Humidity and Bland Aerosol Therapy

Chapter 6

Learning Objectives

- Describe how airway heat and moisture exchange normally occur.
- State the effect of breathing dry gases
- Describe how various types of humidifiers work.
- Describe how to enhance humidifier performance.
- State how to select and safely use humidifier heating and feed systems.
- Identify the indications, contraindications, and hazards of humidity therapy
- Describe how to monitor patients receiving humidity therapy.
- Describe how to identify and troubleshoot common problems with humidification systems.

Outline for Humidity Therapy

- Humidity Therapy
- Physiologic control of heat and moisture exchange
- Indication for humidification
- Types of humidifiers
- Problem solving and trouble shooting for humidification
- Selecting the appropriate system

Humidity

- Water that exists in the form of individual molecules in the vaporous or gaseous state.
- Water vapor exerts pressure that results from the continuous random movement of water molecules (P_{H2O}=47 mm Hg at sea level).
- Humidity usually described in terms of an *absolute humidity* or *relative humidity.*
- Humidity can be measured with *a hygrometer.*

Humidity Therapy (cont.)

- Absolute humidity
  - Amount of water in given volume of gas; its measurement is expressed in mg/L or gm/m^3
- Relative humidity
  - Ratio between amount of water in given volume of gas & maximum amount it is capable of holding at that temperature
  - Expressed as percentage & is obtained with hygrometer

  Relative humidity =Content(absolute humidity)/Water capacity x 100

Relative Humidity (Cont.)

TABLE 6-1 Absolute Humidity and Water Vapor Pressure at Various Temperatures when the Gas Is Saturated with Water

Temperature (°C)	Absolute Humidity (mg/L)	Water Vapor Pressure (mm Hg)
19	16.3	16.5
20	17.3	17.5
21	18.4	18.6
22	19.4	19.8
23	20.6	21.0
24	21.8	22.3
25	23.0	23.7
26	24.4	25.1
27	25.8	26.7
28	27.2	28.3
29	28.8	29.9
30	30.4	31.7
31	32.0	33.6
32	33.8	35.5
33	35.6	37.6
34	37.6	39.8
35	39.6	42.0
36	41.7	44.4
37	43.9	46.9
38	46.2	49.5
39	48.6	52.3
40	51.1	55.1
41	53.7	58.1

Humidity Therapy (cont.)

- Body Humidity
  - Relative humidity at body temperature & is expressed as percentage
  - Capacity of water at body temperature is 44mg/L

  Body humidity = absolute humidity/ 44mg/L x 100

- Humidity deficit
  - Inspired air that is not fully saturated at body temperature
  - Deficit is corrected by body's own humidification system

  Humidity deficit = 44 mg/L – absolute humidity

Actual water content (absolute humidity) of a sample of room air is measured with a hygrometer and is found to be 12 mg/L. if the room air temperature is 20° C (68° F).

What is the relative humidity?

TABLE 21-2 **Humidity terms and their mathematical expressions**

Term	Definition	Mathematical Expression
Absolute humidity	The actual amount of water vapor in a gas	Content = mg/L Pressure = mm Hg
Relative humidity	The actual amount of water vapor in a gas compared with the amount necessary to cause 100% saturation, multiplied by 100	$\%RH = \frac{AH}{\text{capacity}} \times 100$
Body humidity	The absolute humidity of inspired gas saturated at body temperature	$\%BH = \frac{AH}{\text{capacity at } 37°C} \times 100$
Humidity deficit	The difference (usually in mg/L) between the water vapor content of gas at BTPS (fully saturated air at normal body temperature and pressure) and the water vapor content of inspired gas	Humidity deficit = BH – AH

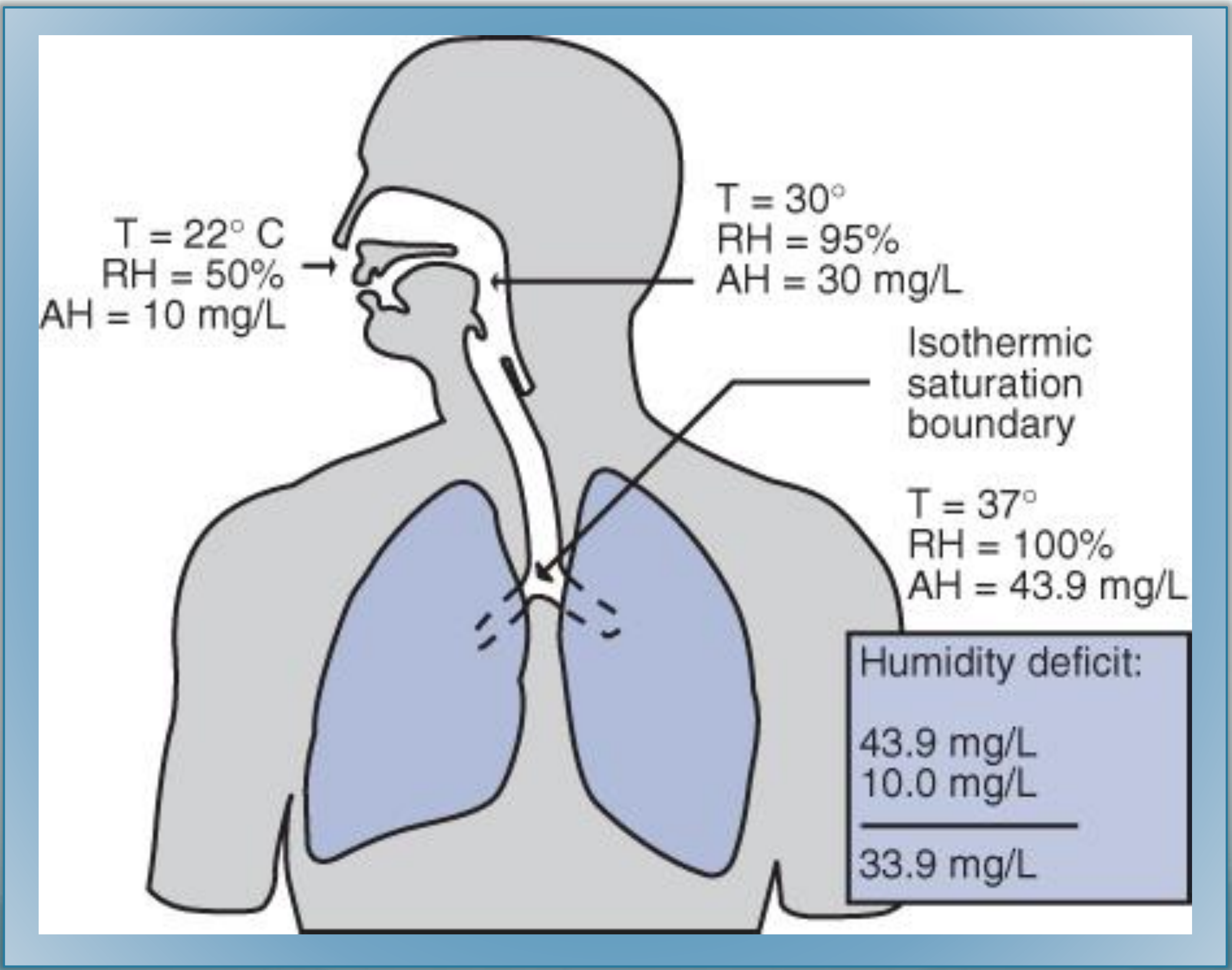
Humidity Therapy

- Adding Water vapor to inspired gas
- Physiologic control of heat & moisture exchange
  - Heat & moisture exchange is primary role of upper airway, mainly nose
    - Nose heats & humidifies gas on inspiration & cools & reclaims water from gas that is exhaled
  - BTPS conditions
    - Body temperature at 37° C; barometric pressure; saturated with water vapor [100% relative humidity at 37° C]
    - As gas travels through the lungs it achieves BTPS
    - Normally ~5 cm below carina is isothermic saturation boundary (ISB)

Humidity Therapy

- Isothermic saturation boundary
  - Above ISB, temperature & relative humidity decrease during inspiration & increase during exhalation
  - Below ISB, temperature & relative humidity remain constant
  - ISB shifts deep WHEN…
    - person breathes cold, dry air
    - airway is bypassed (breathing through an artificial airway)
    - minute ventilation is higher than normal
  - Shifts of ISB can compromise body's normal heat & exchange mechanisms
    - humidity therapy may be indicated

Humidity Therapy (cont.)



