our future through science

Distributed power generation using microturbines

S SZEWCZUK
CSIR Built Environment, PO Box 395, Pretoria, 0001, South Africa
Email: sszewczuk@csir.co.za – www.csir.co.za

INTRODUCTION

At present, the bulk of the world's electricity is generated in central power stations. This approach, one of 'economy of size', generates electricity in large power stations and delivers it to load centres via an extensive network of transmission and distribution lines. An alternative approach, that of distributed generation, which can be described as 'economy of mass production', generates electricity by many, smaller power stations located near the load centres. One such form of small power generation system is that based on microturbines. Microturbines, as the name implies, are much smaller versions of the conventional gas turbine. A major advantage of a microturbine is its ability to provide firm power, provided that it is kept supplied with fuel. The primary source of fuel is currently based on fossil fuels. However, gas turbines have the ability to accept various fuels, such as those based on liquid or gas. Being able to accept a diverse range of fuels, this opens possibilities of non-fossil based fuels to be used. Microturbines are small combustion turbines that produce between 25 kW and 500 kW of power. Microturbines were derived from turbocharger technologies found in large trucks or the turbines in aircraft auxiliary power units (APUs). Most microturbines are single-stage, radial flow devices with high rotating speeds of 90 000 to 120 000 revolutions per minute (rpm). This poster describes the research work undertaken by the CSIR that led to the demonstration of a microturbine to generate electrical power. The CSIR is currently undertaking research into the production of biogas from wet organic waste sources as an alternative renewable fuel for microturbines.

EXPERIMENTAL AND NUMERICAL INVESTIGATIONS

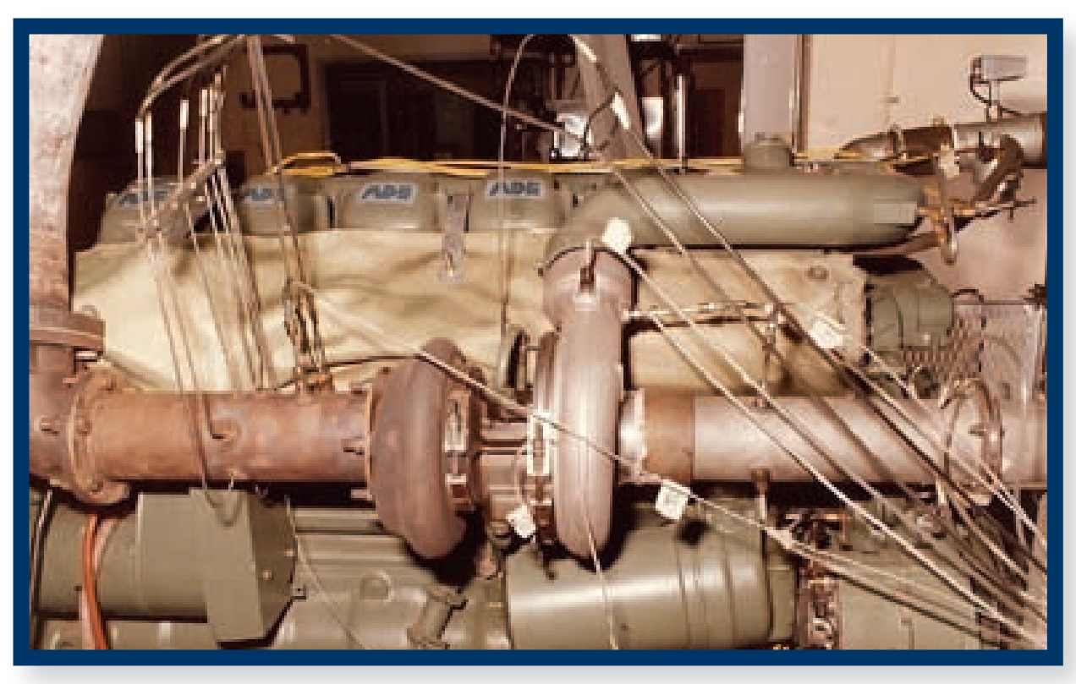
Figure 1: Instrumented turbocharger on diesel engine

To complement research on axial turbines for aerospace applications, research was undertaken to develop an understanding of the characteristics and performance of radial inflow turbines. Initially this was done on a diesel engine dynamometer where a turbocharger, which uses a radial compressor and a radial turbine, was instrumented to be able to measure the various characteristics of the turbocharger. Figure 1 shows an instrumented turbocharger on a diesel engine where experiments were done in a CSIR engine dynamometer test cell.

