Ventilator

- principles of operation
- construction
- Ventilator assisted breathing
- Troubleshooting
- preventive maintenance
- safety considerations
- performance monitoring

13.7.2 Maintain a Ventilator

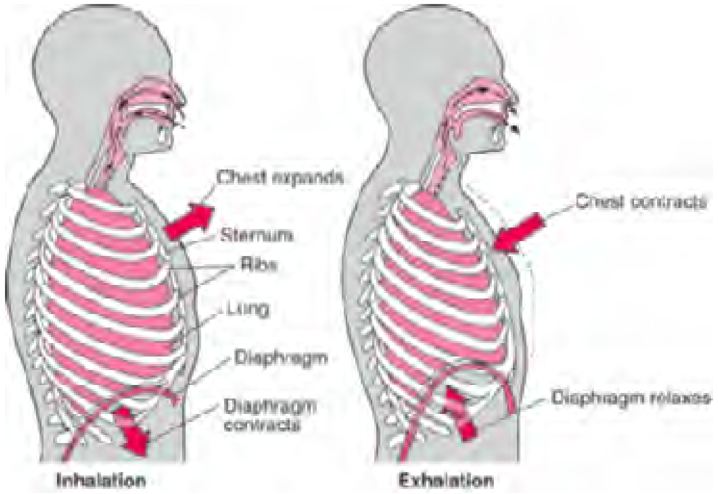
Unit B 13.7 Maintaining Ventilation and Anaesthesia equipment

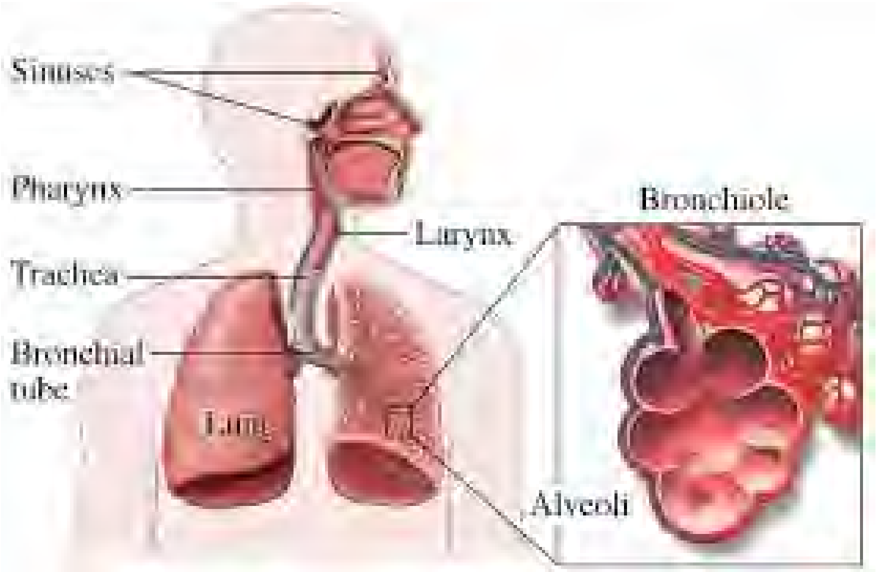
Module 279 18 B Medical Instrumentation I

Breathing = Ventilation

Breathing or Ventilation is the process that moves air in and out of the lungs, including **inhalation** and **exhalation**.

Breathing is performed by a range of muscles in the chest, notably the **diaphragm**, a dome-shaped muscle that separates thorax and abdomen. If these muscles do not work, ventilation stops and life is not possible





Gas exchange in the lungs is required to

- **oxygenate** blood for distribution to the cells of the body
- **remove carbon dioxide** from the blood

The gas exchange in the lungs occurs in the alveoli - tiny sacs - by passive diffusion of gases between the alveolar gas and the blood in the lung capillaries. Exhaled air has a relative humidity of 100%.

Breathing therefore results in a **loss of water** from the body.

Ventilator: Function and Use

A (medical) ventilator is a machine designed to mechanically move breathable air into and out of the lungs, to provide breathing for a patient who is physically not able to breathe.

Some patients only need some assistance in breathing; others need the ventilator to fully take over their breathing function.

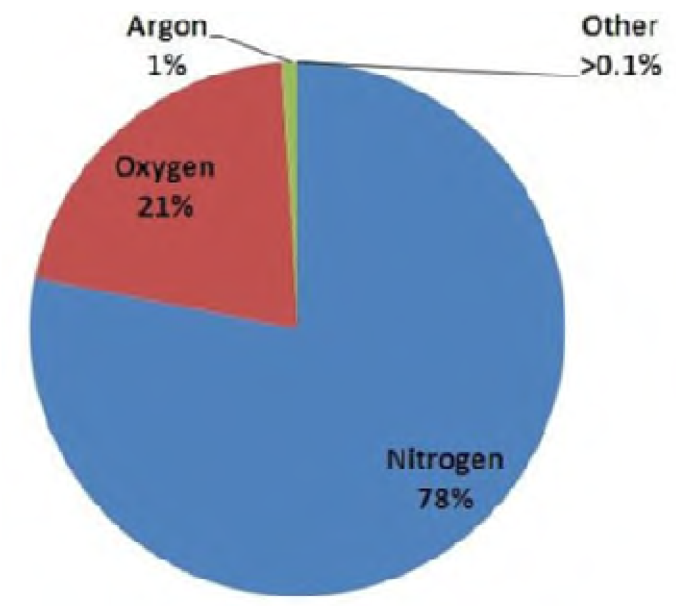
Many patients in an **intensive care** and the **operating room** require mechanical ventilation of their lungs, for example thoracic surgery patients. Ventilators are also used during surgery as a component in an anaesthesia machine.

A respirator is a mask-like device (‘gas mask’) that filters fine particles from inhaled air. It is not a ventilator: with a respirator the person is breathing on his/her own.

Ventilator: Main functions

1. **Air-oxygen mixture sensing**
   By monitoring the pressure of the gas flows of air and oxygen, the controller can calculate the correct mixture.
2. **Air-oxygen mixture control**
   The controller can change the mixture by manipulating the state of the solenoid valves connecting the input gases.
3. **Inspiration control**
   An adjustable valve sets the maximum airway pressure, and a solenoid valve forces periodic inspiration at a rate determined by the therapist. The system to control this solenoid valve has multiple modes, enabling the therapist to deal with a range of patient needs from **occasional assistance** to **complete support**.
4. **Communication interface with technician/doctor**: display information and receive input from the medical team. This includes LCD drivers, touch-screen controllers and audio alerts (beeps, tones, etc.).
5. **Alarm system**: All aspects critical to safe operation must be monitored, including power-supply status, maximum and minimum inspiration pressures, and timing integrity.

Ventilator: Steps in Operation



composition of untreated air

1. the right **air-oxygen mixture** is determined - between 21% and 100%.

2. The **inspiration period** is determined: the period that the patient is forced to breathe in.
3. The **maximum inspiration pressure** is set: the pressure with which the ventilator forces inspiration periodically.