What is the term for inspired air that is not fully saturated at body temperature?

A. relative humidity
B. absolute humidity
C. humidity deficit
D. body humidity

Humidity Therapy (cont.)

- Indications for humidification & warming of inspired gases:

1. Administration of dry medical gases at flows greater than 4 L/min.
2. Overcoming humidity deficit created when upper airway is bypassed, such as after endotracheal intubation
3. Managing hypothermia
4. Treating bronchospasm caused by cold air

Signs of Inadequate Humidification

BOX 6-2	Clinical Signs and Symptoms of Inadequate Airway Humidification

- Atelectasis
- Dry, nonproductive cough
- Increased airway resistance
- Increased incidence of infection
- Increased work of breathing
- Substernal pain
- Thick, dehydrated secretions

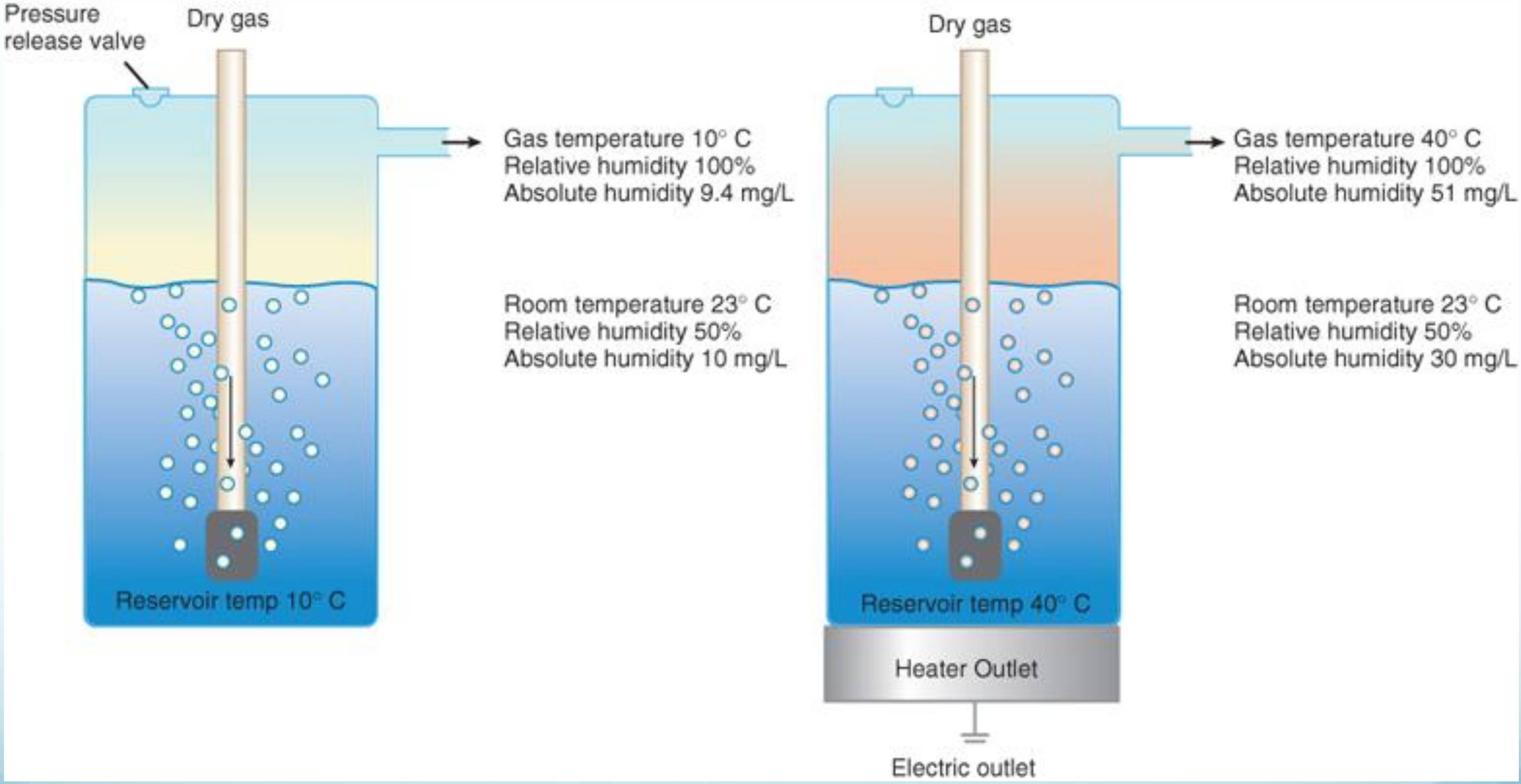
Humidity Therapy

- Pulmonary patients need:
  - adequate humidification of their inspired gases
  - controlled fluid balance
  - otherwise patients can become dehydrated.
- Dehydration can make secretions more viscous and inhibit the mucociliary escalator activity of the airways, making secretions difficult to dislodge.
- If these secretions block functional gas flow through the distal airways infections, atelectasis and other respiratory problems can easily occur.

Equipment (cont.)

- Physical principles governing humidifier function:
  - Temperature – the higher the temperature of gas, the more water it can hold
  - Surface area – affects rate of evaporation
  - Time of contact – evaporation increases as contact time increases
  - Thermal mass - the greater the amount of water in humidifier, the greater the thermal mass & capacity to hold & transfer heat to therapeutic gas

Equipment (cont.)



