Humidification devices

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Abstract

Humidification is a process of adding water vapour to a volume of one or more gases. Natural humidification is achieved in the nasal cavity, but this process is often bypassed during anaesthesia and critical care. Various devices are used for artificial humidification the commonest being the heat and moisture exchanger, often combined with a microbial filter. Electrically heated water baths and other devices are discussed.

Keywords Bubble humidifier; heat and moisture exchanger; heat and moisture exchange filter; HME; HMEF; hot water bath humidifier; humidification; nebulized humidifiers; soda lime

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Learning objectives

After reading this article, you should be able to:

- understand the requirement for humidification devices in anaesthesia and critical care
- list the commonly used humidification devices
- understand the principles of use and their limitations

Humidification is the addition of water vapour to a volume of gas; either air, or a mixture of medical gases and volatile agents (in other words, an inhalational anaesthetic). This is achieved by using a variety of devices using different physiochemical principles. All are based on the energy-dependent transfer of water molecules from liquid to gas phase which is called evaporation. At the molecular level the gas:liquid boundary is indeterminate; this is called the *Knudsen layer*.

Humidity is the term used to define the mass of water vapour held in a given volume of gas in g/m^3 (equivalent to mg/l). *Absolute humidity* is the mass of water vapour present in a given volume of gas, and this therefore increases with temperature. The maximum value possible is *saturation humidity*. At BTPS conditions (Body Temperature Pressure and Saturation), this is 44 g/m^3 water vapour at 37°C.

Relative humidity is the ratio between absolute humidity and saturation humidity and is expressed as a percentage.

Natural humidification

Effective gas exchange and maintenance of the mucociliary escalator require that gases are humidified to saturation humidity (44 g/m^3 at 37°C). By comparison, the absolute humidity of inspired air is 34 g/m^3 at 20°C so in normal circumstances there is a '*moisture deficit*'. The upper respiratory tract, particularly the nasal cavity, functions as a conditioning system for respiratory gases delivered during the phases of inspiration and expiration.

During inspiration the passage of air past the nasal turbinates produces turbulent flow and increases contact of inspired air with the airway epithelium, warming and humidifying it. This continues throughout the respiratory tract and the point where optimal warming and humidification occurs is termed the *isothermic saturation boundary*; for nasal breathing at rest this is the proximal trachea.

On expiration the opposite occurs; water condenses onto the airway surface, rewarming the fluid lining the airway. This bidirectional mechanism is termed as a *countercurrent exchange system* for heat and water conservation and is more active when breathing colder, drier air.

The requirement for humidification in anaesthesia and critical care

Humidification of medical gases and volatile anaesthetic agents (vapours) is needed for two reasons.

First, they are supplied at room temperature and devoid of water. Secondly, they are usually delivered to the patient *via* airway devices, such as tracheal tubes or supraglottic airways, which bypass the natural conditioning system.

Delivery of dry gases risks harm. The degree of injury is related to the volume of dry gas delivered and duration of exposure. Williams et al. describe increasing harm arising from delivery of sub-optimally humidified gases:

- no detectable effect
- impaired mucociliary clearance
- mucociliary clearance stops
- ciliary activity stops
- epithelial damage detectable
- macroscopic evidence of harm.

Harm at Level 6 includes measurable reduction in functional residual capacity, reduction in lung compliance and increased shunt fraction. In critical care patients these effects are associated with an increase in complications such as ventilation-associated pneumonia.

Delivery of dry gases to the trachea results in Level 3 harm within 10 minutes and Level 5 harm within an hour.

Humidification devices

Artificial humidification is designed to prevent airway drying during anaesthesia and critical care. Ideally, humidification would replicate the levels achieved by natural processes and for critical care patients a standard of 33 g/m^3 at 30°C is advised to prevent inspissation of secretions. For patients under anaesthesia 20 g/m^3 at BTP is advised even though not all devices in

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common use can achieve this. There is a trade-off between achieving adequate humidity (these stated targets), or a higher more ideal humidity and the risk of harm, such as airway flooding and water lock.

A variety of devices are available, each having its own strengths and weaknesses. Classification varies according to the selection criteria used (e.g. energy source, efficiency, cost, etc), but one common classification is by division into *passive or active*.

