Using a context-based approach to undergraduate chemistry teaching – a case study for introductory physical chemistry

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Appendix 1.
Student worksheets for the *Capital City* case study, Session 2, which addresses fossil fuel combustion. The worksheets include e-mail correspondence for the beginning and end of the session, a briefing paper and a description of the operating conditions for one of the fuels.

From: <M Spark>
To: <Capital City Advisory Group>
Subject: Capital City project
Attachment: <<Energy sources seminar doc 998 675-98>>

Dear All

Having considered the outcomes from our initial discussions, together with those from some of our competitors, the Department of Energetic Affairs has ruled out a number of options and drawn up a list of their top 6 energy preferences. They want us to look at steam plants powered by various fossil fuels in the first instance.

We all need to come up to speed, so I've attached a background paper on steam power plants. Please review this, and then I'll let you know what they need from us in more detail.

Thanks

M Spark
Account Director

These notes were found from a previous study and are not complete

Steam power plants

The heat engine cycle in a steam turbine power plant operates as shown in Figure 2.1.

The combustion of the fuel in the firebox generates water and carbon dioxide and releases heat (Q_H) according to standard enthalpy changes. This energy is transferred to the steam in the boiler, which under increasing pressure, becomes a superheated steam. By considering the first law of thermodynamics (i.e. energy cannot be created nor destroyed but merely changed from one form to another), the energy released can be calculated. The superheated steam leaving the boiler then enters the steam turbine throttle, where it powers the turbine with subsequent generation of electricity, W.

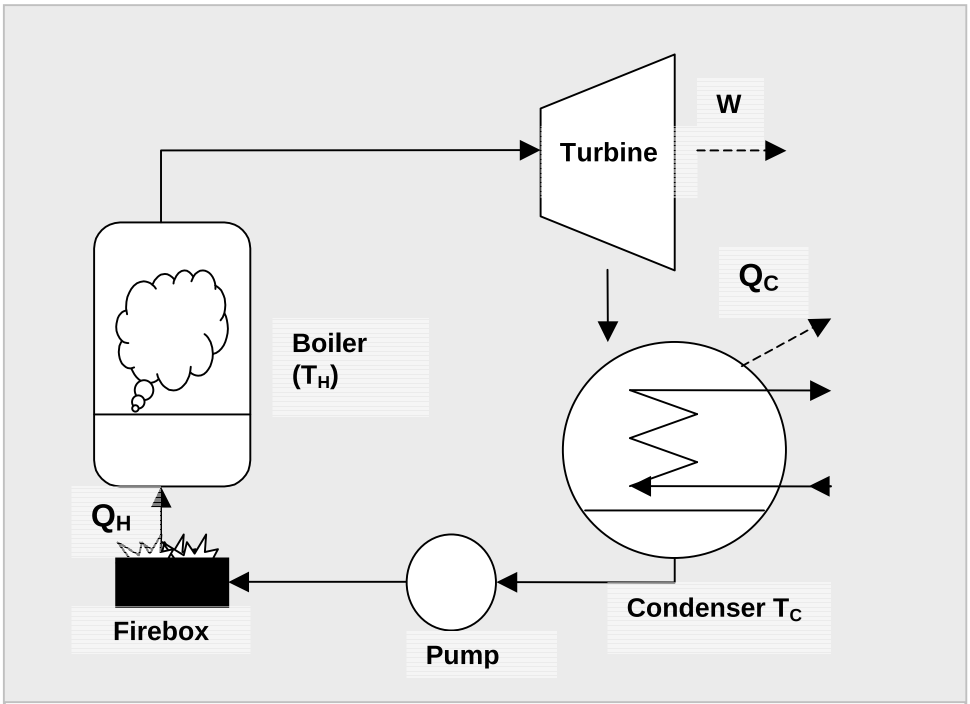


Figure 2.1 Schematic diagram of a fossil fuel driven steam turbine

After the steam expands through the turbine, it is condensed with heat transfer, Q_C, to the cooling water. This condensate is then returned to the boiler through high-pressure pumps for reuse.

