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Contamination of Medical Gas and Water Pipelines in a New Hospital Building

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Medical gases and water were sampled and tested for purity prior to the opening of a 176-bed addition to a 450-bed general hospital. Contamination was found. In delivered oxygen, compressed air, and nitrous oxide, this consisted of a volatile hydrocarbon at an initial concentration of 10 parts per million and a dust of fine gray particulate matter. In water from new taps bacterial contamination with as many as 400,000 organisms per 100 ml was present. All these contaminants were considered potential hazards to patient safety. Studies were done to help delineate the nature and origin of these contaminants. Each contaminant was eventually largely eliminated by purging the respective pipeline systems with continuous flows. Planners, builders, and responsible medical personnel must be aware of the potential for such hazards in a new hospital building. (Key words: Operating rooms, construction; Equipment, gas pipelines; Oxygen, delivery systems.)

BEFORE A NEW HOSPITAL BUILDING can be used for patient care, the facilities in it must be tested and determined to be safe. Prime among these are medical gas pipeline systems. In the United States,[1] Great Britain,[2] and Canada,[3] there exist codes of standards for the installation and testing of medical gas pipeline systems. The standards include specifications for the cleaning of the copper pipe by the manufacturer, for pipe handling and storage, for pipe installation and joint soldering, for cross-connection testing, and for testing for the purity of the gas delivered. In the United States, these standards must be met to obtain accreditation by the Joint Commission on Accreditation of Hospitals and to obtain insurance coverage, but they are rarely incorporated into law, and there exists no regulatory agency with authority over medical gas pipeline systems. Tap water is delivered through the same type of copper pipe. It appears that, when water is qualitatively evaluated at all, local or municipal purity standards prevail.

Many hazards exist with bulk gas storage and delivery via medical gas pipeline systems. Insufficient or excessive pipeline pressure, crossed pipelines, regulator or alarm failure, and leaks have been described.[4] There is, however, no description of exogenous contamination of new pipeline systems, which is the subject of this report.

A new eight-story hospital building containing 176 patient beds, an 11-room operating suite, and facilities for several support services was opened in stages over the first half of 1976.

During routine testing for cross-connections and purity of oxygen delivered to the first completed patient-care floor, a distinct odor accompanied the flow of oxygen. Inhalation of the contaminated oxygen was followed by headache and nausea in the respiratory therapist performing the test. The odor was not readily identifiable.

In addition to the odor from the medical gas outlets, a fine gray dust was propelled from these wall outlets with the flow of gas. This particulate contamination was initially concentrated enough to be easily visible coming from the outlet nozzles.

Initial bacterial cultures of sink drains (used only rarely by workmen) showed nondescript gram-negative bacillary environmental flora; there were no *Pseudomonas aeruginosa*. Coincident tap water samples were obtained from two patient care floors prior to their opening.

Methods

To investigate the odor-causing contaminant in the medical gas pipelines, gas samples from both oxygen and compressed air pipelines were taken from several rooms on each of the four patient-care floors in the new building. Each sample consisted of 180 liters of gas (6 l/min for 30 min), which were allowed to pass through a glass gas trap cooled with liquid nitrogen. A condensate that averaged 100–200 μl was recovered. It smelled strongly of the same "organic chemical" odor. The compound in the condensate was separated and detected using a research gas chromatograph with dual-flame hydrogen ionization detectors. The condensate was largely water, but the contaminant was found to be a hydrocarbon with a boiling

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point of about 92 C. It was quantitated by relating the peak areas of the chromatographic curve to a known standard of n-heptane (similar boiling point). Measurements were done in duplicate. The initial samples probably had two other organic compounds comprising less than 2 per cent of the total contamination; these additional compounds were not present in later samples.

