WEST AFRICAN GAS PIPELINE (WAGP) PROJECT: THE PROSPECTS, ASSOCIATED PROBLEMS AND POSSIBLE REMEDIES

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ABSTRACT

Global focus is gradually turning away from crude oil as a major source of energy to natural gas due to its abundant availability, environmental friendliness and cost effectiveness. This has effectively increased the transboundary pipeline networks with minimal consideration to the impact at which the offshore segment of such projects could have on the environment.

This article considers Nigeria's present engagement in transboundary transportation of 11.3 billion cubic meters per day (11.3bcmpd) of natural gas to Benin, Togo and Ghana for thermal and industrial uses through a 1033km pipeline network out of which 617km is a submerged offshore pipeline network. The study is necessitated by the alarming frequency at which hydrocarbon pipeline failure occurs in Nigeria with the resulting economy, environmental and human consequences. It was discovered that though, the project is a plausible one, any failure along the offshore segment of the pipe-length poses high risk of hydrate formation and dissolution of some acidic constituents which could result to problems ranging from behavioral nature (e.g. fish excitement, increased activities and scattering in the waterbody) to chronic poisoning, fire outbreak, loss of human lives and livestock and climate change.

Development of pragmatic management scheme, robust leak detection model and predictive model on natural gas flow pattern in waterbody are recommended while many existing viable models are discussed for possible modification.

Keywords: WAGP Project, Natural Gas, Transboundary Pipeline Network, Pipeline failure

INTRODUCTION

Global demand for petroleum products is in the increase due to increase in population and industrialization. Oil and natural gas today constitute the most important primary energy sources; their share in total consumption is over 65% (Janovic, 2005). Measured in financial indicators, 90% of chemical products in industrially developed countries pertain to organic chemical products, while production based on oil products and natural gas participates in the obtaining of over 98% of basic organic chemical feeds (Janovic, 2005). Presently however, global focus is now turning away from crude oil as the major source of energy to natural gas due to its economical and environmental friendliness. This has increased the natural gas transboundary pipeline networks with minimal consideration to the impact at which the offshore segment could have on environment.

Natural gas's world proven reserves estimate is put at 207,890 billion cubic meters (bcm) and grows at an estimated 5% annually (Oyekunle, 1999). The former Soviet Union (FSU) and the Middle East have 70% of the total gas reserves while the United States of America's natural gas demand for 2003 is put at 786.32 bcm (Hill, 2005). Africa's proven gas reserves in 1995 was totaled about 6.3 trillion cubic meters (tcm) with potential reserves estimated at 17.65tcm in the year 2010.

The gas, which in total fuel cycle is superior to electric heating sources in terms objectionable discharges in residential space (AGA, 1984) is also a better replacement for wood and coal as energy source. The gas system is used for cooking, water heating and cloth drying. It is a raw material for the new Gas-To-Liquids (GTL) technology (Prohaska, 2004), production of methanol/MBTE, fertilizer and petrochemical plants. The gas is also useful for electric power generation.

About 78% of African natural gas resources is deposited at the Niger-Delta region of Nigeria with others at Libya, Algeria, Egypt, Angola, Mozambique, Namibia, Tunisia and Tanzania. This gas which is of low utilization presently in Nigeria due to lack of adequate technological advancement is flared off to the environment (Fig. 1), resulting into heating effects, production of noise, soot and particulate at the region, as well as economy wastage to the country. Current gas flared at the region is estimated at 56.5 x 10^6 M^3/day (2 billion standard cubic feet per day) which is about a quarter of the gas flared globally and over 50% of the flaring level by OPEC member countries (Obanijesu and Sonibare, 2005). To minimize this flaring, the WAGP project was proposed by World Bank to develop the abundantly available natural gas fields in Nigeria.

WAGP project involves the transportation of 11.3bcmpd (450 MMscfd) natural gas supplies from Nigeria to power generators and industrial consumers in Ghana, Benin and Togo for thermal and industrial uses through an additional installation of 617km of offshore pipeline and 57km of onshore pipeline from an offtake at the existing 359km Escravos-Lagos natural gas system.

The WAGP project, estimated to cost \$550million includes pipeline installation and metering, pressure regulation, gas scrubbing and compression facilities. The project is undertaken by a joint venture project of NNPC, ChevronTexaco West African Gas Pipeline Co. Ltd, Shell Overseas Holdings Ltd and Takoradi Power Co. Ltd. The transboundary project whose construction work commenced in 2005 is expected to last for minimum of 20 years after takeoff before renewal.