A dedicated test rig was designed and built in a test cell in the CSIR's high speed wind-tunnel building to evaluate the performance of a 9,6 cm radial inflow turbine of a turbocharger[1]. This was done so that radial inflow turbine design tools could be validated experimentally. Testing was done under 'cold' steady flow conditions and the tests were automated and controlled by a computer-based data acquisition system. This test rig allowed for a comparison between an experimental investigation and analytical prediction of the performance of the radial inflow turbine. A novel feature of this test rig was the design and construction of an air bearing dynamometer to measure the power generated by the turbine directly. Here the compressor housing was isolated from the rest of the turbocharger, mounted on air bearings and torque measured on a loadcell. Evaluation of the aerodynamic performance of the turbine was conducted over a range of pressure ratios and shaft speeds. Figure 2 shows the instrumented radial inflow turbine with the compressor connected to the air bearing dynamometer.

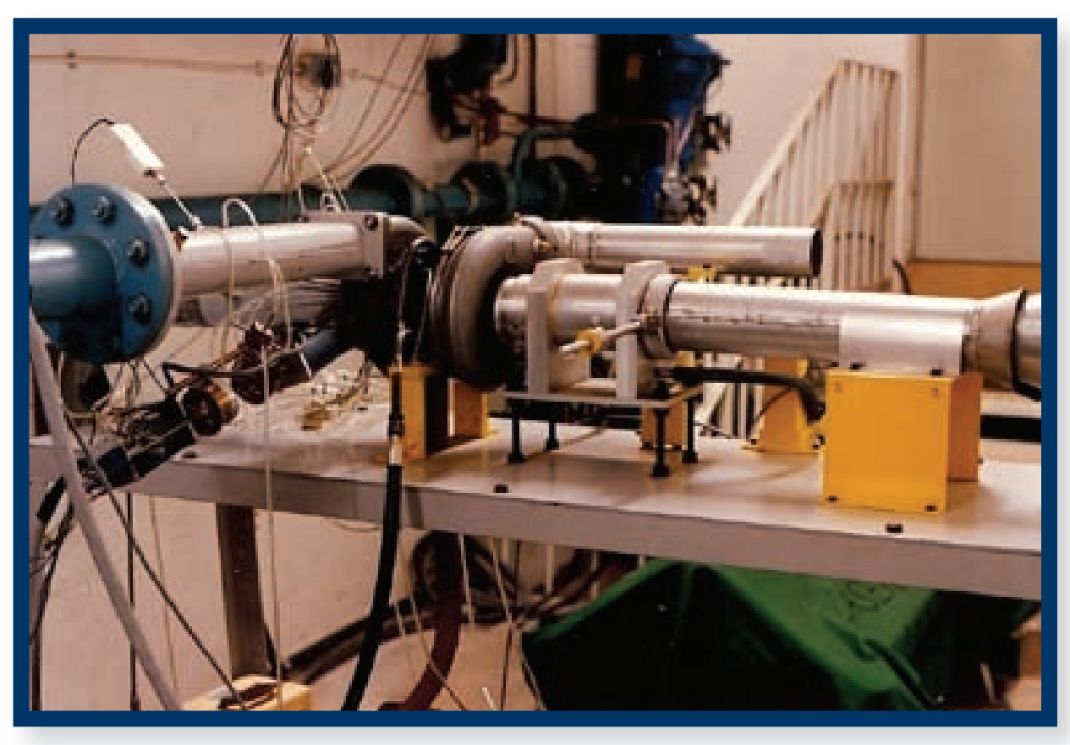
Figure 2: Instrumented turbocharger in test cell

