UNIT 4 ENERGY EFFICIENCY AND ENERGY CONVERSION

Structure

4.1 INTRODUCTION

You are now familiar with the concept of energy and the fact that energy can exists in many form. You have also seen that energy is the capacity of doing work. Now the question is that when energy from one form is converted into another form, does all energy is available to do useful work. The simple answer to this question is that energy which goes into an energy converter device; we get several kind of output. We get the desired form of energy which is available to us for doing useful work. We also get undesired form of energy which is not available to us to do equivalent amount of useful work. The law of conservation of energy holds true which means that the total amount of energy at the end of conversion process is the same as was at the beginning of the process.

In this unit, you will learn about various energy conversion processes and their efficiency.

Objectives

After studying this unit, you will be able to

- energy efficiency, and
- energy loss in conversion.

4.2 ENERGY CONVERSION EFFICIENCIES

Any energy use device (for example an engine) extracts energy from some energy source and converts this energy into useful work at a certain efficiency 'η' defined by the following expression :

$$\eta = \text{Efficiency of conversion}$$

$$= \frac{\text{Work done}}{\text{Energy used}} = \frac{\text{Useful energy output}}{\text{Total energy input}} \qquad \ldots (4.1)$$

This can be represented by a diagram shown in Figure 4.1. The useful work may be electric power, mechanical work or heat.

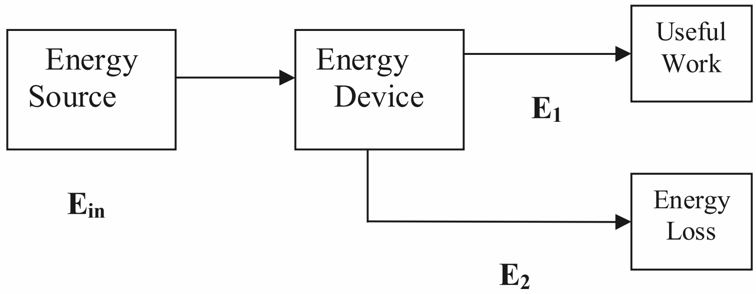

Figure 4.1 : Energy Flow in a System

In the conversion process, all the input energy entering into a conversion device is converted into another form of energy and finally we end up with the same amount of energy which went into the conversion device.

This is another way of defining **First Law of Thermodynamics** which says that energy can neither be created nor destroyed. However, not all the energy is converted into the useful work. You may be wondering then what happened to the remaining energy. This brings the concept of quality of energy. Although the quantity of energy is the same (before and after the conversion), the quality of energy is different.

Let us take an example. Suppose you have a 100 W incandescent bulb in your home. After few minutes of its operation, if you touch this bulb, you will observe that it is very hot. The bulb is using electricity, giving you the light and heat. You may ask what is the efficiency of a incandescent bulb. Usually it varies from 5 to 10%. If we take efficiency at 10%, this means that only 10% of the electricity equivalent is used to provide the light and the remaining equivalent to 90% is lost as the heat. This heat so produced is called the waste heat simply because it is difficult to use this waste heat to do any kind of useful work.

This defines the **Second Law of Thermodynamics**. It says that with each energy conversion from one form to another, some of the energy becomes unavailable for doing any further useful work.

> **A point to Remember :**
>
> 100 units of electrical energy can not be converted to 100 units of light energy.
>
> No conversion device is 100% efficient.

Referring to Figure 4.1, we have

Total energy input = useful energy output + energy wasted

or $$E_{in} = E_1 + E_2 \qquad \text{. . . (4.2)}$$

Using Eq. (4.1), the conversion efficiency is given as follows :

$$\eta = \frac{E_1}{E_2} = \frac{(E_{in} - E_2)}{E_{in}} = 1 - \frac{E_2}{E_{in}} \qquad \text{. . . (4.3)}$$

Although energy is conserved in an energy conversion process, the output of useful energy or useful work will be less than the energy input.

You can see that for any energy conversion device to be 100% efficient, E_2, i.e. energy loss has to be zero. However, it is not possible for any energy conversion device to be 100% efficient. If, however, we are able to utilize the rejected heat in another generator, the efficiency could be increased as shown in Figure 4.2.