Of the new 674km pipe-length to be constructed, 57km of the pipe-length would transport the gas from Alagbado (Lagos) to Badagry beach in Nigeria while 617km transboundary portion will run offshore from Badagry beach through Cotonou (Benin), Lome (Togo) to Takoradi Power Station (Ghana), which is the final terminal of the pipeline system. Another 80km offshore pipe-length would be run from Takoradi to Effasu in Ghana.

Specifically, the existing Escravos-Lagos pipeline with 24'' internal diameter has the capacity for about 4.24 x 10^9 m^3 (2.5bscfd) and the tie-in point to the proposed project is at Alagbado West of Lagos with pipeline of internal diameter of 30''. The Alagbado-Badagry would be 30km onshore and 27km offshore. This will be an extension of the existing Escravos-Lagos Pipeline System. The onshore portion will commence at Alagbado and terminate at the Atlantic Beach in south of Ajido near Topol Badagry in Lagos State after crossing the Badagry Creek. The Badagry Lagoon Creek and the Atlantic beach crossing will be by horizontal directional drilling or if not feasible, it will be by trenching and burial operations.

The onshore pipeline system will include a mid-line relief system located off the Otta-Idi Iroko highway near Canaan Land in Ogun state. An 18000-horse power onshore compressor station would be put in place at the Lagos beach from where 20'' by 51km pipeline is connected and extended 15km offshore before turning west across the Nigeria-Benin border to Cotonou. While maintaining the 15km offshore extension, the internal diameter is reduced to 16'' for 276km to Tema where a further size reduction to 12'' for another 233km to Takoradi is made (Fig. 2) before another 12'' by 80km offshore pipeline from Takoradi to Effasu in Ghana is linked. Along base route, additional lateral spurs, averaging 15km will extend from the base pipeline route to landfall regulating and metering facilities at Cotonou, Lome and Tema. The pipeline system will have laterals of 8'' to Cotonou, 10'' to Lome and 18'' to Tema. At Cotonou, a compression station operating between 40 and 150MW shall be installed. The Cotonou-Tema pipe-length with the initial cost estimate of \$130million is designed for conveying 2.26 x 10^9 m^3 (80MMscfd) natural gas initially with the ultimate expectation of 3.39 x 10^9 m^3 (120MMscfd).

The ultimate destination in Ghana is Volta River Authority Plant in Takoradi. The pipe-length with the initial cost estimate of \$106million (Tema-Takoradi) is designed to supply 1.70 x 10^9 m^3 (60MMscfd) of natural gas to Takoradi Power Plant with gas demand of 1.22 x 10^9 m^3 (43MMscfd) and the additional Hydro Power Plant in Effasu. In Tema, it is expected to supply VALCO power plant whose gas demand is 0.60 x 10^9 m^3 (21MMscfd). The specific status of each segment is summarized Tables 2 - 7. The offshore segment of the pipeline is to be submerged inside the water at between 26 and 70 meters

Pipeline transportation of natural gas is globally acceptable. Shell Transmission owns or has an interest in 17 Gulf of Mexico natural gas pipelines in operation or under construction with capacity of almost 9 billion cubic feet per day (Shell, 2004). Also, Equitable Gas Company, USA supplies over 250,000 customers in Southwestern Pennsylvania while providing natural gas distribution services to over 260,000 residential, commercial and industrial customers located mainly in the city of Pittsburgh and surrounding municipalities in Southwestern Pennsylvania through pipeline network systems (Equitable, 2004). With the successful operation of the existing pipeline networks, more countries are getting involved thereby promoting cross-boarder networking. Saipem s.p.A started building a 370km, 48in natural gas export pipeline between Qatar and UAE in 2004 with completion scheduled for 2006 (Saipem, 2004) while Libya equally started constructing pipelines to Egypt and Tunisia for natural gas supply in 2004 (Buddy, 2004). Most of these gas projects involve offshore transportation. Offshore pipeline transportation is the laying of pipelines through an ocean or sea over several kilometers deep inside water. Such pipelines are usually submerged between 26m and 70m underneath the water surface (Obanijesu et al, 2007). In recent times however, considerable public and regulatory attention is focused on the rate of pipeline failure in Nigeria. Pipeline failure is the failure of the pipe body due to metallurgical or processing abnormalities. Apart from pipeline vandalization, WAGP project is susceptible to failure through corrosion, defect welding, incorrect operation, defective pipe and malfunction of equipment amongst others (Obanijesu et al, 2006). After a failure along any part of the offshore portion of the project, the conveyed fluid escapes into the immediate environment (which is waterbody) to cause hazardous impacts on the ecosystems. Each accident leads to intensive vertical flow of the gas from the leak point to the surface. This is otherwise referred to as vertical dispersal. This vertical dispersal is often affected by the ambient current of the sea.

