Developments in sodium technology

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Sodium, because of its good heat transfer and nuclear properties, is used as a coolant in fast reactors. It is also used largely as a reducing agent in pharmaceutical, perfumery and general chemical industries. Its affinity to react with air and water is a strong disadvantage. However, this is fully understood and the design of engineering systems takes care of this aspect. With several experimental and test facilities established over the years in this country and abroad, 'sodium technology' has reached a level of maturity. The design of sodium systems considering all the physical and chemical properties and the development work carried out in this country are broadly covered in this article.

FAST breeder reactors are energy systems which breed more fissionable material than they consume while producing power. These reactors are attractive where available natural uranium reserves are modest or limited; for example, in the case of India. Plutonium produced in the usual (thermal) nuclear reactors is ideally suited as the fuel material for use in a fast reactor as it possesses highest fission neutron yield (2.87) under fast neutron-induced fission process. Also, it makes available more than one neutron for conversion of U^{238} (more than 99% constituent of natural uranium) into Pu^{239}.

Since a fast reactor does not have a neutron moderator such as heavy water or light water, the reactor core has to be compact resulting in high volumetric power density. For example, the power produced per unit cubic metre core of a fast reactor plant is 550 MWt compared to a meagre 8 MWt for a heavy water-moderated reactor plant of the same capacity (600 MWe). Thus it is imperative to use efficient heat-transfer fluid as coolant, which should also possess favourable nuclear characteristics of low neutron moderation/absorption. Liquid metals, and among them liquid sodium, meet almost all the requirements of a fast-reactor coolant with its high thermal conductivity, reasonable specific heat, low neutron moderation and absorption, and high boiling point, giving a large operating temperature range at near atmospheric pressure. Thus sodium has been adopted universally in about 20 fast reactors that have accumulated over 280 reactor years operating experience. The high chemical activity of sodium, including its violent reaction with water has been

a matter of concern, but the technology has been mastered to circumvent the same. This article examines various developments in sodium technology resulting in its handling as a conventional engineering heat-transfer medium. The article also briefly covers sodium production and other uses before proceeding to describe special characteristics of sodium posing design challenges for equipment/components of fast reactors. An overview of sodium technology evolution in India is also covered.

The fast reactor

A fast reactor is one which does not use a moderator to slow down the neutrons produced during fission and the fuel used is fissioned directly by high energy or 'fast' neutrons emitted during the fission process. The reactor uses a fairly high concentration of fissionable isotope, either U^{235} or Pu^{239}. However, Pu^{239} has a distinct advantage when used as a fuel since the number of neutrons produced in Pu fission is high (approximately three), making sufficient number of excess neutrons to produce more Pu from U^{238} used as a blanket surrounding the fuel core. The high power generated in the compact core of the fast reactor necessitates the use of a liquid metal like sodium as the reactor coolant. Figure 1 shows the schematic flowsheet of a fast reactor plant.

Sodium – occurrence, production and applications[1]

Pure sodium is a soft, silvery-white metal with a faint pink colour when freshly cut. It melts at 98°C and boils at 883°C (under atmospheric pressure). Its atomic number is 11 and mass number is 23. The atomic structure of sodium represents a single electron in its outer orbit, accounting for its strong chemical activity.

Sodium is one of the six most abundant elements in nature, representing about 2–6% of the crust mass at the earth's surface. Because of its strong chemical reactivity, sodium is found only as chemical compounds among which sodium chloride is most widely distributed. The only manufacturing process for production of metallic sodium presently used on industrial scale is the electrolysis of pure sodium chloride in a mixture of calcium and barium chlorides at about 600°C. (The other two chlorides help in lowering the melting temperature of pure sodium chloride from about 900 to 600°C). The process is also called 'fused salt electrolysis' and is substantially

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energy-intensive. Presently, there is a glut of metallic sodium at the international market, because large production capacities set up many years ago for production of tetraethyl lead via sodium metal route, a compound used extensively until recently in leaded petrol, have become surplus following a ban on leaded petrol.

