Convective Energy Conversion Cycle

Summary

A new energy cycle is proposed for the efficient conversion of heat into electricity using natural convection. Solar energy or combustion produces warm gases which rise because of their buoyancy. If the current of warm gases is suitably contained it can drive a turbine. If the configuration is structured as a closed cycle, post turbine air which is cooler, falls under gravitation to repeat the cycle. Thus buoyancy is the expander, gravity is the compressor and there is no energy sink in the Convective Energy Conversion Cycle (CECC). The author asserts that this configuration is not subject to the Carnot efficiency limit; it is the First Law of Thermodynamics, the Principle of Conservation of Energy that applies giving a theoretical efficiency for the conversion of heat into electricity of up to 100 per cent.

CECC was devised for conversion of solar energy into electricity in large scale solar collectors. Subsequently the author has come across three instruments from nineteenth century physics that each employs CECC. In each case light is converted into mechanical energy with anomalously high efficiency. They provide a proof of concept. An adaptation of CECC for the conversion of natural gas into electricity in power stations is described. But its main application will be in harnessing solar energy. An experimental approach is outlined that could lead to large scale, low level, sealed glass dome structures that will convert solar energy into electricity at a fraction of the cost of other solar technologies and cheaper than from fossil fuels.

Introduction

The convective energy conversion cycle described in this paper has considerable parallels with atmospheric convection. About one half of the solar energy intercepted by the earth penetrates the atmosphere and is absorbed in the surface layers of the land and oceans. Air molecules at ground level strike the hot surface and are warmed and there is evaporation of water from the surface. The warmed air and water vapour rise. The atmosphere is in effect heated from below by this giant solar absorber – the earth's surface. As warm air rises at the equator, it draws cooler air from the poles. Rotation of the earth adds to this circulation that produces wind and weather. The configurations suggested in this paper involve a large solar absorbing surface causing air to rise within containment, producing its own convection current or wind which can drive a turbine.

There are few examples of useful work deriving from natural convection. Gliders and birds of prey use thermal currents. Land and sea breezes are caused by atmospheric convection and can drive sailing boats … All uses of wind energy are an application of convection. Tornadoes caused by rising hot air can lift trees or houses … Hot air balloons are raised by convection.

Convection drives the earth's atmosphere, dictates the distribution of life in the world's oceans, is the motive force in the earth's mantle causing continental drift and conveys the energy of nuclear fusion in the sun to its surface. Convection is of overwhelming importance in the processes of nature. Yet in school and university physics text books it barely deserves mention. Although there is great interest in harnessing solar energy to make electricity there is only one example of the use of natural convection – the solar chimney [1].

The Second Law of Thermodynamics

There are several statements of the second law of thermodynamics e.g. Clausius, Kelvin-Planck … but its most popular expression is the Carnot theorem which gives the maximum efficiency for the conversion of heat into work as $\Delta T/T$.

In heat engines there are usually four stages in the energy cycle involving changes in pressure, volume and temperature of the working gas. Energy is lost in the exhaust or during compression into a heat sink. Indeed the compressor may consume 40 to 70 per cent of the turbine output [2].

Whilst the second law was deeply controversial from 1850-1900 and whilst it is not amenable to rigorous proof [3], it has stood the test of time. No heat engine has been devised with an efficiency greater than Carnot. The author accepts that the Carnot efficiency limit applies to all the classical energy cycles and to all of today's heat engines.

Exceptions to the Carnot Efficiency Limit

It is claimed that the second law of thermodynamics is a universal law and that the maximum efficiency for the conversion of heat into work is $\Delta T/T$.

It is however accepted that it does not apply to the electric motor, hydroelectric generation, digestion by a workhorse, or to the conversion of solar energy into electricity by photovoltaics. It is only when a temperature difference is essential to the operating cycle that Carnot applies.

The author believes, however, that there are two ways for heat engines to bypass the Carnot efficiency limit:

repeated recycling of waste heat
convective energy conversion cycle (CECC).

Repeated Recycling of Waste Heat

Rankine [4,5] tried to devise the 'perfect air engine'. He argued that very high efficiency should be possible by using the energy released during compression in the heating phase.

