NEW DESIGN OF HEAT EXCHANGER FOR FOAM-FILM TYPE OXYGENATORS

B. S. Bobrov and T. I. Turchaninova

The successful conduct of operations on the open heart and main vessels, with due observation of all modern medical requirements, requires that there should be proper control of the temperature of the blood while in the extracorporeal circulation, and provision for proper gas exchange (saturation of blood with oxygen and removal of carbon dioxide). Exclusion of the heart from the circulation with the patient in a state of hypothermia is now a well-established method. The heat exchanger has become just as much an integral part of the artificial heart-lung apparatus as the oxygenator.

The effectiveness of heat transfer, like the effectiveness of blood oxygenation, depends on the area of the exchange surface per unit of blood flow. The two processes generally take place in separate units of the heart-lung apparatus, oxygenators and heat exchangers (connected in series with one another in the main line through the pump). Many specialists, working on the design of artificial heart-lung apparatuses, have concerned themselves with the idea of building an apparatus in which heating or cooling of the blood would be effected along with the processes of gaseous exchange in a single unit of the apparatus. A combination of oxygenator and heat exchanger offers a number of advantages over the separate unit system; it will reduce the quantity of donor blood required for priming the working chambers, reduce local hydraulic resistances, and eliminate a number of tubes, connections, communications, and other ancillary elements, all tending to complicate operation of the apparatus. Within recent years the idea has been realized in the case of film, bubble, and membrane oxygenators, both in the Soviet Union and abroad. One example is the Kay-Cross disk oxygenator [1] in which a system of coils, consisting of series of steel tubes connected in parallel, is accommodated in the bottom part of the cylindrical casing. In the bubble oxygenator, the gas-exchange chamber, in which the blood is saturated with oxygen, contains a coil in the form of a spiral tube through which the heat-regulating fluid is passed [2]. Among Soviet designs may be mentioned a bubble oxygenator with an inbuilt heat exchanger, developed by the Leningrad "Krasnogvardeets" industrial combine and the Institute of Cardiovascular Surgery of the Academy of Medical Sciences of the USSR [3].

Technically, the problem of housing a heat exchanger in a bubble oxygenator is simpler than the problem of building one into a foam-film type oxygenator.

Specialists acknowledge that foam-film oxygenators are functionally superior to bubble types [1]. It would be of great advantage, therefore, if a heat exchanger could be combined with a foam-film oxygenator in one unit.

In 1966 one of us designed a new heat exchanger which could be combined with the settling chamber of a foam-film oxygenator [4]. Figure 1 is a diagram of such an oxygenator with the inbuilt heat exchanger.*

The venous blood passes through pipe (1) into the centrifugal chamber (2) of the venous distributor, and through the nozzles (3) of the individual jets to trickle down through the foam column (4). In the foam-quenching chamber excess bubbles are quenched by means of perforated disks (15), covered with special composition (e.g. Antifoam). Foaming of the blood in the working chamber is produced by the bubbles of oxygen coming from the orifices in the oxygen distributor membrane (5). The heat exchanger, essentially a water jacket, consisting of a casing and series of tubes, is housed in the settling chamber in the lower part of the oxygenator (12). A section of the settling chamber would show the stem of the oxygen distributor surrounded by cylindrical tubes (6). Inserted into the cavity of each tube is a mandril (7) made of fluoroplastic or other poor heat-conducting material. The diameters of the tubes and mandrils are 20 and 18 mm respectively. To simplify the work involved in operation of the tubular-jacket type heat exchanger the tube

*Inventor's certificate No. 187246 for a foam-film type oxygenator with inbuilt heat exchanger has been granted to B. S. Bobrov and T. I. Turchaninova with priority from October 10, 1965.

Fig. 1. Foam-film oxygenator with inbuilt heat exchanger (diagrammatic). 1) Inlet pipe for venous blood; 2) centrifugal chamber; 3) nozzles; 4) foam column; 5) oxygen distributor; 6) cylindrical tubes; 7) mandrils; 8) water inlet pipe; 9) filter; 10) oxygen delivery pipe; 11) blood outflow pipe; 12) water jacket; 13) humidifying chamber; 14) water outlet pipe; 15) perforated disks.

diameter has been increased to 20 mm (easier cleaning of inner surfaces of numerous tubes, in contact with blood). The oxygenated blood passes through the cylindrical clefts formed by the walls of the tubes and their mandrils, and is heated (or cooled) to the required temperature by the water circulating in the jacket. Leaving the heat exchanger, which is connected to the main tube of the perfusion pump of the heart-lung apparatus. Water enters the jacket through the lower pipe (8) and flows out through the upper pipe (14), and thus there is counterflow of refrigerant and blood in the heat exchanger.

To heighten the effectiveness of heat exchange still more, provision is made for heating or cooling the oxygen going to the distributor (6). The humidifying chamber (13), containing normal saline, through which the oxygen passes in the pipe (10), is mounted in the center of the water jacket.

Both laboratory and experimental clinical investigations have demonstrated the high functional qualities of apparatuses of this design. The quantity of donor blood or blood-replacement fluids required for priming of oxygenator and heat exchanger is reduced to less than one-third of the quantity required for certain apparatuses used for the same purpose (AIK RP-64); the actual quantity is 250 ml for artificial heat apparatuses with limited outputs, such as the AIK RP-3 apparatus for regional perfusion (maximum output 1.2 liters/min), and 400 ml for the oxygenator with heat exchanger for an output of 3 liters/min.

Furthermore, tests have shown that heat exchangers dealing with volume rates of flow of 1.2 liters/min (heat exchange area 480 cm²) and 3 liters/min (heat exchange area 780 cm²) produce a fall of temperature of the order of 15° from oxygenator inlet to outlet, when blood enters at 36° and the temperature of the cooling water is 1–2° (Fig. 2).

Refrigerant flow rates of from 16 to 30 liters/min were tried in these investigations, but doubling the rate of water flow in the heat exchanger did not affect the change produced in the temperature of the blood (in view of the great difference between the flow rates of the water and the blood).