Energy Scavenging in Thermal Power Plants equipped with Carbon Capture and Storage technology

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Abstract:
In recent times there has been an increased focus on the environmental impact of growing energy consumption of both developed and developing countries. With global energy consumption expected to rise by 30% by the year 2030 [1], improving the thermal efficiency of power plants forms part of a long term goal in reducing these plants carbon footprints in order to meet legislative targets. This poster presents the background to a research project investigating the performance of thermoelectric devices in the conversion of waste heat energy to useful work in order to improve cycle efficiency in thermal power plants including those equipped with carbon capture and storage technologies.

1. Improving Cycle Efficiency

Modern supercritical coal fired power plants are now able to achieve 45% efficiency [2] in converting heat energy to electrical power, however applying Carbon Capture and Storage (CCS) technologies to a supercritical plant typically results in an efficiency reduction of 10% points. In order to improve this, the amount of waste heat energy in supercritical coal fired power plants with and without CCS technologies was investigated with a view to reclaiming waste energy and converting it to useful energy.
Focusing on the two CCS technologies that are being researched by Doosan Power Systems, namely Post Combustion CO_2 Capture (PCC) shown in Figure 1, and Oxyfuel Combustion, there were found to be several locations where heat energy is rejected. This rejected heat energy can be converted to electrical power by Thermoelectric Generators (TEG's).

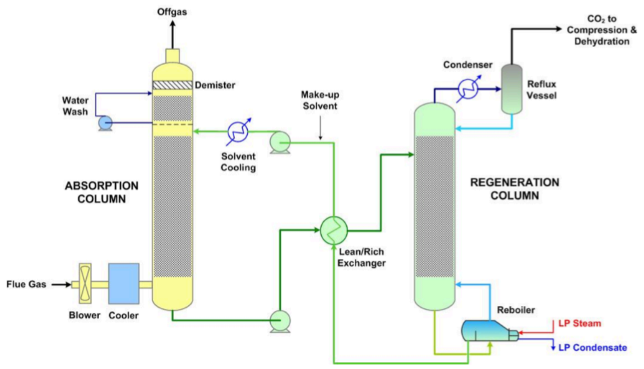

Figure 1: Example of the Post Combustion CO_2 capture process currently being developed by Doosan Power Systems [3].

2. Heat Scavenging

The Seebeck effect occurs when a temperature gradient is applied to a p-type or n-type semiconductor and as a result, a current flows generating a DC voltage (Figure 2). Hence from Equation 1, large temperature differentials will maximise the power output from the TEG [4].
The opposite of the Seebeck effect is the Peltier effect (see Equation 2), where the application of a voltage results in the pumping of heat from one side of the device to the other. The performance of a heat pump can be measured by the Coefficient of Performance (CoP) (Equation 3). This shows that for a desirable large CoP, heat produced (Q_H) should be greater than the power in (W). Although CoP of heat pumping is generally low, this application has further advantages leading to a reduction in coal required to generate the electricity required to power the heat pump.

The efficiency of a thermoelectric generator operating at a temperature differential of 100°C is typically 2-3% and the figure of merit (ZT) is set to increase with developments in semiconductor technology.

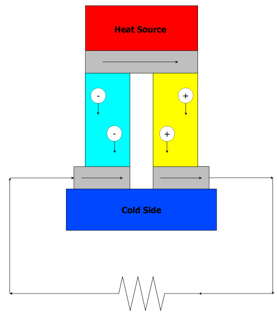

Figure 2: Flow of current (depicted by arrows) in a thermoelectric generator operating in the Seebeck mode.

$$\alpha_{ab} = \frac{V}{\Delta T}$$

Equation 1: Seebeck coefficient for materials a and b.

$$\pi_{ab} = \alpha_{ab} T_{cold}$$

Equation 2: Peltier coefficient for materials a and b.

$$CoP = \frac{Q_H}{W} = \frac{T_H}{\Delta T}$$

Equation 3: Coefficient of Performance of heat pumping.

3. Benefits

The cost of generating electricity is set to increase due to rising fuel costs and the introduction of carbon credits [5]. Using TEG's to increase the cycle efficiency of plant results in a reduction in coal consumption and CO_2 emissions.
Plant cycle efficiency will increase due to the net plant generation capacity increasing for the same amount of coal or fuel supplied. Plant components can be operated using power from thermoelectric generators, reducing the auxiliary power overhead to the plant. This directly impacts the cost of generation and will reduce the wholesale price (£/MWh_e).
Similarly for CO_2 emissions, reducing these costs will lead to a significant advantage as carbon will soon become an expense that has to be minimised to ensure plants remain profitable.

4. Future Work

Both power generation efficiency and CoP of thermoelectric devices are set to improve with several promising developments striving towards obtaining a figure of merit (ZT) >>1.
There is sufficient scope to investigate thermoelectric devices in energy scavenging applications for thermal power plants, including those equipped with CCS technology. Further work includes a thermodynamic model of thermoelectric devices in both power generation and heat pumping configurations for application around a plant.

References:
1. World Energy Outlook Executive Summary, International Energy Agency. Report (2009)
2. A Strategy for Developing Carbon Abatement Technologies for Fossil Fuel Use. Department for Trade and Industry Report (2005)
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4. CRC Handbook on Thermoelectrics, Macro to Nano. DM Rowe
5. Cost and Performance Comparison Baseline for Fossil Energy Power Plants. U.S Department of Energy, U.S. Government. Parsons et al. (2007)

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