Hoffman [6] describes a modified multistage Joule cycle, with interstage heat transfer to and from a circulating combustion system. The heat of compression is transferred to combustive air, followed by combustion and heat transfer to turbine expanders. With rigorous application of such energy recovery, the theoretical efficiency could approach 100%.

The author similarly suggests extensive energy recovery post turbine in his proposal for the use of recuperation in the solar chimney. (See paper on this website – December 2001.)

Convective Energy Conversion Cycle

Air is heated in a sealed enclosure. The warm air rises and, in a suitable configuration, will drive a turbine. The air post turbine is cooler and falls under gravitation. All stages are at constant volume and there is no need for an energy sink. It is the author's belief that this simple energy cycle has a theoretical efficiency of up to 100%.

Bejan [7] describes a similar hypothetical energy cycle as follows: "Think of an old-fashioned stove in the middle of a room. Since air at constant pressure expands on being heated, the air layer adjacent to the stove expands – becomes lighter, less dense – and rises. At the same time any cooler air is displaced en masse, downward. This convection loop is equivalent to the cycle executed by the working fluid in a heat engine. In principle, this heat engine cycle should be capable of delivering useful work if we insert a suitably designed propeller in the stream; this is the origin of the "wind power" discussed nowadays in connection with the harnessing of solar work indirectly from the atmospheric heat engine loop."

Consider the energy cycle depicted in Figure 1

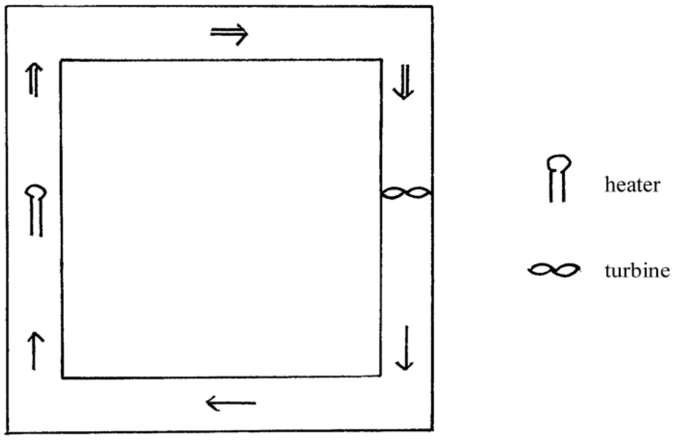

Figure 1

Warm air rises from the heater, drawing cooler air from beneath to replace. A convection current is set up provided there is some way to dissipate the excess heat energy. It is the author's belief that a modern air turbine placed as shown in this closed cycle will absorb the kinetic energy of the air flow with a theoretical efficiency of up to 100%.

The energy cycle involved is fundamentally different to the classical thermodynamic cycles and to modern heat engines. All of the heat introduced is converted into the kinetic energy of air flow. Warm air rises because of its buoyancy and this expansion will drive the turbine. Post turbine, the air is cooler, contracts and falls under gravitation. A turbine placed in this uniform air flow has very high efficiency eg the cased turbines used in the solar chimney at Manazares, Spain [8] had an efficiency of 77-80%. Wells turbines used in the oscillating water column method of harnessing wave energy [9] can have an efficiency of up to 90%. The only energy loss in this cycle is that due to the turbine. This very simple cycle involves straightforward conversion of heat into kinetic energy and into work. It is the First Law of Thermodynamics that applies and the theoretical efficiency is up to 100%.

The Convective Energy Conversion Cycle above forms the basis of three proposals by the author for harnessing solar energy. See earlier papers on this website:

Solar Electricity Night and Day – March 2002
Solar Electricity using Convection Currents and a Volume Equaliser/Turbine – September 2002
Simple Solar Engine – March 2003

It is the author's assertion that each of these proposals will allow conversion of solar energy into electricity with a theoretical efficiency of up to 100%.

Nineteenth Century Instruments that use CECC

The above proposals were devised during 2001-03 and published on this website. During January-July 2003, whilst working in the Science Museum Library at Imperial College, London, trying to achieve a fundamental understanding of Crookes' radiometer, the author came across three instruments from 19^{th} century physics that use exactly the energy cycle described above. Each converts light into mechanical energy with an efficiency orders of magnitude greater than would be predicted by Carnot.

