromatic dispersion does affect its performance. Chromatic dispersion is due to the fact that different color of light or different wavelength travels at different speeds so it will spread or arrive in different time along the fiber. That is, if two different colors (wavelengths) of light are sent at the same time in a fiber, each will arrive at different time at the receiver end of the fiber, thus spreading the data pulse. To overcome this, one color of light sources, should be used /4, 10, 11/.

Alternately, there are newer types of lasers, which are more expensive than LED light sources. These lasers have narrow spectral bandwidth, usually its light output is within a 1nm range. So, the light output from a 1550 nm laser will be within a range of 1549.5 nm and 1550.5 nm, unlike LED sources, which have wide spectral bandwidth of 20 nm. Thus, light output from 850 nm LED will be with a range of 840 nm and 860 nm /4, 10, 11/.

3.3.2 Multimode (MM) Fiber

The multimode fiber is characterized by a large dimension size of its core, usually in the range between 50 µm to 100 µm and cladding of 125 µm to 140 µm, as displayed in Figure 4.

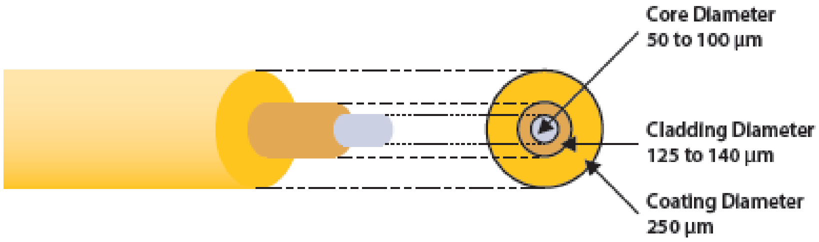

Figure 4. Composition of multimode fiber /10/

The core dimension size is larger compared to the single-mode which enables multiple light signals or pulses of different rays or modes to travel along the relative larger core dimension (as shown in Figure 5). As a result of this multiple paths of light, a situation called modal or intermodal dispersion occurs, making the light pulse or signals to spread, thereby distorting light signal or pulse. The input light pulse is made up of multiple modes. As the modes travel along the fiber, light energy distributed among the modes is delayed by different amounts, making the modes to travel at different speeds. So spreading of the light pulse occurs, that is, each of the modes – which are travelling in different direction propagate in varying distances to each other.

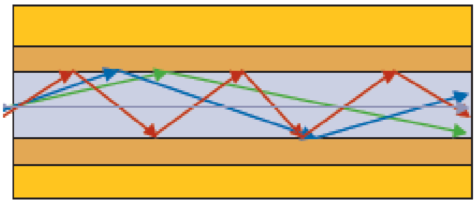

Figure 5. Multiple modes of light pulse travelling in multimode fiber /10/.

The multimode fiber may be considered for shorter distance coverage. In reality, intermodal dispersion increases as the fiber lengths increases, since each mode of the light pulse travels at different distances over the same time span. Also, as a result of the modal dispersion, the bandwidth of the multimode fiber is limited compared to the single-mode fiber. However, modal dispersion can be reduced but not completely eliminated, by the use of multimode graded index fiber. This fiber data link is 10 Gbit/s and with a bandwidth of over 3.5 GHz for a one kilometer length and wavelength at 850 nm. Intermodal or chromatic dispersion affects its performance as well. However, the multimode fibers are beneficial with regards to its lower cost transmitters and easier splicing procedures /4, 10, 11 /.

3.4 Communication Systems of Fiber Optics

The basic concept of fiber optics, referred as a medium, is the transmission of light signal (information) from one point to another. This optical communication system consists of a starting point (Optical Transmitter), medium (communication channel) and an end point (Optical Receiver) /4/, as shown in Figure 6.

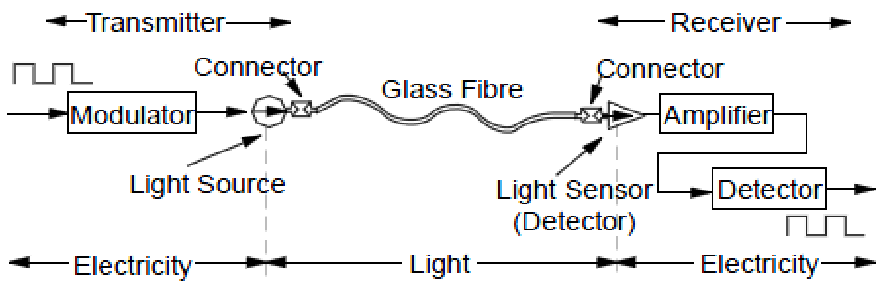

Figure 6. Schematic of optical communication system /4/

The workings of these three main components (Figure 6) are as follows: /4, 10, 11/

Optical Transmitter

- The serial bit stream, which is in electrical form, is fed into a modulator to encode the digital signal (data) appropriately.
- At the light source, a laser or LED circuit directly modulates the intensity of the semiconductor laser with the encoded digital signal.
- The light signal together with the encoded digital signal, which is driven by the modulator, is ready to be feed into the fiber – as converted electrical signal into light signal.

Communication channel

- The light signal travels along the fiber which in turn is directly linked with the fiber sensors or distributed sensing as the case may be.
- There is no electrical signal generated along the fiber but only light signal, so the fiber is laid parallel to the buried pipeline for the actual monitoring.

Optical Receiver

- The oncoming light is fed to a detector, which converts the light signal to electrical signal.

- Also at this point the signal is amplified to provide gain and fed to another detector, which isolates the individual state changes and timing, as well as decodes the signal processing and noise bandwidth reduction.
- The sequence timed bit stream will then be fed to a monitoring device for final results

3.5 Fiber Optics Monitoring Device

A device used in monitoring or measuring the characteristics of fiber and optical networks is the Optical Time Domain Reflectometer (OTDR). This fiber optic tester is simply used to detect faults – breaks, sharp bends, poor splicing – and measure events as well as estimate its location along the fiber cable. Figure 7 and Figure 8 show different types of OTDR

This instrument can also indicate estimated fiber cable length, attenuation which is the reduction or loss of signal strength of the fiber, whereby repeaters may be required at regular intervals to amplify the signal strength and joined connector losses /10/.

Figure 7. Optical Time Domain Reflectometer /10/

Also, a handheld OTDR is available for easy and quick testing.

