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MEDICAL GAS PIPELINE DISTRIBUTION SYSTEM DESIGN USING MATLAB

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A thesis submitted to the school of mechanical and industrial engineering graduate studies of Addis Ababa University in partial fulfillment of the requirement for the degree of Masters of Science in Mechanical Engineering (Thermal Engineering stream)

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Declaration

I, the undersigned, declare that this MSc thesis is my original work, has not been presented for fulfillment of degree for this or other university, and all sources and materials used for the thesis work is acknowledged.

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This thesis work has been submitted for examination with my approval as a university advisor.

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Medical Gas Pipeline Distribution System Design using MATLAB

This is to certify that the thesis prepared by Natnael Belachew entitled "Medical Gas Pipeline Distribution System Design using MATLAB" in partial fulfillment of the requirement for the Degree of Master of Science in Thermal Engineering complies the regulation of Addis Ababa University and meets the accepted standards concerning orginality and quality.

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ABSTRACT

A medical gas pipeline system is a standardized method by World Health Organization (WHO) to deliver different medical gases from a centralized source of supply to the required terminal units using a carefully and well-designed pipeline distribution system. Since the expensive cost of an exclusive system designing software, most commercial companies use customized and unofficial Excel spreadsheet templates. This made the research area very demanding and unwieldy for further investigation. Hence powerful & explanatory MATLAB program is introduced for an optimized system design analysis. This thesis follows a conservative approach of the Health Technical Memorandum (HTM 02-01, UK) part A: Medical gas pipeline system design manual for the analysis. The thesis aimed to provide the safe and reliable Medical Gas Pipeline Distribution System design simulation platform using MATLAB software for the following 6 major & frequently used medical gases. Namely: Oxygen (O_2), Medical Air (MA), Medical Vacuum (MV), Surgical Air (SA), Nitrous Oxide (N_2O), Anesthetic Gas (AG). The system design analysis solves the pipeline distribution layout name coding for the main pipes and its sub branches, flowrate analysis, determination of the most remote pipeline and its pressure drop analysis. The manual system design analysis is also introduced and compared with the MATLAB analysis result for the sample two floors building. Therefore, the MATLAB program can analyze any number of floors with unlimited number of pipe arrangements in a well-organized design procedure. therefore, it’s a generalized design platform for designing the medical gas pipeline distribution system for any healthcare centers.

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CHAPTER ONE

INTRODUCTION

On this chapter the background of the study on medical gas pipeline distribution system and its overview. statement of the problem, objective of the study, scope of the study and significance of the study is presented.

1.1 Background of the study

A medical gas pipeline system (MGPS) comprises a source of supply, pipeline distribution system, terminal units (to which the user connects and disconnects medical equipment) and a warning/alarm system. Which is designed to supply a protected and effective method of delivering medical gases, medical air and surgical air from the source of supply to the appropriate terminal unit by means of a pipeline distribution system. Medical vacuum is also provided by means of a pipeline system. Anesthetic gas scavenging disposal systems are provided to control occupational exposure to waste anesthetic gases and agents [1].

Pipelines are devoted to a particular type of gas, and these systems will also include a medical vacuum and waste anesthesia exhaust system. Lines are accessible by outlets located around the facility. Accompanying these pipeline systems are various alarms and gauges to ensure the pipeline maintains pressure and flow. It reduces the problems associated with the use of gas cylinders such as safety, porterage, storage and noise [1].

A gas network basically consists of a number of controllable elements such as compressor stations and control valves that are connected via pipes. In the pipes of the network, the pressure of flowing gas decreases due to the friction with the walls of the pipes. This pressure loss makes more difficult to guarantee the security of supply: to meet the demand at the exit points with gas supplied at the entry points within the pressure bounds. Therefore, the pipeline distribution system is needed to be carefully designed [2].

It is essential to ensure that there is no possibility of a cross-connection between any system and that all parts of each system to which connections can be made by users are gas-specific. Dental compressed air and vacuum systems have differing requirements, and these are covered in Health Technical Memorandum 2022 Supplement 1 – ‘Dental compressed air and vacuum systems'. During the installation stage, extensive tests are carried out to verify that there is no cross connection [3].

Medical gas systems may be extended to those departments where respiratory equipment or surgical tools are serviced, such as in electronic and biomedical equipment (EBME) workshops and sterile services departments (SSDs) [3].

1.2 Overview of the system

The general use of the pipeline distribution with its gas flow, pre-requests and the design tents are explained on the following subtopics.

1.2.1 General uses of Medical Gases and pipeline installations

- Oxygen (O_2) is one of the most extensively used gases for respiratory therapy and life-support and is additionally used in anesthetic procedures. For oxygen systems the source of supply can be bulk liquid oxygen in a vacuum insulated evaporator (VIE), liquid or gaseous cylinders, or an oxygen concentrator (PSA) system. When cylinder supply systems are used, the source of supply comprises a primary and a secondary bank/group of cylinders which automatically change over to ensure continuity of supply [3]. it used at 370 to 420 Kpa (50 to 60 psig) [2].
- Medical air is mainly used in respiratory therapy as a power source for patient Ventilators, and for blending with oxygen. It is also used as the driving gas for nebulized drugs and chemotherapy agents. For medical air systems for respirable use, the source of supply can be either a medical gas manifold system or a medical compressor system, or an oxygen and nitrogen mixing system (referred to as synthetic air). When air powered ventilators are used regularly, the consumption of air is high and cylinder supply systems are not recommended [3]. it used at 370 to 420 Kpa (50 to 60 psig) [2].

- Surgical air (of medical air quality) is also used, at a higher pressure, to power a variety of surgical tools and other devices such as tourniquets. (As an alternative, nitrogen can be used for this purpose.) [1]. it used at 1100 to 1275 Kpa (160 to 185 psig) [2].

- Nitrous oxide (Entonox, N_2O/O_2) is used for anesthetic and analgesic purposes, being mixed with air, oxygen, and nebulized agents [1]. it used at 370 to 400 Kpa (50 to 60 psig) [2].
- Air or nitrogen for surgical tools is required at 700 Kpa. The supply can be provided by either a small automatic manifold system or a small dedicated compressed air system. No reserve supply is required since the surgical air is not used in a life-support role. A free-standing cylinder complete with regulator should be available in the event of system failure [3]. it used at 1100 to 1275 Kpa (160 to 185 psig) [2].

- Medical vacuum pipeline system provides immediate and reliable suction for medical needs, particularly in surgical accommodation. Medical vacuum is provided by means of a central vacuum plant. The vacuum system should always be used in conjunction with vacuum control units which include vacuum jars. In the event of inadvertent contamination of the pipeline systems resulting from vacuum jars overflowing, immediate action is required to clean the system before any fluids etc. dry out [3]. it used at 40 to 60 Kpa (300 to 450 mmHg). [2].

- Medical gases and vacuum are distributed throughout the hospital via the pipeline distribution system to provide gas (and vacuum) at the terminal units. Terminal units may be wall-mounted or installed within medical supply units, for example operating room fittings, bed-head trunking and walling fittings which include other facilities such as nurse-call systems, connections for patient monitoring, electrical services, audio systems, etc [3].

- Carbon dioxide (CO_2) is used less commonly now as a respiratory stimulant, and for insufflation during surgery. Pipeline systems for respiratory use have not been installed in the UK but they are now being installed for this latter purpose [3]. it used at 370 to 420 Kpa (50 to 60psig) [2].

- Helium/oxygen mixture (Heliox HE/O_2) is used to treat patients with respiratory or airway obstruction and to relieve symptoms and signs of respiratory distress; guidance on pipeline systems is now included [1]. it used at 370 to 420 Kpa (50 to 60 psig) [2].

- Waste Anesthesia Gas Disposal (WAGD) is used to capture & carry away gases vented from the patient breathing circuit during the normal operation of gas anesthesia or analgesia equipment. It used at 15 to 20 Kpa (114 to 152 mmHg) [4].
- The internal pipelines transport medical gases in large 42 mm pipes from a central source branching into smaller 15 mm pipelines. Color-coded gas outlets are either flush fitting to walls or in the form of suspended hoses which are gang mounted called pendant.
- The pipeline distribution system also includes area valve service units (AVSUs). These permit isolation of certain parts of the system for servicing or repair. They are also intended for use by the user, that is a nurse or clinician, in an emergency. For example, in the event of a fire in a ward requiring patient evacuation, or system damage to the extent that serious gas loss occurred, the valve should be turned off to prevent further gas loss [3].

1.2.2 Medical Gas flow

Various layouts of an MGPS need to be designed to take into account the anticipated design flow. There are several aspects of gas flow to consider when designing the pipeline distribution system [1].

a. the test flow that is required at each terminal unit for test purposes (this flow is essentially to establish that the terminal unit functions correctly and that there are no obstructions; see Appendix 1 - Glass flow – flows required at terminal units);
b. the typical flow required at each terminal (this is the maximum flow likely to be required at any time in clinical use; see Appendix 1 - Glass flow – flows required at terminal units);
c. the likely numbers of terminal units in use at any time;
d. the flow required in each sub-branch of the distribution, for example from the terminal unit or a number of terminal units (for example four in a four-bed ward) to the pipeline in the false ceiling of the ward corridor;
e. the total flow to the ward/department, that is, the sum of the diversified flows in each sub branch;

f. The flow in the main branches/risers, that is, the summation of all diversified flows; g. The flow required at the plant. In most cases this will be the flow in

g. Above except in the case of vacuum that is not used continuously.

The pipeline system should be designed so that the flows given in Appendix 1 - Glass flow – flows required at terminal units can be achieved at each terminal unit: the flows are expressed in free air. Diversified flows are used for the purposes of pipe size selection.

The designer should always ensure that due account is taken of the stated use of a particular department. There is a limited range of pipe sizes, and where there is any doubt about flow requirements, a larger pipe size should be selected.

Note

When calculating diversified flows, it is the number of bed spaces, treatment spaces or rooms in which the clinical procedure is being performed that is used; this is not the individual number of terminal units since, in many cases, more than one is installed. For example, a bed position in a critical care area may have four or more oxygen terminal units. The overall pipeline design should be based on a 5% pressure drop from the plant/source of supply to that measured at the terminal unit outlet at the specified test flows [1].

1.2.3 Pre-requests for Medical Gas Pipeline distribution system design

The following general information is required to design an MGPS [1].

1) schedule of provision of terminal units;

2) design flow rates and pressure requirements at each terminal unit;

3) diversified flows for each section of the pipeline system;

4) Total flow.

1.2.4 The Four Tenets of Medical Gas System Safety:

According to the listed international scholars the Four Tenets of Medical Gas System Safety [4].

a. Identity: Identity is assured by the use of gas-specific connections throughout the pipeline system, including terminal units, connectors etc., and by the adherence to strict testing and commissioning procedures of the system.

b. Adequacy: Adequacy of supply depends on an accurate assessment of demands & the selection of plant appropriate to the clinical/medical demands on the system.

c. Continuity: Continuity of supply is achieved by:

- The specification of a system that (with the exception of liquid oxygen systems which may include a secondary vessel) has duplicate components;
- The provision of a third means of supply for all systems except vacuum;
- The provision of alarm systems; and
- Connection to the emergency power supply system.

Surgical air systems are not considered to be life-support systems and therefore duplicate components are not normally required; an emergency/secondary supply is provided.

d. Quality of supply: Quality of supply is achieved by the use of gases purchased to the appropriate Ph. Eur. Requirements or produced by plant performing to specific standards, by the maintenance of cleanliness throughout the installation of the system, and by the implementation of the various testing and commissioning procedures [1].

1.3 Statement of Problem

Since the Medical Gas Pipeline Distribution System (MGPDS) design software used by various designer's & equipment manufacturer companies across the world is very costly, most commercial companies use unofficial customize and non-standardized Excel spreadsheet templates, which's tedious, time, energy consuming to design & even to made a slight design modification of the system. Hence, a more powerful & explanatory program as a design standard is needed but an optimized design of the system using MATLAB software isn't done yet. So, this research can fill the gap.

