The Ins and Outs of Coal Fired Power Generation.

People find it amazing that the tonnage of gases produced by coal fired power stations is far greater than the tonnage of coal burnt in that station. Magic multiplication? No, it's just chemistry.

The Composition of Coal

Figures vary from station to station depending on the precise composition of the coal. Below is a reasonable approximation of the relevant compositions of black coals burnt in Australian power stations:

- Carbon 67%
- Hydrogen 4%
- Oxygen 5%
- Water 10%
- Ash 13%
- Other 1%

TOTAL 100%

(Brown coal is different with far more water and less of everything else.)

What is in "ash" and "other"?

Coal is derived from natural plant material, so its constituents are as harmless as plant material. Once the hydrocarbons are burnt, converted into gases, what is left are mainly minerals containing elements such as calcium, sodium, magnesium, silica, sulphur, nitrogen and phosphorus, with minor chlorine and minute quantities of other trace elements all required by growing plants.

The Process of Combustion

Every organic compound can be burnt in air to produce heat, water vapour and carbon dioxide.

The fuel elements in coal, as in all vegetable matter, are carbon and hydrogen, and in the combustion process these fuels combine with oxygen from air to produce water vapour and carbon dioxide.

For efficient combustion that extracts the maximum heat from the fuel, the boiler needs exactly the right amount of oxygen to ensure all coal is burnt – not enough and some fuel will remain unburnt; too much and the boiler is cooled by the excess air.

To burn one tonne of pure carbon needs 2.67 tonnes of oxygen and will produce 3.67 tonnes of carbon dioxide. That is calculated like this:

Here is the chemical equation for combustion of carbon in coal:

$$C + O_2 = CO_2 + HEAT$$

Each carbon atom (with an atomic weight of 12), combines with two oxygen atoms (with a combined atomic weight of 32) to produce one molecule of carbon dioxide (whose molecular weight is 44). So for every 12 tonnes of carbon, you need 32 tonnes of oxygen and will produce 44 tonnes of carbon dioxide. And if you start with just one tonne of carbon, it will need 32/12 = 2.67) tonnes of oxygen to produce 44/12 =3.67) tonnes of carbon dioxide.

Our typical thermal coal assumed above has only about 67% carbon, so each tonne of coal will need 67% of 2.67 tonnes of oxygen (1.8 tonnes) and will produce 67% of 3.67 tonnes of carbon dioxide (2.5 tonnes).

The Input/Output Balance

Matter cannot be created or destroyed – in a power station the matter just moves around and changes its form, releasing heat energy in the process.

From the above calculation we see that 1 tonne of coal and 1.8 tonnes of oxygen goes into the boiler and 2.5 tonnes of carbon dioxide comes out.

But a little more oxygen is required to burn the hydrogen in the coal – in the case above, an extra 0.2 tonnes of oxygen per tonne of coal. This combustion produces water vapour.

So to efficiently burn all carbon and hydrogen in one tonne of coal needs about 2 tonnes of oxygen from the air. (In practice, in order to ensure all fuel is consumed, a small amount of excess air is added.)

Let us now consider the nature of our air.

“Air” is mainly nitrogen. The approximate figures for the composition of air today are:

- Nitrogen 75%
- Oxygen 19%
- Water 4%
- Argon 1%
- Carbon Dioxide 0.036%
- Other 0.964%

TOTAL 100%

Using these figures we can calculate that if the boiler takes in enough air to get 2 tonnes of oxygen per tonne of coal, it must take in 2 X 100 /19 tonnes of air, which is about 10 tonnes of air.

So the total input into the boiler per tonne of coal burnt is:

- 1 tonne of coal.
- 10 tonnes of air.

TOTAL INPUT 11 tonnes

The boiler cannot create or destroy matter – it just changes form and releases heat in that process. It follows then that 11 tonnes of matter must come out of the boiler.

Our final homework assignment is thus to account for the 11 tonnes that came into the boiler. What happened to it?

