Convector Generator* - *Efficient Conversion of Natural Gas into Electricity Using Convection Currents

Natural gas currently provides 20% of the world's electricity generation. A recent study by the International Energy Agency [1] forecasts that global electricity demand will grow by 85% from 2000 to 2030. The contribution made by oil and nuclear power will not increase; electricity from renewable sources will double or treble from a low base. Nearly all of the extra demand will come from an 80% increase in the use of coal and a **trebling in the use of natural gas. The conversion of natural gas into electricity is the most rapid growth market in the fossil fuel industry.**

Natural gas is used with high efficiency in domestic and industrial heating. Modern boilers can achieve over 90% efficiency. But its conversion into electricity is much less efficient. The most modern gas power station built by GEC at Baglan, South Wales [2] using combined cycle technology has a peak thermal efficiency of 60%. But with natural gas so clean, easy to handle and controllable – it is an ideal fuel - surely higher conversion efficiencies should be possible.

It is the author's belief that if air is heated in a sealed enclosure the convection currents set up can drive a turbine converting heat into electricity with high efficiency. The thermodynamic background is elaborated in the document 'Energy Cycles at Constant Volume' in the Appendix (on Page 8). See also earlier entries on this website. In a suitable geometric configuration, the source of heat warms air which rises; the warm air can be channelled to drive a turbine – such cased or ducted turbines have very high efficiency. The turbine absorbs the excess kinetic energy of the air current, cooling the air which then descends. It is gravitation that drives this flow pattern. Since the macroscopic volume is constant there is no nett loss of energy from the expansion of air or rejected gases. There is no need for an energy sink. There is no energy loss other than through the walls of the vessel into the environment. Heat is converted into mechanical or electrical energy with a theoretical efficiency of up to 100%.

The proposals outlined in this paper have many similarities to the condensing gas boiler (Figure 1). The latter achieves an efficiency of over 90% by incorporating a second large heat exchanger to cool flue gases to below 60°C. The main difference is that whereas the condensing gas boiler heats ***water*** in a closed circuit, the combustor here warms ***air*** in a closed circuit which includes a turbine for the export of energy. The convector generator is illustrated in Figure 2.

