JOURNAL OF ENERGY R & D IN SOUTHERN AFRICA

Vol 3
No. 3
AUGUST 1992

Vol.3 No.3 August 1992

Journal of Energy R & D in Southern Africa

A quarterly publication

Supported by the Energy Branch, Department of Mineral and Energy Affairs

It is the policy of the Journal to publish original research covering the technical, economic, political and techno-social aspects of energy in Southern Africa. Only previously unpublished work will be accepted. However, conference papers delivered but not published elsewhere are also welcomed. Short comments, not exceeding 500 words, on articles published in the Journal are also invited. Announcements of relevant publications, reviews, conferences, seminars and meetings will be included.

Those wishing to submit contributions for publication should refer to the guidelines set out in *Information for Authors* printed on the inside back cover of the Journal. All contributions are refereed by experts drawn from the Editorial Advisory Panel before publication.

The Editor does not accept responsibility for viewpoints or opinions expressed, nor the correctness of facts or figures.

Contents

Subscriptions:

Individuals (Southern Africa)
R66/year or R27,50/single copy

Individuals (Elsewhere)
US$60/year or US$25/single copy

Corporate (Southern Africa)
R132/year or R33/single copy

Corporate (Elsewhere)
US$120/year or US$30/single copy

This includes VAT, postage and packing in Southern Africa. Elsewhere, the subscription includes airmail postage and packaging.

Enquiries may be directed to:
The Production Editor, Journal of Energy R&D in Southern Africa, Energy Research Institute, University of Cape Town, P O Box 33, Plumstead 7800, South Africa.
Tel.: (021) 705 0120
Fax.: (021) 705 6266

ISSN 1016-1686

IGNITION-IMPROVED ETHANOL AS A FUEL FOR DIESEL ENGINES

*A C HANSEN, *E R DE LA HARPE and *M P DILMITIS

The use of ethanol as a fuel has considerable merit as a source of "clean" energy that can be produced from regenerative biomass. The overall objective of this project was to evaluate the use of ethanol with an additive in an ADE 236 direct injection diesel engine, commonly fitted to tractors and light-duty trucks. This evaluation included combustion and engine performance tests, durability tests on the engine under field conditions and on the fuel injection equipment. Results from in-field durability tests showed that ethanol fuel can compete favourably with coastal diesel in an ADE 236 engine provided that the compression temperatures are increased, the exhaust valves are protected from the engine oil additives and a more durable fuel injection system is used. The aqueous component and the relatively high heat of vaporisation of the ethanol fuel contributed to quenching effects during injection and subsequent combustion. An increase in the compression ratio provided a marked improvement in the combustion characteristics of ethanol. Further optimisation of the injection timing of the ethanol pump was necessary over the complete working range in order to achieve maximum combustion efficiency. Peak pressures generated by ethanol combustion were similar to those for diesel fuelling and therefore it was predicted that combustion of the ethanol blend would not affect engine life adversely. The maximum rates of pressure rise, and hence combustion noise, were considerably reduced during ethanol combustion. Thus, from an environmental perspective, the ethanol fuel showed considerable advantages over diesel. The overall conclusion was that with a few relatively simple adjustments and modifications to the engine and fuel injection system, a standard ADE 236 engine was able to perform as well on wet ethanol with an additive as on diesel fuel, and that engine durability would not be compromised if a suitable engine oil was used.

KEYWORDS: ethanol; diesel engines; tractors

INTRODUCTION

The global fuel crises in 1973 and 1978 generated an awareness among many countries, including South Africa, of their vulnerability to oil embargoes and shortages. Considerable attention was focussed on the development of alternative fuel sources, with particular reference to the alcohols. Apart from an oil embargo, South Africa was initially faced with an imbalance in the supply and consumption of diesel and petrol, resulting in a shortage of diesel. This shortage added impetus to the search for a viable alternative to diesel that could be introduced in the event of severe deficiencies. Subsequently the pendulum has swung the other way as a result of the unprecedented growth in the mini-bus population.

In spite of these changes in the local fuel market, and hence a decline in support for research on alternative fuels for both crude oil and coal-based diesel fuels, discussions in global energy forums indicate that the long-term need to replace mineral-, oil- and coal-based energy supplies with alternative energies remains undisputed. A strong focus on the environmental effects of present fuels has added further motivation to the search for alternatives. The most effective solution is represented by fuels derived from regenerative biomass as they are inexhaustible and, even in the long term, would not increase the carbon dioxide content of the atmosphere. Nevertheless, large areas of agricultural land and a favourable climate are prerequisites to the viable production of fuel energy resources.

Hardenberg and Schaefer[1] stated that the combustion of ethanol in compression ignition engines revealed some attractive properties of this fuel, such as, reduced black smoke, NO^x and hydrocarbon emissions. These results were confirmed by a theoretical examination of the diesel combustion process. Ethanol can be synthesised and produced from a wide spectrum of feedstocks at relatively low cost. The increase in environmental awareness has exposed the potential of alcohols to burn cleanly and thus meet certain stringent emission standards[2]. In South Africa ethanol can be produced by fermentation of biomass and, in particular, sugar-cane which is grown over large areas along the coastal regions of Natal.

A project was initiated with the overall objective of evaluating the use of ethanol plus an additive produced by Chemical Resources (Pty) Ltd in an ADE 236 diesel engine, the most common engine fitted to tractors. The evaluation included combustion and engine performance tests, and durability tests on the engine under field conditions and on the fuel injection equipment. Other related specific objectives were to:

(1) modify or adjust the existing fuel injection system in order to obtain the same engine power on ethanol fuel as could be achieved on diesel fuel,

(2) ensure that the fuel formulation was satisfactory for sustaining combustion under practical running conditions for a tractor, and

(3) monitor durability and changes in performance over 1200 hours with the engine running for alternate 100-hour periods on diesel fuel and on ethanol fuel.

During the first phase of the project some serious problems that influenced the practical application of the fuel were identified. Two major issues that were evident during a 1200-hour durability test were misfiring of the engine under certain conditions, and reduced delivery from the rotary distributor fuel injection pump. The use of a higher compression ratio was seen as a means of solving the first problem, while a modified or totally different pump was required for overcoming the second problem. This paper covers the most notable results obtained with respect to engine performance, durability and combustion. Further details are provided by Hansen *et al.*[3].

* Department of Agricultural Engineering, University of Natal, P O Box 375, Pietermaritzburg 3200, South Africa

FUEL SPECIFICATIONS

Ethanol cannot be used to run a standard diesel engine without the addition of, at least, an ignition improver. Furthermore, anhydrous ethanol is hygroscopic and can absorb moisture from the atmosphere until the water concentration reaches approximately 5% when the solution becomes azeotropic. Hence, azeotropic ethanol was used in the fuel blend. Apart from being slightly cheaper, another benefit from using this grade of ethanol was that the reduction in power was less than that expected from the drop in calorific value due to the dilution[4]. Therefore, in this project, the test fuel was formulated with 93,5% hydrous ethanol and 6,5% of a locally produced additive containing an ignition improver similar to tri-ethylene glycol di-nitrate, a lubricity enhancer and a corrosion inhibitor. The manufacturers of the additive had recommended a 6% additive concentration based on a number of engine tests. However, combustion tests with this amount indicated marginal ignition quality with the occurrence of a misfire and an extra $^1/_2$ % was necessary to achieve acceptable engine operation. The ethanol blend composition and some fuel properties are provided in Table 1.

Table 1: Specification of the ethanol blend and fuel properties

	% BY VOLUME	% BY MASS	GROSS CALORIFIC VALUE (MJ/kg)	DENSITY (kg/m^3)
Dry Ethanol	88,83	85,43	29,70	0,79
Blendol MW	6.50	8,89	16,10	1,12
Water	4,67	5,68	–	1,00
Ethanol Blend			26,80	0,82
Diesel			45,00	0,84

ENGINE MODIFICATIONS

In the first phase of the project the effect on engine performance and durability of ethanol fuel was investigated with an ADE 236 engine fitted to a Ford 5610 tractor that had already completed 1000 hours of low load operations on diesel fuel. The engine was serviced, and the valves and seats were re-lapped before the start of the project.

The lower calorific value of the ethanol fuel necessitated a substantially increased maximum delivery to obtain the same output that was achieved with diesel fuel. A larger capacity pump was calibrated and fitted in conjunction with injector nozzles of larger orifice diameter[3]. The increased volume and higher heat of vaporisation of the fuel resulted in a longer ignition delay, so the ignition timing was re-opimised. A second fuel tank, a standard fitting from a higher capacity tractor, was fitted to the test tractor with a minimum of modifications, and the filler cap of the main fuel tank was provided with an anti-slosh cylindrical extension to prevent leakage and damage to the paintwork while the tanks were full.

Additives in the engine oil which enter the combustion chamber usually remain unburnt and combine with the soot to form a soft, lubricative compound. During the combustion of alcohols, however, negligible soot is produced because of the low stoichiometric air fuel ratio, and Myburgh[5] showed that the additives form hard, abrasive deposits which cause severe wear of the exhaust valves. A low additive package spark ignition engine oil was therefore used in the test tractor.

As a result of a misfire that developed during the durability tests it was concluded that the naturally aspirated engine was not generating compressed air temperatures high enough for adequate fuel vaporisation and ignition of the ethanol. Consequently, it became necessary to fit a turbocharger to the engine after 700 hours, the use of which eliminated all performance difficulties with the ethanol fuel under normal operating conditions. However, under cold start conditions, there was still some evidence of a misfire as the turbocharger was ineffective at low loads. The fitting of high compression pistons was seen as a more reliable solution to this problem.

In the engine durability tests ethanol and diesel fuels were each used for six alternate 100-hour periods of field work consisting mostly of high load soil tillage operations. The same engine test procedures reported by Meiring *et al.*[6] were used to make extensive evaluations of engine performance and the condition of the two separate sets of fuel injection equipment after each 100-hour period. Engine wear was monitored with the aid of an oil analysis and visual inspections of the valves, pistons, cylinder head and liners after each 100-hour period by means of a borescope.

In the second phase of the project, modifications were carried out on the injection pump, and higher compression pistons were designed and fitted in place of the standard pistons. The problem of inadequate fuel delivery and the need for excessively high transfer pressures were identified by Williams[7] as being related to insufficient registration of the inlet port during the plunger charging stage, and he subsequently recommended that four axial filling slots coinciding with the inlet ports should be machined on the rotor. He also advised that the advance mechanism, with a 0-6 degrees advance range, be limited to 0-3 degrees to ensure an acceptable lead angle (being the angle of rotation of the rotor between the start of outlet port registration and the commencement of the pumping stroke). The slots in the rotor were machined relatively easily using a precision grinding machine.