Passive devices, such as heat and moisture exchangers (HMEs) and circle breathing systems using soda lime, function independently of external energy or gas flow. The *active* systems, such as heated humidifiers (HHs) and nebulizers require a driving gas and/or electrical energy to add vapour or water droplets.

Comparison of the main types available is shown in Table 1.

Passive humidification devices

Heat and moisture exchangers (Figure 1): HMEs are in common use, usually combined with a microbiological filter, and thus termed an HMEF.

They are used for three reasons: first, to warm and humidify a patient's respiratory tract; secondly, to protect the patient from contamination from permanent equipment; and thirdly, to prevent the patient contaminating this equipment.

Original HMEs consisted of a chamber containing a mesh or screen of metal or plastic, placed into a breathing system *via* standard 15/22 mm connectors. The device acts as a counter-current exchanger during the respiratory cycle. In expiration, the *latent heat of vaporization* of water (now called *massic enthalpy*) is transferred to the screen with condensation of water; this heat and water is then available to warm and humidify inspiratory gases. Efficiency is enhanced by coating the screen with a salt such as calcium chloride.

HMEFs, introduced in the late 1980s are also designed to filter microbes. The pore size of less than 0.2 μm will trap 99.9% of bacteria. They are available as pleated (high density) or electrostatic (low density) varieties.

HME and HMEFs are lightweight and efficient, humidifying to 25–35 g/m^3. They are generally single-patient use with about 100 different devices available, about 30 of these are for paediatric use.

Disadvantages: All HMEs and HMEFs increase the work of breathing; large devices incur a pressure drop of 0.4 cm water (at a flow of 50 l/min) whilst smaller devices produce up to ten times this. This additional resistance may be managed with additional respiratory support in critical care environments. HMEs and HMEFs add *deadspace* to the breathing system, an important consideration for infants. HMEs and HMEFs may block, especially when nebulizers are used to deliver drugs or when the patient produces copious secretions, despite this, in critical care current advice is to avoid changing HMEs or HMEFs on a routine basis during an episode of patient care.

Electrostatic HMEFs are not recommended for use with circle systems, since condensate may be transmitted through the device into the patient. Prolonged (>4 hours) use of high-dose (>2 MAC) desflurane has been reported to impair efficiency of electrostatic devices although this is a situation unlikely to be found in clinical practice.

Soda lime: soda lime is an absorber of carbon dioxide used in anaesthetic circle breathing systems commonly composed of a mixture of calcium hydroxide (80%) and sodium hydroxide (20%) with a coloured chemical indicator to signal its exhaustion. In a series of reactions carbon dioxide is removed from the expirate, whilst generating heat and water. Acceptable humidification takes time (about 1 hour to provide 20 g/m^3) and low flows (<2 l/min). An HME or HMEF is included in the system to provide the initial humidification during the 'wash in phase' of high gas flow and until acceptable humidity is reached, as well as to protect the equipment and patient from contamination.

Active humidification devices

Active humidifiers use a variety of energy sources. In general, they extract water from a reservoir, humidifying a carrier gas (oxygen-enriched air) passing into a delivery system for the patient. The reservoir risks contamination, either microbial or by chemical (if liquids other than sterile water are added). Highly efficient devices may have a humidified output sufficient to cause condensation in the delivery system and blockage of tubing ('water lock') in dependent loops is possible. If a device is positioned above a patient, condensate

Comparison of humidification devices

	HME	Cold water bath	Hot water bath	Nebulizer	Soda lime
Driving gas required	No	Yes	Yes	Yes	No
Efficiency	≤70%	≤40%	100%	100%	100% (1 hour)
Cost	£	£	££	£££	£
Portable	Yes	No	No	No	No
Infection risk	↓	↑	↑	↑	↓
Possible respiratory complications	Obstruction ↑resistance	Nil	Scalding/burns	Condensation	CO production

Key: £, ££, £££ Least cost, more expensive, highest cost.
↑, ↓: Greater, lesser magnitude.
CO, carbon monoxide; HME, heat and moisture exchanger.

Table 1