Figure 8. A mini handheld OTDR /10/

This device is an optoelectronic, which uses the combination of two different forms of energy concurrently in their operation, that is optical (light)-to-electrical or electrical-to-optical transducers.

The OTDR works by injecting at one end of the fiber under test, optical pulse which can be configured at different wavelengths (850/1300 nm for MM fiber and 1310/1550 nm for SM fiber) and the returning backscattered, reflected signal are eventually analyzed (Rayleigh scattered technique). This analyzed data may be displayed numerically or graphically, and interpreted for desired result or correction.

3.6 Monitoring System of Fiber Optics

The essential purpose of pipelines in the oil and gas industry is the adequate distribution and transportation of pipeline fluids – petroleum products, natural gas, etc.

However, decaying or aging pipeline system infrastructure would cost lots of money to replace, so a continuous and automatic monitoring system such as fiber optic sensing, would be able to detect defects early and give a warning at the likely location or position of the defects, such as spillage and leaks, before a major disaster occurs, e.g. environmental pollution, loss of property or even loss of lives of people.

To achieve this monitoring, fiber optic sensors, which is laid parallel on the pipeline or close to it will be able to sense any defect on the structural integrity of the pipeline /5, 22/.

Since a light signal, configured with certain characteristics such as phase, intensity, amplitude, wavelength, time of flight etc, is expected to travel in the fiber cable unhindered except if an external influence is acted upon a cable, then a warning is sent to the monitoring device system to track a possible location of the fault and also a possible cause or influence along the pipeline route /5, 22/.

The wide range of influence or parameters – physical, mechanical, chemical and biological – around or on the pipeline could be the following: /5, 7, 13, 21, 22/

- Cracking/leaking
- Vibration/frequency/ground movement
- Displacement/digging/intrusion
- Pressure
- Liquid levels
- Stress/strain
- Temperature/heat
- Acoustic-emission

Due to the different light modulation as a result of various configurations of the fiber sensing devices, monitoring specific parameters alighted earlier will easily be identified.

3.7 Basic Principles of Fiber Optics Sensor System

Fiber optics sensor is essentially a sensor which measures a physical quantity as a result of alterations on the light modulation – intensity, spectrum, phase or polarization – of such light travelling through the optical fiber.

As illustrated in Figure 9, the fiber optics sensor system is made up of: optical source (LED, laser), optical fiber, sensing or modulator (a transducing component for converting the measurand to an optical signal), an optical detector and an electronic processing device (optical spectrum analyzer, etc) /5/.

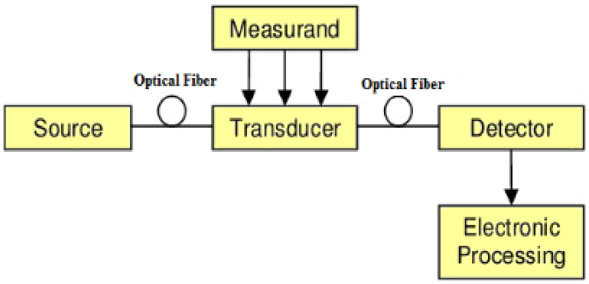

Figure 9. Basic principle of fiber optics sensor system /5/

3.8 Classification of Fiber Optics Sensors

Fiber optics can be classified into three categories: sensing location, operating principle, application /5/. Table 1 shows the three categories, classes and attributes.

Table 1. Classification of fiber optics sensors /5/

CATEGORY	CLASS	ATTRIBUTE
sensing location	point sensors	individual sensors at discrete region of optical fiber
	distributed sensors	entire length of the optical fiber continuously acts as sensors (measurand)
	quasi-distributed sensors	finite number of locations of the entire length of optical fiber is monitored
operating principle	intensity (amount of light) sensing	strain, displacement, pressure (bends, break) in optical fiber is monitored
	wavelength modulation sensing	temperature, vibration causes shift in wavelength of light (Example is Fiber Bragg Grating – FBG distributor sensor)
	phase modulation	strain causes shift in the phase of light detection (Example is Fabry-Perot Interferometers- FPI sensor)
application	physical sensing	temperature, stress, velocity, etc
	chemical sensing	for gas analysis, pH

3.9 Types of Fiber Optics

Fiber optics sensors types are categorized into two - intrinsic (all-fiber) and extrinsic (hybrid) fiber optic sensors /5/.

Intrinsic (All-fiber) fiber optic sensor

An external parameter causes changes on the fiber (measurand) thereby causing some changes (sensing) in the defined characteristics of the travelling light inside the fiber. The sensing takes place inside the optical fiber, so the fiber functions as both a sensing element and transmission medium.

Extrinsic (Hybrid) fiber optic sensor

The fiber carries the light to an external source (sensing region) outside the fiber where the sensing takes place and then back to the fiber to produce measurand information by a device. The modulation of the light occurs outside the optical fiber as a result of an external parameter, so the fiber play no role in the sensing mechanism but is only a transmission medium.

3.10 Distributed Fiber Optics Sensors

A distributed fiber optics sensor is an optical sensor cable in which the entire cable serves as linear sensors to measure specific parameters (temperature, intrusion, pressure, leaks, stress/strain, etc) and indicate on an electronic monitoring system. This is unlike point sensors, which are individual sensors at discrete region of optical fiber. Thus, the monitoring systems are optoelectronic devices.

Temperature changes are the main measuring parameter in the monitoring system in my project, so a critical look was taken at a distributed temperature sensing systems such as the Omnisens DIGEST™ (Distributed Temperature and Strain sensing system).

This temperature and strain monitoring system uses standard telecommunication-grade single mode optical fiber – Strain Measurement Cable (SMC) and Temperature Measurement Cable (TMC) as sensors are deployed or laid parallel alongside the pipeline in order to perform a continuous uninterrupted monitoring over great distances /13, 21/.

The following are various performance specifications for Omnisens DIGEST™ (Distributed Temperature and Strain sensing system): /13, 21/

- **Longer distance range measurements**

Capable of achieving the maximum fiber sensor length over which the instrument's stated performance are met. Up to 50 km range per channel from a single interrogator or remote signal regeneration modules.

- **Meter spatial resolution accuracy**

  Device ability to measure accurately two adjacent locations subjected to different temperature/strain conditions. The configuration of spatial resolution range is from 0.5 m to 10 m.

