Bringing new energy to Southern Africa
- gas from coal seams

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Over the preceding eight years various exploration studies into potential natural gas reserves in Botswana have been undertaken by different parties. The results of these studies indicate that there are substantial resources of natural gas, in the form of coal bed methane (CBM) that have the potential for commercial development to the benefit of Botswana.

The most strategic benefit to Botswana would be to very significantly reduce the country’s dependence on imported energy supplies as a direct replacement for liquid petroleum products – petrol, diesel, liquid petroleum gas (LPG), heavy fuel oil in the transport and manufacturing industries – and as fuel for the generation of electricity in sufficient volume to meet present electricity imports (approximately 60% of total consumption in Botswana) as well as providing “bridging power” during the period it takes for the expansion of the Morupule Power Station to come into effect and (potentially) the country’s future “peak” demands.

The development of a local gas industry and the associated infrastructure and other spin-off economic activities would all contribute towards the diversification of the Botswana economy in line with the goals of Vision 2016.

Source of Botswana’s natural gas - coal bed methane (CBM)

The decomposition of organic matter deposited has resulted in strata of carbonaceous shales and mudstones. Gaseous methane and carbon dioxide (whilst being generated during decomposition of organic matter) became adsorbed within the coals and the carbonaceous shales. These gases can be liberated once penetrated by a well (suitably cased off and cemented) through which the hydrostatic pressure (water level) is lowered to a pressure lower than the desorption pressure – below which the gas will be liberated and flow into the well.

A byproduct of a CBM well is the water which is pumped only from the gas “pay” zones. The well casing is cemented into the formation to prevent communication or draw down from any intersected or overlying aquifers. The reduction of the coal seam water pressure is unlikely to have any effect on the overlying aquifers. The flow of the gas rises with time (until peak flow is reached) as the hydrostatic pressure is reduced whilst the flow of water from the well decreases accordingly (see Fig. 4).

Summary of results

The initial exploration was designed to accomplish two objectives. The first objective was to provide a structural and stratigraphic framework for coal seams in the lease areas. The second objective was to explore for and locate areas of enhanced permeability that could provide the sites for commercial development. The first objective was achieved through the compilation and mapping of existing geologic and borehole data. Data sources for this step included geologic survey reports, mining company data, and journal publications. The second objective, locating areas of enhanced permeability, was accomplished through the integration of satellite imagery and aeromagnetic data. Using this information, core and test wells were sited in areas thought to possess natural fractures which had the potential to be areas of higher permeability.

After selecting well site locations, a coring program was undertaken. The coring program established the essential information on gas content and gas saturation and provided stratigraphic information for the well testing program. Results of the gas desorption work showed gas content to be generally in the range of 2 m³/ton to 5 m³/ton (60 cf/ton to 160 cf/ton) on an as-received basis for the combination of organically rich shales and interbedded coals in the total pay sequence.

Adsorption isotherm studies performed at a US laboratory indicate that the coal seams are fully saturated with respect to gas. The coring program established that the potentially productive formations in the lease area are a combination of carbonaceous shales (such as the Antrim shales of the Michigan basin) and interbedded coal seams. These coal/shale sequences are stratigraphically equivalent to the coal/shale sequences in Zimbabwe and South Africa that have yielded positive test results and appear to represent commercially viable projects.

The well testing program was used to establish the permeability and, thus the productive capacity of the interbedded coal seam and gas shales. The presence of open, natural fractures was confirmed by a borehole televiewer logs that showed well developed, vertical fractures over several of the coal-bearing sections.

Using the geologic and reservoir data obtained from the coring and well testing programs, a reservoir simulation study was performed to predict 20 year gas and water recoveries on a per well basis.

The final step was to multiply the per well recovery for each area by the number of drillable wells to arrive at an estimate of total potentially recoverable gas.

Subsequent to the initial work, the Department of Geological Survey carried out the Central Kalahari Karoo Basin Study which showed a substantially greater resource of gas available. It should be noted that the reserves of the British North Sea Gas are stated to be 26.8 Tcf. The major findings of the CKKB study are [2]:

![Fig. 1: Sedimentary Basins of Southern Africa (after Johnson et al., 1996).](image_url)
• Botswana possesses a gas-in-place resource of 196 Tcf in the coal (60 Tcf) and carbonaceous shales (136 Tcf) of the Ecca formation.

• A significant portion, 40 Tcf, of the total gas in place has the potential to be economically recovered based on reservoir simulation of key reservoir data obtained during the drilling, coring and testing phase of the study.