While physical uses of sodium are many, its 'chemical' uses still control the majority of its applications. These refer to pharmaceutical, perfumery and general chemical industries making use of its strong reducing and synthesis properties. Among 'physical' uses, the most important one is its application as a heat-transfer fluid/medium. This has led to extensive development of what is called 'sodium technology'.

The following characteristics of liquid sodium metal make it an excellent heat-transfer medium.

- Exceptional thermal stability up to high temperatures (unlike most other commonly used thermic fluids, e.g. diphenyl–diphenyl oxide).
- Low vapour pressure resulting in high boiling point (883°C) under atmospheric pressure – no need to pressurize the system, a distinct advantage over other fluids at temperature of 400°C and above.
- Excellent thermal conductivity – about 90 times that of water and reasonable specific heat – about one-third that of water.
- Low viscosity and density, lower than that of water, requiring modest pumping power.
- Quantities required are modest and investments are equally modest.

Table 1 lists the important properties of sodium[1]. Sodium is therefore used as the heat-transfer medium in the following:

- Cooling of valves for internal combustion engines using hollow stem valves filled with sodium.
- Die-casting of certain metals and alloys, e.g. magnesium.
- Heat-treating furnaces, fractional condensers for metallic vapours.
- Heat pipes, high temperature solar energy power plants.
- Fast breeder reactors. In fact, fast breeder reactors were amongst the first industrial units to use sodium as a heat-transfer medium.

The development of sodium technology has been largely due to its application as heat-transfer fluid and has addressed the shortcomings arising out of high chemical reactivity (especially with air and water), and radioactive activation product (isotope Na^{24}) in system and component designs for safety. Development of sodium technology during the past 40 years or more has been enormous. Currently sodium cooling for fast reactors is a proven technology.

There is growing interest in heavy liquid metal coolants, e.g. lead/lead–bismuth, in some advanced countries

Table 1. Physical properties of sodium

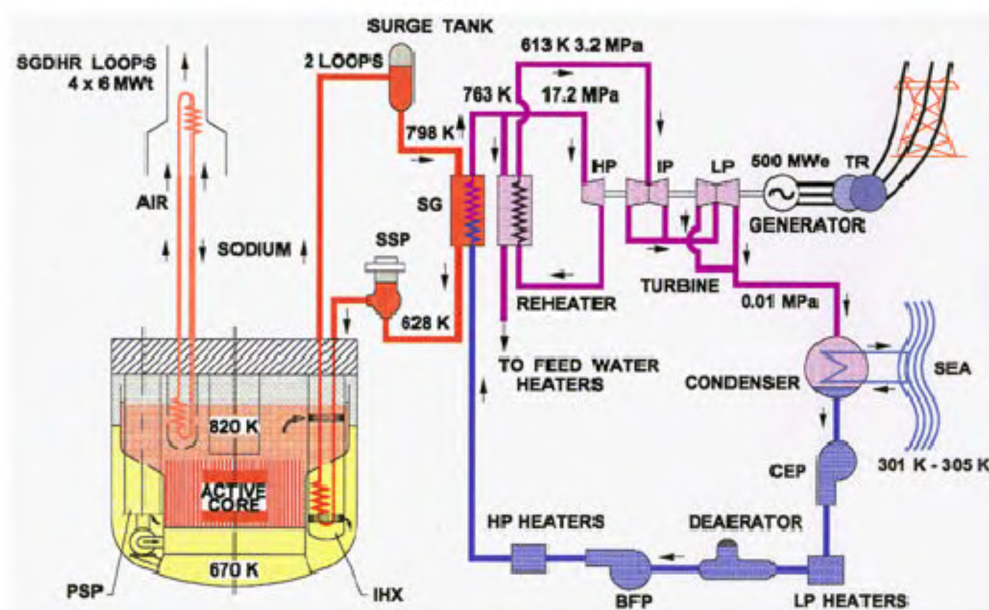| |
|---|
| Melting point: 370.8 K |
| Boiling point: 1155.9 K |
| Density: 0.904 g/cm^3 at 473 K |
| Latent heat of fusion: 0.113 kJ/g |
| Latent heat of vapourization: 4.31 kJ/g |
| Specific heat: 1383 J/kg/ K at 371 K |
| Thermal conductivity: 0.84 J/cm/s/°C at 473 K |
| Viscosity: 0.45 cps at 473 K |
| Electrical resistivity: 13.5 µΩ cm at 473 K |
| Vapour pressure: 2 Pa at 573 K |

