MEDICAL GAS SYSTEMS

The Definitive Guide

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Introduction

Most people think of the medical gas system as oxygen that is pumped to patients in surgery or in their hospital room. In fact, there are several gases that make up the average medical gas system including the anesthesia gases that are part of the cart in the operating room.

Medical gas systems sustain life and are regulated as a drug. This means multiple layers of restrictions and instruction on the proper, safe and legal way to do things.

According to CBC News, the first recorded medical gas cross connection deaths were at a former Sudbury General Hospital in Canada back in 1973. The outcome of this tragic event was the evolution of a code requiring 3rd party verification and later installer certifications.

The concern for patients and the efficiency of hospitals has led to several layers of oversight of medical gas systems from the government (CMS and OSHA) their agents (TJC and NPV) and the industry in the NFPA 99-2012 code. While all these organizations have oversight and regulatory power over medical sites using gases, their regulations do not always seem to completely agree.

Since there is so much scrutiny over the use of these medicinal gases, most hospitals hire third party inspectors annually to check every element of their system to confirm they are working correctly to keep patients and staff safe and meet the standards set by the organizations above. Not passing a medical gas inspection (or receiving citations) can affect a hospital's reimbursement and or accreditation status.

This guide is to provide an overview of medical gas systems including:

1. Medical Gas Source Equipment
2. Manifold Rooms and Equipment
3. Medical Gas Alarm Systems
4. Patient Room Gas Connections
5. Hoses, Pigtails and Connectors
6. Additional Resources

Chapters

Chapter 1

Medical Gas Source Equipment

Piped medical gas comes from somewhere and like running water, you don't think about it until you open the faucet and nothing comes out. Source equipment are the pumps, compressors, manifolds and bulk containers that provide or create medical gases in the hospital piping system.

Source equipment may have multiple pieces of hardware to filter, pressurize, clean, dry or regulate the gas to provide a clean and safe pressurized medical gas that meets the NFPA required pressure and volume rates at each medical gas terminal.

Let's first consider the most popular medical gas, Oxygen.

Oxygen

Oxygen can come from a high pressure cylinder and in some cases like dentist offices, may in fact be connected directly to the equipment that touches the patient. Most hospitals and even medical buildings though have an oxygen supply that comes from a tank of liquid oxygen stored in a special room or most often outside the building.

Commonly, in the back of the hospital you will see a very tall white tank connected to pipes at the bottom and surrounded by a fence. This tank contains hundreds of gallons of liquid oxygen. A hospital is required to have a minimum of one day's supply on hand as well as a one normal day's back up supply should the main system fail to sustain their patients giving them time to fix or replace the primary oxygen supply.

The liquid oxygen boils at normal temperatures and the gaseous phase is piped at a regulated pressure into the hospital building where it is measured and the pressure regulated before being piped throughout the building. At the entry point, there must be a shut off valve and a pressure sensing alarm.

In fact, the main and back up oxygen sources are monitored so that the alarms can tell not only that the gas is present and at the right pressure, but how much is in the primary and back up supply as well. This information is presented to the facility manager on a Master Alarm panel as well as the duplicate master alarm panel usually in the security office that is monitored 24/7.

Cylinders of oxygen are defined by their color, green, their label and their unique gas specific connection fitting. They may be connected to a manifold and then to a master alarm and control valves and gauges. Some organizations use small tanks of liquid oxygen commonly referred to as dewars or cryos that function like the big tank outside, but can be inside the building in a special room. (see manifold rooms below).

Once the oxygen is in the piped gas system it follows through a special kind of copper pipe that has to be brazed together in a nitrogen atmosphere. These oxygen pipes in the walls and ceilings of the hospital deliver the pure oxygen to the outlets on the wall we are used to seeing. Before the oxygen gets to those outlets it is valved, gauged and alarmed one or two more times.

The system is set up to be able to isolate a section of the hospital piping for repair, maintenance and inspection purposes. Zone valves are accessibly located on the patient floors to isolate a group of patient rooms in the event of an emergency or maintenance. Some zone valves will have a zone alarm panel located on the same floor to monitor the pressure that is delivered to each terminal.

These valves must have visual gauges attached downstream of the valve to give a visual reading of the pressure so that hospital personnel will know the pressure in the line. Zone valves and gauges are most often built into a box set into the wall so that only authorized people can touch them.

The oxygen flows from the zone valve to outlets in patient areas or to another local alarm and valve setup near, but not in, the operating or procedure rooms. The oxygen flow may then be connected to anesthesia equipment or a breathing mask.

