CHAPTER

4

Humidity and Aerosol Therapy

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CHAPTER OBJECTIVES

1. Describe the natural physiologic humidification process.
2. Identify indications and contraindications for humidity therapy.
3. Understand the principle of operation of different types of humidifiers used in clinical practices.
4. Recognize the consequences of inadequate humidification.
5. Compare the different types of humidifiers. Compare and contrast the different types of humidifiers in terms of their functions, applications, and characteristics.

KEY TERMS

Aerosol therapy
Bubble humidifier
Heat and moisture exchangers (HMEs)
Heated humidifier
Humidification
Large volume jet nebulizer
Passover humidifier
Relative humidity
Vibrating mesh nebulizer (VMN)

Introduction

Providing humidity and aerosol therapies are common practices in the field of respiratory care. Respiratory care practitioners are often in charge of the tasks to provide optimal humidity and efficient aerosol therapies to patients who are either spontaneously breathing or receiving invasive ventilatory support with mechanical ventilation.

It is essential that respiratory care practitioners not only have a firm understanding of the rationale, physiological basis, indications, and contraindications for humidity and aerosol therapies, but also have a good grasp of the different technical considerations regarding the multitude of devices available for such use in the clinical arena. The respiratory therapist's understanding of the classifications, principles of operation, range of applications, specifications, and hazards of these devices is as important as the therapies these devices are intended to provide.

This chapter describes the various devices currently used in the clinical practice of providing humidity and aerosol therapies in spontaneously breathing and mechanically ventilated patients.

Before proceeding any further, it is important that some terms are defined:

- *Humidity:* The presence of moisture in its molecular form in a gas or gas mixture
- *Absolute humidity:* The weight of water in a volume of gas or gas mixture expressed as milligrams per liter (mg/L)
- **Relative humidity***:* The absolute humidity of a volume of gas expressed as a percentage of the water vapor capacity of the gas (i.e., capacity is absolute humidity when saturated with water vapor).

Physiologic Control of Heat and Moisture

The upper respiratory tract system, and in particular the nose, has the essential function of conditioning inspired gases for optimal heat and moisture before they flow through the bronchial tree and expand the lung parenchyma. It is crucial for the proper functioning of the lower airways and alveoli that inspired gases

are fully saturated with water vapor and warmed to body temperature upon reaching just below the carina. This point in the upper airways is called the isothermic saturation boundary (ISB). At this boundary, the inspired gas should have 100% relative humidity and a temperature of 98.6°F (37°C).

During inspiration, the induced turbulence in the flow of the inspired gas as it passes through the nasal turbinates increases the contact between the molecules of inspired gas and the nasal mucosa and results in efficient warming of the inspired gas. This is called turbulent convection. With the efficient warming of the inspired gas, water is then transferred and added to the inspired gas by evaporation from the mucosa. Evaporation results in cooling and decreasing the water content of the tracheal and nasal mucosa. During expiration and as the gas is exhaled, the tracheal and nasal mucosa cools the exhaled gas and reclaims part of its water content. This is called condensation.

Below the isothermic saturation boundary, temperature and relative humidity remain constant with body temperature and pressure, saturated (BTPS) conditions (i.e., 98.6°F [37°C] body temperature, barometric pressure, and 100% relative humidity). When the ISB is not achieved just below the carina, there will be a further distal downshift in the ISB. Several clinical and technical conditions can lead to such displacement of the ISB.[1] These include situations when patients breathe cold and dry air, as when breathing medical gases provided by hospitals' medical gas supply systems; when patients breathe through their mouths at higher minute ventilation, which is mostly the case during respiratory distress situations; or when patients' natural anatomical **humidification** and heating structures are bypassed by artificial airways or endotracheal tubes during mechanical ventilation. With the distal shift of the ISB, additional surfaces from the lower airways will be required to provide humidity and heat. This can negatively impact the epithelial integrity of these airways, make them susceptible to infection and inflammation, and lead to the narrowing of their cross-sectional areas.[2] As such, whenever the body's capability for humidifying and heating inspired gas is compromised, external measures for humidifying and heating of these inspired medical gases are indicated and needed to prevent a negative impact on a patient's health. The recommended humidity and heat levels are shown in **Table 4-1**.

Effects of Inadequate Humidification

The objective of humidity therapy is to condition medical gases to approximate normal inspiratory conditions. With proper humidification, the ISB remains just below the carina with no downward shift toward the small airways. Extrinsic humidification and heating of inspired dry medical gases should be ensured (whether the nose and upper airways are bypassed or not) during different modalities of respiratory support using either medical gas therapies or invasive and noninvasive ventilator support. Inadequate humidification can result in substantial water and heat loss from the airways that can lead to the disruption of the mucociliary transport system and an increase in mucus production with thickening of the pulmonary secretions, an increase in the airway irritability, and ultimately structural damage to the lung.[2]

There are several signs and symptoms of inadequate humidification.[3] These are more evident and significant during invasive mechanical ventilation when the normal water and heat exchange capabilities of upper airways are bypassed with the use of endotracheal tubes. The clinical signs and symptoms usually include thick, dehydrated, and encrusted secretions; dry and nonproductive cough; patient complaint of substernal pain; atelectasis; increased incidence of infection; bacterial infiltration of mucosa; increased airway resistance; and increased work of breathing.

Application

Indications for Humidity Therapy

Humidity and heat therapy is administered during numerous respiratory care therapeutic modalities to a wide variety of patients under different clinical scenarios and medical conditions. This can be provided in both the hospital and home setting. The generally accepted indication for this type of therapy is

TABLE 4-1
Recommended Heat and Humidity Levels

Site	Temperature Range (°C)	Relative Humidity (%)	Absolute Humidity (mg/L)
Nose/mouth	20–22	50	10
Hypopharynx	29–32	95	28–34
Trachea	32–35	100	36–40
Carina	37	100	44

Reproduced from Chatburn R, Primiano F. A rational basis for humidity therapy. *Respir Care*. 198;32:249, 1987; permission conveyed through Copyright Clearance Center, Inc.

TABLE 4-2
Indications for Humidity Therapy

1. Delivering adequate humidity when spontaneously breathing medical gases for therapeutic purposes
2. Providing adequate humidification in the presence of artificial airway during invasive mechanical ventilation
3. Providing adequate humidification in the presence of high gas flows during noninvasive ventilation and high flow nasal cannula oxygen therapy
4. Thinning dried and/or thick secretions
5. Promoting bronchial hygiene
6. Managing hypothermia in intubated and mechanically ventilated patients
7. Treating bronchospasm caused by cold air in spontaneously breathing patients

conditioning the dry inspired mix of medical gases, particularly when the normal and anatomical structures of the body (nose and upper airways) are either compromised or bypassed.[4] The different indications for humidity therapy are summarized in **Table 4-2**.

Contraindications for Humidity Therapy

In general, there are no contraindications to providing humidification of inspired gas during spontaneous breathing or mechanical ventilation. However, there might be some contraindications for using certain humidification devices during specific clinical conditions.[5] A heat and moisture exchanger (HME) is contraindicated in patients with thick, copious, or bloody secretions. A minute ventilation greater than 10 L/min is a contraindication for the use of an HME as the means for providing humidification during ventilator support. Also, HMEs are contraindicated in patients with expired tidal volume less than 70% of the delivered tidal volume, such as in patients with large bronchopleural fistulas, severe tracheomalasia, or uncuffed endotracheal tubes. The use of heat and moisture might also be contraindicated in patients with body temperature of less than 89.6°F (32°C). Unless it is bypassed, the HME has to be removed from the patient's breathing circuits when he or she is receiving in-line aerosol drug treatments.