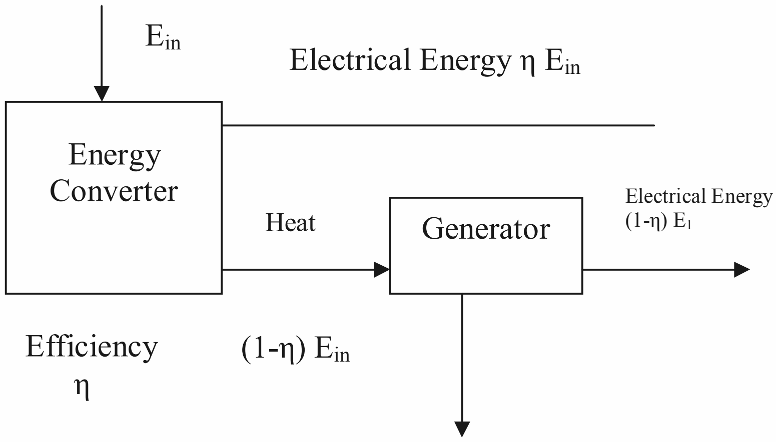

Figure 4.2 : Energy Conversion with Rejected Heat

Example 4.1

A boiler has an hourly input of 30 KWh. Energy equivalent to 15 KWh is extracted and is utlised for heating water. What is the energy conversion efficiency?

Solution

The energy flow is shown in Figure 4.3.

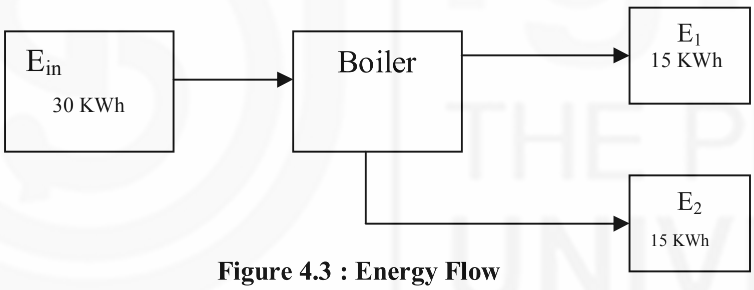

Figure 4.3 : Energy Flow

We have the following data :

E_{in} = 30 KWh

E_1 = 15 KWh

E_2 = 15 KWh

Thus, energy conversion efficiency, η

= 5 KWh/30 KWh

= 0.5 or 50%

Example 4.2

If in Example 4.1, another waste heat equivalent to 9 KWh is extracted through a waste heat recovery system, determine the final conversion efficiency.

Solution

E_{in} = 30 KWh

E_1 = 15 KWh + 9 KWh = 24 KWh

E_2 = 6 KWh

Thus energy conversion efficiency is 24 KWh/30 KWh = 0.8 or 80%.

4.3 VALUES OF ENERGY CONVESION EFFICIENCIES

The efficiencies of energy conversion of many devices are listed in Table 4.1. It can be observed that energy conversion efficiencies vary from about 10% for incandescent bulbs to about 95% for energy efficient motors.

The efficiency of an energy conversion process is the product of efficiencies of the individual steps. This is shown in Table 4.2 for a lighting system where electricity is generated by a fossil fuel powered thermal power station.

Table 4.1 : Energy Conversion Efficiencies of Some Devices

Energy Conversion Device	Energy Conversion Processes	Energy Conversion Efficiencies
Electric motor	Mechanical-electrical	50-95%
Electric generator	Electrical - mechanical	70-95%
Wind	Mechanical-electrical	35-50%
Gas furnace	Chemical-thermal	70-95%
Power plant (fossil fuel based)	Chemical-thermal-mechanical-electrical	30-40%
Power plant (nuclear)	Nuclear-thermal-mechanical-electrical	30-35%
Automobile engine	Chemical-thermal-mechanical	20-30%
Fluorescent Lamp	Electrical-light	20-22%
Incandescent bulb	Electrical-light	5-10%
Solar Cell	Light-electrical	5-30%

Table 4.2 : Energy Conversion Efficiency of a Process

Energy Conversion Process	Efficiency of Step (%)	Overall Efficiency (%)
Chemical-thermal-mechanical-electrical		
Production of coal	95	95
Transportation of coal	95	95 x 95/100 = 90
Generation of electricity	40	90 x 40/100 = 36
Transmission of electricity	85	36 x 85/100 = 30.6
Lighting by Incandescent Bulb	10	30.6 x 10/100 = 3
The overall efficiency of the entire process is 3%		

SAQ 1

Describe the energy conversion process of electricity generated in a gas fired thermal power station and used in lighting.