- **Reliable temperature/strain measurement**

  The device is able to measure either temperature or stain, or both using same optical fiber. For temperature monitoring by the optical fiber, protective loose tubing is installed thereby preventing strain conditions from having a significant effect on the temperature measurements. Also, for strain monitoring by the optical fiber, a dedicated strain sensor is required, in order to accurately transfer stain to the fiber.

- **Superior reliability, accuracy and repeatability**

  User friendly configurations to optimize measurement for various operating conditions and application.

- **Durability and flexibility**

  Optical fiber durability exceeds over 40 years and different types of optical fiber sensor for both temperature and strain monitoring are available and suitable for demanding environments such as tough conditions and challenging installations.

- **Precision**

  High precision is achievable in locating any given warning over a distant up to 1 m precision. Temperature resolution from 0.1 degree Celsius and strain resolution of 2 microstain, is achievable.

4 PIPELINE MONITORING

This chapter deals with the pipeline systems.

4.1 Fundamentals of Pipeline

A pipeline is a long tubular conduit or cylinder through which pipeline fluids (crude oil, petrol, natural gas, water etc) is transported from one place to another under the influence of pressure, especially over great distances. They are laid in series with each usually 12m (40feet) in length and in various sizes, such as 2 inches (100 mm), 18 inches (450 mm), 60 inches (1524 mm), etc.

Pipelines are considered as either surface (above ground) or buried (underground). My interest lies in the buried oil and gas pipelines, and they are made from carbon steel (polyethylene coated, concrete coated) and plastic (High-Density Polyethylene pipe). As a standard practice for these pipelines, are usually buried at depth of 0.9 to 1.9 meters (3 to 6 feet). Figure 10 shows a typical PE coated steel pipe to be buried in the ground /9, 19, 20/.

Figure 10. PE coated steel pipe. /20/

4.2 Classification of Pipeline

Oil and gas pipelines are classified into four categories: /2/

4.2.1 Gathering Pipelines

These pipelines form an interconnected networks of pipes, usually small in diameter, and are used to gather crude oil or natural gas from various oil and gas wells/rigs/platforms, either onshore (land production) or offshore (deep sea production), to treatment plants (oil and gas refinery) to be processed into final products.

4.2.2 Transportation Pipeline

These networks of pipelines are used to transport refined final products (petrol, gas) from treatment plants into cities, regions, counties, continents. The pipelines are usually in large diameter and require several compressor/pump stations along its path.

4.2.3 Distribution Pipeline

These networks of pipelines are used along various roads network within cities to transport refined final products to potential consumers, usually diameter size could range from 6 to 20 inches and fitted with safety valves.

4.2.4 Internal Pipelines

This network of pipelines is usually within the consumer's properties or compound (house, factories) and links the distribution pipelines for the refined final product. They are usually for natural gas as an energy source, the consumer metering facilities – PRMS – is always installed within its vicinity to measure its consumption/intake. The networks of pipeline are usually of small diameter size, less than 6 inches. The PRMS regulates the high gas pressure from the distribution pipelines, to the consumer's low pressure intake level and flow rate requirements. Also, PRMS is used to measure, analyze, filter and regulate the gas flow from distribution line to the consumer's facilities (oven, burner, generator set, turbine, dryer, boiler, heater, furnace, cremation machine, etc).

4.3 Integrity and Testing of Pipeline

The integrity of the pipeline could be summarily referred to as measures to certify the successful operations and that all related components of pipelines are running satisfactorily. The pipeline operators guarantee the effective and safe running of these pipelines so as to provide optimum services to its workers, public and environment.

As important as these pipelines are, the pipeline regulatory authorities must ensure, as a matter of fact, concentrate on these three core areas /2/.

4.3.1 Pipeline Design and Construction

Oil and gas pipeline conception stages to its actual operations and future use must be thoroughly and professionally evaluated, designed and constructed at every step of its building processes.

It is important to use the right building materials, laboratory tested and proper construction stages, such as ground excavation and backfilling, welding processes, destructive testing (pressure test, mechanical test), non-destructive testing(visual inspection, magnetic particle test, radiography test, ultrasonic test), protective coatings and polyethylene wrapping materials (corrosion protection). Figure 11 and Figure 12 show various steel fittings and PE coated steel pipes suitable for the pipeline.

Figure 11. Various standard steel fittings and PE coated steel pipes /19/

Figure 12. Various PE pipes and its fittings /18/

4.3.2 Pipeline Monitoring

Proper and constant monitoring of these pipelines is of paramount importance to the relevant pipeline operators and authorities, such as medium through which information are gathered, analyzed, processed and stored. This information is utilized at the control centers of the pipeline monitoring systems through right devices and equipments

Highly qualified engineers and technicians with extensive, up-to-date training and emergency response capabilities are stationed to monitor these processes at the pipeline control centers, whereby thorough evaluation of this information is utilized and actions carried out if necessary.

4.3.3 Pipeline Inspection and Maintenance

Pipeline inspection and maintenance, like monitoring earlier alighted, is an ongoing processes, in as much that highly sophisticated tools, equipment and technologies are employed both in the inspection and maintenance operations of the pipelines.

A process known as Pigging, constant inspection (pipeline wall thickness, abrasion, dents) and maintenance (cleaning) of an operational pipeline is adequate required so as not to adversely affect the integrity of the pipeline.

4.4 Preventive Measures on Pipeline Failures

Basically, the objective of this thesis project is using optical communication as a safety measure to monitor the oil & gas pipelines. However, the best safety means will always be preventive capabilities in any fields of engineering.

Leakage in pipelines occurs as a result of mechanical failure in pipeline networks. Several tests and researches have revealed that most failures in pipeline networks occur at the joints areas, a place of connection between pipes, fittings or relevant components occurs in the pipeline networks.

