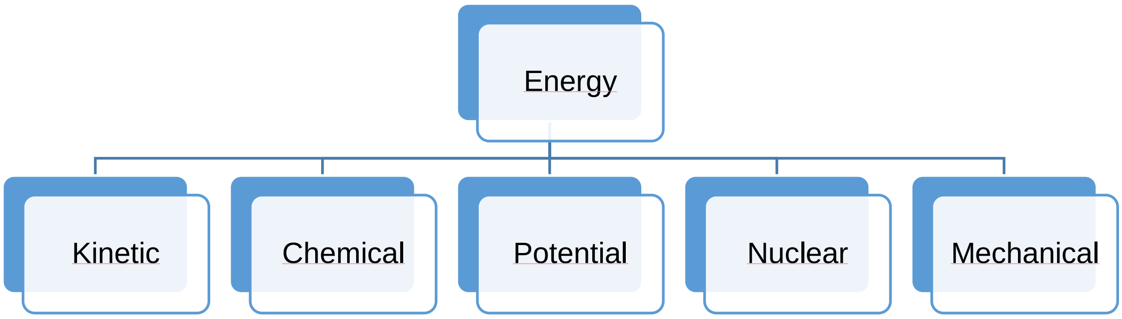
ENE 302 – Energy Conversion Processes II

WEEK 2: FOSSIL FUELS

INTRODUCTION

Generally, energy is defined in science as the capability of matter to perform work. All available energy forms may be classified as either accumulated (stored) energy or transitional energy. Examples of stored energy are chemical energy of fossil fuels, internal energy of a substance, potential energy associated with position of a mass in a force field, such as the gravitational field of the earth or an electrostatic field. Transitional energy is the energy transferred between a system and its surroundings. In the case of heat-to-work conversion, heat and work are the transitional forms of energy.
Energy is manifested in the following forms:

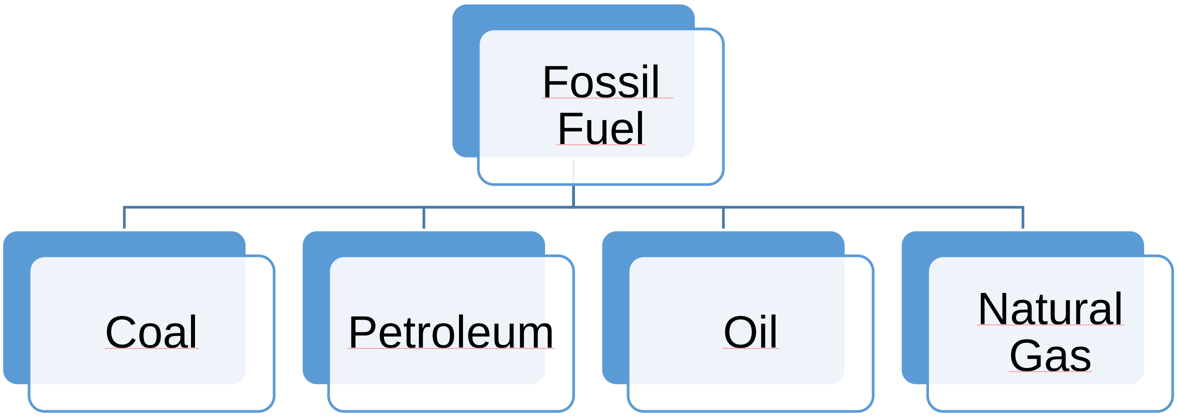


Mechanical, chemical, and electrical energy can be completely converted into thermal energy (heat). The conversion of thermal energy (heat) into mechanical energy (work) occurs in heat engines, such as steam and gas turbines, internal combustion engines (ICE), and Stirling engines.