Therefore, on this thesis a conservative and effective approach will be introduced to provide the safe and reliable Medical Gas Pipeline Distribution System design simulation platform using MATLAB software for the following 6 major & frequently used medical gases for the sample layout. Namely: Oxygen (O2), Medical Air (MA), Medical Vacuum (MV), Surgical Air (SA), Nitrous Oxide (N2O), Anesthetic Gas (AG).

The system design analysis uses MATLAB software, which's a prior choice in data analysis and visualization, simulation for many engineering problems solving tools with highly reliable, flexible, excellent error diagnostics & code tracing capabilities. It solves the pipeline distribution layout name coding for the main pipes and its sub branches, flowrate analysis, determination of the most remote pipeline and its pressure drop analysis. Therefore, the MATLAB program will gave us a generalized platform which can analyze any number floors with unlimited number of pipe arrangements in a well-organized design procedure for any healthcare facilities.

1.4 Objectives of the thesis

1.4.1 General objective

The major aim of the thesis is to prepare a generalized platform to design the medical gas pipeline distribution system using MATLAB software for the 6 major and frequently used medical gases.

1.4.2 Specific objective

The specific objective of this thesis is to solve the following medical gas pipeline distribution design using a MATLAB software.

- Medical gas pipeline distribution layout name coding
- Determination of gas flowrate
- Estimation of Pipe sizing
- Pressure drop determination

1.5 Scope of the study

This paper only focused on the optimized pipeline design analysis platform for the selected major & frequently used 6 types of medical gases. Therefore, it doesn’t include other medical gases and auxiliary equipment selection of the system.

1.6 Significance of the study

This study aimed to prepare a general designing platform of the medical gas pipeline distribution system by introducing a MATLAB program. which include solving a gas flowrate, pipe diameter & pressure drop for the pipeline distribution system layout of the selected major & frequently used medical gases. Namely: Oxygen (O_2), Nitrous Oxide (N_2O), Surgical Air (SA), Medical Air (MA), Medical Vacuum (MV). Therefore, the study enables to design the medical gas pipeline distribution for the clinics & hospitals.

In addition to designing the medical pipeline distribution system by applying engineering knowledge for health care applications, it has the following comparative advantages:

- It will help to reduce the system designing software purchasing cost
- It will help to improve the system parameter design optimization
- It enables the hospitals to be a standardized & profitable health care facility in its long-term use of the system.
- Since our country haven't a design standard for the MGPS, this document will be helpful as a design reference and guidance.

CHAPTER TWO

LITERATURE REVIEW

On this chapter a literature review of medical gas pipeline system design manuals are presented with the selection of a standardize design manual selection is carried out, a literature review of different scholars research have been introduced.

2.1 Medical Gas Pipeline Distribution System (MGPDS) Design Standards

An MGPS is designed to provide a safe and effective method of delivering medical gases, medical air and surgical air from the source of supply to the appropriate terminal unit by means of a pipeline distribution system [1].

There are two types of hazards associated with medical gas equipment: general fire and explosions, and mechanical issues such as physical damage to compressed gas cylinders [3].

Fire and explosions can be caused by incidents involving oxygen, which is the most common gas used in health care facilities, and nitrous oxide, which is used frequently as an inhalation anesthetic. These gases are oxidizers that, when present in sufficient quantity and concentration, form one side of the “fire triangle.” When the other two sides of the triangle, heat and fuel, are added, fire and/or explosion can result. The hazard is intensified because many materials commonly available in health care facilities that are not flammable in normal room air become flammable (or extremely flammable) when the concentration of oxygen is raised above that in room air. Nitrous oxide is not an oxidizer at room temperature, but it dissociates and forms oxygen under elevated temperatures that might be present during a fire [5].

Compressed gas cylinders that sustain mechanical damage can also be a hazard. Gases inside cylinders are generally under high pressures, and the cylinders often have significant weight. The cylinders can cause injuries directly due to their weight and inertia. Damage to the regulators or valves attached to a cylinder can allow the escaping gas to propel the cylinder violently in a dangerous manner. The pin-index safety system and gas regulators can also suffer physical damage and cause hazards to patients if the wrong gas is delivered [5].

There are three main standards in use internationally that provide best practice guidance for medical gas systems and products

2.1.1 Health Technical Memorandum (HTM 02-01, UK)

It supersedes HTM 2022 & HTM 22, It's used in various countries in the Middle East, Africa & Asia.

The British standard HTM 2022 published by the UK Department of Health is one of the most well used guidelines in the United Kingdom and in other parts of the world. The first volume of HTM 2022 covers the design, installation, verification and validation of medical gases, the installation of compressed medical air and vacuum, and all installed [3].

MGPS in health facilities. Furthermore, the second volume of HTM 2022 targets the operational management of MGPS. Following a standard revision in 2006, the British Ministry of Health reorganized these documents. Thus, the volumes are now HTM02-01 Part A and HTM 0201 Part B [1].

2.1.2 National Fire Protection Association (NFPA 99, US)

It supersedes NFPA 56F & 56K, used in various South American & Asian countries. The US standard NFPA 99, 2005 edition, was drawn up by the Compressed Gas Association and the. National Fire Protection Association. in the United States. The next revision of this standard is scheduled for 2012. This standard aims to minimize the hazards of fire, explosion, and electricity in health care facilities providing services to human beings [2].

2.1.3 European Code (ISO 7396-1, EU)

It supersedes EN 737, which is used in various South America & Asian countries. Part 1: Pipeline systems for compressed medical gases and vacuum. The standard ISO 7396-1: 2007 was developed by the International Organization for Standardization. It has been fully reproduced by the European standard EN ISO 7396-1:2007 and the French standard NF EN ISO 739 6:2007. The standard ISO 7396-1:2007 specifies requirements for the design, construction, operation, performance, documentation, testing and commissioning of the pipeline systems for compressed medical gases, gases for driving surgical tools and vacuum in healthcare facilities. It seeks to ensure a continuous supply of vacuum and medical gases. It includes requirements for systems of supply, distribution, control and surveillance, and no interchangeability between components of several gas distribution systems [2].

2.2 Medical Gas Pipeline Distribution System (MGPDS) Design Standard comparison

- ✞ The two main international standards in use that provide best practice guidance for medical gas systems and products – NFPA 99 (US) and HTM 02-01 (UK).

Figure 1:HTM 02-01 Parts A and B (UK) and NFPA 99(US) [12]

The above medical gas pipeline distribution system design standards follow different design perspectives on the system design and installation. The following table shows their basic difference and one of these two design manuals will be selected for the design analyses.

Table 1: World Standards for Medical Gas Systems Comparison [12]

Overview & Principles	NFPA 99	HTM 02-01
Date of first Publication	1986	1972
Years of Embedded Experience	21	34
Number of pages Dedicated to Medical Gases	136	330
Published by a Government Agency	x	✓
Equipment Fault Tolerance Levels	1	2
Management Structure Defined- CP, AP, DNO roles	x	✓
Products Regulated-CE Mark to the MDD	x	✓
Quality Control Pharmacist Verification of Gas Purity	x	✓
European Pharmacopoeia Quality Compliance	x	✓
Risk Management to ISO 14971	x	✓
Design Elements		
Terminal Unit & Gas Flow Schedules	x	✓
Auto Ignition Testing of High-Pressure Regulators	x	✓
Halogenated Polymers Banned in HP O2 Service	x	✓
Bacteria Filters for Protection of Medical Vacuum	x	✓
Refrigerant Dryers Disallowed	x	✓
Medical Air Dew Point (ppm v/v)	1833	67
Minimum Pressure Vessel Sizes	x	✓
Liquid Sealed Pumps/Compressors Disallowed	x	✓
AGS & Medical Vacuum Supplies Separate	x	✓
Duplex Emergency Backup Manifold	x	
Operational Management Elements		

Operational Policy	x	✓
Maintenance Contract Guidance	x	✓
Equipment Maintenance Procedures Defined	x	✓
Verification Procedures and Forms	x	✓
Permit to work System	x	✓
Management Processes-CP, AP, DNO roles	x	✓
Minimum Training Requirements Defined	x	✓
Medical Air Safety Limits		
Component	**NFPA 99**	**HTM 02-01**
Oxygen (O_2)	19.5-23.5 %	20.4-21.4 %
Oil	Not specified	0.1 mg/m3
Water (H_2O)	1833 ppm	67 ppm
Carbon Monoxide (CO)	10 ppm	5 ppm
Carbon Dioxide (CO_2)	500 ppm	500 ppm
Nitrogen Dioxide (N_2O)	Not specified	2 ppm
Nitric Oxide (NO)	Not specified	2 ppm
Sulfur Dioxide (SO_2)	Not specified	1ppm
The Four Tenets		
Continuity	**	***
Adequacy	**	***
Identity	***	***
Quality	*	***
Other Key Measures		

Sustainability	*	***
Usability	**	***
Overall Value	******	*******

*HTM 02-01 Reflects European Law. Must be verified by an independent QC pharmacist [6].

Note:

As we seen from the above table HTM 02-01 (UK) have many advantages with respect to different criteria. So, the selected module is **Health Technical Memorandum HTM 02-01 (UK)** standard for the design guidance.

2.3 Different researches on gas pipeline networking system

The development and construction of a gas pipe flow network is a very time consuming and costly endeavor. Therefore, it is paramount to be able to calculate critical properties, such as mass flow rates through pipes and static pressures at nodes in the pipe flow network [3].

There're some scholars who has done researches on gas pipeline networking system but most of them didn't focused specifically on the medical gas pipeline networking systems. So the literature review contains the general gas pipe networking related studies.

The two researchers Sita Bhaskaran and Franz J. M. Salzborn had worked on the Optimal Diameter Assignment for Gas Pipeline Networks, which discussed on optimally assigning diameters to a gas pipeline network by using a linear programming model. The pipeline diameters will determine the pressure drops between the plant and each of the wells. The constraints on the diameters are caused by the restriction that these pressure drops are not allowed to exceed a certain limit: the gas has to arrive at the plant at a certain pressure and there is a maximum for the pressure at which the gas can be delivered at the wells. The diameters are selected from a finite set of possible diameters, for each of which the cost per mile is given. But it is possible for a link to consist of sections of different diameters connected in series [7].

An impressive researcher has done by Gerald Recktenwald, who developed a MATLAB programs for pipe flow analysis for steady, incompressible flow. Using these functions, it is possible to perform head loss calculations, solve flow rate problems, generate system curves, and find the design point for a system and pump [8].

Dr. David Keffer works on pipe networking using MATLAB program. He discussed the flow behavior of a piping network, using material balances and mechanical energy balances for incompressible fluid, so the density is constant and the temperature changes is not need to consider [9].

The SREE Conference on Engineering Modelling and Simulation (CEMS 2011) presented the transient flow simulation of municipal gas pipelines and networks using semi implicit finite volume method. The study explains an efficient transient flow simulation for gas pipelines and networks is performed. The proposed transient flow simulation is based on the transfer function models and finite volume method. The equivalent transfer functions of the nonlinear governing equations are derived for different boundary condition types. To verify the accuracy of the proposed simulation, the results obtained are compared with those of the experiments. The effect of the flow inertia is considered in this simulation with discretization by TVD scheme. The accuracy of the proposed method is discussed for two test cases. It is shown that the proposed simulation has a sufficient accuracy [10].

The four Chinese researchers: Hélène van den Brink, Eric Fouassier, Alejandro Berardi, Shuo Lin, proposed the solution to improve the quality management of medical gas pipeline system in china. several deficiencies relating to the distribution and use of medical oxygen, which may lead to a n umber of fatal accidents like gas pipeline explosion and cause illicit product use, have been revealed in health facilities. They are the result of a lack of the relevant standards, management and practical experience. To overcome these facilities, it might be interesting to refer to the experience and regulations of other countries, for example, those of France [11].