Joule's thermoscope was devised in 1863 to detect the energy of moonlight. A cardboard, painted black is arranged vertically inside a sealed glass tube. The light of a full moon is absorbed by the black surface which warms air in its vicinity setting up a convection current which deflects a finely suspended magnetic needle. From the angle of deflection Joule calculated that the passage of a full moon caused a temperature rise in his apparatus of "a few ten thousandths of a degree F". Joule's estimate is correct to within an order of magnitude. The Carnot theorem would give this instrument a maximum efficiency of less than 10^{-6}. It is clear that conversion of heat into mechanical energy in this instrument is not subject to the Carnot efficiency limit. (See paper on this website – July 2003.)

Crookes' otheoscope (1879) involves a fixed blackened disc inside a sealed glass bulb. Above, very close to the disc, and finely suspended to allow rotation, is a turbine made of vanes of mica set at 45° to respond to any heated air rising from the disc. Crookes found that the vanes rotate "with great speed when set in action with even a faint light." Again it is clear that the energy of light is converted into mechanical energy with an efficiency orders of magnitude greater than would be predicted by Carnot. (See [10] and paper on this website – March 2003.)

The Convection Mill was devised by A. R. Bennett in 1896 as a simple demonstration of natural convection. A hollow metal cylinder painted black stands on short legs inside sealed glass containment. When exposed to sunlight the black surface absorbs solar energy heating air inside the cylinder which rises drawing cooler air from beneath. A convection current is established which drives vanes inside the cylinder viewed through an observation window. A second set of vanes, outside the cylinder, rotates in the reverse direction in the downstream of the convection current. (See [11] and paper on this website – March 2003.) Bennett devised many experiments using the Convection Mill [12] and found that "Nearly all the introduced heat is expended in causing air currents." The instrument is again sensitive to moonlight (10^{-5} solar). This must mean that heat is converted into mechanical energy with very high efficiency – several orders of magnitude greater than would be predicted by Carnot.

Each of the above instruments works by natural convection and involves an energy cycle at constant volume. It is exactly the Convective Energy Conversion Cycle that had been devised independently by the author during 2002. They provide a proof of concept. It is the author's belief that CECC allows the conversion of heat into mechanical energy with a theoretical efficiency of up to 100 per cent.

Application of CECC to Fossil Fuel Combustion

The Convective Energy Conversion Cycle was devised for harnessing solar energy. But nearly all the world's energy comes from fossil fuels. Is it possible to devise configurations for combustion to drive a turbine using natural convection alone?

The products of combustion are hot gases that will rise – this gaseous flow could drive a turbine. It is also possible to recover energy from the exhaust gases post turbine using natural convection in a countercurrent heat exchanger. These ideas form the basis of a proposal for a Convector Generator as in Figure 2 for the generation of electricity using natural gas.

