weight of approximately 2,00,000 and molecular weight distribution of about two. As manufactured Pyro Chek 68PB contains at least 66% bromine.

Because it is a polymer, Pyro Chek 68PB has several advantages. It has very good thermal stability and therefore can be used as fire retardant at high temperatures. It is relatively non-toxic and has a very important advantage in todays market.

(B) Halogen free fire retarding plastics

A few important examples are :

(i) Bisphenol A polycarbonate (BPAPC)
(ii) Polybutylene terephthalate (PBT)
(iii) Polyphenylene sulphone (PPSU).

5.11. BIOMEDICAL POLYMERS [CONTACT LENS, DENTAL POLYMERS, ARTIFICIAL HEART, KIDNEY, SKIN AND BLOOD CELLS]

Today synthetic polymers have wide spread use in everyday life and in different fields of technology. We hope that these uses will continue to increase in future years also. However, there exists one important area in which the use of synthetic polymers has generally been cautious and limited—the area of medical science. But it is expected that as new synthetic polymers are developed there will be intense changes in medical techniques also.

The types of synthetic polymers needed for biomedical applications can be grouped into following three categories :

(1) Polymers that are sufficiently biostable to allow their long-term use in artificial organs like blood pumps, heart valves, skeletal joints, kidney prostheses etc.
(2) Polymers that are bio-erodable. These are materials that will serve a short-term purpose in the body and then decompose to small molecules that can be metabolized or excreted.
(3) Water soluble polymers : They are also bio-erodable that form part of plasma or whole blood substitute solutions.

5.11.1. Biostable Materials

General Principles : We know that body organs can be transplanted from one person to another. Now-a-days heart, kidney and corneal transplants are performed frequently. However there are several problems in this connection. Firstly there are very few donor organs and very few persons can afford the expenditure. Secondly the antibodies of the recipient often reject the donor tissues and attempt to destroy them. Although this effect can be suppressed by immunosuppressor drugs, the transplant may not be successful. Moreover, immunosuppressor drugs reduce the body's ability to combat microorganisms or to destroy abnormal cells. Hence, a risk of serious infection or even cancer is associated with their use.

Due to these reasons, there is an increasing demand of the use of artificial organs made from synthetic polymers rather than live organ transplants. Synthetic polymers are now been developed that can fulfill the functions of the heart valves, blood vessels, lungs or kidneys. Also polymers are now used in bone or socket replacements, intra-ocular lenses, artificial corneas and permanently implanted artificial teeth as well as in tooth reconstruction materials.

In all these uses, synthetic polymers have many advantages over metals, glass or ceramics. Important among these advantages are their low density, chemical inertness, flexibility, elasticity or rigidity according to need, and ease of fabrication into complicated shapes.

Almost all the major classes of polymers have been investigated for possible biomedical uses. A polymer must fulfill following requirements to be used in an artificial organ.

(1) It must be physiologically inert.
(2) It should be stable during many years of exposure to possible hydrolytic or oxidative conditions at body temperature. It must be resistant to enzyme attack, and it must not change dimensions, disintegrate or dissolve in aqueous media or in contact with lipids or other fatty materials.

(3) If it is to be used as a structural material to replace bone, it must be strong and resistant to impact.

(4) It must be sufficiently stable chemically or thermally that it can be sterilized by chemicals or by heat.

Thus we see that use of synthetic polymers in biomedical applications is not an easy job and the comparison of different polymers for biomedical uses is not a straightforward process. Research workers in this field are always busy to answer the question : which polymer is the best for a particular biomedical application? Though it has been found that at least four polymers account for most of the materials currently used in biostable medical applications. These are : Poly (tetrafluoroethylene), polyesters, poly (dimethyl siloxane) and polyurethanes.