High compression pistons were designed with a reduced combustion bowl depth thereby reducing the clearance volume. These pistons were of the mono-metallic (MM), pre-topped type, commonly used as service replacements, and therefore a greater piston crown-head clearance was provided as compared to the controlled-expansion (CE) pistons fitted at the time of engine assembly. Measurements showed that the compression ratio increased from approximately 15:1 for the standard MM pistons to 17:1 for the high compression MM pistons, while the compression ratio for the standard CE pistons was approximately 16:1.

ENGINE PERFORMANCE

Preliminary tests on the engine fitted to the tractor using a 6% Blendol concentration as recommended by the additive manufacturer produced a constant misfire and the concentration was initially increased to 7,5% to eliminate it (see Figure 1). Further tests indicated that a practical minimum additive concentration of 6,5% could be used and this concentration was maintained for the rest of the project.

Figure 1 also illustrates the effect of increasing the transfer pressure in the rotary pump. The rounding off of the power curve as maximum fuelling was reached was largely eliminated.

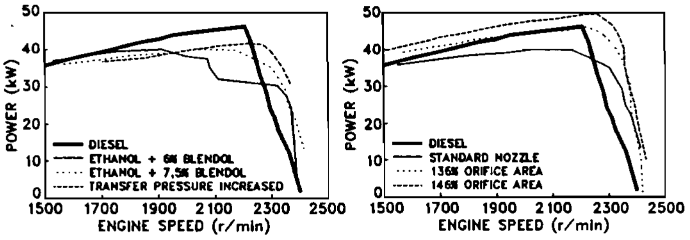

Figure 1:
Effect of additive concentration, fuel transfer pressure in the pump and injector nozzle size on engine performance

Figure 1 also shows the results from experiments conducted to determine the effect of nozzle size on engine performance. It can be seen that the cross-sectional orifice area was critical to fuel flow and engine performance. For the remainder of the project, nozzles with a 46% larger orifice area were used for ethanol fuelling.

The engine power and specific fuel consumption recorded for both fuels with the high compression MM and standard CE pistons are displayed in Figure 2. For the tests with different compression ratios the engine was fitted with the injection pump containing the modified rotor. A study of the performance variables revealed that the type of piston used had little effect. Under high compression conditions ethanol and diesel fuel behaved similarly in terms of torque and power output. Even at the lower compression ratio the maximum variation in power output was measured at less than 5%. An increase in specific fuel consumption of approximately 55% was recorded under ethanol fuelling. However, again the effect of increasing the compression ratio was not significant.

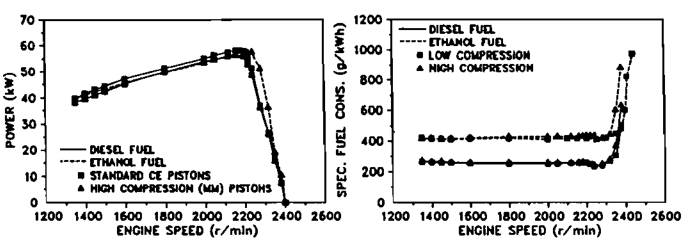

Figure 2:
Engine power and specific fuel consumption for both fuels with high compression MM, standard MM and standard CE pistons

COMBUSTION ANALYSIS

Comprehensive combustion tests were conducted with both fuels using standard and high compression pistons in a naturally aspirated ADE 236 engine instrumented with a pressure transducer, needle lift transducer, crank angle indicator and thermocouples. A multi-channel data acquisition system[8] was used to monitor and record the signals emanating from the transducers. The system incorporated a means of recording both high speed and steady state variables simultaneously as well as the display, processing and storage of data.

A much greater insight into the combustion processes can be achieved with the aid of a combustion model that computes the rate of heat release. The model used in this study was based on the one developed at the University of Illinois, Urbana, Illinois, U.S.A., by Faletti *et al.*[9] that employed the equations derived by Krieger and Borman[10]. Inputs required for the execution of this program included:

(a) engine speed,
(b) measured cylinder pressure and needle lift-crank angle data for the cycle,
(c) fuel composition and consumption rate,
(d) surface temperature of the combustion chamber,
(e) intake air temperature, and
(f) air flow rate through the engine.

A rigorous calibration and testing procedure and carefully selected speed-load conditions were implemented to enable a thorough investigation of the two fuels and the different piston configurations. For each piston configuration of the engine a pair of tests was conducted, the first with diesel fuel and the second with the ethanol blend. After every test the fuel injection equipment had to be exchanged to accommodate the other fuel. This involved the switching of the fuel injection pump and nozzles.

It is appropriate to begin this analysis by studying the delay period between the start of injection and the start of combustion. This variable is one of the important measures of combustion quality and forms the basis of the cetane index. The ignition delay recorded with the ethanol fuel was reduced significantly by increasing the compression ratio from 15:1 to 17:1 with the engine fitted with mono-metallic pistons. With high compression pistons the ignition delay with ethanol was shorter than for diesel fuel, whereas low compression pistons extended the delay obtained with ethanol so that it exceeded that of diesel. These effects are illustrated in Figure 3. It can be concluded that for the given amount of ignition improver present in the ethanol, a compression ratio setting midway between 15 and 17 would then give an ignition delay that was approximately the same as for diesel fuel.

Under similar load and speed conditions the maximum rates of pressure rise recorded in the combustion chamber for each fuel were significantly different. Diesel fuel tended to produce rates of pressure rise one-and-a-half to two times greater than those experienced with ethanol, as shown in Figure 3. Even though the ignition delay could be similar for the two fuels, different proportions of each fuel may have reached a prepared state for pre-mixed combustion. In the case of ethanol, because of its high latent heat of vaporisation and its poor self-ignition quality, less fuel is made ready for combustion in the delay period than diesel. Hence, the rate of pressure rise was less prominent for ethanol. The combustion noise associated with ethanol fuel would therefore be reduced as there is a strong correlation between maximum rates of pressure rise and diesel engine noise[11].

The peak pressures generated in the engine during combustion have been shown to be strongly correlated to engine stress, and hence engine life[12]. The peak pressures from the combustion of ethanol were generally similar to those produced by diesel fuel. The presence of water in the ethanol may have contributed to the peak pressures through partial vapour pressures or a possible "steam engine" effect. The exact effect and mechanisms of the

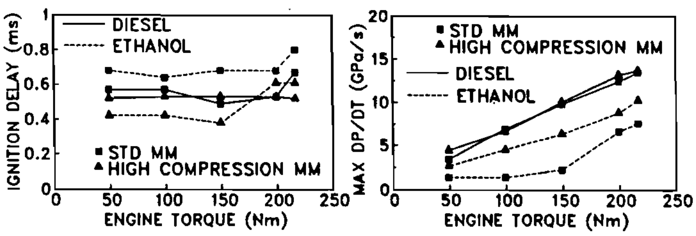

Figure 3:
Variation of ignition delay and rate of pressure rise with engine torque for diesel and ethanol fuel at two different compression ratios.

aqueous component are, however, still unclear. At a load of 200 Nm the peak pressure had a tendency to decrease as speed increased for diesel fuel. In the case of ethanol a maximum in the peak pressures was evident at approximately 1800 r/min whereafter peak pressures declined sharply with reduced engine speeds as shown in Figure 4.

A study of the heat release curves in Figure 5 for the points at the lower speeds with the load set at 200 Nm revealed that the heat release from ethanol occurred later in the cycle, and therefore lower peak pressures were generated. This was attributed to the retarded injection timing of the pump calibrated for ethanol usage[3].

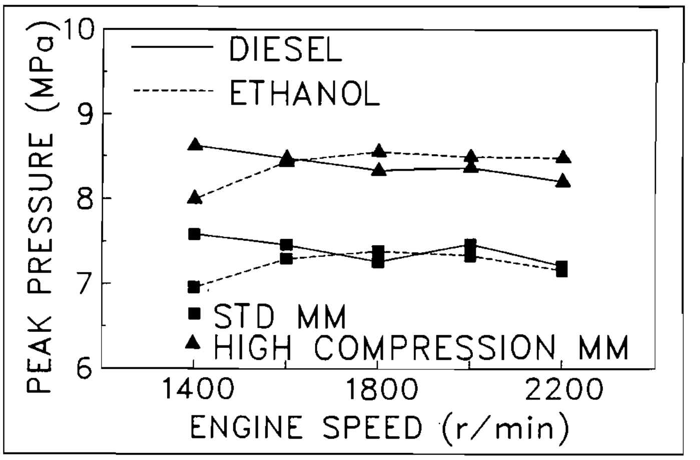

Figure 4:
Variation of peak pressure with engine speed for both fuels at two different compression ratios for an engine load of 200 Nm.

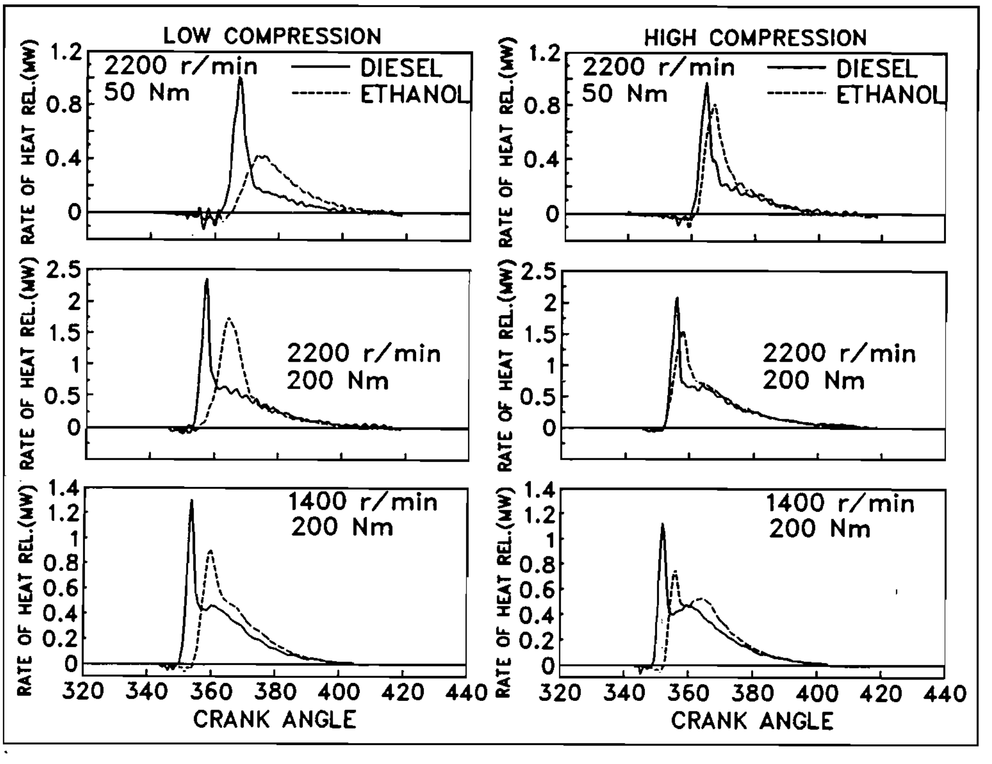

Figure 5:
Variation of rates of heat release with crank angle for both fuels at two different compression ratios for three load-speed settings

The heat release analysis indicated significant differences between the two fuels. Figure 5 illustrates these differences at two load-speed settings for the two different compression ratios. At rated speed and a low load of 50 Nm the major portion of the fuel is burnt in the pre-mixed phase. It is interesting to note a small shift in burning from pre-mixed to diffusion for diesel fuel in Figure 5 when the compression ratio is increased. This shift, which also occurs at the other load-speed settings, can be attributed to a small reduction in ignition delay with the high temperatures in the combustion chamber caused by the higher compression ratio. A corresponding reduction in the peak rates of heat release is also evident.