MICROTURBINE TECHNOLOGY DEMONSTRATOR

Having acquired understanding of and expertise in the characteristics of radial inflow turbines, resources were allocated towards the understanding of the various components that would convert a turbocharger into a microturbine. Barnard and Caroline[2] discussed the radial flow turbomachines as a power generator and describe in detail the components of the microturbine technology demonstrator. Figure 3 shows the core of the demonstrator, which is based on the Holset Model 3LD turbocharger, with a reserve flow combustor designed by Stellenbosch University. A digitally-controlled single-point injection system was employed and a Bosch L-Jetronic injector was combined with A Hago 80° swirl atomiser to deliver the fuel, diesel, into the combustor. The control system, for which software was developed, made use of an Intel8052AH central processing unit that controlled the various parameters of the microturbine. The Holset turbocharger has an operational range of between 40 000 and 120 000 rpm. A high speed alternator, with a maximum shaft speed of 30 000 rpm, had been designed by the then University of Natal and to integrate the alternator with the microturbine, a power turbine was added to accept the hot exhaust gases from the Holset turbocharger-based free turbine. The power turbine was based on a standard KKK turbocharger that was directly coupled to the high speed alternator. The reason why direct coupling of the alternator to the microturbine was investigated was to demonstrate that the overall system could be simplified by eliminating the need for gearboxes.

Killey[3] described the testing of the microturbine technology demonstrator where the concept of a turbocharger-based gas turbine was coupled to a high speed alternator. The electricity that was produced by the demonstrator proved that the concept was feasible. However, it was recognised that further optimisation of the overall concept was necessary.

The purpose of the microturbine/alternator demonstrator had been to illustrate the feasibility of such a concept by using as many off-the-shelf components as possible. To illustrate a more optimal microturbine/alternator configuration, a mock-up was made of a high-speed alternator directly coupled to the free turbine, as shown in Figure 4.

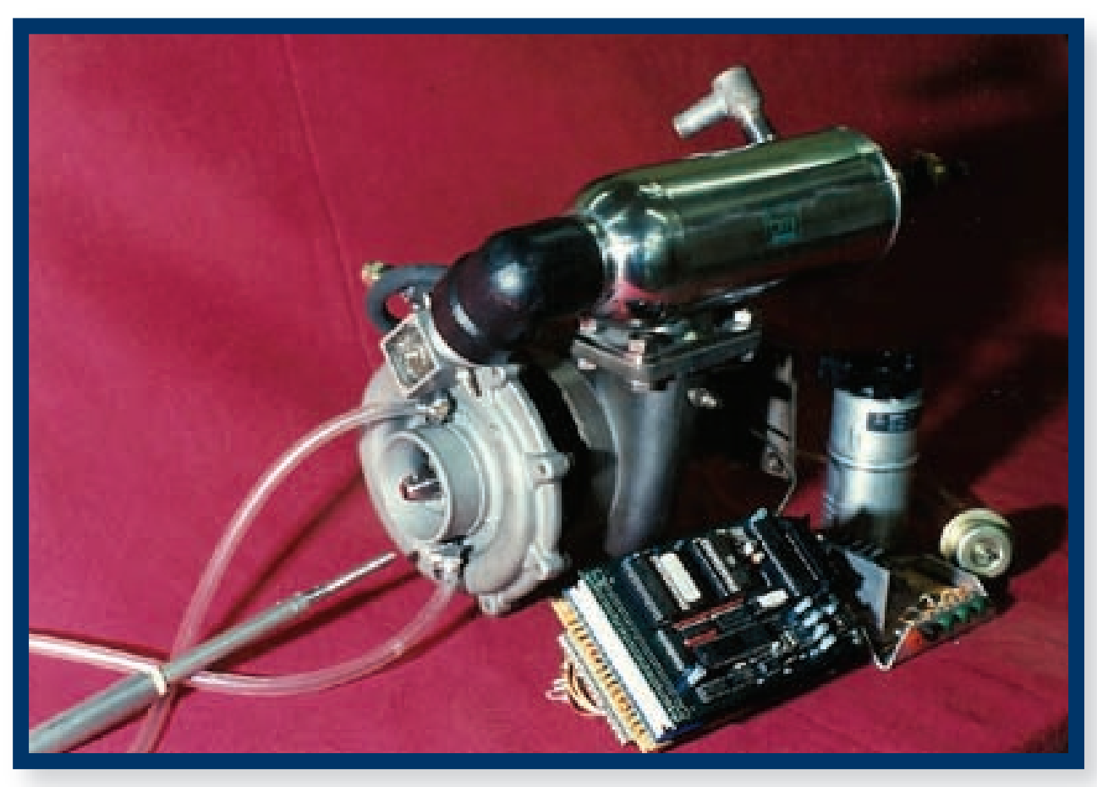
Figure 3: Core of microturbine technology demonstrator