Fiber optics sensors at the joint area of the pipeline network must be highly considered, during the construction and installation activities of these pipelines. The importance of joints must not be overlooked for the success operations of the pipeline industries. Critical factors affecting the pipeline networks such as the following: /9, 19, 26/

4.4.1 Welding

This is the process of uniting or fusing metallic materials (steel), of same nature, under great heat together. Approved international standard codes and practices must be adhered to during welding processes, such as the following: /9, 18, 19, 26/

- Welding machine, equipment and tools (welding tongs, electric cables, welding masks and glasses, etc).
- Welded steel materials (approved pipe schedule or grade, elbows, tees, flanges, weldolets, end caps, reducers, etc).
- Qualified welders and fitters.
- Welding consumables (electrodes).
- Qualified welding inspectors (detect weld defect – radiographic / ultrasonic processes, if any, such as undercut, penetration, blow hole, overlap, slag inclusion, lack of fusion, etc).
- Qualified engineers, technicians, safety personnel, workers, etc.
- Approved protective coatings and polyethylene wrapping material (overlapping wrapping)

However, welding for HDPE pipe or PE pipe materials (plastic) differs to an extent, such as:

- PE welding machine, equipment and tools (for electrofusion welds, butt fusion welds).
- Welded materials (approved PE pipes, PE elbows, PE tees, PE flanges, PE transition fittings, PE end caps, PE reducers, PE couplers, etc).
- Qualified PE welders.
- Qualified engineers, technicians, safety personnel, workers, etc.

Figure 13 and 14 show a welding process for two joined steel pipe and PE wrappings at the steel joint area.

Figure 13. A welding process for two joined steel pipe and already marked steel pipe by welding inspectors' /19/.

Figure 14. Wrapping a PE tape around a weld joint area /19/.

4.4.2 Hydrostatic Test

This involves the pressurization of the pipelines network through water to an approved specified test pressure over a given period so as to detect leaks. The leakage area can be visually identified easily if a colorant is mixed with the water, and also a pressure drop will be experienced

The pressure testing, if successful, helps to maintain safety standards and durability of the pipeline networks. The test pressure, which is a margin of safety, is always higher than the maximum operating pressure. This could be as high as 125%

of the designed pressure, which is dependently on the oil & gas pipeline regulatory authorities /2, 24/.

4.4.3 Backfilling of Excavated Pipeline Route

As the pipeline construction gradually begins to round up, after all necessary tests, the backfilling of the excavated pipeline route must be done in conformity with international standards. Backfill materials around the pipeline must be free from rocks, stone or sharp objects (see Figure 15). And, also a warning plastic tape and signs should be placed at pipeline routes /2, 24/.

Figure 15. Backfilling of pipeline route /19/

4.5 Regulatory Authorities of Pipeline

The oil & gas pipeline regulatory and supervisory authority is the Nigerian National Petroleum Corporation (NNPC), through its subsidiaries, Nigerian Petroleum Development Company (NPDC) and Nigerian Gas Company (NGC), are all responsible for the operations of these pipelines to ensure optimum operations, and also safety monitoring of this vital aspect in the economic growth of the country /12/.

Also, importance must be placed for the supervisory authorities to work hand in hand with the regulatory authorities for the environment, town and regional planning of the state and the host communities of these pipeline routes. Various activities such as digging, excavation, tunneling, or any form of construction activities around pipeline areas must be approved before their commencement. Illegal or unapproved permit for these activities, along pipeline routes, has caused great extent of damage when these pipes burst open as a result of digging.

The highest level of conformity must be placed to international standards and best practices for the successful operations of the oil and gas industry. The engineering companies working in the country – foreign and indigenous engineering companies – alongside the regulatory authorities must all be focused in achieving the overall interest for the country, so as not to cause economic wastage, environmental pollution and even loss of lives.

Advanced and new technologies in all fields of engineering must be embraced at all times, so as to be up-to-date and ensure that the country is not left out in this ever increasing world of advance technologies.

Figure 16 shows a typical backfilled trench of fine soil enclosing a warning tape placed above the 12 inches PE coated steel pipe and fiber optic cable running parallel along the length of the buried pipe.

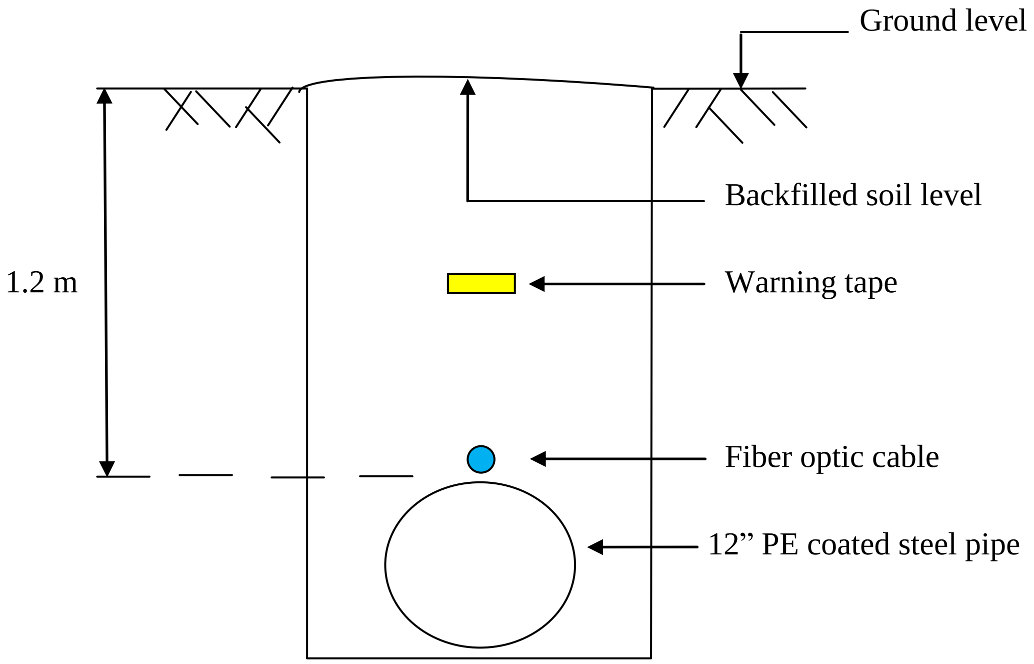

Figure 16. Buried 12” PE coated steel pipe with fiber optic cable

5 IMPLEMENTATION OF PROJECT

This chapter describes the following stages in the implementation of the project.

5.1 Purpose of Implementation

The purpose of the project was to use the Optoelectronics temperature sensor, Optris Compact Infrared Pyrometers (OPT-CS-LT15 IR Transmitter) to monitor the integrity and performance of oil and gas pipeline smooth operations, which is expected from regulatory authorities, and to indicate warnings especially abnormal temperature changes immediately in real time situation to the regulatory authorities, who normally observe from the control rooms, thereby allowing pipeline operators to take immediate and strategic actions to prevent losses of a great extent, spillage of pipeline product, environmental pollution or even people's lives.

