Humidity

Humidity is used to describe the amount of water vapor in air or gas. The mass of water vapor in the gas is **absolute humidity**. The maximum amount of humidity that gas can contain is limited by temperature. At the maximum humidity for a particular temperature, the gas is said to be saturated with water vapor, and the level of humidity is the humidity at saturation. The **relative humidity** is the absolute humidity of the gas at a particular temperature as a percentage of the humidity at saturation at the same temperature.

HUMIDIFIERS

Inhaling dry gases can cause damage to the cells lining the respiratory tract impairing ciliary function. Within a short period of just 10 min of ventilation with dry gases, cilia function will be disrupted. This increases the patient's susceptibility to respiratory tract infection, A decrease in body temperature (due to the loss of the latent heat of vaporization) occurs as the respiratory tract humidifies the dry gases. Air fully saturated with water vapor has an absolute humidity of about 44 mg/L at 37°C. During nasal breathing at rest, inspired gases become heated to 36°C with a relative humidity of about 80-90% by the time they reach the carina, largely because of heat transfer in the nose. Mouth breathing reduces this to 60-70% relative humidity. The humidifying property of soda-lime can achieve an absolute humidity of 29 mg/L when used with the circle breathing system. The isothermal boundary point is where 37°C and 100% humidity have been achieved. Normally it is a few centimeters distal to the carina. Insertion of a tracheal or tracheostomy tube bypasses the upper airway and moves the isothermal boundary distally.

Characteristics of the ideal humidifier

- Capable of providing adequate levels of humidification.
- Has low resistance to flow and low dead space.
- Provides microbiological protection to the patient.
- Maintenance of body temperature.
- Safe and convenient to use.
- Economical.

Humidification equipment

Gas can be humidified using either passive or active systems. Passive systems, such as heat and moisture exchangers (HMES), rely on the patient's ability to add moisture to the inspiratory gas, circle breathing systems. Active systems, such as a Hot water bath humidifier, add water vapor to a flow of gas independently of the patient.

Passive humidification systems

1. Heat and moisture exchangers (HMEs)

These are compact, inexpensive, passive, and effective humidifiers for most clinical situations. Devices intended to retain a portion of the patient's expired moisture and heat and return it to the respiratory tract during inspiration. The efficiency of an HMEAs is gauged by the proportion of heat and moisture it returns to the patient. Adequate humidification is achieved with a relative humidity of 60-70%. Inspired gases are warmed to temperatures of between 29° and 34°C. HMEs should be able to deliver an absolute humidity of a minimum of 30 g/m3 water vapor at 30°C, HMEs are easy and convenient to use with no need for an external power source.

Components

1. Two ports, designed to accept 15- and 22-mm size tubing and connections. Some designs have provision for connection of a sampling tube for gas and vapor concentration monitoring.
2. The head contains a medium with hydrophobic properties in the form of a mesh with a large surface area. It can be made of ceramic fiber, corrugated aluminum or paper, cellulose, metalized polyurethane foam, or stainless steel fibers. A layer of filter material may also be added to the device (heat and moisture exchange filters, HMEFS). Devices are also available that consist only of a layer of filter material. An electrostatic filter layer used on its own has a very low moisture-conserving performance, but a pleated hydrophobic filter layer used on its own can return some moisture as a temperature gradient builds up within the pleats, allowing condensation during expiration and evaporation during inspiration.

Mechanism of action

1. Warm humidified exhaled gases pass through the humidifier, causing water vapor to condense on the cooler HME medium. The condensed water is evaporated and returned to the patient with the next inspiration of dry and cold gases, humidifying them. There is no addition of water over and above that was previously exhaled.
2. The greater the temperature difference between each side of the HME, the greater the potential for heat and moisture to be transferred during exhalation and inspiration.
3. The HME humidifier requires about 5-20 min before it reaches its optimal ability to humidify dry gases.
4. Some designs with a pore size of about 0.2 µm can filter out bacteria, viruses, and particles from the gas flow in either direction. They are called heat and moisture exchanging filters (HMEF).
5. Their volumes range from 7.8 ml (pediatric practice) to 100 ml. The increases the apparatus dead space.