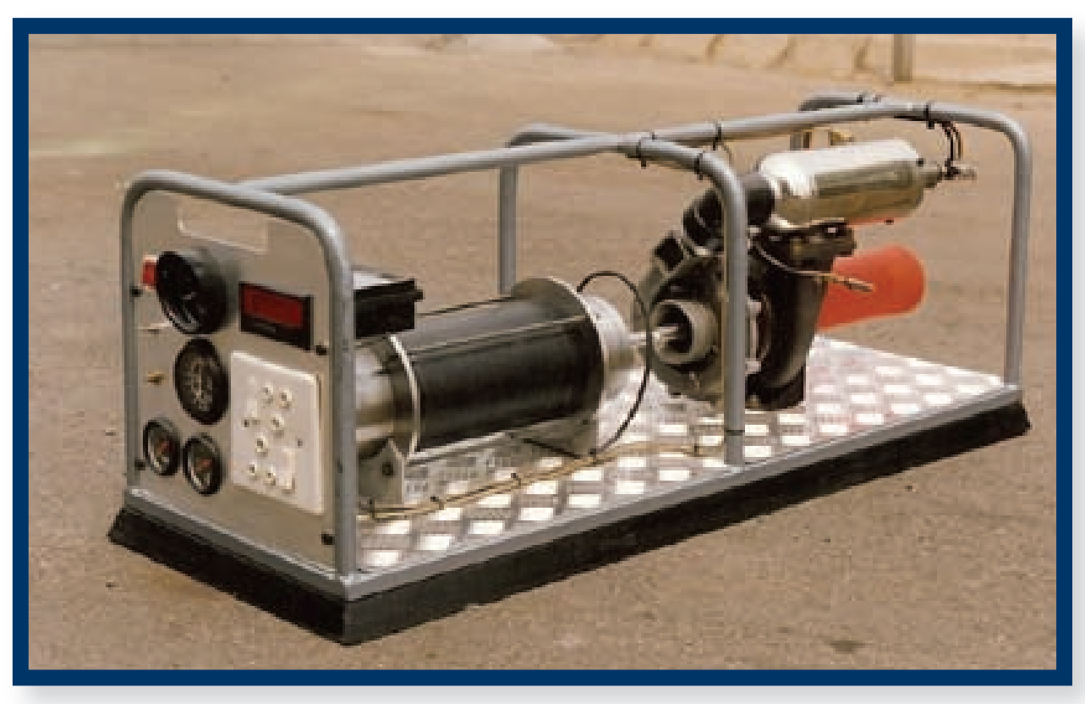
Figure 4: Mock-up of directly coupled microturbine/alternator

RADIAL TURBINE CASTING TECHNOLOGIES

Due to the high temperatures and stresses that turbines need to endure, nickel-based super alloys are employed to ensure that turbines achieve the designed operational life. As part of the overall programme to demonstrate a microturbine the CSIR developed technologies to cast the complex three-dimensional (3D) shapes of radial inflow turbines out of these superalloys. This was done with the view to gain experience to cast turbine components as part of the concept of 'economy of mass production'. Figure 5 shows the iris type dye that was made to cast the component out of wax. A wax casting of the radial turbine is included on the photo. Figure 6 shows the superalloy casting of a radial inflow turbine with its complex 3D flow passages.