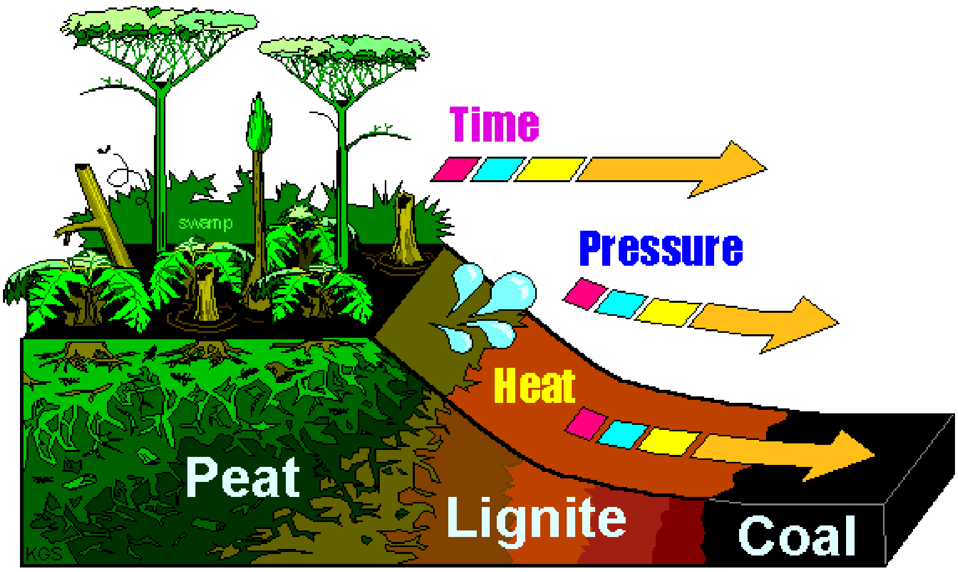
Energy can also be categorized as conventional energy, alternative energy, renewable energy, primary, secondary, end-use energy, and useful energy. Conventional energy sources are fossil fuels, including hard coal, lignite (brown coal), natural gas, coal-bed methane, pit, petroleum oil products (petrol, diesel, fuel oil), as well as artificially produced fuel types such as coal gas, liquefied gas, coke, char, as well as combustible waste materials.

Fossil fuels are the accumulated remains of living organisms that were buried millions of years ago. The term fossil fuel includes hydrocarbon-containing natural resources that are derived from animal or plant sources.

Fossil fuels described in the following forms:



Pressure and temperature are the key factors of creation mechanism of fossil fuels. this mechanism described above;



There are many using areas of fossil fuels which is;

- Energy source (Fuels) of power plants,
- Heating source of households,
- Power source of cars,
- Melting metal ores (with burning processes),

Advanteges of fossil fuels

- **Well- developed techniques**
  - The technology we use to harness the energy in fossil fuels is well developed.
- **Cheap and Reliable**
  - Fossil fuels are cheap and reliable sources of energy. They are excellent types of fuel to use for the energy base-load, as opposed to some of the more unreliable energy sources such as wind and solar.
- **Abundance**
  - here's a whole lot of fossil fuels left,. They also happen to be available pretty much anywhere in the world, it is believed there is a 300 year supply of coal.
- **Transportation**
- **High calorific effect**
- **Byproducts**

Disadvantages of fossil fuels

- **Contribute to Global Warming**
  - Fossil fuels are not green sources of energy. In fact, they contain high amounts of carbon and have been blamed for being the main contributor to global warming.
- **Unsustainable (Non-Renewable)**
  - We are spending our fossil fuel reserves in a non-sustainable manner
- **Pollution**
  - When we burned of fossil fuels a lots of chemical by products generates and these materials polluted environment.
- **Environmental hazardous**
  - The mining of coal results in the destruction of wide areas of land. Mining this fossil fuel is also difficult and may endanger the lives of miners.
- **Non-Renewable**

- Fossil fuels are non-renewable energy sources. This means that there is a finite amount of fossil fuels available and the reserves are not replenished naturally.

THEORY

Minerals and Coal are non-renewable natural resources that occur in the earth's crust. As defined by Dana, a well known physicist, mineral is a substance having definite chemical composition and internal atomic structure and formed by the inorganic processes of nature[1].

Coal is a solid stratified rock, a natural fossil fuel, occurred in layers in the earth's crust, formed many millions of years ago from the remains of decaying trees and vegetation. Large trees, many resembling giant ferns, grew in dense forests on the low lying land or in the shallow waters of the lake and succeeding generations of trees as they died and accumulated on the floor of the lake, form a vegetable sludge.

There are two kinds of coal analysis. One is proximate analysis where the percentage of moisture, volatile matter, ash and fixed carbon are determined. The other is ultimate analysis where the elements carbon, hydrogen, nitrogen, sulphur, and oxygen are determined.