The Optris Compact Infrared Pyrometer (OPT-CS-LT15 IR Transmitter) was used as a point sensor to read a temperature of a given environment or object. The sensors are non-contact (optical reading system) infrared temperature sensors /17/.

A pipeline failure may be as a result of mechanical failure (cracks, corrosion and welded joint failure) or illegal tampering (drilling, bursting, hot tapping). Such failures could be detected in time due to advanced communication systems employed in optoelectronics devices in oil and gas pipeline industries of the volatile nature.

5.2 Infrared Radiation of Measuring Material

Pipeline materials (steel pipe, concrete pipe, PE pipe (plastic)) and its surroundings (water, ice, backfilled soil or sand) must be considered in the monitoring systems.

This is based on the fact that these factors (background bodies of the pipelines) affect accurate measuring results by interfering with the infrared radiation emitted by these background bodies.

Depending on the temperature of each body, there is an amount of infrared radiation emitted by them. This amount is known as the intensity of infrared radiation. So the intensity of the emitted radiation depends on the material /17/.

5.3 Emissivity (ε) Measuring Material

Depending on the temperature of each material, there is an amount of infrared radiation each material emits. That is, changes in temperature of objects result in changes in the intensity of radiation being emitted.

So the intensity of infrared radiation, which is emitted by each body, depends on the temperature as well as radiation features of the surface material of the measuring object.

The intensity of the infrared radiation of material along with the material known values of emissivity (ε – epsilon) helps to describe such material. That is, "emissivity is used as a material constant factor to describe the ability of the body to emit infrared energy" /17/.

5.3.1 Emissivity

Emissivity is defined as the "ratio of the energy radiated by an object at a given temperature to the energy emitted by a perfect radiator, or blackbody, at the same temperature. The emissivity of a blackbody is 1.0. All values of emissivity fall between 0.0 and 1.0" /17/.

So, emissivity is significant and controllable factors in IR temperature measurement which must not be ignored as it affects a body's ability to emit IR energy.

Also, related to emissivity are Reflectivity (R) and Transmissivity (T).

5.3.2 Reflectivity

Reflectivity is defined as "a measure of an object's ability to reflect infrared energy" /17/.

5.3.3 Transmissivity

Transmissivity is defined as "a measure of an object's ability to pass or transmit IR energy" /17/.

"The ideal surface for infrared measurements is a perfect radiator, or a blackbody with an emissivity of 1.0. Most objects, however, are not perfect radiators, but will reflect and/or transmit a portion of the energy" /17/. Figure 17 shows the total infrared radiation of a body reaching an infrared measuring device.

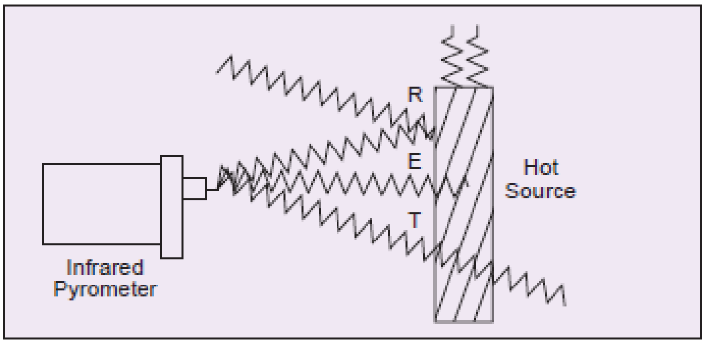

Figure 17. Total infrared radiation of a body reaching an infrared measuring device /17/

5.4 Flame Temperature of Pipeline Fluid

Flame temperature of pipeline fluids is one of the parameters earlier mentioned as conditions, which negatively affect or hinder the smooth operations of pipeline fluids or products. A study of flame temperature has been considered, as it relates to the temperature rise of different pipeline products and monitoring devices settings.

5.4.1 Basics of Adiabatic Flame Temperature

Flame is the burning gas or vapor from flammable substance or object such as petroleum products, gas products, candle, blowtorch, wood products, etc, as a result of combustion process (oxidation) thereby releasing heat (rise in temperature) and light to the environs.

However, when a combustion process occurs, energy is released to the combustion product and no heat loss (no heat transfer to the environs) takes place in this process; therefore the temperature of the combustion products is referred as adiabatic flame temperature. See Table 2, adiabatic flame temperature of pipeline products.

Table 2. Adiabatic flame temperature of pipeline products /25/

Pipeline Products (Fuel)	Adiabatic flame temperature (degree Celsius)	Oxidizer
Acetylene	3100	Oxygen
Blowtorch	2400	Air
Butane	1970	Air
Carbon monoxide	2121	Air
Ethane	1960	Air
Hydrogen	2660	Oxygen
Methane	1957	Air
Natural gas	1960	Air
Propane	1980	Air
Light fuel oil	2104	Air
Medium fuel oil	2101	Air
Heavy fuel oil	2102	Air
Bituminous coal	2170	Air

5.5 Lists of Instrumentation and Equipment

- OPT-CS-LT15 IR Transmitter, which contain:
  - Temperature sensing head (range -40 to +1030 degree Celsius)
  - USB cable adapter connection
  - Optris compact connect software

  - All accessories – Close focus lens, Air purge collar, Mounting bracket
- Personal computer (PC)
- Small piece of steel pipe tube
- Fire/Light burner with lighter

5.6 Implementation Plan and Overview

As illustrated in Figure 18, if a small piece of steel pipe tube on fire, a temperature sensing head which is close to the generated heat source will be able to indicate the rise in temperature of the affected environment.

Due to the connection of the temperature sensing head by a USB cable to the PC, this will be able to signal a warning of a rise in temperature in the already installed software, thereby indicating a specific cause of problem.