In the case of ethanol at the low compression ratio the rate of heat release is initially slower than diesel fuel, particularly at the low load where combustion chamber temperatures are low. A broader period of pre-mixed burning is also noticeable in Figure 5. The major reasons for these differences are longer ignition delay with ethanol and its higher latent heat of vaporisation, coupled with the presence of an aqueous component. An increase in compression ratio provides a significant change in the heat release pattern with a narrower stage of pre-mixed burning.

At the high load, the reduced ignition delay has resulted in more diffusion burning.

At the low speed-high torque setting the start of the combustion of ethanol with a high compression ratio is still somewhat retarded compared to diesel fuel. This difference is caused by retarded injection timing in the ethanol fuel pump. At rated speed and 200 Nm, it can be seen that diesel fuel and ethanol start burning at approximately the same crank angle. In future work involving ethanol fuel it would be necessary to optimise the injection timing over the complete working range of the engine in order to achieve maximum combustion efficiency. This optimisation should lead to improved engine operation, particularly under low load where cylinder temperatures tend to be lower and therefore more critical for ethanol fuel combustion.

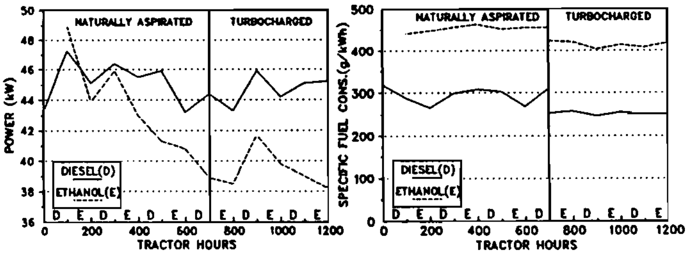

Figure 6:
The power output and specific fuel consumption of the engine on both fuels over 1200 hours

ENGINE DURABILITY

The maximum power output of the tractor at 100-hour intervals on both fuels is shown in Figure 6. A continuous line is shown for each fuel as the tractor was tested at the beginning and at the end of each 100-hour interval on each fuel, with the exception of ethanol. The vertical line at 700 hours indicates the point from which the engine was turbocharged.

In Figure 6 three distinct trends can be observed:

(1) The diesel power output was generally higher at the end of a diesel-fuelled, 100-hour period and generally lower after 100 hours of ethanol fuelling. This was attributed to the effect of the fuels on combustion chamber insulation associated with the alternate removal and re-deposition of a layer of carbon inside the chamber. On the whole, however, there did not appear to be any deterioration of the engine while operating on diesel over the 1200 hours.

(2) There was a very sudden loss of 5 kW during the first 12 hours of ethanol fuelling. This loss of performance was attributed to the initially high rate of carbon layer removal.

(3) A gradual loss of power with ethanol fuelling took place over the 1200 hours.

Figure 6 also shows the specific fuel consumption of the engine with both fuels over the 1200 hours. There appeared to be no decline in the performance of the engine on either diesel or ethanol fuel. An improvement in specific fuel consumption as a result of turbocharging was the only noticeable characteristic of the graph. It was therefore concluded that the loss of power with ethanol fuelling was solely a result of a loss of fuel delivery.

The thickness of a lubricating film in a journal-type bearing is directly proportional to the fluid viscosity and the rotor speed, and indirectly proportional to the load imposed upon it. The rotary-type pump makes use of the fuel for lubrication, and the viscosity of the ethanol fuel, even with the additive, is significantly lower than that of diesel. The combined effect of a high fuel demand and low rotor speed during acceleration, together with a low fuel viscosity during summer, may have reduced the thickness of the film of ethanol fuel to such an extent that it is incapable of supporting hydrodynamic lubrication. Excessive wear and high leakage rates would have resulted, causing a loss of power and governor response. It was concluded that the lubricity additive in the ethanol fuel should be upgraded to overcome this problem.

Ethanol injector needle-seat wear was high as a result of reduced damping by the low viscosity fuel. Opening pressures dropped substantially and had to be reset three times over the 600-hour ethanol fuel test period. Leakage rates also increased significantly, but none of these problems appeared to have any effect on engine performance. A possible reason was that the needle valve required a greater seat area than normal and that once this had been established the wear rates were normalised. The steel injector pipes were sectioned and examined after the completion of the 1200 hours. Neither evidence of pitting from cavitation erosion nor any differences between the diesel and ethanol pipes could be found.

An oil analysis showed that the engine oil pH was generally superior after ethanol fuel had been used than when diesel was used. This was attributed to the absence of sulphur in the fuel for which a reserve in oil alkalinity is normally provided for neutralisation. The resulting high sump oil pH could have extended crankcase component durability. This improvement in engine lubrication durability paralleled the findings of Hardenberg and Schaefer[1].

Figure 7 shows the concentrations of various substances from contaminants and additives found in the engine oil at the completion of each 100-hour period. Based on the oil analysis results it was concluded that engine wear was generally less with ethanol fuelling than that with diesel fuel before the engine was turbocharged. Ishizuki, Sato and Takose[13] showed that the durability of a combustion chamber is inversely proportional to the amount of carbon in it. Therefore the improvement in engine durability was attributed to the reduction in carbon deposition in the combustion chamber.

Turbocharging resulted in higher wear rates with both fuels, neither appearing to be more detrimental than the other. These higher wear rates may have been due to the increased operating temperatures and to an increase in the amount of dust, aluminium and silicon entering the engine after the turbocharger and its corresponding larger capacity air filter were fitted. The large quantities of copper in the lubricating oil detected immediately after turbocharging were believed to have originated from the oil supply plumbing installed with the turbocharger. On the whole, however, it was concluded that the use of ethanol fuel did not adversely affect engine crankcase durability.

The oil additives were depleted more rapidly by ethanol fuelling, and led to the formation of granular deposits on the cylinder head and piston crown. The deposits on an exhaust valve were analysed and found to be composed mainly of zinc and phosphorus, which are two of the engine

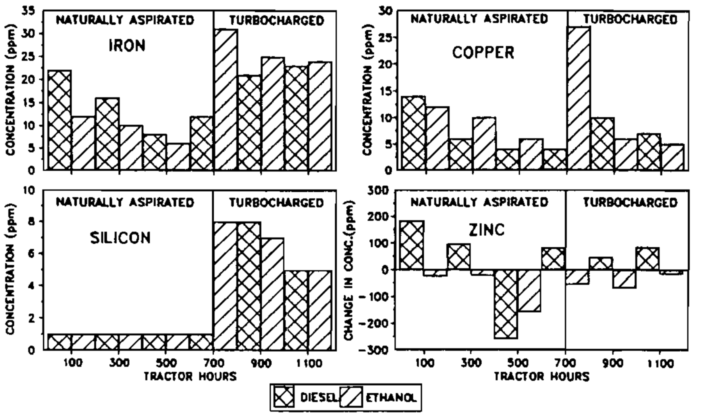

Figure 7:
The concentration of selected contaminants and additive in the engine oil after each alternate 100-hour test period for each fuel

oil additives that were consumed by ethanol fuelling (see Figure 7).

Exhaust valve-seat wear resulted from the abrasive oil additive deposits. The engine was more sensitive to poor exhaust valve-seating when fuelled with ethanol than when diesel was used, and a misfire developed and deteriorated to a backfire. Re-seating of the valves and turbocharging solved the misfire problem, but the suitability of the engine oil when using the turbocharger was called into question and the need for further research into low-additive oils for this application was highlighted.

Visual inspections with the aid of a borescope of the piston, cylinder liner and head condition after each 100-hour period, and inspections of each component at the completion of the 1200 hours revealed few differences between the two fuels in their effects on engine wear. The alternate deposition of the carbon layer by diesel and the removal thereof by ethanol fuel, and the formation of engine oil additive deposits were the most significant findings of these inspections.

CONCLUSIONS AND RECOMMENDATIONS

1. The standard fuel injection pump fitted to the ADE 236 engine was incapable of producing the 70% increase in ethanol fuel delivery required to match the power output of the engine when fuelled with diesel. A higher capacity pump incorporating a rotor with machined slots to extend port registration provided a satisfactory solution to this problem. In addition, injector nozzles with a larger orifice size had a substantial effect on fuel delivery, and hence on power. The advance range should be limited to 0-3 degrees.
2. The 6% additive concentration recommended by the additive manufacturer was insufficient to sustain reliable combustion. A concentration of 6,5% provided more uniform burning of the fuel.
3. With the modified injection pump and nozzles with a 46% larger orifice area, engine power on ethanol could be matched easily with that on diesel fuel. An increase of approximately 55% in specific fuel consumption was recorded under ethanol fuelling. High compression pistons did not affect power nor specific fuel consumption with ethanol significantly.
4. An increase in cylinder gas temperatures is required in order to provide acceptable combustion under cold start and normal running conditions. The fitting of high compression pistons is a more viable option than a turbocharger to achieve the required temperatures. In addition, the turbocharger is not effective under low load conditions.
5. A compression ratio of 16:1 in the ADE 236 engine fitted with mono-metallic pistons should provide ethanol combustion quality that is comparable to diesel fuel. The aqueous component and the relatively high heat of vaporisation of the ethanol fuel contributed to quenching effects during injection and subsequent combustion. However, it was predicted that combustion of the ethanol fuel would have a beneficial effect on engine thermal and mechanical stresses, and hence, on engine life.
6. Optimisation of injection timing over the complete working range of the engine, particularly at low loads, was necessary to achieve maximum combustion efficiency. From an environmental viewpoint the ethanol blend had an advantage over diesel with regard to engine noise.
7. Earlier durability tests indicated that the rotary distributor injection pump was not sufficiently durable to maintain peak performance of the engine. The machined slots in the rotor should result in a substantial improvement in the durability of the pump. Nevertheless, the fitting of an in-line injection pump in place of the rotary pump should be investigated as a more effective solution.
8. Exhaust valve wear, even when using a low oil additive package, was excessive. Further research into oil additive package compatibility with ethanol fuel is needed.
9. It was concluded overall that, with a few relatively simple adjustments and modifications to the engine and fuel injection system, a standard ADE 236 engine was able to perform as well on wet ethanol with additive as on diesel fuel, and that engine durability would not be compromised if a suitable engine oil was used.