Types of Humidifiers

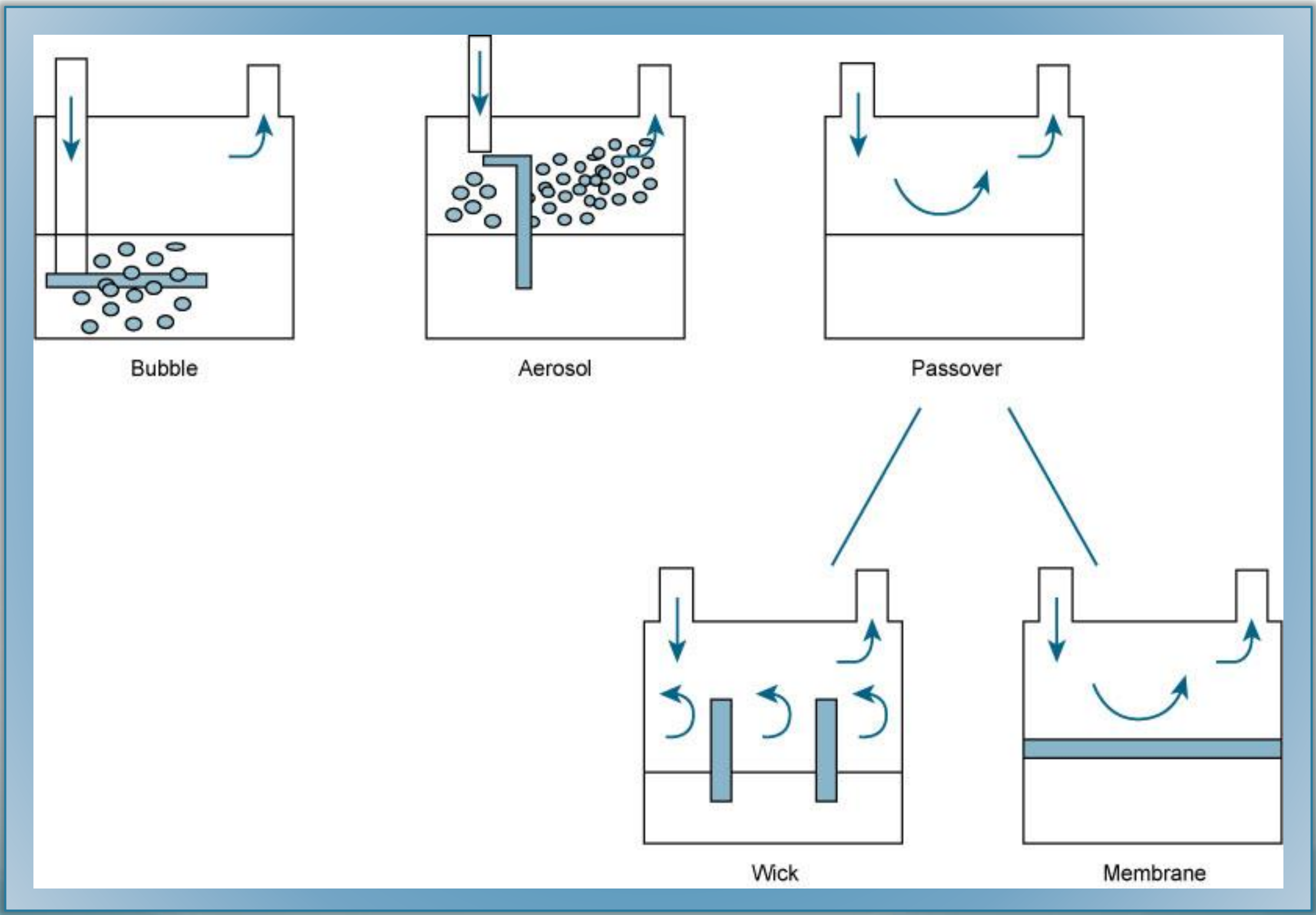
- Humidifiers are either ***active*** (actively adding heat or water or both to the device-patient interface) or ***passive*** (recycling exhaled heat and humidity from the patient).

- Active humidifiers typically:

1. bubble humidifiers
2. passover humidifiers
3. nebulizers of bland aerosols.

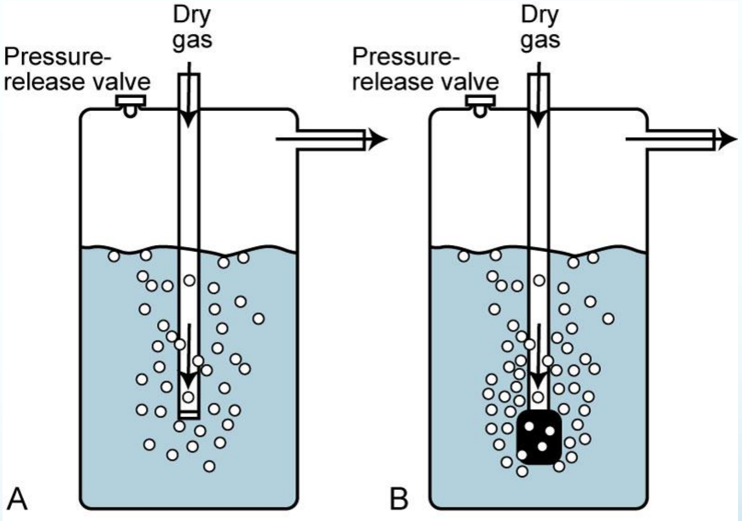
- Passive humidifiers refer to typical **heat and moisture exchangers (HMEs).**

Types of Humidifiers



Types of Active Humidifiers

1. Bubble humidifiers
   - Gas passes through tube to bottom of water reservoir
   - Use of foam or mesh diffuser produces smaller bubbles than open lumen, allowing greater surface area for gas/water interaction
   - Usually used unheated with oxygen delivery systems to raise water vapor content of gas to ambient levels
   - Includes simple pressure relief valve, or pop off to warn of flow-path obstruction & to prevent bottle from bursting
   - Can produce aerosols at high flow rates
     - Poses risk of infections



Bubble Humidifier (Cont.)

Types of Active Humidifiers

2. Passover
   - directs gas over water surface
   - Three types
     1. Simple reservoir type
     2. Wick type
     3. Membrane type
   - Advantages over bubble humidifier:
     - Maintains saturation at high flow rates
     - Add little or no flow resistance to spontaneous breathing circuits
     - Do not generate any aerosols that can spread infection

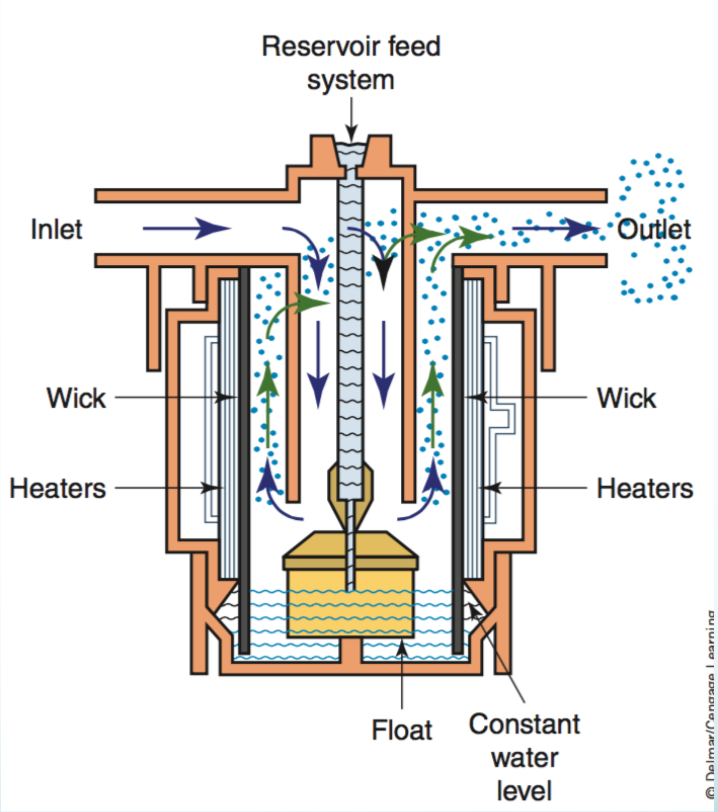
Passover Humidifiers (Cont.)c

1. Simple reservoir
   - Gas flows over surface of volume of water
   - Usually used as heated system to provide humidity to mechanically ventilated patients

Passover Humidifiers (Cont.)

2. Wick humidifier

- Wick placed upright with the gravity dependent end in a heated water reservoir
- Heating elements might be below or surrounding the wick
- Gas passes over or through water saturated material
- Uses an absorbent material to increase the surface area for dry air to interface with heated water
- Usually heated system used with mechanical ventilation
- No bubbling occurs, so no aerosol is produced.



