TURNING WASTE HEAT INTO LOW COST ELECTRICITY

Electricity prices in Australia are on a strong upward trend due to increases in fuel costs (coal, gas and diesel), significant network investment, increases in the cost of grid electricity, regulatory changes, including the cost of carbon and renewable energy targets. This has a negative impact on the "Bottom Line" of businesses and is driving (or should be), improved Energy Efficiency.

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An Australian team has implemented a number of subtle improvements to the conventional Organic Rankine Cycle (ORC) technology for utilising, for example, waste heat to produce electricity, with the resultant efficiency gain delivering low cost power and genset fuel savings to remote sites.

Since its development in the 1960s the Organic Rankine Cycle has been increasingly used to capture low grade waste heat and turn this into electricity. However, recognising the potential to further increase the efficiency of low grade energy conversion, in 2006 the University of Newcastle's Priority Research Centre for Energy, lead by Professor Behdad Moghtaderi, working with Granite Power Ltd (GPL), started development of an advanced ORC cycle. The key realisation of this research was that by bringing the fluid to a supercritical state in the boiler (as done in modern large thermal power stations), a temperature mismatch was avoided between the heat source and the working fluid.

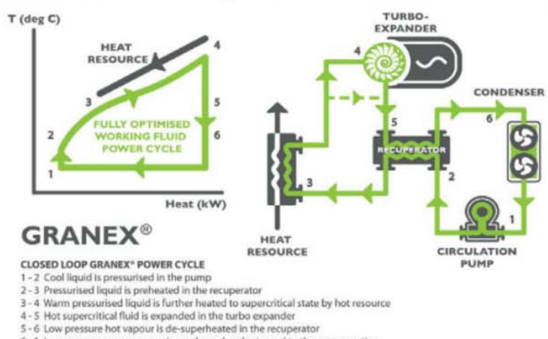

Figure 1 *GRANEX® Power Cycle Diagram*

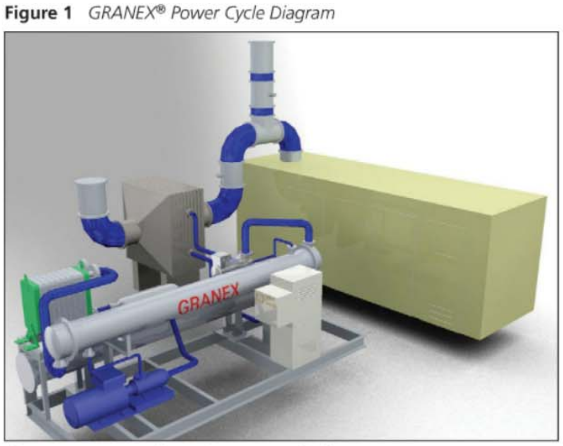

Figure 2 *GRANEX® 400 kW Power Block*

COMPUTER MODELLING WAS ACCURATE

After theoretical examination of many fluids, five fluids were tested in a special purpose built test rig to quantify their behaviour in the supercritical state. This rig was actually a working Rankine cycle that measured the state points of the fluid through the circuit and validated the computer modelling was accurate. From this plant a larger 100 kW plant was built to demonstrate the system could be scaled up.

Figure 3 is a temperature entropy diagram of a fluid in the standard sub-critical Rankine cycle, and the same fluid in the supercritical heated Rankine cycle. As shown, the supercritical fluid doesn't change phase at a constant temperature like the sub-critical fluid, meaning more effective heat transfer from the heat resources. Also shown in the diagram, the power from the turbine is available between the high side and low side temperature of the circuit. Effectively, the larger this temperature head, the more turbine power available and hence the greater the efficiency. As the ambient temperature in Australia, particularly remote outback, is high relative to other parts of the world, this temperature head is less. It is therefore important to take the high side temperature as close as possible to the heat source and, as a supercritical fluid, the temperature head across the turbine is greater. To go one step further, the testing validated the temperature limits these fluids can be safely brought to without degradation, thus enabling this cycle to operate at a higher working temperature than standard Organic Rankine cycles. This Australian technology has been registered under the trade mark of GRANEX® and is commercialized through GPL.

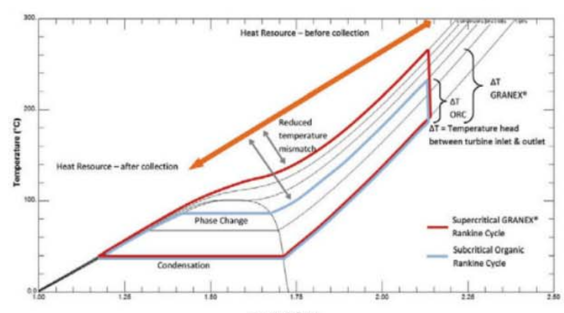

Figure 3 *Temperature – Entropy Diagram*

There are a range of applications for GRANEX such as industrial waste heat, geothermal and in particular, heat recovery from large reciprocating engines used for off-grid power generation. There are many remote communities and even more mining sites throughout Australia which rely on diesel fuel to be trucked in at continuously increasing prices. GRANEX captures the waste heat from the engines and delivers an additional 10 % of the diesel generator output, thereby reducing the cost per kWh and providing the option to save

10% of diesel fuel costs. GRANEX is also well suited to operate from the heat of a solar thermal source, which is a current project of GPL's.