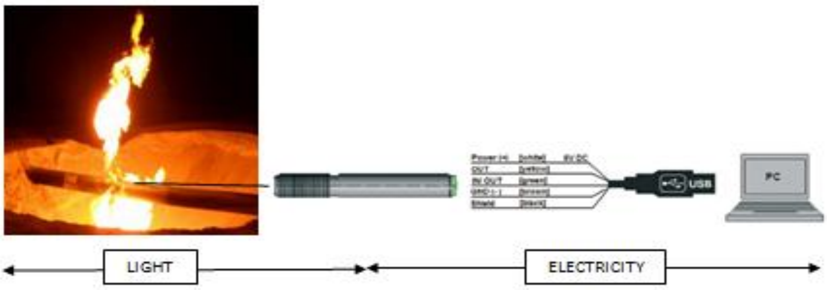

Figure 18. Layout of the pipeline on fire, sensor connected to the PC /16/

5.7 Installation and Configuration of Monitoring Software

Firstly, the temperature sensing head was fixed to the USB cable. Then the Optris compact connect CD software was inserted into the PC drive for the installation process to commence. In the course of installation, the USB was connected through to the PC to allocate the necessary settings required by the compact connect software. Figure 19 shows the selection of CS device.

Figure 19. Compact connect CS device /16/

Secondly, some major configurations were then made, which included selecting the CS device, temperature unit, and the emissivity value for material (iron and steel) 0.55 was set (As shown in Figure 21).

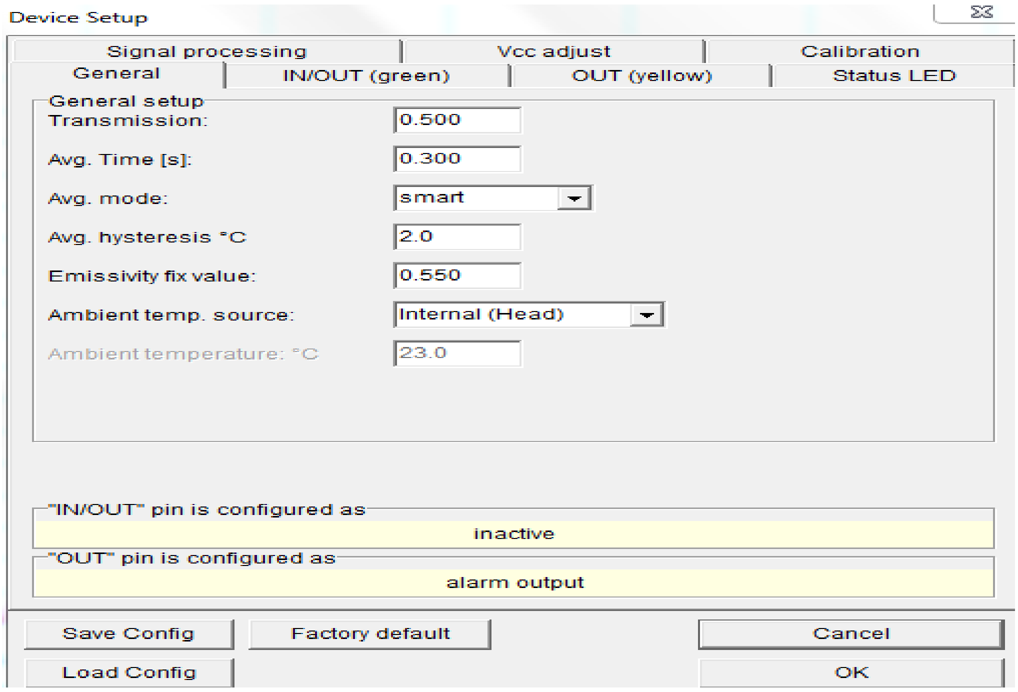

Figure 20. Emissivity value set to 0.55 for iron and steel test material /16/.

Since the test material was steel, this value was selected from Emissivity Table, as shown in Table 3.

Table 3. Emissivity Table /16/

Material	Specification	Temperature in °C	Spectrum	Emissivity	R
Gold	brightly polished	200 - 600	T	0.02 - 0.03	1
Gold	strongly polished	100	T	0.02	2
Gold	polished	130	T	0.018	1
Granite	polished	20	LLW	0.849	8
Granite	harshened	21	LLW	0.879	8
Granite	harshened, 4 different samples	70	LW	0.77 - 0.87	9
Granite	harshened, 4 different samples	70	SW	0.95 - 0.97	9
Gypsum		20	T	0.8 - 0.9	1
Gypsum, applied		17	SW	0.86	5
Gypsum, applied	gypsum plate, untreated	20	SW	0.9	6
Gypsum, applied	harshened surface	20	T	0.91	2
Ice:	see water				
Iron and Steel	electrolytic	22	T	0.05	4
Iron and Steel	electrolytic	100	T	0.05	4
Iron and Steel	electrolytic	260	T	0.07	4
Iron and Steel	electrolytic, brightly polished	175 - 225	T	0.05 - 0.06	1
Iron and Steel	freshly milled	20	T	0.24	1
Iron and Steel	freshly processed with sandpaper	20	T	0.24	1
Iron and Steel	smoothed plate	950 - 1100	T	0.55 - 0.61	1

Last, the LED Alarm was set at 800 degrees Celsius. This was necessitated due to the fact that the flame temperature of the test material (steel pipe) was over 1030 degrees Celsius (the maximum temperature sensing head). A set value below the flame temperature limit for the test material was assumed to give an LED alarm once the threshold value was reached. As displayed in Figure 21, the alarm indicates a temperature rise from the normal operating temperatures (safe level) monitoring system /16/.