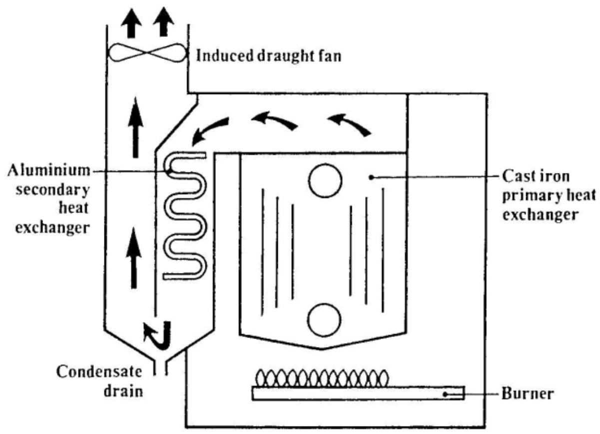

Figure 1

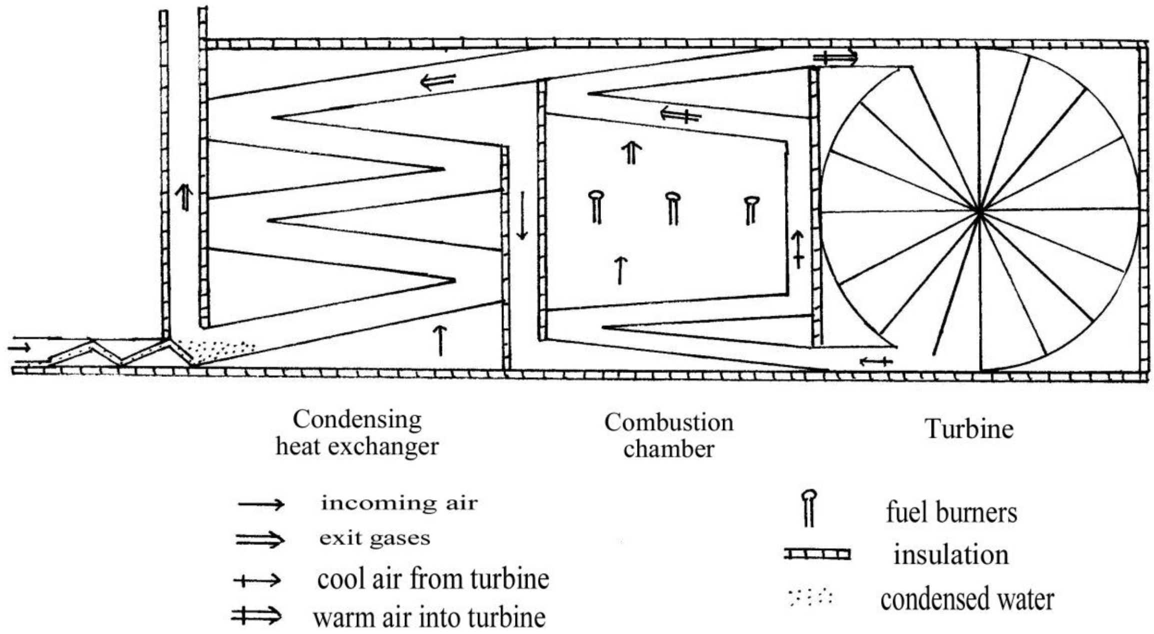

Figure 2

Combustion takes place in the central chamber. This warms air inside the heat exchanger which rises drawing cooler air from beneath. A convection current is established where warm air in the upper heat exchanger drives the turbine. It loses its excess kinetic energy, cools and descends in the turbine chamber then returning to the lower heat exchanger.

The combustion products rise and pass into the second heat exchanger but also drawing in fresh air to maintain combustion. The exit gases travel through the countercurrent heat exchanger transferring their residual energy to incoming air. As the latter cools the exit gases, water vapour will be condensed and can itself be used to preheat incoming air.

The turbine air circuit will convert heat into electricity with high efficiency. If the entire outer structure is rigorously well insulated, the only major energy loss is in the flue gases. The configuration should then have an efficiency of conversion of heat into electricity almost equivalent to that of the condensing gas boiler.

There are no fans or pumps in the system described. The entire structure depends only on convection currents; hence its description as the **Convector Generator**.

Turbine Circuit Gas Pressure

This paper is written, assuming for illustrative purposes that the gas in the turbine circuit is air at atmospheric pressure. But since it is a closed circuit the gas could be nitrogen, carbon dioxide or an inert gas to minimise corrosion. Perhaps the gas should be at 10-100 atmospheres pressure to provide large heat capacity for efficient transfer of the heat of combustion. Alternatively, it may be better to have very low pressure, 0.1 atmosphere or less and rapid circulation through the turbine air circuit. These are matters for theoretical calculation and experimental investigation.

Choice of Turbine

The turbine must convert the kinetic energy of air flow in a ducted channel into electricity with high efficiency. Wind turbines, hydro power, aircraft engines, steam turbines … all provide possible designs. The author's choice would be a Wells turbine developed for harnessing wave energy by periodic displacement of a column of air. This has an efficiency of up to 90% [3].

Balanced Flue

In the configurations described it is assumed that incoming air would enter at ground level and that exit air would leave above the highest level. This need not be so. Incoming and exit air can be at the same vertical level in a 'balanced flue'. The flue must be above the level of combustion for exhaust gases to rise.

Heat Transfer - Combustion Chamber to Turbine Air Circuit

It is critically important that heat transfer takes place from the combustion chamber to the turbine air circuit with very high efficiency. This is achieved in water heat exchangers in the condensing gas boiler and in power station boilers. In this case however we have a gas to gas heat exchanger driven only by convection currents. The author is insufficiently well read in these disciplines to make clear-cut suggestions but will instead highlight some of the factors to consider.