The oxygen is distributed through the outlet on the wall with a gas specific "quick connect" type fitting that comes in 7 different mechanical configurations. Oxygen outlets, fittings and flexible hoses are colored green and will only connect with oxygen components.

Patients connected to house oxygen will have a volume regulator usually connected to the wall outlet to control the amount of oxygen coming to their mask or canella. The pressure regulator will also function as an on/off valve for the gas coming out of the wall. Because these outlets are plugged and unplugged constantly they are the biggest wear component of the system.

Medical Vacuum

Vacuum is the second most popular medical gas in use and one often seen by patients and visitors. The vacuum is created by running a mechanical pump like a compressor in many regards, but instead of creating a high pressure in the pump and sending that compressed gas to the receiver tank, this pump sucks the gases out of the receiver tank and forces the compressed air outside leaving a vacuum in the receiving tank that is connected to the house piping.

Vacuum pumps come in several mechanical designs and must be redundant. Since they may be running 24/7 under varying loads they will have various controls and alarms to maintain the pressure, but also to activate the second (or third) pump if needed.

In some cases, the running of these pumps is alternated to provide equal wear. The vacuum pressure is metered and sent to the master alarms. Commonly, zone valve boxes will have a vacuum line valve, gauge and perhaps a sensor inside along with the oxygen equipment. There may be other pipes, valves, gauges and sensors for additional gases in the zone box depending on the setup.

Patient area vacuum is connected by inlets with the same gas specific quick connect set up as the oxygen. Each gas has its own unique kind of hose connection. Therefore, you cannot plug a vacuum device into an oxygen outlet or any other.

These unique fittings are meant to protect against cross connections where the wrong gas could be inadvertently sent to the patient. The vacuum inlets and connectors are white. In most cases, patient use of vacuum is done having a regulator plugged into the wall inlet and the regulator displays the strength of the vacuum and acts as the on/off valve at the site.

One of the challenges of maintaining vacuum is that in actual use it draws fluids and solids out of bodies to make surgery and breathing easier. Inherently, this means "gunk" of many kinds and consistencies is pulled into the plumbing. In surgery, there are gravity traps called canisters that capture most of the liquids and solids, but cannot stop the matter that has been aerosolized.

At the point of use, these fine particles are hardly visible, but as the material gets pulled through the system they may accumulate inside the piping even getting into receiving tank and the pump itself. This is most often a problem in surgery where the greatest amount of matter is suctioned. The lines from the inlets, and even the plumbing in the operating room can occlude which reduces the volume and pressure the inlet can deliver to the surgical staff.

Typically, the remedy when this happened would be to replace the plumbing in the wall which was expensive, time consuming and took the operating room and adjacent areas out of service. Today CHT has developed a patented VacWash machine that allows the surgical vacuum system to be cleaned during off hours without replacing any inlets or plumbing.

Waste Anesthetic Gas Disposal

The Waste Anesthetic Gas Disposal system is also considered a medical gas though it really is a special vacuum system for surgery or procedure areas. Anesthesia gases put patients out during their surgery and the anesthesiologist will mix the anesthetic gas with nitrous and oxygen to get the right combination of sedation while maintaining breathing.

This is very tricky and requires the doctor to monitor respiration and heart rate very closely while administering gases to the patient breathing mask or equipment. Not all these gases are consumed by the patient, in fact with every exhale the patient returns some of the anesthesia to the mask. Exposure of even small amounts of these anesthesia gases over a long period of time can be harmful to the staff doing the surgery so the WAGD system uses vacuum pumps to draw the excess and exhaled gases away from the patient, the anethesiologist and the others in the operating room.

Depending on the volume of surgeries performed the WAGD system may be plumbed completely separately from the vacuum system or merged with the general vacuum piping at some point outside the operating room. The focus is to draw away these excess gases and pump them outside the building usually through a roof vent that is placed away from people and any other air intakes.

WAGD inlets, tubing and piping will be labeled and colored purple. The fittings for WAGD are gas specific unique and cannot be connected to any other outlet or inlet. The vacuum pumps for the WAGD system are inspected like the other mechanical equipment in the source equipment room. The only concern for this system is that the vacuum pressure is maintained at a level strong enough to pull the flammable mixture of anesthesia, nitrous and oxygen through the system and out of the building before it can ignite.