4. The patient breathes out automatically when the inspiration pressure is off. The air is vented to the atmosphere. During this period, the patient can also breathe in, if he/she is able and willing to do so.

5. An **alarm system** monitors the critical pressures and takes action should overpressure or under pressure fault conditions be detected, or if the timing of inspiration events falls outside pre-set limits.

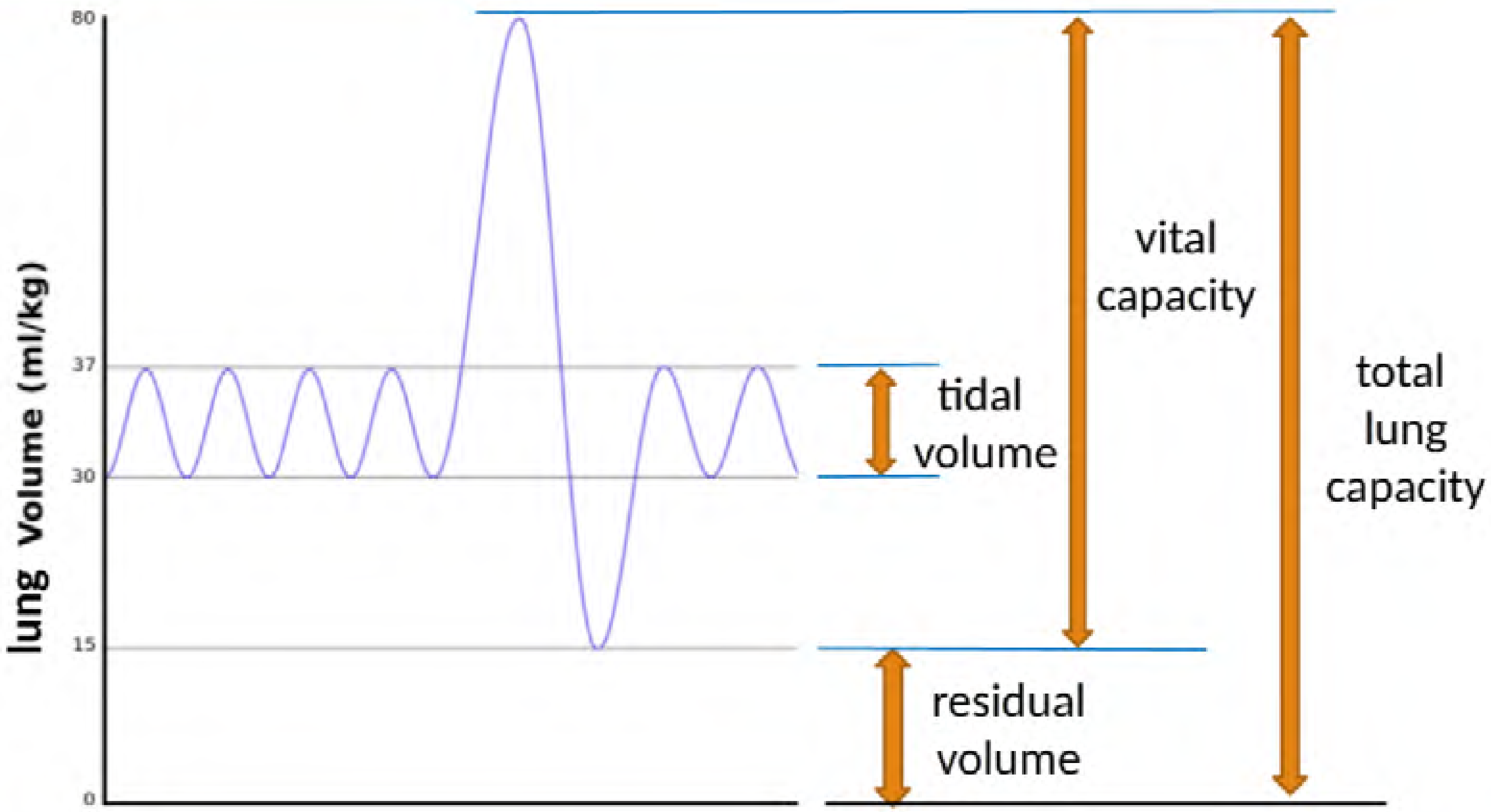
A ventilator is a **life-critical** device. It must default to a safe condition if a single component fails and it must monitor its own activities and deliver alarms when necessary.

Ventilation Rate

To determine whether enough gas is being exchanged to keep a person alive, the **ventilation rate** is measured. Ventilation rate is the volume of gas entering or leaving the lungs in a given amount of time.

It can be calculated by multiplying the volume of gas, either inhaled or exhaled, during a breath (the **tidal volume**) by the **breathing rate.**

for example
0.4 liter (or 0.4L) × 15 breaths/min = 6L/min

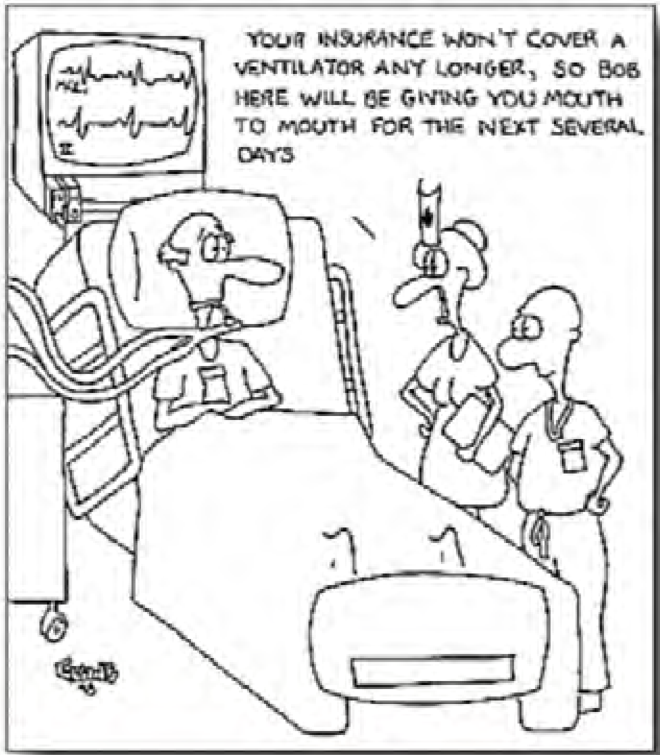


A ventilator needs to produce a tidal volume and a breathing rate that provide enough ventilation, but not too much ventilation, to supply the gas exchange needs of the body.

Use: Ventilation modes

The basic modes for controlling the ventilator are **Controlled** and **Assisted ('supported spontaneous')**.

In the **Controlled ventilation mode** the patient makes no effort to initiate respiratory effort. The ventilator delivers a pre-set volume of gas at a set rate for as long as needed. Some units have a "sigh" level where every so many breaths or minutes the machine automatically provides the patient with a greater volume of gas.



