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CHP AND ENERGY CONSERVATION

James A. McGovern, Director of the Applied Thermodynamics and Energy Research Group at Trinity College Dublin, responds to the article by Peter J. Byrne in the April issue and continues the debate on energy conservation, environmental and economic aspects, in the use of gas engines for combined heat and power.

CHP IS PREFERABLE to the provision of heating by the direct combustion of gas while also using electricity that is generated in power stations from gas. Less fuel energy is required to produce the same end effects. There is less impact on the environment.

The Value of Heat

One unit of energy as heat can generally be provided at a much lower fuel-energy-cost than one unit of energy as electricity. The Second Law of Thermodynamics distinguishes between heat and work or electricity. The Second Law value of heat depends on the temperature at which it is supplied. Heat would only be as valuable as work (or electricity) if it were supplied at an infinite temperature. Heat at the temperature of the environment has no Second Law value. Indeed, such heat is freely available from the environment. The economic value of heat is rather more complex, but is strongly influenced by the Second Law value. By means of a relatively simple plant, most of the calorific value of a fuel can be converted to heating. A rather more complex plant is required to convert a third (or possibly half) of the the calorific value to electricity. Heating is therefore less valuable than electricity in economic terms. By using heat pumps, or using reject heat from existing processes, heating at low temperatures can be provided at lower cost than high temperature heating. Therefore the economic value of heating depends on its temperature level. A CHP plant has two types of energy output. Therefore it is not very meaningful to describe its efficiency as the total energy output as heat and electricity divided by the fuel energy input. Such an "energy efficiency" is also unsatisfactory as the *"efficiency"* could turn out to have a value greater than 100%; even given the non-ideal characteristics of real components. For instance, a power station with a thermal efficiency of 50% that supplied half of its electricity to a heat pump having a coefficient of performance of f our would have an *efficiency* as a CHP plant of 125%.

The Efficiency Problem

CHP is often justified in a way that would seem to imply that electricity generating stations are needlessly and unavoidably wasteful of energy. This is not so. The best modern gas-fired electricity generating stations (combined cycle plants) produce electricity w ith a thermal efficiency greater than 50%. They reject an amount of energy to the environment that is the balance of the calorific value of the fuel burned. This heat transfer to the environment occurs at a temperature close to that of the environment itself. Situations where the heat rejected from a high-efficiency power station of this type could be used for some other useful purpose (without increasing the temperature at which the heat rejection occurs) are practically non-existent. The energy that is rejected is worthless; both practically and economically. Yes, there is an efficiency problem in even the best electricity generating stations. However, this problem cannot be solved by simply using the energy that is transferred to the environment. The problem is due to a technological barrier that, fortunately, is being pushed forward steadily. The true efficiency problem in a generating station lies almost entirely in the combustion process. It is in the combustion process that much of the potential of the fuel to produce electricity (or any other useful effect such as heating or cooling) is destroyed. Except for this one weakness, a modern power station is highly efficient due to the many efficiency-enhancing features that are incorporated within it. The efficiency problem associated with combustion is common to all fuel-fired engines (including power stations) and all direct-combustion heating devices. Indeed, the magnitude of the problem is much greater for direct-combustion devices that provide heat at moderate temperatures (for instance, 80°C to 120°C) than it is for power stations. There is a figure of merit used by thermodynamicists that takes account of the different Second Law values of heat and work (or electricity): this is the rational efficiency (1)(2). While the overall *rational efficiency* of a high-efficiency power station would be about 50%, the corresponding rational efficiency for a high-efficiency boiler that provided steam heating at 120 C would be only about 23%. Heaters or boilers that provided heating at lower temperatures would have even lower rational efficiencies. The potential of a fuel for producing work (e.g., by means of an ideal fuel cell) is known as its exergy. For natural gas this is 1. 068 times the Lower Calorific Value. The wastage of the potential work of a fuel that inevitably occurs with combustion can be reduced. To achieve this the heat transfer from the combustion process must be used at the highest possible temperature. The most efficie nt gas turbine engines make use of the combustion heat transfer at very high temperatures (up to 1093° C). At present a combined cycle plant that consists of a high-efficiency gas turbine engine and a steam cycle can out-perform single cycle plants (such as conventional steam power plants, gas turbine engines, or reciprocating engines) by a large margin. Significant further improvements are expected in the thermal efficiency of gas turbine engines and thus of combined cycle plants (3).