• The deep portions of the Karoo Basin which were the original focus of the study as per the Terms of Reference, are not highly prospective for CBM for two reasons. First, the Lephephe “low” area is likely too deep (>900 m) for commercial CBM production. Second, as one moves westward into the deeper portions of the basin, the coal seams thin considerably. The most prospective area for development is the eastern portion of the basin where coal represents about 30% of the total coal/shale section and depths are in the range of 300 m to 500 m, comparable to commercially productive areas in the US.

Based on the favorable geologic and reservoir properties measured during the coring and well testing portions of the study, coupled with the acute need for natural gas for industrial applications, manufacturing, and power generation in Botswana, it would be logical for Botswana to continue to pursue this coalbed methane development program.

The next phase of the development will be a small-scale (4 to 5 well) pilot production project. The pilot project will help achieve two objectives. First, the closely spaced pattern of wells (benefitting from early interference) will help accelerate the demonstration of the commercial viability of the area. Second, the pilot project will help define geologic and reservoir variability over a larger area, thus providing greater confidence and perspective on the properties measured in the wells.

Pilot production project

In accordance with the requirements of the next phase of the development, a 5 well (known as a 5-spot) pilot production development is in progress.

Environmental Impact Assessment

An environmental impact assessment (EIA) has been carried out in accordance with the requirements of the Botswana Government. This EIA has been accepted and monitoring is ongoing.

Drilling

The drilling of the five wells in a symmetrical array was completed with the well spacing being 200 m (instead of 750 to 800 m) in order to ensure rapid hole interference. These holes have been logged using wireline logging equipment having been first cored in order and the gas saturation measured. Very little water was encountered in these holes which encountered the coals from 250 m onwards.

Cementing

Three of the five holes have been successfully cemented – two having been damaged owing to both operator inexperience and lack of proper equipment. Should the results of
the first three holes warrant same, these holes will be re-drilled and re-cemented. Purpose made cementation plant has been assembled and shipped out from the United States of America and is ready for use.

Well stimulation

The well casing will require perforation/slotting at the relevant “pay” zones areas. The coals and shales will require fracturing together with the concurrent pressurized insertion of sub-angular round sand (400 to 800 µm) which serves as a the path for the gas once the hydro-static pressure has been reduced.

The equipment for this casing perforation and subsequent fracturing has been purpose built and has arrived from the United States of America.

Five-spot well

The Kalahari Gas Corporation (KGC) work programme is to have a total of five fully equipped gas wells in production before December 2005.

The production output of these five wells will initially be flared (i.e. all piped to a single point where it will be fed into a stack and set to burn) for a period of three to six months over which time the production capacity of each well will be monitored.

Pilot power plant

Once the production capacity of this initial pilot production plant has been established, it is the intention of KGC to expand production to the level whereby gas, sufficient to fuel the continuous generation of up to 10 MW of electricity, is produced. To achieve this level of production, based on exploration data collated to date, it is anticipated that in the region of thirty additional wells will have to be drilled.

The step-up to this level of production will be adequate to prove the production capability of the gas field, whilst also being a sufficient quantity of gas to fuel a useful and meaningful project. Since the infrastructure necessary to package and distribute the gas from the production site to a remote market is not already in place in Botswana, the alternative is to utilize the gas in-field for electricity production. Due to the vicinity of the existing Botswana Power Corporation (BPC) electricity grid, power produced in the field can relatively easily be transmitted from the site for remote consumption. However, due to the nature of the grid at the location of the gas field, there are constraints that limit the amount of electricity that can be absorbed into the grid without significant grid up-grading.

The recommended way forward, will not only enable the production capacity of the gas field to be better determined, but will also prove the local application of gas-engine generator technology and the commercial viability of the gas-fields.

Having proved the ability to produce gas from a single location, in relatively limited quantity, the next requirement is to prove production in greater quantity suitable for commercial use, and hence this motivation for a 10 MW power plant project.

Based on KGC data obtained to date, it is anticipated that one gas well would typically yield sufficient gas flow to sustain the production of 0.33 MW of electricity and hence of the order of 30 production wells are required for a nominal 10 MW rated power plant.

It is proposed to construct the generation plant in a modular manner based on a number of individual smaller (typically in the range from 1.5 MW to 1.75 MW) generator sets. This approach will enable the first production of power to be achieved at an earlier date, i.e. on completion of the first five or six production wells, sufficient gas would be available to immediately commission the first generator set of approximately 1.6 MW capacity. As the well drilling programme progresses, so the generation capacity may be correspondingly ramped up in these 1.6 MW stages to the final 10 MW if appropriate.
This 10 MW capacity could naturally be extended in future with the addition of further modules. However, 10 MW is the initial proposed capacity since the existing BPC network would not be able to accept any more than this at the proposed input point into the grid, (i.e. the 33 kV overhead line near Shoshong).

