DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

CBM352 HUMAN ASSIST DEVICES

UNIT-I Heart Lung Machine and Artificial Heart

1.2 Different types of Oxygenators and Blood Pumps

1.2.1 What is blood oxygenator?

A blood oxygenator, also known as an oxygenator, is a crucial component in medical devices designed to oxygenate the blood outside the body. One common application of blood oxygenators is in extracorporeal membrane oxygenation (ECMO) systems. These systems are used in critical medical situations where a patient's lungs or heart are not functioning adequately.

Blood oxygenators play a vital role in supporting patients with severe respiratory or cardiac failure, providing a temporary means of oxygenation and allowing time for the lungs or heart to recover. They are a critical component in various medical procedures, such as cardiac surgery, lung transplantation, and ECMO therapy.

1.2.2 Types of blood oxygenator:

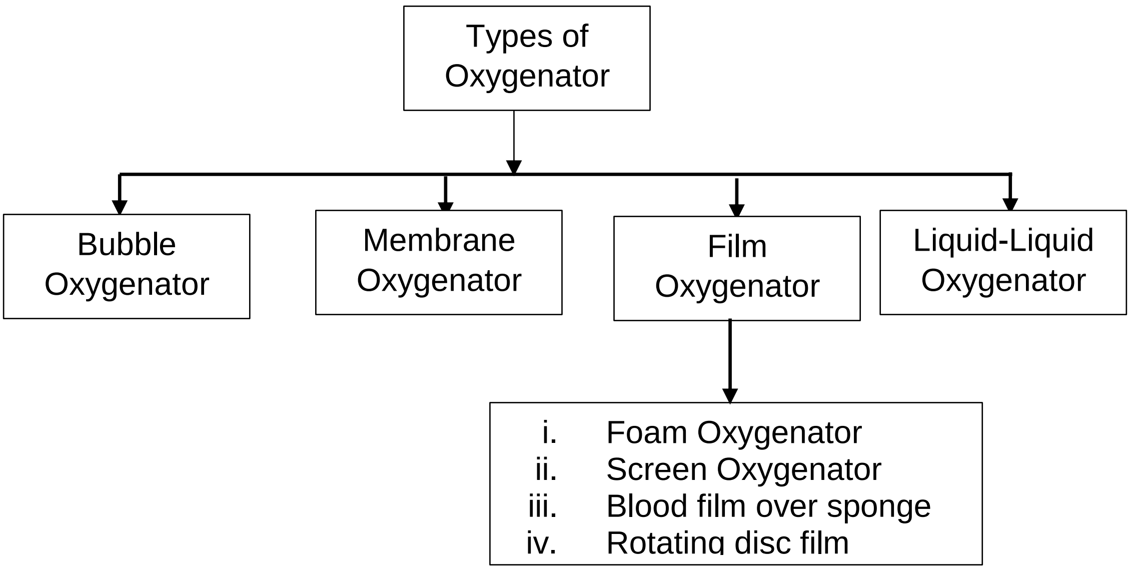


Fig. 1.2.1 Types of Blood Oxygenators

1.2.3 Bubble Oxygenator:

In bubble oxygenators, gas is introduced into the blood directly in the form of bubbles. The oxygenation takes place effectively because of the large surface area of the bubbles and so it is one of the most effective and simplest oxygenators.

Because of the mechanical stress induced by the introduction of air bubbles into the blood and also because of the direct contact of air bubbles with the blood, the trauma caused by this means of oxygenation is the highest of all oxygenators. In addition, it is necessary to ensure the removal of bubbles to avoid complications. A settling chamber is required to allow air bubbles to dissolve out of the blood. This is accomplished in an arterial reservoir. Even though blood trauma induced by this oxygenator is high, it was widely used for short-duration bypass procedures because it is not only inexpensive but also easy to use.