The Temperature Matching Problem

The most efficient gas turbine engines currently available have thermal efficiencies of about 39%. They have exhaust temperatures of about 465° C. Such temperatures are well above those that are usually required for industrial heating. The only practical method of avoiding Second Law wastage of potential work is to use a steam cycle to accept the heat rejection from the gas turbine engine. The steam cycle provides additional electricity and its condenser serves as an isothermal source of process heat at an appropriate temperature. Alternatively, the steam cycle can produce even more electricity by rejecting heat to the environment.

CHP Options

CHP can be provided on-site using reciprocating or gas turbine single-cycle engines, even on quite a small scale. It can also be pro vided, in the more traditional way, using a steam plant with a back pressure turbine. Where a combined cycle CHP plant can be installed on site, the overall rational efficiency can be significantly higher and can equal that of the best power-only generating stations. Electricity generating stations can be built to provide CHP by exporting hot water or steam as well as electricity. In principle, these are capable of achieving similar rational efficiencies to power-only stations. Existing power stations can provide CHP that is distributed as electricity. The conversion of some of the electric power to heating can be done by the end-user by means of heat pumps. This may be an economically viable option where the heating is required at temperatures up to about 60° C and where the environment (air, water, or ground) is used as the "heat source" for the heat pumps. The overall rational efficiency of this arrangement will be somewhat lower than that of the power station that supplies the electricity.

Load Matching

Most CHP plants have a ratio of heating output to power output that cannot be varied much without wastage. There may also be constraints on the possibilities for efficient power turn-down. A relatively steady heating demand is therefore desirable. Electricity can be bought or sold to cope with large power demand variations.

Conclusions

CHP plants are an option to be considered in situations where both heating and electricity are required. Their contribution to the conservation of fuel energy is because they reduce the provision of heating by the highly inefficient direct-combustion process. In terms of reduced environmental impact and the conservation of fuel energy, CHP plants can make a very significant contribution. They should incorporate efficient engines for the production of the power component and should not involve large temperature differences in the provision of heating. However, the promotion of small and medium sized CHP installations should not be viewed as an alternative to the construction of new high-efficiency electricity generating stations as demand requires or to the upgrading of existing power stations to improve their efficiency when advances in technology allow this. Eventually, economics (in the context of Irish Government and European Union policy and actions) will determine the level of uptake of on-site CHP by users.

References

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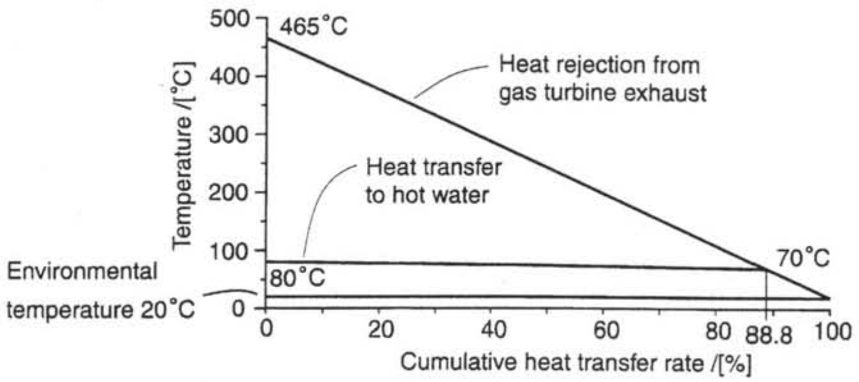
Temperature Mismatch



The large difference between the temperature at which heat rejection occurs from the exhaust gases and that at which heat is supplied to the hot water causes great wastage of potential work. It can be shown that the potential work of the heat rejected from the exhaust is 39% of the total heat rejection, while the potential work of the heat supplied to the hot water is only 1.8% of the total heat rejection.

The Second Law Value of Heat

By using the Second Law of Thermodynamics, heat transfer at a given temperature can be associated with the work input or output of an ideal heat engine. The ideal engine would also transfer heat to or from the environment. In this sense the heat transfer can be ex pressed as potential work:

$$W_Q = \frac{T - T_0}{T} Q$$

where

Q is the amount of heat transfer

W_Q is the Second Law potential work of the heat transfer (this is also known as the exergy transfer)

T is the absolute temperature (in kevin) at which the heat transfer occurs

T_0 is the absolute temperature of the environment.

The Second Law potential work can be regarded as the minimum amount of work that would be required to produce the heat transfer. Equally, it can be viewed as the maximum work that could be produced as a result of the heat transfer.

Example

Assume that the temperature of the environment is 20° C (293.15 K). Assume heat transfer is provided at the rate of 100 kW and at a temperature of 80° C (353.15 K). The potential work rate according to the Second Law is

$$\frac{353.15-293.15}{353.15} \ 100 \text{ kW} = 16.99 \text{ kW}$$