Disposable Heat Exchanger

Dr. A. ROBERTS, Liverpool College of Technology, and Mr. J. L. ROBINSON, Regional Neurosurgical Centre, Liverpool, write: The estimation of the transfer of heat between two flowing media separated by a solid wall consists essentially in computing the resistance to heat transfer (1) within the fluid in the tube, (2) across the wall of the tube, and (3) within the fluid on the outside of the tube.

CONVENTIONAL HEAT EXCHANGERS

In the normally constructed heat exchanger made of stainless steel factor 2 is reduced to a minimum. Though this makes

the side arm, while the blood tube passes straight through, being held in place by a compression joint. The coolant tube is itself encased in a further, larger tube with a small quantity of silica gel lying free in the intervening space. This provides good insulation with a layer of dry air and prevents condensation from affecting the performance of the heat exchanger in different physical conditions.

For higher blood flows it is more economic in respect of priming volume to use two blood tubes of half the required size running in parallel, and these can be joined together with a "Y" piece from a larger

to the increase in flow above 10 ml. per minute. The maximum flow rate, which is still laminar, is given for each tube, assuming a Reynold's number of 1500, which is comfortably below the theoretical safe limit of 2000.

HEAT TRANSFER CALCULATION

The overall net effect in the heat exchanger can be expressed in terms of an overall heat transfer coefficient in the blood-tube-water combination:

$$\frac{1}{U} = \frac{1}{h_1} + \frac{1}{h_2} + \frac{t}{k_m}$$

Where U is the overall heat transfer coefficient, h_1 is the blood side heat transfer coefficient, h_2 is the water side heat transfer coefficient, t is the wall thickness, and k_m is the thermal conductivity of the wall.

The figure for h_1 is calculated from the data presented by Shore (1963), h_2 is conventionally calculated, and k_m is measured in the laboratory. For polyvinyl chloride tubing this is 0.156 watt per metre per °C.

The heat exchanger performance is expressed as:

$$Q = UA\Delta T_{\log}$$

Where A is the total area through which heat transfer takes place, Q is calculated from the mass flow rate of blood with specific heat and temperature drop, the specific heat being taken as 1 cal. per g. per °C. $\Delta T_{\log}$ was calculated by using the blood and water inlet and outlet temperatures in the laboratory.

The length of tubing required (L) is therefore:

$$\frac{Q}{UA\Delta T_{\log} \pi D_m}$$

Where D_m is the bore of the tube carrying the blood plus the outer diameter of the blood tube divided by two.

CONCLUSION

Though these heat transfer calculations involve a number of approximations, and the concept of a heat exchanger made of insulating material is somewhat strange, we have found this apparatus simple, cheap, and effective in use. There have been no major problems with the circuit, which we are currently using for inducing profound selective cerebral hypothermia in dogs. Sterilization can be done by autoclaving or by filling the circuit first with a suitable sterilizing fluid; ethylene oxide may be used or, perhaps best of all, irradiation with gamma-rays.

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REFERENCE

Shore, D. T. (1963). *Proceedings of the Institution of Mechanical Engineers*, 177, 491.

Heat exchanger apparatus.

for extremely efficient heat exchangers it also has disadvantages. For example, stainless steel heat exchangers are expensive; the flow at the points of entry and egress is not laminar; the heat exchanger has to be carefully cleaned after each use, which is time-consuming; the highly polished blood surfaces may become scratched, and repolishing is expensive; and the blood and coolant circuits are separated by only an "O" ring seal, so the possibility of leakage is always present, even if the pressure on the coolant side is maintained below that on the blood side. This last factor limits the flow rate in the coolant circuit.