Since the cyclic nature of the process requires that there is no change in the internal energy upon completing one cycle, the first law of thermodynamics implies that

$$Q_H = W + Q_C \qquad \text{Equation 2.1}$$

The second law of thermodynamics states that not all of the supplied heat in a heat engine can be used to do work, and the efficiency, ε, is defined by Equation 2.2.

$$\varepsilon = W/Q_H \qquad \text{Equation 2.2}$$

The most efficient heat engine cycle allowed by physical laws, the Carnot cycle, takes place when no energy is wasted, with an increase in the total entropy (S = Q/T), which means that:

$$Q_H / T_H = Q_C / T_C \qquad \text{Equation 2.3}$$

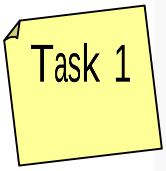
The temperatures (T) are given in Kelvin. However, due to heat/energy losses occurring in the boiler, the turbine and the generator, this is only the theoretical efficiency of the plant and a true efficiency of ca. 60% of the theoretical one for the Carnot cycle can be expected (Equation 2.4).

$$\varepsilon = \varepsilon_{carnot} \times 0.6 \qquad \text{Equation 2.4}$$

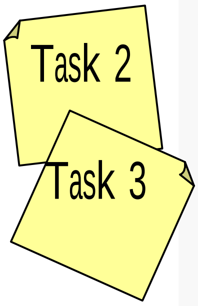
From: <M Spark>
To: <Capital City Advisory Group>
Subject: Capital City project

Dear All

The Department of Energetic Affairs has asked that we summarise and compare data on fossil fuel plants for them. I think the quickest way is to divide ourselves into groups and then pool our efforts in one report.



I have summarised the scenario for each group. The key numbers common to all of us are in the table below. You'll firstly need to derive an expression of ε_{carnot} which depends only on the two temperatures T_C and T_H. Some of you may already know this expression.



Then we need to compare all the data. Let's make a comparison (e.g. in a table format) of your power plant with those of other groups, and with the currently used power source.

I would also like each group to consider why, in view of the efficiency, the volume of water in a pond is more crucial than in a stream when they are used as sources of cooling water. This may be important if we wish to reconsider building a new power plant on a new site.

Let's meet later today – it is essential that you present your results so that they can easily be compared to the current plant and those of other groups. I'll also need you to outline any advantages and disadvantages of the different alternatives that you may have thought of.

Molecular formula	State	ΔH_f^0 [kJ mol^{-1}]
H_2O	l	-286
NO	g	90
NO_2	g	33
HNO_3	l	-174
O_3	g	143
SO_2	g	-297
SO_3	g	-454
H_2SO_4	l	-814
CO	g	-110.5
CO_2	g	-393.5
CH_4	g	-74.4
C_2H_6	g	-84
C_4H_{10}	g	-126
C_6H_{14}	l	-199
C_8H_{18}	l	-250
Fuel oil ($C_{18}H_{38}$)	l	-660.1
(-CH-) in a Bituminous coal (Bit)	s	-117.4
(-CH-) in a Sub-bituminous coal (Sub)	s	-219.6

M Spark
Account Director

Group 1

From: <M Spark>
To: <Capital City Advisory Group>
Subject: Group 1. Large coal fired steam power plant using high rank fuel

Dear All

You are looking at a large-scale coal fired steam power plant with an estimated working life of 50 years. The building material to be used allows an average boiling temperature of about 550°C.

The construction of this type of plant takes about 4 years and will result in fixed charges (capital and interest repayments) of approximately M$65 ($\$6.5 \times 10^7$) per year in use. On top of this there are operation and maintenance costs in the region of M$15 per year.

The fuel, burned at 2400 K at a rate of 50 kg s^{-1}, is a bituminous coal. This is the most common type of coal used in combustion in the USA, where it is found primarily east of the Mississippi River. It is known to have a relatively high sulphur concentration (2% by mass) and some bound nitrogen (2% by mass).

The cost, including transport, is $38 per ton of coal. It is estimated that the average cooling water temperature in the condenser would be approximately 35°C. In combustion reactions, coal can be written -CH-, since the H/C ratio can be approximated to one.

M Spark
Account Director

From: <M Spark>
To: <Capital City Advisory Group>
Subject: Capital City project

Dear All

I think we have made a good start to this project, and it is certainly very valuable to have an economic handle on a broad range of fossil fuels. However, I am aware that we must not lose sight of all the issues involved. In view of the increasing demand to produce 'green power', I think we must consider the environmental impact of burning fossil fuels, principally the production of CO_2, NO and SO_2. I will need you to produce some data on these emissions for your fuel before we next meet. It is essential that we have this data before we consider the environmental impact further.

Thanks

M Spark
Account Director