Reactor-Boiler and Auxiliaries - Course 433

HEAT TRANSPORT SYSTEMS

There is a fairly large variety of materials which can be used in heat transport systems, and there is no clear advantage for any one, although each may have particular advantages and disadvantages keeping in mind the two objectives of reactor construction given in a previous lesson. The first of these objectives was that the reactor produce heat at high temperature. Since the main job of the heat transport system is to carry heat from the reactor to the boiler, it must capable of doing so at high temperature. The second objective was to obtain the maximum amount of energy from the fuel which implies, keeping neutron losses to a minimum. The heat transport system must therefore, capture as few neutrons as possible while it passes through the reactor.

Various materials which have been used in heat transfer systems will be reviewed, and the type of system associated with each will be discussed. Emphasis will again be given to the materials which are used or proposed for Canadian nuclear power stations.

Heat Transfer Materials

Water is the most common heat transfer material in the Canadian nuclear program, and may be used in a number of forms. First of all, a choice must be made between light and heavy water and either of these may be used as liquid, steam or fog (steam which has water droplets in it). In discussing moderators, we noted that light water would not sustain a chain reaction with natural uranium because it captured too many neutrons. The capture of neutrons is still important, and is a strong factor in favour of heavy water, but because the volume of heat transport fluid in the reactor is much less than the volume of moderator, light water cannot be ruled out in this case. This is particularly true, if the systems uses steam or fog, so that due to lower density, there are fewer pounds of water in the core. A disadvantage of any water system is that it must operate at high pressure (at least 1000 psi) in order to obtain high temperature. The high pressures make the leakage problem worse and gives a factor in favour of light water which is much cheaper.

Organics, which are compounds made of hydrogen and carbon similar to wax, may be used to transfer heat in a nuclear station. The heat removal or carrying properties of these materials are not nearly as good as water, but they have a much higher boiling point. This allows operation at high temperature without much pressurization. Organics also have disadvantages in that they form tars under irradiation, and leaks are both toxic and highly flammable (may even ignite spontaneously).

Liquid metal such as sodium or sodium-potassium are used in some cases because of good heat transfer properties and no need for pressurization. Sodium however, becomes highly radioactive in the reactor, and the system must be kept shielded for approximately 2 weeks after shutdown. It also reacts violently with water, and hence care must be exercised in the design of sodium-water boilers. One further disadvantage for a large natural uranium reactor is the relatively large number of neutrons it captures. This type of heat transfer material is only likely to be found in enriched reactors which have small cores.

Gases are inherently poor heat-transfer agents because of their low density compared to liquids. This difficulty can be overcome to some degree by operating the gas at high pressure, but this creates other problems. The low density also makes pumping difficult and a large amount of power is required to drive the necessary pumps. The main advantage of gases are their ability to operate at high temperatures. Some gases, such as helium, create no corrosion problems at high temperatures, and hence extend the life of the system components and possibly the fuel.

Direct and Indirect Cycles

The most common type of heat transport system is one which carries the heat produced in the reactor to a boiler where light water is boiled and the steam used in a conventional turbine cycle. This is known as an indirect cycle since there are two steps. It is also possible, however, to heat a gas, or boil water in a reactor to form steam, then take the gas directly to the turbine. This is known as a direct cycle. Schematic drawings of both are shown in Figure 1.

The direct cycle appears somewhat simpler since it eliminates the boiler, and it also eliminates the temperature drop which occurs in the boiler, giving more efficient operation. It has a number of difficulties, however, some of which are:

1. It is difficult to construct the pressure tubes in the reactor and the fuel so that they will stand the boiling and partial steam conditions without problems of corrosion.