There's a journal presented at the 3rd Trondheim Gas Technology Conference, TGTC-3 that focused on the simulation and optimization models of steady-state gas transmission networks, which discussed on Managing a gas transport network. This work deals with mathematical modeling and optimization of gas transport networks, where a two-stage procedure is proposed. In the first stage, optimization algorithms based on mathematical programming are applied to make some decisions (whether to activate compressor stations, control valves and other control elements) and gives an initial solution to the second stage. This last stage, which is based on control theory techniques, refines the solution to obtain more accurate results. Due to the reduced complexity in each stage, both can be solved within reasonable runtimes for relatively large gas networks. Based on the mathematical methods involved, a software called GANESOTM has been developed [2].

A recent journal is published by Jolanta Szoplik studied the changes in the gas pipeline depending on the network foundation in the area, the article presents an analysis of the results of overpressure distribution, velocity and gas streams obtained during the simulation of gas flow in the low-pressure pipeline network. The calculations were made for the section of an existing gas network and the actual data describing gas consumption from the network by municipal customers and actual weather data characteristic to the specific city. Minimum and maximum overpressure of gas stream entering the network was determined, depending on the size of the network load and the difference in height between the gas station supplying the network and the most distant network connection (parameter DH). It was demonstrated that taking into account in the calculation the differences in the height of particular pipelines location in the network affects the selection of overpressure limit values of gas stream supplying the network. Moreover, gas overpressure distributions were compared in particular pipelines in the network for different cases of pipeline location in the area [12].

2.4 Chapter summary

There're many studies on the fluid flow through pipes for the specific objectives using different commercial software's. But the medical gas pipeline distribution system design for the specific medical gas system isn't done yet using MATLAB software. So, it's clear that this research results will fill the gap. Hence on this research the **Health Technical Memorandum HTM 02-01 (UK)** standard is selected as a design manual for the MATLAB analysis.

CHAPTER 3

METHODOLOGY

On this chapter a logical and a systematic approach using MATLAB software is carried out to solve the design analysis.

Since the standards for pipeline distribution designing calculation follow a very conservative approach, designing using the analytical method isn't recommendable because it's a tedious & also it's a tedious, time, energy consuming to design & even to make a slight design modification of the system.

On this study, MATLAB software is introduced in effective approach for the analysis by importing the input data from an Excel spreadsheet. Which is an interactive programming language that can be used in many ways, including data analysis and visualization, simulation and engineering problem solving tools.

3.1 Research Methodology

The following sequence of methods could be a better approach for solving medical gas distribution problem. [5]

1. Problem Definition:

The first steps in problem solving include:

- Recognize and define the problem precisely by exploring it thoroughly (may be the most difficult step).
- Determine what question is to be answered and what output or results are to be produced.
- Determine what theoretical and experimental knowledge can be applied.
- Determine what input information or data is available

If the problem is not well defined, considerable effort must be expended at the beginning in studying the problem, eliminating the things that are unimportant, and focusing on the root problem. Effort at this step pays great dividends by eliminating or reducing false trials, thereby shortening the time taken to complete later steps.

After defining the problem:

- Collect all data and information about the problem for the selected sample layout & decide the following data: (Number of beds, Number patient in each room, Number wards the hospital has, Number intensive care units (ICU), Number surgical room, building drawing, Free spaces for installing & Others related data)
- Verify the accuracy of this data and information.
- Determine what information you must find: intermediate results or data may need to be found before the required answer or results can be found.

2. Mathematical Model:

To create a mathematical model of the problem to be solved:

- Determine what fundamental principles are applicable.
- Draw sketches or block diagrams to better understand the problem.
- Define necessary variables and assign notation.
- Reduce the problem as originally stated into one expressed in purely mathematical terms.
- Apply mathematical expertise to extract the essentials from the underlying physical description of the problem.
- Simplifytheproblemonlyenoughtoallowtherequiredinformationandresultstobeobtained
- Identify and justify the assumptions and constraints inherent in this model.

3. Computational Method:

A computational method for solving the problem is to be developed, based on the mathematical model.

- Derive a set of equations that allow the calculation of the desired parameters and variables.

- Develop an algorithm, or step-by-step method of evaluating the equations involved in the solution.
- Describe the algorithm in mathematical terms and then implement as a computer program.
- Carefully review the proposed solution, with thought given to alternative approaches.

4. Implementation of Computational Method:

Once a computational method has been identified, the next step is to carry out the method with a computer, whether human or silicon.

Some things to consider in this implementation:

- Assess the computational power needed, as an acceptable implementation may be hand calculation with a pocket calculator.
- If a computer program is required, a variety of programming languages, each with different properties, are available.
- A variety of computers, ranging from the most basic home computers to the fastest parallel supercomputers, are available.
- The ability to choose the proper combination of programming language and computer, and use them to create and execute a correct and efficient implementation of the method, requires both knowledge and experience.

The mathematical algorithm developed in the previous step must be translated into a computation algorithm and then implemented as a computer program. The steps in the algorithm should first be outlined and then decomposed into smaller steps that can be translated into programming commands.

One of the strengths of MATLAB is that its commands match very closely to the steps that are used to solve engineering problems; thus, the process of determining the steps to solve the problem also determines the MATLAB commands. Furthermore, MATLAB includes an extensive toolbox of numerical analysis algorithms, so the programming effort often involves implementing the mathematical model, characterizing the input data, and applying the available numerical algorithms.

5. Test and Assess the Solution:

The final step is to test and assess the solution. In many aspects, assessment is the most open-ended and difficult of the five steps involved in solving computational problems.

The numerical solution must be checked carefully:

- A simple version of the problem should be hand checked.
- The program should be executed on obtained or computed test data for which the answer or solution is either known or which can be obtained by independent means, such as hand or calculator computation.
- Intermediate values should be compared with expected results and estimated variations. When values deviate from expected results more than was estimated, the source of the deviation should be determined and the program modified as needed.
- A “reality check” should be performed on the solution to determine if it makes sense.
- The assumptions made in creating the mathematical model of the problem should be checked against the solution.

❖ **Materials for designing are:**

- Medical gas distribution system design books: by reading different design books, catalogs and charts.
- MATLAB software books & other tutorials
- Internet: it can be a source for different books and course lecture videos.

3.2 Research approach

Engineering often involves applying a consistent, structured approach to the solving of problems. A general problem-solving approach and method can be defined, although variations will be required for specific problems. Problems must be approached methodically, applying an algorithm, or step-by-step procedure by which one arrives at a solution.

This thesis majorly uses theoretical and numerical study approach. First theoretical description is made about the working principle of MGPDS. On this basis, appropriate mathematical formulations selection is made. Later numerical analysis is performed using MATLAB. The results obtained are validated by comparing numerical results with the design standards. Finally, parametric study and optimization is performed. To complete the aforementioned tasks the following the problem-solving process for a computational problem can be outlined as follows:

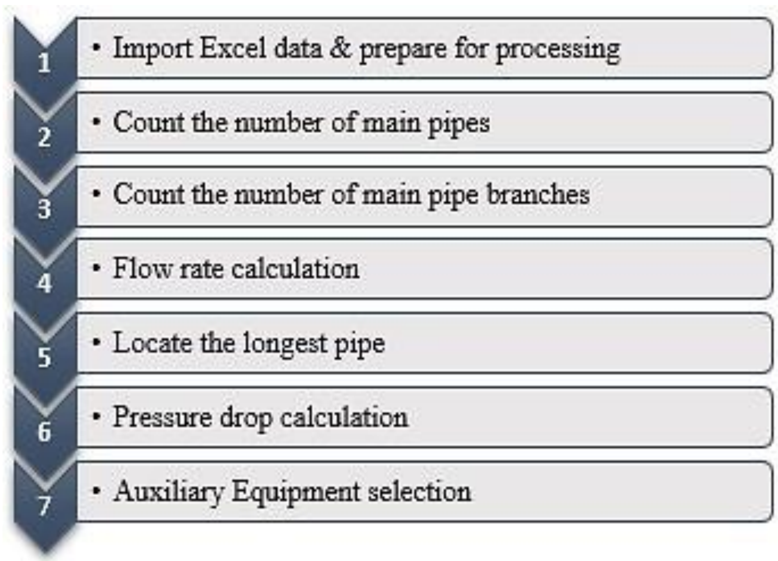


Figure 2: Problem-solving process for a computational problem

The boundaries between these steps can be blurred and for specific problems one or two of the steps may be more important than others. Nonetheless, having this approach and strategy in mind will help to focus our efforts as we solve problems.

3.3 Mathematical modelling of MGPDS

3.3.1 MGPDS diversified flow equations & calculation analysis

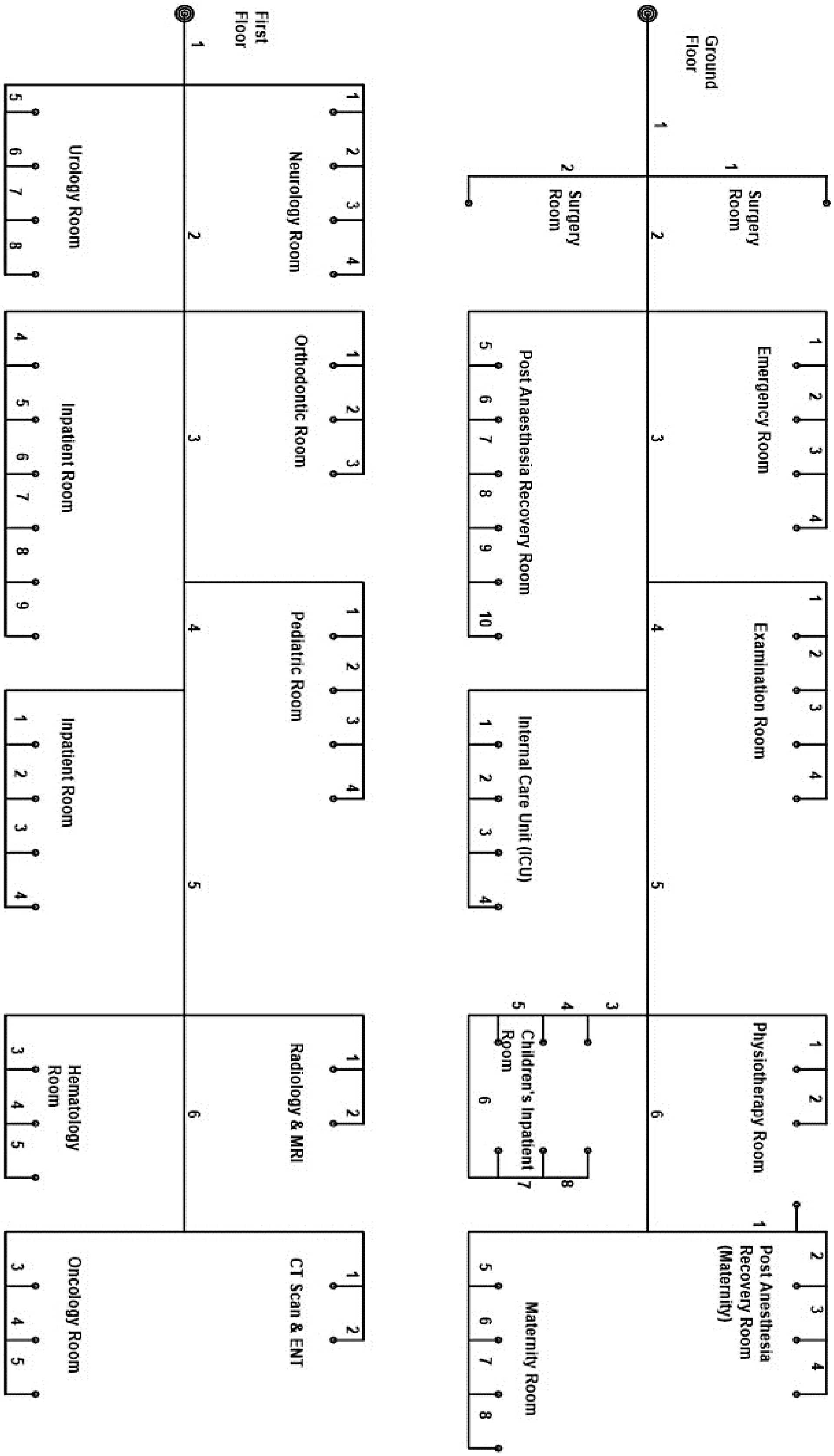
In this thesis the included six type of medical gases are: Oxygen (O_2), Medical Air (MA), Surgical Air (SA), Medical Vacuum (Medical), Nitrous Oxide (N_2O) and also Anesthetic Gas (AGS).

