A. EFFICIENCY AND ENERGY CONVERSION

ENABLING OBJECTIVES:

4.1 Describe the energy transfer and energy conversions that occur as part of the steam and feedwater cycle.

4.2 Determine the overall efficiency of a CANDU unit using the following parameters:

a) Unit gross thermal power;
b) Unit net thermal power;
c) Unit gross electrical power;
d) Unit net electrical power.

ENERGY CONVERSIONS IN A CANDU STATION

The primary task of Ontario Hydro is to produce electrical energy. It is accomplished in our hydraulic, fossil fuel and nuclear power plants through a chain of energy conversions. For all three types of power plants the objective is identical, but the thermal energy we start with and the energy conversions differ substantially.

A CANDU energy cycle is shown in Figure 4.1. In the HTS the heat energy generated by fission of the fuel is picked up by pressurized heavy water. Hot heavy water (~300°C) comes to the boilers, flows through the tubes and gives some of its heat to the feedwater circulated over the boiler tubes. Cooler heavy water (260°C) goes to the heat transport pumps from where it is circulated back to the reactor. The HTS is a closed loop system, pressurized (~10MPa) to get its saturation temperature about 40°C higher than the secondary side steam requirement, so that heat transfer can occur. Approximately 95% of the heat energy released in the reactor is transferred to light water in the boiler. The remaining 5% is lost (mainly to the moderator).

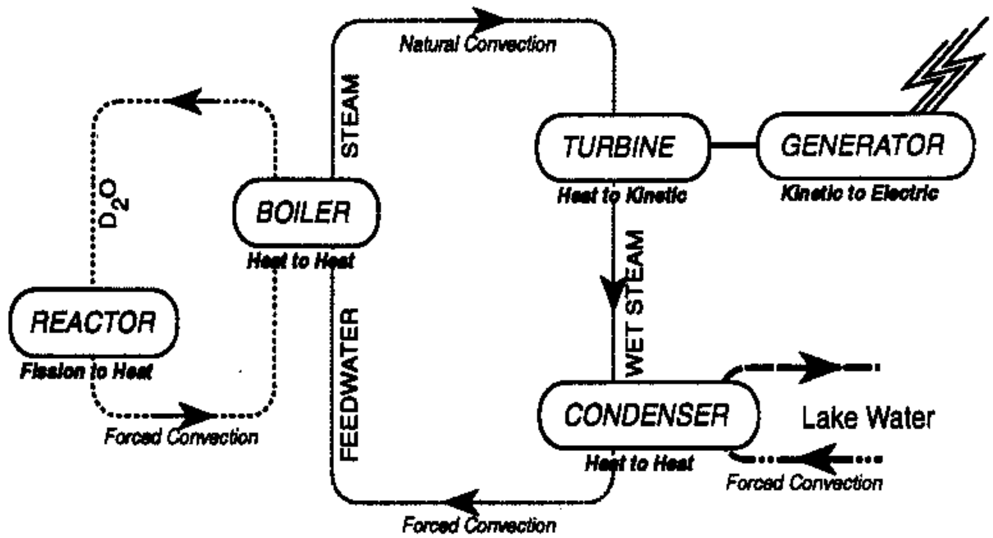

Figure 4.1
Energy Cycle

The light water in the Steam-Feedwater System uses HTS heat to generate steam in the boiler. The steam generated is taken to the turbine where it exerts force on turbine blades causing rotation of the turbine shaft. In the process, heat energy is converted to mechanical energy. The turbine drives the generator which in turn produces electrical energy. The mechanical energy is converted to electrical energy and the chain of conversions is completed.

It is possible to convert only about 30% of the heat energy in steam delivered to the turbine into mechanical energy. The heat energy that cannot be used is transferred through condensing the exhaust steam to the CCW and then to the lake. The steam leaving the turbine still possesses considerable energy but it is at too low a temperature (35°C) and pressure (5 kPa) to be useful. The condensate is pumped back to the boiler through different stages of feedheating as feedwater to complete the steam-feedwater cycle.

EFFICIENCY OF NUCLEAR GENERATION

By defining a few terms associated with power production, we will be able to determine the overall efficiency of a nuclear unit.

Unit gross thermal power is the power in thermal megawatts (MWth) that is produced by the reactor. For example, a Pickering A unit produces 1744 MWth.[1]

Unit net thermal power (reactor thermal power) is the power in thermal megawatts (MWth) that is delivered to the boilers by the HTS coolant. For example, at Pickering A this is 1660 MWth. Unit thermal power is significantly higher than the actual electrical output of the unit.

Unit gross electrical power is the power in electrical megawatts (MWe) that is produced by the generator of a single reactor unit. For example, a Pickering A unit produces 540 MWe of electrical power. Some of this power is used to operate plant equipment. The rest is delivered to the grid.

Unit net electrical power is the power in electrical Megawatts (MWe) that is delivered to the grid from the generator of a single reactor unit. For example, a Pickering A unit delivers 508 MWe of electrical power to the grid.

By calculation we can see that a unit at Pickering A operates at a **unit thermal efficiency** of

$$\frac{\text{unit gross electrical power}}{\text{unit net thermal power}} = \frac{540MWe}{1660MWth} \times 100\% = 32.5\%.$$

This is a measure of the effectiveness of the unit in converting the heat delivered to the boiler into electrical energy. This level of efficiency is fairly typical of a CANDU unit.

The **unit net electrical efficiency** is

$$\frac{\text{unit net electrical power}}{\text{unit gross thermal power}} = \frac{508MWe}{1744MWth} \times 100\% = 29.1\%.$$

This is a measure of the overall efficiency of the unit in terms of electrical output to the grid compared with the heat produced by the fuel.

1 This is the maximum fuel power output allowed by the operating licence.

ASSIGNMENT

1. What is the energy conversion in the following parts of the CANDU station?

    a) Reactor

    b) Boiler

    c) Turbine

    d) Condenser

    e) Generator

2. Roughly how efficient is a CANDU reactor in converting the heat from fission into electrical energy delivered to the grid?