Figure 1. Fast reactor plant.

where the fast reactor programme has slowed down (for reasons convenient to their missions). Heavy liquid metal coolants may offer important advantages, high passive safety and proliferation resistance measures, but these coolants need a much longer time frame for development, at least up to 10–20 years[2]. It is concluded that sodium benefits any near-term reactor development programme owing to its extensive and readily available database.

Sodium system design

The design of a liquid sodium system (usually as heat-transfer medium) should take into account the high chemical reactivity and incompressibility of liquid sodium[3]. The system is designed to be leak-tight with provision of inert argon blanket/cover gas to cover free sodium surfaces in components in order to avoid any ingress of air and to accommodate sodium volume changes with temperature. Austenitic stainless steels of type AISI 304/316 grade are usually preferred as construction materials due to their good corrosion resistance and high temperature strength. The system components and pipelines are trace-heated using electrical surface heaters to preheat the system before sodium charging and to maintain sodium in liquid state during operation, especially in static systems or static parts of the system where liquid metal is not flowing. The volumetric expansion of sodium (about 2.7%) on melting requires that consideration be given for *in situ* melting of sodium in tanks or pipelines by means of graded heating to allow free expansion of the metal to take place thus avoiding any incident. This is also the reason why freezing of sodium in the system should be prevented as far as possible. A storage-cum-dump tank located at the bottom is an important part of a sodium system, as also an expansion tank located at the highest point. The system is usually provided with a pump, a heating vessel (with immersion heaters), an air-heat exchanger to cool the system rapidly, and a purification equipment to maintain purity of liquid sodium. The purification equipment consists mainly of 'cold trap', preceded by an economizer heat exchanger. The cold trap works on the principle of precipitating temperature-dependant impurities such as sodium oxide and sodium hydride in its wire mesh-packed zone, where sodium is progressively cooled. The outgoing 'cold' sodium is of purer quality, which goes back to the system.

Special characteristics influencing system/component design:

- The excellent thermal conductivity of liquid sodium results in high heat-transfer coefficient even at modest liquid velocities. This results in communicating temperature changes rapidly to the container material whenever significant heat addition or removal is effected in the system, e.g. rapid lowering of coolant temperature when the heat source is stopped as during

fast shutting down of the reactor. The imposed rapid temperature changes, known as thermal transients must be carefully considered in the mechanical design of components and usually call for thermal baffles/screens to protect the container vessel walls.
- The high volumetric expansion coefficient of liquid sodium is useful in setting up with ease, natural convection–circulation of the coolant produced by modest temperature difference during decay heat removal after periodic shutting down of the reactor. However, the capacities holding sodium need to be designed keeping in mind the volumetric coolant expansion/level changes and with a provision for accommodating coolant expansion in the totally leak-tight system.
- Chemical characteristics: The high chemical activity of sodium has several implications on the system and component designs as discussed below.

Sodium–air reactions

Liquid sodium reacts readily with air and oxidation reaction can occur in a run-away manner leading to sodium fire. The ignition temperature of sodium is 220°C in damp air, 200 in dry air and as low as 120°C in stirred liquid pool. Sodium burning is accompanied by production of dense sodium oxide fumes though the heat produced is much less compared to conventional hydrocarbon fires. The system is therefore required to be helium leak-tight to prevent sodium leaks in the first place. The pipings/components are to be equipped with leak-detection devices to detect any leakage early in order to limit the effects of fire. Furthermore, provisions are to be made to collect the leaking sodium in steel drip-trays and to avoid reaction of sodium with structural concrete.