5.11.2. Cardiovascular Applications

Heart valves : Damaged heart valves, weakened arterial walls, and blocked arteries constitute some of the most common cardiovascular disorders, and polymers have been used extensively to correct such problems. Defective heart valves can be replaced by mechanical valves of various designs. For this purpose, silicone rubber is used because if its inertness, elasticity and low capacity to cause blood clotting.

Aneurisms (balloon-like expansions of the arterial wall) can be repaired by reinforcement of the artery with a tube of woven polyester or poly (tetrafluoroethylene) fabric. Completely blocked arterial sections are removed and replaced by a tube of porous poly (tetrafluoroethylene).

The Artificial Heart : Heart disease and circulatory disorders are responsible for more deaths in the world than any other common ailment. The most serious problems arise from arteriosclerosis and from the progressive narrowing of the cardiac arteries. A blockage of one of these arteries leads to "heart attack". For patients with an irreversibly damaged heart, two things can be done. First a heart transplant may be possible, but it has a limited scope due to obvious reasons. Secondly, the functions of the damaged heart may be taken over permanently or temporarily by an artificial pump. A lot of work has been done to design and testing of artificial heart pumps. Unfortunately, most synthetic polymers accelerate the clotting of blood. This problem is so serious that animals on which the pumps are tested sometimes die within hours from the massive, gelatinous blood clots that form in the pumps. Aviodance of the clotting process is a complex problem because it depends mainly on the design of the pump and the materials used for its construction.

Heart pump designs : Two types of heart pumps have been developed.

(i) auxiliary blood pumps to bypass or supplement the action of a damaged heart until it can repair itself.

(ii) total artificial heart pumps that can completely replace the living organ.

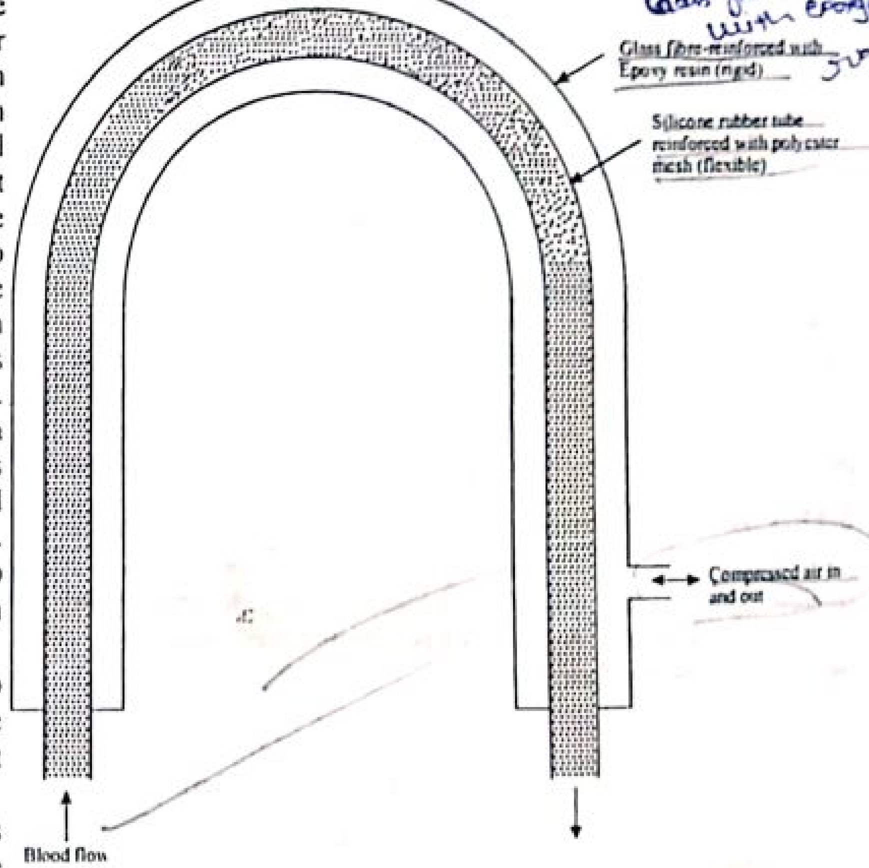


Fig. 4. Relatively simple 'artificial heart' device designed for implantation in the body

The figure 4 shows a relatively simple "artificial heart" device designed for implantation in the body.