ASSOCIATED PROBLEMS

Hydrate Formation

Natural gas boils at -162^{O}C, hence, its release into waterbody results in formation of hydrates. Hydrates are formed during the interaction of many components of the gas with water under certain combination of high pressure and relatively low temperature. They appear in form of crystallized solid (like compressed snow). The hydrate formation sometimes accompanies vertical flow of the fluid resulting to problems ranging from behavioral nature (e.g., fish excitement, increased activity, and scattering in the water) to chronic poisoning depending on the quantity of the gas and the total period of exposure (Patin, 2004).

Dissolution of Component

In its untreated state, natural gas sometimes contains relatively small but undesirable quantities of carbon-dioxide (CO_2) (table 1), hydrogen sulfide (H_2S), O_2 e.t.c. (Stress 2003), thereby posing high risk to the people around and the living organism in the water. The release of this gas into the waterbody poses high risk of dissolution of acidic constituents which is taken in by the sea animals. Through the bioaccumulation process, man takes in the poisoned fish which could be very detrimental to his health. The acidified water could be taken up by plants within the watercourse through their roots to impair their growth. This dissolution also reduces the reproduction rate in fish which also reduces the availability for human consumption thereby leading to increase in price. Dissolved CO_2 indirectly affects seawater temperature, salinity, ice-cover, turbulence and current while all these abiotic effects have biotic consequences (US DOE, 1985).

Loss of Human Life and Livestock

Due to high pressure of discharge at the point of failure and insolubility of most of the components, the gas is ultimately released to the atmosphere at a particular distance away from the point of discharge either through vertical transport or by water inversion to cause air pollution which could lead to deaths. Typical of this is the Lake Nyos (Cameroon) incidence of August 1986 where an enormous volume of carbon dioxide (CO_2) was released from an underwater pipeline, killing about 1700 people (Clarke, 2001) and livestock up to 25km away; and Lake Monoun incidence of 1984 where a smaller release of CO_2 killed 37 people (Steven, 2000).

Climate Change

Nigerian natural gas contains between 68% and 90% methane (CH_4) (table 1) which is insoluble in water. Much of this gas is expected to have been oxidized in the water by bacteria before reaching the water surface (Dickens, 2001) but with the pressure at which the gas is been discharged from the point of failure, this could not be achieved.

With 8.4years global mean atmospheric lifetime (Prather et al, 1995), 12years perturbation lifetime (Schimel et al, 1996) and average transport distance by wind in the lower atmosphere of 500 – 1000 km per day (NEGTAP, 2001), it is easy to see how substantial quantity of CH_4 will be exchanged between countries in Africa.

CH_4 is a greenhouse gas (GHG) which aids climate change. The dangers posed by atmospheric abundance of CH_4 increase from 1520ppb in 1978 to 1745ppb in 1998 (Prather and Ehbalt, 2001) has led to global desired declination which has been observed annually over the last two decades. Global methane production from energy source (in Tg (CH_4/yr)) is estimated as 75 (Fung et al, 1991), 97 (Hein et al, 1997), 110 (Lelieveld et al, 1998), 89 (Houweling et al, 1999) and 109 (Olivier et al, 1999). Based on its atmospheric burden and climatic impacts (Alcamo, 1994), CH_4 was among the GHGes listed in the Kyoto Protocol. Hence, through an accidental discharge of natural gas through WAGP project, this desire would be jeopardized.

CH_4 oxidizes in stratosphere with OH, Cl and O leading to in-situ source of stratospheric water vapor (equation 1)

$$CH_4 + O_3 \rightarrow CH_3^{\cdot} + OH + O_2$$
$$CH_4 + OH \rightarrow CH_3 + H_2O \quad \cdots\cdots\cdots \quad (1)$$
$$CH_3 + Cl \rightarrow CH_3Cl$$
$$CH_4 + Cl \rightarrow CH_3Cl + H^{\cdot}$$