Sodium–water reactions

Sodium reacts readily with water or steam to form sodium hydroxide and hydrogen. This reaction is highly exothermic. The reactions of water/steam and sodium have major implications in the design, material consideration and protection system for sodium-heated steam generators (SG) which are the most critical components for successful operation of a fast-reactor power plant. The implications in the steam-generator design arise due to high temperatures produced in the reaction zone, propagation of leaks in the same tube or adjacent SG tubes by material erosion/wastage and due to possible high pressures generated in the sodium side of the steam generator.

Cavitation effects

Like in conventional industrial fluids, cavitation can also occur in flowing liquid sodium, in pump suction pas-

sages, or in narrow coolant channels in reactor fuel elements, and due care must be taken to completely avoid or limit the extent of the degree of cavitation if it cannot be totally prevented for practical or economic reasons. Cavitation in significant proportions produces severe damage to the structural parts in the vicinity of the cavitating zone and its severity is found to be 1.5 to 2 times compared to that in water. The cavitation phenomenon which results in producing sodium vapour cavities, is of course not acceptable in case of fuel element passages, due to the resulting overheating of fuel clad and its implications.

Purification of sodium[4]

Sodium has to be purified and maintained in pure state to reduce the corrosion of construction materials and to reduce the possibility of plugging of narrow passages in the system; for example, in fuel channels and in narrow pipes. Once purity is maintained, corrosion problems are much less compared to those in a water system. Corrosion of structural materials (SS 304/316) in a pure system is less than 20 micron(μm)/year. The main impurities encountered in sodium are oxygen, hydrogen, calcium and carbon. Because of the reactive nature of sodium with atmospheric oxygen and moisture, sodium oxide and hydride impurities are formed. Since metallic calcium is highly soluble in sodium, sodium from the electrolytic cell usually contains calcium. Carbon is picked up from the electrodes of the cell. Commercial-grade sodium can be purified to the required purity by filtration in the first stage and by 'cold trapping' in the second stage. Filtration of sodium through sintered stainless-steel microfilters at the lowermost operating temperature (120°C) will reduce the impurity levels considerably. Further, purification is carried out on-line by 'cold trap' through which part the sodium flow from the system is diverted. This component contains a wire mesh which provides large surface area and is maintained at around 120°C. At this temperature, impurities like oxides, hydrides, etc. precipitate out on these surfaces allowing relatively pure sodium to return to the system. All systems usually have a device called plugging indicator, wherein the saturation temperature of impurities can be monitored by cooling a stream of sodium passing through small orifices to produce controlled plugging. The temperature at which controlled plugging takes place is known as the plugging temperature and this is nearly equal to the saturation temperature of impurities. A low saturation temperature is desirable in sodium systems to avoid plugging of narrow passages. This is a simple on-line system that gives the gross concentration of impurities within an hour.

Components in sodium systems

The main components of the sodium system are storage-cum-dump tanks, centrifugal pumps, electromagnetic pumps, heat exchangers, sodium-to-air coolers, bellow sealed valves, cold trap, etc. The hydraulic properties of sodium are similar to those of water or any other Newtonian fluid. Hence the process design is according to conventional hydraulic engineering practices. Design includes calculations for sizing of pipes and valves, pressure drop, cavitations, heater transfer, flow induced vibration, etc.

The pumping requirements of sodium vary between a few thousand m^3/h in the main heat-transport system to a few m^3/h in the auxiliary systems. Because of the highly reactive nature of sodium, conventional pumps cannot be used. For large flow rates, where centrifugal pumps are employed, the selection is normally in favour of vertical mounted centrifugal pumps with a free level of sodium and argon above free level, thus avoiding shaft sealing-related problems. For low flow rates, electromagnetic pumps such as flat linear induction type, annular linear induction type, AC or DC conduction type are used. These pumps have very low efficiencies (nearly 20%), but have the advantage of being hermetically sealed; they hardly need any maintenance as there are no moving parts. Besides, they can be installed at convenient locations in the loop as part of the piping.

