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Profiles

Understanding coal-fired power plant cycles

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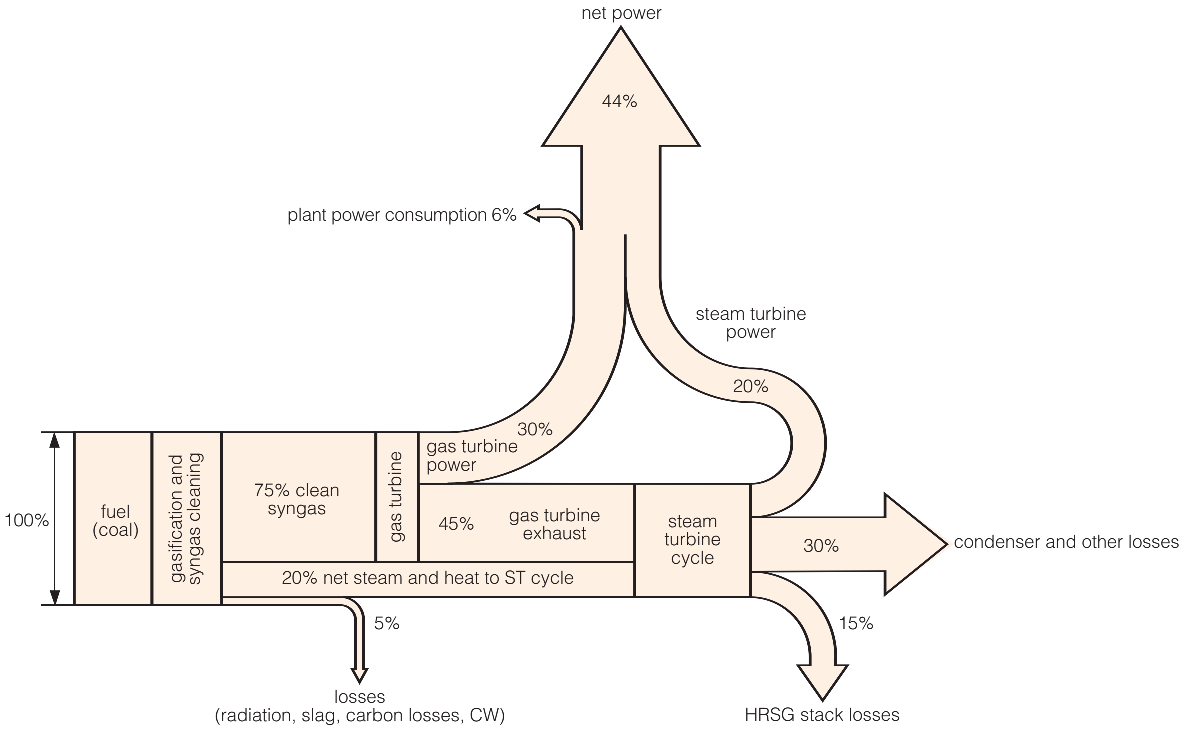

Indicative energy flow diagram for IGCC

Heat engines exploit the work done in a cycle of expansions and compressions of a fluid as heat is added and lower temperature heat is rejected. Large scale power generation systems use heat engine cycles to convert heat into rotational energy for turning an alternator. Most coal-fired units use pulverised coal combustion (PCC) to provide high pressure superheated steam that drives a turbine. Coal-fuelled plants can also, like natural gas fired plants, be based on combined cycles, which use gas turbines as well as steam turbines. This report provides an introduction to the principles of both types of system with background on the thermodynamics of heat engines to support the descriptions of cycles.