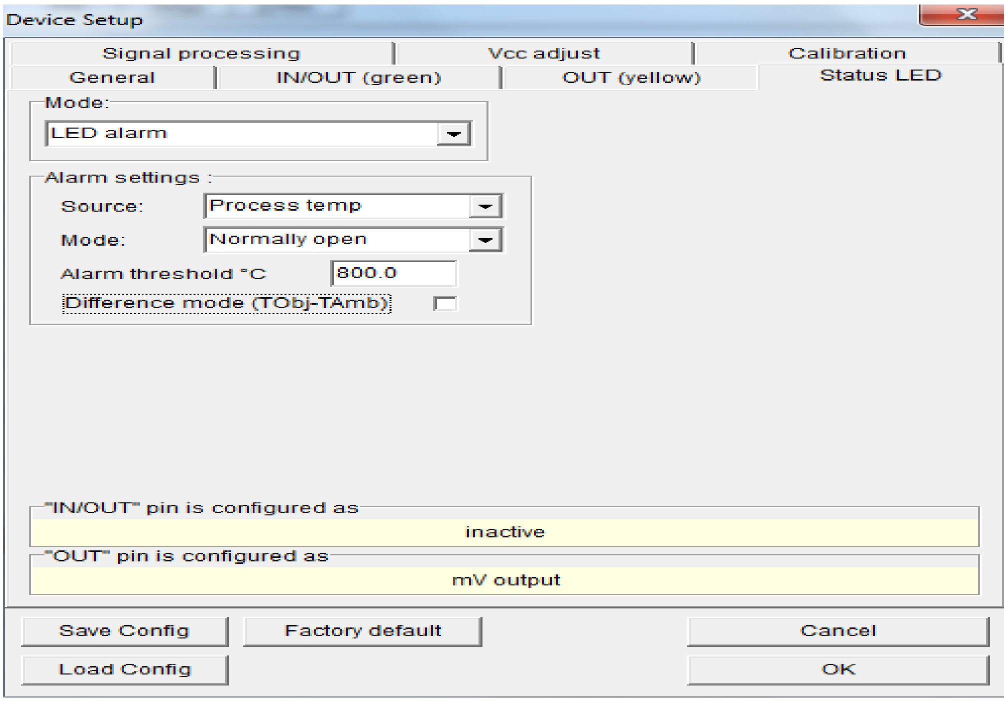

Figure 21. Status LED alarm threshold set at 800 degree Celsius /16/

6 TEST RESULT

In the course of implementing the pipeline monitoring system, the following test results were observed and noted:

6.1 Testing the Ambient Temperature

Firstly, Optris compact connect software temperature monitoring device on the PC was started, and the temperature in the controlled environment or the ambient temperature, was noted to be 24.2 degrees Celsius, which was displayed on the PC before the temperature sensing head or sensor was placed close to the piece of pipe. The ambient temperature displayed by the monitoring device is shown in Figure 22.

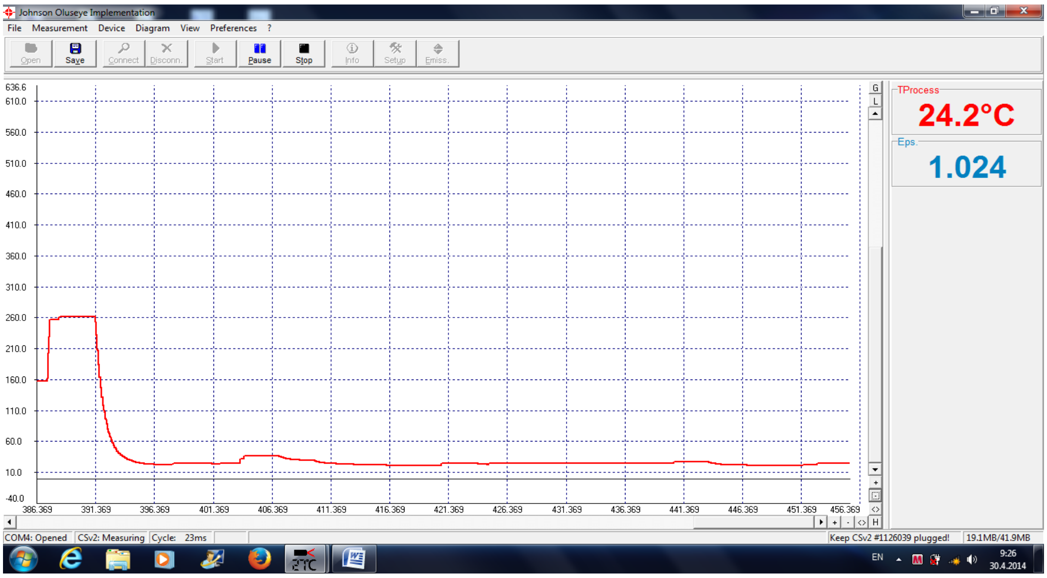

Figure 22. Monitoring device indicate ambient temperature of 24.2 degrees Celsius

6.2 Testing the Pipeline Temperature

The piece of pipe was set on fire, using a blowtorch, as shown in Figure 23. The temperature sensor was placed close to it, and the following observations were made:

Figure 23. Pipeline on fire

The surrounding pipeline temperature was gradually increasing, as shown in Figure 24.

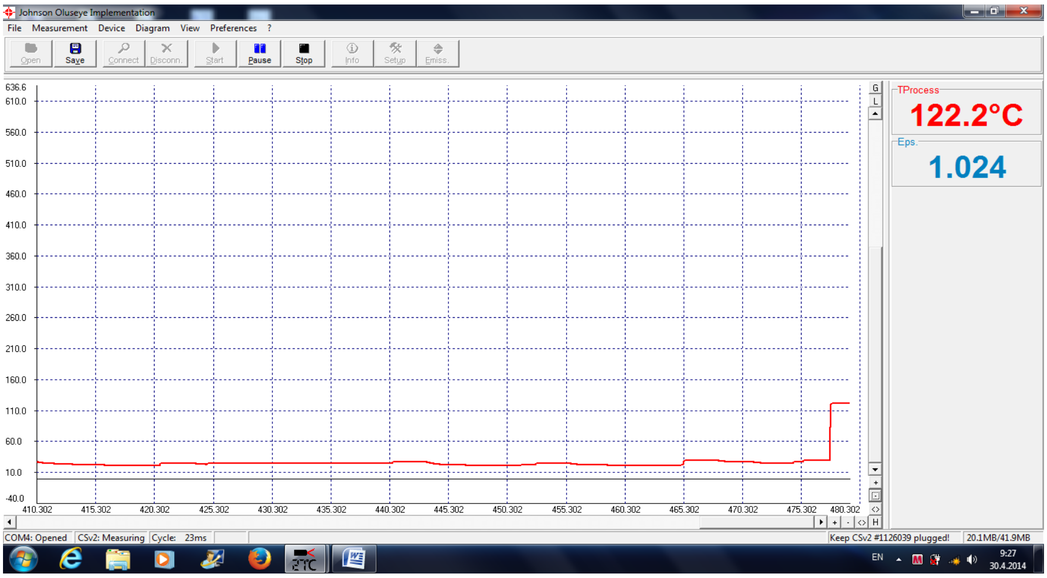

Figure 24. The gradual increase in temperature.

The monitoring device displays a temperature of 862.5 degree Celsius (see Figure 25).