According to the selected design standard of HTM 02-01 Part A, the design of the pipe work system is based on the diversified flows and the permissible pressure loss from the source of supply to, and including, the terminal unit pressure loss. The pipe sizes should be selected to ensure that the pressure loss is below 5% [1].

- Legend for the following medical gas design and diversified flows:
  - Q = diversified flow for the department;
  - Q_w = diversified flow for the ward;
  - Q_d = diversified flow for the department (comprising two or more wards);
  - n = number of beds, treatment spaces or single rooms in which the clinical procedure is being performed, not the individual numbers of terminal units where, in some cases, more than one is installed;
  - nS = number of operating suites within the department (anesthetic room and operating room).
  - nW = number of wards
  - nT = number of theatres

The selected health care center for the design analysis is Yekatit 12 hospital ground & first floor (Appendix 31 – Sample hospital plan layout for MGDS - Ground floor (Floor 1)Appendix 32 – Sample hospital plan layout for MGDS - First floor (Floor). Hence the following figure shows the simplified medical gas pipeline distribution layout of the hospital.

Figure 3: Medical gas pipeline distribution layout



3.3.1.1 Oxygen (O_2)

- In-patient accommodation

Oxygen is used at a typical flow of 5–6 L/min. Each terminal unit should, however, be capable of passing 10 L/min (at standard temperature and pressure (STP) at supply pressure of 400 KPa (nominal) as shown in Appendix 2 - Oxygen: design and diversified flows .

- Operating departments

The diversified flow for operating departments is based on 100 L/min required for the oxygen flush. Therefore, each oxygen terminal unit in the operating room and anesthetic room should be able to pass 100 L/min [1].

- Critical care, coronary care and high-dependency units

The flow for these units assumes that, although all bed spaces may be occupied, threequarters of these will require the use of oxygen. Each terminal unit should be capable of delivering 10 L/min. The diversified flow is calculated assuming 10 L/min for the first bed space and 6 L/min for three-quarters of the remainder [1].

- Maternity

For LDRP (labor, delivery, recovery, post-partum) rooms, the diversified flow is based on 10 L/min for the first terminal unit and 6 L/min for 25% of the remainder [1].

Note:

> For Oxygen gas design and diversified flow equation see Appendix 2 - Oxygen: design and diversified flows .

 # Floor 1

Flowrate calculation

Main pipe 6

Maternity room, [Q = 100 + (n - 1) 6]

[68], n=1, Q = 100 + (1 - 1) 6 = 100

[67], n=2, Q = 100 + (2 - 1) 6 = 106

[66], n=3, Q = 100 + (3 - 1) 6 = 112

[65], n=4, Q = 100 + (4 - 1) 6 = **118**

Post Anesthesia Maternity recovery room, [Q = 10 + (n - 1) 3/4]

[64], n=1, Q = 10 + (1 - 1) 3/4 = 10

[63], n=2, Q = 10 + (2 - 1) 3/4 = 10.75

[62], n=3, Q = 10 + (3 - 1) 3/4 = 11.5

[61], n=4, Q = 10 + (4 - 1) 3/4 = **12.25**

Total flow rate for main pipe 6 = 118 + 12.25 = **130.25**

Main pipe 5

Children's inpatient room, [Q = 100 + (n - 1) 6/6]

[58], n=1, Q = 10 + (1 - 1) 6/6 = 10

[57], n=2, Q = 10 + (2 - 1) 6/6 = 11

[56], n=3, Q = 10 + (3 - 1) 6/6 = 12

[55], n=4, Q = 10 + (4 - 1) 6/6 = 13

[54], n=5, Q = 10 + (5 - 1) 6/6 = 14

[53], n=6, Q = 10 + (6 - 1) 6/6 = **15**

Physiotherapy room, [Q = 10]

[52], n=1, Q = 10

[51], n=2, Q = **10**

Total flow rate for main pipe 5 = 130.25 + 15 + 10 = **155.25**

Main pipe 4

Internal Care unit (ICU room), [Q = 10 + ((n - 1)6)3/4]

[44], n=1, Q = 10 + ((1 - 1)6) 3/4 = 10

[43], n=2, Q = 10 + ((2 - 1)6) 3/4 = 14.5

[42], n=3, Q = 10 + ((3 - 1)6) 3/4 = 19

[41], n=4, Q = 10 + ((4 - 1)6) 3/4 = **23.5**

Total flow rate for main pipe 4 = 155.25 + 23.5 = **178.75**

Main pipe 3

Examination room, [Q = 10 + (n - 1)6/4]

[34], n=1, Q = 10 + (1 - 1) 6/4 = 10

[33], n=2, Q = 10 + (2 - 1) 6/4 = 11.5

[32], n=3, Q = 10 + (3 - 1) 6/4 = 13

[31], n=4, Q = 10 + (4 - 1) 6/4 = **14.5**

Total flow rate for main pipe 3 = 178.75 + 14.5 = **193.25**

Main pipe 2

Post Anesthesia recovery room, [Q = 10 + (n - 1) 6]

[210], n=1, Q = 10 + (1 - 1) 6 = 10

[29], n=2, Q = 10 + (2 - 1) 6 = 16

[28], n=3, Q = 10 + (3 - 1) 6 = 22

[27], n=4, Q = 10 + (4 - 1) 6 = 28

[26], n=5, Q = 10 + (5 - 1) 6 = 34

[25], n=6, Q = 10 + (6 - 1) 6 = **40**

Emergency room, [Q = 10 + (n - 1) 6/4]

[24], n=1, Q = 10 + (1 - 1) 6/4 = 10

[23], n=2, Q = 10 + (2 - 1) 6/4 = 11.5

[22], n=3, Q = 10 + (3 - 1) 6/4 = 13

[21], n=4, Q = 10 + (4 - 1) 6/4 = **14.5**

Total flow rate for main pipe 2 = 193.5 + 40 + 14.5 = **247.75**

Main pipe 1

Surgery rooms: [Q = 100 + (n - 1) 10]

[11], n = 1, Q = 100 + (1 - 1)10 = **100**

[12], n = 1, Q = 100 + (1 - 1)10 = **100**

Total flow rate for main pipe 1 = 248 + 100 + 100 = **447.75**

 # Floor 2

Flowrate calculation

Main pipe 6

Oncology room, [Q = 10]

[65], n=1, Q = 10

[64], n=2, Q = 10

[63], n=3, Q = **10**

CT Scan & ENT room, [Q = 10]

[62], n=1, Q = 10

[61], n=2, Q = **10**

Total flow rate for main pipe 6 = 10 + 10 = **20**

Main pipe 5

Hematology room, [Q = 10]

[55], n=1, Q = 10

[54], n=2, Q = 10

[53], n=3, Q = **10**

Radiography & MRI room, [Q = 10 + (n - 1)2]

[52], n=1, Q = 10 + (1 - 1)2 = 10

[51], n=2, Q = 10 + (2 - 1)2 = **12**

Total flow rate for main pipe 5 = 20 + 10 + 12 = 4**2**

Main pipe 4

Inpatient room, [Q = 10 + (n - 1)6/4]

[44], n=1, Q = 10 + (1 - 1) 6/4 = 10

[43], n=2, Q = 10 + (2 - 1) 6/4 = 11.5

[42], n=3, Q = 10 + (3 - 1) 6/4 = 13

[41], n=4, Q = 10 + (4 - 1) 6/4 = **14.5**

Total flow rate for main pipe 4 = 42 + 14.5 = **56.5**

Main pipe 3

Pediatric room, [Q = 10]

[34], n=1, Q = 10

[33], n=2, Q = 10

[32], n=3, Q = 10

[31], n=4, Q = **10**

Total flow rate for main pipe 3 = 56.5 + 10 = **66.5**

Main pipe 2

Inpatient room, [Q = 10 + (n - 1) 6/4]

[29], n=1, Q = 10 + (1 - 1) 6/4 = 10

[28], n=2, Q = 10 + (2 - 1) 6/4 = 11.5

[27], n=3, Q = 10 + (3 - 1) 6/4 = 13

[26], n=4, Q = 10 + (4 - 1) 6/4 = 14.5

[25], n=5, Q = 10 + (5 - 1) 6/4 = 16

[24], n=6, Q = 10 + (6 - 1) 6/4 = **17.5**

Orthodontic room, [Q = 10 + (n - 1) 6/3]

[23], n=1, Q = 10 + (1 - 1) 6/3 = 10

[22], n=2, Q = 10 + (2 - 1) 6/3 = 12

[21], n=3, Q = 10 + (3 - 1) 6/3 = **14**

Total flow rate for main pipe 2 = 66.5 + 17.5 + 14 = **98**

Main pipe 1

Urology rooms: [Q = 10]

[18], n=1, Q = 10

[17], n=2, Q = 10

[16], n=3, Q = 10

[15], n=4, Q = **10**

Neurology rooms: [Q = 10]

[14], n = 1, Q = 10

[13], n = 1, Q = 10

[12], n = 1, Q = 10

[11], n = 1, Q = **10**

Total flow rate for main pipe 1 = 98 + 10 + 10 = **118**

The total diversified flowrate is the sum of individual floors flowrate

$Q_{Total} = Q_1 + Q_2$

$= 118 + 447.75$

$\mathbf{Q_{Total} = 565.75}$

Riser flowrate

$Q_{Riser} = Q_{Total} = 565.75$

3.3.1.2 Medical Vacuum (MV)

Medical vacuum pumps are used to supply the required vacuum for the hospitals. Vacuum Pumps are manufactured as air cooled, oil lubricated and oil free rotary vane types. The motor capacity is about 0, 18 kW and 30 kW. The Vacuum Pumps don't have any risk to draw over current and cut off. One of its properties is to run at the maximum vacuum value. The maximum vacuum level is about 720 mmHg and it can also run at the vacuum level about 500-620 mmHg. The capacity of the vacuum pump is determined according to the calculation result of the hospital flow. Vacuum pumps have a range of 4-630 m^3/h depending upon size of the hospital [1].

Vacuum is provided for the surgical team and anesthetist in the operating room. It is also provided in the anesthetic and recovery rooms. Since it is possible for both the surgical team and anesthetist to use vacuum simultaneously, each operating room will require 80 L/min and each terminal unit should be capable of passing 40 L/min. duplex arrangement of bacterial filter group prevents bacteria accumulated [1].

In the Pipeline to reach vacuum tank and thus provide hygiene in hospitals where Medical Vacuum plants are used. The duplex bacterial filter system shall incorporate high efficiency filter elements. Each filter shall be designed and sized to carry the full plant design flow capacity with a pressure drop not exceeding 33mbar (25mmHg). This process is significant in those situations where the plant is used and in hospitals where hygiene is top important. This part of the plant is located between the reservoir and the service [1].

The vacuum reservoir is manufactured to meet the requirements of the hospital and has the function to start or to stop the vacuum pump [1].

Note:

> For Medical Vacuum design and diversified flow equation see Appendix 3 – Vacuum: design and diversified flows .
>
> For the manual design calculation of the flowrate refer Appendix 19 - Manual design analysis for Medical vacuum

3.3.1.3 Medical Air (MA)

Medical air is usually supplied from a compressed air plant that includes high-quality drying and filtration equipment. Blending oxygen and nitrogen on-site to provide a high-quality product with minimum maintenance can also provide medical air. Where such systems are installed to provide both oxygen and medical air, nitrogen can be used for the power source for surgical tools [1].

Medical air is mainly used in respiratory therapy as a power source for patient ventilators, and for blending with oxygen. It is also used as the driving gas for nebulized drugs and chemotherapy agents [1].