6. The performance of the HME is affected by:
   a) Water vapor content and temperature of the inspired and exhaled gases.
   b) Inspiratory and expiratory flow rates affect the time the gas is in contact with the HME medium hence the heat and moisture exchange.
   c) The volume and efficiency of the HME medium - the larger the medium, the greater the performance. Low thermal conductivity, i.e. poor heat conduction, helps to maintain a greater temperature difference across the HME increasing the potential performance.

Problems in practice and safety features.

1. The estimated increase in resistance to flow due to these humidifiers ranges from 0.1 to 2.0 cm H_20 depending on the flow rate and the device used. Obstruction of the HME with mucus or because of the expansion of saturated heat exchanging material may occur and can result in dangerous increases in resistance.
2. It is recommended that they are used for a maximum of 24 h and single patient use only. There is a risk of increased airway resistance because of the accumulation of water in the filter housing if used for longer periods.
3. The humidifying efficiency decreases when large tidal volumes are used.
4. For the HME to function adequately, a two-way gas flow is required.
5. For optimal function, HME must be placed in the breathing system close to the patient.

2. Circle breathing systems:

In this breathing system. a portion of the exhaled gas is usually returned to the inspiratory limb of the breathing system to recycle the anesthetic agents. This gas is first passed through a container of absorbent to remove the exhaled carbon dioxide. This reaction generates both heat and water. The removal of one mole of carbon dioxide from exhaled gas generates one mole of water. If all this water vaporizes and assumes ideal gas conditions exist, an identical volume of water vapor will replace the volume of carbon dioxide. If the exhaled gas contains 5% carbon dioxide, sufficient water vapor could be produced to saturate gas at 33°C, as saturated gas at 33°C contains 5% water vapor by volume (36 g/m" water vapor). This is much more than the minimum of 20 g/m recommended when the upper airways are bypassed during short-term procedures.

Hence, provided low fresh-gas flows are used with the circle breathing system (so that the humidity in the gas is not diluted excessively by the dry fresh gas), adequate levels of humidity may be produced by the circle system alone.

During anesthesia, the humidity of the gas in the circle system, therefore, increases, although it may take up to 1 hour or more to reach a maximum level.

The humidity in the breathing system will augment the moisture content of the gas delivered to the patient from a filter or HME sited at the patient connection port.

Active humidification systems

In these devices, water vapor is added to the inspired gasses independently of the patient.

Components

1. A disposable reservoir of water with an inlet and outlet for inspired gases heated sterile water partly fills the container.
2. A thermostatically-controlled heating element with temperature sensors, both in the system close to the patient.
3. Tubing is used to deliver humidified and warm gases to the patient. It should be as short as possible. A water trap is positioned between the patient and the humidifier along with the tubing. The trap is positioned lower than the level of the patient.

Mechanism of action

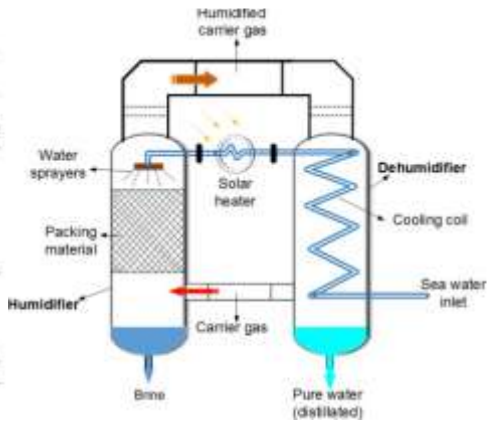
1. Powered by electricity, the water is heated to between 45°C and 60°C.
2. Dry cold gas enters the container where some passes close to the water surface, gaining maximum saturation. Some gas passes far from the water surface, gaining minimal saturation and heat.

