19CH101– ENGINEERING CHEMISTRY

Unit -5 ENERGY SOURCES AND STORAGE DEVICES

LIGHT WATER NUCLEAR REACTOR

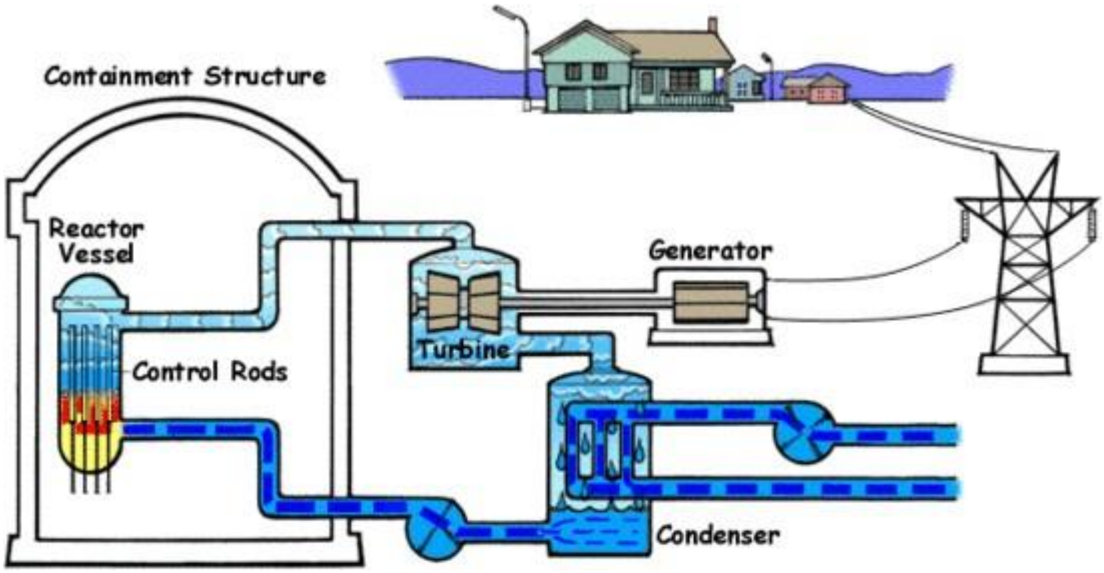
The light-water reactor (LWR) is a type of thermal-neutron reactor that uses normal water, as opposed to heavy water, as both its coolant and neutron moderator; furthermore a solid form of fissile elements is used as fuel. Thermal-neutron reactors are the most common type of nuclear reactor, and light-water reactors are the most common type of thermal-neutron reactor.

REACTOR DESIGN

The light-water reactor produces heat by controlled nuclear fission. The nuclear reactor core is the portion of a nuclear reactor where the nuclear reactions take place. It mainly consists of nuclear fuel and control elements. The pencil-thin nuclear fuel rods, each about 12 feet (3.7 m) long, are grouped by the hundreds in bundles called fuel assemblies. Inside each fuel rod, pellets of uranium, or more commonly uranium oxide, are stacked end to end. The control elements, called control rods, are filled with pellets of substances like hafnium or cadmium that readily capture neutrons. When the control rods are lowered into the core, they absorb neutrons, which thus cannot take part in the chain reaction. On the converse, when the control rods are lifted out of the way, more neutrons strike the fissile uranium-235 or plutonium-239 nuclei in nearby fuel rods, and the chain reaction intensifies. All of this is enclosed in a water-filled steel pressure vessel, called the reactor vessel.

In the boiling water reactor, the heat generated by fission turns the water into steam, which directly drives the power-generating turbines. But in the pressurized water reactor, the heat generated by fission is transferred to a secondary loop via a heat exchanger. Steam is produced in the secondary loop, and the secondary loop drives the power-generating turbines. In either case, after flowing through the turbines, the steam turns back into water in the condenser.

The water required to cool the condenser is taken from a nearby river or ocean. It is then pumped back into the river or ocean, in warmed condition. The heat can also be dissipated via a cooling tower into the atmosphere. The United States uses LWR reactors for electric power production, in comparison to the heavy water reactors used in Canada.[13]



Control rod

A pressurized water reactor head, with the control rods visible on the top

Control rods are usually combined into control rod assemblies — typically 20 rods for a commercial pressurized water reactor assembly — and inserted into guide tubes within a fuel element. A control rod is removed from or inserted into the central core of a nuclear reactor in order to control the number of neutrons which will split further uranium atoms. This in turn affects the thermal power of the reactor, the amount of steam generated, and hence the electricity produced. The control rods are partially removed from the core to allow a chain reaction to occur. The number of control rods inserted and the distance by which they are inserted can be varied to control the reactivity of the reactor.