Future expanded power plant

At the same time as the field and exploration studies have been on-going, KGC has also undertaken market feasibility studies to identify uses for their coal bed methane gas production. One of the proposed uses identified for the gas is electricity generation. Traditionally gas fired plant is more suited for peak power generation, rather than base load, due to the relatively short run-up times of a gas fuelled unit but with a higher running cost as opposed to, for example, a typical coal fired base load plant.

However, the present situation in Botswana is uniquely different. Botswana currently has in-country, coal-fired generation capacity of the order of 108 MW, whereas the maximum demand is nearer to 350 MW and hence the shortfall has to be imported or else shed. The bulk of this imported requirement is sourced from Eskom in South Africa under a Power Supply Agreement between BPC and Eskom. The terms of this agreement permit BPC to purchase power from the Eskom at a very favourable (to BPC) tariff until 2007, whereafter the agreement is subject to renewal and the indications are that Eskom has no spare capacity.

Although steps are proactively being taken to reduce the country’s dependence on imported power, by way of expanding the coal-fired base load capacity, this expanded capacity may not be available before 2007. Should additional internal generation capacity not be available in 2007, this would weaken Botswana’s position in negotiating renewal of the Eskom Supply Agreement, more so in light of the looming power generation shortfall in South Africa in particular and the region in general.

This situation can be significantly improved if construction of a gas-fired generation capacity is pursued in tandem with the expansion of the coal-fired capacity simply on the basis that the lead time, from inception to commissioning of gas-fired plant, is typically significantly shorter than for a traditional coal-fired type plant.

Thus, the suggested pursuit of the gas-fired plant is proposed, not as an alternative to the coal-fired plant, but rather as an enhancement of the coal-fired expansion programme. The optimal solution is considered to be to construct both plants simultaneously but, whereby the gas-fired plant could be progressively commissioned into service, some years ahead of the coal plant, to provide base load generation in the intervening time, until the new coal fired plant is commissioned. Once adequate coal-fired base load capacity is available, the gas-fired plant would be removed from base load duty, to remain available for use only for peak power generation, as and when required, or alternatively to generate surplus capacity for export.

However, even if it is accepted that there is a substantial gas fuel reserve available in Botswana and notwithstanding the sound motivation for developing a local gas-fired generation capability, there may still remain some degree of resistance to this, on the basis that the technology is not locally proven, as it has not previously been employed in Botswana.

This then is a further motivation for the construction of the proposed 10 MW pilot plant, to prove the application of this technology under local conditions.

Gas engine power generation

It is proposed to utilise gas engine generators for the power plant. A typical gas engine generator is manufactured by Caterpillar USA. Their gas engines have a proven track record and they are well represented by a local company, Barloworld. They have an established record of operating power generation plant in Botswana for Botswana Power Corporation and other clients.

There are a number of major advantages of using gas engine generation (GEG) technology instead of gas turbine (GT) technology.

These include:

- **Efficiency** - Overall thermal efficiency is in excess of 45% compared with single cycle turbine efficiency of less than 30%.
- **Capital cost** - The cost of plant / MW is substantially lower using GEG compared to GT.
• Power generation redundancy - The generation capacity can be increased incrementally and need not be housed together thereby ensuring redundancy. In addition, instead of throttling each engine to deal with a particular load, the generators could be run at their point of peak efficiency (typically 100% load) and shut down when not needed. A gas turbine would have to be throttled typically from 40% to 100% of its output. During maintenance, the entire generation capacity of a GT power station would be lost whereas with GEGs, only a small portion of the generation capacity would be offline during maintenance or shut down periods.

• Water - No cooling water would be required at all unlike that required for combined cycle gas turbines and coal-fired power stations. Water is a scarce and expensive commodity in Botswana.

• Fuel storage - GTs would require the gas to be stored and pressurized such that it could be drawn on during peak conditions whilst this would not be necessary for GEGs.

• Cost of power - The cost of power generated by GEGs is low enough to enable Botswana’s existing power supply tariff to be adhered to. An estimated generation cost of US$0.04 to 0.045/kWh is anticipated. This compares favourably with the existing retail tariff of approximately US$0.055/kWh. In the event that this power is used for peak power generation, a substantially higher tariff could be realised.

**Gas liquefaction [3]**

One of the obvious advantages of fossil fuels is its energy density which is substantially greater than gas in its normal form. The energy density of natural gas or methane can be increased by compression and storage in expensive heavy gas cylinders or high pressure pipelines which are very capital intensive.

Substantially more energy is dissipated in order to pressurize gas in order to increase its energy density than if it were “shrunk” by refrigeration techniques.