High reactivity of sodium with air/hydrocarbons has precluded use of conventional rolling contact bearings in sodium. If rolling contact bearings are to be used, they should be without normal lubricants and must be able to retain adequate material hardness at operating temperatures. Journal and sleeve bearings with hydrodynamic lubrication within sodium have also severely limited load-carrying capacity due to poor viscosity of sodium and hence are not used. Therefore, hydrostatic pressure-fed bearings making use of sodium available from pump discharge have been developed for running of high-speed pumps.

Globe or gate valves used in sodium systems are SS bellow-sealed valves with a secondary gland packing and leak detector port. Because of the zero leakage of process fluids, such valves find wide applications not only in sodium systems but also in other toxic or costly fluid systems. A fully welded construction of the valve is preferred.

Construction of components

For the construction of components and systems, the conventional procedures followed in high-temperature stainless steel systems is generally adequate for heat-transport systems. However, reactor systems call for more stringent procedures and quality control. For conventional heat-transport systems, the materials procured have to meet the requirements of ASME Section-III, Class-1 unfired pressure vessels. The design and fabrication will in general meet the requirements of Section-VIII, Division-1. All sodium-wetted parts are of welded construc-

tion, welded by a qualified welder according to ASME Section-IX and radiographed. All systems are subjected to leak test, pressure test and helium leak-test according to standards.

Sodium instrumentation

Besides temperature measurement, the important process instruments used in sodium systems include electromagnetic flow meters that measure the flow rate of sodium in pipelines and level probes mounted in sodium capacities and leak detectors. Different types of level probes such as discontinuous (resistance) type and continuous (mutual inductance) type are available to measure the level of sodium in different capacities. Generally, pressure measurements in sodium systems are avoided because of the complications involved in the sensor while handling liquid sodium. However, they can be measured if required. Other special instruments such as sodium ionization leak-detector system under sodium ultrasonic viewing are available for special applications, but they may not be required for conventional systems.

Sodium removal from components/waste disposal

The components in sodium systems need to be cleaned free of sodium before attempting their repair, reuse or dismantling them. Various cleaning techniques employed are alcohol dissolution, water vapour–nitrogen process, water vapour–carbondioxide–nitrogen process and vacuum distillation process. The high chemical reactivity of sodium metal is an important consideration in selecting the cleaning process, besides the quantity of residual sodium in the component and structure of the component (thickness, shape, etc.) involved. In all these processes, hydrogen is one of the reaction products, which above 4% in air can form an explosive mixture. Thus care must be taken to keep the hydrogen concentration well below this limit by diluting with inert gas.

Alcohol dissolution is usually employed for small and delicate components like valves, bellows, etc. In this process, ethanol is generally employed, while isopropanol or a mixture of alcohol containing a small percentage (5%) of water is also employed occasionally. The advantage of the alcohol process is the low boiling point or the high vapour pressure of the alcohol in use. This limits the temperature excursion during the dissolution process by alcohol evaporation, thus effectively controlling the reaction.

Large components such as sodium pump, heat exchangers, etc. are cleaned by water vapour–carbon dioxide in inert gas atmosphere. This method is preferred over the moist-inert gas cleaning method where the sodium hydroxide formed could lead to caustic stress corrosion of the component during reuse. The CO_2 present in the

cleaning mixture reacts with sodium hydroxide to form sodium bicarbonate and sodium carbonate which do not cause caustic stress corrosion.

Sodium disposal

The conventional method of disposal of sodium wastes is by conversion to sodium hydroxide, followed by neutralization and disposal. However, if large quantities are to be disposed, they need an elaborate system, wherein liquid sodium is injected in a controlled way in a circulating, concentrated sodium hydroxide solution. The hydrogen liberated must be tackled suitably. Finally, the hydroxide is converted to salt and disposed-off.