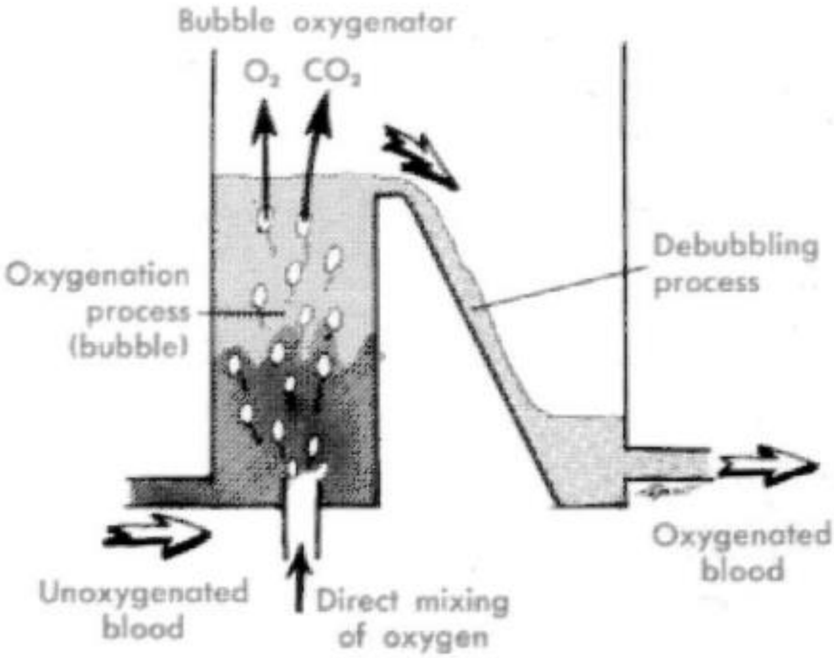


Fig. 1.2.2 Bubble Oxygenator

Features of Bubble Oxygenator:

1. The oxygenation is effective because of the large surface area. It is suitable for short operations.
2. Simplest among different oxygenators.
3. Due to mechanical stress introduced by the bubbles, trauma produced in, it is the highest.

4. In the case of disposable unit, except the long preparation time and expensive material cost, we can get cleanliness, sterility, simplicity and inexpensive manpower cost.

1.2.4 Membrane Oxygenator:

Membrane-type oxygenator. In membrane oxygenators, the blood is exposed to oxygen through a gas-permeable membrane. Because the gas does not have any direct contact with the blood, trauma is minimal. The membrane oxygenator is considered the most atraumatic blood oxygenator; however, the membrane introduces resistance to the permeating gases, which necessitates a rather large surface area. Consequently, a large volume of priming blood is necessary if the gas transfer rate of the membrane is not good. To enhance gas transfer, microporous membranes were used, rather than homogeneous nonpermeable membranes, for oxygenators used in cardiopulmonary bypass applications.

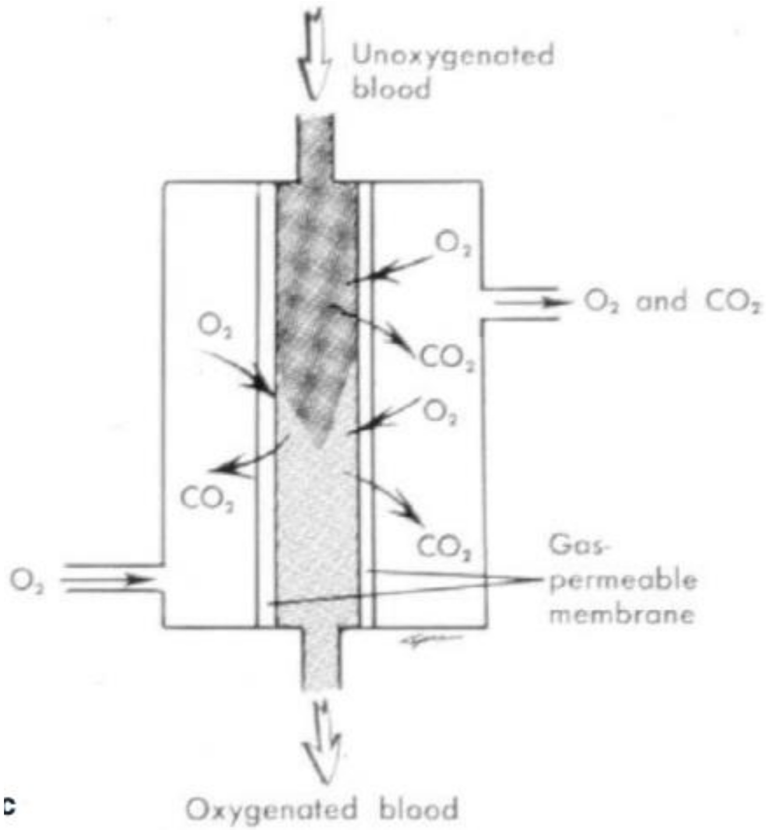


Fig. 1.2.3 Membrane Oxygenator

Features of membrane oxygenator:

1. So expensive. Not commonly used.
2. Trauma produced in these oxygenators is very small when we compare it with others. Bubbles and foam do not form.
3. These are difficult to clean

1.2.4 Film Oxygenator:

In film-type oxygenators, various techniques are employed to produce a thin blood film, and gas exchange takes place on the surface of the exposed blood film. Because there is no mechanical introduction of the gas into the blood, the blood trauma caused by this pump oxygenator is generally less than that of the bubble oxygenator. A large surface area is usually necessary, thus requiring a high priming volume for this type of device

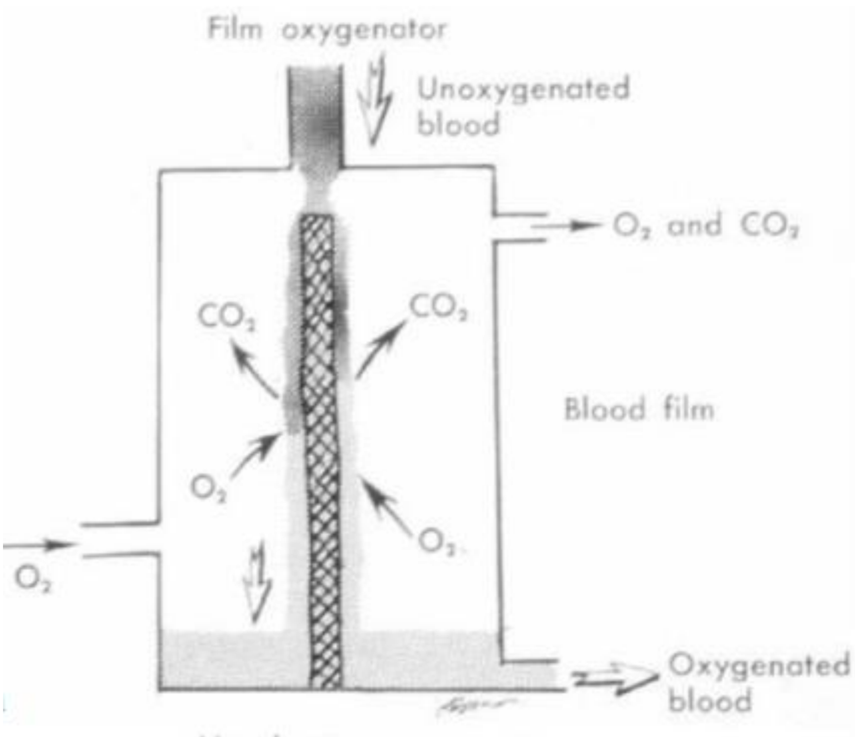


Fig.1.2.4 Film Oxygenator

Here a thin film of blood is spread on a rotating disc or metal screen and an oxygen mixture flows over this thin layer of blood. There are several types in this oxygenator.

a) <u>Foam Oxygenator</u> – Blood is poured over the top of the blood foam. The oxygen mixture is bubbled through the blood in the opposite direction. The blood is spreading over the surface of the bubble in a thin film form and effectively it is exposed to oxygen. The filmed blood is oxygenated while falling down. Defoaming is done afterwards.

b) <u>Screen Oxygenator-</u> A thin film of blood over a screen (stationary or rotating) is exposed to oxygen for oxygenation. This causes less trauma to blood. Disposable units are also available in this type.