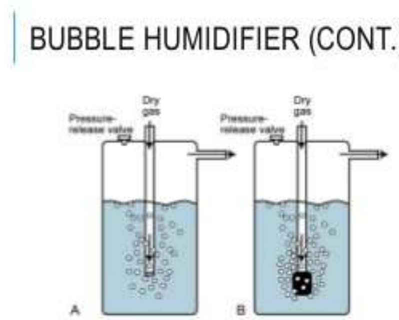
3. The container has a large surface area for vaporization. This is to ensure that the gas is fully saturated at the temperature of the water bath. The amount of gas effectively bypassing the water surface should be minimal.
4. The tubing has poor thermal insulation properties causing a decrease in the temperature of inspired gases. This is partly compensated for by the release of the heat of condensation.
5. By raising the temperature in the humidifier above body temperature, it is possible to deliver gases at 37°C and fully saturated. The temperature of gases at the patient's end is measured by a thermistor. Via a feedback mechanism, the thermistor controls the temperature of water in the container.
6. The temperature of gases at the patient's end depends on the surface area available for vaporization, the flow rate, and the amount of cooling and condensation taking place in the inspiratory tubing.
7. Some designs have heated elements placed in the inspiration and expiratory limb of the breathing system to maintain the temperature and prevent rainout (condensation) within the tube.

Problems in practice and safety features.

1. The humidifier, which is electrically powered, should be safe to use with no risk of scalding, overhydration, and electric shock. A second backup thermostat cuts in should there be a malfunction of the first thermostat.
2. The humidifier and water trap(s) should be positioned below the level of the tracheal tube to prevent flooding of the airway by condensed water.
3. Colonization of the water by bacteria can be prevented by increasing the temperature to 60°C. This poses a greater risk of scalding.
4. The humidifier is large, expensive, and can be awkward to use.
5. There are more connections in a ventilator setup and so the risk of disconnections or leaks increases.

Fig: Ambient temperature or bottle humidifier A. Simple bottle humidifier, B. bubble-through humidifier, C. bubble through humidifier with a sintered filter to reduce the size of bubbles and hence increase surface area for evaporation, D. wick humidifier.





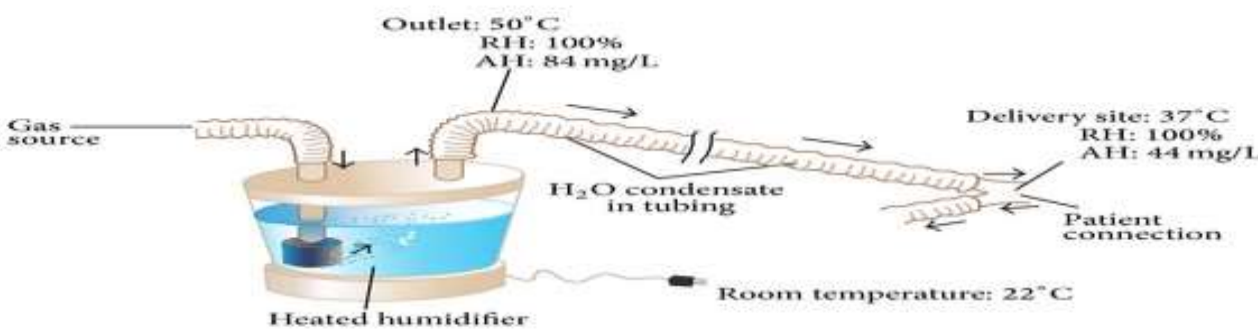


Fig. Breathing systems with different methods of humidification. A. Open breathing system; B. breathing system with HME; C. breathing system with heated humidifier; D. circle breathing system; E. circle breathing system with HME. The width of the arrows indicates the level of humidity at various points in the breathing system. High levels of humidity can cause condensation if an appropriate temperature is not maintained.