Sodium fire and safety

It is not difficult to handle solid metallic sodium as long as it is covered with a thin layer of paraffin/kerosene/oil to prevent significant oxidation. On the other hand, liquid sodium ignites in air above 200°C producing low flame with modest heat evolution. However, the white oxide fumes accompanying sodium combustion produce thick clouds of opaque smoke rendering fire-fighting difficult. It is therefore best to avoid sodium leakage by high-quality construction of the system and further by having sensitive leak-detection arrangement to limit the leakage in an eventuality. Sodium fire comes under Class-D metal fire and can be handled with dry chemical extinguishers. The reaction of sodium with water/steam is vigorous and, explosive with liberation of heat and hydrogen, and hence water and water-based extinguishers are ruled out for sodium fire-fighting. When used in process systems, the compatibility of sodium with the process fluid must also be ensured. With water and hydrocarbons, special instruments are available to detect leakage of such fluids into sodium at an early stage. Such instruments are essential for the safety of the plant.

Developments in India

Before application of sodium as a heat-transfer fluid, the use of sodium was largely in pharmaceutical and other industries as a chemical agent in solid form. With the application of sodium as a coolant in fast reactors, a lot of experimental/development work has been carried out in India and abroad to master this technology. The work was initiated in early 70s in a modest way and over the past 30 years, sodium technology has developed considerably. The technology improvements that have taken place are largely at the Engineering Development Group, Indira Gandhi Centre for Atomic Research, Kalpakkam. The programme initially focused on safe handling of liquid sodium in pumped engineering-scale loops, reactor

component tests, sodium instrumentation and last but not the least, in preparing 150 tonnes of sodium coolant of reactor grade for Fast Breeder Test Reactor (FBTR) from commercially available grade[5].

By 1985, when the FBTR attained criticality, the experimental sodium technology and engineering programme had matured enough to tackle future developments in support of the 500 MWe Prototype Fast Breeder Reactor (PFBR); (Figure 2), the conceptual design of which had taken shape by then. Several small and medium size sodium loops were in operation for studies in liquid metal corrosion, liquid metal heat transfer and calibration of certain reactor instrumentation. The major advancements are highlighted below.

Experimental facility

Considering the earlier requirements of FBTR and presently that of PFBR, many experimental sodium facilities have been constructed and operated at temperatures up to 550 to 600°C (ref. 6). Major facilities include Large Component Test Rig (80 t Na), Sodium–Water Reaction Test Facility, Steam Generator Test Facility (5.5 MWt), 500 kW Sodium Loop, etc. The design, construction and operation of these facilities have given enough confidence in the design of heat-transport systems for reactors and other facilities. Even though sodium is having a high boiling point, the vapours generated at 550°C can cause problems in narrow crevices in the reactor systems. To study aspects such as heat transfer from hot sodium to the upper-cover gas regions, temperature distribution in critical areas and convection currents in annular spaces in cover-gas region of the reactor systems, elaborate experimental studies have been carried out in the Large Component Test Rig. Also, critical components of the reactor such as control and safety-rod drive mechanism, diverse safety-rod drive mechanism and fuel-handling equipments are tested at rated reactor environments before installing in the reactor system. The components have to qualify the performance requirements in such testing processes. Special requirements are imposed on components such as cold trap (used for purification), sodium vapour trap, etc. The secondary side of the reactor cold trap is loaded heavily by hydrogen and needs to be regenerated. Regeneration of the FBTR secondary cold trap has been demonstrated. The cover gas argon carries a large amount of sodium vapour/mist along with that in flowing systems. This mist has to be separated using special techniques for condensation and filtration. All these experiments are carried out in these test facilities.

Sodium purification

Even though pharmaceutical industries use large quantities of sodium, the sodium is in solid form with high impurity content. Purification of sodium to nuclear grade was

demonstrated during 1975–78, and about 150 t of sodium was purified to nuclear grade and supplied in 1983–84 to the FBTR at Kalpakkam. Subsequently, about 100 t was purified for use in experimental facilities operating at high temperature. The road map for processing 1750 t of sodium required for PFBR has been laid. Besides purification, monitoring of impurities in sodium in ppm and ppb levels has been developed. Diffusion-type (in sodium and cover gas) hydrogen meters (using the principle of diffusion of hydrogen through nickel to a high vacuum system) and electrochemical-type meters have been developed. For measuring the saturation temperature of impurities, a plugging indicator is installed as part of the sodium system. In addition, oxygen sensors were also developed and used.

