

Humidification and the HME filter

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Introduction and definitions

The process of intubation and ventilation bypasses both the physiological humidification system and protective filtering processes. Various devices have been developed to aid in providing humidification of medical gasses and to serve as filters to reduce transmission of microbes.

The following types of devices are available:

- Heat and moisture exchanger without filter (HME)
- Electrostatic filter with or without HME
- Pleated filter with or without HME

Humidity

Background physics

If a liquid is left within a closed container, molecules will move between the liquid and vapour above the liquid. The vapour above the liquid will saturate the gas and exert a partial pressure. At equilibrium this is known as the **saturated vapour pressure**.¹

An **increase in temperature** within the container will increase the kinetic energy of the molecules. This will result in more molecules moving out of the liquid state. **This increases the saturated vapour pressure**. The amount of heat required to raise the temperature of 1 kg of substance by 1 kelvin is known as **specific heat capacity**. The amount of heat required to convert 1 kg of substance from one phase to another phase (i.e. liquid to vapour) at a given temperature is known as **specific latent heat**.¹

Humidification is the addition of water vapour to a gas. As the temperature of a gas increases the amount of water vapour it can hold and therefore its saturated vapour pressure increases (Figure 1).²

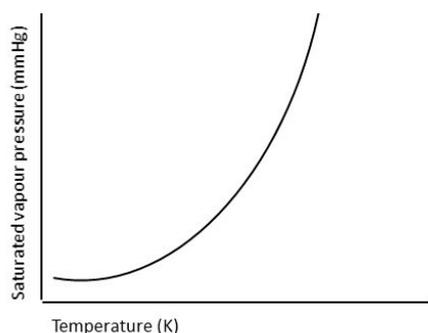


Figure 1

Humidity may be expressed as either absolute or relative humidity.

Absolute humidity (mg.litre^{-1} or g.m^{-3}) is defined as the mass of water vapour present in a given volume of air.¹

Figure 2 illustrates the relationship between temperature and absolute humidity.¹

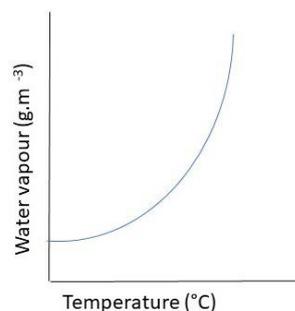


Figure 2

Relative humidity (%): is the ratio of amount of measured water vapour in a given volume of gas divided by the amount of water vapour required to saturate the same volume of gas at the same temperature.¹

Relative humidity may also be expressed as the ratio of actual water vapour pressure divided by the saturated water vapour pressure.¹

Explanation

Relative humidity = current mass of water vapour / mass of water vapour required for saturation

$$n = (PV)/(RT)$$

$$\text{mass} \propto n$$

V, R and T are constant.

$$\text{Therefore: relative humidity} = \frac{\text{actual vapour pressure}}{\text{saturated vapour pressure}}^1$$

There is a positive exponential relationship between the mass of water vapour in air and temperature. So, if the ambient temperature decreases the relative humidity will increase and vice versa. The temperature of air at which there is 100% relative humidity is called the **dew point**.²

Other definitions

Boiling point: the temperature at which vapour pressure equals atmospheric pressure.

Critical temperature: the temperature above which it is not possible to liquefy a given gas by increasing its pressure.¹

Specific latent heat: amount of heat required to convert 1 kg of substance from one phase to another phase at a given temperature (J.kg^{-1}).¹

Latent heat of vapourisation: energy required to change a unit of mass from a liquid to a vapour.¹

The importance of humidity physiologically

During normal nose breathing air is heated and saturated. At alveolar level, at 37 °C the absolute humidity is 44 g m^{-3} . The airway has anatomical and physiological features which provide for the humidification of air. Humidification is made possible through evaporation of water from the mucous along airway surfaces. The isothermic saturation boundary (usually the carina) is the point in the airway below which air is fully saturated. In anaesthesia and critical care, the upper airway is often bypassed reducing the ability for physiological humidification.²

Inadequate humidification results in:

1. Increased viscosity of mucous (more water molecules are lost from the mucous layer). Practically this can result in difficulty in clearing secretions, obstruction of endotracheal tubes (ETs), atelectasis, V/Q mismatch, increased risk of infections.
2. Ciliary dysfunction.
3. Eventual loss of cilia and cell damage.
4. Increased energy requirements to heat and humidify medical gasses.²

Current evidence has demonstrated that lower than physiological levels of humidity can be tolerated for short periods of time and a minimum level of 20 gm^{-3} for up to 10 hours will not damage airway epithelium.³

**This talk will not cover humidity measurement devices.*

How do we achieve humidification?

Humidification devices may be classified into active humidifiers and passive humidifiers.

Characteristics of an ideal humidification device:

- Ability to warm and humidify gases to physiological conditions.
- No additional resistance to gas flow.
- No additional dead space.
- No additional risk of infection.
- Easy and safe to use.
- Cost-effective.²

Note: the ideal size of a water droplet produced by a humidification device is 1 micron. Larger droplets serve no

benefit and may cause harm including water condensation in tubing and water intoxication.²

Active humidifiers

By definition, active humidifiers require water supply, power source or both.