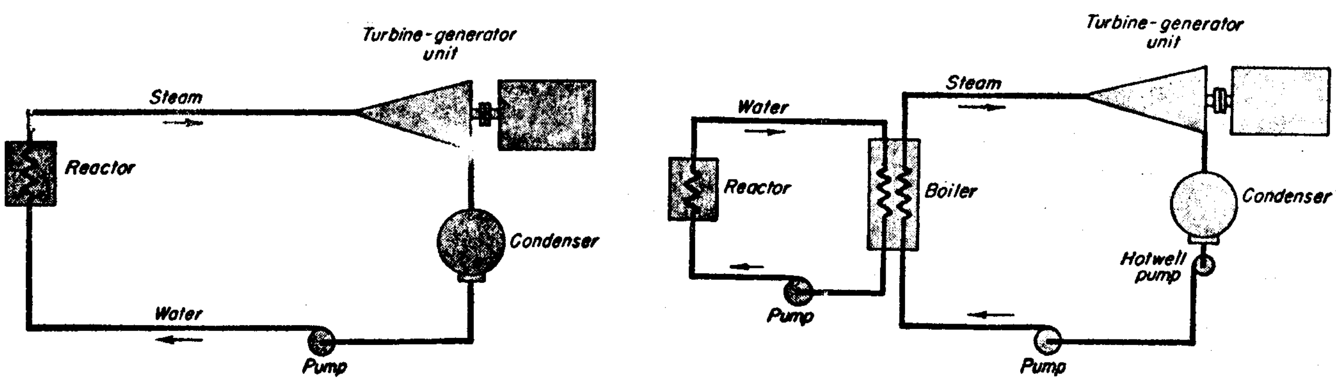
2. The turbine and associated equipment will require shielding due to radioactive material formed in the reactor.

3. If heavy water is used, in-leakage in the condenser and other low pressure areas of the system will carry in light water and down grade the heavy water.

4. The turbine and its auxiliaries will become contaminated with radioactive material and any out leakage will up-read contamination.

The indirect cycle allows the use of ordinary water in the turbine cycle combined with any of the heat transport materials discussed previously. This results in the advantage of standard equipment for the turbine and auxiliaries. The indirect cycle loses efficiency since the temperature of the turbine cycle is lower than whatever heat transport temperature is permissible due to the temperature drop in the steam generator.

Most power reactors presently use an indirect cycle, but as the problems associated with boiling and steam cooling are overcome, there is likely to be a swing towards direct cycles.



Direct Cycle Fig. 1 Indirect Cycle

Heat Transport System Components

The heart of system is the section passing through the reactor since it must meet special conditions and is extremely difficult to repair. Both pressure tubes and pressure vessels were discussed in the earlier lesson on reactor construction and it was noted that the pressure tube design was the most promising for large natural uranium stations. There must also of course be piping external to the reactor to carry the heat transport fluid and a pumping system to circulate it. If we consider an indirect cycle, a boiler must be added, which will have a heat exchanger as part of the heat transport system.

As with a moderator system, the materials used in the heat transport system must be compatible. The most common pressure tube material for a natural uranium reactor is a zirconium alloy (zircaloy) which can be used with a carbon steel piping system. More expensive materials such as stainless steel may still be used for special applications in valves, etc, where long life and high reliability of operation is required.

Leakage may be a very important consideration in choosing components or methods of construction. This is particularly important in the case of heavy water which is very expensive. A heavy water system will have the majority of joints welded, and will use double seals whenever possible on pump shafts, valve stems, heat exchanger joints etc. As well as the effort to prevent leakage, there will be associated systems to detect and recover losses. The detection devices may include level switches or probes in collection tanks or trays, indicators which visibly change when wetted or instruments, which detect increased vapour or activity in the air. The recovery systems are normally a part of the ventilation and drainage systems. Leakage may also be very important in a liquid metal system. The most common liquid metal used is sodium which reacts violently with light water. This makes leakage between the sodium and the water in a boiler most undesirable.

The main circulating pumps in a heat transport system represent not only a fairly large initial investment, but also require from 2 to 3% of the net output of a large station during normal operation. There are a number of ways in which these expenses can be minimized. It has already been noted that materials such as gas and organics require more pumping power than water. The size of the piping can also influence pumping power which would become excessive, if the piping was made too small. The initial cost of the pumps can vary considerably, and a balance must be reached between attempts to keep the cost down and obtaining reliable pumps which will not require excessive maintenance.

ASSIGNMENT

1. Why is it possible to use light water as a heat transport material in a natural uranium reactor when it cannot be used as a moderator?

2. Why must a heat transport system using water operate at high pressure?

3. Give two advantages of a direct cycle over an indirect cycle.

4. Given the following information:

   (a) heavy water cost = $28/lb
   (b) 1 drop/sec = 20 lb/day

   Calculate the cost of replacing the heavy water from a leak of 2 drops per sec which is not repaired for 4 months.

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