Hazards of Humidity Therapy

Hazards and complications encountered during humidification therapy are infrequent and mainly associated with the use of the humidification devices rather than the therapy itself.[6] With the use of **heated humidifiers**, there are potentials of electrical shock, hyperthermia, thermal injury to the airways, tubing meltdown if circuits and heated humidifiers are incompatible, burns to caregivers from the humidifier's hot metal, and pooled condensation in the patient's breathing circuits. With excessive pooled condensation, there will be risks for patient–ventilator dysynchrony and improper ventilator performance, elevated airway pressures, inadvertent tracheal lavage from pooled condensation or overfilling of humidifier, and nosocomial infection for both patients and clinicians when pooled condensates are aerosolized into the patient's environment when breathing circuits are disconnected while the ventilator is generating high flows.[7]

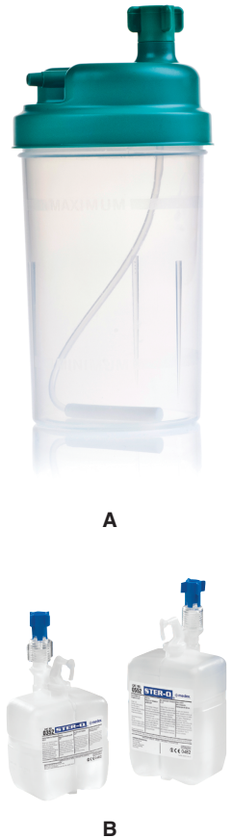
With HMEs, there are risks for hypothermia; possible increase in the resistive work of breathing through the HME, particularly after long use (> 24 hours); and possible hypoventilation due to increased mechanical dead space.[8]

Monitoring Therapeutic Effectiveness

The primary goal for humidity therapy is to condition medical gases to achieve normal inspiratory conditions of 100% relative humidity and 98.6°F (37°C) just below the carina and before the medical gases enter the airways. Ideal measurement and monitoring of the therapeutic effectiveness of humidity therapy requires the placement of a hygrometer (a device that measures humidity) and a thermometer at the level of the carina. Currently this is not available; the closest point for measurement of these parameters is at the patient Y for mechanically ventilated patients and the mouth opening for spontaneously breathing patients. However, hygrometers are not widely used in clinical practice; most of the time the temperature is measured and monitored at the patient's Y during mechanical ventilation. Therefore, monitoring therapeutic effectiveness of humidity therapy is not direct and remains mainly subjective and widely dependent on the careful qualitative assessment of the patient and patient's breath sounds, patient's cough along with the characteristics of the sputum expectorated, and secretions and formation of mucus plugs as surrogates for effective humidification therapy.[9] In general, the absence of underhydration, thick secretions, mucus plugging of airways, obstruction of the endotracheal or tracheostomy tube, and mechanical ventilation–induced inflammatory responses, along with normal breath sounds can be considered as signs of effective humidity therapy.

Active Humidifiers

Active humidification can be accomplished using either bubble, passover, or heated humidifiers. The levels of humidification achieved with these humidifiers depend greatly on the design and principle of operation of each of these devices.



A

B

FIGURE 4-1 Simple bubble jet humidifiers: A. Disposable. B. Prefilled.

Photo A courtesy of Teleflex. Photo B courtesy of Smiths Medical.

Bubble Humidifiers

A **bubble humidifier** consists of a bottle or reservoir partially filled with water attached to a conduction system that allows the inspired medical gases to be introduced below the water surface. A diffuser that is usually either a foam or a metallic mesh is attached to the end of the conduction system. Bubble humidifiers are either reusable or single patient use humidifiers.[10] Furthermore, single patient use humidifiers are either dry or prefilled. Bubble humidifiers incorporate a pressure relief valve that releases pressure from inside the humidifier bottle to prevent bursting of the bubble in the event there is an obstruction to the flow path out of the humidifier bottle. Usually these pressure relief valves function at a pressure of greater than 2 psi. Bubble humidifiers are also known as bubble diffuser humidifiers or just diffusers (**Figure 4-1**).

Indications: The bubble humidifier is used to humidify the inspired medical gases delivered to patients via a cannula or face mask.

Contraindications: This type of humidifier is contraindicated for patients with an endotracheal tube, a tracheostomy, or tenacious secretions.

Hazards: If heated, bubble humidifiers result in excessive condensate that tends to obstruct the small bore delivery tubing that connects between the humidifier output and the patient's interface. With prolonged use, there is a risk that the pressure relief valve becomes dysfunctional, which can lead to the build-up of excessive pressures and burst the humidifier bottle whenever a flow obstruction occurs. Whenever high flow rates (usually in excess of 10 L/min) are used, bubble humidifiers can produce aerosols. These water droplets can transmit pathogenic bacteria from the humidifier reservoir to the patient.

Principles of operation: As inspired medical gases leave the diffuser and enter the water, gas bubbles are formed that flow through the liquid. This allows for greater exposure time and contact area, thereby increasing the capability of the flowing dry medical gases to extract humidity from the water. With these types of unheated bubble humidifiers, an absolute humidity level between approximately 15 and 20 mg/L is usually achieved. Bubble humidifier units function at a flow rate of 2 L/min and should not be operated at greater than 6 L/min because they start to lose their efficiency in providing humidity. The higher the flow rate, the less exposure time in the water medium and the higher risk for cooling the reservoir.[11] These humidifiers are not recommended for use at flow rates greater than 10 L/min. In the event of a flow obstruction out of the humidifier bottle, the pressure relief valve opens and releases pressure from inside the bottle while giving an audible alarm. Once the flow obstruction is eliminated, the pressure relief valve automatically resumes its normal position.

Currently available devices: Bubble humidifiers remain widely used in the practice of respiratory care. Almost every single patient using low flow oxygen therapy via a nasal cannula or a face mask will need a bubble humidifier. There are many commercially available bubble humidifiers with different specifications, as presented in **Table 4-3**.

Passover Humidifiers

These are mainly of three types: the simple passover, the wick, and the membrane device (**Figure 4-2**). The simple **passover humidifier** is just a reservoir/jar containing water over which the dry inspired gas will flow and increase its water content. The wick humidifier consists of a reservoir in addition to a porous material (wick) that absorbs water and provides a larger area for air-water mix for better evaporation. Some of these wick humidifiers include a fan to aid in the evaporation of the water.

TABLE 4-3
Types and Specifications of Bubble Humidifiers

Manufacturer	Product Name/ Number	Type	Sterile/ Closed System	Volume (mL)	Audible Safety Pressure-Relief Valve	Pressure-Relief Level (psi)	Min/Max Indicators	Lid	Nut	Diffuser	Heater
Afton Medical	80300	Dry-disposable	No	300	Yes	3	Yes	Plastic	Plastic	NS	No
	80400	Dry-disposable	No	400	Yes	4	Yes	Plastic	Plastic	NS	No
	80600	Dry-disposable	No	400	Yes	6	Yes	Plastic	Plastic	NS	No
Allied Health Care Products, Inc.	64375	Dry-disposable	No	300	Yes	3	Yes	Plastic	Plastic	Foam	No
	64376	Dry-disposable	No	300	Yes	3	Yes	Plastic	Metal	Foam	No
	64377	Dry-disposable	No	300	Yes	6	Yes	Plastic	Plastic	Foam	No
	64378	Dry-disposable	No	300	Yes	6	Yes	Plastic	Metal	Foam	No
	61350S	Prefilled-disposable	Yes	350	Yes	6	N/A	Plastic	Plastic	Foam	No
	61550S	Prefilled-disposable	Yes	350	Yes	6	N/A	Plastic	Plastic	Foam	No
	34-10-0001	Dry-reusable	No	NS	NS	NS	Yes	Plastic	Plastic	Metal	No
	34-10-0005	Dry-reusable	No	NS	Yes	NS	Yes	Plastic	Plastic	Metal	No
	34-10-0025	Dry-reusable	No	NS	Yes	NS	Yes	Plastic	Plastic	Metal	No
Besmed	HB-1130	Dry-disposable	No	300	Yes	3	Yes	Plastic	Plastic	PVC or ceramic	No
	HB-1132	Dry-disposable	No	500	Yes	4	Yes	Plastic	Plastic	PVC or ceramic	No
	HB-2401	Dry-disposable	No	400	Yes	6	Yes	Plastic	Plastic	PVC or ceramic	No
	HB-2411	Dry-disposable	No	400	Yes	4	Yes	Plastic	Plastic	PVC or ceramic	No
	HB-2601	Dry-disposable	No	400	Yes	6	Yes	Plastic	Plastic	PVC or ceramic	No
	HB-2611	Dry-disposable	No	400	Yes	4	Yes	Plastic	Plastic	PVC or ceramic	No

(*continues*)

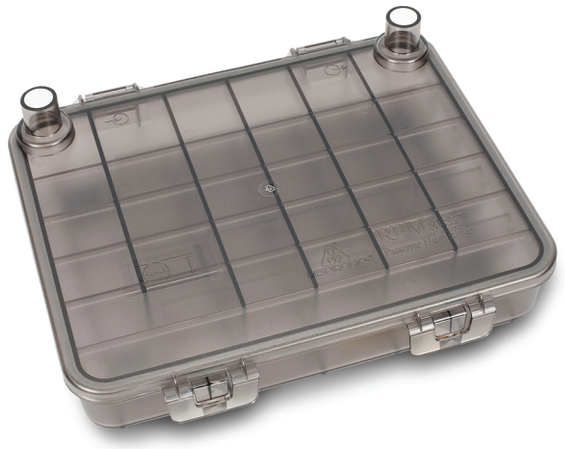
TABLE 4-3
Types and Specifications of Bubble Humidifiers (*Continued*)