This is what is produced from the combustion of 1 tonne of coal and 10 tonnes of air:

- Nitrogen 7.5 tonnes
- Carbon dioxide 2.5 tonnes
- Water Vapour 0.9 tonnes
- Ash and other wastes 0.1 tonnes

TOTAL GASES 11 tonnes per tonne of coal burnt

The first three are gases which are exhausted from the stack. As can be seen, the dominant gas emission is nitrogen which comes from the atmosphere and goes back there. It goes through the combustion process without any change in chemistry.

Most of the carbon dioxide comes from burning of the coal, but a very small amount is derived from the carbon dioxide present in all air. The carbon in the coal was extracted from the air by growing forests eons ago, and is now returning to the atmosphere to feed new forests and other plants.

Water vapour is produced from burning the hydrogen component of the coal. Some is also added because the feed coal fuel usually has moisture in it.

Ash and other waste products make up just 0.1 tonnes per tonne of coal burnt. Most of them emerge from the combustion chambers as fused clinkers, ash and minor gases such as oxides of sulphur and nitrogen (SOX and NOX). Ash is removed by electrostatic precipitation or caught in bag filters and often used for making cement.

SOX is removed from combustion fumes by wet scrubbing, sprays, absorbent minerals or a process called flue gas desulfurization. NOX is carefully controlled by choosing low nitrogen coals and by improved burner design which keeps flame temperature low.

The water used in the steam generators is mainly recovered in the cooling towers, which are the large structures you see nightly on TV. The air that emerges from the cooling towers starts off invisible, but it is still warm and moist. Like our warm moist breath on a cold morning, as soon as this moist air hits the cooler outside air, the moisture condenses to fog. Sometimes small clouds develop above the cooling towers.

So the "dreadful dangerous fumes" shown belching into a clear blue sky on TV every second night is actually as dangerous as a fluffy white cloud and as hazardous as the fog you can see in the valleys on any foggy morning.

Comparison of Various Hydrocarbon Fuels.

Carbon based fuels (natural black coal, natural brown coal, natural oil, natural gas or natural wood) will always produce the same two so called "greenhouse" gases when burnt – carbon dioxide and water vapour.

Natural gas is composed entirely of fuel elements – just carbon and hydrogen with no ash or moisture. Thus it has high energy content per tonne. It also produces the most "greenhouse gases" per tonne of fuel when burnt in air.

Black coal has high carbon content but much lower hydrogen content per tonne of coal. It also has low moisture content. Thus it produces high carbon dioxide but less water vapour when burnt in air.

Brown coal has a very high content of moisture and low carbon per tonne of coal. Thus it produces lower carbon dioxide (and lower energy per tonne of fuel) than the other fuels.

FUEL	Carbon dioxide *Tonnes produced per tonne of fuel burnt*	Water Vapour *Tonnes produced per tonne of fuel burnt*
Methane (natural gas)	2.8	3.1
Black Coal	2.5	0.9
Brown Coal	1.0	1.0

Note on weights of gases.

A gas is just like a liquid, only far more diffuse. A diffuse gas can also be compressed far more than liquids – in fact gases can be compressed so much under high pressure that they become liquid – that is how we make "liquefied natural gas".

Some people find it difficult to imagine a gas having any weight. Those people have never taken a big empty bar-b-que bottle to the filler station. Once full (of compressed gas), it is very much heavier.

To a diver under water, a bucket of water weighs nothing. But to a human out of water, a bucket of water is very heavy – the water certainly has weight, but in water it is supported by the surrounding water and the weight cannot be noticed.

The same applies to humans who live in air – the air appears to have no weight. But to a spaceman on an airless planet, a cylinder of air is heavier than an empty cylinder. How much heavier depends on how much gas was compressed into the limited volume of the cylinder. So when we talk about "2 tonnes of oxygen" it means just that. If you had that oxygen in a cylinder, on an airless planet, it would weigh 2 tonnes more than the empty cylinder.

A barometer actually measures the weight of the column of air in the atmosphere above the instrument. A column of air with a base of one square metre weighs about 10 tonnes.

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