c) <u>Blood film over sponge</u>: - A small volume of sponges saturated with blood provides a large surface area for blood oxygenation if oxygen is simultaneously distributed in the sponge

d) <u>Rotating disc film oxygenator</u> –

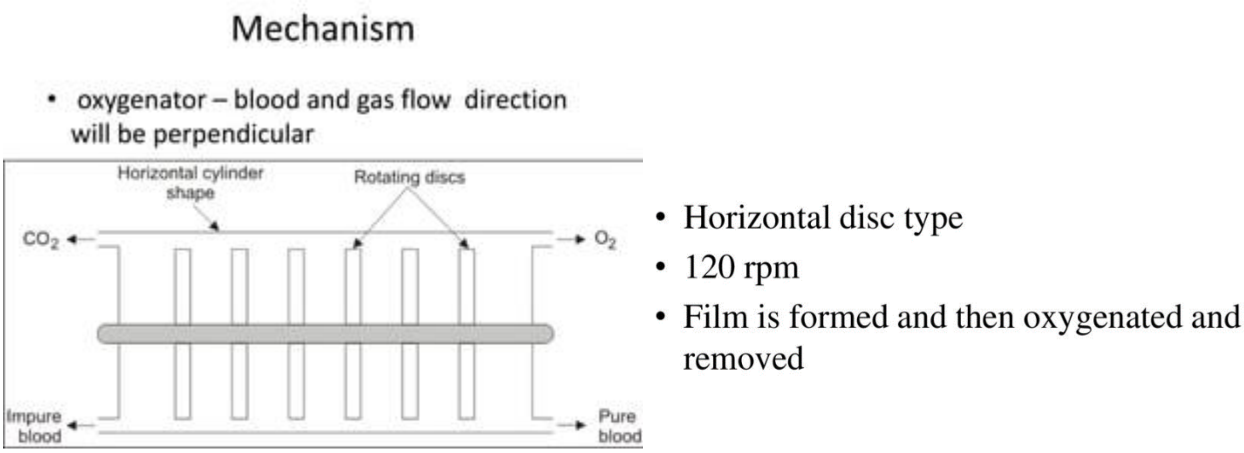


Fig.1.2.5 Rotating disc film oxygenator

i. Blood level is maintained at the bottom of the cylinder so that only outer edge of each disc is immersed in the blood.

ii. Rotation of the central axis if the cylinder causes a thin blood film to form on the periphery of the discs.

iii. After a short exposure to oxygen which is filled in the oxygenator housing, the blood is washed off from the discs. At the same time a new blood film is formed on the same discs. This new film is also washed off at the next revolution.

iv. Since the cylinder is rotated at 120 rpm, the exposure time of the blood with the oxygen atmosphere is only 0.5 seconds.

Features:

- These are difficult to clean
- Trauma produced in these are very small
- Effective oxygenation can be done.

1.2.5 Liquid-Liquid Oxygenators:

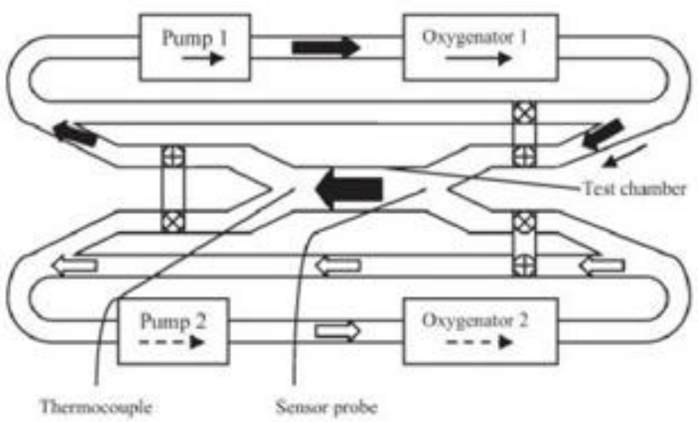


Fig.1.2.6 Liquid-Liquid oxygenator

The oxygen dissolved fluoridised organic fluid and blood are flowing in the opposite directions and oxygenation of the blood takes place.

Working:

Fluoridised organic liquid is the working liquid with readily dissolves oxygen and carbon dioxide which then diffuse to and from the blood respectively. Even though the blood is in direct contact with the working liquid, it is entirely a different chemical compound with respect to the blood constituents and so there is no chemical reaction between them. During their opposite flow through a small tube, gaseous exchange takes place.