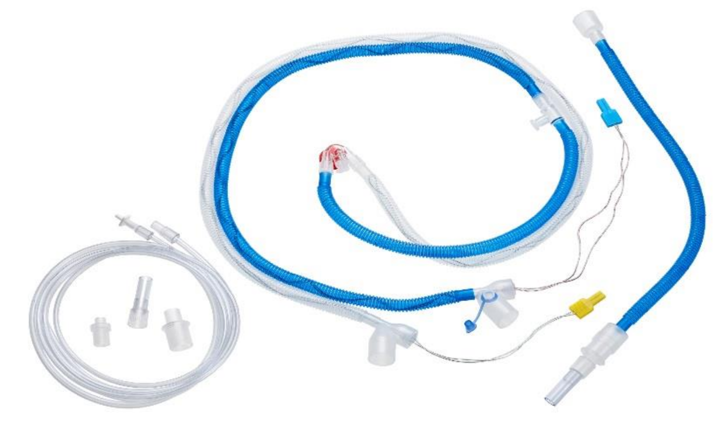
Passover Humidifiers (Cont.)

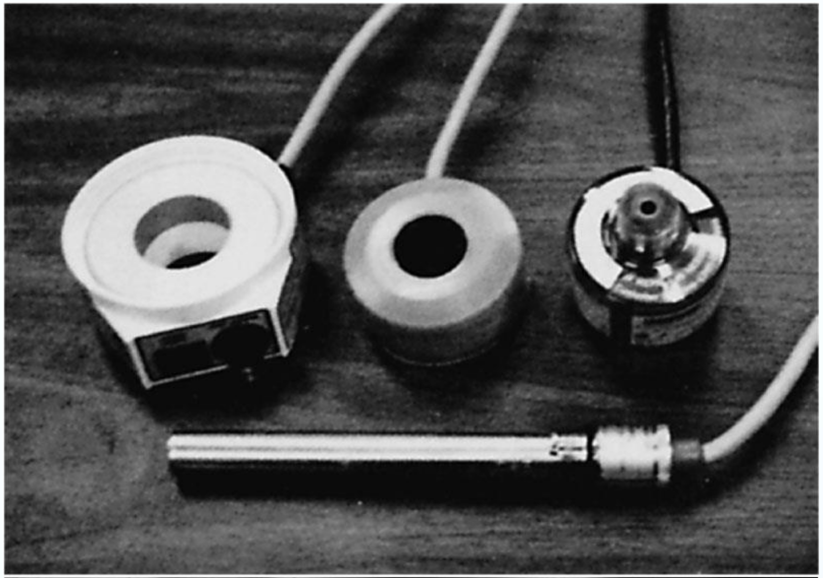
3. Membrane type

- Separates water from gas stream by means of hydrophobic membrane
- Water vapor molecules can easily pass through this membrane, but liquid water (and pathogens) cannot.
- bubbling does not occur.
- If a membrane-type humidifier were to be inspected while it was in use, no liquid water would be seen in the humidifier chamber.

Humidifier Heating Systems

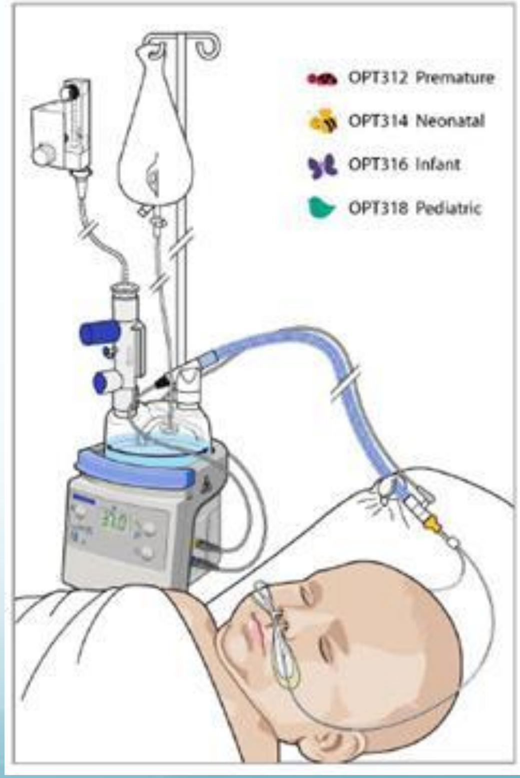
- Types of heating elements::
  - Hot plate
  - Wraparound element
  - Yoke (collar)
  - Immersion heater
  - Heated wire in inspiratory line
  - Thin film, high surface area boiler





Reservoir and Feed System

- Manual system
  - Humidifier is opened for filling
  - Mechanical ventilation is interrupted
  - Increased risk of cross contamination
- Gravity feed system
  - Gravity fed system uses float to maintain preset amount of water in reservoir



Setting Humidification Levels

- At least 30 mg/L of humidity is recommended for intubated patients
- Humidifiers should provide optimal levels of humidity in inspired gas
- Some experts recommend heating inhaled gas to maintain airway temperatures near 35-37 ºC

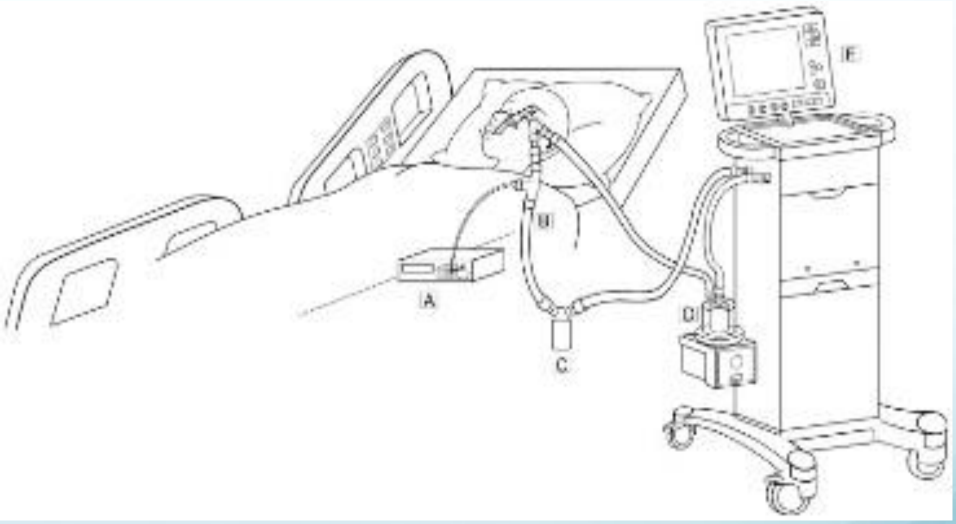
Problem Solving & Troubleshooting

1. Condensation: gas cools as it leaves the point of humidification

- Factors that affect amount of condensate:
  1. Temperature difference across system
  2. Ambient temperature
  3. Gas flow
  4. Set airway temperature

- Complications of condensation:
  - Poses risks to patient & caregivers
  - Can waste a lot of water
  - Can occlude gas flow through circuit
  - Can be aspirated

- Problem can be minimized by:
  - use water traps
  - heated circuits
  - positioning circuits so it drains condensate away from patient,
  - checking humidifier & nebulizer often



Problem Solving & Troubleshooting (cont.)

2. Cross-contamination
   - Water in circuit can be source of bacterial colonization
   - Minimizing condensation is helpful to reduce risk of colonization
   - Wick-or membrane type passover humidifiers prevent formation of bacteria-carrying aerosols
   - HMEs have low risk of causing infection
   - Frequently changing circuit is not needed to reduce chance of nosocomial infection

Problem Solving & Troubleshooting (cont.)