Sodium pump

The reactor systems require a range of flow rates of sodium. For low flow rates, flat linear induction pumps,
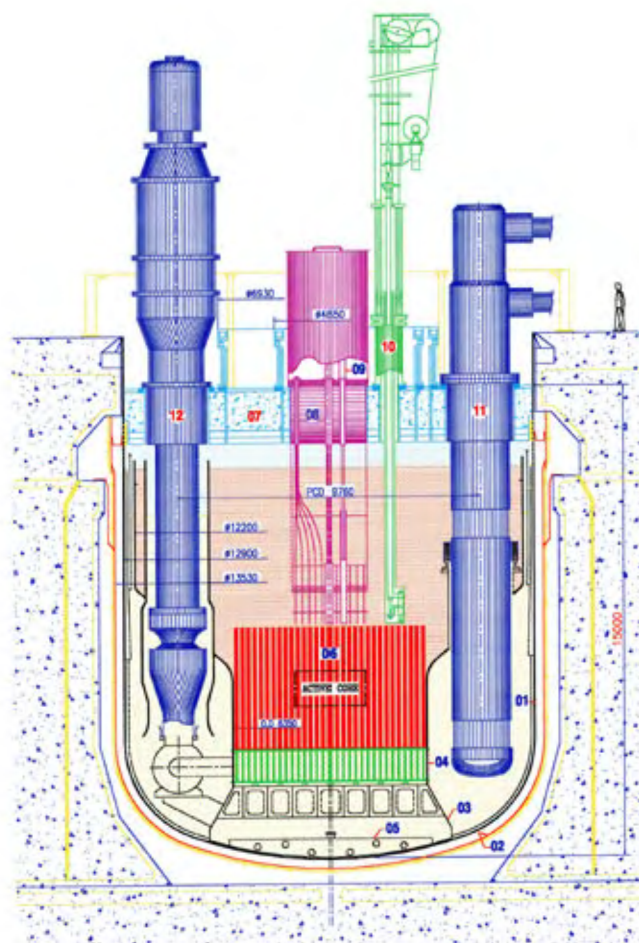

Figure 2. Prototype fast breeder reactor – Reactor assembly. 01, Main vessel; 02, Safety vessel; 03, Core support structure; 04, Grid plate; 05, Core catcher; 06, Core; 07, Top Shield; 08, Control Plug; 09, Control and safety rod drive mechanism; 10, In-vessel transfer machine; 11, Intermediate heat exchanger; 12, Primary pump and drive.

annular linear induction pumps, d.c. conduction pumps (immersible in sodium) and a.c. induction pumps are used. Many such pumps have been designed (with the support of IIT-Madras) and fabricated indigenously. They were also tested in sodium facilities for performance. To meet the requirement of large flow rates in primary and secondary circuits of the PFBR, centrifugal pumps with flow rates of 4.13 m^3/s and 3.34 m^3/s have been designed. The hydraulic design of these pumps posed a formidable challenge because of their large capacity to be delivered under modest net positive suction head coupled with the need to restrict their overall diameter, which in turn influenced the overall diameter of the reactor vessel. This implied that the pump would operate with cavitation to a small extent but again without producing significant erosion damage to the impeller. The design was developed in collaboration with an Indian industry after a long-drawn experimental programme on scale models. Similarly, the manufacturing technology of pump components such as shaft, impeller, hydraulic bearings, etc. has been carried out indigenously.