The cost of a pipeline is extremely high – this cost being avoided by transporting gas in its liquefied form – thereby creating a “virtual” pipeline with the added advantages of being able to deliver the fuel more extensively and in smaller quantities.

Liquefying methane increases its energy density more than 600 fold and is a well proven technology and is a clean “green” fuel.

**What is LNG (liquefied natural gas)?**

LNG is natural gas in its liquid form, clear like water, but weighing half as much as the same volume of water. LNG is a cryogenic liquid cooled to minus 161°C. It is not the coldest cryogenic liquid, but nevertheless very cold and thus requires specialist well insulated storage containers.

**History of LNG**

In the early 1900s Dr. Karl Von Linde, a German scientist invented a way to separate air by cooling it in stages until the various constituents (oxygen, carbon dioxide) condensed to liquid. Godfrey Cabot applied for a patent in the United States to liquefy natural gas. He could solve storage and transportation problems by condensing the gas to a liquid. This soon gave way to pipelines; it wasn’t until the late thirties that utilities began liquefying gas as a way of stockpiling it for colder months. These plants were dubbed “peak shaving” plants because they allowed gas companies to meet demand in excess of pipeline capacity, thereby reducing the peak delivery requirements of incoming pipelines.

There are many peak-shaving plants in the United States with some selling LNG for automotive fuel use. There are several hundred gas plants that could be modified to provide LNG for motor-fuel purposes if market demand were to increase. In the United States, approximately 120 plants produce or store LNG as part of their normal operations, these plants can be categorized as: peak-shaving facilities; satellite storage plants; import terminals; nitrogen-rejection units; and certain types of chemical plants, such as olefin plants and synthesis gas plants. LNG is becoming more and more popular with the transit and heavy duty truck market, and the demand increases every month.

**Advantages of natural gas vehicles**

• Clean: Natural gas vehicles (NGVs) produce far fewer pollutants than conventional vehicles. NGVs can reduce nitrogen oxide (NOx) emissions and reactive hydrocarbons - which form
ground-level ozone, the principal ingredient of smog – by as much as 98%. NGVs also reduce emissions of carbon dioxide by as much as 30%, carbon monoxide (CO) by 86% and carcinogenic particulate emissions by 99%.

- Safe: Natural gas is safe because it has a high ignition temperature, is lighter than air and dissipates rapidly when released. It is also non-toxic. Thirty years of experience and millions of problem-free miles driven by NGVs have proven that natural gas is an extremely safe fuel for vehicles. Since NGVs became popular in the 1970s there have been no reported fatalities related to natural gas in North America. The storage containers are significantly stronger than gasoline or diesel fuel tanks and have withstood impact and bonfire testing and exceeded US Department of Transportation safety standards, DOT and ASME standards.

- Abundant: Natural gas/CBM are available from the abundant domestic supplies. At projected levels of consumption, such supplies are sufficient to meet demand for the foreseeable future. Since it’s not imported, its increased use could help national energy security and substantially improve the nation’s trade as a supplement to Botswana’s existing exports.

- Performance: Since natural gas burns cleaner than other fuels, it provides longer engine life and lower maintenance costs. NGVs can travel significantly more miles before required maintenance, such as spark plug and oil changes are necessary. NGVs do not manifest “cold start” problems and do not generate evaporative or running-loss emissions.

- Refuelling convenience: Natural gas is well suited for fleet vehicles, which return to a central facility for refuelling. By rapidly developing a network of public natural gas refuelling stations, this will make clean-burning fuel more readily accessible to everyone.

- NGVs are on the market today: Unlike some other alternative-fuelled vehicles, advanced natural gas vehicle technology is here today. Major automobile, truck and bus manufacturers offer vehicles powered by natural gas.

The primary component of natural gas is Methane (CH₄). Minor components include; ethane (C₂H₆), propane (C₃H₈), butane (C₄H₁₀) and pentane (C₅H₁₂) and inert gases such as nitrogen and carbon dioxide.

The liquefaction of natural gas removes the impurities found in its composition. i.e. water, carbon dioxide, sulphur and some of the heavier hydrocarbons mentioned above.

LNG is typically found and sold for vehicle consumption in the 97.5 - 99.5% methane range while CNG or compressed natural gas is typically found in the 81.3 - 97.5% Methane range and that is highly dependent on its source.

Conclusion

The discovery of coal bed methane is likely to have a profound effect on the economies of Botswana and the region. However, as an industry it will require economic stimulation from both the private sector and government to ensure the gas related opportunities are fully realized – particularly with respect to obtaining carbon credits and the associated reductions of greenhouse gas emissions.

An entrepreneurial approach must be adopted by all parties wishing to participate in Botswana’s new found potential.

References

[1] (SADC, 2001)


[3] Chart Industries – Houston, Texas

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