ACKNOWLEDGEMENTS

This project was funded by the National Energy Council. The authors wish to acknowledge substantial contributions and assistance from the CSIR, BP (SA), Chemical Resources (Pty) Ltd, Natal Cane By-Products Ltd, Atlantis Diesel Engines (Pty) Ltd and Lucas CAV (SA and UK).

REFERENCES

(1) HARDENBERG H O and SCHAEFER A J (1981). The use of ethanol as a fuel for compression ignition engines. SAE paper 811211.

(2) HAVENITH C, KUEPPER H and HILGER U (1987). Performance and emission characteristics of the Deutz glow plug assisted heavy duty methanol engine. SAE paper 872245.

(3) HANSEN A C, DE LA HARPE E R and DILMITIS M P (1991). Comprehensive evaluation of ethanol in agricultural tractors. Draft Report for National Energy Council prepared by the Dept. of Agricultural Engineering, University of Natal, Pietermaritzburg.

(4) GOERING C E and SCHRADER G W (1988). Effects of ethanol proof on engine performance. *Transactions of the ASAE*, Vol.31 No.4, pp.1059-1062.

(5) MYBURGH I S (1985). Evaluation of "diesanol", an ignition-improved methanol as alternative fuel for diesel engines. Proceedings of a Seminar on Alternative Fuels, CSIR, Pretoria.

(6) MEIRING P, ALLAN R S and LYNE P W L (1981). Ethanol based multiple component fuels for diesel tractors. ASAE paper 81-1055.

(7) WILLIAMS D (1988). Personal communication. Lucas Industries SA (Pty) Ltd., Paarden Eiland.

(8) HANSEN A C, TAYLOR A B, LYNE P W L and MEIRING P (1989). Alternative fuels combustion and performance monitor for compression-ignition engines. Report for National Energy Council by the Dept of Agricultural Engineering, University of Natal, Pietermaritzburg.

(9) FALETTI J J, SORENSON S C and GOERING C E (1984). Energy release rates from hybrid fuels. *Transactions of the ASAE*, Vol.27 No.2, pp.322-325.

(10) KRIEGER R B and BORMAN G L (1966). The computation of apparent heat release for internal combustion engines. ASME paper 66-WA/DGP-4.

(11) CHAN C M P, MONCRIEFF I D and PETTIT R A (1982). Diesel engine combustion noise with alternative fuels. SAE paper 820236.

(12) TAYLOR A B, HANSEN A C, LYNE P W L and MEIRING P (1989). Engine stress from combustion of alternative fuels in compression-ignition engines. Report for National Energy Council by the Dept of Agricultural Engineering, University of Natal, Pietermaritzburg.

(13) ISHIZUKI Y, SATO F and TAKOSE K (1981). Effect of cylinder liner wear on oil consumption in heavy duty diesel engines. SAE paper 810931.

THE MABIBI WIND ENERGY PROJECT: PART II

*D LIGOFF, **R D DIAB, ***R P VILJOEN, and ****H U KIDGELL

This paper describes the design and implementation of a wind energy system for providing electricity to the Mabibi Primary School. The wind energy assessment, socio-economic studies and environmental impact studies have been described in Part I***** of this paper.

As no local experience could be drawn on in estimating potential loads and designing wind systems for this type of application, a conservative approach to system design was applied. The constraints of locally available equipment, and erecting and commissioning a wind turbine in such a remote area had an impact on the project lead times and ultimate system configuration. Wind data and electricity usage patterns will be monitored for at least one year, with a view to ascertaining the available surplus capacity and future electricity applications to enhance the quality of life of the local community. Experience gained with this project will lead to greater efficiency and cost-effectiveness in future similar applications.

KEYWORDS: electricity; wind energy; underdeveloped areas

INTRODUCTION

The primary school in the remote rural community of Mabibi had been identified as having satisfied all the requirements for South Africa's first commercial wind energy demonstration project. It represents a joint undertaking between Eskom, Natal University, the Energy Branch of the Department of Mineral and Energy Affairs and the Rotary Club of Durban Musgrave. As mentioned above, the first phase of the project, consisting of wind data assessment, modelling and measurement, environmental impact assessment and socio-economic impact assessment has been discussed in detail in Part I of this paper.

Besides the analysis of the available wind resource, the other data required and issues to be considered before the wind system could be designed and sized included:

- predicted electricity usage patterns of the school
- availability and cost of wind generators and associated equipment
- siting of the wind turbine
- appropriate appliances
- maintenance requirements
- future system expansion
- accessibility of the site.

This project was also intended to provide all parties involved with valuable experience in the implementation of wind energy systems, to ensure that future projects can be undertaken efficiently and cost-effectively.

* Senior Engineer, Small Customer Pricing, Eskom National Marketing, P O Box 1091, Johannesburg 2000, South Africa

** Department of Geographical and Environmental Sciences, University of Natal, King George V Avenue, Durban 4001, South Africa

*** Deputy Director: Energy for Development, Energy Branch, Department of Mineral and Energy Affairs, Private Bag X03, Lynnwood Ridge 0040, South Africa

**** Senior Energy Specialist, Energy Branch, Department of Mineral and Energy Affairs, Private Bag X03, Lynnwood Ridge 0040, South Africa

***** In: *Journal of Energy R&D in Southern Africa,* Vol.3 No.2, May 1992, pp.13-17

LOAD DETERMINATION

At present lighting is by paraffin lamp and the only electrical load is a two-way radio powered by battery. Water is pumped by hand. As no previous data were available on electricity usage in the area, the potential future electricity needs of the school had to be estimated. As the benefits of electricity become increasingly apparent, the variety of appliances and educational aids is expected to increase. Cost of appliances and equipment, and the affordability thereof will also have a bearing on the growth of electricity usage. The initial electrical loads would be:

- lighting
- refrigerating
- water pumping
- communications.

Lighting

Forty-watt fluorescent luminaires are to be used for all indoor lighting.

ROOM	NUMBER
Outside	3
Office	1
Staff	2
Hall	3
Classrooms	5 x 2

There are thus 19 lights. It is assumed that they will be used for an average of 3 hours per day. This gives an average daily energy consumption of 2,28 kWh.

Refrigerating

An average-sized fridge draws some 200 W and has a 40% duty cycle. The start-up load varies (up to 1 kW) and influences the sizing of the inverter. The duty cycle varies with respect to manufacturer and ambient temperature. A continuous consumption of 80 W is assumed for simplicity. The average daily consumption is 1,92 kWh.

Water pumping

Electrical pumps in the 300 W to 500 W region are being considered. If the pump is the first stage of load dumping, as is envisaged, the energy requirements are not critical.

Communications

The small two-way radio, which is currently powered by batteries, will be connected to the wind energy system.

An average total daily load of 4,2 kWh is anticipated. This could be reduced by careful management of light usage, and by the purchase of a relatively energy-efficient fridge. Future loads, such as TV, video recorder and possibly a battery charging facility have been considered. Figure 1 shows the forecast diurnal load profile.

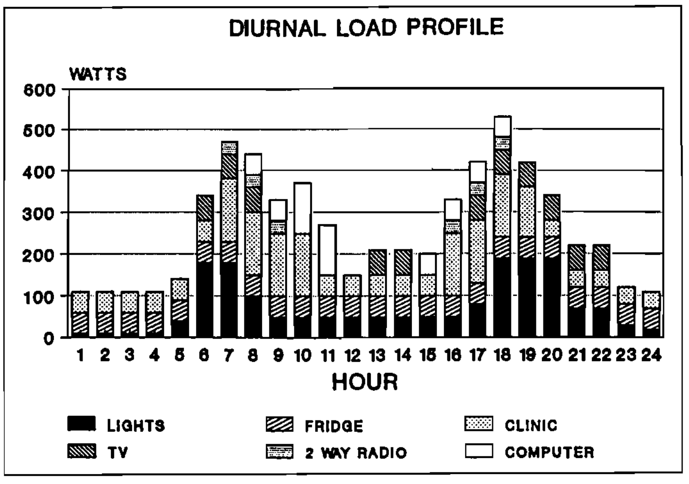

Figure 1: Diurnal load profile

POWER SUPPLY SYSTEM

Referring to the system block diagram shown in Figure 3, the components of the power supply system include:

- wind turbine
- tower and foundations
- lightning protection
- cabling
- battery
- controller and load dump
- inverter
- distribution board and wiring.

There is a selection of energy-efficient DC appliances for use in remote area power supply (RAPS) systems ranging from lights, TV's and videos to fridges. These appliances are specialised items, however, with parts and spares available only in the major centres. Their low level of production tends to make them expensive. The remoteness of Mabibi led appliances to be chosen that would have spares available close by, and that would be inherently reliable. For these reasons standard 220V AC appliances are recommended, with replacement parts available off the shelf from hardware stores or supermarkets. The efficiency of the total system suffers somewhat, but adequate wind energy appears to be available to overcome this.

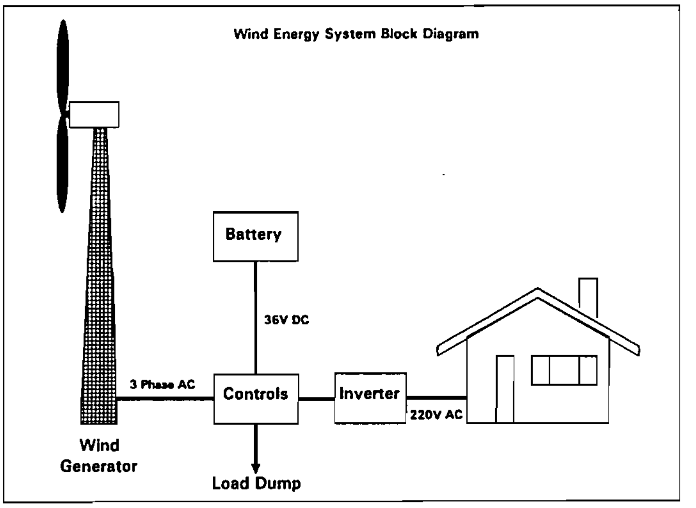

Figure 3: Wind energy system block diagram

Wind turbine

The turbine is a 5 kW Whirlwind turbine model WG5x5-LV. This is an upwind horizontal axis, permanent magnet device with spruce blades. The specifications are as follows:

rated power	5 kW
peak power	7 kW
RPM at rated power	420
typical tip speed ratio	8:1
rated wind speed	12 m/s
cut-in wind speed	2-3 m/s
furling wind speed	18 m/s
survival wind speed	55 m/s
blade diameter	5 m
length of generator	790 mm
width of generator	300 mm
blade tip/tower centre	680 mm
min. tip/tower clearance	280 mm
tower top weight	98 kg

The power output curve of the turbine is shown in Figure 2.