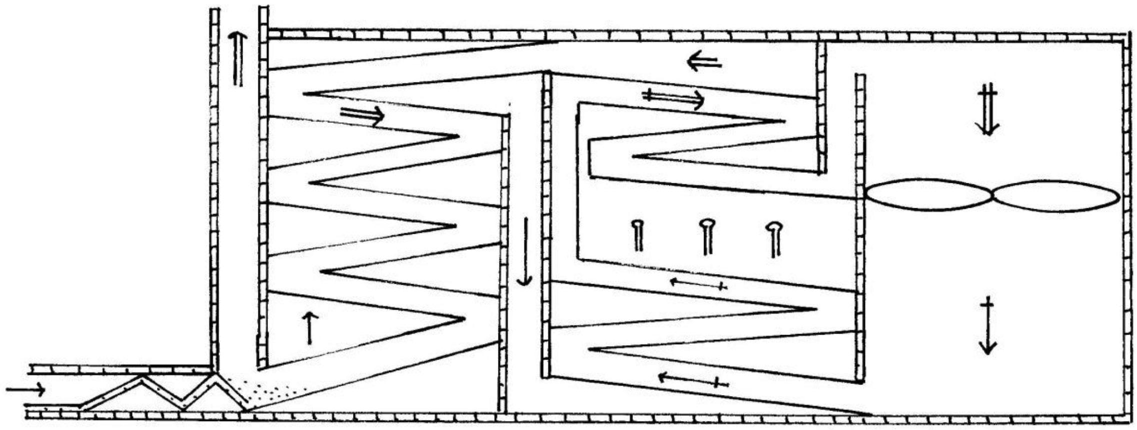

Figure 3

Figures 2 and 3 illustrate air from the turbine chamber flowing through the heat exchanger. This parallels domestic boilers where water flows through the heat exchanger and power station boilers where water tubes take heat from the furnace. In Figure 3 the heat exchanger is designed so that cool air from the turbine equilibrates with incoming air for combustion; the turbine air then passes to the top of the combustion chamber and is then brought down to immediately above the flames so that it leaves the combustion chamber at the highest available temperature to drive the turbine.

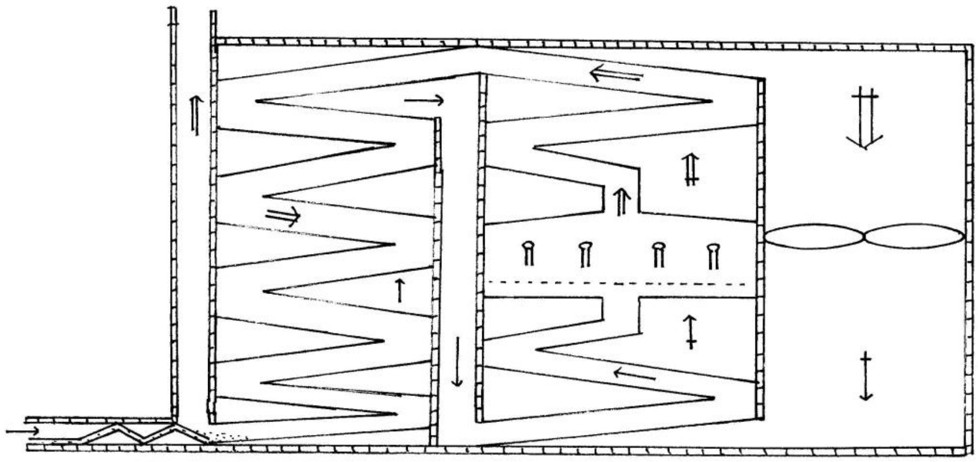

Figure 4

Figure 4 describes an alternative configuration where the incoming air for combustion and the exhaust gases are in a combustion chamber which also serves as the heat exchanger. This has the advantage of providing a faster route for the turbine air to carry kinetic energy to the adjacent chamber. The heat exchanger would be of elaborate bends and finning so that it increases the residence time of exhaust gases in the combustion chamber to enhance heat transfer.