The supply system for medical air 400 kPa may be a manifold system, a compressor system or a proportioning system (synthetic air), and includes an emergency reserve manifold. A compressor plant, or synthetic air supply, should always be specified where air-powered ventilators are to be used [1].

One of the major uses of medical air is for patients' ventilators, which fall into two main categories – those used during anesthesia and those used during critical care. Pneumatically powered ventilators can use up to 80 L/min free air continuously. The exact flow requirements will depend on the design of the ventilator [1].

Current models of anesthetic ventilator are very similar to critical care models, and may require peak flows of up to 80 L/min and average flows of 20 L/min. Almost all such units are pneumatically driven and electronically controlled [1].

Medical air 400 kPa is also used for other equipment such as anesthetic gas mixers, humidifiers and nebulizers. The flow rates normally required would not exceed 10 L/min, and this flow is always in excess of the actual volume respired [1].

Note:

For Medical Air design and diversified flow equation see Appendix 4 - Medical air: design and diversified flows .

For the manual design calculation of the flowrate refer Appendix 20 - Manual design analysis for Medical air.

3.3.1.4 Surgical Air (SA)

The pressure requirements of surgical tools are between 600 and 700 kPa and flows may vary between 200 and 350 L/min (STP). Most surgical tools are designed to operate within this pressure range. Higher pressures are likely to cause damage to tools. Inadequate tool performance, however, is likely to result from the lack of flow at the specified pressure. The introduction of synthetic air (from on-site blending of oxygen and nitrogen) leads to the possibility of using nitrogen as the power source for surgical tools [1].

The pipeline systems should be designed to provide a flow of 350 L/min at 700 kPa at the outlet from the terminal unit. Existing systems may not meet this requirement (but should be capable of delivering 250 L/min at the terminal unit) [1].

Note:

For Surgical Air design and diversified flow equation see Appendix 5 - Surgical air 700 kPa – design and diversified flows .

For the manual design calculation of the flowrate refer Appendix 21 - Manual design analysis for Surgical air.

3.3.1.5 Nitrous oxide (N_2O)

Nitrous oxide is provided for anesthetic purposes and occasionally for analgesic purposes. In all cases, each terminal unit should be capable of passing 15 L/min, but in practice the flow is unlikely to exceed 6 L/min. The common source of nitrous oxide is a cylinder-manifold system. High-pressure manifold systems consist of two banks of cylinders, primary and reserve [1].

System demands for nitrous oxide can be more difficult to determine than they are for other medical gases. The number of surgeries scheduled, the types and lengths of surgery, and the administering techniques used by the anesthesiologists cause extreme variations in the amount of nitrous oxide used. Because of this variation, considerations must be given to the size and selection of the nitrous-oxide manifold system [1].

When calculating diversities in a department, 15 L/min is allowed for the first and 6 L/min for the remainder, subject to the appropriate diversity factor being applied (see Appendix 6 - Nitrous oxide: design and diversified flows).

It is assumed that, for an operating department, nitrous oxide may be in use simultaneously in all operating rooms. As it’s unlikely that a patient would be anaesthetized in the anesthetic room at the same time that a patient in the associated operating room was continuing to be treated under an anesthetic (and because the duration of induction is short), no additional flow is included [1].

Note:

For Nitrous Oxide design and diversified flow equation see Appendix 6 - Nitrous oxide: design and diversified flows .

For the manual design calculation of the flowrate refer Appendix 22 - Manual design analysis for Nitrous Oxide.

3.3.1.6 Anesthetic gas scavenging systems (AGSS)

For anesthetic gas scavenging systems, it should be assumed that for each operating suite two terminal units could be in use simultaneously, for example in the anesthetic room and operating room (receiving systems may be left connected when patients are transferred from the anesthetic room to the operating room) [1].

Note:

For anesthetic gas scavenging systems design and diversified flow equation see Appendix 7 - Anesthetic gas scavenging systems: design and diversified flows .

For the manual design calculation of the flowrate refer Appendix 23 - Manual design analysis for Anesthesia gas.

3.3.2 Medical Gas Pressure Drop Calculation

Each system is sized individually, and it is not good practice to size one and transpose the sizing to another, even if the two looks to have exactly the same outlets and run to all the same locations. The density of different gases does influence the sizing of the pipe [1].

The sizing operation is iterative, involving working backwards, section by section, along the pipe. Each section is sized and its loss calculated, with the total loss being aggregated to ensure it is below the accepted maximum. Looking over the plans it is usually reasonably obvious which outlet is most distant from the source, but in some designs, it may require some rough measurements [1].

I. Estimate the pipe size: There are two absolute rules in estimating pipe size.

- Pressure gas pipelines to the end of the hard pipe may never be smaller than 12mm (1/2”) nominal size.
- Vacuum and high vacuum WAGD piping to the end of the hard pipe may never be smaller than 19mm (3/4”) nominal size.

II. Size the branches: The procedure for each branch is the same as for the main line, beginning at the outlet most distant from the source and working backwards toward the source a section at a time. When the branch joins the previously sized main line, simply add to the branch all of the main line sections from the branch to the source and evaluate the total as if that was now the main line. Total loss must be less than the permitted maximum and also should be less than or equal to the total loss calculated earlier for the main line itself.

III. Consideration in Pressure loss analysis:

- The most "remote" in this instance can mean furthest away or worst case ie. the highest flow rate requirement
- The path from this terminal unit back to the source equipment may comprise of up to twenty branches or sections of pipeline. A table can be constructed detailing this path, with columns for length and flow rate.
- The sum of all the branch losses on the direct route back to the plant will give a total design pressure loss for the terminal unit.
- This loss should be within the allowable loss of 10% of the start pressure.

- Pipe sizes should be selected in order to balance cost with the final performance of the system.
- The latest HTM 02-01-Part A shows on the tables/charts give details of the pressure loss down particular pipe sizes for given flow rates.

Compensating for Fittings There are several ways to compensate for fittings. One way is to add a percentage to every section run, for instance multiplying each section's run by 1.2 or 1.25 to add additional length reflecting the effect of the fittings. Another technique is simply to ensure the total loss is less than 75% of the total allowed loss [1]. therefore, the allowable total pressure loss will be 3.75% of the nominal pressure.

$$\Delta P = 0.05P_n \quad (1)$$

$$\Delta P_T = 0.75\Delta P \quad (2)$$

$$\Delta P_T = 0.0375\, P_n \quad (3)$$

Table 2: Pressure drop criterions for medical gas pipeline distribution system [4]

Service	**P_n (Nominal,** Kpa**)**	**ΔP_T (Loss,** Kpa**)**
Oxygen	400	15
Nitrous Oxide	400	2
Medical Air (4 bar)	400	15
Surgical Air (7 bar)	700	26.25
Vacuum	40	15
Anesthetic Air	400	20

Note:

- Identify the points to be used for design purposes – "Most Remote Points" – Typically start at the plant and follow the highest flow path, taking into account the lengths
- Once the primary design path has been completed, secondary paths can be calculated as necessary.

✞ The general equation of the pressure drop calculation is as follows:

$$\Delta P = \left[\frac{l}{L}\right]\left[\frac{q}{Q}\right]^2 [P] \quad \ldots\ldots (4)$$

Where;

l-Measured (actual) length of pipe

L-Nearest (theoretical) length of pipe from Appendix

Q-Nearest (theoretical) flow from Appendix

q-Design (actual) flow(l/m) from

P-pressure drop from Appendix

As we seen from Fig 7, the longest pipe for floor 1 is (1, 2, 3, 4, 5, 6, 65, 66, 67, 68) and for floor 2 is (1, 2, 3, 4, 5, 6, 61, 62). The total pressure drop is the sum of the first, second and the riser pressure drop. Therefore, the pressure drop calculation for each pipeline system is as follows.

Note:

- ✓ Sample manual design calculation of the pressure drop for Oxygen gas is shown on the next page.
- ✓ For the manual design calculation of the pressure drop for other gases refer Appendix

3.3.2.1 Oxygen gas pressure loss calculation

 # Floor 1

[1], l=1200, L=1500, q=447.75, Q=2283, p=7

$\Delta P = \left[\frac{1200}{1500}\right]\left[\frac{447.75}{2283}\right]^2 [7] = 1.0983$

[2], l=925, L=3000, q=247.75, Q=738, p=7

$\Delta P = \left[\frac{925}{3000}\right]\left[\frac{247.75}{738}\right]^2 [7] = 0.69626$

[3], l=962, L=3000, q=193.25, Q=768, p=7

$\Delta P = \left[\frac{962}{3000}\right]\left[\frac{193.25}{768}\right]^2 [7] = 0.56482$

[4], l=315, L=6100, q=178.75, Q=518, p=7

$\Delta P = \left[\frac{315}{6100}\right]\left[\frac{178.75}{518}\right]^2 [7] = 0.12474$

[5], l=3045, L=9100, q=155.25, Q=411, p=7

$\Delta P = \left[\frac{3045}{9100}\right]\left[\frac{155.25}{411}\right]^2 [7] = 0.88478$

[6], l=901, L=9100, q=130.25, Q=411, p=7

$\Delta P = \left[\frac{901}{9100}\right]\left[\frac{130.25}{411}\right]^2 [7] = 0.21964$

[65], l=740, L=9100, q=118, Q=140, p=7

$\Delta P = \left[\frac{740}{9100}\right]\left[\frac{118}{140}\right]^2 [7] = 0.47978$

[66], l=300, L=9100, q=112, Q=140, p=7

$\Delta P = \left[\frac{300}{9100}\right]\left[\frac{112}{140}\right]^2 [7] = 0.18462$

[67], l=300, L=9100, q=106, Q=140, p=7

$\Delta P = \left[\frac{300}{9100}\right]\left[\frac{106}{140}\right]^2 [7] = 0.17473$

[68], l=490, L=9100, q=100, Q=140, p=7

$\Delta P = \left[\frac{490}{9100}\right]\left[\frac{100}{140}\right]^2 [7] = 0.26923$

ΔP^1_{total} = 1.0983 + 0.69626 + 0.56482 + 0.12474 + 0.88478 + 0.21964 + 0.47978 + 0.18462 + 0.1747 + 0.26923

= **4.6969**

 # Floor 2

[1], l=1500, L=1500, q=118, Q=2283, p=7

$\Delta P = \left[\frac{1200}{1500}\right]\left[\frac{118}{2283}\right]^2 [7] = 0.3618$

[2], l=925, L=3000, q=98, Q=738, p=7

$\Delta P = \left[\frac{925}{3000}\right]\left[\frac{98}{738}\right]^2 [7] = 0.27541$

[3], l=962, L=3000, q=66.5, Q=768, p=7

$\Delta P = \left[\frac{962}{3000}\right]\left[\frac{66.5}{768}\right]^2 [7] = 0.19436$

[4], l=315, L=6100, q=56.5, Q=518, p=7

$\Delta P = \left[\frac{315}{6100}\right]\left[\frac{56.5}{518}\right]^2 [7] = 0.039427$

[5], l=3045, L=9100, q=42, Q=411, p=7

$\Delta P = \left[\frac{3045}{9100}\right]\left[\frac{42}{411}\right]^2 [7] = 0.23936$

[6], l=901, L=9100, q=20.25, Q=411, p=7

$\Delta P = \left[\frac{901}{9100}\right]\left[\frac{20}{411}\right]^2 [7] = 0.033726$

[61], l=1030, L=9100, q=10, Q=140, p=7

$\Delta P = \left[\frac{1030}{9100}\right]\left[\frac{10}{140}\right]^2 [7] = 0.056593$

[62], l=345, L=9100, q=10, Q=140, p=7

$\Delta P = \left[\frac{345}{9100}\right]\left[\frac{10}{140}\right]^2 [7] = 0.018956$

ΔP^2_{total} = 0.3618 + 0.27541 + 0.19436 + 0.039427 + 0.23936 + 0.033726 + 0.056593 + 0.018956

= **1.2196**

Riser flowrate & pressure loss calculation

$Q_{Riser} = Q_{Total} = 565.75$

l=1500, L=1500, q=565.75, Q=2283, p=7

$\Delta P_{Riser} = \left[\frac{1500}{1500}\right]\left[\frac{565.75}{2283}\right]^2 [7]$

= 0.3618

The total pressure loss is the sum of individual floors & riser pressure loss

$\Delta P_{Total} = \Delta P^1_{total} + \Delta P^2_{total} + \Delta P_{Riser}$

= 4.5969 + 1.2196 + 0.3618

ΔP_{Total} = 6.2783

The total pressure loss should be less than the allowable design pressure loss (ΔP_{All} = 15)

$\Delta P_{Total} < \Delta P_{All}$; 6.2783 < 15

Therefore, the design is **SAFE!**

3.4 MGPDS design analysis using MATLAB software

The following diversified flowrate formulas of the medical gas system are carefully selected from the design catalogue of HTM 02-01 standard in order to simplify the analysis process of the selected six gases as shown on Table 3.