Features:

- No Trauma is produced
- Effective oxygenation can be obtained

1.2.6 Blood Pumps:

A "blood pump" typically refers to a medical device designed to circulate blood within the body. There are different types of blood pumps used for various medical purposes, and they play a crucial role in supporting the cardiovascular system in different scenarios. Here are a few examples:

Role of blood Pumps:

1. **Heart-Lung Bypass Machine**: This type of blood pump is commonly used during cardiac surgery. It temporarily takes over the function of the heart and lungs, allowing surgeons to operate on the heart while maintaining oxygenation and circulation of the blood.
2. **Ventricular Assist Device (VAD)**: VADs are mechanical devices implanted into the chest or abdomen to assist the heart in pumping blood. They are commonly used as a bridge to transplantation for individuals awaiting a heart transplant or as a long-term treatment for those with heart failure.
3. **Extracorporeal Membrane Oxygenation (ECMO):** ECMO is a system that uses a blood pump to provide both cardiac and respiratory support. It is used in critical care situations, such as severe respiratory failure or cardiac failure, and involves circulating the patient's blood through an external oxygenator and pump.

Characteristics if ideal Blood Pump:

1. **Biocompatibility**: The blood pump should be made from materials that are compatible with the human body to minimize the risk of adverse reactions, inflammation, or clotting. It should not cause any damage to cellular and non-cellular components of blood.
2. **Appropriate Pressure**: It is able to pump the blood up to 6 litre/minute. It should deliver the blood with appropriate pressure.
3. **Pulsatility:** In certain applications, such as ventricular assist devices (VADs), a blood pump with pulsatile flow more closely mimics the natural pulsatile flow of the heart, which can be beneficial for maintaining physiological functions.
4. **Compact and Lightweight**: Especially for implantable devices, a blood pump should be compact and lightweight to minimize the impact on the patient's daily life and mobility.

5. **Low Thrombogenicity**: The pump design should minimize the risk of blood clot formation (thrombosis) to ensure continuous and safe blood circulation.
6. **Adjustable Flow Rate**: The ability to adjust the flow rate is crucial to accommodate different patient needs and physiological conditions.
7. **Reliability and Durability**: Blood pumps, especially those used for long-term support, need to be reliable and durable to ensure continuous operation over an extended period without frequent maintenance or replacements.
8. **Ease of Implantation**: For devices that are surgically implanted, an ideal blood pump should be designed for ease of implantation, reducing the complexity and risks associated with the surgical procedure.

1.2.6 TYPES OF BLOOD PUMPS

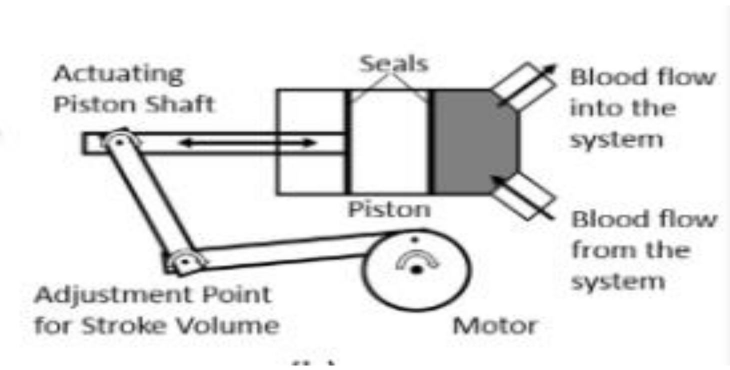
Blood pumps, also known as circulatory assist devices or ventricular assist devices (VADs), are mechanical devices designed to support or replace the pumping function of the heart. These devices play a crucial role in managing heart failure, providing temporary assistance for patients awaiting heart transplantation, and serving as long-term therapy for those who are not eligible for transplantation. There are different types of blood pumps, and their specific designs and functions may vary, but they generally fall into two main categories: pulsatile pumps and continuous flow pumps

- Pulsatile Blood Pump
- Continuous Type Blood pump

(A) Pulsatile Blood Pump:

A pulsatile blood pump is a medical device designed to mimic the natural pulsatile flow of blood through the cardiovascular system. Unlike continuous flow pumps, which provide a constant stream of blood, pulsatile blood pumps generate pulsatile flow patterns that mimic the rhythmic beating of the heart. These pumps are commonly used in various medical applications, including temporary circulatory support during cardiac surgeries or as a bridge to transplant for patients awaiting heart transplantation.