In the **Assisted ventilation mode**, the patient will trigger the flow of gas by starting to inhale. When the patient reaches a pre-set withdrawn volume or a pre-set negative pressure, the ventilator will start the pumping of gas into the lungs. The assisted mode is typically used while the patient is being weaned from the ventilator.

Weaning is accomplished in the assisted mode by slowly increasing the amount of negative pressure or withdrawn volume required to trigger the flow of gas. This weaning process can take from hours to months depending upon the patient's condition. If the patient fails to initiate a respiratory effort in a certain number of seconds the machine will automatically switch back to controlled ventilation mode, ventilating the patient until another respiratory effort is made by the patient.

Ventilation strategies

In addition, modes vary according to regulation mechanism: **Volume-controlled, Pressure-controlled** or **Dual-controlled.**

Volume controlled (VC) mode of ventilation is the most common: a pre-set tidal volume of gas is delivered to the patient. When the ventilator detects that the set volume has been reached, the ventilator cycles to exhalation.

In **Pressure-controlled** (PC) mode, a pre-set positive pressure is maintained throughout the inspiratory cycle. The tidal volume is therefore variable.

Dual-controlled (DC) modes of ventilation are auto-regulated pressure controlled modes with a user-selected **tidal volume target**. The ventilator adjusts the pressure limit of the next breath as necessary according to the previous breath's measured exhaled tidal volume. Peak airway pressure varies from breath to breath according to changes in the patient's airway resistance and lung compliance.

Control Variable	Breath Sequence	Symbol
Volume	Continuous Mandatory Ventilation	VC-CMV
	Intermittent Mandatory Ventilation	VC-IMV
Pressure	Continuous Mandatory Ventilation	PC-CMV
	Intermittent Mandatory Ventilation	PC-IMV
	Continuous Spontaneous Ventilation	PC-CSV
Dual	Continuous Mandatory Ventilation	DC-CMV
	Intermittent Mandatory Ventilation	DC-IMV
	Continuous Spontaneous Ventilation	DC-CSV

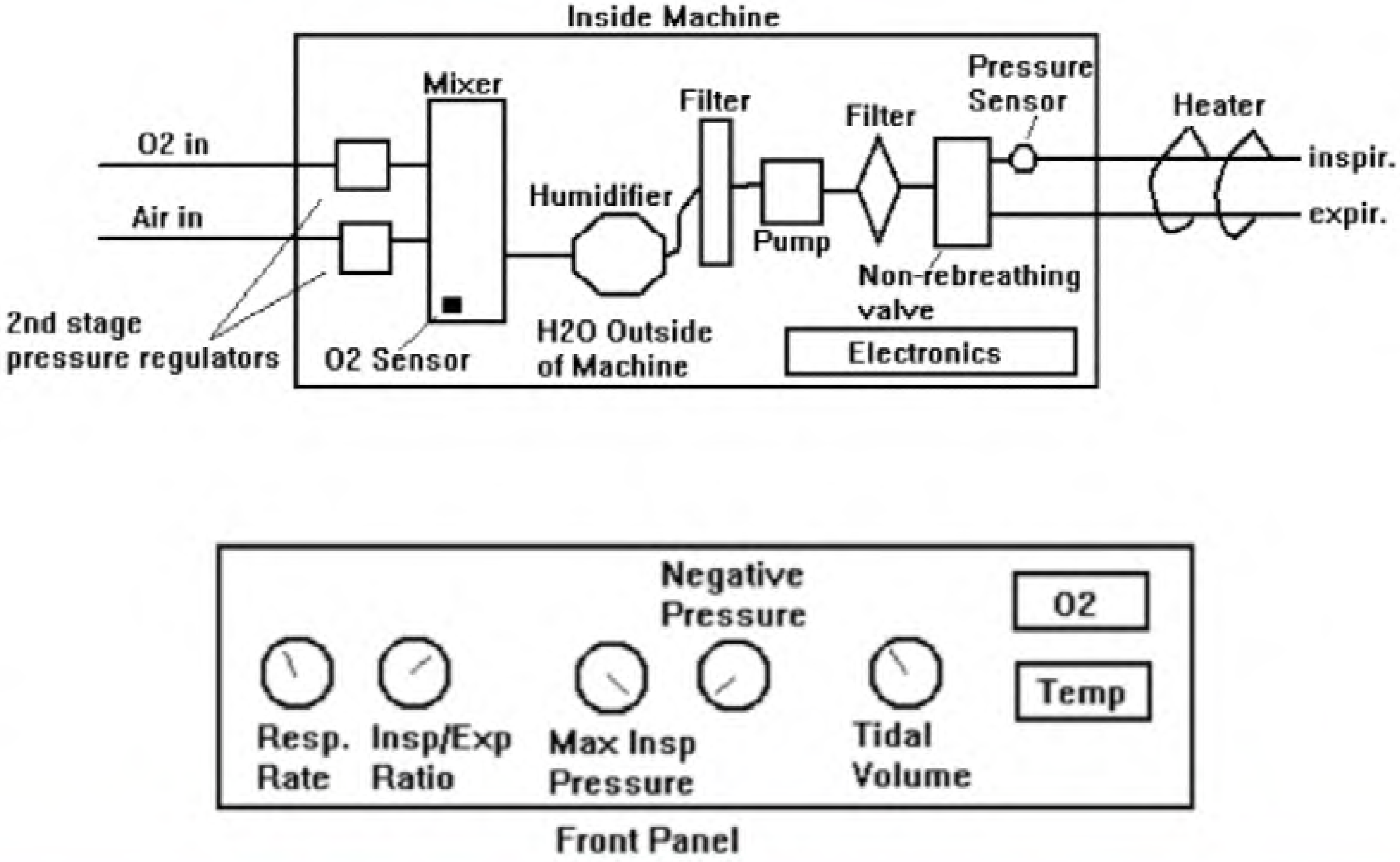
Ventilation Strategies depend on clinician preferences and the patients circumstances. It's important to know that there are many different strategies, but for a BMET not crucial to know the detailed differences between them.