In a steam turbine, the steam is expanded while its energy is converted into mechanical work as it passes over static and moving blades within high-, intermediate- and low-pressure turbine sections. The emerging steam is re-condensed then pumped back to the boiler after pre-heating. Main steam temperature and cooling water temperature have a major effect on efficiency since this is thermodynamically increased as the temperature range over which the engine operates is increased. Higher main steam pressure and feedwater temperatures also have a positive effect on efficiency. The efficiency of state of-the-art PCC units is 45-47%, LHV (lower heating value) basis, at cold sea water cooling locations. Such plants use supercritical main steam conditions with pressures approaching 30 MPa and temperatures around 600ºC. All large steam turbine cycles use reheat of intermediate pressure steam and multiple stages of feedwater pre-heating.

Heat for the steam cycle has to be extracted from the chemical energy in the coal first. Modern PCC boilers have percentage efficiencies in the low-mid 90s. It appears unlikely that there is much room for further large gains in the efficiency of such boilers.

Materials development programmes are in progress in different parts of the world to reach higher steam conditions in boilers to realise coal-fired power plant efficiencies beyond 50%, LHV basis. Superalloys based on nickel are promising, but are more expensive than current materials, although costs are decreasing and only parts of the plant will need to accommodate the most extreme conditions. For turbines, advanced materials, also based on nickel alloys, and more effective cooling arrangements are being developed.

Combined cycles exploit the thermodynamically more favourable high inlet temperature of gas turbines in an arrangement in which the hot turbine exit gases also provide heat for a steam cycle. Gas turbine damage from combustion residues has to be avoided, and two main approaches are in use. The first, pressurised fluidised bed combustion (PFBC), employs pressurised combustion of the coal then particulates removal before expansion of the hot flue gas through the turbine expander. The other approach, integrated gasification combined cycle (IGCC), is to convert coal into a fuel gas, clean the gas, then fire it in a gas turbine. IGCC permits higher turbine inlet temperatures to be achieved compared with PFBC.

In PFBC, the effect of using the gas turbine is to increase the efficiency by around 3 percentage points compared with PCC using similar steam conditions. Factors determining performance include carbon utilisation, main steam temperature and pressure, cooling water temperature and gas cleaning system. Reheat steam cycles are economic for larger units. PFBC has reached efficiencies of 44%, LHV basis, using supercritical conditions, and further advance would in principle be possible if steam conditions continued to be raised.

For IGCC, there are many alternative gasifier types and configurations and the nature of the coal to be used will determine which technology to use. The associated water-steam cycle depends on the gasification and gas clean- up technologies. Factors determining performance include gasification technology, carbon utilisation, cold gas efficiency, gas turbine design and gas clean-up system. Expected future progression in the efficiency of IGCC cycles beyond their current 45%, LHV basis, will come largely from the use of advances in gas turbines, with new materials, compressor intercooling and reheat.

Future coal-fired power stations will probably need to accommodate carbon dioxide (CO_2) capture. This will change energy flows and reduce efficiency. PCC-based systems with CO_2 capture may use chemical scrubbing systems to remove CO_2 from the flue gas stream of a relatively conventional plant, or a more radical approach would use a recycled flue gas/oxygen mixture for combustion of the coal. The CO_2-rich gases from the boiler would be cooled, condensate removed, the recycle stream returned, and the balance of CO_2 taken off. For IGCC, cleaned gasifier product gas would be converted to hydrogen plus CO_2 using a shift reaction, the CO_2 separated, then the hydrogen burnt in the gas turbine. The advantage of such a system is that the shifted fuel gas is at elevated pressure and the CO_2 in higher concentration so it should be removable by purely physical means at lower efficiency penalty.

There are alternatives to heat engines for converting the chemical energy in the fuel into work. This can avoid the inherent limitations on efficiency that heat engines have. An example is the fuel cell, although these are still in need of much development for use in large scale power generation from coal. Integrated gasification fuel cell configurations have been conceived that maintain high efficiency while capturing CO_2.

Each issue of *Profiles* is based on a detailed study undertaken by IEA Clean Coal Centre, the full report of which is available separately. This particular issue of *Profiles* is based on the report:

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