Oxidation of CH_4 is a source of mid-stratospheric H_2O and currently causes its abundance to increase from about 3ppm at the tropopause to about 6ppm in the upper stratosphere. Water vapor in the lower stratosphere is a very effective GHG. Baseline levels of stratospheric H_2O are controlled by temperature of the tropical tropopause, a parameter that changes the climate (Moyer et al, 1996; Rosenlof et al, 1997; Dessler 1998; Mote et al, 1998). Finally, stratospheric ozone depletion increases tropospheric OH (Bekki et al, 1994; Fuglestvedt et al, 1994) which reacts with CH_4 to produce more water vapor. CH_4 also reacts with Cl atoms in the troposphere (Singh et al, 1996). An assessment undertaken by IPCC (1991) generated some speculations about possible climate change impacts on fish population and aquatic life such as drastic declination in the availability of king crab stock in the eastern North Pacific such as eastern Bering Sea and Gulf of Alaska (Wooster, 1982) and the rapid disappearance of California Sardine (Ueber and McCall, 1982) amongst others.

Development of Predictive Model on Natural Gas Flow Pattern in Waterbody

Since the failure rate could only be minimized and not fully prevented, there is a dire need for a proactive and a comprehensive study of such scenario to identify the spots of high risk of pollution by preparing spill contingency plans for such accident and an important element in such plan is the use of mathematical models to predict the transport (trajectory and fate) of the gas in waterbody. Some of the numerical schemes commonly to these predictive models are Eulerian, Langragian, Eulerian-Langrangian and Crank-Nicholson methods. Paraschivoiu and Cai (2005) applied Eulerian method to obtain the accurate location of CO_2 gas in ocean while Hubbard (1993) used one-dimensional Euler equations to predict the flow of the gas in North Sea. Roache (1982) applied Euler's FDM numerical solution to simulate an ocean dispersion model developed by using centered schemes to approximate both the convection and diffusion. Slack et al (2003) applied Lagrangian tracking approach in single phase flow prediction for crude oil following an accidental discharge from a pipeline into waterbody while Johansen (2005) used the Lagrangian method to formulate computational fluid dynamics in dispersed multi-phase flows. Budnikov et al (2000) applied a 2-dimensional Lagrangian method to describe a technique for automatic determination of gas flow in the ocean where a global correction is required while Johansen and Laux (2005) used Lagrangian methods to calculate the trajectory of individual particles in granular flows. Also, Yapa and Zheng (1998) developed a three-dimensional comprehensive numerical model to simulate the behavior of buoyant oil jets that result from underwater accident based on Lagrangian integral technique. Zheng and Yapa (1998) simulated the model and tested it against a variety of conditions in order to compare the numerical model's result with the observed data set.

Furthermore, Laurien (2002) developed a model on gas dispersal pattern in a river and applied Euler-Lagrangian method for the phase flow simulations by combining the Lagrangian description of fluid mechanics with the Eulerian NSE (Navier – Stokes Equation). Lain et al (2000) used Eulerian – Lagrangian method for numerical computation of two-phase (oil-water) flows in water while Bourloutski and Sommerfield (2005) applied Euler-Lagrangian approach to three-phase bubble columns by describing in details bubble and particle motion and accounting for all relevant forces.

Finally, Obanijesu (2007) developed such model around the four main mechanisms of transport that occur to the leaked gas which are vertical bubble transport (bulk flow), vertical turbulent diffusion, dissolution of components and horizontal advection by ambient currents. The model was simulated using Crank Nicholson method as an appropriate numerical scheme with full consideration of downstream and upstream boundary conditions. Matlab 6.5 was used to solve the resulting algorithm.

These models could be modified for the peculiar WAGP project and made available to the operator's Accident Response Plan Unit (ARPU) in predicting the spread point (location) of the gas with time in the waterbody.

Development of Pragmatic Management Scheme

A pragmatic management scheme should be developed by the operator. This scheme should include compensation for any affected individual or community in case of accident. Immediate response and instant arrival of ARPU personnel to such point of accident should be considered. For this to work perfectly, the personnel must be well trained and equipped with necessary materials. Inventory of the available materials should be regularly taken (probably quarterly) for immediate replacement. Since offshore problem is being considered, the Unit must also be equipped with helicopters in case of multiple accidents at the same time. To ensure effectiveness, various types of insurance schemes be considered for each of the ARPU personnel.

CONCLUSION

This paper has established that maximum utilization of the abundantly deposited natural gas reserve in Nigeria through the WAGP project is necessary in order to drastically minimize her global contribution to environmental degradation through flaring. However, in as much as this project is financially and environmentally beneficial to Nigeria as a country, any failure along the offshore segment could be disastrous to Africa as a continent since the resulting accidental discharge could result into loss of lives and livestock and global warming amongst others. It is therefore important to prevent failures along the pipe-length as much as possible. The best possible means of achieving this could be by full commitment of the operators by investing in research and development to develop various relevant scientific models and management schemes.