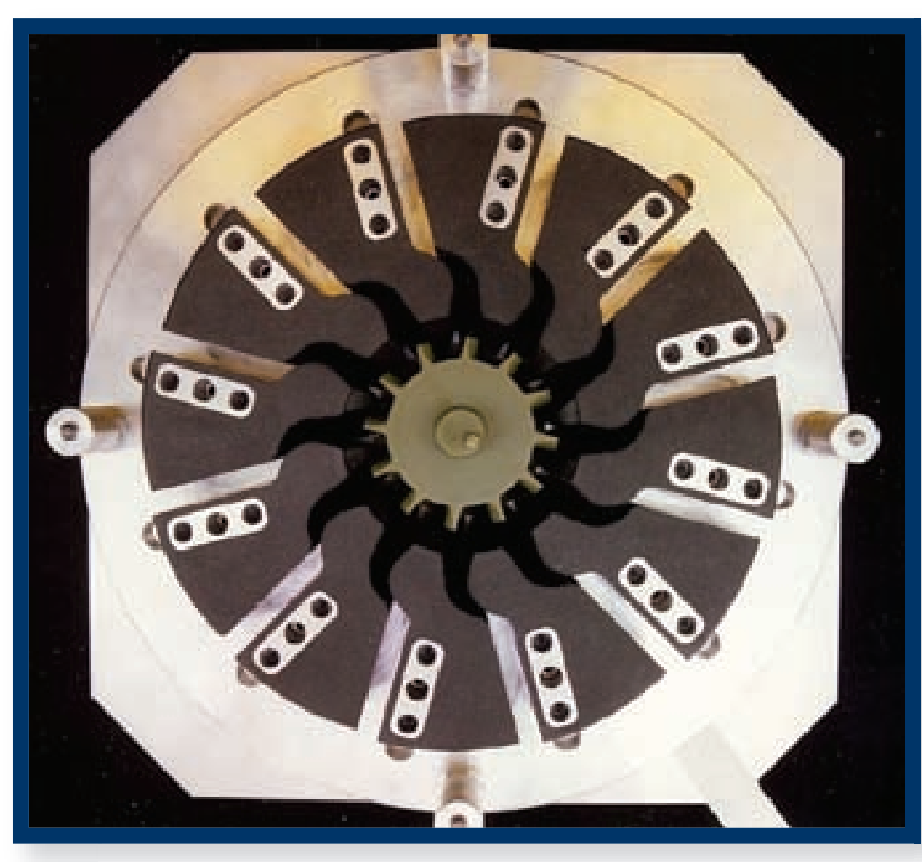
Figure 5: Iris type dye with wax casting