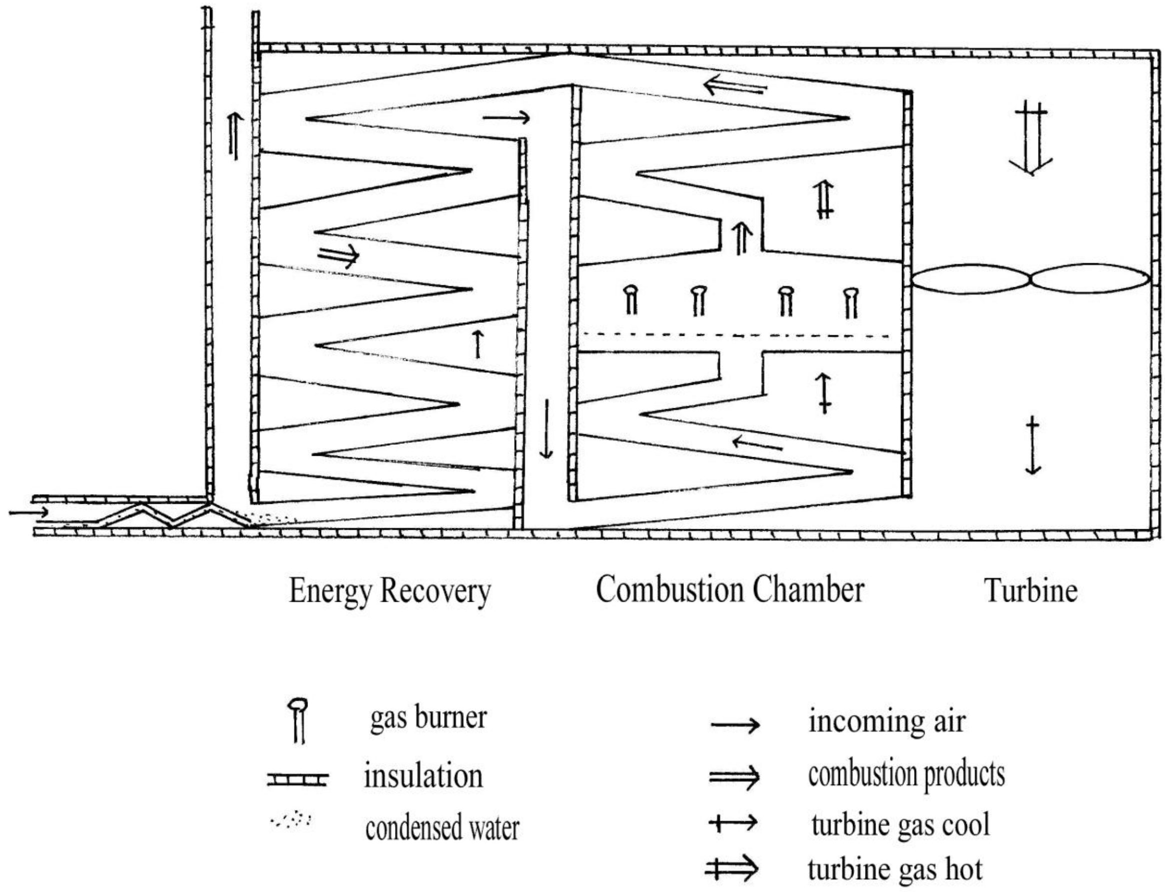

Figure 2

Natural gas burns in the combustion chamber at atmospheric pressure using natural convection alone. There are no pumps or fans. The combustion products rise drawing fresh air from beneath for continued combustion. There is a separate closed turbine gas cycle. Most of the heat of combustion is transferred to the turbine gas circuit which will develop its own secondary convection current to drive the turbine. The gas in this circuit loses kinetic energy as it strikes the turbine and equilibrates with preheated incoming air entering the combustion chamber. It is the author's assertion that the CECC involved in the turbine gas circuit has a theoretical efficiency of up to 100%. As combustion products leave the combustion chamber they then pass through an energy recovery unit. This is a countercurrent heat exchanger working by natural convection alone. This should allow condensation of water vapour from the flue gases. The author believes that the Convector Generator will allow generation of electricity from natural gas with an efficiency of over 90%.

Several correspondents suggested that the above structure would be large and cumbersome as is the history with air engines. The author devised a more compact Convector Generator Revised and Restructured (CGRR) where the three chambers above are brought into one unit. (See earlier paper on this website – June 2004.) The turbine is sited immediately above the combustion chamber. There is better cooling of the turbine gas circuit and extensive recuperation from the combustion products. Again there are no fans or pumps – the entire configuration is driven by natural convection. It is the author's assertion that this more compact CGRR will also have an efficiency of over 90% in the generation of electricity from natural gas.

Solar Electricity using CECC

This is the most important application of the Convective Energy Conversion Cycle. The author's most recent proposal 'Solar chimney plus bell jar … a thought experiment' (SCBJ – website – March 2005) is illustrated in Figure 3