Manufacturer	Product Name/ Number	Type	Sterile/ Closed System	Volume (mL)	Audible Safety Pressure-Relief Valve	Pressure-Relief Level (psi)	Min/Max Indicators	Lid	Nut	Diffuser	Heater
CareFusion	AirLife 2620	Prefilled-disposable	Yes	500	Yes	4	N/A	Plastic	Plastic	NS	No
	AirLife 2702	Prefilled-disposable	Yes	750	Yes	4	N/A	Plastic	Plastic	NS	No
	AirLife 2003	Dry-disposable	No	370	Yes	3	Yes	Plastic	Plastic	Foam	No
Carefusion	AirLife 2006	Dry-disposable	No	370	Yes	6	Yes	Plastic	Plastic	Foam	No
Galemed	BH-1	Dry-disposable	No	NS	Yes	2, 4, or 6	Yes	Plastic	Plastic	NS	No
	BH-2	Dry-disposable	No	NS	Yes	2	Yes	Plastic	Plastic	NS	Yes
	BH-3	Dry-disposable	No	NS	Yes	4	Yes	Plastic	Plastic	NS	No
	ECO	Dry-disposable	No	NS	Yes	4	Yes	Plastic	Plastic	NS	No
Genstar Technologies, Inc.	7100R	Dry-reusable	No	300	Yes	NS	Yes	Plastic	Plastic	NS	No
	7200R	Dry-reusable	No	140	No	NS	Yes	Metal	Metal	NS	No
	638-001	Dry-disposable	No	250	Yes	NS	Yes	Plastic	Plastic	NS	No
	638-002	Dry-disposable	No	400	Yes	NS	Yes	Plastic	Plastic	NS	No
	638-003	Dry-disposable	No	400	Yes	NS	Yes	Plastic	Plastic	NS	No
GF Health Products, Inc.	BF61550S	Prefilled-disposable	Yes	550	Yes	6	N/A	Plastic	Plastic	NS	No
	GF64375	Dry-disposable	No	250	Yes	6	Yes	Plastic	Plastic	NS	No

TABLE 4-3
Types and Specifications of Bubble Humidifiers

Manufacturer	Product Name/ Number	Type	Sterile/ Closed System	Volume (mL)	Audible Safety Pressure-Relief Valve	Pressure-Relief Level (psi)	Min/Max Indicators	Lid	Nut	Diffuser	Heater
Intersurgical	AquaFlow 1507	Dry-disposable	No	120 & 500	Yes	NS	Yes	Plastic	Plastic	NS	No
	AquaFlow 1521	Dry-disposable	No	120	Yes	NS	Yes	Plastic	Plastic	NS	No
Ohio Medical Corp.	6700-0338-800	Dry-reusable	No	300	Yes	2	Yes	Plastic	Plastic	Chrome-plated brass	No
Salter Labs	7100	Dry-disposable	No	350	Yes	3	Yes	Plastic	Plastic	PVC	No
	7600	Dry-disposable	No	350	Yes	6	Yes	Plastic	Plastic	PVC	No
	7900	Dry-disposable	No	350	Yes	NS	Yes	Plastic	Plastic	PVC	No
Teleflex	003-40	Prefilled-disposable	Yes	340	Yes	NS	N/A	Plastic	Plastic	NS	No
	005-40	Prefilled-disposable	Yes	540	Yes	NS	N/A	Plastic	Plastic	NS	No
	006-40	Prefilled-disposable	Yes	650	Yes	NS	N/A	Plastic	Plastic	NS	No
	3230	Dry-disposable	No	500	Yes	4	Yes	Plastic	Plastic	NS	No
	3260	Dry-disposable	No	500	Yes	6	Yes	Plastic	Plastic	NS	No
Ventlab Corp.	VTB6900	Dry-disposable	No	350	NS	NS	Yes	Plastic	Plastic	NS	NS
Westmed	0480	Dry-disposable	No	NS	Yes	NS	Yes	Plastic	Plastic	PVC	No
	0795	Dry-disposable	No	NS	Yes	NS	Yes	Plastic	Plastic	PVC	No

N/A: Not applicable, NS: Not specified, PVC: Polyvinylchloride



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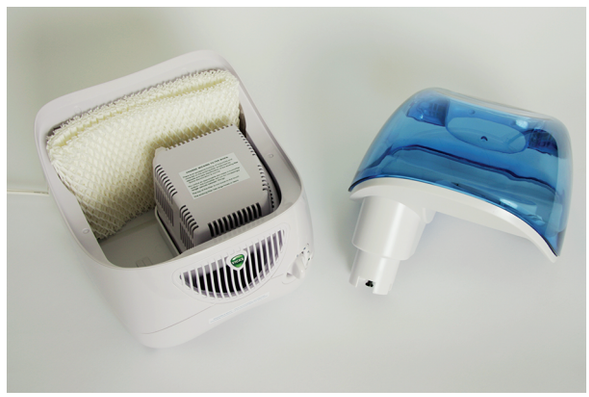

B

FIGURE 4-2 Different types of passover humidifiers: A. Simple. B. Wick type.

Photo A reproduced with permission from Philips Healthcare.

Membrane Devices

Membrane passover humidifiers consist of a jar that can be filled with water with no conduction system for the inspired gas inside the jar. A hydrophobic membrane separates the gas stream from the water. Inspired gases flow in one side, pass over the water surface and membrane, and exit from another side of the humidifier. There is no bubbling of water inside the humidifier. The efficiency of this unit is rather low, because exposure area and time of contact are limited and the water is usually not heated. Membrane passover humidifiers can maintain saturation at high flow rates with no or little resistance to spontaneous breathing circuits.[12] Additionally they do not generate aerosols, leading to minimal risk for spreading infection.

Indications: Passover humidifiers are usually used with invasive and noninvasive ventilator support (e.g., nasal continuous positive airway pressure or bilevel positive airway pressure support).[13]

Contraindications: There are no contraindications for using passover humidification to provide physiologic conditioning of inspired gas during invasive and noninvasive mechanical ventilation.[14]

Hazards: Passover humidifiers have minimal hazards. However, if a heat element is used, then there will be the risk of electrical shock. Hypo- or hyperthermia can result from inadequate adjustment of the temperature. Excessive heating and evaporation can result in accumulation of condensate in the breathing circuit with the risk of contamination, patient–ventilator asynchrony, and condensate aerosolization whenever the patient is disconnected from the ventilator. In addition, if the compressible volume losses from the humidifier reservoir are not compensated for, there is a risk for inaccurate tidal volume measurement.

Principles of operation: As the inspired gases pass over the water surface and hydrophobic membrane, the water vapor can easily pass through the wick or membrane, mix with the dry inspired gas, and increase its water content. Liquid water will not cross the hydrophobic membrane.

Currently available devices: Passover humidifiers are very common during invasive and noninvasive mechanical ventilation. There are several commercially available passover humidifiers with different specifications and features, as presented in **Table 4-4**.

Heated Humidifiers

A heated humidifier consists of a reservoir and a heating element. Some heated humidifiers include a wick element. The wick is usually surrounded by the heating element to maintain adequate saturation of the wick during the operation of the device.[15] The heating element improves water output and usually has a controller that regulates the element's heating power and subsequently maintains a set temperature of inspired gas at the patient airway. These systems incorporate alarms and alarm-activated heater shutdown.

There are four different types of heating systems:

- A hot plate located at the base of the humidifier chamber
- A wraparound that surrounds the humidifier chamber
- A collar that sits between the water reservoir and the gas outlet
- An immersion type where the heating element is placed in the water

All modern heated humidifiers are equipped with automatic feed systems with a flotation valve control for adequate and continuous control of the water level inside the humidifier chamber (**Figure 4-3**).