Functional diagram

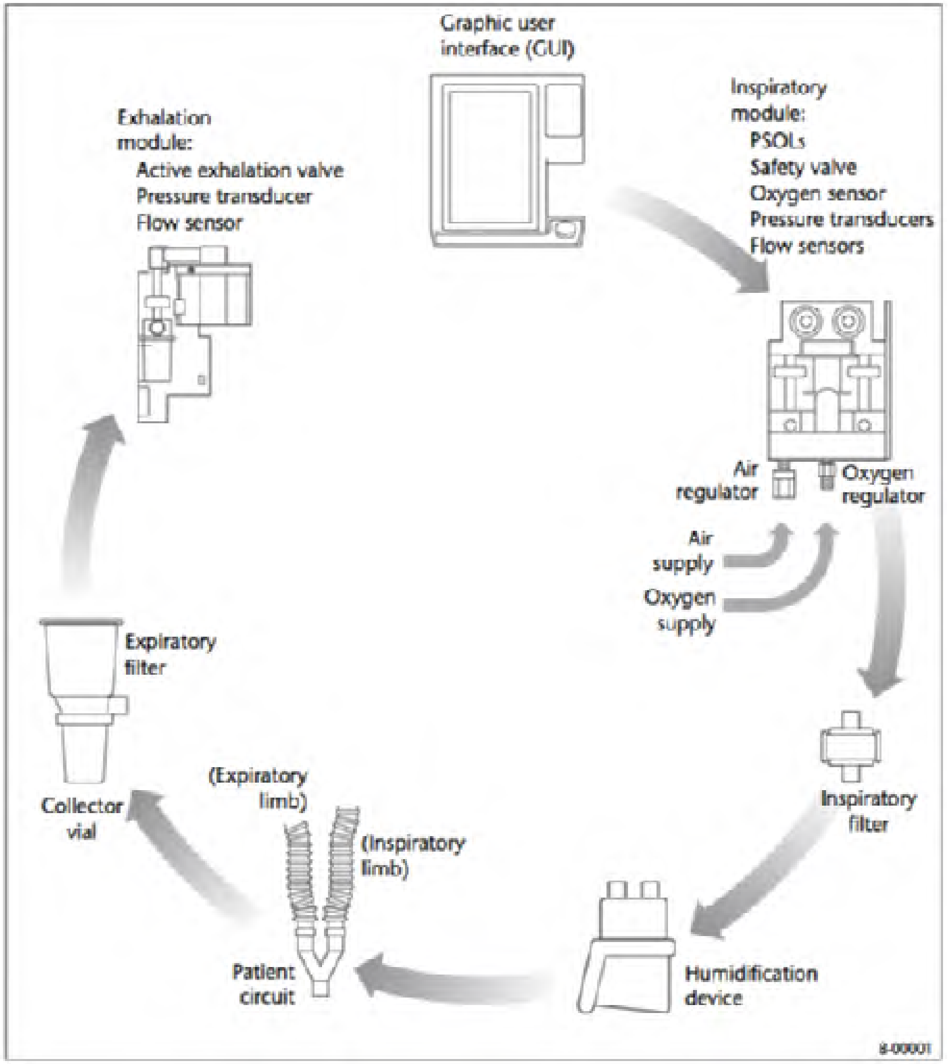
Some ventilators include a **pump** to create air pressure for ventilation of the patient.

Alternatively, **compressed gasses** are connected to the machine. The compressed gas cylinder has a very high pressure, so a pressure regulator is connected to the bottle or to the ventilator or both.

There are generally **moisture traps** and **particle filters** in line with the incoming gases, with considerable variation between manufacturers.



Logical diagram and GUI



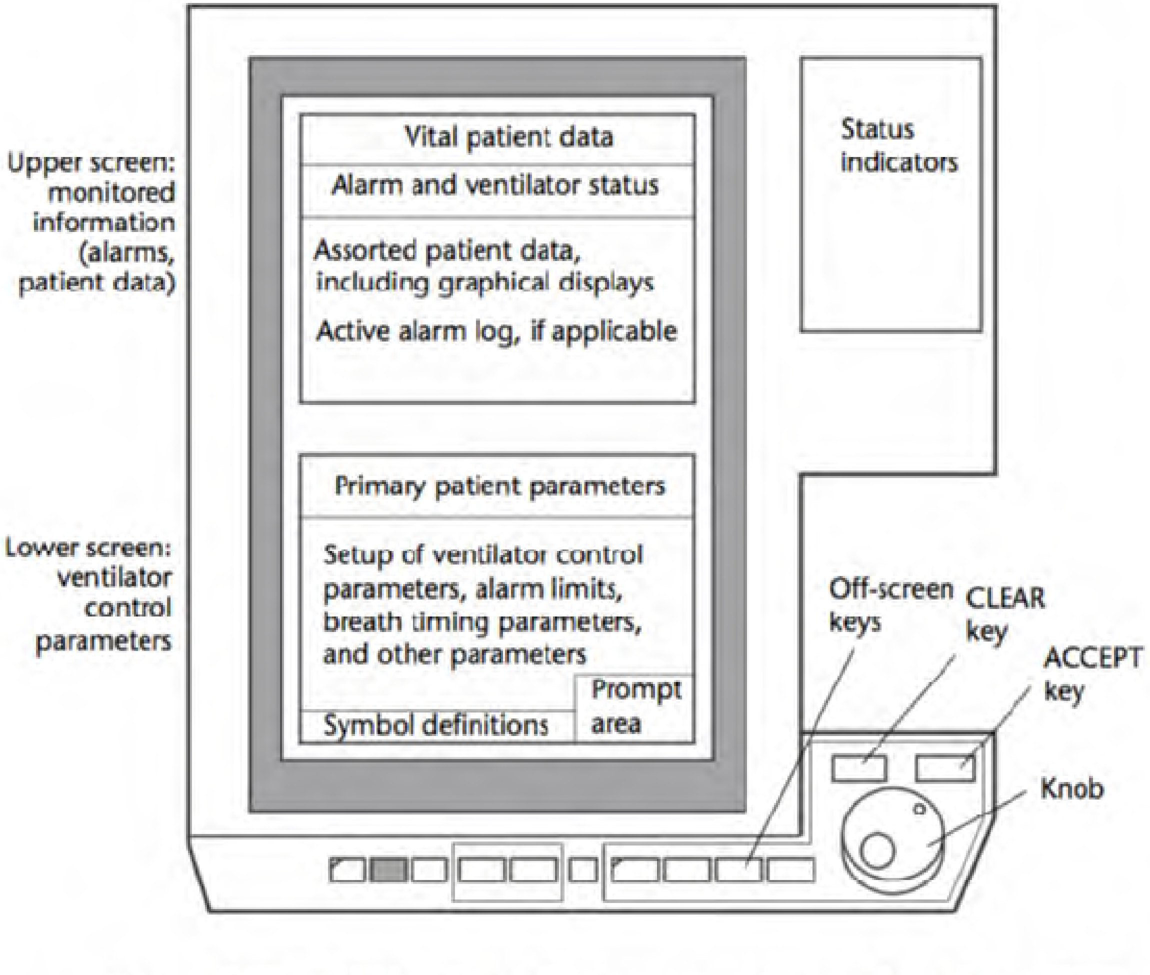
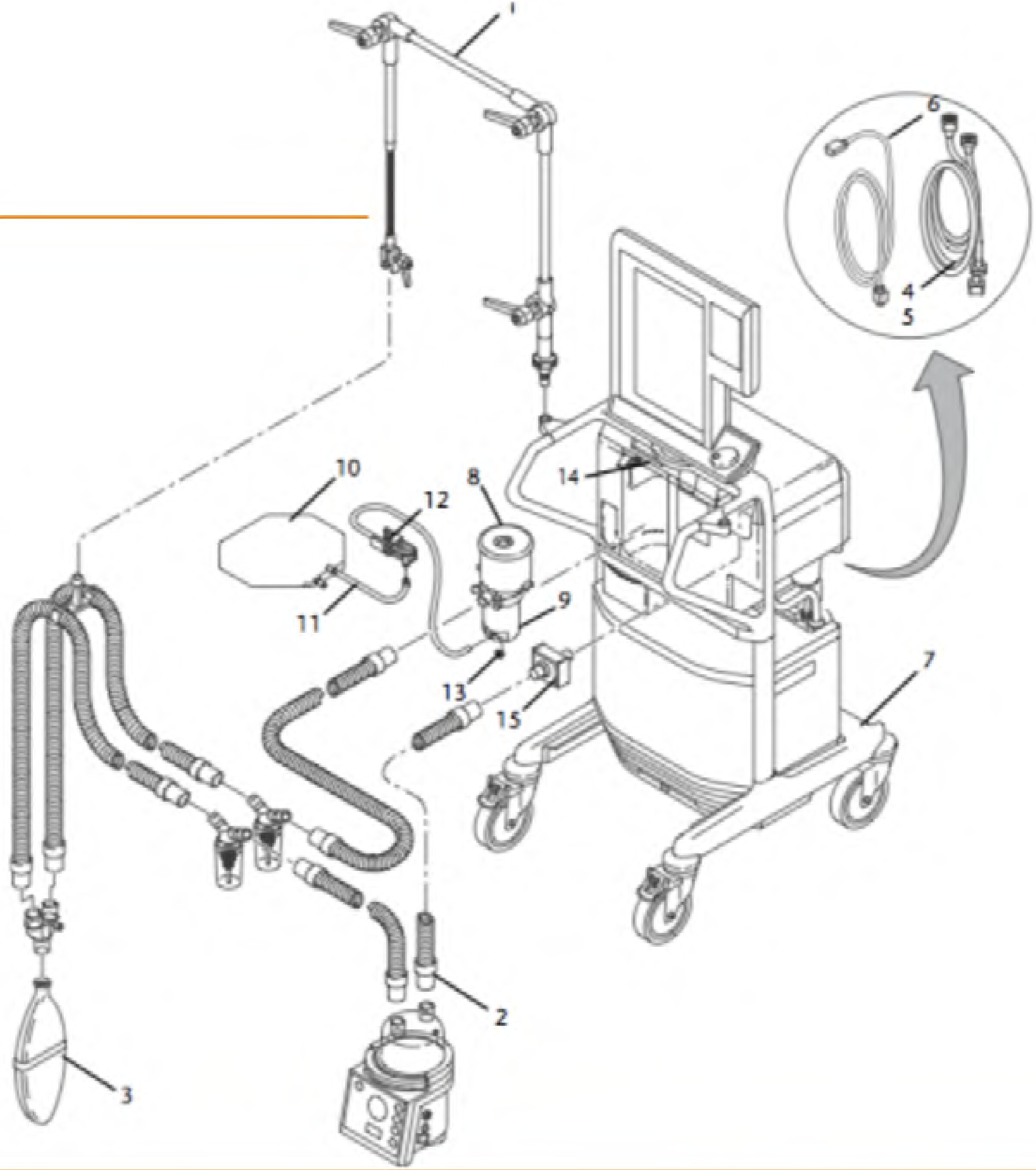