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Example 4.3

One thousand Kg of coal is burned in a thermal power station to generate electricity. Determine the KWh produced if the efficiency of the conversion is 30%. The calorific value of the coal is 17000 KJ/Kg.

Solution

Energy value of 1000 Kg of coal = 1000 Kg × 17000 KJ = 17×10^6 KJ

But 3.6×10^6 J = 1 KWh = 3.6×10^6 J = 3.6×10^3 KJ

Therefore, 1000 Kg of Coal = $17 \times 10^6 / 3.6 \times 10^3$ = 4722 KWh for 100% efficiency. Since conversion efficiency is 30% and hence 1000 Kg of coal = 4722 KWh × 0.3 = 1416 KWh.

Example 4.4

The efficiency of individual steps in an electrical car is given in Table 4.3. Determine the overall efficiency.

Table 4.3 : Energy Conversion Efficiency of an Electrical Car

Energy Conversion Process	Efficiency of Step (%)
Production of fuel	95
Generation of electricity	35
Transmission of electricity	90
Battery	80
Engine	85
Transmission system	90

Solution

The overall efficiency is 18.30% as calculated in the following Table 4.4.

Table 4.4 : Computation of Overall Efficiency of an Electrical Car

Energy Conversion Process	Efficiency of Step (%)	Overall Efficiency (%)
Production of fuel	95	95
Generation of electricity	35	33.25
Transmission of electricity	90	29.92
Battery	80	23.93
Engine	85	20.34
Transmission system	90	18.30
The overall energy conversion efficiency is 18.3%		

4.4 POWER AND ENERGY CONVERSION EFFICIENCY

Energy has been defined as the capacity to do work. You can not see the energy, the way you can not see wind but you can feel the power which wind has or for that matter energy has. Thus,

Energy = Capacity to do work

The word 'work' here has the specific meaning and is defined as force multiplied by the distance. Thus,

$$\text{Work} = \text{Force} \times \text{Distance}$$

or $$= F\, d \qquad \ldots (4.4)$$

The unit of work is Newton. Meter (Nm) which is known as Joule (J) and is also the unit of energy.

You have seen that Eq. (4.4) is independent of time. What does it mean? Let us try to understand by taking an example. Suppose that you have to lift 100 bricks and have to place them from one place to another. You can do this work in 5 seconds, 5 minutes, 5 hours or 5 days. The amount of work done will remain the same.

Why then we are worrying about energy when we know that energy is the capacity of doing work and work can be done the way we want to do. Our worry is not the energy but the rate at which energy is being extracted or used. The energy of fossil fuels is finite and if we are able to delay the rate of energy use which means energy conservation, it can last long.

The rate of energy use or energy conversion is called Power.

Thus, $$\text{Power} = \frac{\text{Energy converted}}{\text{Time}} \qquad \ldots (4.5)$$

or $$P = \frac{E}{t} \qquad \ldots (4.6)$$

where E is the energy converted in time t and P is the rate of energy conversion or Power.

Thus, $$E = P\, t \qquad \ldots (4.7)$$

You can see the significance of this equation. You know that performance of a motor car is usually expressed by the maximum speed (equivalent to power) it can attain rather than the total distance travelled (equivalent to energy).

Let us take another example. An electric heater of 1000W (1KW) rating is used for six seconds. The energy transformed in 6 seconds will be 1000W (J/s) × 6 s = 6000 J. Another electric heater of 3000 W (3 KW) rating is used for 2 seconds. The energy transformed in 2 seconds will be 3000 J/s × 2 s = 6000 J. This indicates that 3 KW heater in 2 seconds produce the same amount of heat energy as 1 KW heater but it takes three times longer.

Let us take another interesting example. In summer, the demand of electricity suddenly gets enhanced because people start using coolers and Air Conditioners. There may be enough energy sources (coal, oil, gas etc) available at the energy converter station (called Power Station) but it may not be possible for it to meet the demand of electricity and therefore the demand for bigger power station arises and not for bigger energy station.