Table 3: The selected Medical gas design and diversified flow formulas of different departments

Department, Gas	O_2	V	MA (400 kPa)	SA (700 kPa)	NO3	AGS
Emergency	10 + [(n – 1)6/4]	40 + [(n – 1)40/4]	40 + [(n – 1)20/4]	_	10 + [(n – 1)6/4]	V + [(n – 1) V/4]
Operating: Operating rooms Post-anesthesia recovery	 100 + (nT – 1)10 10 + (n – 1)6	 80 + [(nS – 1)80/2] 40 + [(n – 1)40/4]	 40 + [(nT – 1)40/4] 40 + [(n – 1)10/4]	 350 + [(n – 1)350/2] _	 15 + (nT – 1)6 _	 V + (nT– 1) V _
Maternity: Operating suites Post-anesthesia recovery	 100 + (nS – 1)6 10 + [(n – 1)3/4]	 80 + [(nS – 1)80/2] 40 + [(n – 1)40/4]	 40 + [(nS – 1)10/4] 40 + [(n – 1)40/4]	 350 + [(n – 1)350/2]	 15 + (nS – 1)6	 V + (nS – 1) V
Radiological	10 + [(n – 1)6/3]	40 + [(n – 1)40/8	40 + [(n – 1)40/4]	_	10 + [(n – 1)6/4]	V + [(n – 1) V/4]
ICU	10 + [(n – 1)6]3/4	40 + [(n – 1)40/4	80 + [(n – 1)80/2]	_	10 + [(n – 1)6/4]	_
Orthodontic	10 + [(n – 1)6/3]	40	40 + [(n – 1)40/2]	_	10 + [(n – 1)6/4]	V + [(n – 1) V/4]
In-patient (child) In-patient room	10 + [(n – 1)6/6] 10 + [(n – 1)6/4]	40 40 + [(n – 1)40/4]	40 + [(n – 1)40/4] 20 + [(n – 1)10/4]	_	_	_
Other departments	10	40	40	350	10	V + [(n – 1) V/8]

The sampled Hospital floor plan that are token as a reference for the design analysis of Medical Gas System pipeline distribution. The Hospital includes many floors with emergency rooms, operating rooms, maternity rooms, ICU rooms, recovery rooms, orthodontic rooms, etc. therefore, for this specific report only the MGDS design analysis of the Oxygen gas is included. But the MATLAB analysis is done for any layout of all types of gases. So, it's a generalized platform for the design analysis of the system.

Note:

Refer Appendix 31 – Sample hospital plan layout for MGDS - Ground floor (Floor 1) & Appendix 32 – Sample hospital plan layout for MGDS - First floor (Floor for sample of the Hospital plan for MGDS design analysis layout.

3.4.1 MGPDS layout and room type coding

The pipe coding is very useful in designing MGPS. It has the following advantages:

- It helps the MATLAB to understand the design numerical data's
- Simplify the design nomenclature complexity
- Easy for understanding the architectural drawing
- Easy for understanding the system
- It also saves time to design the system

✦ **Room Coding description:**

Main distributer pipes…………. a

Surgery rooms ………………..… sr

Emergency rooms ……………... em

Recovery rooms ………………... rc

Maternity recovery rooms………. mr

Examination rooms..……………..ex

Internal care unit rooms ……….. ic

Orthodontic rooms ……………… or

Child care unit rooms …………… ch

Radiography rooms ………..…….rd

Maternity operating rooms ……...mo

In-patient rooms ……………….....ip

Other rooms ………………..….....ot

Not required……………….……....no

✦ **Other terminologies:**

n-number of beds (for diversified flow calculation input)

Ø-diameter of pipes (assumed) *l*-Measured (actual) length of pipe

L-Nearest (theoretical) length of pipe

Q-Nearest (theoretical) flow

q-Design (actual) flow(l/m)

P-pressure drop

ΔP-Pressure drop of the pipeline

3.4.2 MGPDS analysis procedure

The numerical analysis is performed using MATLAB. The results obtained are validated by comparing numerical results with the design standards. Finally, parametric study and optimization is performed.

Step 1: Import Excel data & prepare for processing

The first step on the analysis is importing the pipeline distribution property data from the Excel workspace and separating the numerical data from the text (string) data and extracting the numerical data, which facilitate the easy analysis process for the MATLAB. The algorithm is shown on figure 4.

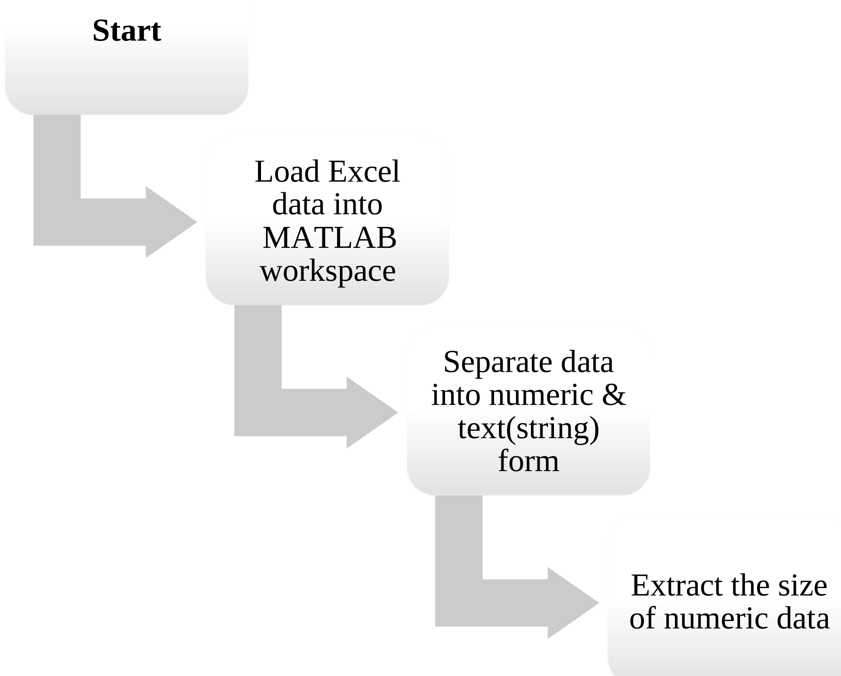


Figure 4: Import Excel data & prepare for processing

Step 2: Count the number of main pipes: On this second step, the main distributer pipes are counted by computing the pipe number to its base and register the main distributer pipe number to the side branches, then exclude these main branch data from the next analysis of identifying the side branches. The algorithm is shown on figure 5.

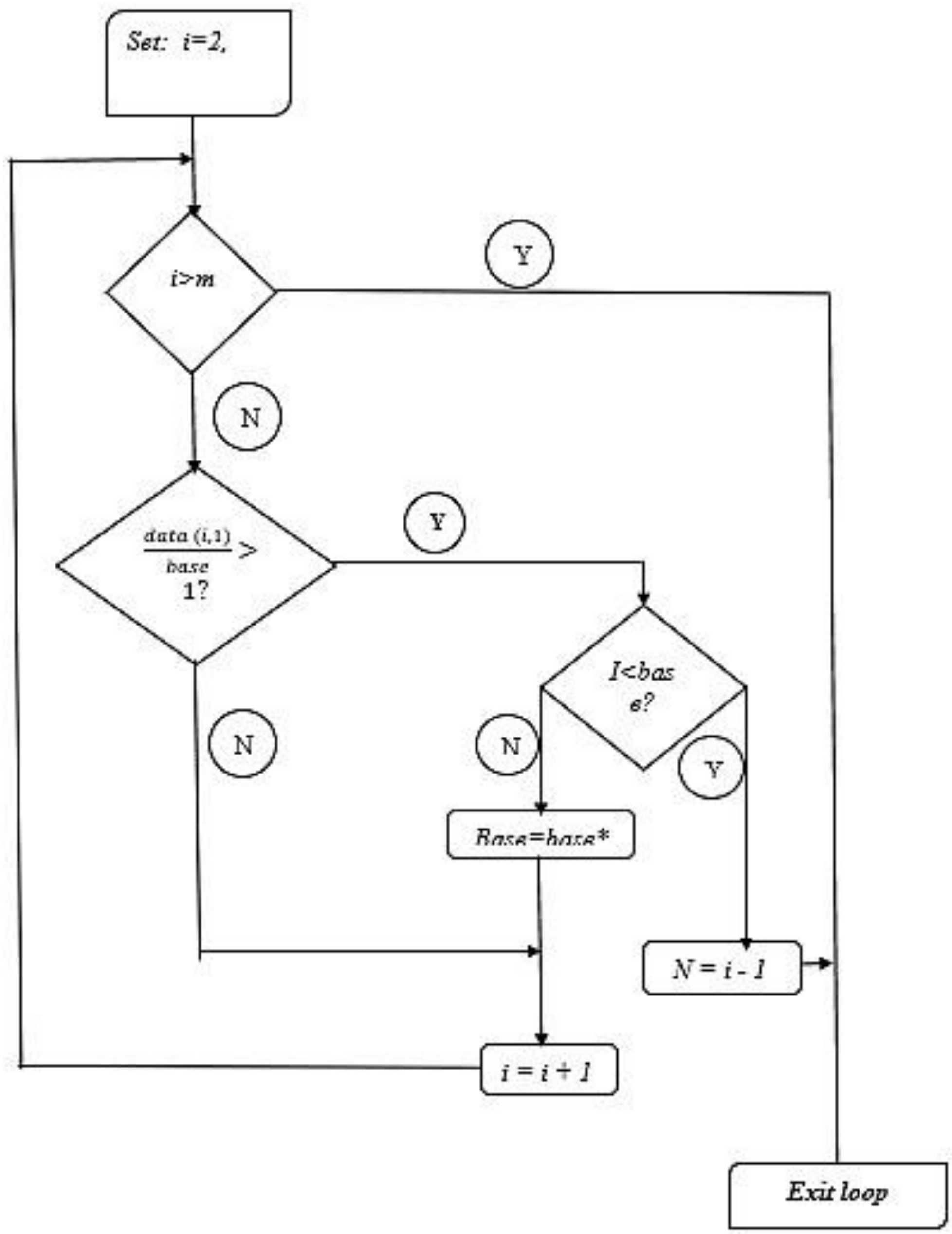


Figure 5: Algorithm for counting the number of main pipes

Step 3: Count the no main pipe side branches: The third step is identifying the main pipe side branches from the source Excel data by computing the branch pipe number to the most significant number (msb(num)) function and register all the designated side branch pipes for the main distributer pipes. The algorithm is shown on figure 6.