3. Proper conditioning of Inspired Gas
   - RT's role
     - Ensure proper conditioning of inspired gas received by patients by:
       - Regularly measuring patients' inspired FiO_2 levels
       - Providing ventilatory care & monitoring selected pressures, volumes, & flows
       - Using hygrometer-thermometer system

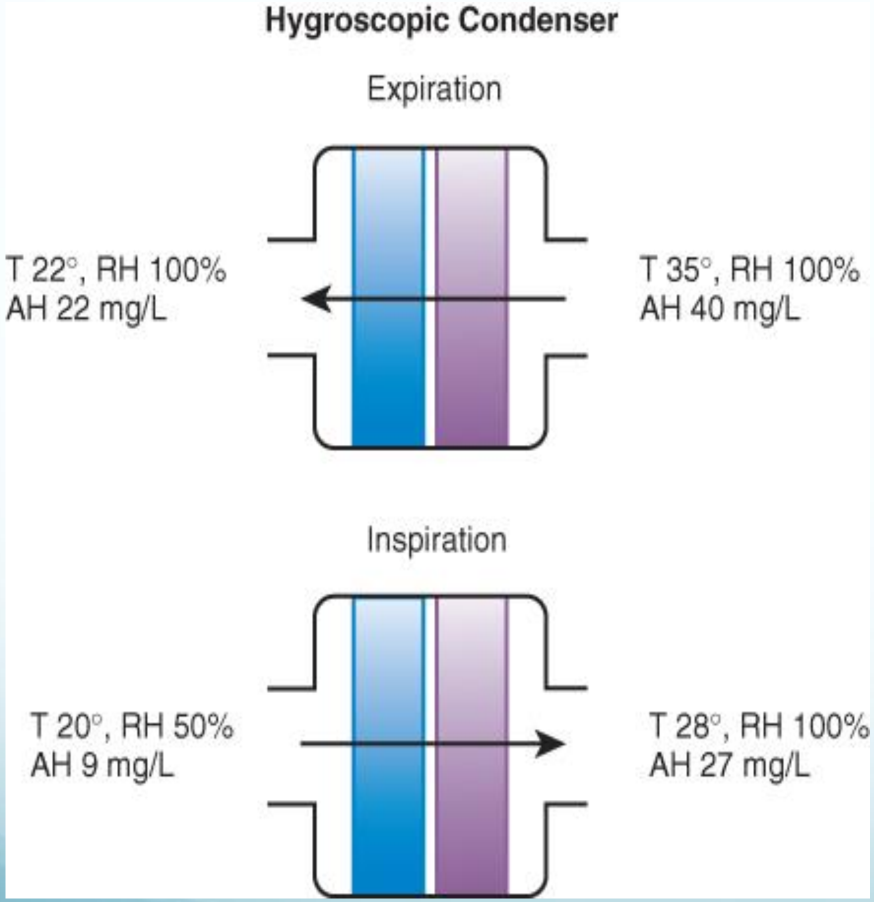
Common problems with humidification systems include all of the following, except:

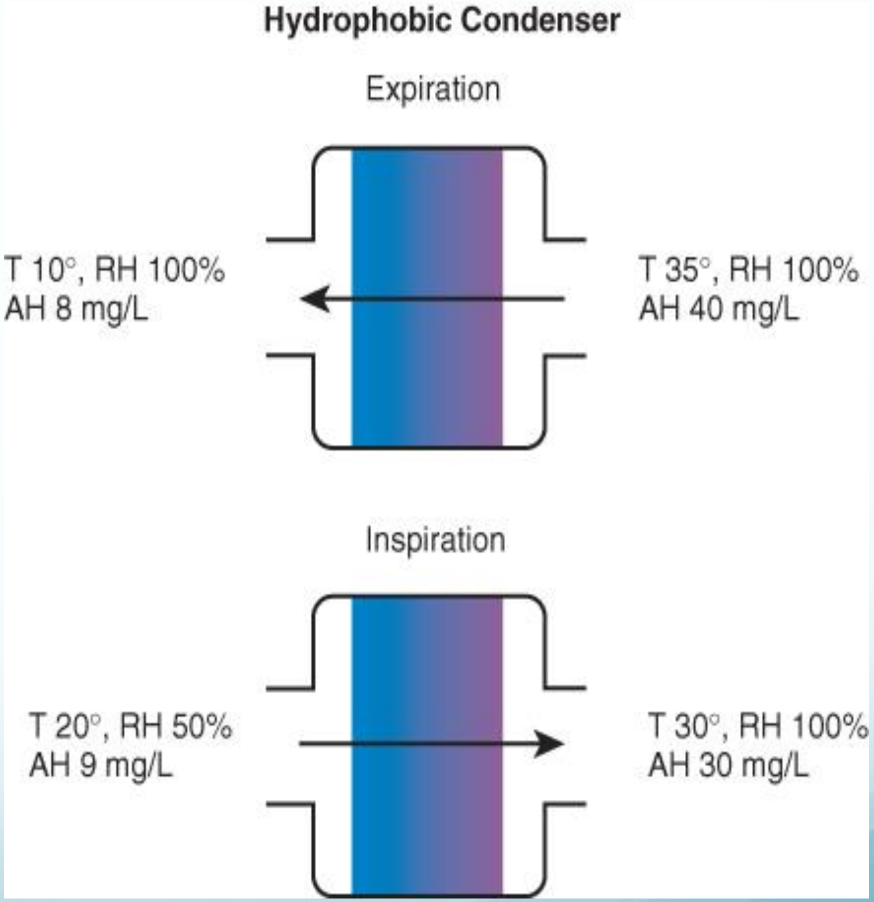
A. dealing with condensation
B. avoiding cross contamination
C. ensuring proper conditioning of inspired gas
D. hypothermic interpretation

Types of Humidifiers (cont.)

3. Heat-moisture exchangers (HMEs)
   - Often passive humidifier that has been described as "artificial nose"
   - Does not add heat or water to system
   - Captures exhaled heat & moisture, which is then applied to subsequent inhalation
   - Has been used to provide humidity for spontaneously and mechanically ventilated patients
   - Types of HMEs
     1. Simple condenser humidifiers
     2. Hygroscopic condenser humidifiers
     3. Hydrophobic condenser humidifiers
   - Adds 30-90 mL of dead space

Types of Humidifiers (cont.)





Heat Moisture Exchanger (Cont.)

- Simple condenser humidifier
  - Contains condenser element with high thermal conductivity (metallic gauze) with/without fibrous element
  - Retains about < 50% of expired heat and humidity
  - Maximum absolute humidity is 18 to 28 mg/L

Heat Moisture Exchanger (Cont.)

- Hygroscopic heat exchanger
  - Uses condenser element low thermal conductivity made of paper, wool, or foam
  - Material includes a hygroscopic salt
  - It achieves approximately 70% efficiency
  - Maximum absolute humidity is 22 to 34 mg/L

Heat Moisture Exchanger (Cont.)

- Hydrophobic heat exchanger
  - Uses water repellent element with a large surface area and low thermal conductivity
  - The efficiency of these devices is comparable to hygroscopic condenser humidifiers (approximately 70%)

Types of Humidifiers (cont.)

- Active HMEs
  - Humid-Heat
    - Absorbs expired heat & moisture & releases it into inspired gas
    - Consists of supply unit with microprocessor, water pump, & humidification device
    - Capable of providing 100% relative humidity at BTPS
- HME Booster
    - Designed for patients with minute volumes of 4-20L
    - Not appropriate for pediatric patients & infants
    - Consists of T-piece containing electrically heated element

Contraindications for HMEs

- Increased volume of secretions
- Thick or dehydrated secretions
- Hypothermia
- Large tidal volumes (>700 mL)
- Small tidal volumes (HME volume >30% of tidal volume)
- Uncuffed endotracheal tube
- Large leak around endotracheal tube
- Exhaled tidal volume <70% of inspired tidal volume
- Administration of aerosol drug therapy
- HME cannot be used with heated humidification

Which humidifier can deliver gas at 100% body humidity?