It is assumed that combustion takes place under natural draft with no pumps or fans. As the hot combustion products rise they draw in replacement air. For highest efficiency there needs to be the least possible excess air and the lowest possible flue gas temperature. For these reasons low temperature combustion is preferred where heat transfer will take place from the burners mainly by convection.

Energy Recovery/Condensing Heat Exchanger

Efficient heat recovery from the flue gases is of critical importance including condensation of the water vapour present. This can be achieved by using exit gases to prewarm incoming air in a countercurrent heat exchanger as in Figure 5.

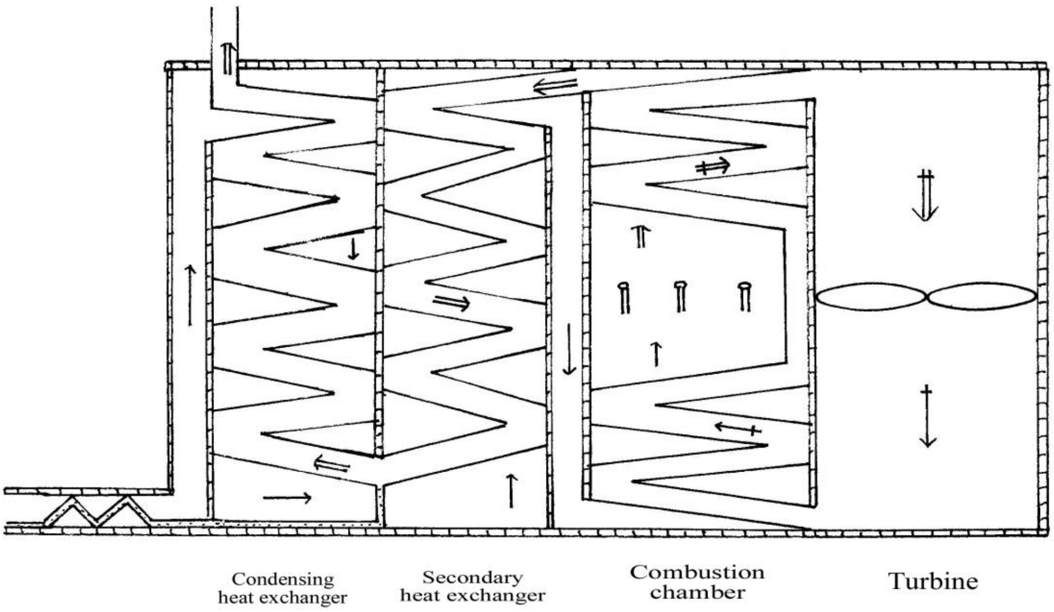

Figure 5

Incoming air and exit gases both follow a quite tortuous route but this will ensure efficient heat transfer. Combustion produces warm gases which rise drawing in replacement air. Over 90% of the heat of combustion is transferred to the turbine air circuit. Flue gases leave the combustion chamber but will be cooled to below 50°C by incoming air in the secondary heat exchanger. As the exit air travels up the condensing heat exchanger, water vapour condenses. This follows the drainage path indicated and can be used to preheat incoming air.

For a condensing gas boiler [4]

flue gas temperature	60	50	40	30	°C
condensing boiler efficiency	88	92	94	97	%

The lower is the flue gas temperature the higher will be the efficiency of the convector generator.