Medical Air

Medical air is the only gas we manufacture on site and deliver to the patient for breathing purposes. Medical air is a prescribed drug by a doctor, because of that the air quality of the gas must meet the United States Pharmacopeia (USP) requirements. Medical air is created centrally to provide a reliable supply of breathing air that has the right humidity for breathing. Medical air is drawn from outside air using an intake vent away from other gas activity and pulled into a compressor to boost its pressure. The compressed air is sent through an aftercooler to the receiver tank. On the way to the receiver tank the medical air goes through a drier that removes moisture that accumulates during the compression process. The medical air passes through a "dew point" sensor that adjusts how much the drier has to do to make air comfortable for breathing. There is likewise a sensor in the medical air line to check for Carbon Monoxide which could be fatal if administered during surgery. As it is used the medical air comes from the receiver tank through a one micron filter, and past a test port. The medical air flows into the house system through a valve, sensor, alarm and mechanical gauge in the source equipment room. Medical air fittings are colored yellow and will only fit medical air outlets.

Like vacuum, medical air needs to be available 24/7 so the compressor has to have at least one redundant partner. These pumps are typically inspected every three months or 300 running hours. The preventative maintenance inspector measures electrical inputs to diagnose any internal friction in the pump as well as visually inspecting belts, driveline parts and the sensors in and around the pump to make sure they are sending the proper signals to the alarms.

A compressed air dryer is used to remove water vapor from compressed air. Redundant compressed air dryers are mandatory for medical usage. The process of air compression concentrates atmospheric contaminants, including water vapor. This raises the dew point of the compressed air relative to free atmospheric air and leads to condensation within pipes as the compressed air cools downstream of the compressor. Excessive water in compressed air, in either the liquid or vapor phase, can cause a variety of operational problems for users of compressed air especially breathing medical air.

The dryer's performance is measured by the dew point or the amount of water contained in the air coming out of the dryer. Too much water in the air (dew point too high) will trigger alarms. All driers require a drain to evacuate the water taken from the compressed air and these drains must be kept clear.

Desiccant Dryer

A regenerative desiccant dryer typically delivers a dew point of between −40 °F (−40 °C) and −100 °F (−73 °C). A refrigerated dryer delivers a dew point not lower than approximately 32 (0 °C). A deliquescent dryer delivers a dew point suppression that fluctuates with air temperature. Typically, this suppression is 20 °F (11 °C) below the compressed air temperature.

In a desiccant dryer compressed air is passed through a pressure vessel with two "towers" filled with a media such as activated alumina, silica gel, molecular sieve and other desiccant material. This desiccant material attracts the water from the compressed air via adsorption. As the water clings to the desiccant, the desiccant "bead" becomes saturated. The dryer is programmed to switch towers based on a standard cycle time or amount of moisture accumulated. The dryer switches the flowing air to the second tower for drying. While the first tower's beads are purged by a blast of compressed air from the system simply blowing off the water that has adhered to the desiccant. While the second tower collects the water from the air flowing to the receiving tank, the water in the first tower is blown to a drain that opens at the bottom of the first tower. At the end of the cycle determined by time or desiccant saturation the system reverses so that the first tower resumes purifying and the second tower is blown dry.

The duty of the desiccant is to bring the dew point of the compressed air to a level in which the water will no longer condense, or to remove as much water from the compressed air as possible. Many newer dryers come equipped with a dew dependent switching (DDS) which allows for the dryer to detect dew point and shorten or lengthen the drying cycle to fulfill the required dew point. Often this will save significant amounts of energy which is one of the largest factors when determining the proper compressed air system.

In smaller facilities, medical air may be supplied in cylinders through a manifold or through a regulator to the patient.

Instrument Air

Instrument air is similarly generated by compressors in the source equipment room. This compressed and filtered outside air is used only to power equipment. The compressors and dryers in this circuit need to be inspected quarterly like the medical air above. Medical air piping, fittings and hoses are red and their fittings are unique to that gas and the equipment that uses it. An instrument air dew point that is expected from a regenerative dryer is -40 degrees Celsius.

Source equipment rooms must be ventilated and maintained at a temperature that will allow the cooling mechanisms of the pumps to work well. Pumps that over heat trigger alarms and will shut down if the source equipment room air flow is not sufficient and do not maintain an equipment safe room temperature.