A. wick humidifier
B. passover humidifier
C. bubble humidifier
D. HME

Learning Objectives

- Differentiate between the physical properties of aerosol and humidity
- State when to apply bland aerosol therapy.
- Describe how large-volume aerosol generators work.
- Identify the delivery systems used for bland aerosol therapy.
- Describe how to identify and resolve common problems with aerosol delivery systems.
- Describe how to perform sputum induction.
- State how to select the appropriate therapy to condition a patient's inspired gas.

Bland Aerosol Therapy

- Bland aerosol consists of liquid particles suspended in gas (oxygen or air), it contains actual droplets of liquid water
- Humidity is water is the gas phase
- Variety of liquids may be used
  - Sterile water
  - Sterile saline
    - hypotonic
    - isotonic
    - Hypertonic
- CPG for bland aerosol administration.

Bland Aerosol Therapy

- Devices used to generate bland aerosol include:
  - Large volume jet nebulizers
  - Ultrasonic nebulizers.

- Aerosol delivery systems can include a variety of direct airway appliances such as:
  - Aerosol face masks
  - Tracheostomy masks
  - Face tents
  - Enclosures such as mist tents or hoods

Large-Volume Jet Nebulizers

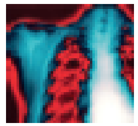
- Most common device used for bland aerosol therapy
- Pneumatically powered & connected directly to flowmeter & compressed gas source
- Unheated large-volume nebulizers can produce 26 to 35 mg H_2O/L
- Heated nebulizers can produce 35 to 55 mg H_2O/L
  - Mainly due to increased vapor capacity
- Variable air-entrainment port allows air mixing to increase flow rates & to alter FiO_2 levels
- Operate at flow of 6 to 15 LPM with various level of FiO_2

- Jet nebulizers should be treated as fixed performance devices only when set to deliver low O_2 concentration (≤35%).
- When a nebulizer is used to deliver a higher concentration of O_2, the RT must determine whether the flow is sufficient to meet patient needs.

1. simple visual inspection
2. compare it with the patient’s peak inspiratory flow.
   - A patient’s peak inspiratory flow during tidal breathing is approximately three times MV

MINI CLINI

Computing Minimum Flow Needs



PROBLEM: A physician orders 40% O_2 through an air-entrainment nebulizer to a patient with a tidal volume of 0.6 L and a respiratory rate of 33 breaths/min. If maximum nebulizer input flow is 12 L/min, will the patient receive 40% O_2? If not, what total flow is needed to meet this patient's needs?

SOLUTION:

1. Estimate the patient's inspiratory flow:

$$\text{Peak inspiratory flow} = \dot{V}_E \times 3 = (0.6 \times 33) \times 3 = 59.4\ \text{L/min}$$

2. Compute the total flow of the nebulizer:

$$\text{Sum of ratio parts } (3:1) \times \text{Input flow } (12\ \text{L/min}) = 48\ \text{L/min}$$

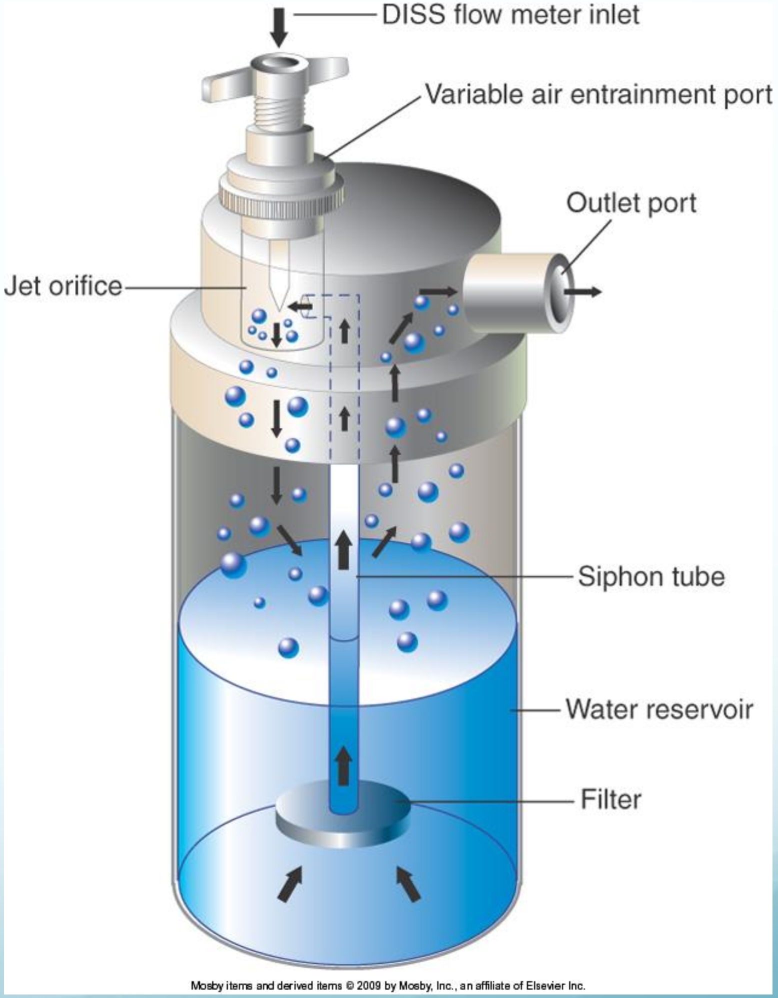
3. Compare value 1 with value 2 (patient with nebulizer):

$$59.4\ \text{L/min (patient)} > 48\ \text{L/min (nebulizer)}$$

Under these conditions, the patient does not receive 40% O_2. To deliver a stable 40% O_2 concentration, the total flow would have to be at least 59.4 L/min.

Large-Volume Jet Nebulizers (cont.)

- Mechanism
  - Liquid particles are generated by passing gas at high velocity through small jet orifice
  - Low pressure at jet draws fluid from reservoir up siphon tube
  - Water is then shattered into liquid particles
  - Smaller particles leave nebulizer through outlet port in gas stream



Large-Volume Jet Nebulizer

Troubleshooting AE Systems

The major problem with air-entrainment systems is

1. Providing Moderate to High FiO2 at High Flow..

- Most AEMs can be set to deliver no more than 50% O2.

Box 38-2 **Increasing FiO_2 Capabilities of Air-Entrainment Nebulizers**

- Add open reservoir to expiratory side of T tube
- Provide inspiratory reservoir with one-way expiratory valve
- Connect two or more nebulizers together in parallel
- Set nebulizer to low concentration; bleed-in O_2; analyze and adjust
- Use a commercial dual-flow system

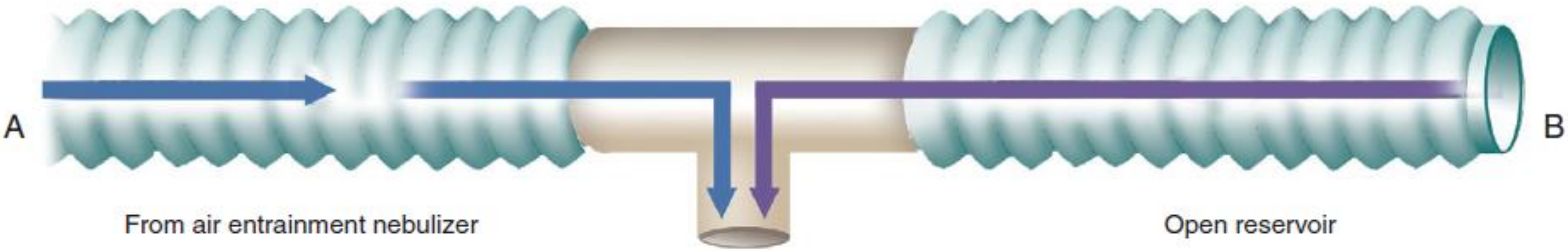


FIGURE 38-17 Use of an open volume reservoir to enhance delivered O_2 concentration with a T tube. From 50 to 150 ml of aerosol tubing is connected to the expiratory side of the T tube. **A,** When the patient inhales, gas at the set FiO_2 is drawn first through the inspiratory side of the circuit. **B,** If the patient's flow exceeds nebulizer flow, gas is drawn from the reservoir side. After the reservoir volume is fully tapped, room air is entrained, and FiO_2 decreases.