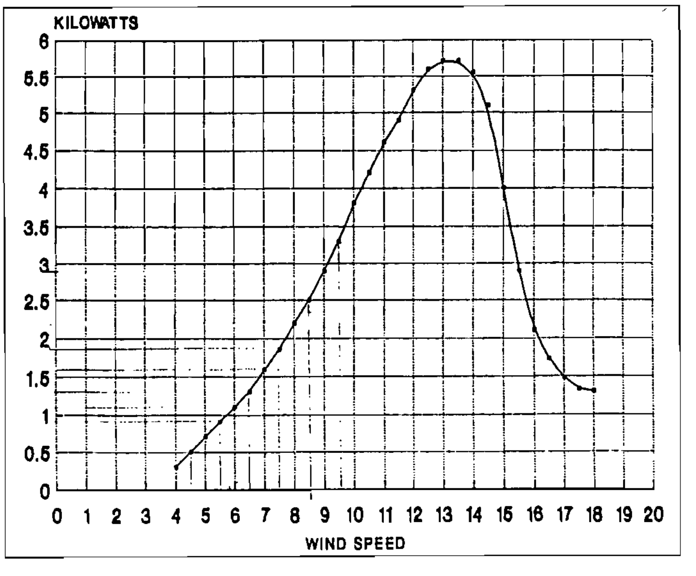

Figure 2: Wind turbine power output

Tower and foundations

Based on wind data analysed by Natal University, the optimum height of the tower was found to be 15 m. No significant increase in available power would be gained by moving up to 20 m. A simple cylindrical galvanised steel tower was chosen with a hinged base to allow for easy lowering and raising of the tower. An important design criterion was the blade tip clearance, which determined the maximum diameter of the tower. The structure is secured with three stainless steel guy wires. The base and guy wires are all attached to concrete foundations, each one cubic metre in size.

The siting of the tower was also critical in the overall system design. Trade-offs had to be made between gains in siting the turbine far away from obstacles, such as, trees or the school buildings, losses due to long cable lengths, and safety of the schoolchildren with respect to the possibility of the tower collapsing or blades being thrown in extreme wind conditions. A compromise between these options resulted in the tower being located as shown in Figure 4. It was felt that this position of the turbine would offer a compromise between having a reasonable distance from the tower to the school from a cabling and power loss point of view, and degradation of performance due to tree and building obstacles. Danger to the community in the advent of the turbine throwing a blade would be no greater in this location than any other, as the playing-fields are generally behind the school and passing traffic would be as great here as in any of the other suitable locations.

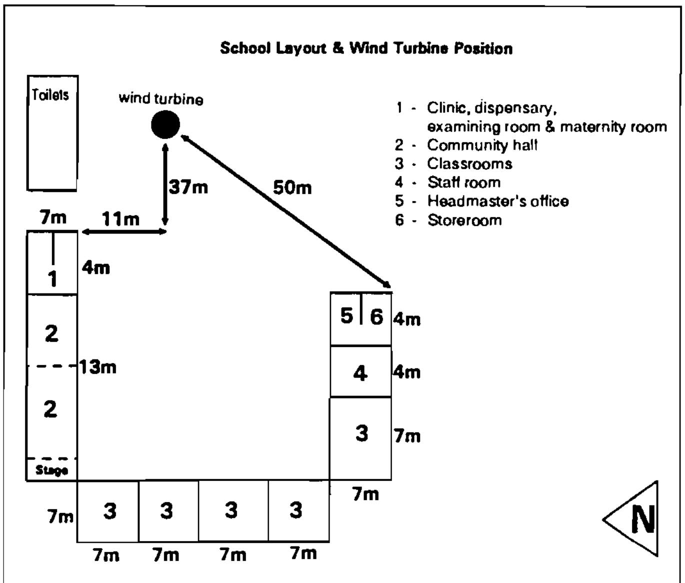

Figure 4: School layout and wind turbine position

Lightning protection

The expected relatively high frequency of lightning strikes in the area meant that one could not afford to install the wind energy system without adequate lightning protection. Soil surveys showed a soil resistivity of 378 ohm-metres. These tests were undertaken under dry conditions, which is the worst case. On this basis an earth mat was designed and installed, together with a stand-alone lightning conductor near the turbine tower. The electrical equipment in the school itself was also securely earthed to provide adequate protection to the total system.

Cabling

The wind turbine output takes the form of a three-phase AC voltage of variable voltage and frequency. The output is a floating neutral star configuration. Some 50 m of cabling was required from the turbine to the corner of the school building where the electrical equipment would be housed. This excludes the additional 15 m from the turbine to the base of the tower. Three-phase insulated screened cable was used for this purpose, with sufficient size to minimise the voltage drop in the cable at maximum load.

Battery

As wind is by its very nature variable and unpredictable, some form of energy storage would be required to derive maximum benefit from windy periods, and to have electricity available during periods of little or no wind. Standard tubular vented lead-acid batteries were chosen for this application, as batteries of this type have been used extensively in RAPS systems in the past, with much success.

The battery bank consists of 18 cells, each with a nominal voltage of 2 V and a capacity of 400 ampere hours (Ah). The cells would be connected in series, giving a 36 V, 400 Ah system. The battery bank would be mounted on a varnished wooden stand and located in the store-room behind the headmaster's office. Adequate ventilation in the store-room would be needed, as the cells give off hydrogen gas during use. It is expected that the cells would need to be topped up only once or twice per year.

The batteries would be filled and initially charged prior to transport to site, and care would need to be taken during transportation to avoid spillage of electrolyte.

Controller and load dump

The wind turbine generates a three-phase sinusoidal voltage of varying voltage and frequency depending on wind speed. This voltage would need to be rectified and controlled in order to produce a stable DC voltage suitable for charging the 36 V battery bank. The controller was designed specifically for this project. It is rated according to the maximum output of the turbine, namely 5 kW, and provides adequate overvoltage protection to ensure that the voltage applied to the battery bank does not exceed 2,3 to 2,4 V per cell. The controller also has the facility to allow load to be dumped to heating elements once the battery bank is fully charged and the turbine continues to generate. Load should always be connected to the turbine to prevent the machine from over-spinning and causing damage.

An important design criterion for the controller was that the technology should be rugged and reliable, as any equipment requiring repair would have to be sent to Empangeni, causing possible lengthy disruptions to the electricity supply. The controller is housed in the store-room behind the headmaster's office together with the battery bank.

Inverter

The DC voltage of the batteries needs to be converted to 220V AC to power standard domestic appliances. The inverter chosen to perform this task is rated at 5 kW, and produces a quasi-square wave AC voltage. The technology is proven, and quasi-square wave inverters have higher efficiencies than pure sine wave systems, without adversely affecting the appliances.

Distribution board and wiring

The output of the inverter is then fed into a distribution board, allowing for earth leakage protection and a number of circuit-breakers for different sections of the school. The distribution board also allows for additional power inputs, such as, photovoltaics or a diesel generator. The wiring of the school was undertaken using conventional surface-mounted cable, with plug points in each room.

APPLIANCES

Standard 40 W four-foot fluorescent lights have been used for the rooms and classes. These are mounted on the overhead rafters so as to provide maximum overall illumination. The reflective material lining of the roof will tend to enhance the lighting level in the rooms as well. Each light contains its own switch so that no lights are left on unnecessarily. Three 40 W outside bulkhead lights would be installed, one on each of the wings of the school.

A communal fridge could be placed in the staffroom. A chest-type fridge with good insulation will reduce the energy needed to run this appliance.

The existing two-way radio could simply be run off the battery bank with no further modifications. The system allows for a TV set and video recorder to be installed, perhaps in the hall, at a later stage.

A pump could be used as a load dump during periods of excess generation. Water could be pumped to the existing reservoirs, or be used for irrigation purposes. At present the existing hand pump is kept and used as normal.

ERECTION AND COMMISSIONING

The remoteness of the Mabibi school and the poor access via deeply rutted sand roads through the Manzengwenya forest plantations meant that each item of equipment had to be in an easily transportable form. The wind turbine and control equipment are relatively compact, but the turbine tower and lightning conductor proved more difficult to transport. Eskom's Empangeni District provided the transport, cranes and labour for the installation of the system.

OPERATIONAL EXPERIENCE

The closest Eskom depot to Mabibi is some 300 km away, which means that service calls become rather costly. Effort has been spent on familiarising the school's headmaster with the basic operation of the system so that basic problems can be dealt with locally. The radio at the school is linked to the nearby hospital and therefore direct communication with the school proves difficult on occasions.

FUTURE DEVELOPMENTS

Wind resource data as well as electrical parameters of the system will be gathered and analysed for at least one year in order to verify the design assumptions and develop accurate load profiles of the school. The introduction of new appliances and equipment will be monitored as well.

An important aspect of the project is the effect of electricity supply to the school on the local community. There is still a perception that electricity will be supplied to each household. This is beyond the capability of the present system and impractical considering the distances between houses. The only solution being considered at this stage is the introduction of a battery charging service at the school to make 12 V battery-powered appliances more accessible to the community.

CONCLUSIONS

The Mabibi wind energy project has provided valuable experience in the design and implementation of stand-alone power supplies in remote areas. Future projects will need to ensure that accessibility and transport problems are addressed, that good communications with the local community are established to ensure that ownership of the system is accepted and that perceptions are addressed, and that efforts are made to train someone locally to deal with the basic system operations.

ACKNOWLEDGEMENTS

Funding of the project stems predominantly from the Energy Branch of the Department of Mineral and Energy Affairs, Eskom, and equipment donations from a number of private companies. The authors acknowledge, with thanks, the contributions made by their organisations and members of the following groups towards the success of this project:

- Eskom's Technology Research and Investigations
- Eskom's Empangeni District and Depot
- Rotary Club of Durban Musgrave
- Headmaster and staff of the Mabibi Primary School
- Mabibi community

A DEMONSTRATION CENTRE FOR RENEWABLE ENERGY

*W N CAWOOD

Interest in renewable energies has undergone periodic resurgences, brought about by world events and environmental pressures. However, over the past few years this industry has shown substantial and sustained growth, as renewable energy systems frequently meet the customer's energy needs in a more economical and environmentally friendly manner than conventional energy sources. Provision of a centre where these technologies can be demonstrated and evaluated is of vital importance in order to promote their correct application. This paper describes the development of such a centre which will demonstrate those renewable energy technologies expected to find greatest application in the South African context. The systems to be demonstrated will be installed in the same manner as they would typically operate, so that the viewer can assess the suitability of the technology in relation to his requirements and particular set of circumstances. The centre will also provide facilities for testing and developing renewable energy equipment, and for training prospective users.