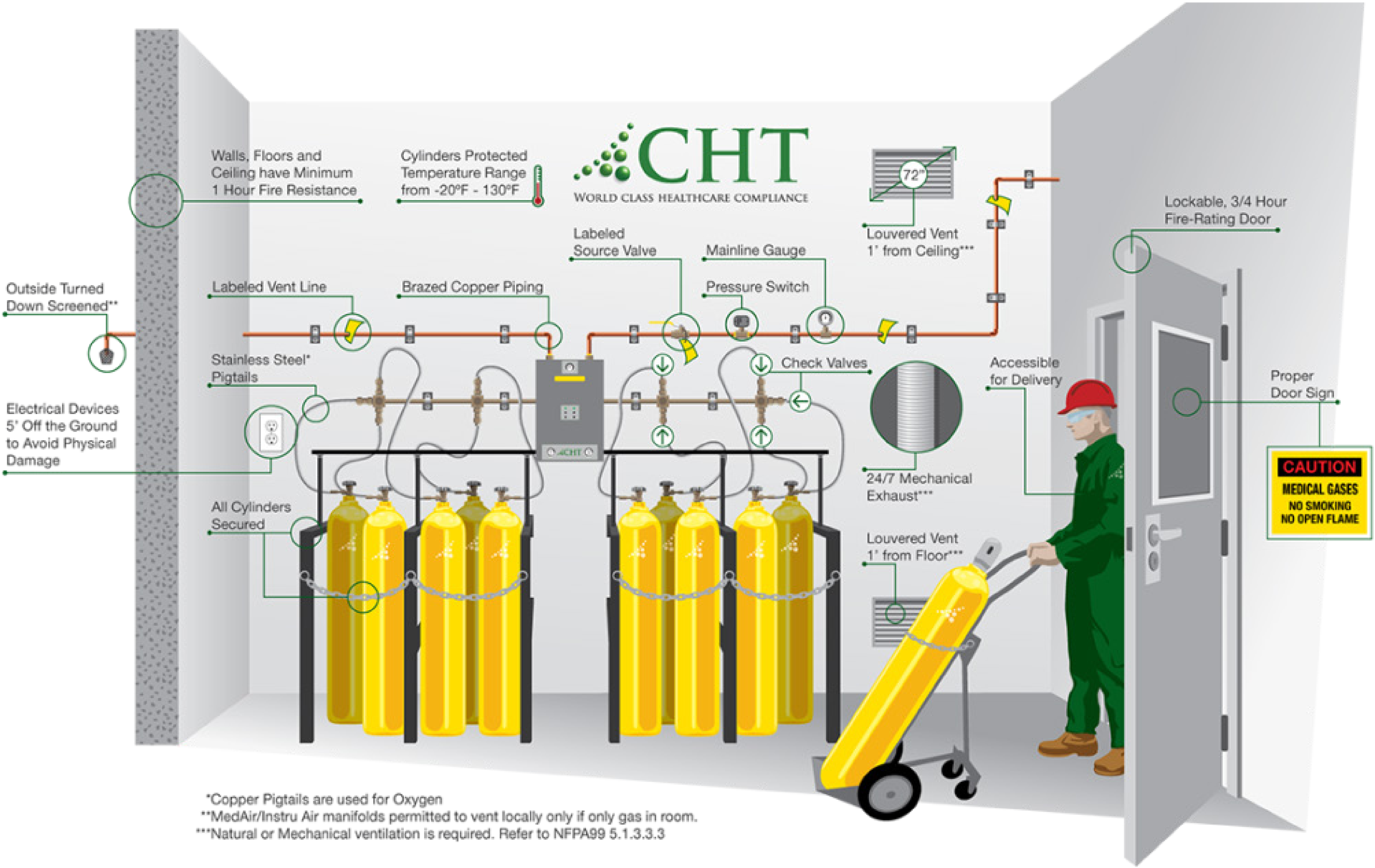
Chapter 2
Manifold Rooms

While vacuum, WAGD, Medical air and Instrument air are generated locally in most hospitals, lower volume gases may come through a piped system from cylinders connected to a manifold. Commonly hospitals will have nitrogen, nitrous oxide and maybe a carbon dioxide produced through a manifold.

The manifold room typically has various numbers of cylinders of different kinds of gas all lined up against the walls. Cylinders contain very high pressure and must be protected with heavy duty screw on caps and supported (usually chained) in vertical position. Some of the gas may liquify inside the cylinder and the liquid can freeze the fittings, valves and alarm sensors if it squirts through the pigtails or connecting lines. Keeping the cylinders vertical means any compressed liquid will be at the bottom of the cylinder and not likely to foul the equipment. Each kind of gas will come in cylinders that are color coded, plainly labeled with their contents name and have unique connectors to make sure there is no cross connection of gases. Cylinders must be labeled full or empty as well.