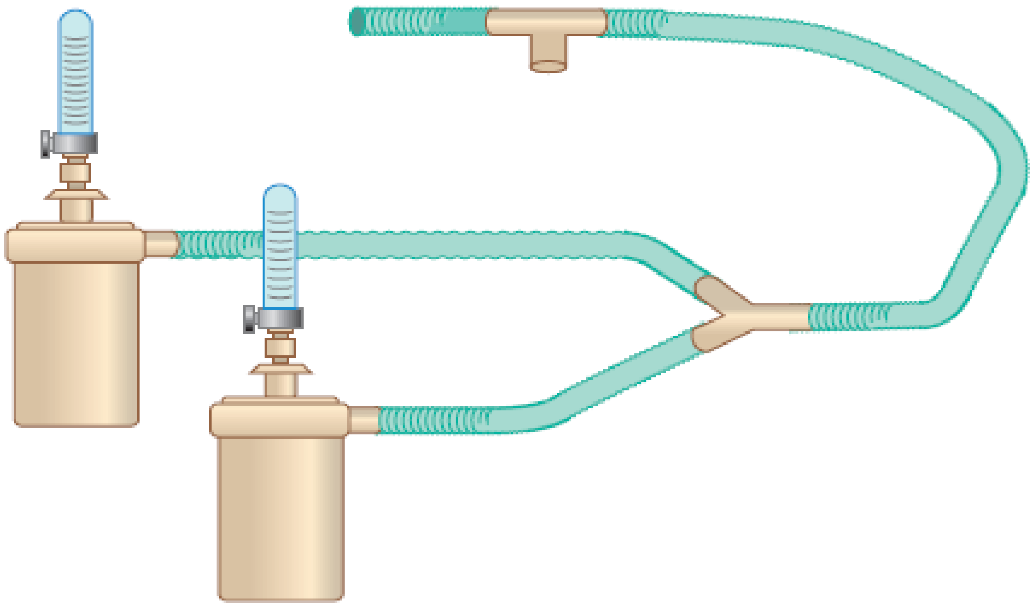


FIGURE 38-18 Use of two nebulizers in parallel to provide high FiO_2 at high flow.

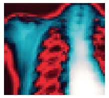
Troubleshooting AE Systems

2. Downstream Flow Resistance

- ↑ downstream flow resistance causes backpressure
  - ↑ O_2 concentration increases
  - ↓ the total flow output of these devices.
- High downstream flow resistance usually turns AE systems from fixed O_2 delivery systems into variable O_2

MINI CLINI

Effect of Downstream Flow Resistance on Performance of an Air-Entrainment Device

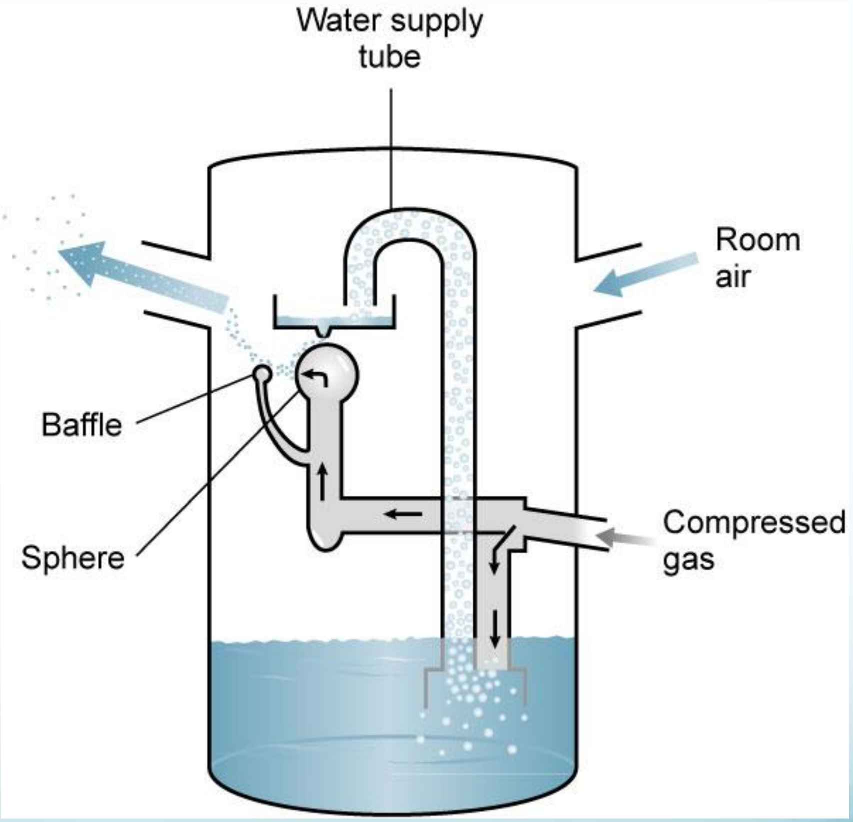


PROBLEM: A tracheostomy patient is receiving O_2 therapy through a T tube attached to an air-entrainment nebulizer set at 35% O_2 with an input flow of 10 L/min. Over the past 30 minutes, the patient's SpO_2 has decreased from 93% to 88%. When assessing the patient, the RT finds that the large-bore delivery tubing of the nebulizer is partially obstructed with condensate and that aerosol mist at the T tube is not visible throughout inspiration. What is the likely problem, and what is the best solution?

SOLUTION: The likely problem is a decrease in FiO_2 owing to the increased downstream resistance caused by the condensate. At 10 L/min input flow, the device was probably delivering approximately 60 L/min of 35% O_2 before the tubing became obstructed. Because aerosol mist is not visible at the T tube throughout inspiration, it is clear that the total output flow is no longer sufficient and that the patient is now diluting the delivered O_2 with room air. Draining the tubing restores the system flow and ensures delivery of the set FiO_2.

Babington Nebulizers

- Fluid is spread over glass sphere surface, struck by gas passes through hole in sphere
- These devices usually produces aerosol with relatively:
  - High aerosol output
  - Small particle size

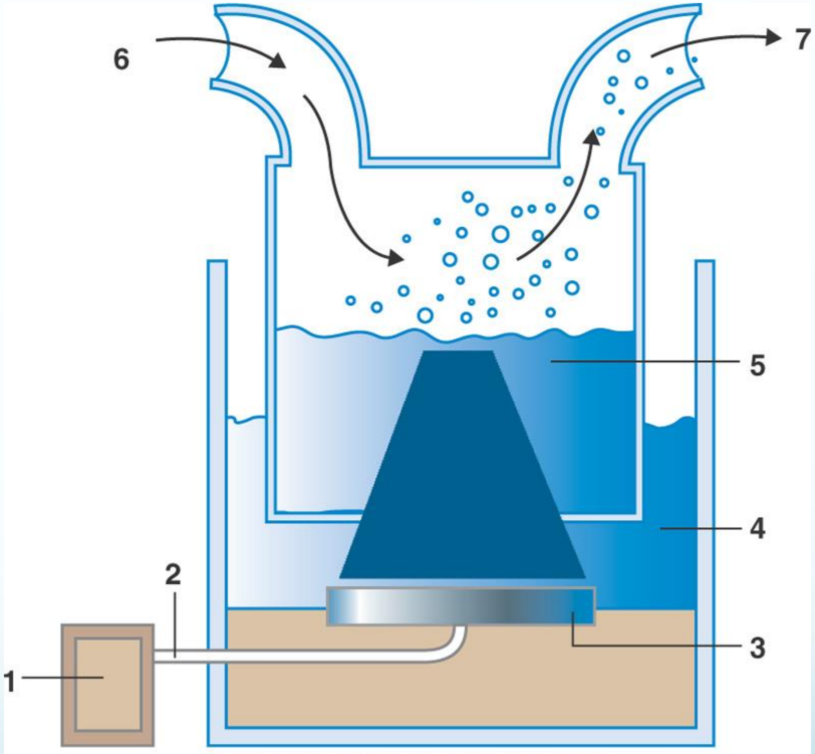


Spinning Disk Devices

- Also referred to as centrifugal nebulizer
- Mechanical aerosol generator
- Operates on the principle of spinning disk with a hollow shafts draws liquid from the reservoir
- Used to produce high-density aerosol
- Most common application is home use

