HISTORY OF MEDICAL GAS PIPELINE SYSTEMS

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Medical Gas Pipeline System have been in use in Hospitals since 1930, but their evolution has been dependent on other inventions and discoveries in Medical Technology. The following is a brief record of this evolution.

PIPES FOR GAS TRANSPORT

For thousands of years, pipelines have been constructed in various parts of the world to convey water for drinking and irrigation. In Crete, the largest and most populous of the Greek islands, during the Bronze Age (3000 BC) the Minoans developed a plumbing system that involved underground clay pipes. The Minoan civilization is also credited for the first flushing toilets that were referred to as Water Closets. Ancient Egyptians created one of the oldest plumbing systems. Their construction was based on the rise and fall of the River Nile. Egyptians used delicate pipe systems made from clay to move water from the Nile to their farms. The ancient Chinese used pipes made of hollow bamboo for moving water. They even transmitted natural gas using bamboo pipes to light streets in their capital, Peking, as early as 400 BCE. The Romans and Persians used aqueducts to create the Plumbing Systems for their cities.

Archaeologists have discovered terracotta piping system underneath the floor of the many ancient palaces, including in the ruined city of Ephesus on the west coast of Turkey, that delivered water to the faucets and fountains and drainage systems that were made of stone.

By then Man had discovered Copper (9000 BC) and started making Copper Pipes (2150 BC).

Archaeologists probing ancient ruins have discovered that tools for handicraft and agriculture, weapons for hunting, and articles for decorative and household uses were wrought from copper by early civilizations. The craftsmen who built the great pyramid for the Egyptian Pharaoh, Cheops, fashioned copper pipe to convey water to the royal bath. A remnant of this pipe was unearthed some years ago still in usable condition, a testimonial to copper’s durability and resistance to corrosion.

In the sixth century, Romans constructed Cloaca Maxima, a sewer system that featured an open channel. This sewer system exists till date, although it’s now closed and vaulted.

In 1834, in USA, cast-iron pipelines were installed to carry manufactured gas for gas lighting purposes in major cities. After oil was discovered in Pennsylvania in 1858, pipeline was laid to transport oil in 1863. Use of cast-iron pipes commercially brought significant improvement in pipe manufacturing technology. Use of steel pipe, which greatly increased the strength of pipes of all sizes made it possible to transport natural gas and oil over long distances. The application of welding to join pipes in the 1920 made it possible to construct leakproof, high-pressure, large-diameter pipelines.

USE OF OXYGEN IN HEALTHCARE

In early part of 1700, inhalation of Oxygen, called Factitious (manufactured) Airs, as Medicine started. In 1796, Oxygen Inhalation Devices were available with Oxygen contained in rubberised bags with or without cloth covers and a tube connection. It is interesting that the necessity for inspiratory and expiratory valves was appreciated at the inception of inhalation apparatus design, and these were incorporated to economise the use of the Oxygen.

The use of Medical Gases for Respiratory Therapy and Dental Anaesthesia dates back as early as 1799. Nitrous oxide was first imported into the United States for use as a Dental Anaesthetic in 1870. At that time, the gases were transported in Bags in limited quantities. In 1846, WTG Morton demonstrated use of ether for anaesthesia. This was also integrated with use of Medical Gases for Anaesthesia.

The lack of patient co-operation during anaesthesia necessitated the development of the face mask and a Sibson's face mask, made of oiled silk cloth, was made available to medical fraternity in February 1847.

Prior to 1868, the Doctors always had to manufacture their own oxygen gas but in that year, Barth presented 15 gallons of freshly produced oxygen, compressed into a copper bottle at 450 p.s.i. using a Hand pump. Nitrous Oxide was made available in Steel cylinder, at the same time. This development removed the need for self-manufacture of Gases by the Physician.

In 1869, a rubber bellow was added to Oxygen Inhalation Device to mix Air with Oxygen for Inhalation. This paved the way for production of Anaesthesia Ventilator.

In 1871, a device was reviewed by "Department of Analysis and Inventions" which consisted of a 'Polished Mahogany Box, which was divided into two compartments, one containing the storage bottle of compressed gas, the other fitted with a dilatable India rubber bag, into which the gas passed by a tube on opening a stopcock. Another tube was provided, by which the air is propelled into the bag by squeezing a handball to dilute the Gas. A third tube leading from the Bag, terminated in an ivory mouthpiece to be placed between the lips and it delivered the gas to the patient. The Clover's Chloroform Inhaler (demonstrated in 1862) with Hair Spring Valve could be integrated to this device and it was the early anaesthesia Ventilator. The device was successfully marketed by the Fannin and Co in 1892 and later by the Brin Bros. in 1899.