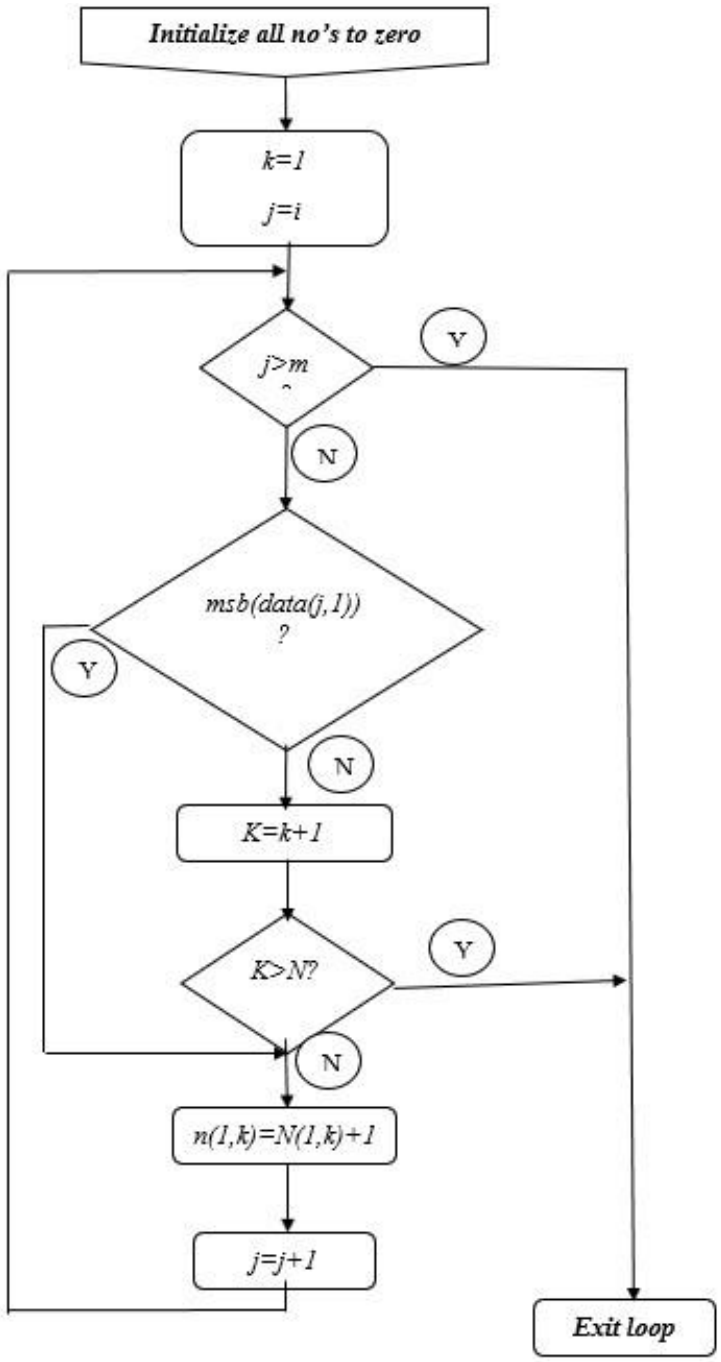


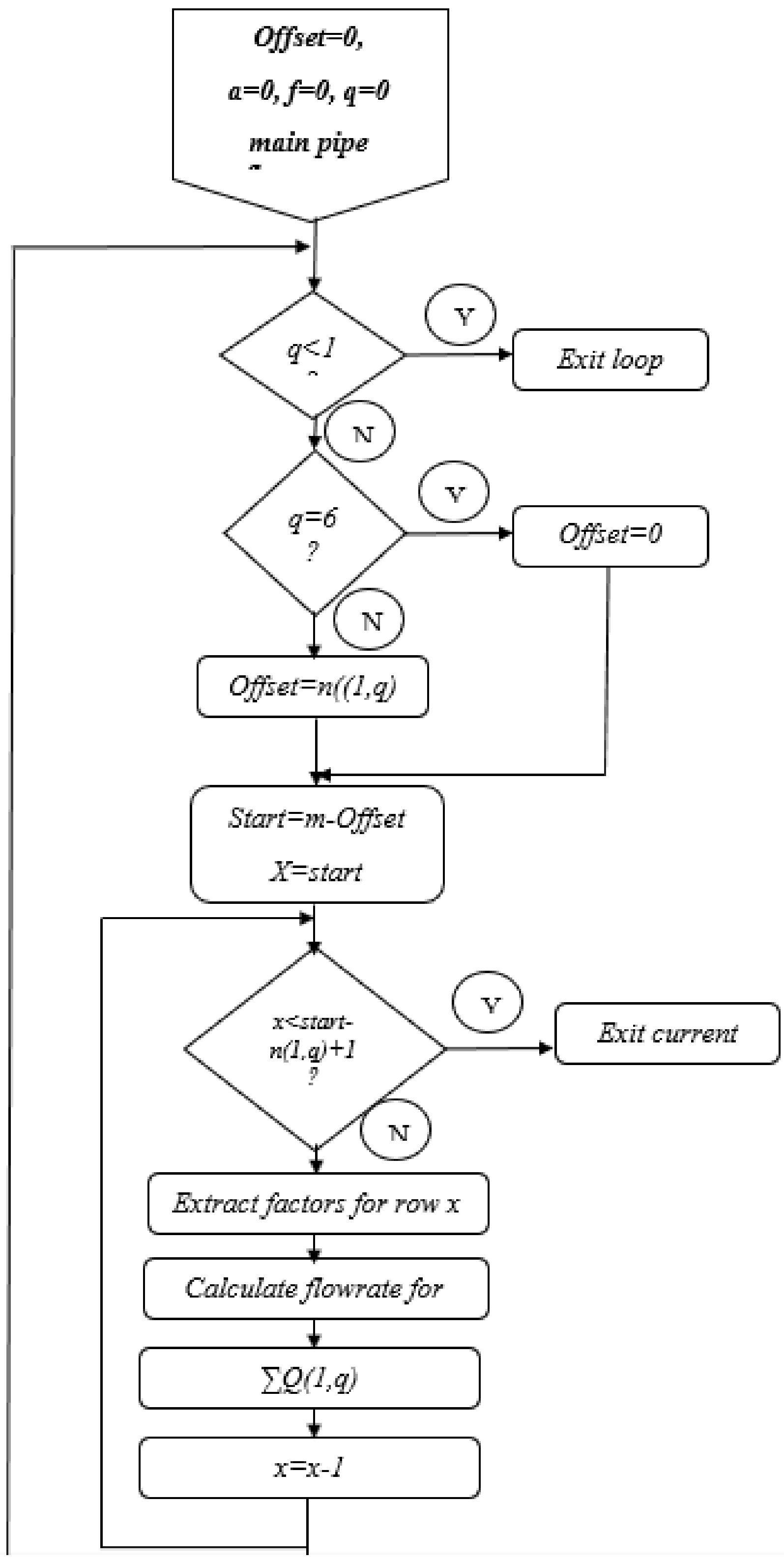
Figure 6: Algorithm for counting the number of main pipe side branches

Step 4: Diversified Flowrate Calculation: On this analysis the MATLAB follows the HTM 02-01 medical gas design standard formulas in the backward tracing method, which added the flow rates starting from the last terminal units by encountering the main distributer pipe and the side branches relation on the third step. When the flow rate calculation for each floor main pipes and side branch pipeline is analyzed, it has the same pattern of "[a + (n-1) f]" formulas (see Table 4). So, the function "factor (a, f)" is introduced for all types of gas flow rate analysis.

Table 4: Factors for calculating a medical gas diversified flowrate

Room type	code	oxygen		vacuum		mair		sair		noxide		ansthesia	
		a	f	a	f	a	f	a	f	a	f	a	f
Surgery	sr	100	10	80	40	40	10	350	175	15	6	80	80
Emergency	em	10	1.5	40	10	40	5	0	0	10	1.5	80	20
Recovery	rc	10	6	40	10	40	2.5	0	0	0	0	0	0
Examination	ex	10	1.5	40	0	40	0	0	0	0	0	80	10
ICU	ic	10	4.5	40	10	80	40	0	0	10	1.5	0	0
Orthodontic	or	10	2	40	0	40	20	0	0	10	1.5	80	20
Child Care	ch	10	2	40	0	40	10	0	0	0	0	0	0
Radiography	rd	10	2	40	5	40	10	0	0	10	1,5	80	20
Maternity Operating	mo	100	6	80	40	40	2.5	350	175	15	6	80	80
Maternity Recovery	mr	10	0.75	40	10	40	10	350	0	0	0	0	0
Inpatient	ip	10	1.5	40	10	20	2.5		0	0	0	0	0
Other	ot	10	0	40	10	40	0	350	0	10	0	80	10
None	no	0	0	0	0	0	0	0	0	0	0	0	0

The algorithm to calculate the flowrate is shown on figure 6.


Offset=0,
a=0, f=0, q=0
main pipe
q<1
Y
Exit loop
N
q=6
?
Y
Offset=0
N
Offset=n((1,q)
Start=m-Offset
X=start
x<start-
n(1,q)+1
?
Y
Exit current
N
Extract factors for row x
Calculate flowrate for
∑Q(1,q)
x=x-1

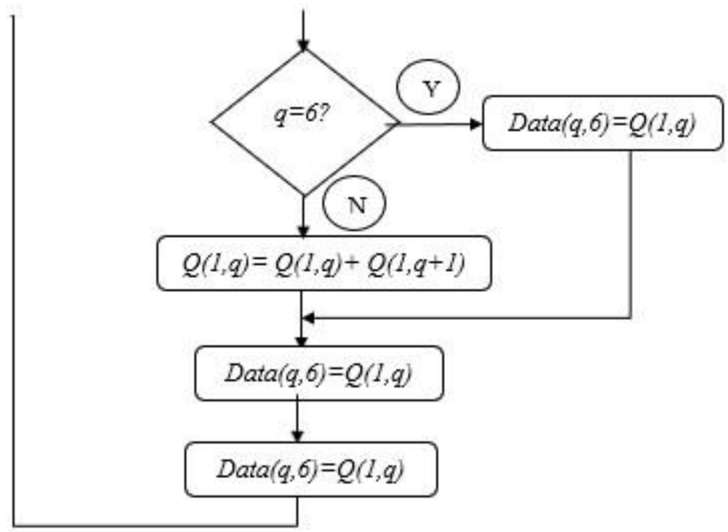
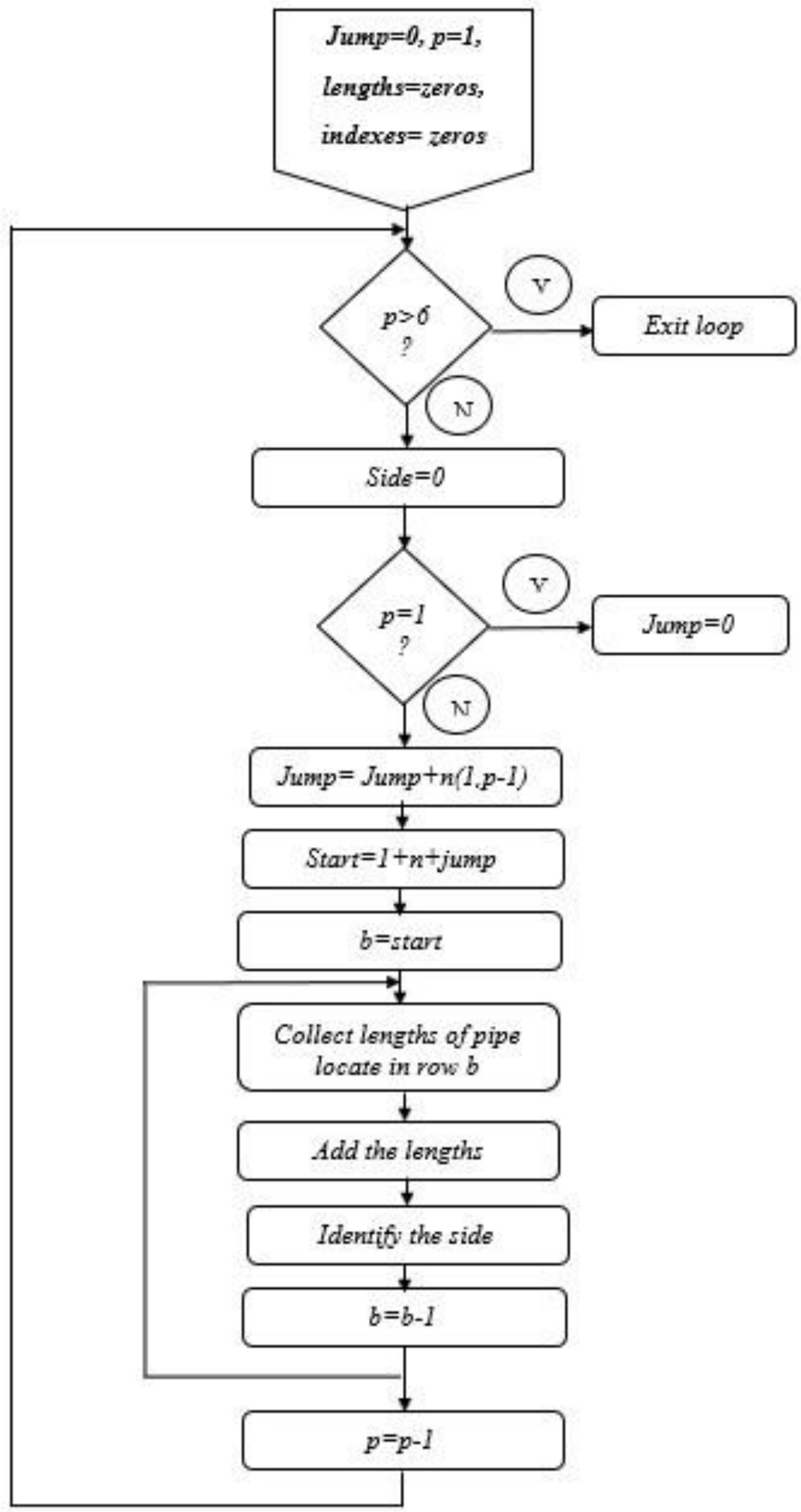