Each kind of gas will be connected to the manifold through a "pigtail" or semi flexible hose or tubing with the appropriate fittings to match the kind of gas being used. If oxygen is supplied by a manifold these pigtails must be the special copper tubing. Other gases will use reinforced rubber or plastic hoses. Usually four or more cylinders are connected at one time to the manifold and each connection point has a one-way check valve so the cylinders can be changed without lowering the pressure of the whole system. The gas flowing from the cylinders goes to a pressure regulator, and an alarm where there is a mechanical valve to allow isolation of the system and a visible gauge before the gas goes into the house piping.

The infographic on the next page shows most of the requirements for a manifold room as described by NFPA 99-2012.



*Copper Pigtails are used for Oxygen
**MedAir/Instru Air manifolds permitted to vent locally only if only gas in room.
***Natural or Mechanical ventilation is required. Refer to NFPA99 5.1.3.3.3

Chapter 3

Medical Gas Alarm Systems

Medical gas alarm systems can vary in what they report and measure, NFPA and other agencies set the minimum standards, but with current technologies many alarm panels display more than the minimum requirements. Medical gas alarm panels come in three general descriptions or level of protection:

1. Master alarm panels that monitor source equipment, manifolds and main oxygen supply.
2. Zone alarms that will protect a section of the hospital and typically monitor the presence and pressure of oxygen.
3. Area alarms that monitor at least oxygen and vacuum in surgical, procedure and recovery rooms. Critical care and anesthizing locations are required to have area alarms to monitor each gas in that zone. With newer sensors and digital internal components, pressures can be read directly on the alarm screen along with other values.

Each kind of alarm is associated with a valve and a visual gauge to allow isolation of part of the system in emergency or for maintenance purposes. Modern alarms can be connected by wireless signals to the sensors and to other alarm panels. There are a multitude of restrictions and safety requirements with this method to avoid radio frequency interference and even hacking.

Each pipeline coming to the valve has a sensor of some sort in it. The kind of sensor will determine what values are measured. At least the presence of the required gas and the pressure of it supplied are determined and that information sent to the alarm panel. The alarm is required to show a light or signal when the pressure is not correct and sound an audible alarm. Alarms can be silenced to reduce stress, but will sound again when another signal is activated. Some alarms can be programmed to resume sounding if the out of spec condition continues.

Master Alarm panels are redundant: one in the area of responsible surveillance like the facility's office or engineering office and one in a place monitored 24/7 like a security office. If there is a break in the supply of any these life-saving gases the alarm needs to warn everyone.

For most hospitals with cryogenic oxygen in an outdoor tank farm the master alarm will have lights to show:

Oxygen:

- High main line pressure
- Low main line pressure
- Primary liquid level low (Less than an average day's supply)
- Reserve in use
- Reserve liquid level low (Less than an average day's supply)
- Reserve low pressure
- Manifolds with dewars or cylinders (usually Nitrogen, Nitrous, CO2,) each gas will most often have lights for:
- High main line pressure
- Low main line pressure
- Secondary in use (changeover)
- Reserve in use
- Reserve low pressure

Vacuum:

- Low vacuum pressure
- Lag*

Medical Air:

- High main line pressure
- Low main line pressure
- High dew point
- Carbon monoxide level*
- High temperature* (operating temperature of the compressor)
- Lag*
- *if using liquid ring compressors there must also be a high water in the tank
- (LPM* & high water in the separator)

Instrument Air:

- High main line pressure
- Low main line pressure
- High dew point
- High temperature at compressor*
- Lag*

*These signals can be listed on the master alarm as a common alarm like "Maintenance required."

The number of lights and the arrangement can vary depending on the details of the source equipment being used. Some types of pumps require extra alarms and some backup systems will also require alerting the 24/7 station. Alarms must be powered by the emergency back up supply circuit so they work even if outside power is interrupted.

Where there are multiple sources, perhaps in multiple buildings, these sources will also need to be identified on a master alarm. In those cases, facilities should be told which system is alarming as well as the symptom.

The most important action to be taken by the person that monitors a master alarm is to ensure maintenance is immediately called to look into any alarm sounding. Telling the person which light is on can save them time to confirm the life sustaining medical gas continues to flow.

Annual and CMS inspections will go over the panel to make sure the correct signals are available and all lights are working. While not part of a regular inspection the sensors on the pipeline can and should be tested.