Figure 1-2. *840* **Ventilator System graphic user interface (GUI)**

Components

1. Flex arm assembly
2. Ventilator breathing circuit connection to humidifier
3. Test lung
4. Hose assembly Oxygen
5. Hose assembly air
6. Power Cord
7. Cart
8. Expiratory Bacteria Filter
9. Collector Vial
10. Drain bag
11. Tubing Drain bag
12. Clamp
13. Drain Cap
14. Seal Expiratory Filter
15. Inspiratory Bacteria Filter



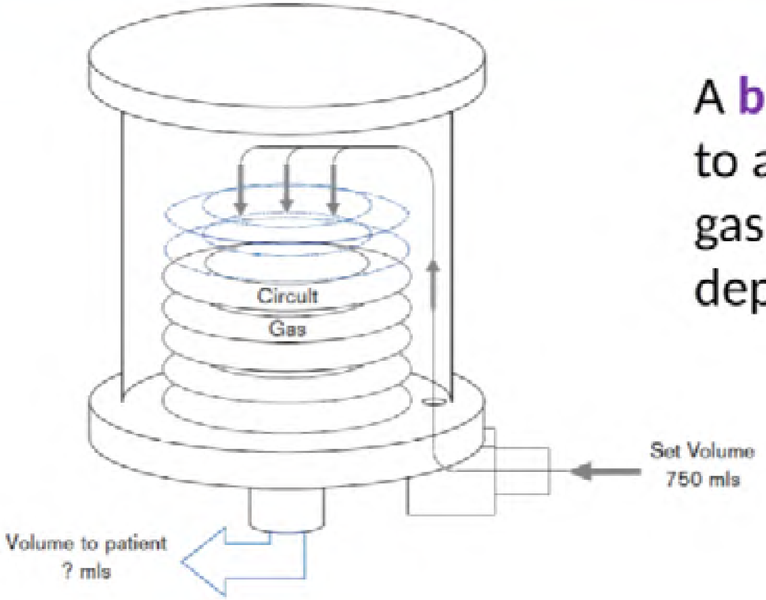
Variations in ventilator construction

Some ventilators can accept air, oxygen or a combination of both. Some will measure the concentration of oxygen delivered to the patient, sounding an alarm if it becomes too high or low.

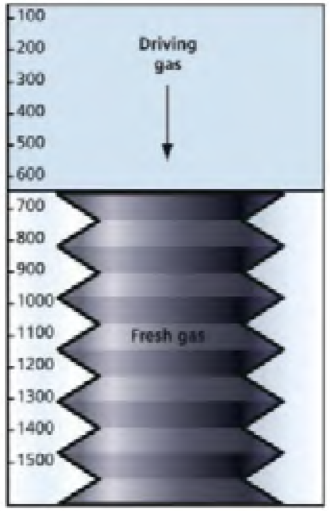
Usually, the ventilator measures the volume (usually derived from measured flow) and pressure of the delivered gases. A computer then controls the timing and pressure for the next cycle.

All ventilators must make sure that the patient does not re-breath his own, untreated expired gases, as these will become excessively concentrated in carbon dioxide. Therefore, the ventilator contains a "**non-rebreathing" valve** that opens to allow fresh gas into the cylinder, closes during inflation and opens to allow expiration of the gases from the lungs into the room or in a waste collection canister. In most modern ventilators, the non-rebreathing valve is in the disposable tubing set.