Pulses of compressed air applied inside the rigid casing compresses the silicone or polyurethane rubber inner tube which is connected to the aorta and this forces blood from the pump. Valves may be used to prevent backflow. The phase of the pumping cycle is synchronized with the pumping motion of the patients heart.

Figure 5 shows another design of pump which uses hemispheres of titanium, polycarbonate, poly (tetrafluoroethylene) or poly (methyl methacrylate) containing a polyurethane diaphragm. Pulses of compressed air or carbon dioxide actuate the diaphragm and cause the pumping of the blood.

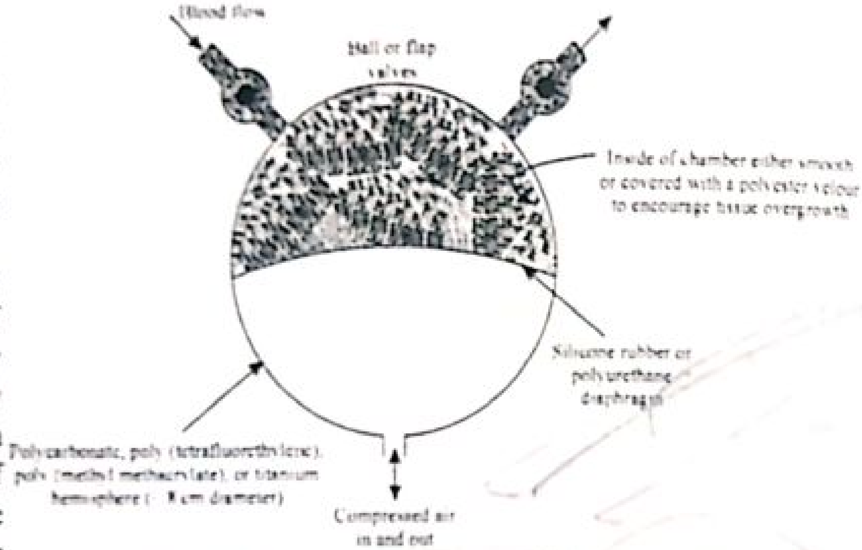


Fig. 5. Schematic design of a hemispherical "artificial heart" pump, designed to operate outside the patient's body

Synthetic polymers for heart pumps

A wide variety of different polymers have been used for the fabrication of heart pumps. Some of the examples are : silicone rubber, polyurethane rubber, Dacron polyester, Teflon, poly carbonate, poly (methyl-methacrylate), poly (vinyl chloride). Most of these materials cause blood clotting and destruction of red cells, although some are markedly better than others. Polyurethanes are among the most commonly used flexible biomaterials. They have excellent flexing strength. (The diaphragm in a heart pump would have to withstand about 90 million flexing motions without breaking over a 10 year period). However, they are chemically unstable during long term exposure to aqueous media.

Silicone rubber is also an ideal biomaterial. It is chemically inert, soft and flexible. However it can promote blood clotting if the blood is flowing slowly, and it can fail after continuous flexing. Another problem is the tendency of silicone rubber to absorb fats from the blood to swell and finally to weaken.

Researches show that fluoro-alkyl siloxane polymers or poly phosphazenes may prove to be more suitable for artificial heart applications. Also, the ability of a synthetic polymer to initiate blood clotting largely depends on the nature of the surface. (Smooth surfaces are better than rough). Highly water repellent polymers appear to be among the best materials for contact with blood. Since the inside lining of blood vessels is negatively charged, it has also been found that polymers with a surface charge is more effective than neutral polymers. If an anticoagulant like heparin is bonded to the surface or absorbed into the polymer, it may help in the problem of blood incompatibility.