1. Water bath humidifiers: dry gas is bubbled through water at room temperature. The gas will lose heat (latent heat of vapourisation). This may be overcome through heating the system. In addition, large bubbles result in inefficiency. Complications include bacterial contamination (if temperature is less than 60 °C), airway burns with too high a temperature, condensation within the circuit and water aspiration.²
2. Nebulisers:
 - a. Ultrasonic: vibration of the surface allows for small droplet formation. Ideal droplet size is 1 micron. Complications include bacterial contamination, increase in resistance to gas flow (with the increase in density), water overload.²
 - b. Jet nebulisers: make use of the Venturi effect and entrainment of water droplets, which are broken up by an anvil into a spray.²
3. Heated humidifiers: gas is either bubbled through, passed over or exposed to wicks from a heated water reservoir. Similar complications to those of water bath humidifiers occur.²

Passive humidifiers

By definition, passive humidifiers require no external power or water supply.

1. Circle system and low flow: Through the use of low flow in a circle system and a carbon dioxide absorber, a basic level of humidification can be achieved. This can provide adequate humidity levels (20 g.m^{-3}) for up to 10 hours of ventilation.³
2. Heat and moisture exchangers: This basic device consists of a casing with standard connectors and CO_2 sampling port; typically, with the addition of hygroscopic material which traps the water vapour of the expired air, allowing for humidification of inflowing gas.³

Filters

Historically with the advent of mechanical ventilation, various case reports of cross infection and perioperative mortality have been documented resulting in the development of breathing system filters.

Filters may be placed at different locations along the breathing system: at the patient connection port, gas inlet port, inspiratory port, expiratory port and exhaust port. When placed at the patient connection port, the device can serve as both filter and humidification device.⁴ The HMEF is typically used.

There are two types of filter with regards to mechanism:

1. Electrostatic filters: woven fibre material that is electrically charged as the barrier. Any opposing particle with charge is attracted and bound to the material. There is less resistance to flow and a smaller surface area. Hygroscopic layer is added

to provide humidification of gas and reduce condensation on the filter surface.⁵ Increased risk of transmission from contaminated liquid during low flow circle systems (this can be helped with the use of a HME which will keep the circuit dry).

2. Pleated filters: densely packed glass fibre material, with high resistance to airflow. The material is pleated to increase the surface area and reduce resistance. These filters are also hydrophobic so water droplets are not absorbed into filter material.⁵ Gas can pass over the filter material and become humidified.³ Large particles (> 0.3 microns) are filtered through inertial impaction and interception. Smaller particles are filtered through Brownian motion (random movement).⁵ Note: a micron = 0.001 mm. Bacterial size is usually 0.3 microns, and viruses are usually much smaller (0.1–0.017 microns).⁵

Filters may also be classified according to the number and size of particles they capture: commonly as 95%, 99% and 100%. In addition, they are categorised as not resistant to oil (N), resistant to oil (R) or oil proof (P). Hence N95 as an example.⁵

HMEs and HMEFs are tested by manufacturers using the same methods and conditions (34 °C and 37.6 mg/litre⁻¹ for 24 hours) to ensure standardisation.⁵

Evidence

Current filters have been shown to reduce contamination of the breathing systems.^{2,3} However, a filter does not necessarily result in complete absence of contamination.^{2,3} A single-use breathing system should be used for one patient only (with or without a filter) and then be discarded. Other practices involve reprocessing of the breathing system before additional use. In our setting, a single-use breathing system is often used for more than one patient with the addition of a filter.

Complications of HMEFs

Resistance to gas flow

If liquid accumulates in the filter, then this will be more so. Increased resistance leads to increased work of breathing.⁴

Blockage

Liquid can accumulate on the patient side (sputum or oedema) or from condensation in the circuit. This may not be visible. Blockage may be reduced by keeping the filter vertical and above the level of the lungs. Blockage can also occur if the filter is placed on the expiratory limb.⁴

Dead space

Some filters have up to 100 ml internal volumes. Keep in mind a smaller device may have less dead space, but then may also offer higher resistance to flow and work of breathing. An increase in pressure support can overcome this.⁴

Effect on capnography

This is greater with larger dead space and smaller tidal volumes. The sample should be taken from the machine-side (drier and less risk for contamination).⁴

Other

Prolonged exposure to desflurane reduces efficacy of electrostatic filters.⁴

Practical recommendations

Ventilator associated pneumonia

The CDC recommend using bacterial filters on both inspiratory and expiratory limbs as well as at the patient side. HMEs should not be changed routinely more frequently than every 48 hours. HMEs should be changed if suspected malfunction or if obvious soiling and between patients. HME(F)s decrease colonisation but have not been shown to decrease incidence of VAP.⁴

Tuberculosis

Pleated filters prevent the transmission of *mycobacterium tuberculosis*. The CDC recommends filter placement on expiratory limb, and patient side. Increased gas flow will reduce filtration efficiency.⁴

Viruses (SARS, H1N1)

Electrostatic filters allow the passage of viruses when wet. Recommendations for SARS, H1N1 included the use of hydrophobic filters (low volume) on both inspiratory, expiratory limbs and patient side. Note: pleated filters specifically for the patient side and expiratory limb are recommended.⁴

Paediatrics

Uncuffed ET tubes may reduce the efficacy of humidification. Filters have implications with regards to dead space and resistance to gas flow.^{4,5}

Conflict of interest

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