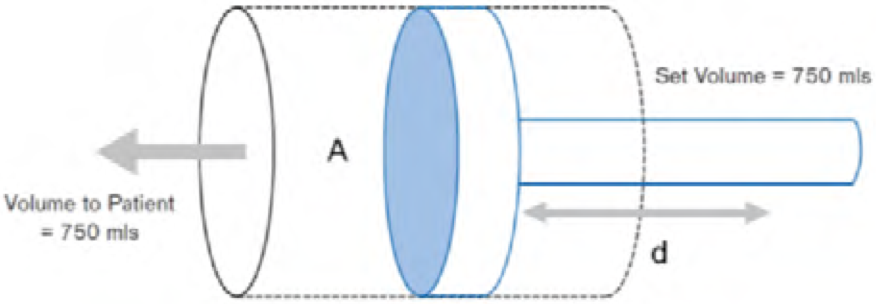
Variations in ventilator construction



A **bag-in-bottle based ventilator** fills to a pre-defined volume with external gas pressure; the output volume depends on lung elasticity.



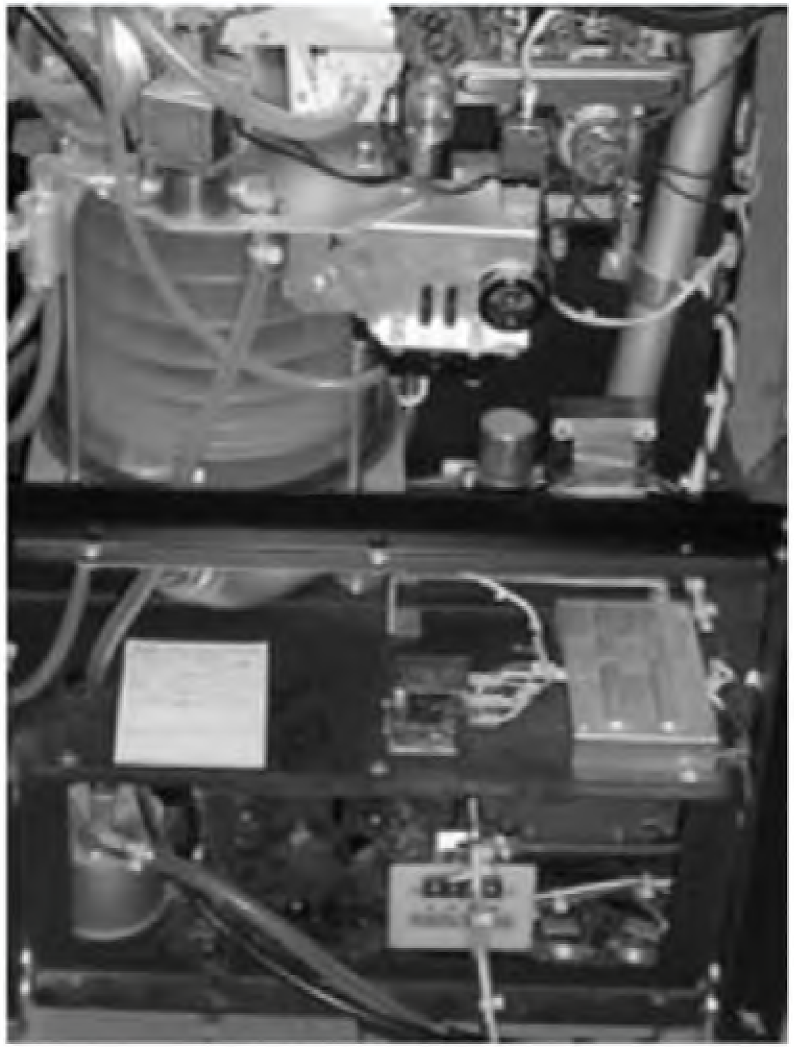
A piston based ventilator can deliver ventilated volume more precisely



Volume (V) = Area (A) x Displacement (d)

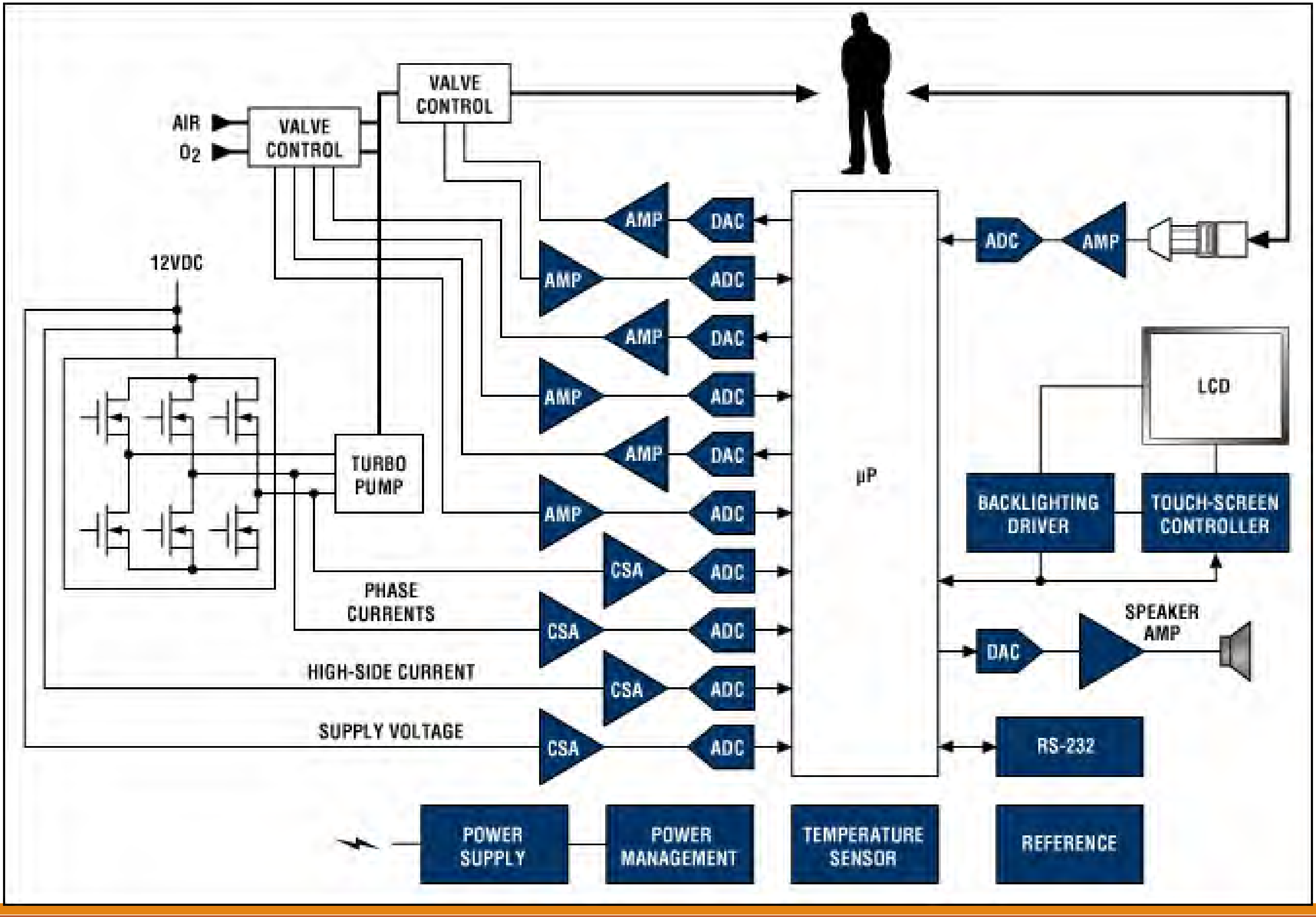
Construction: Breath Delivery Unit & Inside

The Breath Delivery Unit is the core of the Ventilator system. Under control of a CPU, it mixes oxygen and air and controls gas flow to the patient, according to the settings provided by the user. Oxygen is provided by an external supply and air is provided by either an external supply or a internal compression unit.