In 1890, John Aulde, when reviewing a similar device made by the White Dental Manufacturing Company of Philadelphia, added the half-filled water bottle through which oxygen was allowed to bubble and get humidified. It was done to prevent injury to the Mucosal Lining. This water bottle was later used to vaporise ether, by T. S. K. Morton, and it became the Vaporiser. Lime Soda was used to remove Carbon Dioxide from the Exhaled Air, and this gave birth to closed circuits for ventilation.

Leonard Hill in 1912 produced his own mask for infusing warm and moist oxygen. At 30 LPM flow rate, it was the beginning of High Flow Oxygen therapy.

The nasal administration of oxygen using a catheter was introduced by Arbuthnot Lane in 1907. It was used extensively in the first world war (1914-18) by Adrian Stokes. Later, Geoffrey Bourne recommended it for use in sick children for safety of gas administration. The nasal catheter is the only piece of Oxygen Therapy Apparatus that persists virtually unchanged to the present day.

Almost as a parallel, sometime around 1885, Oxygen was produced on large scale and was used as a respiratory stimulant.

In 1885 two French brothers and chemists, demonstrated their patented method of making oxygen and in 1886, they established Brin's Oxygen Company Limited. By 1900, Dr. Carl von Linde patented a new method of producing oxygen by converting air to liquid. Brin's Company adopted this and in 1906, Brin's Company became the British Oxygen Company Limited, or BOC.

In 1935, BOC set up a separate Medical Division to install the Piped Medical Gas Service to supply oxygen which would be available "on tap" by means of an extensive circuit of copper pipes connecting Hospital wards and Operating Theatres to a battery of cylinders usually located in the basement of the Hospital.

In the same year, BOC also introduced an improved anaesthetic gas, called "Entonox," a 50:50 mixture of Oxygen and Nitrous Oxide, for analgesia during Childbirth,

In 1917, Henry E. G. Boyle demonstrated a modified Gwathmey apparatus of 1912 as a continuous flow Anaesthesia Machine. The Boyle's Machine had five elements, which are still present in modern machines: (1) A high pressure supply of gases, (2) pressure gauges on Oxygen cylinders, with pressure reducing valves, (3) Flow meters (4) Metal and Glass vaporiser bottle for ether, and (5) a breathing system. The apparatus was mounted on a table with wheels. The Boyle's Apparatus minimised anaesthesia related risks to patients and staff. BOC acquired the rights and marketed this machine successfully. BOC updated the machine so it could use Compressed gas Cylinders or could be connected to pipe line supplying the Gas. Boyle's Machine sells even today. The following noted modifications were made over the years.

- In 1921, the Carbon Dioxide Absorption using the "to and fro" system for complete rebreathing of anaesthetic mixtures with absorption of exhaled carbon dioxide was added.

- In 1930, Brian Sword added Circle Absorption Systems to enable the low-flow anaesthesia.

- In 1933, Dry-Bobbin flow meters were added.

- In 1952, The Medical Gas Pin-Index Safety System (PISS) (by Woodbridge) which ensures that the correct medical gas cylinder is hung in the correct yoke was added to ensure gas Specificity for Gas Cylinders.

- In 1958, an incombustible neoprene washer with a peripheral metal reinforcing ring to prevent splaying, called the Bodok Seal was added which further improved performance of the PISS.

GAS CYLINDERS

In 1800, first Compressed Gas Cylinders were produced by the Harrisburg Pipe and Pipe Bending Company as its first “Gas Shipping Drum.” It was a container that was “hammered, patched, and hand-welded” from a piece of steel pipe 55 inches long and 5 inches in diameter.

In 1900, inventor Paulus Heylandt built the first tank car for transporting liquid oxygen, called the Laubfrosch” or “Tree Frog”.

In 1920, Heylandt built the first specially insulated storage vessels and tank trucks, which would allow the extremely cold cryogenic liquid products of the air separation plants to be drawn off as liquids, stored in insulated tanks or vehicles, and transported to market in bulk form. Large scale transport of Liquid Oxygen started in 1932. This was the advent of Liquid Cryogen Transport and is now used as Liquid Medical Oxygen in **Medical Gas Pipeline System (MGPS).**

In 1931, the first vacuum-insulated-containers for motor trucks and railroad tank cars were built to carry gases in their refrigerated liquefied state at extremely low cryogenic temperatures.