This indicates that energy conversion efficiency may also be expressed as the power ratios rather than energy ratios. Thus, when power of the inputs and outputs is constant, we have

$$\frac{\text{Useful energy Outpot}}{\text{Total Energy Input}} = \frac{\text{Useful Power Output}}{\text{Total Power Input}}$$

or $$\text{Efficiency} \quad \eta = \frac{\text{Useful Power Output}}{\text{Total Power Input}} \qquad \ldots (4.8)$$

Example 4.5

An energy conversion device has the efficiency of 80% and the power output of 150 MW. What is the useful power output and the waste power.

Solution

Using Eq. (4.8), we have

Useful power output = Total power input × Efficiency

$= 150 \times 80/100 = 120$ MW

Waste power = 150 MW – 120 MW = 30 MW.

4.5 EFFICIENCY OF ENERGY CONVERSION IN LIGHTING DEVICES

The incandescent bulbs are able to convert only about 10% of energy into visible radiation as shown in Figure 4.4. Energy distribution of a fluorescent lamp is shown in Figure 4.5; about 22% of energy is converted into visible radiation.

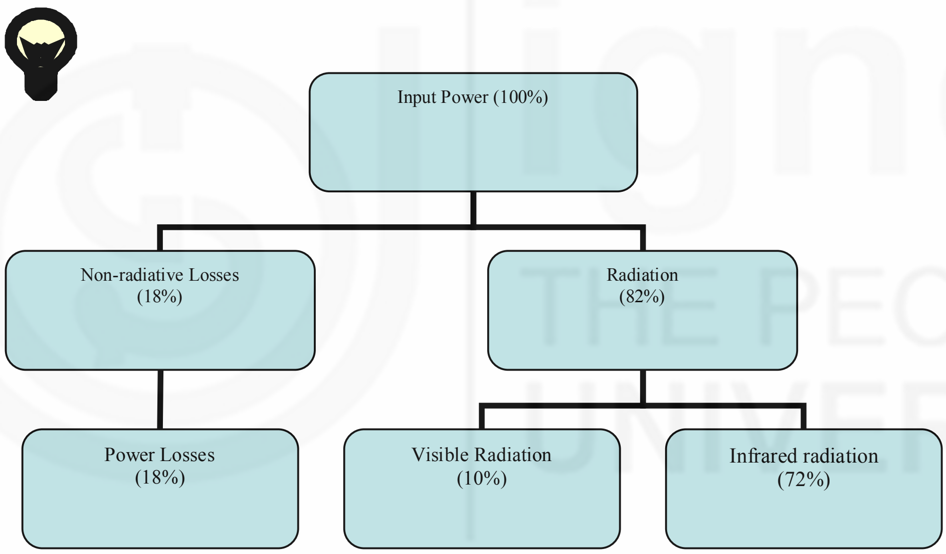

Figure 4.4 : Energy Distribution in an Incandescent Bulb

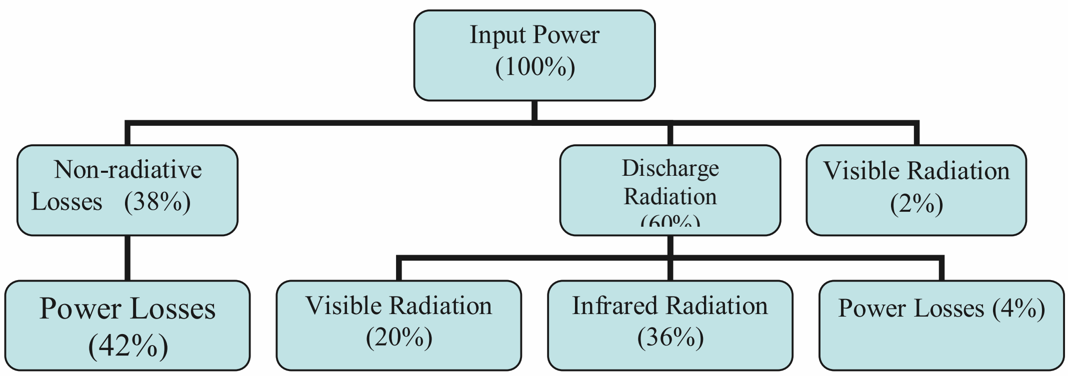

Figure 4.5 : Energy Distribution in a Fluorescent Lamp

4.6 EFFICIENCY OF ENERGY CONVERSION FROM CATTLE DUNG

The efficiency of energy conversion of cattle dung is shown in Figure 4.6. We have shown three conversion routes.