TABLE 4-4
Types and Specifications of Passover Humidifiers

Manufacturer	Product Name/ Number	Type	Sterile/ Closed System	Volume (mL)	Audible Safety Pressure-Relief Valve	Pressure-Relief Level (psi)	Min/Max Indicators	Lid	Nut	Diffuser	Heater Interface
Afton Medical	80300	Dry-disposable	No	300	Yes	3	Yes	Plastic	Plastic	NS	No
	80400	Dry-disposable	No	400	Yes	4	Yes	Plastic	Plastic	NS	No
	80600	Dry-disposable	No	400	Yes	6	Yes	Plastic	Plastic	NS	No
Allied Health Care Products, Inc.	64375	Dry-disposable	No	300	Yes	3	Yes	Plastic	Plastic	Foam	No
	64376	Dry-disposable	No	300	Yes	3	Yes	Plastic	Metal	Foam	No
	64377	Dry-disposable	No	300	Yes	6	Yes	Plastic	Plastic	Foam	No
	64378	Dry-disposable	No	300	Yes	6	Yes	Plastic	Metal	Foam	No
	61350S	Prefilled-disposable	Yes	350	Yes	6	N/A	Plastic	Plastic	Foam	No
	61550S	Prefilled-disposable	Yes	350	Yes	6	N/A	Plastic	Plastic	Foam	No
	34-10-0001	Dry-reusable	No	NS	NS	NS	Yes	Plastic	Plastic	Metal	No
	34-10-0005	Dry-reusable	No	NS	Yes	NS	Yes	Plastic	Plastic	Metal	No
	34-10-0025	Dry-reusable	No	NS	Yes	NS	Yes	Plastic	Plastic	Metal	No
Besmed	HB-1130	Dry-disposable	No	300	Yes	3	Yes	Plastic	Plastic	PVC or Ceramic	No
	HB-1132	Dry-disposable	No	500	Yes	4	Yes	Plastic	Plastic	PVC or Ceramic	No
	HB-2401	Dry-disposable	No	400	Yes	6	Yes	Plastic	Plastic	PVC or Ceramic	No
	HB-2411	Dry-disposable	No	400	Yes	4	Yes	Plastic	Plastic	PVC or Ceramic	No
	HB-2601	Dry-disposable	No	400	Yes	6	Yes	Plastic	Plastic	PVC or Ceramic	No
	HB-2611	Dry-disposable	No	400	Yes	4	Yes	Plastic	Plastic	PVC or Ceramic	No
CareFusion	AirLife 2620	Prefilled-disposable	Yes	500	Yes	4	N/A	Plastic	Plastic	NS	No
	AirLife 2702	Prefilled-disposable	Yes	750	Yes	4	N/A	Plastic	Plastic	NS	No
	AirLife 2003	Dry-disposable	No	370	Yes	3	Yes	Plastic	Plastic	Foam	No
	AirLife 2006	Dry-disposable	No	370	Yes	6	Yes	Plastic	Plastic	Foam	No

(*continues*)

TABLE 4-4
Types and Specifications of Passover Humidifiers (*Continued*)

Manufacturer	Product Name/ Number	Type	Sterile/ Closed System	Volume (mL)	Audible Safety Pressure-Relief Valve	Pressure-Relief Level (psi)	Min/Max Indicators	Lid	Nut	Diffuser	Heater Interface
Galemed	BH-1	Dry-Disposable	No	NS	Yes	2, 4, or 6	Yes	Plastic	Plastic	NS	No
	BH-2	Dry-Disposable	No	NS	Yes	2	Yes	Plastic	Plastic	NS	Yes
	BH-3	Dry-Disposable	No	NS	Yes	4	Yes	Plastic	Plastic	NS	No
	ECO	Dry-Disposable	No	NS	Yes	4	Yes	Plastic	Plastic	NS	No
Genstar Technologies, Inc	7100R	Dry-Reusable	No	300	Yes	NS	Yes	Plastic	Plastic	NS	No
	7200R	Dry-Reusable	No	140	No	NS	Yes	Metal	Metal	NS	No
	638-001	Dry-Disposable	No	250	Yes	NS	Yes	Plastic	Plastic	NS	No
	638-002	Dry-Disposable	No	400	Yes	NS	Yes	Plastic	Plastic	NS	No
	638-003	Dry-Disposable	No	400	Yes	NS	Yes	Plastic	Plastic	NS	No
GF Health Products, Inc.	BF61550S	Prefilled-Disposable	Yes	550	Yes	6	N/A	Plastic	Plastic	NS	No
	GF64375	Dry-Disposable	No	250	Yes	6	Yes	Plastic	Plastic	NS	No
Ohio Medical Corp.	6700-0338-800	Dry-Reusable	No	300	Yes	2	Yes	Plastic	Plastic	Chrome-plated brass	No
Salter Labs	7100	Dry-Disposable	No	350	Yes	3	Yes	Plastic	Plastic	PVC	No
	7600	Dry-Disposable	No	350	Yes	6	Yes	Plastic	Plastic	PVC	No
	7900	Dry-Disposable	No	350	Yes	NS	Yes	Plastic	Plastic	PVC	No
Teleflex	003-40	Prefilled-Disposable	Yes	340	Yes	NS	N/A	Plastic	Plastic	NS	No
	005-40	Prefilled-Disposable	Yes	540	Yes	NS	N/A	Plastic	Plastic	NS	No
	006-40	Prefilled-Disposable	Yes	650	Yes	NS	N/A	Plastic	Plastic	NS	No
	3230	Dry-Disposable	No	500	Yes	4	Yes	Plastic	Plastic	NS	No
	3260	Dry-Disposable	No	500	Yes	6	Yes	Plastic	Plastic	NS	No
Ventlab Corp.	VTB6900	Dry-Disposable	No	350	NS	NS	Yes	Plastic	Plastic	NS	NS
Westmed	0480	Dry-Disposable	No	NS	Yes	NS	Yes	Plastic	Plastic	PVC	No
	0795	Dry-Disposable	No	NS	Yes	NS	Yes	Plastic	Plastic	PVC	No

N/A: Not applicable, NS: Not specified, PVC: Polyvinylchloride

Similar to membrane device passover humidifiers, no bubbling occurs and subsequently no aerosol is produced.

Indications: Heated humidifiers provide a high level of humidity and heat, and for that reason are mainly used with intubated and mechanically ventilated patients.[16] In these patients, the upper airways are bypassed by the endotracheal tubes and the patients are fully dependent on external sources that provide the highest possible levels of humidity and heat for optimal conditioning of the inspired gases.

Contraindications: There are no contraindications for using heated humidifiers in order to provide physiologic conditioning of inspired gas during invasive mechanical ventilation.

Hazards: Like with any other electrical devices, there will always be a risk of electrical shock. If the temperature is not adequately set, heated humidifiers can result in hypo- or hyperthermia. Thermal injury to the airway can occur from heated humidifiers; in addition, burns to the patient and to the caregiver and tubing meltdown can result if heated-wire circuits are covered or circuits and heated humidifiers are incompatible. Pooled contaminated condensate in the breathing circuit can result in patient–ventilator asynchrony or unintentional tracheal lavage or can be aerosolized when disconnecting the patient from the mechanical ventilator, which can put the patient and the caregiver at risk for nosocomial infection. Because the chambers of these humidifiers can be of substantial volume, the compressible volume losses should be compensated for; otherwise, inaccurate tidal volume is measured with a decrease in the ventilator response.[17]

Principles of operation: During operation, the heating element, which is usually either a plate or a rod, increases and maintains the water temperature in the reservoir at 37–38°C via a servo controlled closed system. The dry and cold gas passes over the heated and warm water before being expelled out of the water reservoir during inspiration and more humidification takes place. This device can deliver 100% relative humidity.

Currently available devices: The currently available commercial devices do not include wick elements. The systems are passover humidifiers with either a heated plate chamber or a heated wire chamber. The specifications of commercially available heated humidifiers are presented in **Table 4-5**.

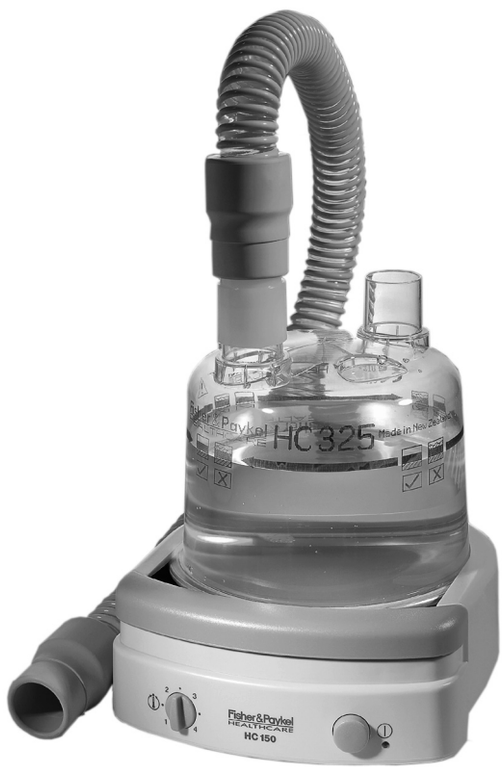

FIGURE 4-3 Heated humidifiers.
Courtesy of Fisher & Paykel Healthcare.