Around 1950, to meet the demand of steel industry, BOC started supplying Liquid Oxygen by Ton, from Oxygen Plants located close to Steel Factories, then have it converted and supplied as gas, by pipeline.

MEDICAL GAS PIPELINE SYSTEM STANDARDIZATION & REGULATION

Standardization of MGPS is fundamental to patient safety. Over the years, the fundamentals of Healthcare Provisioning and Delivery have been standardised across all countries of the world. As Healthcare providers diversify and move across Hospitals and work in different countries, it becomes important that they are provided Standardised Healthcare Systems and Medical Equipment. This requires Standardised manufacturing processes for Equipment and their components. This includes Medical Gas Pipeline Systems also.

In 1901, Sir John Wolfe-Barry, the man who designed London’s Tower Bridge, established British Standards Institute (BSI), the world’s first National Standards Body. One of the first standards BSI published related to steel sections for tramways. The BSI Kitemark was first registered by BSI on 12 June 1903. Originally known as the British Standard Mark, it has grown into one of Britain’s most important and most recognized consumer quality marks.

Since 1930, Medical Gas Pipelines have been increasingly used in Hospitals and Clinics to distribute Medical Gases and Vacuum from a central supply, using Gas Cylinders. To standardise these, BSI started publishing Standards dealing with the construction of Compressed Gas Cylinders, its pressure regulating valves and the anaesthesia apparatus.

The first published Standard dealing with medical equipment, BS. 1319:1955, was for Medical Gas Cylinders and Anaesthesia Apparatus. It laid down safety precautions to be observed when using and handling medical gas cylinders and introduced the flush-fitting pin-index type of cylinder valve and yoke, on all gas cylinders up to a capacity of 5.5 Litre (12 lb). of water. The larger size Gas Cylinders, that were used in pipeline installations were not covered by this Standard. This BSI Standard also provides "Chart of colours for Medical Gas Cylinders" which lists the colour code and labelling system for use on all Medical Gas Cylinders.

Then came BS.2927:1957, Anaesthetic Airways; BS.2050:1961, Antistatic Properties of the rubber used for Breathing Bags; BS.3353:196I, Anaesthetic Breathing Bags; BS.3487:1962, Endotracheal Tubes; BS.3806:1964, Breathing Machines for medical use; BS.4199: Part 1:1967, Surgical Suction Apparatus; etc.

HTM 22: Hospital Technical Memorandum 2022 – Piped Medical Gases, Medical Compressed Air and Medical Vacuum installations was published in May 1972 by HMSO for the Department of Health and Social Security and incorporated a number of BSI standards, available at that time. Now it has become Health Technical Memorandum 02-01 Medical Gas Pipeline Systems, Part A & Part B.

BS.5682: 1978, Dimensions of Probes and Terminal Units for Medical Gas Supply Systems – requirements, dealt with methods to prevent the possibility of cross connection between the supplies at their point of use in the operating theatre or ward. It required that the socket for the MGPS supply, the probe which enters this socket, and the connector to the machine dispensing the gas should all be unique to the particular gas service so that even forced cross connection could not occur. The hoses, their attachment to the probes and machine connectors and their colours were also standardised.

Simultaneously, in USA, in March of 1895, a process of deliberation started which culminated in the formation of National Fire Protection Association (NFPA) on November 6, 1896. In 1903, NFPA was joined by underwriters from England. In 1966, NFPA appointed a committee to deliberate on Industrial and Medical Gases and Fire Hazards in Oxygen Enriched Atmospheres. **In 1979, NFPA decided to combine all its documents under its jurisdiction relating to Healthcare Delivery and thus in 1984, NFPA 99, Health Care Facilities Code, became a reality.** Along with other NFPA codes, it provides comprehensive Life and Fire Safety for Healthcare facilities. Additionally, in March 2005 ASHE included strict precautions for the use of alcohol-based surgical solutions. Now, NFPA 99, 2021 edition has been published.

At the request of the Food and Drug Administration, USA, the Compressed Gas Manufacturers Association (CGMA) formed the Medical Gases Committee which worked to draft Uniform Label Requirements for Medical Gas Cylinders in 1939. In 1940, CGMA worked to support an American Hospital Association recommendation that small cylinders containing medical gases be color-coded to indicate the contents. The final code was published in 1973.