Usually there are also other means of controlling reactivity. In the PWR design a soluble neutron absorber, usually boric acid, is added to the reactor coolant allowing the complete extraction of the control rods during stationary power operation ensuring an even power and flux distribution over the entire core. Operators of the BWR design use the coolant flow through the core to control reactivity by varying the speed of the reactor recirculation pumps. An increase in the coolant flow through the core improves the removal of steam bubbles, thus increasing the density of the coolant/moderator with the result of increasing power.

Coolant

The light-water reactor also uses ordinary water to keep the reactor cooled. The cooling source, light water, is circulated past the reactor core to absorb the heat that it generates. The heat is carried away from the reactor and is then used to generate steam. Most reactor systems employ a cooling system that is physically separate from the water that will be boiled to produce pressurized steam for the turbines, like the pressurized-water reactor. But in some reactors the water for the steam turbines is boiled directly by the reactor core, for example the boiling-water reactor.

Many other reactors are also light-water cooled, notably the RBMK and some military plutonium-production reactors. These are not regarded as LWRs, as they are moderated by graphite, and as a result their nuclear characteristics are very different. Although the coolant flow rate in commercial PWRs is constant, it is not in nuclear reactors used on U.S. Navy ships.

Fuel

A nuclear fuel pellet

Nuclear fuel pellets that are ready for fuel assembly completion

The use of ordinary water makes it necessary to do a certain amount of enrichment of the uranium fuel before the necessary criticality of the reactor can be maintained. The light-water reactor uses uranium 235 as a fuel, enriched to approximately 3 percent. Although this is its major fuel, the uranium 238 atoms also contribute to the fission process by converting to plutonium 239; about one-half of which is consumed in the reactor. Light-water reactors are generally refueled every 12 to 18 months, at which time, about 25 percent of the fuel is replaced.

Moderator

A neutron moderator is a medium which reduces the velocity of fast neutrons, thereby turning them into thermal neutrons capable of sustaining a nuclear chain reaction involving uranium-235. A good neutron moderator is a material full of atoms with light nuclei which do not easily absorb neutrons. The neutrons strike the nuclei and bounce off. After sufficient impacts, the velocity of the neutron will be comparable to the thermal velocities of the nuclei; this neutron is then called a thermal neutron.

The light-water reactor uses ordinary water, also called light water, as its neutron moderator. The light water absorbs too many neutrons to be used with unenriched natural uranium, and therefore uranium enrichment or nuclear reprocessing becomes necessary to operate such reactors, increasing overall costs. This differentiates it from a heavy water reactor, which uses heavy water as a neutron moderator. While ordinary water has some heavy water molecules in it, it is not enough to be important in most applications. In pressurized water reactors the coolant water is used as a moderator by letting the neutrons undergo multiple collisions with light hydrogen atoms in the water, losing speed in the process. This moderating of neutrons will happen more often when the water is denser, because more collisions will occur.

The use of water as a moderator is an important safety feature of PWRs, as any increase in temperature causes the water to expand and become less dense; thereby reducing the extent to which neutrons are slowed down and hence reducing the reactivity in the reactor. Therefore, if reactivity increases beyond normal, the reduced moderation of neutrons will cause the chain reaction to slow down, producing less heat. This property, known as the negative temperature coefficient of reactivity, makes PWRs very stable. In event of a loss-of-coolant accident, the moderator is also lost and the active fission reaction will stop. Heat is still produced after the chain reaction stops from the radioactive byproducts of fission, at about 5% of rated power. This "decay heat" will continue for 1 to 3 years after shut down, whereupon the reactor finally reaches "full cold shutdown". Decay heat, while dangerous and strong enough to melt the core, is not nearly as intense as an active fission reaction. During the post shutdown period the reactor requires cooling water to be pumped or the reactor will overheat. If the temperature exceeds 2200 °C, cooling water will break down into hydrogen and oxygen, which can form a (chemically) explosive mixture. Decay heat is a major risk factor in LWR safety record.