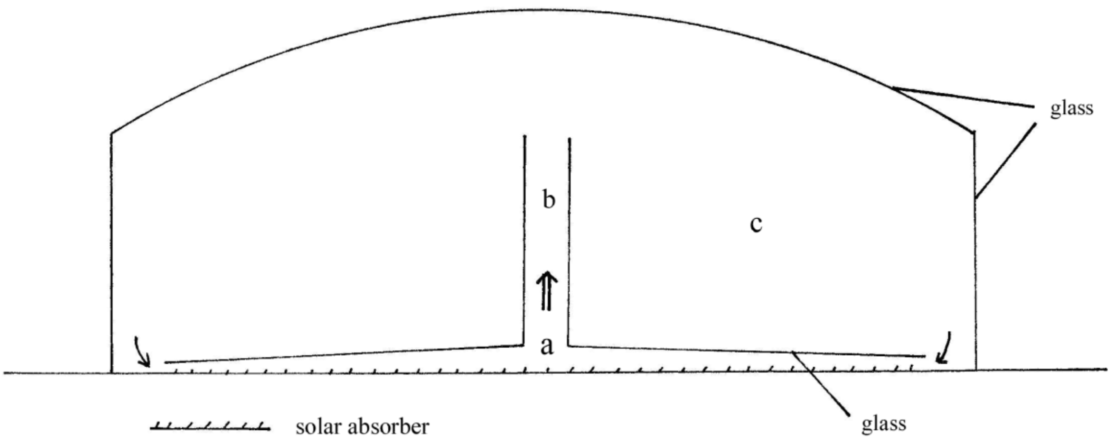

Figure 3

A commercial 200 MW solar chimney is currently being developed in Australia [13]. It involves a chimney of height 1000 metres and diameter 120 metres and a solar collector of diameter 7000 metres. The author asks, simply as an exercise for the imagination – what would happen if a glass bell jar was superimposed on the solar chimney and sealed at ground level?

This is not suggested as a serious structural alternative – it is merely posing the question of what would happen if we imposed a closed cycle on the solar chimney configuration? It is suggested that experiments be conducted using a model solar chimney that could be of laboratory bench dimensions … one metre high, one metre diameter or smaller.

It is the author's clear view that a 'convective energy conversion cycle' will be established in this configuration. Solar energy will be taken up by the absorber with high efficiency. This will warm the air in its vicinity which will rise from (a) because of its buoyancy. The small inclination in the solar collector will be enough to channel this stream of air into the chimney (b). As the warm air rises it will draw cooler air to replace from (c) which will enter the solar collector from around its perimeter. ALL of the solar energy taken up by the absorber will be converted into the kinetic energy of air flow from (a) to (b). If an air turbine is placed at the base of the chimney it will absorb the kinetic energy of the air flow with a theoretical efficiency of up to 100%. As quoted earlier [9] Wells turbines can have an efficiency of up to 90%. Any energy loss due to the turbine will be lost through the walls of the outer vessel.

It is the author's belief that if experiments were conducted on a small model SCBJ it would be found that in this closed cycle the height of the chimney is irrelevant. All that is needed is a small inclination in the glass of the solar collector so that rising warm air is channelled towards the centre. The length of chimney needed is simply that to house conveniently the cased turbine. The tall chimney – the most expensive feature of the solar chimney – is unnecessary in a closed cycle.

Experiments on CECC and SCBJ could pave the way to harnessing solar energy on a large scale using low level, sealed glass dome structures. These could be built on low value land and would have minimal environmental impact. They will convert solar energy into electricity with high efficiency at a fraction of the cost from other solar technologies and cheaper than from fossil fuels.

Conclusion

The author hopes that the convective energy conversion cycle outlined in this paper could become the subject of detailed investigation at 4 or 5 of the world's solar energy research institutes. The principles involved in CECC are completely different to the changes in P, V and T used in the classical thermodynamic cycles and in today's heat engines. All derive their work from the expansion of a gas.

CECC operates at constant volume using only natural convection. There are no pumps or fans and no heat sink. When heat is added to a gas it rises – its buoyancy will drive a turbine. The gas post turbine is cooler and, in a closed cycle, falls under gravitation. Gravity is the compressor – it is free and causes no loss of energy. The cycle involved is continuous flow. This is simple conversion of heat into work following the First Law of Thermodynamics/ Principle of Conservation of Energy with a theoretical efficiency of up to 100%. Further it is generic applying to fossil fuel combustion and the conversion of solar energy into electricity. If the above is correct then that is global warming solved.

Acknowledgements

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