KEYWORDS: renewable energy; demonstration centre

INTRODUCTION

It is estimated that only some 16% of rural communities in South Africa are currently connected to the national electricity grid [1]. Farmers not already connected to the grid often find such connections prohibitively expensive, especially when electricity would be needed only for a small workshop and to meet their own domestic energy needs and those of their labourers. Renewable energies provide an immediate and often the most cost-effective means of supplying these electrical and water-heating needs. The cost-effectiveness of renewable energy power supply (REPS) systems is clearly illustrated by the recent Eskom contract for R1 million[2] to provide electricity to 14 farms in the Molopo area of the Northern Cape, which could not be economically supplied from the grid, even with significant State support.

It is a sobering fact that out of every four dwellings constructed in South Africa today, three are squatter shacks. There are significant practical obstacles which preclude grid connections to these shacks. However, sufficient electricity to power two lights for three hours per night could be provided by means of solar cells (PV cells) for less than half the capital cost of a grid connection, and with no subsequent operating costs.

The complete picture is that only 37% of South Africans have access to grid electricity, or put differently, approximately 22,5 million do not have access to grid electricity [1].

Besides these two major applications, REPS systems are used in a number of other situations, including remote schools and clinics, telephone microwave repeater stations, telephone exchanges, highway emergency phones, rural pumps for human and animal water supplies, and so on - the list is almost endless.

It is clear, therefore, that REPS systems have the immediate potential for dramatic improvements in the quality of life of a significant percentage of the South African population. Their expanded use could also have far-reaching global implications in providing a sustainable and environmentally benign energy source for the future of mankind.

Two questions immediately come to mind: (1) what are REPS systems, and (2) where could one go to see them in operation and obtain unbiased information on their benefits and limitations?

(1) There are a bewildering number of different types of REPS systems, but the following are believed to be the most important ones in the above context:
   - (a) **sunlight,** used directly either for heating or for providing electricity by means of solar cells,
   - (b) **wind energy**, used to drive wind turbines to generate electricity (known as wind chargers in pre-war days) or windmills to pump water,
   - (c) **water** or hydro power, used to power turbines to drive alternators which generate electricity,
   - (d) **biomass**, as a direct combustible fuel or in the form of gas from biogas digesters, or wood-gas producers.

(2) Unfortunately, there is no such single renewable energy centre at present, and one often has to travel long distances to see real installations. There is, therefore, an urgent need for a centre to be established where representatives from government, non-government organisations (NGO's), farmers' organizations, educational institutions, and the public at large can examine renewable energy equipment in operation. The prime purpose of the project reported on here is to meet this need.

It is also envisaged that such a centre would provide a site where renewable energy equipment could be developed and tested, in liaison with other interested parties such as universities, technikons, and industrial entrepreneurs.

Education and training would also form part of the function of this centre. A typical example is the planned use of the centre by Eskom's Agricultural Marketing arm, Agrelec, for the training of their sales engineers in the opportunities that are opening up in this exciting new field.

Such a Renewable Energy Demonstration Centre is now being developed and is scheduled to be opened to the public by November 1992.

The Centre occupies a 0,4 ha site at the premises of the Chief Directorate of Agricultural Engineering and Water Supply in Silverton, approximately 5 minutes from the Pretoria Eastern Bypass/Witbank freeway interchange.

* Deputy Director: Energy for Development, Energy Branch, Department of Mineral and Energy Affairs, Private Bag X03, Lynnwood Ridge 0040, South Africa

SCOPE

It is planned to demonstrate the following renewable energy technologies at the Centre:

- photovoltaics (lighting, pumping, fencing, etc.)
- solar thermal (water-heating, crop-drying, etc.)
- passive or bio-climatic building design
- biomass, biogas and producer gas
- micro-hydro systems
- wind energy.

The Centre is divided into 10 areas where different renewable energy technologies will be displayed. These are described below as follows, with their respective locations indicated on the site plan:

The gas supply will be used for the stove, a refrigerator/freezer in the kitchen, and space-heaters in the office and conference hall.

Area 2: Solar water-heater display area

This area will include integral, close-coupled, split collector storage, and industrial solar water-heating systems. Hot water from this area will be supplied to the kitchen and conference hall, and may at a later date also be piped to the greenhouse and biogas areas.

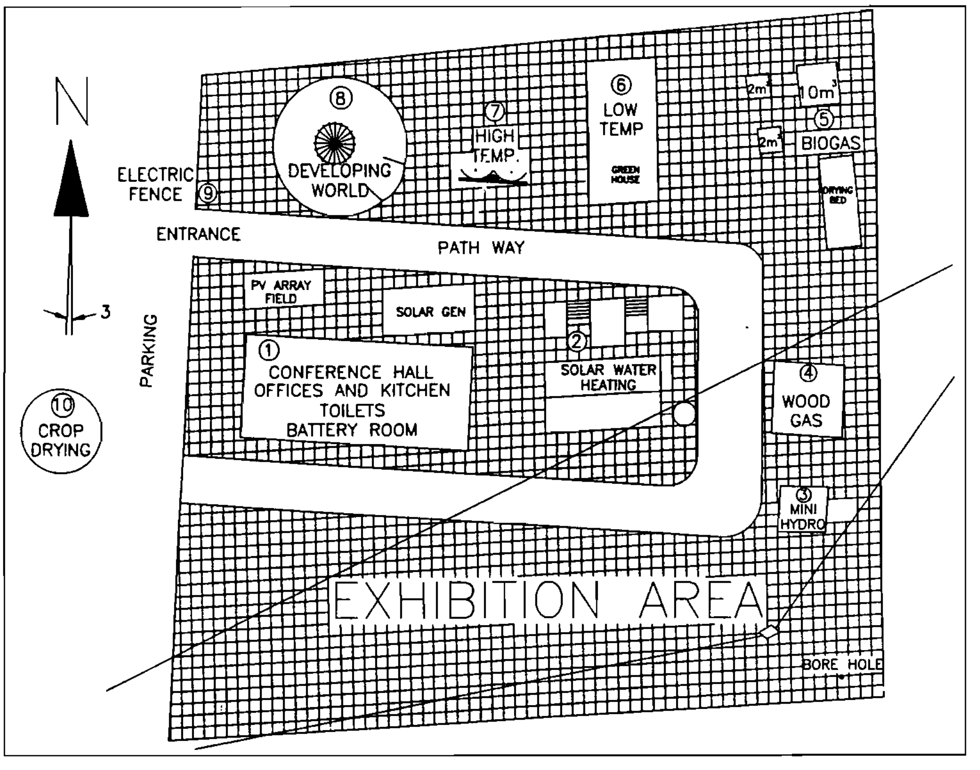

Figure 1: Site plan

Area 1: Reception office

On arrival, visitors would be guided to the reception office where they would be informed as to the aims and objectives of the Centre and the technologies displayed. They would also receive hand-outs explaining the technology at each of the demonstration sites.

Area 1: First World technology area

The First World technology area is adjacent to the Reception office. Energy for this site is provided from four sources, namely, electricity from the PV array field and the 2,5 kW Solar Gen concentrating PV systems, and gas from the wood-gasifier and biogas digesters.

The DC electricity supplied from the solar cells is stored in batteries located in the battery room. An inverter is used to convert the DC electricity to 220V AC power which is used to power appliances in the kitchen, office and conference hall. These include a microwave oven, fridge, freezer and other kitchen appliances in the kitchen. Other appliances receiving PV-generated power are the computer, photostat and fax machines in the office, and the TV monitor, video recorder, overhead projector and fans in the conference hall. All lights in the Centre will be powered by PV cells.

Area 3: Micro-hydro solar pumping and power generation area

Pumps: Various pumps, including hand-powered, PV-driven screw and centrifugal pumps, will be operated at this site.

Power generation: A cross-flow turbine and the centrifugal and screw pumps (used in reverse) will demonstrate the principles involved to generate electricity using the power of moving water.

Area 4: Producer of wood-gas

Wood-gas is formed from the partial combustion of wood in the presence of controlled amounts of air. The gas is of relatively low calorific value but is clean-burning. This technology is largely unknown in South Africa, but could have significant potential either for direct thermal applications (heating or refrigeration), for powering stationary stand-alone internal combustion engines, or coupled to a generator. All three technologies will be demonstrated at the site.

Area 5: Biogas digesters

The anaerobic (without air) decomposition of organic animal waste (manure) to provide a mixture of methane gas (60%) and carbon dioxide (40%), and an excellent odourless fertilizer could change a costly problem into a lucrative opportunity. Hundreds of thousands of these digesters are in daily use in China and India, but for various reasons this technology has not been employed to any meaningful extent in South Africa. Three different types of digesters will be scientifically tested and demonstrated at Area 5 so that farmers and engineers can apply the technology in their particular situations.

Area 6: Low-temperature heating applications

Heating of greenhouses is expensive using current state-of-the-art technology, despite the relatively mild and short winter heating season in most of South Africa. Accordingly, considerable ingenuity and skill need to be employed to develop a relatively low-cost solution that will be cost-effective in this country's situation. This display is scheduled for development during 1993/4.

Area 7: High-temperature heating applications

The availability of high-temperature and high-pressure steam has numerous applications in the farming and industrial environment. Two parabolic troughs, accompanying support structure, and tracking mechanisms are being developed for this site.

Area 8: Developing World area

The latest trend in the developed world is to displace fossil fuels and nuclear energy with REPS systems. This provides the developing world with the opportunity to supplement the direct use of renewable energy, mainly fuelwood, with indirect uses, such as PV, wherever this is advantageous. The availability of small supplies of electricity may help in expediting an improved quality of life for developing communities.

All appropriate REPS systems will be demonstrated at this site. These include PV for domestic and street lighting, television, solar cookers and ovens, smokeless stoves, and high-efficiency, low-cost gas and paraffin stoves.

Area 9: Solar electric fencing

Solar electric fencing can be less expensive and more effective than conventional fencing in many situations. Various techniques and systems will be demonstrated at this site.

Area 10: Solar crop-drying

Most crops are still dried directly by sunshine and generally while the crop is still in the field. If one disregards crop and nutrient losses, lack of moisture and quality control, then field-drying is without rival, cost-wise. However, the sun's energy can be used indirectly to heat air and thereby provide all the benefits of industrial dryers without the attendant high operating costs. A solar barn-dryer is planned for 1993/4.

FUNDING

This project is a joint undertaking by the Chief Directorate Agricultural Engineering and Water Supply (CDAEWS), the Energy Branch of the Department of Mineral and Energy Affairs (EB-DMEA), and corporate members of the Solar Energy Society of Southern Africa (SESSA). Contributions from each organisation are as follows:

(i) The EB-DMEA provided funds for the initial development of the site and its associated equipment.