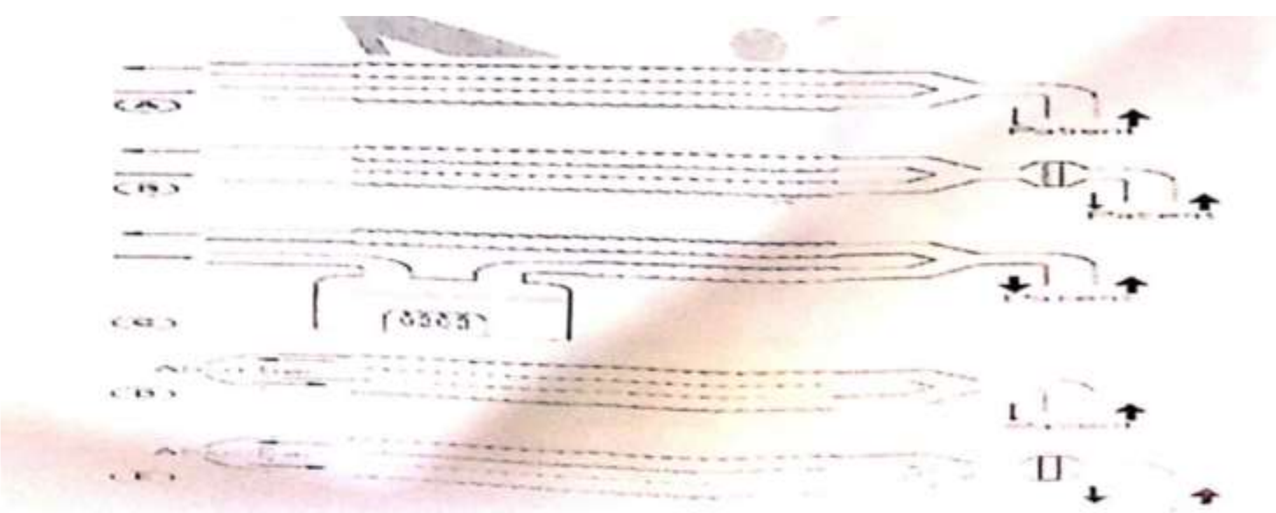


Fig: Mechanism of action of hot the hot water bath humidifier.

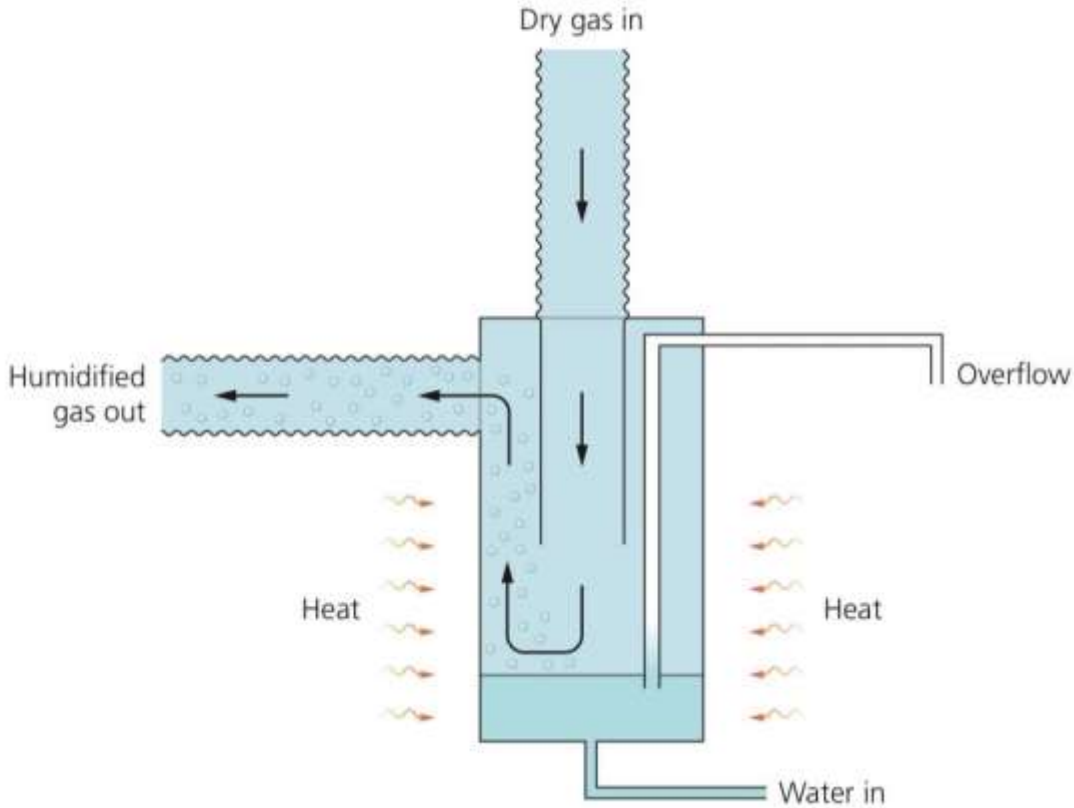


Fig. The Thermovent heat and moisture exchanger with hydrophobic filtration properties. (Courtesy of Smiths Medical.)

Fig. The Equinox hot water bath humidifier. (Courtesy of Smiths Medical.)