Samples of the dust coming from the gas outlets were collected on filter paper and on micropore filters. Scanning electron microscopy revealed the particles to be approximately 100–500 μm in size, heterogeneous in size and shape, and not characteristic of any identifiable substance. The collected dust was subjected to x-ray microprobe analysis to determine the elemental composition of the particles.**

Tap-water samples consisted of 100 ml water obtained after the tap had been on maximal flow for 5 minutes. One-milliliter volumes were delivered to 5 per cent sheep blood agar bacteriologic plates, which were then incubated at 37 C for 24 hours and thereafter at 20 C. Total colony counts were measured daily with an automatic counter. Predominant microorganisms were identified by traditional biochemical criteria utilizing the API Enteric Identification System.[5]

Results

The initial samples of oxygen and compressed air contained an average of 5–10 parts per million (ppm) of the hydrocarbon impurity. Occupancy of the floor was postponed. A program to attempt to purge the pipeline systems of this contaminant was undertaken. All of the 88 oxygen outlets and the 44 compressed air outlets on a floor were opened simultaneously to a flow of 6 l/min and allowed to run continuously for periods of three to five days (table 1). The higher floors took longer to purge. Following the purging period for each floor, the contamination was reduced to trace amounts (less than 0.1 ppm) in the delivered oxygen and to near-trace amounts 0.2–0.5 ppm) in the delivered compressed air. The nitrous oxide pipeline system to the operating suite was purged by flushing oxygen from each outlet at 5 l/min for seven continuous days. This reduced the hydrocarbon contamination to trace amounts (less than 0.1 ppm). However, hydrocarbon contamination of the compressed air pipeline system (both in the new building and in the older parts of the hospital) remained at an average level of 0.2–0.5 ppm. This was below our own arbitrarily set acceptability limit of 1.0 ppm, but still remained significantly more than that in the oxygen pipeline.

TABLE 1. Average Contamination of Medical Gas on a Patient-care Floor

Days of Pipeline Purging	Hydrocarbon in PPM	
	Oxygen	Compressed Air
0	10	10
1	1.2	1.3
3	0.6	0.9
4	0.1	0.4

The dust coming from the medical gas outlets was found to contain silicon, aluminum, and titanium in a 2:2:1 ratio, with traces of sulfur, potassium, calcium, iron, and zinc.

The continuous flushing of the medical gas lines did not remove all the particulate contamination. However, periods of a few minutes of maximal flow from each outlet were sufficient to virtually eliminate the residual particles. There were only one or two particles in 720 l of gas in a final test for particulate contamination prior to the opening of the floors for patient care.

The two initial tap-water samples were found to yield colony counts indicating 4,800 and 3,200 organisms per 100 ml water. The local water authority supplying water to the hospital has a routine maximum acceptable limit of 300 organisms per 100 ml in water for general consumption, and suggests a limit of 100 organisms per 100 ml for water in hospitals.

Because of these high colony counts, further studies were done. Samples of the first water out of a new tap, without any flushing, were taken from isolation room sinks. Total colony counts were 300,000 to more than 400,000 organisms per 100 ml. *Pseudomonas* spp. were the predominant organisms. Other samples after 5 minutes of flushing consistently showed 3,000 to 11,000 organisms per 100 ml.

To attempt to reduce the bacterial contamination, all water taps on one floor were fully opened and allowed to run overnight (a minimum of 15 hours). The water was then resampled. The colony counts showed a decrease to an average of 1,500 organisms per 100 ml, and on the following day, the counts ranged from 500 to 900, with an average of 700 organisms per 100 ml. Without further flushing, four days later (five days after the flushing), the counts showed 400–500 organisms per 100 ml. Since this was similar to the counts in water in the remainder of the hospital, the water supply system to that floor was considered ready to serve patients and hospital personnel. A similar purging process was then carried out for each remaining floor of the new building prior to occupancy. Ice from the new machines was found to contain from a few

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** The specimen is bombarded with a finely focused electron beam and characteristic x-rays are generated by the interaction of the beam and the atoms of the component elements. The x-rays have distinct energies and wavelengths. They can be sorted and quantified, revealing the proportionate elemental make-up of the specimen. Elements having atomic numbers below 11 are unlikely to be detected unless present in large concentrations. Oxygen, carbon, and nitrogen would not be detected with this system.

thousand to more than 100,000 organisms per 100 ml. It was necessary, therefore, to clear the machines of ice made from the initially contaminated water.

Discussion

Each type of contaminant probably would have been eventually purged from the respective pipeline system through normal use, without any special attention or procedure. However, the high-level hydrocarbon contamination of the medical gas pipeline systems was a fire hazard, potentially toxic, and certainly unpleasant. Recently, an oxygen-driven ventilator in use in a nearby newly-opened hospital caught fire, apparently due to hydrocarbon contamination of the pipeline. The particulate matter in our gas pipelines could have damaged gas flow control equipment on anesthesia machines, ventilators, or wall outlets and could have been inhaled by patients receiving oxygen therapy. A water tap with very high bacterial contamination, when used for the first time by hospital personnel, could have contaminated a compromised-host patient.