(ii) The CDAEWS' contribution will be by way of providing the site and appropriate manpower to erect, manage and man the Centre. They are also including equipment which they already have on hand from previous projects.

(iii) SESSA is assisting substantially with the supply of solar equipment to be installed at the site. Their expertise will also be employed in the application and installation of the equipment.

MANAGEMENT

A steering committee, comprising representatives from the CDAEWS, the SESSA and the EB-DMEA, has been set up to guide the long-term development of the Centre.

The day-to-day running of the Centre, including maintenance and security, is the responsibility of the CDAEWS.

CONCLUSION

This Renewable Energy Demonstration Centre will play a significant role in promoting the appropriate use and development of renewable energy technology in Southern Africa. In so doing, the well-being of many people could be enhanced.

REFERENCES

(1) GILL P K (1992). Population growth and housing as a critical success factor for electrification. Electrification for Development Research Forum, Midrand.

(2) VAN NIEKERK B (1992). Remote areas to be lit up. *Engineering News*, 12 June.

DETAILS OF AUTHORS

CAWOOD W

BSc (Agric. Eng.)(Pretoria), MSc (Agric. Eng.)(Nebraska), Honours (Bus. Admin.)(Potch.)
Deputy Director: Energy for Development, Energy Branch, Department of Mineral and Energy Affairs, Private Bag X03, Lynnwood Ridge 0040, South Africa
Tel.: (012) 348 9564/5/6, Fax.: (012) 348 9676

Mr Cawood completed a BSc degree in Agricultural Engineering at the University of Pretoria and his MSc at the University of Nebraska, U.S.A. He also has an Honours degree in Business Administration from the University of Potchefstroom.
His experience in industry varies from Resident Engineer, Ford Motor Company, to Chief Engineer at National Spring Manufacturers. On the research side, he was Laboratory Test Engineer at Massey Ferguson, and Head of the Solar Energy Group at the National Building Research Institute of the CSIR from 1973 to 1980. He then returned to industry and was Managing Director of the Solar Development Co. until he joined the National Energy Council in March 1991. He is currently Deputy Director: Energy for Development at the Energy Branch of the Department of Mineral and Energy Affairs.

DE LA HARPE E R

Pr Eng, BSc (Eng)(Agric.)(Natal) MSc (Eng)(Natal), M(SA)IAE
Research Engineer, Department of Agricultural Engineering, University of Natal, P O Box 375, Pietermaritzburg 3200, South Africa
Tel.: (0331)61313, Fax.: (0331)955490.

Eric de la Harpe graduated with BSc (Eng) (Agric.) and MSc (Eng) from the University of Natal. He worked for two years at John Deere(SA) as a Product Engineer and then returned to the University of Natal to take up his present position. He has been involved in a number of projects requiring engine performance and combustion evaluations. In addition he has developed expertise in the area of engine control. He recently registered for his PhD, the topic of which is the optimisation of engine performance and reduction in emissions.

DIAB R D

MSc (Natal), UED (Natal), PhD (Virginia)
Department of Geographical and Environmental Sciences, University of Natal, King George V Avenue, Durban 4001, South Africa
Tel.: (031) 816 2416, Fax.: (031) 816 1391

Professor Roseanne Diab has lectured in the Department of Geographical and Environmental Sciences since 1974. She was promoted to Senior Lecturer in 1984, Associate Professor in 1989, and has recently been appointed a full Professor. She is currently Head of Department. Research interests include wind energy, air pollution, metereology and ozone.

DILMITIS M P

BSc (Eng)(Agric.)(Natal), MSc (Eng)(Natal)
Graduate Assistant, Department of Agricultural Engineering, University of Natal, P O Box 375, Pietermaritzburg 3200, South Africa
Tel.: (0331) 955487, Fax.: (0331) 955490.

Moose Dilmitis completed BSc Eng (Agric) and MSc Eng degrees at the University of Natal. He has subsequently returned to Zimbabwe to work on the family farm.

HANSEN A C

Pr Eng, BSc (Eng)(Mech)(Natal), MSc (Eng)(Natal), PhD (Natal), M(SA)IMechE, F(SA)IAE, M(SA)InstE
Senior Lecturer, Department of Agricultural Engineering, University of Natal, P O Box 375, Pietermaritzburg 3200, South Africa
Tel.: (0331) 955484, Fax.: (0331) 955490.

Al Hansen graduated with BSc Eng (Mech), MSc Eng and PhD from the University of Natal. For his PhD he developed a heat transfer and two-zone combustion model for use with diesel engines. After joining the University of Natal initially as a Research Engineer, he was appointed a lecturer and then promoted to senior lecturer. His research commitments lie in the fields of diesel engine combustion, performance and durability, machine vision, and modelling the energy requirements of confined livestock housing.

KIDGELL H U

BA (Stellenbosch), BA (Hons.) (Development Administration) (Stellenbosch)
Senior Energy Specialist, Energy Branch, Department of Mineral and Energy Affairs, Private Bag X03, Lynnwood Ridge 0040, South Africa
Tel.: (012) 348 9564/5/6, Fax.: (012) 348 9676

Ulrike Kidgell is a Senior Energy Specialist at the Energy Branch (formerly National Energy Council) of the Department of Mineral and Energy Affairs involved primarily in the management of research projects which focus on socio-economic issues. She holds the degrees of BA and BA (Hons.) from the University of Stellenbosch, and has also completed the National Diploma in Personnel Management at the Pretoria Technikon.
Prior to joining the NEC, she lectured at the Department of Development Administration & African Politics at UNISA, and worked as a liaison officer at the National Programme for Energy Research of the Foundation for Research Development, CSIR.

LIGOFF D

Pr Eng, BSc (Elec. Eng.)(Wits)
Senior Engineer, Small Customer Pricing, Eskom National Marketing, P O Box 1091, Johannesburg 2000, South Africa
Tel.: (011) 800 5014, Fax.: (011) 800 5384

David Ligoff joined Eskom in 1984 and has been involved in remote area power supplies (RAPS) and numerous Eskom RAPS projects providing electricity to customers in remote, sparsely populated areas since 1987. After spending some time in Eskom's Engineering Group, he moved to the Marketing Group in 1989, where he was involved in sales training and sales system development. He is currently involved in small customer pricing and tariffs.

VILJOEN R P

BSc (Town and Regional Planning)(Wits), MSc (Applied Science) (UCT)
Deputy Director: Energy for Development, Energy Branch, Department of Mineral and Energy Affairs, Private Bag X03, Lynnwood Ridge 0040, South Africa
Tel.: (012) 348 9564/5/6, Fax.: (012) 348 9676

Reinhold Viljoen is a Deputy Director at the Energy Branch (formerly National Energy Council) of the Department of Mineral and Energy Affairs. He is primarily involved in the formulation of policy and management of projects. He matriculated at St Albans College, Pretoria, and holds the degrees of BSc (Town and Regional Planning) from the University of the Witwatersrand and MSc (Applied Science) from the University of Cape Town. Prior to joining the National Energy Council he was involved in development consultancy and land use planning in South Africa and abroad.

FORTHCOMING ENERGY AND ENERGY-RELATED CONFERENCES: 1992/1993

1992

AUGUST 1992

17-19 WATER WEEK CONFERENCE Pretoria, South Africa
Enquiries (General): The Secretariat, Water Week Conference, P O Box 36815, Menlo Park 0102, South Africa
Tel./Fax.: (012) 47 3398
Enquiries (Technical): Mr H Maaren, Water Research Commission, P O Box 824, Pretoria 0001, South Africa
Tel.: (012) 330 0340, Fax.: (012) 70 5925

SEPTEMBER 1992

9-11 FRIGAIR '92 Cape Town
Enquiries: Frigair '92, P O Box 36505, Chempet 7442, South Africa

14-18 EARTHLIFE AFRICA INTERNATIONAL ENVIRONMENT CONFERENCE : WHAT IT MEANS TO BE GREEN Pietermaritzburg, South Africa
Enquiries: David Hallowes, 32 Dalton Avenue, Bellair 4094, South Africa
Tel.: (031) 465 4689, Fax.: (031) 465 8614

15-17 TRIBOLOGY '92 Pretoria, South Africa
Enquiries: The Conference Co-ordinator: Mrs Toy Bester, LGI Short Courses, P O Box 30536, Sunnyside 0132, South Africa

18 2ND SOUTH AFRICAN CONFERENCE ON INDOOR ENVIRONMENTAL QUALITY Midrand, South Africa
Enquiries: Conference Planners, Attn.: Cilla Taylor & Ammie Wissing, P O Box 82, Irene 1675, South Africa
Tel.: (012) 63 1681, Fax.: (012) 63 1680

OCTOBER 1992

14-15 NINTH ANNUAL CONFERENCE ON ATMOSPHERIC SCIENCES Pretoria, South Africa
Enquiries: Chairman of the Organizing Committee, Dr L du Pisani, S A Society for Atmospheric Sciences, c/o S A Weather Bureau, Private Bag X097, Pretoria 0001, South Africa
Tel.: (012) 290 2932, Fax. (012) 290 2170

NOVEMBER 1992

3-5 WASTECON '92: WASTE MANAGEMENT IN A CHANGING SOCIETY Johannesburg, South Africa
Enquiries: Professional Conference Services, Attn.: Miss Una Wium, P O Box 95557, Waterkloof 0145, South Africa
Tel. & Fax.: (012) 46 5453

10-11 NATIONAL ASSOCIATION FOR CLEAN AIR NATIONAL CONFERENCE Vereeniging, South Africa
Enquiries: The Conference Chairman (Professional Services), P O Box 4187, Vanderbijlpark 1900, South Africa
Tel.: (016) 813 165, Fax.: (016) 817 473
Theme: Responsible wealth creation

1993

MAY 1993

31-1/6 ITEC - 93 : FIRST INTERNATIONAL THERMAL ENERGY CONGRESS Marrakesh, Morocco
Enquiries: Prof. A Mir, Cadi Ayyad University, Faculty of Science I, Bd Prince Moulay Abdellah, BP S-15 Marrakesh, Morocco

OCTOBER 1993

11-12 SUSTAINABLE DEVELOPMENT IN A CHANGING SOCIETY : CHALLENGES FOR SOUTHERN AFRICA Pretoria, South Africa
Enquiries: Mrs Louise Botten, SDSA Conference Secretariat, Foundation for Research Development, P O Box 2600, Pretoria 0001, South Africa
Tel.: (012) 841 4429, Telex: 3-21356 FRD SA,
Fax.: (012) 841 3791

RECENT ENERGY PUBLICATIONS

BOTHA W J *et al.*

Geophysical techniques in coal exploration and exploitation. National Energy Council, February 1992, 42p.