Table 1: Molar Composition of Nigerian Natural Gas

	Molar Composition (%)		
Chemical Compound	Kokori Field Study	Utorogu Gas Plant	Sapele West Field
Methane	68.42	90.19	68.14
Ethane	7.65	6.94	14.22
Propane	11.27	2.09	10.27
N-butane	4.00	0.361	3.23
I-butane	4.42	0.414	2.38
N-pentane	0.94	0.005	0.75
I-pentane	1.55	0.007	1.07
Hexane	0.18	-	-
Nitrogen	0.16	-	-
Carbon-dioxide	1.02	-	-

Source: Sonibare and Akeredolu (2006)

Table 2: Benin Power Plant

Item	Comment
Operator	CEB
Capacity	40-150MW
Status	Preliminary Studies Done

Table 3: Segment 2 of the Proposed Pipeline System (Cotonou to Tema)

Item	Comment
Capacity	80mmscfd (2.26 x 10^9 m^3) (initial) 120mmscfd (3.39 x 10^9 m^3) (final)
Length	276km
Diameter	16in
Cost	$130million (initial)

Table 4: Operating Capacity of Valco Power Plant in Tema

Item	Comment
Operator	Valco
Capacity	Up to 100MW
Gas Demand	21MMSCFD (0.60 x 10^9 m^3) (Max.)
Type:	Combined Cycled Gas Turbine
Status	Under Evaluation
Remarks	Valco considering supplemental power to allow them to restart their 25% of capacity that is currently idle

Table 5: Segment 3 of the Proposed Project (Tema to Takoradi)

Item	Comment
Capacity	60MMSCFD (1.70 x 10^9 m^3)
Diameter	12in
Length	233km
Cost	$106million (initial)

Table 6: Takoradi Power Plant

Item	Comment
Operator	Volta River Authority
capacity	40MMSCFD (1.13 x 10^9 m^3)
Type	Combined Cycle Gas Turbine.
Type	Start-up: 2Q 1997
Status	Under construction
Initial fuel	Light crude oil
Financing	World Bank
Remarks	Two-100MW GE turbine to be installed.

Table 7: Tema power plant

Item	Comment
Operator	GNPC
Phase 1	
Capacity	131MW (simple cycle)
Expanded capacity	200MW (Combined Cycle)
Start-Up	Funding Pending
Phase2	
Capacity	120MW

Figure 1: A Gas flaring scene at Niger-Delta region of Nigeria

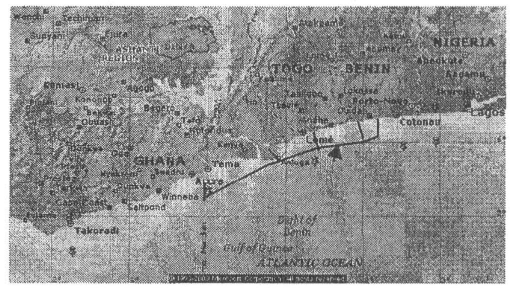

Fig 2: View of the WAGP Project from Nigeria to Ghana with Laterals at Cotonou, Lome, Tema and Takoradi.

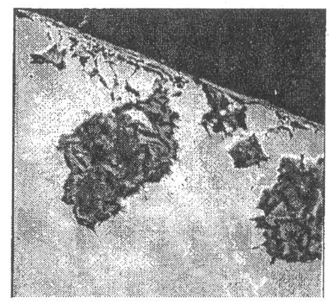

Plate 1: SEM image of the corroded steel surfaces taken from the study of CO_2 Corrosion in multiphase flow
Source: Nesic and Lunde (1994)

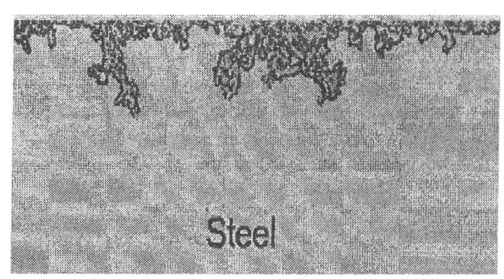

Plate 2: Simulated metal surface morphology following moderate precipitation leading to a partially protective film and localized corrosion. ST = 0.53
Source: Nesic et al (2004)

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