Purging the pipeline systems proved effective in reducing contamination. The persistence of a low level of the hydrocarbon contamination in the compressed air led to the suggestion that there was an ongoing input of contamination into this system from the hospital's compressor unit. Accordingly, samples of the outside ambient air were collected and analyzed in the same manner as the gas samples. A similar condensate having a similar odor was collected. Analysis with gas chromatography demonstrated that the contaminant was identical to that collected from the medical gas outlets, thus indicating that the local atmosphere was the likely source of the ongoing contamination of the compressed air.

It is also possible that the atmosphere was the source of the original hydrocarbon contamination of the oxygen, air, and nitrous oxide pipelines. The copper pipe used in the new building had been stored in a local warehouse for two years prior to its use. While such pipe should be sealed at both ends, according to United States National Fire Protection Association standards, it is not uncommon for the rubber or plastic end plugs to become broken or dislodged during handling of the pipe. This would expose the inside of the pipe to the local air and its contents. A soluble hydrocarbon could be trapped in the water vapor that would naturally collect inside the pipe and then volatilized by the initial flow of gas through a newly constructed pipeline system. The result would be a very high initial hydrocarbon contamination that would rapidly disappear, as was the case in this new building. The solder flux used in making joints in many pipeline systems may be another potential source of contamination. Stray bits of flux inside the pipe might remain as solid particles or be vaporized by the heat of the soldering process into gaseous contaminants.

The purging process was expensive and not without complication. During the purging, hospital oxygen use was four times normal. This led to a system failure which created a potentially hazardous situation. On a day when the supply in the main liquid oxygen storage tank had fallen to a low but not dangerous level, new liquid oxygen was delivered in the usual manner. The large inflow apparently allowed liquid oxygen into the piping system, freezing the pressure regulator and the high-pressure-relief safety valve, and thereby allowing a pressure of 90 pounds per square inch gauge (621 kilopascals) to reach the main hospital oxygen delivery system. Two anesthesia machines were damaged when the high pressure backed up in the fail-safe system and ruptured the diaphragms of the nitrous oxide regulators. No patient was harmed. The fault was corrected by defrosting the two valves by pouring hot water over them and replacing the faulty high-pressure-relief valve.

The absence of copper in the particulate contamination of the gas pipelines suggested that the pipe itself was not the source of the dust. The preponderance of silicon and aluminum led to the consideration of the abrasive paper used in the soldering of pipe joints as the source of the dust. X-ray microprobe analysis of several of these papers revealed high silicon and aluminum content but no titanium. Therefore, other materials were tested. These included flooring materials, wall insulation, cement, ground-up cinder block, and the inside of the copper piping. None of these materials contained titanium. Finally, a piece of abrasive paper used in pipeline preparation was examined, and a stained area contained particles rich in titanium. Discussion with workmen revealed that during the installation process the ends of pipes had been temporarily color coded with spray paint, and that it would have been possible for some of the paint to be rubbed off as the abrasive paper was used prior to joint soldering. Titanium is a major component of paint pigment. The abrasive paper may have powdered the paint, causing dust to settle inside the pipe.

It is not clear why the hospital water supply contained as many as 500 organisms per 100 ml. This level of bacterial contamination is probably related to the existence of large construction projects in the immediate neighborhood. Whenever there is heavy construction, the bacterial count of water in the surrounding area increases, possibly because heavy equipment impacts the earth sufficiently to vibrate deeply buried old water mains and shake loose bacteria trapped in the calcified mineral deposits lining such pipes. The ability to reduce the organism counts to levels similar to those in the remainder of the hospital argues against an additional ongoing source of bacterial contamination.

Each type of contaminant was detected by testing procedures beyond those prescribed as the minimum standards. None of the piped gas standards includes specific ppm tolerance limits for contaminants. However, the Canadian standard is the most thorough, in that it prescribes parallel testing of the gas both at its source and at the most distant outlet, thus allowing verification that passage through the pipeline adds no significant contaminants to the gas. Such a process seems logical and would merit universal adoption.

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