CONCENTRATED SOLAR THERMAL AS A HEAT SOURCE

The research team at Granite Power are completing commissioning of a Demonstration plant at Wallsend, Newcastle, integrating the GRANEX technology with a concentrated solar thermal heat source. This is a first of its kind in which the supercritical fluid used in the power cycle, is directly heated in the receivers of the solar field. The benefits of this is it eliminates the need for an intermediate fluid such as thermal oil or molten salt which is typically used between the solar field and the power cycle, thereby reducing an additional fluid transfer system and the associated system losses. Also, less equipment means less maintenance, which is important to Granite Power and its mantra of "more power and less maintenance." The parabolic troughs used are produced in Australia by NEP solar, who made some simple modifications to the pipe work to accept the higher pressure of the working fluid circuit.

Another significant advantage of being supercritical is that the working fluid doesn't change phase in the receiver. Currently it is an engineering challenge to design a solar field to operate with two-phase flow, in which a liquid enters, boils in the receivers and exits as vapour. This creates flow control issues which are not present with the GRANEX design.

Centre piece to this project is the integrated Turbine Generator which was developed in-house by GPL with assistance from the University of Newcastle. The stator windings of the generator were encapsulated by Turbo Power Systems in the UK, who modified their existing motor design to suit this generator application. Along with the stator is the permanent magnet rotor which has been designed to deliver 30 kW at 70,000 rpm. This high speed is to match the turbine tip speed to achieve best efficiency and ultimately eliminate the need of a reduction gearbox. This allows the turbine wheel to be coupled directly to the generator rotor which results with this high speed generator having a higher power density than a 3000 rpm generator and presents a very compact unit.

SKF Magnetic Bearings are used to support the rotor and turbine wheel. This means no oil is needed to lubricate any bearings and this turbine generator is completely oil-less. The manufacturing of the casing and turbine components were completed by Archer Enterprise, an Australian precision manufacturer. CFD was used to calculate the nozzle and blade shapes of this impulse turbine, which again was accurately reproduced by Archer.

The generator stator is cooled externally by a small amount of cool working fluid. This fluid is boiled into a low viscous vapour which is then directed inside the generator casing to minimise the windage loses of the high speed rotor. The vapour is at a slightly higher pressure than the turbine outlet, and as there is no gas tight seal between the turbine and generator, this pressure difference prevents any hot turbine gases from heating the generator section. Not only is the absence of a seal good news for maintainers, but the integrated cooling system which uses the same cycle fluid and requires no additional pumps or systems, creates a very neat and low maintenance unit. The high frequency voltage from the generator is converted to DC and inverted to 50 HZ.

For commercial applications, Granite Power Ltd offer a nominal 400 kW unit, a 500 kW and a 1000 kW unit based on this design (these turbines run at a slower 20,000 rpm). For larger installations, multiple 1 MW units are used. Considering remote installations, these compact turbine generators facilitate an easier swap out of units, rather than onsite overhaul.

A feature of the Wallsend demonstration is that it is integrated with the local public swimming pool. As the Rankine cycle relies on a condenser to serve as the cold sink, the swimming pool water offers a win-win service in which GRANEX gets cooling water, and the pool receives hot water. On days when the pool doesn't need more hot water, GRANEX reverts to the air cooled condenser. This feature highlights the usefulness of the combined heat and power. This heat from the condenser could be used in a desalination system to produce fresh water, or used in an absorption chiller system for cool water needs.

Delivery of power after the sun has set is achieved with a thermal storage system. The solar field is oversized to capture additional heat during the day, and this is simply stored in a large insulated tank. When the sun is not available, the heat is slowly released from the tank to drive the Rankine cycle and power the turbine generator. The size of the storage tank and additional over sizing of the field determines how many hours of storage are achievable; the main advantage is, in comparison to electrical batteries required for photovoltaic solar panels, thermal storage is much less expensive and can better cope with industrial start-up loads.

The turnkey energy recovery systems provided by Granite Power Limited are typically supplied under a Power Purchase Agreement, priced at a discount to the customer's existing option, and require no capital expenditure by the customer.

The Australian developed GRANEX low grade waste heat conversion to electricity technology supported by novel manufacturing in Australia and commercialised by Granite Power Limited demonstrates that world class energy efficiency solutions are available within Australia.

For further information, please contact the author by email dhall@granitepwr.com

Figure 5 *G-30 Turbine Installed at Wallsend*