Proximate analysis

Analysis of coal is very important from a point of view for the selection of coal for different purposes like combustion, carbonization, gasification and liquefaction. Proximate analysis is the most often used type of analysis for characterizing coals in connection with their utilization. The proximate analysis determines the percentage of moisture, volatile matter, ash and fixed carbon. Proximate analysis is much more readily made and gives a preliminary indication of quality and suitability for various uses.

Determination of moisture

About 1 g of −72 mesh B.S. Sieve coal sample is kept in a silica crucible and heated in a hot air oven at 105–110 ^{o}C for one hour. Thereafter, the crucible is taken out, cooled in a desiccator and weighed. The process of heating, cooling and weighing is repeated number of times till the constant weight of coal is achieved. The loss in weight is the weight of moisture.

$$\% \text{ Moisture} = \frac{\text{Weight of moisture}}{\text{Weight of original sample}} \times 100 \qquad (1.1)$$

Determination of volatile matter

About 1 g of air-dried coal of −72 mesh B.S. Sieve is weighed in a standard cylindrical silica crucible with lid. The crucible is placed in a muffle furnace of specified dimensions at 925 ^{o}C for a period of exactly seven minutes. Remove the crucible from the furnace and place on a cold iron plate to cool it rapidly. This prevents any oxidation of the contents in the crucible. Transfer the crucible to a desiccator while still warm. Allow it to cool and weigh. The loss of weight is taken as weight of volatile matter and air-dried moisture.

$$\% \text{ Volatile matter and dried moisture} = \frac{\text{Weight of volatile matter and air−dried moisture}}{\text{Weight of original sample}} \times 100 \qquad (1.2)$$

% Volatile matter= % Volatile matter and air-dried moisture − % air-dried moisture (1.3)

Determination of ash

About 1 g of air-dried coal of −72 mesh B.S. Sieve is taken in a clean dry silica crucible. The coal is distributed so that the thickness of the layer does not exceed 0.14 g per square centimeter. The crucible is put into a muffle furnace at 500 ^{o}C for 30 minutes and raised the temperature to 815 ± 10 ^{o}C in another 30 to 60 minutes.

The crucible is kept for one hour or more at this temperature until there is no loss in weight. The crucible is then taken out, cooled in a desiccator and weighed. The weight of the material left in the crucible is the weight of the ash.

$$\% \text{ Ash} = \frac{\text{Weight of ash}}{\text{Weight of original sample}} \times 100 \qquad (1.4)$$

It is also in practice to heat the coal sample directly at 750 ^{0}C till a constant weight is obtained.

Determination of fixed carbon

Fixed carbon is the pure carbon present in the coal. It is the carbon available in the coal for combustion. Higher the fixed carbon content, higher will be its calorific value.

Total carbon is the fixed carbon plus the carbon present in the volatile matters e.g. carbon monoxide, carbon dioxide, methane, hydrocarbons etc. Total carbon is always more than fixed carbon in any coal. High total carbon containing coal will have higher calorific value.

Fixed carbon is not determined directly. It is simply the difference between the sum of the other components and 100.

$$\% \text{ Fixed carbon} = 100 - (\%\text{Moisture} + \%\text{Volatile matter} + \%\text{Ash}) \qquad (1.5)$$

Expression of analytical results on different bases

The analytical results of proximate analysis can be modified by appropriate corrections to allow expressions on different bases. The most commonly used bases for reporting of analytical results are:

As received or As sampled

When the coal is received by a consumer from the mine, samples for analysis are collected, then its analysis is reported on As received basis or As sampled basis. Lot of physical and chemical changes occur during the transportation of coal from mine to the consumer and also during the processing such as size reduction, washing etc. Hence analysis of coal at consumers end is reported on **As received basis.**

Air-dried

Freshly mined coal looses its moisture due to exposure to atmospheric air, during transportation and storage. The data obtained by analyzing the coal at this stage is on air dried basis. The data on As received basis and Air dried basis may be the same because in both cases coal looses its moisture similarly depending on humidity and temperature of atmospheric air.

Dry or moisture free

When it is required to completely eliminate the effect of moisture on analytical data, the coal analysis is reported on Dry or moisture free basis. It is the data expressed as the percentages of the coal after all the moisture has been removed.