The inside of the Bennet ventilator illustrates the complexity of the device. Fortunately, the required repairs are typically simple. If they are not, repair in the field may not be possible.

Construction: Block diagram



Troubleshooting: Common faults

A ventilator is a life supporting device that may cause death if it fails. In addition, the lungs are a very delicate tissue which can be easily destroyed by a poorly calibrated ventilator. It is paramount that the ventilators are kept in **top working condition**.

The dangers posed by a lack of ventilation, combined with the dangers posed by a poorly calibrated ventilator can bring the engineer in a very difficult position. On the one hand, without specific training on the ventilator, you may endanger the patient by working on the device. On the other hand, with no substitute ventilator available, you will surely jeopardize the patient if you do not work on the device.

Ventilators are very reliable devices.
The most common problems are:

- user errors
- power supply
- tubing

When looking for a fault, start from the beginning. For example, is the electricity turned on? Is the gas on? Investigate the device in a planned manner, looking for the obvious things first.

If you have doubts about the machine's safety or correct operation and you are unable to repair it on the spot, take it out of service. If there is no spare machine, the patient must be ventilated with a resuscitation bag while the machine is being repaired.

Troubleshooting: Common faults

The most common problem with **user error** is that the controls are not standardized between manufacturers and that user manuals are not available.

If the problem is related to the **power supply** to the ventilator or a simple mechanical problem (such as the wheels, lid or tubing arm) repair is straightforward.

The most common problem with the **tubing** is caused by re-use of disposable tubing. The non-rebreathing valve may break or the tubing may leak. Leaks can be fixed with epoxy or a silicon sealant. The non-rebreathing valve cannot be repaired in general. It may be possible to adapt the non-rebreathing valve from one leaking circuit to be used on another circuit that doesn't leak, but has a non-rebreathing problem.

If the problem is not one of the problems described here, it is probably better not to attempt to fix the ventilator without specialized training. However, your decision should be made in consultation with the physicians. Discuss what the risks are to the patient if you do not work on the machine and what the risks are to the patient if you work on the machine, and it accidentally over-pressurizes or under-ventilates the patient.

Preventive Maintenance

It is important that all ventilators work safely, since lives depend upon their correct operation. Ventilators should **never** be used without a correctly adjusted **alarm system**, which gives a warning in case of malfunction.

Get the **service manual** for your machine. Even without the manual, it is still possible to ensure that the machine is working correctly, but the proper spare parts / consumables / must be available.

Record keeping is very important when maintaining ventilators and other life-support equipment. All reported faults, repairs, and service details should be noted down, dated, and signed. Machines should be serviced **twice a year**.

If it is not possible to repair a machine properly owing to a lack of spare parts, do not be tempted to carry out temporary repairs. Report the problem to the user, ask for the spares, and remove the machine from use.

Do not agree to put a machine back into service against your better judgement.
If the personnel on the ward insist, get them to sign the service sheet (with the problem clearly stated).

Preventive Maintenance

Tools and materials required

- Normal service tools
- Silicone grease
- Light oil
- Service manuals
- Watch with a second-hand
- Spare parts (if available)
- Device for measuring flow, pressure and tidal volume

Preventive Maintenance

Follow the steps outlined in the official service book. Machines often have self tests in the Service mode. Study the Service Manual of the Puritan Bennet 840 as an example.

1. **Inspect the outside** of the machine, including all tubing, connectors, and any bellows for damage. Replace as required. Lightly rub any antistatic tubing, or bellows, with silicone grease to prevent perishing.

2. Connect the electricity and gas supplies, as required. Put a stopper or test lung on the patient connector and start the machine running. Set the controls to normal settings. **Watch that the operation is regular and smooth.** Listen and check for any unusual noises. It is important to use the same regular settings in each test; in this way, you will get to know the normal movements and sounds of correct operation. Any unusual movements or sounds will alert you to possible problems.

3. Switch off and disconnect the machine from the mains. Remove the covers. **Inspect** any internal tubing or bellows, lightly rub any antistatic tubing or bellows with silicone grease to prevent perishing. Replace as required. Blow clean, and wipe the insides. If there are electronic circuit boards, check that they are secure and show no damage. Check for wear in any moving mechanical parts. Using a light motor oil, or similar, lightly lubricate any moving pivot points. Clean up any drips.

Venti.Plus Test Lung - 0.5 L

4. Start the machine running again, taking care not to touch any internal parts; watch any internal movements (bellows, lever, or valve movements) for **smooth operation**.

Preventive Maintenance

5. Try **each control** in turn and check that it does what is intended; for example, if the breath-rate control says that the machine will do 60 breaths per minute, this must be confirmed. Common sense: do not worry if the breath-rate control says 60 and only 58 are delivered. Every machine has a margin of error.

6. Check that the **pressure gauge is accurate** by comparing it with a test gauge.

7. Check the correct operation of all **lights and indicators**.

8. To check the correct operation of the **oxygen mixer**, an oxygen analyser is needed. If your department does not have one, ask the Anaesthetic Department to provide such an instrument. Note down on the service sheet the output results from 21% to 100%.

9. Check the **alarm system**.

10. Run the machine again on the normal settings and check that it is still working correctly .

11. If it is a machine that uses electricity, give it an **electrical safety check.**

12. Fill out the **service check-sheet**, and sign it.

Return the machine to the user; the doctor in charge should test it to ensure that it operates satisfactorily.

Electrical Safety & Environmental Inspection

1. The electrical distribution needs to be inspected and tested to insure that:
   a. Voltage level is adequate
   b. Receptacle polarity is correct
   c. Receptacle ground is present
   d. Receptacle has mechanical integrity
2. Mechanical clearance between the ventilator and instruments, apparatus, and other devices.
3. Shelves, cabinets or storage space are clean, mechanically secure and free of obstructions.

END

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Performance Checking

Performance checking is an important part of releasing a ventilator back into clinical operation.

The check procedures are very much dependent on the model/ manufacturer of the ventilator and must be carried out exactly as described in the service manual.

In the following sheets some examples are presented.
Also some procedures for checking the gas safety are included.

Preventive Maintenance: Bellows

Most ventilators and anaesthesia machine use Bellows

Inspect the bellows housing and base for cracks, chips, etc. Check the tubing and control knobs for tightness.