CGA developed and published in 1959, the **Diameter Index Safety System (DISS)** to meet the need for a standard for noninterchangeable connections where removable exposed threaded connections are employed in conjunction with individual gas lines of medical gas administering equipment at pressures of 200 psi or less. Noninterchangeable indexing is achieved by a series of increasing and decreasing diameters. This system provided industrywide design standard for low pressure medical gas connections to outlets of medical gas regulators, and connections for Anaesthesia, Resuscitation and Therapy Apparatus. It provides 20 non-interchangeable gas connections.

Now, since 1926, ISO, the International Federation of the National Standardizing Associations (ISA), a voluntary organization whose members are recognized standard authorities, each one representing one country, is actively involved in preparation of Globalised Harmonious Standards. It interacts with organisations similar to the BSI or (BIS in India), in its member countries and prepares International Standard for enhanced product quality and reliability for Equipment and Equipment Systems used in all walks of life.

One of the earliest standards published was ISO 32: 1957, Colour coding of medical gases, gas cylinders and gas pipelines. It also published ISO 407: Small medical gas cylinders, Pin Index Yoke-type valve connections. It has now published **ISO 7396: 2016, Medical Gas Pipeline System Part A & ISO 7396: 2007, Medical Gas Pipeline System Part B,** a comprehensive International Standard for Medical Gas Pipeline System in 2002. There are total of 26 ISO Standards, which relate to MGPS Installation. ISO 18082:2014, Anaesthetic and respiratory equipment, Dimensions of non-interchangeable screw-threaded (NIST) low-pressure connectors for medical gases specifies NIST connectors intended for use with Medical Gases. ISO has also published the ISO 134851:2016, Medical Device, Quality Management Systems, Requirements for regulatory purposes, a very useful practical guide for the industry.

Many countries have adopted ISO 7396 as their National Standard for Medical Gas Pipeline Systems like **India has IS/ISO 7396, 2007**; Canada has CAN/CSA Z 7396.1:2017; Australia has AS 2896:2021 Australia; South Africa has SANS 7396-1: 1ED 2009, etc.

Occupational Safety and Health Administration (OSHA) of USA provides Anaesthetic Gases Guidelines to monitor Workplace Exposures and provisioning of active Anaesthetic Gas Scavenging System (AGSS) which removes anaesthetic gas mixtures from Hospital’s Operating Rooms and any other areas. ISO 7396: 2007, Medical Gas Pipeline System, Part B, deals in detail with this provisioning.

NFPA 101, 2021 provides Fire Safety Guidelines for MGPS installation, especially for Oxygen Tanks and Cylinders Storage and requirements of safety in oxygen enriched environments.

Most of the Standards Organisations now provide skill training for inspection of MGPS Installations. This is of immense help in validation and verification of any MGPS Installations

SUPPLY OF MEDICAL GASES

Medical Gases are drugs, and their production, distribution and therapeutic use is described in National Pharmacopeias' and regulated by specified country specific codes.

Medical Gases are generally regulated as finished pharmaceuticals and their manufacturing is subject to CGMP requirements regardless of the processing stage.

NFPA 704 along with NFPA 55 presents a simple, readily recognized, and easily understood system of markings (commonly referred to as the "NFPA hazard diamond") that provides an immediate general sense of the hazards of Gases as they relate to emergency response for compressed gases and cryogenic liquids. OSHA HazCom 2012 index Informs workers about the hazards of chemicals in workplace under normal conditions of use and foreseeable emergencies.

These codes generally provide the following exceptions.

- Piped Distribution Systems of Gases
- Manufacture of assemblies such as pressure control manifolds, source valves, etc. that are manufactured in a supplier's shop and qualified for Piped Distribution Systems
- Manufacturing Plants or other establishments operated by the supplier or the supplier's agent for the purpose of storing and refilling portable containers, trailers, mobile supply trucks, or tank cars with Medical Gases;
- Medical Vacuum Systems
- Non-health care facilities such as Laboratories, Pharmaceutical, Animal Breeding or Bio-technology facilities
- Supply Systems that generate Compressed Medical Gases on-site for own use

TO CONCLUDE

The MGPS standardisation has, over the years, sublimated professional and commercial interests of Healthcare Providers and the MGPS industry, in favour of patient safety. It has eliminated occurrence of near fatalities from cross connection between the various gases being supplied. Now MGPS has become affordable and cost effective and within reach of a large number of Hospitals. It is hoped, MGPS Standardization will make our Hospitals a safer place for Healthcare Delivery.

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Last Line