Dry, ash free (d.a.f)

If the effect of moisture and ash is to be eliminated, then the data is reported on dry ash free basis. The coal is considered to consist of volatile matter and fixed carbon on the basis of recalculation with moisture and ash removed. This does not allow for the volatile matter derived from minerals present in the air-dried coal. This is the simplest way to compare the organic fractions of coals without diluting the effects of inorganic components. This data is suitable for comparing low ash coals (ash<10%).

Dry, mineral matter free (d.m.m.f)

Here it is necessary that the total amount of mineral matter rather than ash is determined, so that the volatile matter content in the mineral matter can be removed. In case of high ash coals, the mineral matter content is around 10% more than its ash whereas mineral matter is almost equal to its ash in case of low ash coals. Hence the data expressed on dry mineral matter free basis is most suitable for comparing high ash coals (ash>10%).

Calculations on different bases

The details of calculations to express the proximate analysis on different bases are given in the following articles.

As received or As sampled basis

The results of proximate analysis are expressed as percentages of the coal including the total moisture content.

$$\% \text{ Moisture} = \frac{\text{Weight of moisture}}{\text{Weight of coal sample as received}} \times 100 \quad (1.6)$$

$$\% \text{ Volatile matter} = \frac{\text{Weight of volatile matter}}{\text{Weight of coal sample as received}} \times 100 \quad (1.7)$$

$$\% \text{ Ash} = \frac{\text{Weight of ash}}{\text{Weight of coal sample as received}} \times 100 \quad (1.8)$$

$$\% \text{ Fixed carbon} = 100 - (\text{Moisture\%} + \text{Volatile matter\%} + \text{Ash\%}) \quad (1.9)$$

Air-dried basis

The results are expressed as percentages of the air-dried coal, including inherent but not surface or free moisture.

$$\% \text{ Moisture} = M = \frac{\text{Weight of moisture}}{\text{Weight of air-dried coal sample}} \times 100 \quad (1.10)$$

$$\% \text{ Volatile matter} = V = \frac{\text{Weight of volatile matter}}{\text{Weight of air-dried coal sample}} \times 100 \quad (1.11)$$

$$\% \text{ Ash} = A = \frac{\text{Weight of ash}}{\text{Weight of air-dried coal sample}} \times 100 \quad (1.12)$$

$$\% \text{ Fixed carbon} = FC = 100 - (M+V+A) \quad (1.13)$$

Dry or moisture free basis

The results are expressed as percentages of the coal after the inherent moisture has been removed. By using the percentages on air-dried basis, the results of proximate analysis on dry basis can be calculated as follows:
On Dry basis

$$\% \text{ Ash} = \frac{A}{100-M} \times 100 \qquad (1.14)$$

$$\% \text{ Volatile matter} = \frac{V}{100-M} \times 100 \qquad (1.15)$$

$$\% \text{ Fixed carbon} = \frac{FC}{100-M} \times 100 \qquad (1.16)$$

Dry, ash free (d.a.f) basis

The coal is considered, in proximate analysis, to consist of only volatile matter and fixed carbon, on the basis of recalculation with ash and moisture removed. The calculations are as follows:

On d.a.f basis

$$\% \text{ Volatile matter} = \frac{V}{100-M-A} \times 100 \qquad (1.17)$$

$$\% \text{ Fixed carbon} = \frac{FC}{100-M-A} \times 100 \qquad (1.18)$$

Dry, mineral matter free (d.m.m.f) basis

The coal is also considered to consist of solely volatile matter and fixed carbon, but it is necessary that the total amount of mineral matter rather than ash be determined. Allowance is also made in dry, mineral matter free data, for the contribution to the air-dried volatile matter that comes from the mineral components. This may be done directly or indirectly. As it is difficult to determine volatile matter that comes from the mineral matter, it is suggested and agreed that the mineral matter of coal contributes to the volatile matter by an amount approximately equal to 10% of the ash. Accordingly;

% Mineral Matter = MM = A + 0.1A =1.1A (1.19)

The calculations are as follows:

On d.m.m.f basis

$$\% \text{ Volatile matter} = \frac{V-0.1\,A}{100-M-1.1\,A} \times 100 \qquad (1.20)$$

$$\% \text{ Fixed carbon} = \frac{FC}{100-M-1.1\,A} \times 100 \qquad (1.21)$$

Performance Parameters Of Steam Power Plants

Performance of a thermal (steam) power plant is characterized by

- •Mechanical power output, P_{net}
- •Electrical power output, P_{el}
- •Cycle thermal efficiency, η_{th}
- •Heat rate, HR
- •Steam rate, m_s
- •Fuel rate, m_f
- •Electrical (overall) efficiency, η_{el}
- •Capacity factor, CF

Plant net mechanical power output

$$P_{net} = m_s\, w_{net} = m_s\, (w_t - w_p) \text{ kW} \qquad (1.22)$$

where

ms is the steam mass flow rate in kg/s,
wnet is the plant net specific work in kJ/kg,
wt is the specific work of the turbine in kJ/kg, and
wp is the specific work of the feed pump in kJ/kg.

The rate of heat release in the boiler furnace is

$$Q_f = m_f HV, \text{ kJ/s} \quad (1.23)$$

where

mf is the plant fuel consumption rate in kg/s,
HV is the fuel heating value in kJ/kg (it is HHV in the United States, and LHV in Europe).

The plant electrical power output is

$$P_{el} = Q_f \eta_{el} = m_f HV \eta_{el}, \text{ kW} \quad (1.24)$$

The electrical (overall) efficiency of the steam power plant takes into account all energy losses in the plant. The electrical efficiency ηel of a thermal power plant is defined as the fraction of the fuel input energy Qf converted into electric power output Pel. Thus,

$$\eta el = \frac{P_{el}}{Q_f} = \eta_b \eta_{th} \eta_{it} \eta_g \quad (1.25)$$

where

ηb is the efficiency of the boiler (steam generator),
ηth is the cycle thermal efficiency,
ηit is the turbine isentropic efficiency, and
ηg is the efficiency of the electric generator.

If the work of the pump is ignored, the plant thermal efficiency is

$$\eta th = \frac{P_{net}}{Q_{in}} \quad (1.26)$$

$$\eta_{th} = (h_1 – h_2)/(h_1–h_3) \quad (1.27)$$

where

Pnet is the plant net mechanical power output, and

Qin is the plant heat addition rate.

The heat rate of a power plant cycle is defined as the amount of heat in kJ that is required to produce a unit power output kWh. Thus, the plant net heat rate is given by;

$$HR = 3600 \frac{Q_{in}}{P_{net}} = 3600 / h_{th,} \text{ kj/kWh,} \quad (1.28)$$

The parasitic power consumption, P_{aux}, by the plant auxiliary units such as coal mills, fans, pumps reduces the overall efficiency of the power plant. Thereby, the plant net electric power output is

$$P_{net,el} = P_{el} – P_{aux}, \text{ kW} \quad (1.29)$$

Fuel And Steam Rates Of A Power Plant

The useful thermal capacity of the boiler (steam generator) is given by

$$Q_b = Q_f \eta_b = m_f \text{ HV } \eta_b, \text{ kJ/s} \quad (1.30)$$

$$Q_b = m_s \Delta h_b, \text{ kJ/s} \quad (1.31)$$

Where

Qf is the rate of heat released by fuel burned in the boiler furnace in kJ/s,
ηb is the boiler (steam generator) efficiency,
ms is the mass flow rate of steam in kg/s,
Δhb is the enthalpy change of the working fluid water/steam in boiler (steam generator) in kJ/kg.

$$\text{Power plant fuel rate } m_f = \frac{Q_f}{HV} = \frac{P_{el}}{(HV\ \eta_{el})}, \text{ kg/s} \quad (1.32)$$

Plant-specific fuel consumption per kWh of generated electricity

$$SFC = 3600 \frac{m_f}{P_{el}}, \text{ kW h} \quad (1.33)$$

Plant steam rate

$$ms = \frac{Qb}{\Delta hb} = \frac{Pel}{(\Delta hb\ \eta el)}\ , \text{kg/s} \qquad (1.34)$$

Advanced high-performance steam power plants feature a high electrical (overall) efficiency
ηel, a low heat rate HR, a low fuel rate mf, and low specific fuel consumption SFC.

References:

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