Aerosol Generators

Aerosol generators are required for the delivery of sterile water or hypotonic, isotonic, or hypertonic saline aerosols. During bland **aerosol therapy**, liquid particles are generated and delivered to the patient's airway suspended in the inspired gas.[18] Several devices can be used for aerosol generation during bland aerosol therapy. The most common are the large volume jet nebulizers and vibrating mesh or "ultrasonic" nebulizers.

Large Volume Jet Nebulizer

The use of **large volume jet nebulizers** is very common in respiratory care practice. Large volume jet nebulizers are pneumatically powered with direct attachment to a flowmeter and compressed gas source. These devices deliver cool or heated aerosols with the possibility for precisely regulating inspired oxygen concentrations by using a variable oxygen diluter (**Figure 4-4**). When using these units, the flow selected should always match or exceed the patient's peak inspiratory flow rates.[18,19] Similar to heated humidifiers, a hot plate or immersion element can be added if active heating of the inspired gas is required. These devices rarely have automatic servo-controlled systems to control delivered inspired gas temperature. Depending on the design, flow, and air entrainment setting, the total water output of unheated large volume jet nebulizers varies between 26 mg H_2O/L and 35 mg H_2O/L. However, when heated, output can be

TABLE 4-5
Types and Specifications of Heated Humidifiers

Manufacturer	Product Name/ Number	Integrated Flow Generator	Patients	O_2 Range	Flow Range	Disinfection Kit	Temperature Range	Relative Humidity Indicator	Overheat Protection	Dimensions	Weight (lb)
Fisher & Paykel Healthcare	AIRVO 2	Yes	Spontaneously breathing—in hospital	21–80%	5–50 L/min	Yes	37°C	No	No	11.6" x 6.7" x 6.9"	4.6
	myAIRVO2	Yes	Spontaneously breathing—home	No precise control	5–50 L/min	Yes	37°C	No	No	11.6" x 6.7" x 6.9"	4.8
	HC150	N/A	Spontaneously breathing—CPAP/ BiPAP	N/A	N/A	N/A	30°C–65°C	No	No	2.1" x 5.2" x 5.7"	1.8
	MR850	N/A	All groups	N/A	N/A	N/A	10°C–70°C	No	Yes	5.6" x 6.9" x 5.4"	6.3
Galemed	HumiAIDE 7	N/A	All groups	N/A	N/A	N/A	10°C–40°C	Yes	Yes	5.8" x 5.6" x 7.2"	2.9
	HumiAIDE 5	Yes	Spontaneously breathing—home	N/A	NS	NS	10°C–40°C	Yes	Yes	5.8" x 5.6" x 7.2"	0.55
	64377										
Smiths-Medical	Thera-Heat	N/A	All groups	N/A	N/A	N/A	NS	Yes	NS	NS	NS
Vapotherm, Inc.	Vapotherm	Yes	Spontaneously breathing—in hospital	21–100%	1–40 L/min	NS	33°C–43°C	N/A	Yes	11.5" x 8" x 7"	12

N/A: Not applicable, NS: Not specified

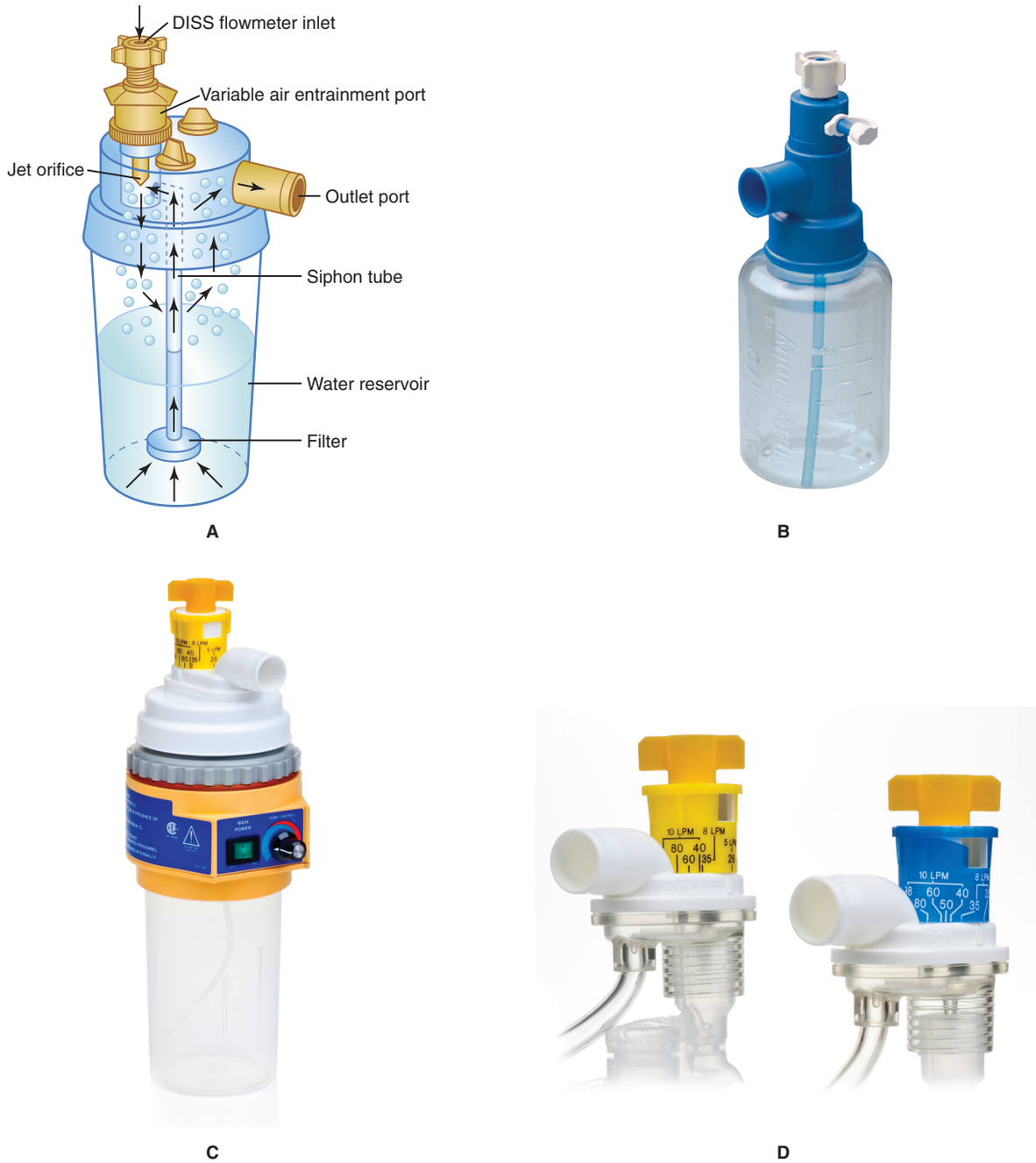

FIGURE 4-4 Large volume jet nebulizer: A. Schematic. B. Dry disposable. C. Heated disposable. D. Prefilled heated disposable.

Photo B reproduced with permission from CareFusion. Photo C courtesy of Teleflex. Photo D coutesy of Teleflex.

increased to between 33 mg H_2O/L and 55 mg H_2O/L. If aerosols are delivered into mist tents, volume jet nebulizers with reservoirs of 2–3 liters are used.

Indications: There are several clinical conditions that warrant the use of large volume jet nebulizers.[18,20] Cool bland aerosol is indicated in the presence of upper airway edema, subglottic edema, and postextubation edema. Furthermore, bland aerosol with large volume jet nebulizers is indicated in patients with laryngotracheobronchitis and whenever mobilization of secretions and sputum specimens are needed.

Contraindications: In patients with a history of upper airway hyper-responsiveness and those who are at risk for bronchorestriction, bland aerosol generation with a large volume jet nebulizer is contraindicated.

Hazards: The hazards and complications associated with bland aerosol therapy are not related to the large volume jet nebulizer per se, but rather to the therapy itself.[18,21] Patients might be at risk for wheezing or bronchospasm during bland aerosol therapy. Also there is a risk for edema associated with decreased compliance and gas exchange and with increased airway resistance. During coughing and sputum induction, the caregivers will be exposed to airborne contagions, and those patients with common respiratory diseases (e.g., chronic obstructive pulmonary disease [COPD], asthma, or cystic fibrosis) will be at risk for bronchoconstriction.

