7 Dialysis

The word, dialysis, is of Greek origin meaning 'to pass through'; the present use implying a filtering (or passing through) process. This is the principal process for removing the end-products of nitrogen metabolism (urea, creatinine and uric acid), and for repletion of the bicarbonate deficit of the metabolic acidosis associated with renal failure in human beings. In all types of dialysis, blood passes on one side of a semipermeable membrane, and a dialysis fluid is passed on the other side. By altering the composition of the dialysis fluid, the concentrations of undesired solutes (chiefly potassium and urea) in the fluid can be reduced and the desired solutes (for example sodium) can be increased.

7.1 PRINCIPLE OF DIALYSIS

Dialysis is a concentration gradient based separation process which uses a semipermeable membrane to separate species by virtue of their different rate of diffusion through membrane (diffusive solute transport). Dialysis requires that the membranes separating the two liquids permit diffusional exchange between at least some of the solutes while effectively preventing any convective mixing between the concentrated and dilute solutions. The feed solution or dialysate, which contains the solutes to be separated, flows on one side of the membrane and the solvent or diffusate stream on the other. Some solvent may also diffuse across the membrane in the opposite direction, thereby reducing the performance by diluting the dialysate. Since, the driving force in dialysis is concentration gradient, membranes should be thin and the transmembrane concentration difference should be large, if high fluxes are to be achieved (see Figure 7.1).

Dialysis is used to separate species that differ appreciably in size and have reasonably large differences in diffusion rates. Solute fluxes depend on the concentration gradient in the membrane. Therefore, dialysis is characterized by

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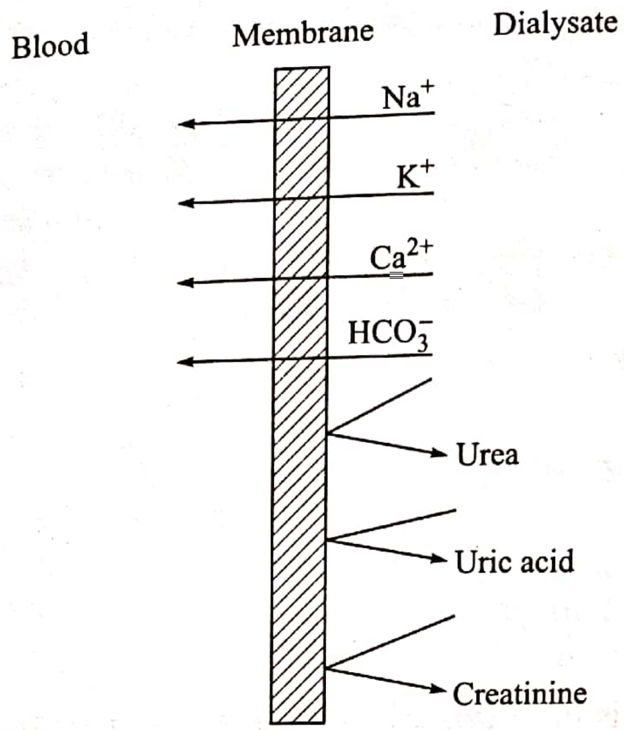

Figure 7.1 Transport through a dialysis membrane.

low flux rates as compared to other pressure driven membrane processes like reverse osmosis and ultrafiltration.

Extracorporeal dialysis employs the artificial kidney (dialyser) as semipermeable membrane, while intracorporeal dialysis employs the peritoneal membrane. The size of the solute is highly correlated with its molecular weight. The heavier, larger solute moves more slowly along the concentration gradient than smaller, lighter solutes. Thus, dialysis is most effective in removing small solutes and less effective in removing larger solutes, particularly those over 1000 Da. Some basic information on dialysis process is given in Table 7.1.

Table 7.1 Some basic information on dialysis process

Driving force	Chemical potential (concentration difference)
Transport mechanism	Diffusion in pores
Separation principle	Difference in diffusion rate (hindered diffusion), sieving
Size of retained species	50–200 Å
Membrane type	Microporous
Membrane materials	Hydrophilic polymers, cellulose acetate, ethylene-vinyl alcohol, cellulose-cuprophan
Pore size	($1.5<d<10$nm, ~500 MW)
Module	Plate and frame and hollow fibre
Flux	12–30 $l/m^2/h$

7.2 DIALYSIS SYSTEMS

Usually four types of modules are widely used in dialysis system. These are:

(a) Plate and frame dialyser

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(b) Rotating drum dialyser
(c) Twin coil dialyser
(d) Hollow fibre dialyser

The process of dialysis was first applied in the recovery of salts and other low molecular weight solutes from serum proteins and vaccines. It was also used for the separation of caustic soda from hemicellulose solution during manufacturing of rayons. Cellophane membranes in a simple plate and frame module were used in these operations. The modules consisted of an assembly of frames, with a membrane between each adjoining pair, held together by a clamping device. A dialyser normally contains a few hundred single compartments filled with alternating sequence with the feed solution and dialysate. The two solutions are operated either countercurrent or cocurrent flow with dense liquid flowing upwards and light liquid flowing downwards.

Kolff and Berk developed the first operating artificial kidney in 1944. It consists of a cellophane sausage casing wrapped around a drum. In this rotating drum dialyser, the dialysis membrane was rotated through a bath of dialysing fluid. The blood was screwed along the tubing by gravity forming a thin film on the wall of the cellophane. In another design known as twin coil dialyser, blood is allowed to flow through a continuously wrapped roll of flattened cellophane tubing. Supporting layers of plastic screening are spaced to ensure dialysate flow crosswise to the coil and perpendicular to the flow of blood. The entire coil is submerged in a large bath, and the dialysate is recirculated through the coil at high flow rate.

The hollow fibre dialyser consists of a bundle of many capillary membranes through which blood flows. The fibres are potted into tube sheets at each end of the device, thereby forming headers for the inlet and outlet blood flow paths. Dialysate flows on the outside of the fibres, and the overall design is similar to a shell-and-tube heat exchanger.

7.3 DIALYSIS MEMBRANES

Membranes used in dialysis include cellulose, cellulose acetate, various acid-resistant polyvinyl copolymers, polysulphones, polymethyl methacrylate and polyacrylonitrile. These are typically less than 50 μm thick and with pore diameters of 15 to 100 Å. But out of these membranes cellulose has been most commonly used. For hemodialysis (dialysis of blood) isotropic cellulose hydrogels with a molecular weight cut off of approximately 1000 are the most common membranes. The membranes are formed by the cuprammonium process ($NH_4OH + CuO$) and they are homogeneous in nature without having a skin. These membranes are known as Cuprofan. Another method of solubilizing cellulose is the xanthate method ($NaOH + CS_2$) and the product is classically known as rayon or regenerated cellulose. These membranes can easily pass the low molecular weight waste products such as urea (MW: 60),

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