5.11.3. Artificial Skin

It has been felt for many years that there is a need of synthetic polymers that can be used to glue tissues together. The use of an adhesive would be much more rapid and effective than the sewing of a wound with a suture. A group of polymers based on the poly (α-cyano acrylate) structure have proved to be effective for this purpose.

$$CH_2{=}\underset{\displaystyle CN}{\overset{}{C}}-\overset{\displaystyle O}{\overset{\|}{C}}-OR$$

α-cyano acrylates

R = methyl, butyl, hexyl, octyl and so on α-cyano acrylates have the general formula as shown where the group R. can be methyl, butyl, hexyl, octyl, and so on. These monomers polymerise by an anionic mechanism in the presence of water. Higher alkyl derivatives polymerise more rapidly on biological substrates and are less irritating to tissues than are the lower alkyl derivatives. However their curing capability is somewhat unpredictable. In addition to their use as skin adhesives, they have been tested as adhesives in corneal and retinal surgery, and as an adjunct to suturing in internal surgery.

Films of synthetic poly [amino acid] and poly (α-cyano acrylates) are newly found polymeric materials that can be used as synthetic skin to cover large burns in the human body.

5.11.4. Bones, Joints and Teeth

Bone fractures are occasionally repaired with the use of polyurethanes, epoxy resins and vinyl resins. Silicone rubber rods have been used as replacement finger and wrist joints, and vinyl polymers and nylon have been searched out as replacement wrist bones or elbow joints. More recently, silicone rubber have been used in knee joints to prevent fusion of the bones. Great advances have been made in hip-joint surgery with the use of stainless steel or polyethylene ball joints attached to the femur by mean of a poly (methyl methacrylate) filler and binder. Teflon fabric and silicone rubber have been used to make synthetic ligaments and tendons.

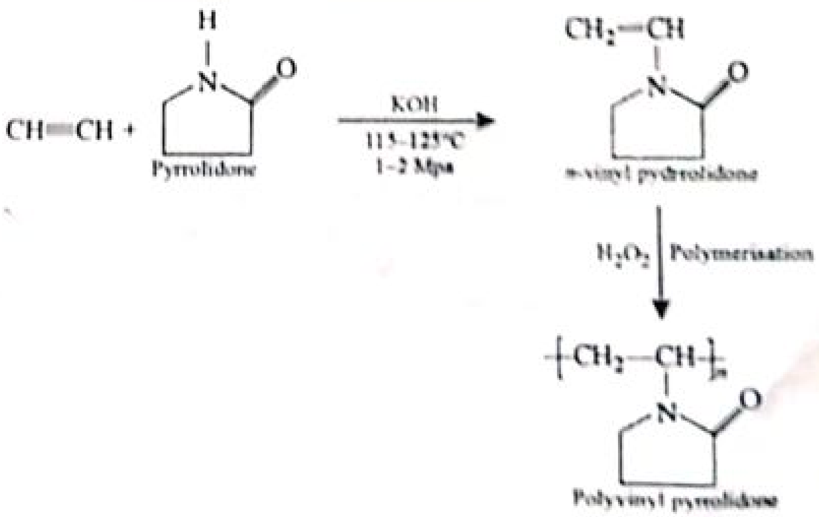
Synthetic polymers have been used for many years in the fabrication of dentures. Poly (methyl methacrylate) is the most important polymer used both for acrylic teeth and for the base material. Acrylic resins are also used for dental crowns, and epoxy resins are sometimes employed to cement crowns to the tooth post.

More recently polymeric coatings or paints are used to prevent the decay of teeth. Also thermo or photo setting polymers are now-a-days used to replace silver amalgam or gold as tooth-filling materials.