Ultrasonic Nebulizers (USN)

- Electrically powered device that uses piezoelectric crystal to generate aerosol
- Crystal transducer converts radio waves into high-frequency mechanical vibrations that produce aerosol
- Several applications:
  - Room humidifiers
  - Sputum induction
  - Medication administration



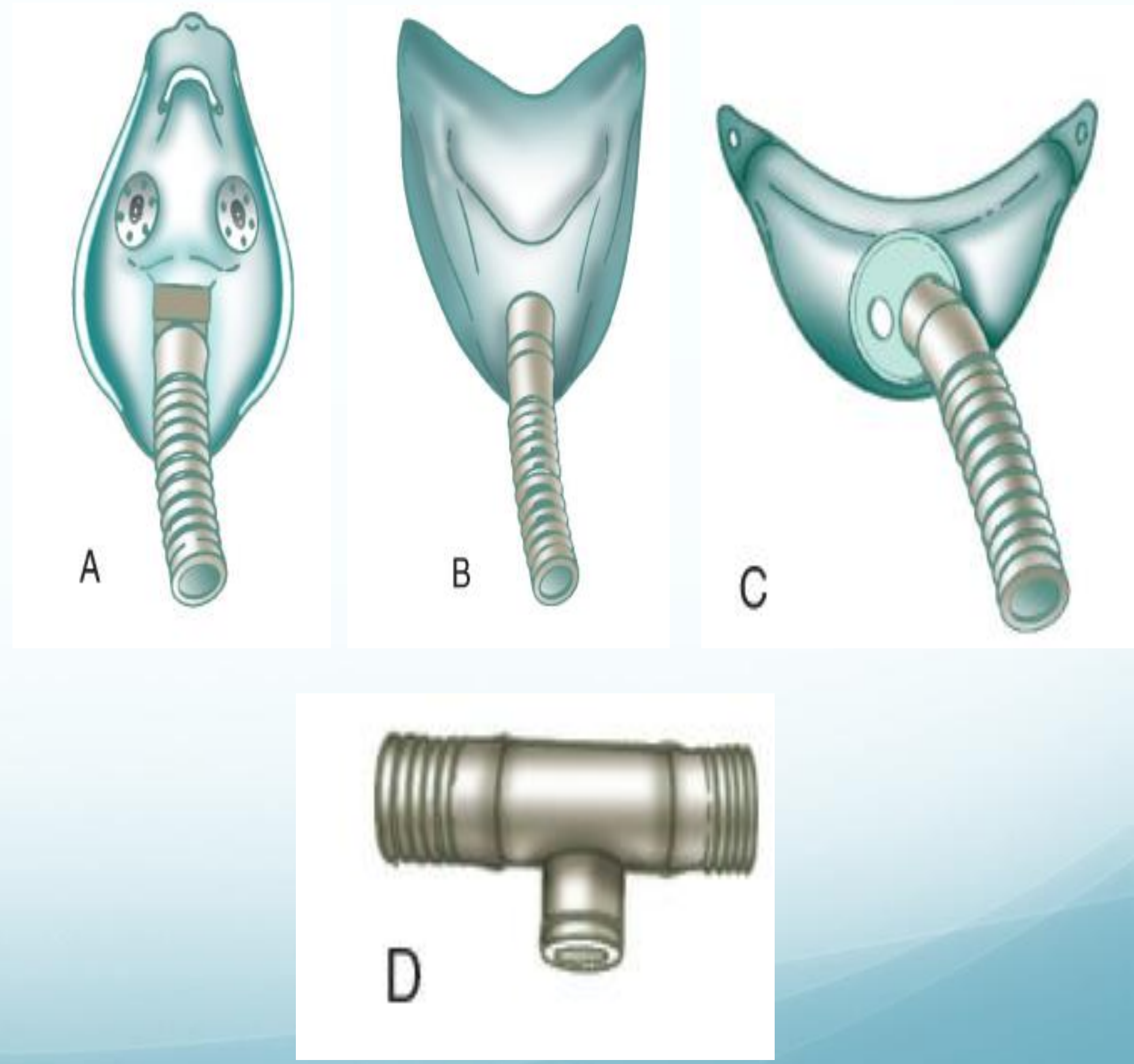
(Modified from Barnes TA: Core textbook for respiratory care practice, ed 2, St Louis, 1994, Mosby.)

Ultrasonic Nebulizers

- The frequency (preset) determines aerosols particle size
- Particle size is inversely proportional to signal frequency.
  - USN operating at a frequency of 2.25 MHz may produce an aerosol with MMAD of 2.5 µm
  - USN with frequency of 1.25 MHz produces MMAD of 4-6 µm
- Signal amplitude (adjustable) directly affects volume of aerosol output
  - ↑ amplitude>>> ↑ the volume of aerosol output
- Flow & amplitude settings interact to determine aerosol density (mg/L) & total water output (mL/min)

Airway Appliances (Interface)

- Types
  - Aerosol mask
  - Face tent
  - T-tube
  - Tracheostomy mask
- All used with large-bore tubing to minimize flow resistance & prevent occlusion by condensate



Enclosures (Mist Tents & Hoods)

- Used to deliver aerosol therapy to infants & children
- Poses problems
  - Heat retention
    - Handled differently by each manufacturer
    - Maxicool use high fresh-gas flows
    - Others may use separate cooling device
  - CO_2 buildup in tents
    - High flows of fresh gas circulating continually through tent help “wash out” CO_2 & reduce heat buildup

Problem Solving & Troubleshooting

- Problems with bland aerosol therapy

1. Cross-contamination and infection
   - Adhere to infection control guidelines
2. Environmental exposure
   - Follow Centers for Disease Control & Prevention standards & airborne precautions
3. Inadequate mist production
   - Check electrical power supply, carrier gas is actually flowing through device, amplitude control, & couplant chamber

Problem Solving & Troubleshooting (cont.)

- Problems with bland aerosol therapy (cont.)
  4. Overhydration
     - Prevention by careful patient selection & monitoring is key
  5. Bronchospasm
     - Treatment must be stopped immediately & provide oxygen
  6. Noise

The main usage for bland aerosol therapy include all of the following, except:

A. treat upper airway edema
B. overcome heat and humidity deficits
C. help obtain sputum specimens
D. provide adequate mist production

Sputum Induction

- Cost-effective, safe method for diagnosing tuberculosis, *Pneumocystis carinii* (aka *P. jiroveci)*, pneumonia, & lung cancer
- Involves short-term application of high-density hypertonic saline (3% to 10%) aerosols to airway
  - Aids in mucociliary clearance
  - High-density aerosols are most easily generated by using ultrasonic nebulization

Selecting the Appropriate Therapy