When inadequate flow is used, when the siphon tube is obstructed, or when the jet orifices are misaligned, large volume jet nebulizers will produce inadequate mist. Also many systems of large volume jet nebulizers do not shut down when the reservoir is empty, resulting in the delivery of dry inspired gas to the patient. Finally, some of these systems tend to be noisy.

Principles of operation: A large volume jet nebulizer works by directing a high flow of gas (usually a mixture of room air and oxygen) through a small jet orifice. The low pressure generated at the jet orifice draws fluid up a siphon tube. Once the water level reaches the top, it is removed by shear forces. This is a continuous process, and the water removed forms a dense aerosol.[18,22] Generated aerosolized particles are of different sizes. Downstream a short distance from the jet is a baffle that serves to stabilize particle size. When the aerosolized particles meet the baffle, larger unstable particles with higher inertia are rained out and fall back into the reservoir to minimize waste. The remaining small and stable particles leave through the outlet port and get carried in the gas stream provided to the patient. Many nebulizers have an air intake or Venturi to allow the entrainment of room air for dilution of the primary gas, usually oxygen, to be able to provide precise concentration of inspired oxygen.

Currently available devices: Large volume jet nebulizers used to be very common in the practice of respiratory care; however, recent technical developments have led to a decrease in the dependence on these devices. Some of the currently available devices are described in **Table 4-6**.

Vibrating Mesh Nebulizer

Vibrating mesh nebulizers (VMNs) are exceptionally good at producing very fine aerosols (up to a mass median aerodynamic diameter of 4.5 μm) with higher respirable fraction (RF) at slower velocities and within a short time (2–30 minutes) depending on the fill volume and the type of drug being nebulized. VMNs are capable of producing consistently high, efficient aerosol outcomes.[23] The integral component of VMNs is a vibrating mesh plate, or aperture plate, with high-precision-formed holes that control the size and flow of the aerosolized particles (**Figure 4-5**). Vibrating mesh nebulizers operate around 128 KHz. A separate or attached power supply provides electricity (via batteries or AC power supply) to the vibrating piezoelectric element. VMNs have medication reservoirs and a patient interface (a mouthpiece for spontaneously breathing patients and a T-piece adapter that fits in-line with the ventilator circuit for intubated and mechanically ventilated patients). Because vibrating mesh nebulizers do not require an external gas source for nebulization, no additional external flow

TABLE 4-6
Types and Specifications of Large Volume Jet Nebulizers

Manufacturer	Product Name/ Number	Type	Sterile/ Closed System	Volume (mL)	Inspired Oxygen Range (%)	Oxygen Flow (L/ min)	MMAD (μm)	Min/Max Indicators	Heater Interface
CareFusion	AitLife 5007p	Disposable	No	350	28–98	5–11	2.8	Yes	No
Galemed	Neb-3 Large Volume Nebulizer	Disposable	No	500	35–100	NS	5	Yes	Yes
Intersurgical	AquaMist 1509	Disposable	No	500	28–60	5–11	NS	Yes	No
Teleflex	Large Volume Neb 1770	Disposable	No	500	28–98	5–10	NS	Yes	Yes

MMAD: Mass median aerodynamic diameter, NS: Not specified

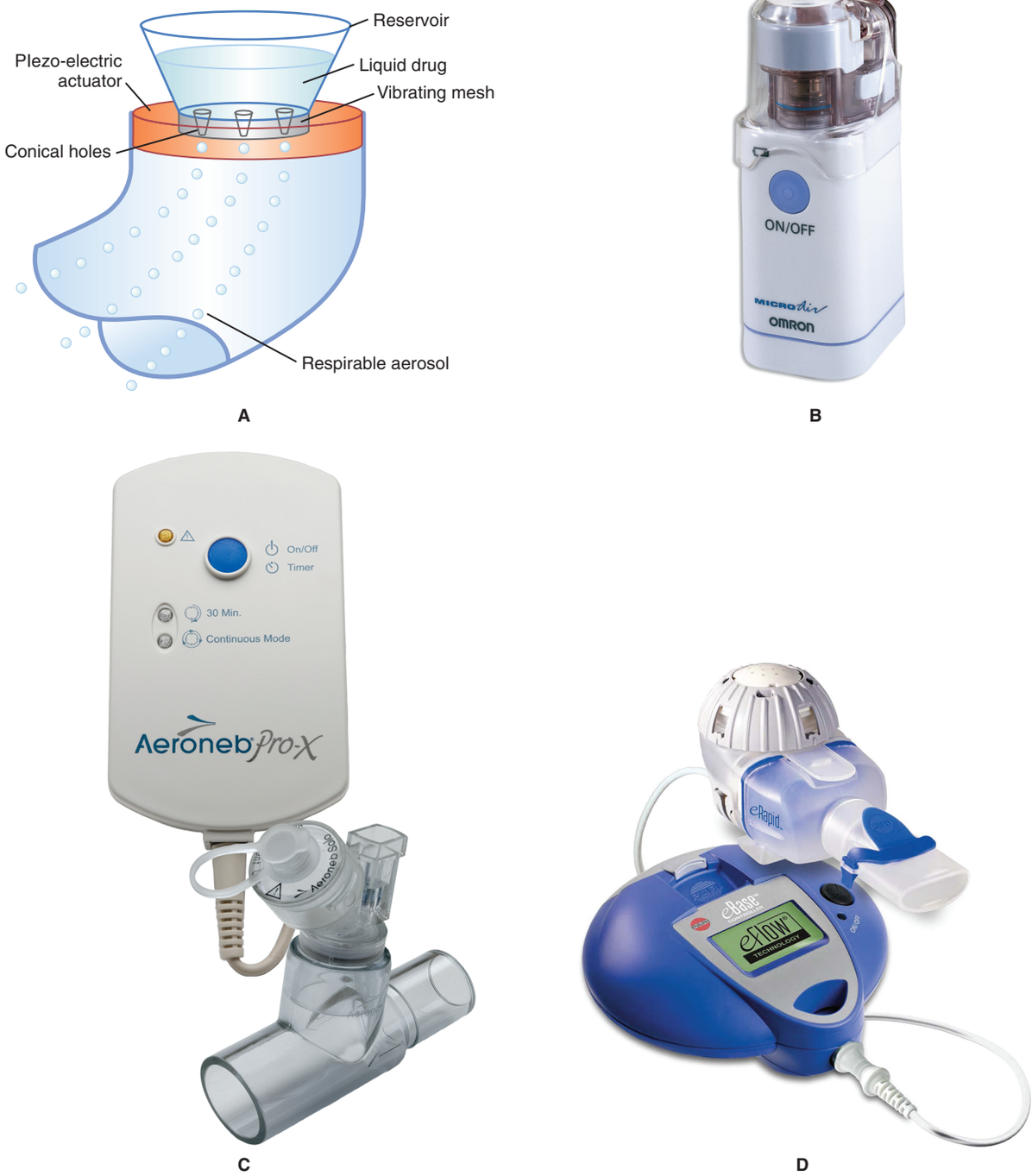

FIGURE 4-5 Vibrating mesh nebulizers: A. Schematic. B. Omron. C. Aerogen. D. Pari.

Photo B courtesy of Omron Healthcare. Photo C courtesy of Aerogen. Photo D courtesy of PARI Respiratory Equipment. "eFlow® Technology" are registered trademarks of PARI GmbH.

will be added to the total inspiratory flow provided by the ventilator; subsequently, the nebulization process will not interfere with the performance of mechanical ventilators. Due to their high efficiency, the residual drug volumes left in vibrating mesh nebulizers are very minimal (0.01 to 0.4 mL depending on reservoir design), ensuring adequate doses delivered to patients during treatments. VMNs are more expensive and

TABLE 4-7
Technical Features and Specifications of Vibrating Mesh Nebulizers

Manufacturer	Product Name/ Number	Patients	Medication Cup Capacity (mL)	MMAD (μm)	Residual Volume	Calculated Respirable Dose Delivered via Endotracheal Tube	Mode
Aerogen	Aeroneb Go	Spontaneously breathing	6	3.6	< 0.3 ml	N/A	Intermittent
	Aeroneb Pro	Mechanically ventilated	10	2.1	0.3 ml	13%	Intermittent
	Aeroneb Solo	Mechanically ventilated	6	3.4	< 0.1 mL for 3 mL dose	13–17%	Intermittent & continuous
Omron	Micro Air NE-U22	Spontaneously breathing	7	4.2	0.1	N/A	Intermittent
Pari	eRapid	Spontaneously breathing	NS	4.1	NS	N/A	Intermittent

MMAD: Mass median aerodynamic diameter

generally more costly to repair than pneumatically powered devices, though they are sometimes replaceable under a limited warranty by the manufacturer.