5.11.5. Contact Lenses

Although rigid polymers such as poly (methyl methacrylate) have been used for 'hard' contact lenses, the modern tendency is towards flexible or "soft" contact lenses. A soft contact lens is made from a lightly crosslinked, water-soluble polymer. Such polymers swell in aqueous media, but do not dissolve. Instead, they form soft hydrogels. Hydrogel research is an important area in many fields of biomedicine because hydrogels can be designed to mimic the physical character of many tissues (cartilage, skin, blood vessel linings, *etc*). The design of hydrogels for intraocular lenses (*i.e.* for lenses to replace the natural lens following eye injury or removal of cataract-damaged lenses) is a special challenge since the replacement lens must be folded without damage into a small volume before insertion through a small incision into the eye.

Porosity and permeability are two important parameters needed in the polymers which can be used for contact lenses. **Hard contact lenses** are made from relatively impermeable polymethylacrylates, while **soft contact** lenses employ hydroxyethyl methacrylate (HEMA) systems, in which the hydroxy group



imparts water-compatibility. The further development of modern contact lenses that can be left in place in the eye for long periods has been made possible by polymers with oxygen permeability that more closely matches the natural properties of the eye. This involves hybrid polymers with hydrophilic (polyviny) pyrrolidone) and hydrophobic (polysiloxan or silicones) components.

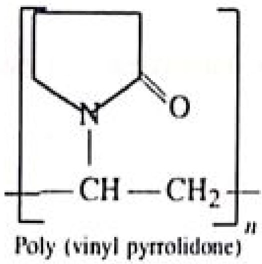
5.11.6. Artificial Kidney

The function of a kidney is to remove low-molecular-weight waste products from the blood stream. Artificial kidneys have been available for several years. They function by passage of the blood between the walls of a dialysis cell which is immersed in a circulating fluid. Because conventional hospital hemodialysis equipment is bulky and expensive, a continuing need exists to construct smaller and cheaper units. Synthetic polymers form the basis of these new developments.

Cellophane (regenerated cellulose) has been used for semipermeable dialysis membranes in conventional kidney machines. However, the need for miniaturization has been responsible for the use of bundles of hollow fibres as a dialysis cell. For example, a bundle of 2000 to 11,000 hollow fibres of modified polyacrylonitrile (17 cm long and 300 μm diameter) are used. The polymer is "heparinized" to prevent blood clotting. Hollow rayon fibres or polycarbonate or cellulose acetate fibres have also been used for the same purpose.

5.11.7. Artificial blood cells

Blood serves many functions, including the transport of oxygen and carbon dioxide, nutrients, minerals, and white cells. To fulfil these functions it must maintain a suitable viscosity to prevent turbulence. Synthetic polymers have been investigated for use in plasma substitutes and as volume expanders to reduce the amount of whole blood needed, for example, during the use of a heart-lung machine.



Poly (vinyl pyrrolidone)

Furthermore, the transmission of hepatitis and other diseases through the use of pooled plasma provides a continuing incentive for the development of a synthetic substitute for this fluid. Poly (vinyl pyrrolidone) was used extensively by the Germans in world war II as a colloidal plasma substitute for the treatment of casualties.

But its main disadvantage in this connection is its poor biodegradability. In fact, it is retained indefinitely in the spleen, lymph nodes, liver, and bone marrow, and it may initiate carcinogenic changes. Hence there is a serious need for the development of a water soluble or hydrophilic polymer that is non toxic and biodegradable. Water soluble polyphosphazenes may be useful for this purpose.

Certain polymers have been investigated to be used as oxygen transport compounds in blood. For example, an emulsion of poly (tetrafluoroethylene) particles (less than 0.001 mm in diameter) or liquid fluorocarbons in water, together with glucose, salts, and surfactants, has been used to replace the blood of rats. The rats remained alive and active for periods from 5 hours to several days. The long-range possibility also exists that biodegradable, water soluble macromolecules can be synthesized that possess oxygen-carrying side groups such as metalloporphyrins. Solutions of such polymers could be used as blood replacement fluids, but would be degraded and excreted as the body produced new blood cells.

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