Vertical Arrangement for Convector Generator

In the preceding figures it has been considered that the most straightforward arrangement for the three main components would be lateral. But other geometries are possible:

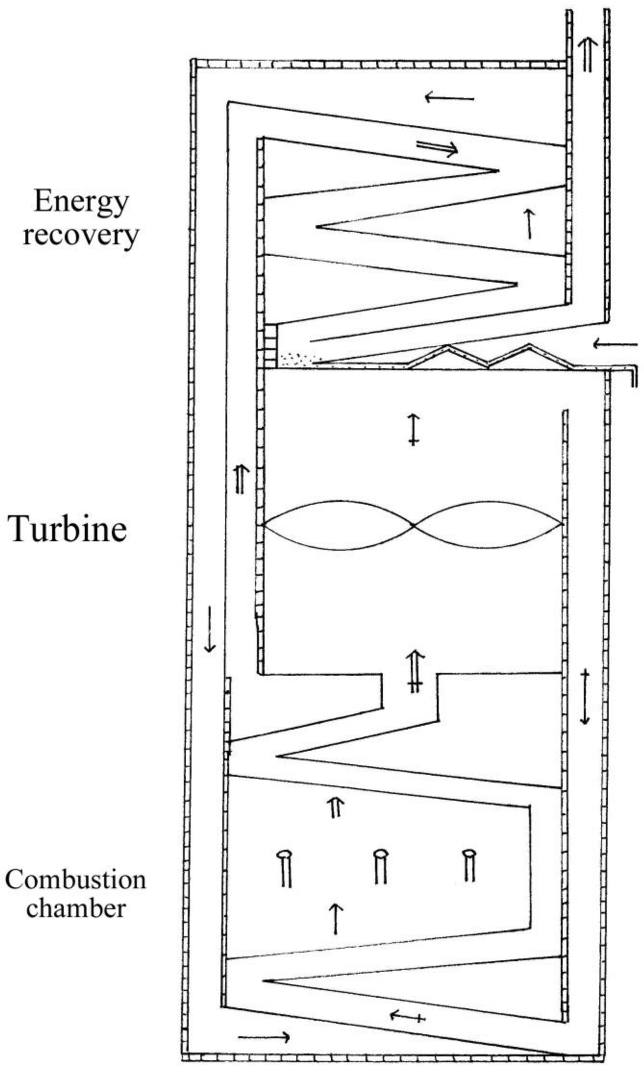

Figure 6

In the vertical arrangement in Figure 6 the combustion chamber is at the bottom with the turbine chamber above and the energy recovery/condensation unit on top. Consider the system in operation. As combustion proceeds over 90% of the heat energy evolved is transferred into the turbine gas circuit. The gas is warmed and rises turning the turbine and surrendering its excess kinetic energy. The cooled gas is heavier and descends as indicated to the lower levels of the combustion chamber. Convection currents will continue the circulation as long as combustion proceeds. The energy cycle completed is at constant external volume and has a theoretical efficiency of up to 100%.

Turning to the combustion products, the exhaust gases rise from the combustion chamber into the energy recovery unit. This is a countercurrent heat exchanger where the excess energy in the exit gases pre-warms incoming air. It is designed to condense the water vapour from the flue gases whose temperature would be reduced to below 50°C. Incoming air at ambient temperature is prewarmed in the upper heat exchanger and then enters the lowest levels of the combustion chamber.

There are no pumps or fans. The entire system is driven by convection currents. The amount of combustion is simply controlled by the amount of fuel. If the exterior structure is rigorously insulated the only energy loss is through that structure and in the flue gases. It should be possible to convert the heat of combustion into electricity with up to 90% efficiency.

Concentric Arrangement

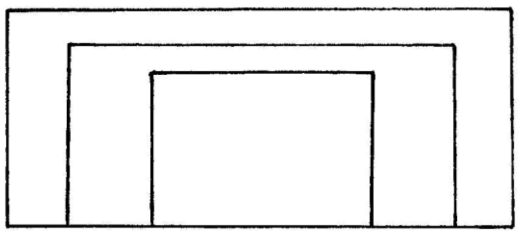

Figure 7

A concentric arrangement could be devised (Figure 7) where the inner cylinder is the combustion chamber, the middle section houses the turbine and the outer cylinder is for energy recovery. This could have the advantage of outstanding energy conservation especially if the outer cylinder heat exchanger was of a wraparound design. If there were several layers of heat exchange surface, cooling as the gases travel outward and with a well insulated exterior, very high efficiency should be possible.