The objectives of the study were briefly to, (i) identify the geological problems associated with the various coal fields in South Africa, and to translate these into geophysical targets in terms of geometry and physical parameters; (ii) identify appropriate geophysical techniques; and (iii) evaluate these in terms of their applicability to South Africa's coal fields.

From the physical characteristics of the geological environment of South Africa's coal fields, it was concluded that only the following two surface geophysical techniques had possible applications, namely, time domain electromagnetic (TDEM), and high resolution seismic reflection. The literature search and computer modelling both found that the surface seismic method could be applied in the South African coal environment.

*BORCHERS M L and GEERDTS P C

Computer simulation of stand-alone photovoltaic systems.
Engineering Research, April 1992, 181p.
Report No. GER 012
R49,50 (incl. VAT)

This report describes a computer program, PVPro, which has been developed to simulate accurately the performance of stand-alone photovoltaic systems with battery storage on an hourly basis for one simulated year. The program incorporates models to simulate the environmental conditions of the system and the energy flows within the system. The program has been developed as a precision simulation tool, incorporating loss of power probability (LOPP), for the theoretical analysis of the performance of photovoltaic systems, the validation of analytical sizing techniques, the fine-tuning of the sizing process, or the estimation of the long-term performance of monitored systems.

*CLARKE R H and BLOMKAMP Y

South African engines and fuels research: 1979-1991.
Engineering Research, May 1992, 220p.
Report No. GER 013
R55,00 (incl. VAT)

The main objective of this project was to compile a report summarising the work carried out during the 1979-1991 period in the field of transport energy and the interaction of fuels and engines, and to provide a comprehensive document which would be available to the oil industry, motor industry and other interested parties. By grouping the research into various categories, an assessment was made of how effective the research had been, thereby providing a basis for assessing what still needs to done. This would assist in reducing duplication of ongoing research by similar organisations.

A bibliographic database of the research was set up using the INMAGIC software, thereby providing a full bibliographic description of all documentation received, and allowing on-line searching of the database for specific information. Author and Keyword indexes were also developed.

GLASSER D

The spontaneous combustion of coal. National Energy Council, April 1992, 114p.
NEC Proj. Ref. No. ESD 10

The work covered in this report took place over a 10-year period. The main aims and objectives were to, (i) derive a fundamental understanding of the important processes that occur during the spontaneous combustion of coal, (ii) use this fundamental understanding to devise simple theoretical methods of predicting whether or not spontaneous combustion would occur in practice, (iii) devise relatively simple laboratory techniques to measure the important parameters required to utilise the theoretical predictions, (iv) transfer this technology to the industry, so that coal and its waste products could be mined, transported, stockpiled and disposed of with minimum risk of spontaneous combustion.

*GOSNELL R J

Demonstration and evaluation of a photovoltaic powered water pump. Energy Research Institute, April 1992, 408p.
ERI Report GEN 150
R77,00 (incl. VAT)

This project attempted to examine whether photovoltaic (PV) pumps are viable and appropriate in South Africa. A case-study consisting of a community vegetable garden in a rural ward of KwaZulu was undertaken. The three main facets of the project were: (i) a technical evaluation, which examines the efficiency of the system and each of its components, their interaction, and the suitability of alternative components, (ii) an economic evaluation, which compares the long-term costs of PV water pumps with those of diesel, petrol and electric pumps, (iii) a social evaluation, which examines the effect of the pump on the host community, the problems encountered, possible solutions, and the attitudes of the host community to the pump and garden.

MAY J *et al.*

An in-depth evaluation of fuel use by rural women: The Ingwavuma district – KwaZulu. National Energy Council, April 1992, 76p.
NEC Proj. Ref. No. NE 14/6/27

The objective of this research project was to provide an in-depth investigation of the role played by fuel attainment and fuel consumption in the lives of rural women in remote areas of South Africa. The area covered included the foothills and plains of the Ingwavuma area of Maputaland. Aspects covered included the demographic, geographic, socio-economic, and wood use characteristics of the District. A detailed investigation was made of the daily energy usage of the households surveyed, their energy-using domestic activities, patterns of fuelwood usage, preferences and prejudices. Attitudes to fuel and fuelwood usage, and the transition to other forms of energy were examined.

*PURCELL C J DE V

Battery performance characteristics in stand-alone photovoltaic systems. Energy Research Institute, May 1992, 400p.
ERI Report GEN 151
R77,00 (incl. VAT)

This report investigated battery performance characterisation in stand-alone photovoltaic (PV) systems. The main objective was to determine accurate empirical data for locally available lead-acid batteries. The study included, (i) a review of battery performance regimes typical of PV systems, (ii) a literature review of lead-acid battery performance and reactions important to PV applications, battery-electrical models, battery life models, a review of specialist PV battery designs, and the interaction of battery and voltage regulator in PV systems, (iii) a review of testing and research literature and the design of experimental procedures, (iv) the design and construction of a specialised battery test-unit, (v) selection, testing and characterisation of five types of batteries which could be used in local applications.

ROSSOUW A M M and FABRICIUS M P

Motherwell energy survey: A socio-economic study of the energy consumption patterns of the community. National Energy Council, March 1992, 55p.
NEC Proj. Ref. No. NE 14/6/29

The study was undertaken to examine all energy sources used by those people living in the area to enable the sponsors of the project to evaluate the need for an energy information centre not biased towards a specific energy source. The main objectives of the study were to: (i) provide a broad background to the socio-economic characteristics of populations in the townships of Port Elizabeth, (ii) scientifically gather information on the general socio-economic characteristics, income and expenditure, residential characteristics, energy usage patterns, attitudes and perceptions towards traditional fuels and electricity, knowledge of the basic facts of electricity of the population of Motherwell, (iii) analyse the survey findings.

ROUSSEAU P G

An integrated design tool for naturally ventilated buildings. National Energy Council, April 1992, 101p.
NEC Proj. Ref. No. 186/89

The primary objective of the study was to produce a user-friendly and accessible design tool for naturally ventilated buildings. Such a tool should, (i) take into consideration all the important thermal properties of the building, (ii) calculate the natural ventilation flow rates through the building, (iii) take into account the interaction between the flow rates and thermal properties, (iv) be sufficiently accurate. The applicability of the new tool is illustrated through a number of case-studies. These indicate that considerable energy and cost-savings may be realised through efficient use of natural ventilation in buildings.

All these reports are Final Reports. The publications can be ordered from: The Librarian, Energy Branch: Department of Mineral and Energy Affairs, Private Bag X03, Lynnwood Ridge 0040, South Africa, unless otherwise indicated. Prices are available on request from the Energy Branch: Department of Mineral and Energy Affairs.

* These reports are also available from the Information Officer, Engineering Research (Pty) Ltd/Energy Research Institute, P O Box 33, Plumstead 7800, South Africa, at the prices indicated.

JOURNAL OF ENERGY R & D IN SOUTHERN AFRICA

INFORMATION FOR AUTHORS

Contributions to the *Journal of Energy R & D in Southern Africa* from those with specialist knowledge in the energy research field are welcomed.

1. All contributions should be submitted in English.
2. Only original work will be accepted and copyright in published papers will be vested in the publisher.
3. The suggested average length for articles and research notes is 3000 to 5000 words, and for book reviews 1200 to 1800 words.
4. The contribution and references should be typed double-spaced with a wide left-hand margin and single-sided using one of the available word processor packages listed at the end. The name and version of the word processor package used must be indicated on the floppy disk. Illustrations, photographs and diagrams should be submitted on separate sheets.
5. Tables should be numbered consecutively in Arabic numberals and given a suitable caption.
6. All graphs, diagrams and other drawings should be referred to as Figures. These should be numbered consecutively in Arabic numerals and placed on separate sheets at the end of the manuscript. Their position should be indicated in the text. All illustrations must have captions, which should be typed on a separate sheet. Graphs, diagrams etc should be printed with a laser printer, using the high quality option. If possible, all graphs should be produced with Harvard Graphics.
7. The format for references should follow that as for footnotes where a number indicates the reference, as shown below:
   Louw [(2)] states that . . .
   Full references for books and journals must appear at the end of the ariticle in numerical sequence. For references to books, all relevant information should be provided, that is author(s) surname and initial(s), full title (and subtitle, where applicable), publisher, place of publication, date of publication, and page reference. For periodical references, the author(s) surname and initial(s) must be provided, as well as the full title and subtitle (if applicable) of the article and the periodical, volume number, part, date, and page reference. Numbers identifying all references at the end of the contribution should be enclosed in brackets.
8. Standard International (SI) units must be used.
9. All mathematical expressions should be typewritten. Greek letters and other symbols not available on the typewriter should be carefully inserted in ink. A list of symbols marked for the use of the Editor, if not included in the body of the text, should accompany the contribution on a separate page. A nomenclature defining symbols must be included. Numbers identifying mathematical expressions should be enclosed in parentheses. All tables and mathematical expressions should be arranged in such a way that they fit into a single column when set in type. All table columns should have an explanatory heading. Equations that might extend beyond the width of one column should be rephrased to go on two or more lines within column width.
10. Line drawings (not photocopies) and accompanying lettering should be of a sufficient size to allow for reduction if necessary. Photographs of equipment must be glossy prints and should be used sparingly.
11. The body of the contribution should be preceded by an Abstract not exceeding 500 words, which should be a résumé of its essential contents, including the conclusions. Below the Abstract the maximum of four Keywords should be included which reflect the entries the author(s) would like to see in an index. The Keywords may consist of more than one word, but the entire concept should not be more than 30 characters long, including spaces.
12. No contribution or figures will be returned following publication unless requested by the author(s) at the time of its original submission.
13. In a covering letter, the author(s) must state that the contribution has not been published, is not being published or being considered for publication elsewhere, and will not be submitted for publication elsewhere unless rejected by the Editor of the *Journal of Energy R & D in Southern Africa* or withdrawn by the author(s).
14. Authors must supply the following personal information: surname, initials, address, qualifications, occupation and/or employment.
15. Authors whose contributions are accepted for publication will receive a free copy of the issue and 5 copies of their contribution.
16. Neither the Editor nor the Publisher accept responsibility for the opinions or viewpoints expressed, or for the correctness of facts and figures.
17. The Editor reserves the right to make editorial changes to all contributions.
18. All contributions and enquiries should be addressed to: Editor, Journal of Energy R & D in Southern Africa, Energy Research Institute, University of Cape Town, P.O. Box 33, Plumstead 7800, South Africa.

Contributions must be submitted on a 5¼ inch floppy disk and use must be made of one of the following word processor packages:

Multimate
Microsoft Word
PC-Write
PFS: Professional
PFS: Write
Wordperfect
Wordstar
XyWrite

The floppy disk must be adequately packed for postage.