JC, CMS also require that the facility demonstrate reporting that the alarms are not only there, but they are properly monitoring the equipment and activating the proper alarms. NFPA and ASSE require alarm sensors and switches to be tested to ensure functionality of the signals. Since these tests may involve interrupting the flow of gas they are done with advance warning, by certified people under special conditions.

The zone alarm typically covers a floor or part of a floor of patient rooms. Likewise, it alerts if the supply drops for some reason with lights and sound.

The area alarm is placed close to, but not in the same room as the gases being used to allow people outside the operating rooms to attend to alarms and the associated valve and gauge inside the wall box.

Chapter 4

Patient Room Gas Connections

In most modern hospital rooms there are at least duplicate sets of oxygen outlets and vacuum inlets. This redundancy allows for continuous functioning in case of some blockage or breakdown and may allow multiple devices to be used on the patient.

Both connections are of the "gas specific quick connect" type. That is, they are spring loaded to turn off the gas supply when nothing is plugged into them. Most often the wall outlet will have a regulator of some kind plugged into it which allows the amount of oxygen or vacuum to be adjusted to fit the patient or machine's needs.

The regulator will display the operating volume (the amount of gas flowing is adjusted by the staff). The regulator will function as the on/off switch for the gas it is connected to.

Because these outlets are the most frequently used and plugged and unplugged they tend to wear out faster than other medical gas equipment.

There are seven (or so) designs for the connectors and inlets designed by different manufacturers. All these fixtures are color coded and have unique construction so that only the proper connector for each gas will fit in the outlet. Hospitals will standardize on one design of outlet to allow connectors to fit in different rooms, however it is common that old buildings and new buildings have connectors that will not fit each other's equipment even though they are both green oxygen hoses.

Each outlet and inlet needs to be regularly tested and approved by a technician certified by ASSE. This test can be done in a few minutes by plugging a rotameter into the outlet and then logging the pressure and volume of the gas moving through the device.

The inspections can be done with the patient in the room and even when they are using one of the outlets at the same time. Leaking or ill fitting outlets and inlets can be repaired without removing them entirely from the wall. Typically, they come with a "front" and "back" structure that allows the most common wear parts to be replaced right in the patient room in a few minutes.

Chapter 5

Hoses, Pigtails and Connectors

There may be hoses that connect equipment to the wall that get reused and these lines should be inspected by the hospital staff to make sure they are not kinked or cracked. This would lower the system pressure or cause vacuum pumps to run excessively by sucking the air out of the room.

More common is the concern about the hoses in surgery areas. They can get bent, stepped on and pinched by equipment. In the case of vacuum, they can also accumulate debris that reduces the efficiency of the system to help the surgical staff. The standard recommendation is that the booms and boom hoses get inspected or replaced every 18 months. Of course, each hose has its own color to indicate the kind of gas it carries and will have connectors at either end unique to the type of gas conveyed.

“Pigtails” or the connecting lines from the gas cylinders to the manifold will usually be inspected and leak tested every 6 months. Since the cylinders containing the various gases run out and must be replaced on a regular basis these fittings and hoses do get worn.

Most of the non-oxygen pigtails (connecting hoses) are stainless steel reinforced plastic to protect them from pinching and kinking among these bulky cylinders and in the tight spaces to connect and use wrenches to tighten fittings. The hoses are inspected for cracks and broken outside fibers. Replacement hoses must match fittings for each kind of gas.

Chapter 6

Additional Resources & Conclusion

Medical gas systems in healthcare facilities are regulated drugs. The actual molecules are provided by outside vendors in liquid or gaseous state. The delivery system is highly regulated and the technologies used to deliver and monitor the administration of these drugs has multiple levels of supervision from the hospital, the industry and the government.

Medical gas systems must be built by certified installers and then verified by a specially trained verifier before they can be used. Once the system is up and running annual inspections make sure the patients and the staff are being protected and served well by the system.

The information in this overview is believed to be accurate at the time of publication. Standards and rules are constantly evolving and each facility may have special requirements that require accommodations.

The best procedure for any specific question about medical gas is to consult a certified expert like those at CHT. More complete and detailed descriptions of these systems, their mechanisms and the required safeguards can be found in the publications and web sites of:

- Center for Medicare and Medicaid Services
- The Joint Commission
- Occupational Safety and Health Administration
- American Society of Sanitary Engineers
- National Fire Protection Association
- American Society of Healthcare Engineering

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