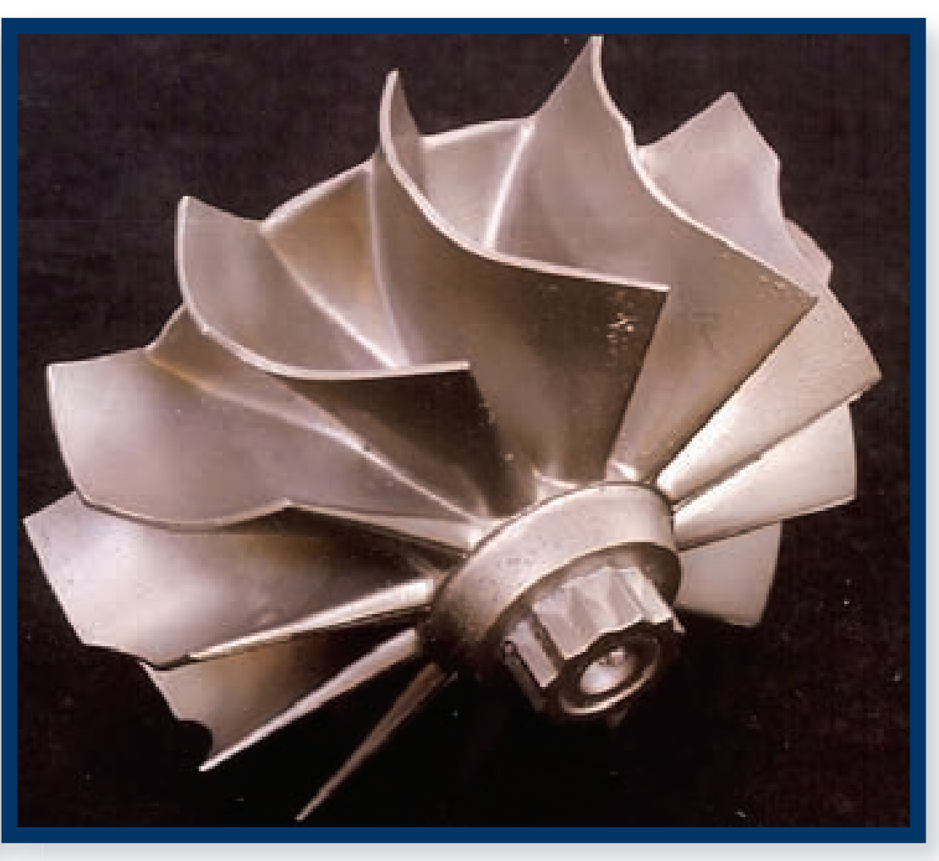
Figure 6: Superalloy casting of radial turbine

MICROTURBINE SPECIFICATION DEVELOPMENT

To develop an optimised microturbine, investigations were undertaken by the CSIR into various gas turbine thermodynamic cycles using turbocharger components. Szewczuk[4,5] investigated a 10 kW and a 25 kW microturbine with a simple cycle and a simple cycle with heat exchanger. Roos and Mtyobile[6] undertook a comprehensive investigation into further thermodynamic cycles that included intercooling, reheating and heat exchange using a TSA turbocharger as the core of the machine. Further work on the development of a microturbine was stopped at that stage. However, internationally, further developments on microturbines continued and these are now becoming readily available on the market with a range of available power outputs.

ALTERNATIVE FUELS - BIOGAS

The most common types of fuels used to power microturbines are based on fossil fuels, namely diesel and natural gas. Pointon and Langan[7] investigated the feasibility of using microturbines for distributed generation and being fuelled with biogas derived from organic waste. The investigations indicated that the microturbine will find application on biogas installations that will benefit from its fixed output, high-part load efficiency and reliability. When the waste management and energy-efficiency elements are linked, analysis indicated that the economic performance makes the concept of distributed power generation using biogas-fuelled microturbines attractive under current market conditions. An example of a microturbine being fuelled by biogas can be found in Hagawik in Sweden and the overall installation is shown in Figure 7. The blue container houses the microturbine and the large reservoir is the biogas anaerobic digestor.


Figure 7: Example of a facility producing biogas to fuel a microturbine.