Steam generator

This is such a critical component that it is described as Achilles heel of a fast reactor plant. PFBR uses a vertical, shell-and-tube steam generator with hot sodium on the shell side and water/steam at 175 bar and 525°C on the tube side. The tube material is 9 Cr 1 Mo. The technology involved in the steam generator takes into account sodium–water reaction and resistance of tubes to its effects, adequacy of heat-transfer area and reduction of excessive heat-transfer margins to reduce the cost of the component, flow-instability problems related to once through type design, flow-induced vibrations and several manufacturing considerations, such as inspection of long tubes (23 m) by eddy current methods, tube thermal expansion design, tube–tube sheet joint and so on. The steam generators of the FBTR are operating satisfactorily over the years, but the design of the PFBR steam generator had to be different because of very large capacity, also it is totally indigenous. To gain confidence on all the above-mentioned aspects, a major test facility with a steam generator of 5.7 MWt that simulates all the conditions of the tube vertically, was designed and constructed at the Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam. Experimental studies on this facility will commence shortly[7].

Sodium instrumentation

Since liquid sodium is a metal, it has high electrical conductivity which is exploited in the design of sensors for sodium. For instance, the flow is measured by permanent magnet flow meters and eddy current flow meters. A large number of such flow meters were designed at IGCAR and are in use. Measurement of sodium level is carried out by resistance-type and mutual inductance-type level probe. The technology for such instruments has been passed on to the Indian industries to enable them to use such instruments in other liquid metal systems, e.g. in the aluminum foundry. Sodium being opaque, viewing the internals in reactor systems is not possible by conventional methods used in water-cooled reactors. Ultrasonic techniques for use at high temperatures have been developed and demonstrated in the FBTR. Sensitive leak detection methods such as sodium ionization-type leak detectors have also been developed with the detector sensitivity that responds to low sodium concentration of ng/cc.

Sodium fire

In the event of unlikely sodium fire, damage to the components and the equipment has to be reduced. Even though leak detectors have been developed to detect minute leakage at an early stage, fire-fighting extinguishers to be used have been validated. To contain a large leakage, leak-collection trays kept underneath the system that work on the principle of self-extinguishing the fire by oxygen starvation, have been developed and tested. These special trays use a corrugated shape cover with entry holes precisely sized and spaced so that almost all sodium that leaked from the system is collected within, with little burning.

Material corrosion

The materials used in reactor systems such as stainless steel 304, 316, 304 LN, 316 LN, Mod. 9 Cr 1 Mo, etc. are exposed to sodium at different operating conditions and the effect on corrosion by leaching of constituent elements, mass transfer of interstitial elements like carbon, etc. have been studied in experimental facilities. Based on the data generated in the last 30 years, thickness loss is established to be less than a micron (μm) per year, which is considered negligible. However, a design allowance of 20 μm/year is considered to account for uncertainties.

Activity transport

In a nuclear reactor, radio nuclides are produced in the core region by neutron activation and fission. They are released slowly by corrosion and mass-transfer processes, and these deposit on other cooler regions. The breach of the clad of the fuel will lead to release of fission products in sodium. The release behaviour and deposition pattern

are modelled using computer codes. They are also being studied in experimental sodium facilities. Some of these are trapped in the cold trap. Radionuclide traps using reticulated vitreous carbon are deployed to trap ^{137}Cs and [134]Cs. Decontamination of radioactive construction materials using chemicals such as sulpho-phosphoric acid solution has been studied and recommended for PFBR.

Summary

Metallic sodium has been used since the beginning of the 20th Century in chemical and pharmaceutical industry, primarily as a reducing agent because of its chemical properties. However, later years saw its growing applications as a heat-transfer agent, thanks to its excellent physical properties, mainly high thermal conductivity coupled with low viscosity and low density. However, its potential was not exploited until the advent of fast (neutron) reactors, where it has earned a place of honour as an effective coolant. Despite its high chemical reactivity, which is a disadvantage, it has been accepted universally as a fast reactor coolant due to its favourable nuclear properties and due to a lot of work on experimental and test facilities in several countries on sodium technology. Today, liquid sodium can be handled without difficulty and safely in engineering-scale systems involving tonnes of quantities. This article has looked at the various developments in sodium technology that have made it like any conventional heat-transfer fluid. The article has also covered development in handling sodium at IGCAR over the past 30 years.

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