Car Engine

If the convector generator provides efficient conversion of heat into electricity, the principles could be adapted for use with a liquid fuel and conversion into mechanical energy. The author has 'designed' (sketched) a concentric spherical or concentric cylindrical engine where the inner vessel is the combustion chamber, the intermediate vessel rotates conveying its energy by a vertical axle, whilst the outer layer is for energy recovery. Combustion is continuous, not by explosion, but high efficiency of conversion of heat into mechanical energy should again be possible.

Oil/Coal Power Stations

The Convector Generator proposal has been developed for application to large scale generation of electricity in gas power stations. It could also be miniaturised to microturbines or even household electricity generation. The principles could also apply to generation of electricity from fuel oil and from coal. These fuels do not have the extraordinary convenience and ease of handling of natural gas but their feed into burners and the clean up of their flue gases could be built on to their combustion in a Convector Generator.

References

[1] IEA, World Power 2003 Page 8-12
[2] Modern Power Systems, July 2003 Page 3, Wilmington Publishers, Kent.
[3] Energy – a guidebook, Janet Ramage Page 225, Oxford University Press, 1997.
[4] www.emeraldenergy.ie/info/boiler-efficiency November 2003

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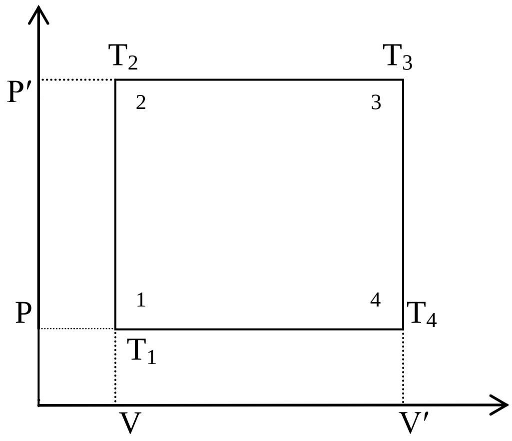
Appendix

Energy Cycles at Constant Volume

Consider the energy cycle depicted in the P-V diagram below with 2 stages at constant volume and 2 stages at constant pressure:



Initial state 1 – a fixed mass of gas volume V pressure P and temperature T_1

Stage 1-2 the gas is heated at constant volume to temperature T_2 raising pressure to P′ Heat input $C_v\,(T_2 - T_1)$

Stage 2-3 the gas is heated at constant pressure to temperature T_3 and volume V′ Heat input $C_p\,(T_3 - T_2)$

Stage 3-4 work done by gas at constant volume so that pressure falls to P and temperature falls to T_4
There is no heat input $Q = \Delta U + W = 0$
work done by the gas $C_v\,(T_3 - T_4)$

Stage 4-1 heat taken out of the gas into energy sink at constant pressure so that volume returns to V and temperature to T_1

$$\text{Efficiency} = \frac{\text{useful work achieved}}{\text{total heat input}}$$

$$= \frac{C_v\,(T_3 - T_4)}{C_v\,(T_2 - T_1) + C_p\,(T_3 - T_2)}$$

Now consider the energy cycle portrayed approximating towards a constant volume heat engine

As $V' \to V$ $T_4 \to T_1$ $T_3 \to T_2$ and $(T_3 - T_2) \to 0$

$$\text{Efficiency} \to \frac{C_v\,(T_2 - T_1)}{C_v\,(T_2 - T_1)} \to 100\%$$

If an energy cycle can be devised with the entire heat input and extraction of work at constant volume, it will have a maximum theoretical efficiency of 100%.