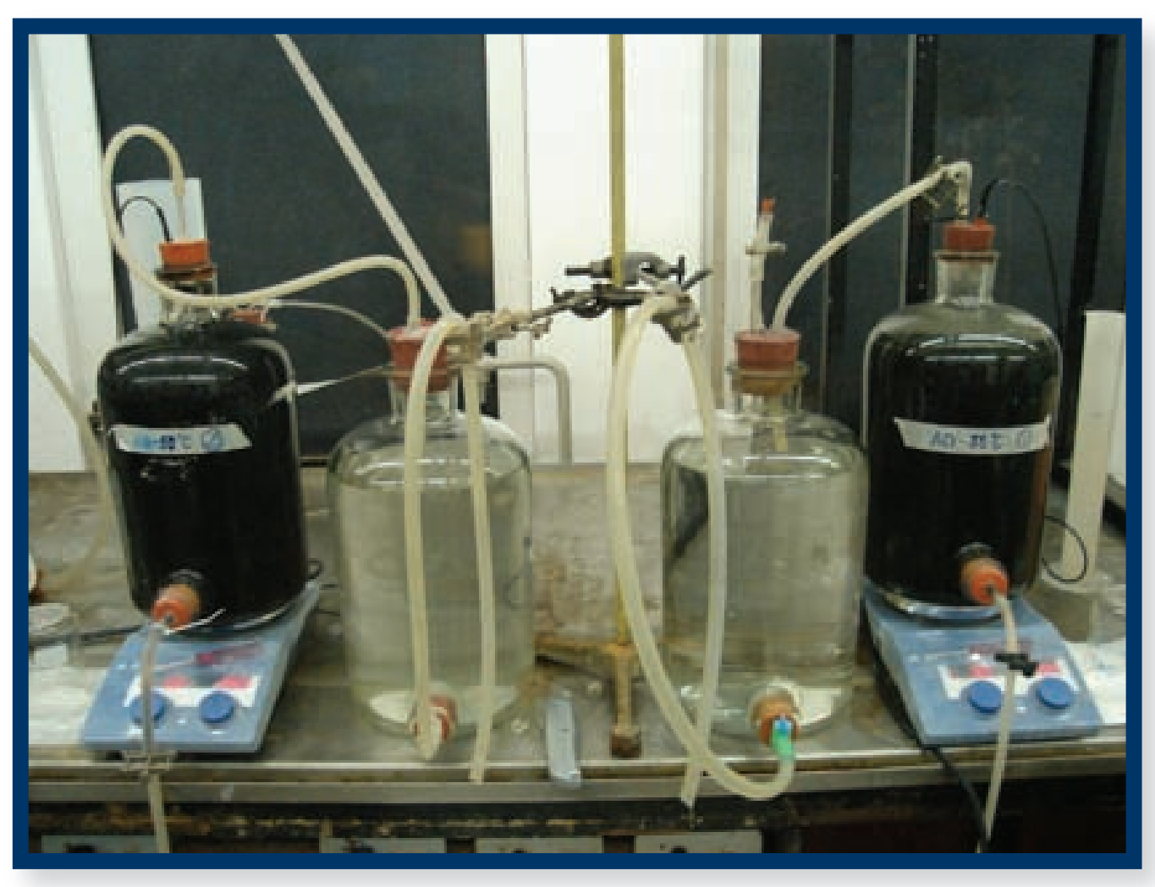
Figure 8: Thermophylic and mesophylic anaerobic digestion of food waste.

The CSIR is currently investigating the use of biogas to fuel a microturbine. Research is being done into the quantification and characterisation of various wet organic waste sources (sewage, animal slurries, food waste) and the quantification of the significant parameters to maximise biogas production. These parameters include loading rate, gas production rate and temperature of the digestor. Temperature directly influences the gas production rate; at 35°C a mesophylic process takes place and at 65°C a thermophylic process takes place. Figure 8 shows a laboratory-scale investigation into the mesophylic and thermophylic anaerobic digestion of food waste as part of the research into maximising biogas production from wet organic waste.

To help secure South Africa's energy future, CSIR researchers are using aerospace know-how and experience to integrate novel energy systems and optimise the use of resources for sustainable economic development.

CONCLUSION

The CSIR has developed capacity and expertise in the field of microturbines, which have the potential to be used for distributed power generation. To reduce the use of fossil fuels, investigations are underway to maximise the production of biogas from various sources of wet organic waste, for example sewage, animal slurries and food waste. Biogas can be used as an alternative fuel for microturbines.

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