Indications: Vibrating mesh nebulizers are useful for the treatment of thick secretions that are difficult to expectorate, and they can help to stimulate a cough and sputum induction. In addition to the classical bronchodilators, current evidence suggests that vibrating mesh nebulizers can play a role in nebulizing and delivering directly to the lung parenchyma a wide range of medications previously known to be delivered only intravenously,[24] such as antibiotics (e.g., aztronam, colistin, tobramycin), pulmonary vasodilators (e.g., ilioprost), insulin, other proteins and peptides, and fragments of DNA.

Contraindications: In patients with a history of upper airway hyper-responsiveness and those who are at risk for bronchorestriction, bland aerosol generation with vibrating mesh nebulizers might be contraindicated.

Hazards: Vibrating mesh nebulizers are limited in that they cannot aerosolize viscous solutions. (Sterile water and normal saline are preferred.) Blockage of the minute apertures with drug particles can result if these devices are not cleaned well. As with any other nebulizer, the reservoirs of these devices can easily become contaminated, resulting in airborne transmission of pathogens. Care should be taken to ensure that these units are cleaned according to the manufacturer's recommendations and that residual volumes of solutions are discarded from the reservoir periodically between cleanings.

Principles of operation: Vibrating mesh nebulizers work on the principle of high frequency sound waves that can break water into aerosol particles.[23,25] When the power supply is turned on, the piezoelectric transducer emits vibrations forcing the liquid solution to pass through the holes and thus producing a dense aerosol at extremely low flow rates. Most currently available vibrating mesh nebulizers are powered by a preset controller; clinicians need only select the duration of the nebulization process.

Currently available devices: Among the new generation of nebulizers are several devices that employ a vibrating mesh or plate with multiple apertures to generate a liquid aerosol. The characteristics and specifications of these devices are presented in **Table 4-7**.

Passive Humidifiers

Passive humidifiers are mainly retainers of water vapor expelled with the exhaled gas from the lungs during the expiratory phase of a breath. During the inspiratory phase of a breath, previously retained water vapor is released into the gas flowing to the patient's lungs. The main type of passive humidifier is the heat and moisture exchanger.

FIGURE 4-6 One type of commercially available heat and moisture exchanger.
Courtesy of Smiths Medical.

TABLE 4-8
Contraindications for Heat and Moisture Exchangers (HMEs)

Thick, copious, or bloody secretions
Expired tidal volume less than 70% of the delivered tidal volume When using low tidal volume
Body temperature less than 89.6°F (32°C)
High minute ventilation (≥ 10 L/min)
Patients on noninvasive ventilation with large mask leaks
Patient receiving in-line aerosol drug treatments

Heat and Moisture Exchangers

Heat and moisture exchangers (HMEs), also referred to as artificial noses, are simple, small, and passive humidifiers. They are of three main types: (1) simple condenser, (2) hygroscopic condenser, or (3) hydrophobic condenser.[26] All HMEs contain a condenser element with low thermal conductivity. The condensers are either impregnated with hygroscopic salt or composed of a water-repellent element (hydrophobic) with large surface area for more efficient humidification (**Figure 4-6**). HMEs are typically used for short-term ventilatory support and for humidification during anesthesia. Whenever filtration capability is added to these humidifiers, they are called heat and moisture exchangers/filters (HMEFs).[27] The efficiency of the HMEs is quite variable, depending on the HME design, tidal volume, patient's characteristics, and atmospheric conditions.[28] While in use, HMEs are usually connected between the endotracheal tube adaptor and the Y of the breathing circuit. A small corrugated tube approximately 10 cm long is usually used to connect the HME to the endotracheal tube in order to decrease the weight effect of the HME and decrease the risk of endotracheal tube displacement. As such, HMEs are the main source of mechanical dead space during mechanical ventilation. All types of HMEs are for single patient use, and almost all of them are fitted with a Luer port for measurement of the end tidal carbon dioxide tension.

Indications: HMEs are typically used for short-term mechanical ventilation (< 72 hours), during patient transport, and during anesthesia.[29]

Contraindications: There are no contraindications to providing physiologic conditioning of inspired medical gases and optimal humidification during mechanical ventilation. However, because of their nature, HMEs are contraindicated under some circumstances (see **Table 4-8**).

Hazards: There are several hazards associated with the use of HMEs.[30] HMEs with low humidity outputs (< 25 mg/L) can result in hypothermia because the patient needs to add a significant amount of humidity to achieve an isothermic saturation condition of 44 mg H_2O/L (100% humidity). The moisture output can decrease significantly as the minute volume increases, and usually HMEs are contraindicated when minute ventilation is ≥ 10 L/min. Trapping water vapor on the condenser elements has the possibility of increasing the HME resistance causing increased work of breathing through the HME. This is seen mainly after prolonged used of the HME (> 24–48 hours). Also the increase of the HME resistance as the water saturates the condenser can lead to an ineffective low-pressure alarm during disconnection of the patient from the ventilator. HMEs remain the main source of mechanical dead space during mechanical ventilation and can lead to increases in minute ventilation. Finally, unless calculated and accounted for during mechanical ventilation, HMEs can cause significant compressible volume loss that can lead to inaccurate effective tidal volume delivery and reduction in the ventilator performance.

Principles of operation: Unless a heating element is added, HMEs do not actively add heat or water vapor to the system.[31] Exhaled heat and moisture in expired gas during a breath are captured by the condenser element of the HME and on the next inspiration, cool and dry inspired gas is warmed and humidified as it flows through the condenser element of the HME. A good heat and moisture exchanger should be at least 70% efficient with humidity output ≥ 30 mg/L water vapor, with standard connections, minimal dead space volume, and minimal flow resistance.

Currently available devices: HMEs are widely used in critical care areas during mechanical ventilation and in operating rooms during anesthesia. Most of these devices have an additional filtration component aimed at protecting the patient from hospital-acquired infections. Several commercial products are available, and their general specifications and characteristics are presented in **Table 4-9**.

TABLE 4-9
Types and Specifications of Heat and Moisture Exchangers

Manufacturer	Product Name/ Number	Recommended Tidal Volume (ml)	Moisture Output (mg H_2O/L)							Resistance in cm H_2O						Filtration Efficiency		Dead Space Volume (mL)	Weight (g)
			VT = 25 mL	VT = 50 mL	VT = 100 mL	VT = 250 mL	VT = 500 mL	VT = 750 mL	VT = 1000 mL	Flow = 5 L/min	Flow = 15 L/ min	Flow = 20 L/ min	Flow = 30 L/ min	Flow = 60 L/ min	Flow = 90 L/ min	Bacterial	Viral		
ARC Medical, Inc.	ThermoFlo	250–1500	N/A	N/A	N/A	N/A	33	N/A	31	N/A	N/A	N/A	0.4	N/A	N/A	N/A	N/A	75	32
	ThermoFlo Filter	250–1500	N/A	N/A	N/A	N/A	33	N/A	31	N/A	N/A	N/A	1.2	N/A	N/A	> 99.9%	> 99.9%	75	33
	ThermoFlo Filter S	250–1500	N/A	N/A	N/A	N/A	32	N/A	30	N/A	N/A	N/A	1/2	N/A	N/A	> 99.9%	> 99.9%	75	33
	ThermoFlo Midi	150–1200	N/A	N/A	N/A	N/A	32	N/A	30	N/A	N/A	N/A	1.5	N/A	N/A	> 99.9%	> 99.9%	47	29
Covidien	DAR 352U5805	300–1500	N/A	N/A	N/A	33.9	33.3	N/A	32.4	N/A	N/A	N/A	0.9	2.1	3.6	≥ 99.999%	99.999%	90	50
	DAR 352U5877	150–1200	N/A	N/A	N/A	34.4	33.6	N/A	32.9	N/A	N/A	N/A	1	2.8	4.7	≥ 99.99%	> 99.99%	51	28
	DAR 352U5996	150–1200	N/A	N/A	N/A	34.4	33.6	N/A	32.9	N/A	N/A	N/A	1.2	2.9	5.2	≥ 99.99%	> 99.99%	61	29
	DAR 354U5876	300–1500	N/A	N/A	N/A	34.7	34.1	N/A	33.4	N/A	N/A	N/A	0.8	2.5	4.2	≥ 99.999999%	≥ 99.999%	96	49
	DAR 354U19028	200–1500	N/A	N/A	N/A	33	31.5	N/A	29.6	N/A	N/A	N/A	1.2	2.7	4.6	≥ 99.999%	≥ 99.999%	66	36
	DAR 355U5430	75–300	N/A	N/A	N/A	32.3	N/A	N/A	N/A	N/A	N/A	1.6	2.6	N/A	N/A	99.999%	> 99.99%	31	21
	DAR 355U5427	30–100	N/A	30	N/A	N/A	N/A	N/A	N/A	0.6	N/A	N/A	N/A	N/A	N/A	99.999%	> 99.99%	10	9
Galemed	HMEF 39012	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	99.99%	99.99%	N/A	N/A
	HME Compact 3485	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	99.99%	99.99%	N/A	N/A
Smiths Medical	PORTEX 002812	120–1500	N/A	N/A	N/A	N/A	31	N/A	N/A	N/A	0.22	N/A	N/A	N/A	N/A	N/A	N/A	42	21