Over-pressure valve
Check the valve, located at the back of the control unit, for cleanliness and operation.

Pop-off valve
Remove the housing, bellows, and pop-off valve from the base. Check that the pop-off valve, glass disc, and seat are clean and dry, and that the retaining screw is tight.

Bellows flexibility
Reassemble the ventilator and connect the test gauge to the common gas outlet. Inflate the bellows to 0.1 litre. If the pressure is above 1.75 cm water (1.3 mmHg) then the bellows should be replaced.

Bellows pressure (low)
Connect the device for measuring pressure to the common gas outlet, open the oxygen flowmeter to 300 ml/min, and allow the bellows to rise to the top. The pressure should be less than 2.5 cm water and the bellows should remain full. If the bellows do not remain up, or the pressure is high, then refer to the ventilator service manual for the necessary repairs.

Bellows pressure (high)
Connect the common gas outlet to the driving gas port on the bellows, and plug the bellows outlet. Pressurize the outside of the bellows to just above 60 cm water
(44 mmHg) and maintain an oxygen flow of 300 ml/min. The pressure gauge should settle at or above 60 cm water. If the pressure drops below 60 cm water, refer to the ventilator service manual for repairs.

Preventive Maintenance: Ventilator Control

Low-oxygen-supply alarm

Check that the low-oxygen alarm activates before the supply pressure to the ventilator drops below 250 kPa, and resets when the pressure reaches 320 kPa.

Low-airway-pressure alarm

Check that the alarm activates if the pressure measured at the patient port remains below 7 cm water (5 mmHg or equivalent on the gauge in use) for between 20 and 30 seconds.

Safety valve

Check that the relief valve opens when the pressure in the patient circuit exceeds 65-75 cm water (48-55 mmHg or equivalent on the gauge in use).

Flow delivery

Set the ventilator as follows: minute volume 10 rate 10 inspiratory: expiratory (I:E) ratio 1:1
Start the ventilator; the tidal volume measured with a spirometer, or ventilator tester, should be between 0.9 and 1.1 litres/min. If it is not, first check the rate with a stopwatch and adjust if necessary. Check the I:E ratio with a stopwatch at a very low rate, and adjust if necessary. After confirming that both are correct, reset the ventilator to the above settings and adjust the minute volume to give a 1 litre tidal volume.

Preventive Maintenance; O2 Analyser

Inspection and calibration

Visually inspect the cables and the display unit for signs of wear or deterioration. Check that the sensor membrane is not nicked or otherwise damaged, and that the O-ring seal is intact. Test the calibration by first placing the sensor in a T-adaptor, in a verified 100% oxygen line, and allow the readings to stabilize. If, after 3 minutes, the display has not stabilized, replace the sensor. If it has stabilized, adjust the CALknob, if necessary, so that the display registers 100%. Remove the sensor from the T-adaptor and expose to room air. A reading of 21% (+ 2%) should be displayed within 1 minute. If a correct reading is not displayed, replace the sensor.

Preventive Maintenance: Regulators & Flowmeters

The **Pressure Regulator**, or reducing valve, is used to reduce the pressure of a gas from the cylinder pressure to a pressure that is safe for delivery to a patient. For example, in the case of oxygen, it is from 14300 to 420 kPa.

A **Flowmeter** can be attached to the regulator to allow a given flow to be set. These assemblies are most common on anaesthetic machines, or on an oxygen therapy unit attached to the top of a gas cylinder.

When used in oxygen therapy, there are three parts to the unit:

- a gauge showing the pressure of the contents of the cylinder,
- a regulator to reduce the pressure
- a flowmeter that indicates the selected flow.

There are a number of different designs of regulator, but generally each unit has one inlet (from the cylinder) and three outlets, one to the pressure gauge, one to the flowmeter, and one to the blow-off valve. While the proper checking of pressure regulators requires some special test equipment, most problems can be overcome with very little equipment. Remember that the flow tube is under regulator pressure. Do not unscrew it before the cylinder is turned off and the pressure released.

Preventive Maintenance: Setting the Output Pressure

Make sure that the cylinder contents gauge and the safety valve are connected to the regulator, remove the flow meter and fit in its place a 0—700 kPa pressure gauge. Connect the regulator to the gas cylinder, and turn on the gas. The test pressure gauge should show a reading of 420 kPa. This is the correct pressure for an oxygen therapy regulator and flowmeter. If it is not 420 kPa, adjust with a socket head key until it is correct. If you are adjusting the pressure downwards, you must release the pressure from the test gauge, turn the adjusting screw out, reconnect the test gauge, and adjust the pressure up to 420kPa. On most makes, the adjustment screw will be found at the end of the piece which sticks out at the front; it may be covered with a sticky label.

At this pressure it should be possible to obtain a flow of up to 55 l/min out of the unit; this is called the flush flow. In some places, the regulator is not set for pressure but adjusted for a given flow with the control wide open; check what is required before adjusting the setting.

For a regulator attached to an anaesthetic machine, adjust the pressure to about 390 kPa (30 kPa lower than the pressure from the pipeline supply to the machine).

Preventive Maintenance: Regulator & Flowmeter

Testing a regulator and flowmeter unit

1. Check for leaks
2. Check that the pointer on the gauge works smoothly and reaches the stop before the flow falls to zero
3. Check that the flow goes to its full rate

Faults

- If a leak is suspected, check as follows:
  - With the flowmeter unit turned off, turn on the gas and allow the pressure to rise. Turn off the gas supply
  - The system is now pressurized to the full cylinder pressure, but with a very small volume
  - If there is any leak, the gauge will show a fall in pressure; the bigger the leak, the faster the fall
  - If the pressure falls, brush the unit with soapy water; any leaks will show up as small bubbles.
  - Do not forget to check inside the back of the gauge.
- Leaks around the bull nose connector are usually caused by a faulty O-ring. Replace the ring.
- Leaks at the blow-off valve:
  - First, check that the regulator is set to the correct output pressure.
  - If the pressure rises to more than it should, yet the regulator is set to the correct output pressure, there is a faulty valve seat (a problem called “creep”). Replace the valve seat

The blow-off valve should normally go off at about 640 kPa

Preventive Maintenance: Regulator & Flowmeter

- If the flowmeter makes a popping noise when the flow is turned on (“motor boating”) there is probably dirt inside the valve; the noise may also be caused by a faulty valve seat
- Low flows: unscrew the needle valve and check that it is clean and undamaged
- If the ball or bobbin, shows a small flow even when the unit is turned off, check the flow tube for leaks.
- If the gauge needle does not drop smoothly, remove the back of the gauge and lubricate the movement of the gauge with a light watch oil. Use of oil is acceptable in this case, as there is no oxygen flowing in this part.
- If there is no flow, even when the gauge shows that there is gas in the cylinder, this suggests that the gauge needle is stuck. Check the movement in the back of the gauge, or reposition the needle on the shaft.

- Unregulated flowmeters, in which the flowmeter is connected directly to the gas cylinder, are dangerous and should not be used.