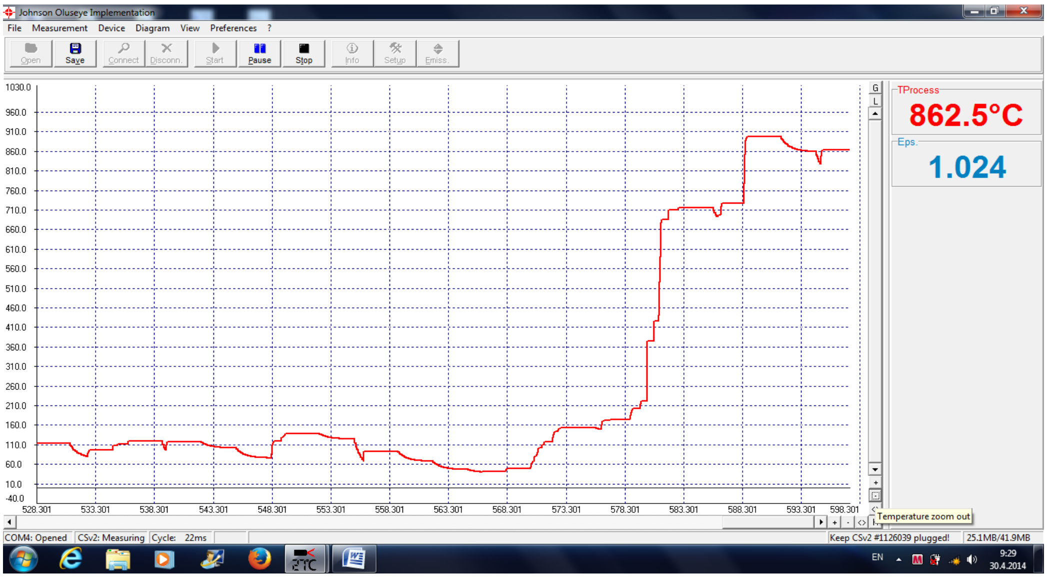

Figure 25. Displayed temperature reached

6.2.1 Display LED Warning Signal

As a result of the preset warning signal temperature (Alarm threshold) 800 degrees Celsius, the LED display was observed due to the temperature reaching 862.5 degrees Celsius, exceeding the threshold temperature. The LED displays a warning signal, as shown in Figure 26.

Figure 26. LED warning signal display

6.3 Test summary of Pipeline Temperature

The monitoring device was eventually stopped and all saved data and history of the test temperature was displayed, as shown in Figure 27. Also, as observed from the displayed temperature history, the sensor was directed to the blowtorch and the maximum temperature was reached, 1030 degrees Celsius, which is the maximum temperature range for the sensing head.

It should be noted that the adiabatic flame temperature for the blowtorch is 2400 degrees Celsius (see Table 2). As observed, at the end of the temperature history, the ambient temperature of the surrounding falls back to 24.4 degrees Celsius.

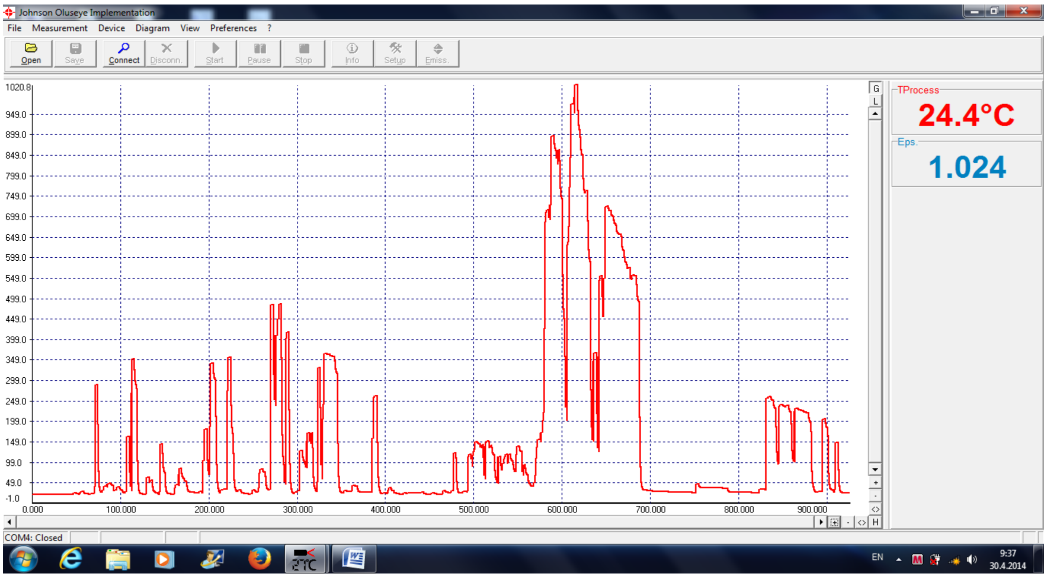

Figure 27. Displayed temparature history.

7 CONCLUSIONS

In the course of this project, in the suitability of fiber optics in the monitoring of oil and gas pipeline industry was considered. An optoelectronics device was selected and its workings was studied and implemented upon.

The implementation of the project involved the optoelectronics temperature sensor – Optris Compact Infrared Pyrometers (OPT-CS-LT15 IR Transmitter) – which was used to monitor abnormal temperature changes around the pipeline and indicate warnings through the software in real time situation. Such monitoring enabled me to setup measurement parameters of the sensor, measurement simulation during the device installation through the output sensor without actual measurement by another means of the surrounding temperature, to read and understand the display of temperature time diagram as well as digital display, to read and record real time display of temperature data, to set automatic or manual adjustment of diagram scales for ideal merit display, and data recording for future detailed analysis and documentation.

Also, this setup enables me to understand and prepare in real life environment of planning and executing projects of such magnitude in the use of Information technology in the field of oil and gas pipeline industry due to the volatile nature it entails.

However, as a result of limitations, the use of the improvised optoelectronic device (temperature point sensor) in the course of the implementation of this project work was not sustainable as a result of the fact that several thousands of point sensors could be used in covering great lengths of pipelines. The use of distributed sensor (optical communication) could be considered instead for the oil and gas pipeline monitoring systems in my future work, as this could replace thousands of point sensors.

Finally, knowledge acquired after the completion of my Bachelors' degree will enable me to improve and better myself in these peculiar fields: the frontiers of engineering.

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