PRESENT APPARATUS

For these reasons we decided to use polyvinyl chloride tubing. This, of course, means that factor 2 is greatly increased. The heat exchanger, however, is so designed that factor 3 can be decreased to a minimum, and the overall heat transfer is much more efficient than might be thought. We use a simple coaxial counter-current system, blood passing one way down the narrower centre tube while in the wider outer tube coolant flows in the opposite direction (see Fig.). At each end is a "T" piece, the coolant entering and leaving via

ducting tube. No modification is needed in the coolant tube, as the velocity of coolant is increased with the decrease in volume of coolant in the tube.

The coolant used is a mixture of water and antifreeze containing melting ice which falls to a temperature below 0.5°C. The flow rate of coolant is about 18 litres a minute, so that factor 3 is negligible as compared with factors 1 and 2.

Since the tubing can be coiled, this system provides acceptable heat transfer characteristics with a low priming volume and laminar flow throughout the whole length of the heat exchanger within a manageable size. Also haemolysis is less than 0.5% per four hours' use in vivo. The blood tube is disposable and cheap, and can be changed after each use, so that time spent on maintenance is minimal. The blood and coolant circuits are entirely separate, so there is no possibility of leakage and no restriction on pressure or rate of coolant flow. The heat exchanger is transparent, so that air bubbles are easily seen.

Data for a blood flow of 10 ml. per minute are given in the Table, which shows the priming volume plus the lengths of tubing required to get a specified fall in temperature. The length of tube required for higher flows increases in direct proportion

Length of Blood Tube Required to Produce Given Temperature Drop (Priming Volume in Parentheses)

Bore	Outer Diameter	Portex Catalogue No.	5°C. (P.V.)	10°C. (P.V.)	15°C. (P.V.)	20°C. (P.V.)	25°C. (P.V.)	30°C. (P.V.)	Maximum Flow Rate (Reynold's No. 1500)
0.91 mm.	1.52 mm.	NT/2	7 cm. (0.05 ml.)	16 cm. (0.1 ml.)	24 cm. (0.15 ml.)	36 cm. (0.23 ml.)	49 cm. (0.32 ml.)	65 cm. (0.42 ml.)	450 ml./min.
2.2 mm.	3.0 mm.	NT/4	5 cm. (0.19 ml.)	11 cm. (0.42 ml.)	17 cm. (0.65 ml.)	26 cm. (0.99 ml.)	35 cm. (1.3 ml.)	46 cm. (1.7 ml.)	1,100 ml./min.
3.05 mm.	4.13 mm.	NT/6	5 cm. (0.37 ml.)	11 cm. (0.80 ml.)	17 cm. (1.24 ml.)	25 cm. (1.83 ml.)	33 cm. (2.41 ml.)	45 cm. (3.29 ml.)	1,500 ml./min.
4 mm.	6 mm.	NT/8	6 cm. (0.78 ml.)	13 cm. (1.69 ml.)	20 cm. (2.6 ml.)	30 cm. (3.9 ml.)	40 cm. (5.2 ml.)	54 cm. (7.0 ml.)	2,000 ml./min.
5 mm.	6.9 mm.	NT/12	5 cm. (0.95 ml.)	11 cm. (2.1 ml.)	18 cm. (3.4 ml.)	26 cm. (4.9 ml.)	35 cm. (6.7 ml.)	46 cm. (8.7 ml.)	2,500 ml./min.
6 mm.	7.6 mm.	NT/14	4 cm. (1.12 ml.)	9 cm. (2.5 ml.)	15 cm. (4.2 ml.)	22 cm. (6.2 ml.)	29 cm. (8.1 ml.)	39 cm. (10.9 ml.)	3,000 ml./min.

Blood inlet temperature 37°C.

Blood flow 10 ml./minute. Tube length for increased flow rate rises in direct proportion.

Coolant temperature less than 0.5°C.

Coolant flow 18 litres/minute.

Coolant tube bore 25.4 mm. Outer diameter 31.75 mm. NT/24.

Outer insulating tube bore 38.1 mm. Outer diameter 47.62 mm. NT/26.

The lengths of tubing required are, if anything, overestimated.