The working principle of a pulsatile blood pump involves the generation of pulsatile flow through mechanical means. Here's a simplified overview of how these pumps typically operate:



1. **Pump Mechanism:**

Diaphragm or Piston: Pulsatile blood pumps often use a diaphragm or piston mechanism to generate pulsatile flow. The movement of the diaphragm or piston creates pressure changes within the pump chamber, leading to the pulsatile flow of blood.

2. **Control System**:

Electronics and Sensors: Pulsatile blood pumps are equipped with control systems that regulate the timing, frequency, and amplitude of the pulsatile flow. Sensors monitor parameters such as pressure and flow within the circulatory system to provide feedback to the control system.

3. **Power Source:**

Electric Motor or Pneumatic System: The pump is typically powered by an electric motor or a pneumatic system. The power source drives the movement of the diaphragm or piston, generating the pulsatile flow of blood.

4. **Timing and Synchronization:**

Synchronization with Native Heart: In some cases, pulsatile blood pumps are synchronized with the patient's native heart rhythm. This synchronization ensures that the pump supports the natural cardiac cycle, enhancing hemodynamic performance.

5. **Implantation:**

Intraoperative or Extracorporeal: Pulsatile blood pumps can be used intraoperatively during cardiac surgeries or implanted temporarily as extracorporeal devices. Extracorporeal devices are typically connected to the patient's circulatory system via cannulas, providing support for a specific duration.

6. **Monitoring and Adjustments:**

Clinical Monitoring: Continuous monitoring of the patient's vital signs, including blood pressure and cardiac output, is essential. Clinicians may adjust pump settings based on the patient's condition and hemodynamic requirements.

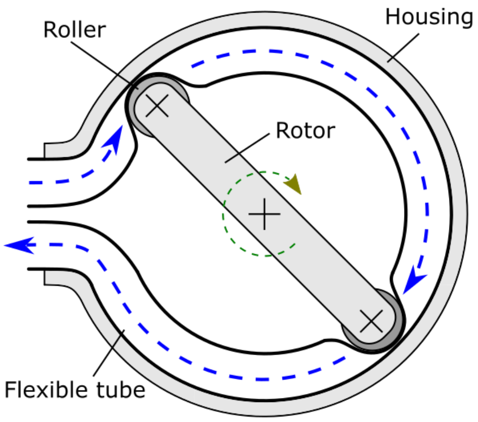
It's important to note that the design and specific features of pulsatile blood pumps can vary among different devices and manufacturers. The goal is to provide circulatory support that closely resembles natural physiological conditions, especially in situations where the patient's heart function is compromised or during specific medical procedures.

Advantages of pulsatile blood pump:

- ✓ Physiological Mimicry
- ✓ Improved Hemodynamics
- ✓ Reduced Risk of Complications
- ✓ Reduced Shear Stress
- ✓ Enhanced End-Organ Perfusion
- ✓ Synchronization with Native Heart:
- ✓ Application in Pediatric Patients:

(B) Continuous Type/ non-pulsatile Blood pump:

Non-pulsatile blood flow can be generated by squeezing a tube filled with blood by a roller. The most commonly used non-pulsatile pump is a roller pump. Single roller ad multiple roller pumps are available. Figure shows a roller pump which acts as a blood pump.



Conventional roller pump with complete tube occlusion in the areas of the rollers

Fig.1.2.8 Blood Pump

Working:

1. In the clearance between the pump housing and the roller, a tube carrying the blood is positioned.
2. Because it has the tendency to move forward as the roller passes over it, an attachment to stop this movement is provided.
3. The tube has also a tendency to escape laterally which must be prevented on most pumps by mounting a guide rod on the central axis of the pump. The clearance between the pump housing and the roller is controlled automatically to avoid high pressure on the blood in the pump.
4. The pump is powered by either external or implantable batteries. Implantable batteries allow greater mobility for the patient as they are not tethered to an external power source.
5. The continuous blood pump is surgically implanted within the patient's chest. It is usually connected to the left ventricle of the heart, the main pumping chamber.

Drawback:

The main disadvantage of this principle it that, due to the complete occlusion of the tube (complete closure of the tube), the pumped fluid is subject to high mechanical stress. In the case of blood pumps this leads to a damage of the red blood cells (hemolysis), which limits the maximum application time of roller pumps due to the strain of the patient's organism. Since this pump producing haemolysis, the maximum time that extracorporeal circulation can be permitted is limited.

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