Route No 1 : 25 Kg. of wet dung is dried up to about 5 Kg. which is then burnt in an ordinary stove resulting in an efficiency of about 8-10%.

Route No 2 : Wet dung is converted into biogas which is then consumed through biogas stove resulting in an efficiency of about 50-55%.

Route No 3 : Wet dung is converted into biogas which is then consumed through biogas engine resulting in an efficiency of about 25-30%.

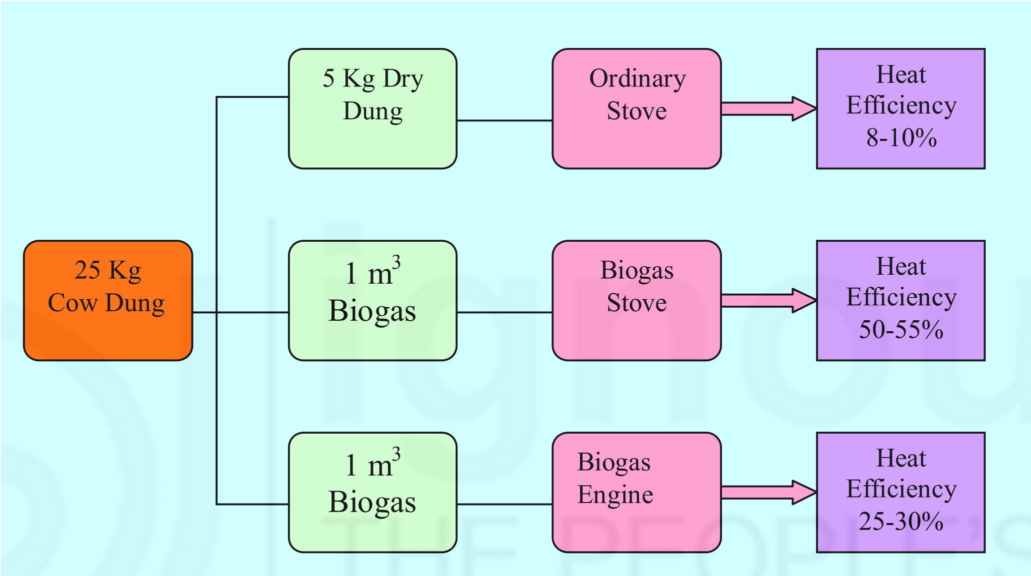

Figure 4.6 : Efficiency of Energy Conversion of Dung

4.7 LET US SUM UP

Energy which goes into an energy converter device, we get several kind of output. We get the desired form of energy which is available to us for doing useful work. We also get undesired form of energy which is not available to us to do equivalent amount of useful work.

Any energy use device (for example an engine) extracts energy from some energy source and converts this energy into useful work at a certain efficiency defined as the ratio of work done to energy used.

In the conversion process, all the input energy entering into a conversion device is converted into another form of energy and finally we end up with the same amount of energy which went into the conversion device.

Although the quantity of energy is the same (before and after the conversion), the quality of energy is different.

The Second Law of Thermodynamics says that with each energy conversion from one form to another, some of the energy becomes unavailable for doing any further useful work. You can see that for any energy conversion device to be 100% efficient, energy loss has to be zero. However, it is not possible for any energy converter device to be 100% efficient.

The rate of energy use or energy conversion is called Power. There may be enough energy sources (coal, oil, gas etc) available at the energy converter station (called Power Station) but it may not be possible for it to meet the demand of electricity and therefore the demand for bigger power station arises and not for bigger energy station.

This indicates that energy conversion efficiency may also be expressed as the power ratios rather than energy ratios.

The incandescent bulbs are able to convert only about 10% of energy into visible radiation whereas about 22% of energy is converted into visible radiation by a fluorescent lamp.

4.8 ANSWERS TO SAQs

SAQ 1

The energy conversion process is Chemical-thermal-mechanical-electrical.