TABLE 4-9
Types and Specifications of Heat and Moisture Exchangers

Manufacturer	Product Name/ Number	Recommended Tidal Volume (ml)	Moisture Output (mg H_2O/L)							Resistance in cm H_2O						Filtration Efficiency		Dead Space Volume (mL)	Weight (g)
			VT = 25 mL	VT = 50 mL	VT = 100 mL	VT = 250 mL	VT = 500 mL	VT = 750 mL	VT = 1000 mL	Flow = 5 L/min	Flow = 15 L/ min	Flow = 20 L/ min	Flow = 30 L/ min	Flow = 60 L/ min	Flow = 90 L/ min	Bacterial	Viral		
Smiths Medical	PORTEX 002813	900–1500	N/A	N/A	N/A	31	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A	N/A	26	18
	PORTEX 002814P	400–1500	N/A	N/A	N/A	N/A	30	N/A	27	N/A	N/A	N/A	1	3	5	N/A	N/A	70	27
	PORTEX 002815	>10	32	N/A	N/A	N/A	N/A	N/A	N/A	0.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3	3
	PORTEX 002816	200–1500	N/A	N/A	N/A	N/A	31	N/A	N/A	N/A	N/A	N/A	0.3	N/A	N/A	N/A	N/A	66	30
	PORTEX 002817P	150–1500	N/A	N/A	N/A	31	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.8	N/A	N/A	N/A	31	27
	PORTEX 002818P	90–1500	N/A	N/A	N/A	31	N/A	N/A	N/A	N/A	0.1	N/A	N/A	N/A	N/A	N/A	N/A	31	19
	PORTEX 002821	200–1500	N/A	N/A	N/A	N/A	31	N/A	N/A	N/A	N/A	N/A	1	N/A	N/A	99.9999%	99.9999%	66	31
	PORTEX 002822	90–1500	N/A	N/A	N/A	N/A	32	N/A	N/A	N/A	N/A	N/A	0.98	N/A	N/A	99.9999%	99.9999%	76	38
	PORTEX 002823P	150–1500	N/A	N/A	N/A	N/A	31	N/A	N/A	N/A	N/A	N/A	1.4	N/A	N/A	99.9999%	99.9999%	55	40
	PORTEX 002825	90–1500	N/A	N/A	N/A	31	N/A	N/A	N/A	N/A	1.1	N/A	N/A	N/A	N/A	99.9999%	99.9999%	32	18
	PORTEX 002841	400–1500	N/A	N/A	N/A	N/A	31	N/A	28	N/A	N/A	N/A	1	2	4	N/A	N/A	70	27
	PORTEX 002851P	N/A	N/A	N/A	N/A	N/A	33	N/A	26	N/A	N/A	N/A	1	2.2	4	> 99.9%	> 99.9%	103	52
	PORTEX 002865	N/A	N/A	N/A	N/A	N/A	25	N/A	17	N/A	N/A	N/A	1	2.2	4	> 99.9%	> 99.9%	32	20

(*continues*)

TABLE 4-9
Types and Specifications of Heat and Moisture Exchangers (*Continued*)

Manufacturer	Product Name/ Number	Recommended Tidal Volume (ml)	Moisture Output (mg H_2O/L)							Resistance in cm H_2O						Filtration Efficiency		Dead Space Volume (mL)	Weight (g)
			VT = 25 mL	VT = 50 mL	VT = 100 mL	VT = 250 mL	VT = 500 mL	VT = 750 mL	VT = 1000 mL	Flow = 5 L/min	Flow = 15 L/ min	Flow = 20 L/ min	Flow = 30 L/ min	Flow = 60 L/ min	Flow = 90 L/ min	Bacterial	Viral		
Smiths Medical	PORTEX 002866	N/A	N/A	N/A	N/A	N/A	27	N/A	24	N/A	N/A	N/A	1	2.2	4	> 99.9%	> 99.9%	67	46
	PORTEX 580021	N/A	N/A	N/A	N/A	N/A	N/A	N/A	25	N/A	N/A	N/A	N/A	1.2	N/A	N/A	N/A	32	18.6
Teleflex	Gibeck 19912	250–1500	N/A	N/A	N/A	N/A	N/A	N/A	30.4	N/A	N/A	N/A	N/A	1.5	N/A	N/A	N/A	57	43
	Gibeck 10011	15–50	30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A	N/A	2.4	4.5
	Gibeck 11112	50–600	N/A	N/A	N/A	30	N/A	N/A	N/A	N/A	N/A	0.3	N/A	N/A	N/A	N/A	N/A	14	11.6
	Gibeck 13312	150–1500	N/A	N/A	N/A	N/A	27	N/A	N/A	N/A	N/A	N/A	N/A	0.8	N/A	N/A	N/A	29	20.9
	Gibeck 17731	250–1500	N/A	N/A	N/A	N/A	27	N/A	N/A	N/A	N/A	N/A	N/A	0.8	N/A	N/A	N/A	54	26.4
	Gibeck 11012	50–250	N/A	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A	1.4	N/A	N/A	N/A	N/A	N/A	13	14.5
	Gibeck 18502	150–1000	N/A	N/A	N/A	N/A	30	N/A	N/A	N/A	N/A	N/A	2.1	N/A	N/A	N/A	N/A	27	22
	Gibeck 18402	150–1000	N/A	N/A	N/A	N/A	N/A	N/A	30	N/A	N/A	N/A	N/A	1.8	N/A	N/A	N/A	38	32.3
	Gibeck 18832	250–1500	N/A	N/A	N/A	N/A	N/A	N/A	31	N/A	N/A	N/A	N/A	2	N/A	N/A	N/A	60	30
Vital Signs (GE)	HMEF 1000	300–1000	N/A	N/A	N/A	N/A	33	32	30	N/A	N/A	N/A	1	2.3	N/A	99.9999%	99.99%	77	24
	HMEF 750	120–750	N/A	N/A	N/A	32	30	27	N/A	N/A	N/A	N/A	0.9	2.2	N/A	99.9999%	99.998%	34	17
	HMEF 500	120–500	N/A	N/A	N/A	31	30	N/A	N/A	N/A	N/A	N/A	1.5	3.3	N/A	99.999%	99.98%	30	15
	HMEF Mini	60–500	N/A	N/A	N/A	31	27	N/A	N/A	N/A	N/A	N/A	1.4	3.2	N/A	99.999%	99.98%	21	14
Westmed	6218	150–1000	N/A	N/A	N/A	N/A	28.4	N/A	N/A	0.48	N/A	N/A	2.7	N/A	N/A	99.99%	99.99%	21.3	N/A
	6219	150–1000	N/A	N/A	N/A	N/A	28.8	N/A	N/A	N/A	N/A	N/A	0.22	N/A	N/A			19.7	N/A
	6220	150–1000	N/A	N/A	N/A	N/A	29.2	N/A	N/A	N/A	N/A	N/A	2.5	N/A	N/A	99.99%	99.99%	19.7	N/A
	6221	350–1500	N/A	N/A	N/A	N/A	32.1	N/A	N/A	N/A	N/A	N/A	1.3	N/A	N/A	99.99%	99.99%	69	N/A
	6229	150–1000	N/A	N/A	N/A	N/A	28.4	N/A	N/A	0.35	N/A	N/A	N/A	N/A	N/A			21.3	N/A
	6379	350–1500	N/A	N/A	N/A	N/A	32.1	N/A	N/A	N/A	N/A	N/A	1.3	N/A	N/A	99.99%	99.99%	69	N/A

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