Figure 7: Algorithm for Diversified Flowrate Calculation

Step 5: Locating the longest pipe path: Locating the most remote pipeline follows the same backward tracing method, which added the pipe lengths starting from the plant to the last terminal unit by encountering the main distributer pipe and the side branches relation on the third step. After computing all distribution path lines, the longest pipeline is identifying and ready for the next pressure drop calculation. The algorithm is shown on Figure 8.


Jump=0, p=1,
lengths=zeros,
indexes= zeros
p>6
?
Y
Exit loop
N
Side=0
p=1
?
Y
Jump=0
N
Jump= Jump+n(1,p-1)
Start=1+n+jump
b=start
Collect lengths of pipe
locate in row b
Add the lengths
Identify the side
b=b-1
p=p-1

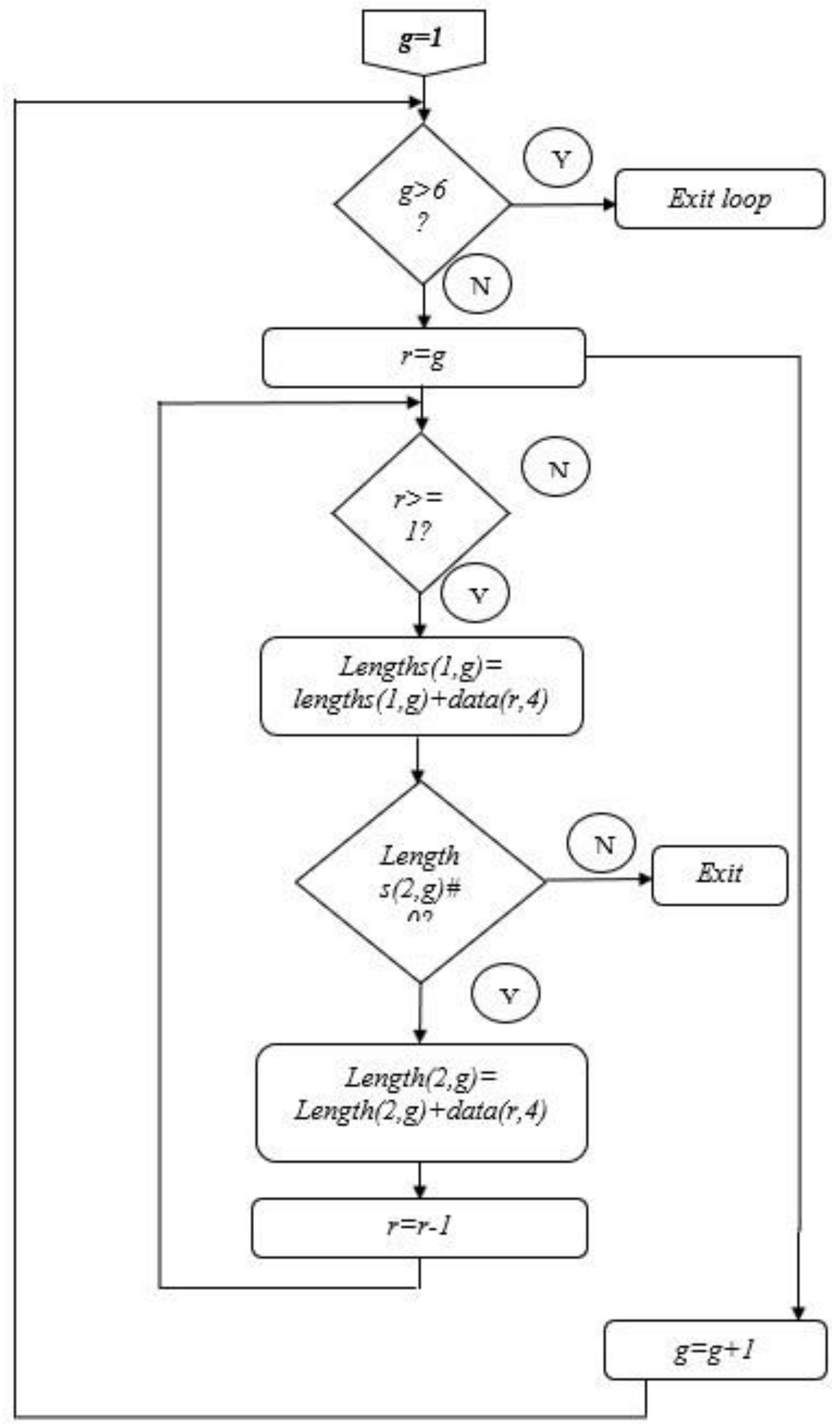


Figure 8: Algorithm for Locating the longest pipe path

Step 6: Calculate the Pressure drop: On this step the longest pipeline pressure drop is calculated by using HTM 02-01 medical gas design standard formulas (see Equation 4) with the same backward tracing method, which added the pipe pressure drop starting from the last terminal unit. If the pressure drop is higher than the design standard (see Table 2), the MATLAB will notify "higher medical gas pressure drops" information. So, we can go back to the first step and try another parameter simulation.

Note:

The MATLAB analysis for the above design steps and their results are included from Appendix 24 – 30.

CHAPTER FOR

In this section results of numerical analysis performed according to procedures and techniques discussed in the previous chapters is presented for the sample pipeline distribution.

RESULT AND DISCUSSION

The MATLAB analysis considers the flow rate, pressure drop with optimized diameter of any type of gases with unlimited number of floors. For this analysis only two floors are included for the simulation purpose and the MATLAB analysis can be used as a generalized designing platform for any types of gases with the given distribution layout.

The design analysis follows the basic approach for solving medical gas distribution problem, which is problem definition, mathematical modeling, computational method and its implementation to test and assess the solution. The results obtained are validated by comparing numerical results with the design standards. Finally, parametric study and optimization is performed.

According to the selected design standard of HTM 02-01 Part A, the design of the pipe work system is based on the diversified flows and the permissible pressure loss from the source of supply to, and including, the terminal unit pressure loss. The design analysis encounters the standard equations from Appendix 2 – 7 for diversified flow rate calculation and from Appendix 8 – 11 for pressure drop calculations. Following these design standards and the sample distribution layout from Appendix 12 – 18, the manual design analysis & the MATLAB simulation result of the system is carried out as per required on section 3.3 & section 3.4.2 respectively.

On this thesis, the optimized medical gas pipeline distribution system is performed. But the other system equipment sizing is not included. So, we can easily select the system auxiliary equipment according to the standards, which is not the basic objective of this thesis and it’s not included on the design analysis.

The following tables shows the design analysis comparison of the manual calculation (section 3.3) and MATLAB result analysis (section 3.4).

Table 5: Result comparison for Oxygen gas

	Flowrate result		Pressure Drop result	
Pipe	MATLAB	Manual	MATLAB	Manual
Floor 1				
1	447.75	447.75	1.0983	1.098
2	247.75	247.75	0.69626	0.696
3	193.25	193.25	0.56482	0.565
4	178.75	178.75	0.12474	0.125
5	155.25	155.25	0.88478	0.885
6	130.25	130.25	0.21964	0.22
65	118	118	0.47978	0.48
66	112	112	0.18462	0.18
67	106	106	0.17473	0.17
68	100	100	0.26923	0.27
Floor 2				
1	118	118	0.3618	0.36
2	98	98	0.27541	0.27
3	66.5	66.5	0.19436	0.19
4	56.5	56.5	0.039427	0.04
5	42	42	0.23936	0.24
6	20	20	0.033726	0.03
61	10	10	0.056593	0.06
62	10	10	0.018956	0.02
Riser	554.5	554.5	0.3618	0.36
Total	554.5	554.5	6.1783	6.28

Table 6: Result comparison for Medical vacuum

	Flowrate result		Pressure Drop result	
Pipe	MATLAB	Manual	MATLAB	Manual
Floor 1				
1	790	790	0.55514	0.55
2	630	630	0.51747	0.52
3	470	470	0.40149	0.40
4	430	430	0.088007	0.09
5	360	360	0.60231	0.60
6	270	270	0.13366	0.13
65	200	200	0.081319	0.08

66	160	160	0.026374	0.02
67	120	120	0.01978	0.02
68	80	80	0.021538	0.02
Floor 2				
1	615	615	0.5402	0.54
2	485	485	0.39837	0.39
3	355	355	0.30325	0.30
4	285	285	0.039206	0.04
5	215	215	0.35971	0.36
6	110	110	0.054456	0.05
61	50	50	0.028297	0.03
62	40	40	0.0075824	0.01
Riser	1405	1405	0.5402	0.54
Total	1405	1405	4.7184	4.72

Table 7: Result comparison for Medical air

	Flowrate result		Pressure Drop result	
Pipe	MATLAB	Manual	MATLAB	Manual
Floor 1				
1	675	675	1.6557	1.65
2	595	595	1.6721	1.67
3	487.5	487.5	1.4248	1.42
4	447.5	447.5	0.31228	0.31
5	247.5	247.5	1.4105	1.41
6	117.5	117.5	0.19814	0.2
65	47.5	47.5	0.19313	0.19
66	45	45	0.074176	0.07
67	42.5	42.5	0.070055	0.07
68	40	40	0.10769	0.10
Floor 2				
1	190	190	0.58257	0.58
2	190	190	0.53396	0.53
3	77.5	77.5	0.22651	0.22
4	77.5	77.5	0.054082	0.05
5	50	50	0.28495	0.28
6	0	0	0	0
61	0	0	0	0
62	0	0	0	0
Riser	865	865	0.5825	0.58
Total	865	865	9.3833	9.38

Table 8: Result comparison for Surgical air

	Flowrate result		Pressure Drop result	
Pipe	MATLAB	Manual	MATLAB	Manual
Floor 1				
1	1575	1575	2.9558	2.95
2	875	875	1.8717	1.87
3	875	875	1.9466	1.95
4	875	875	0.46377	0.46
5	875	875	3.7814	3.78
6	875	875	1.1189	1.12
65	875	875	2.6778	2.68
66	700	700	0.86849	0.86
67	525	525	0.65136	0.65
68	350	350	0.70926	0.71
Riser	1575	1575	2.9558	2.95
Total	1575	1575	20.0008	20.0

Table 9: Result comparison for Nitrous oxide gas

	Flowrate result		Pressure Drop result	
Pipe	MATLAB	Manual	MATLAB	Manual
Floor 1				
1	102	102	0.2502	0.25
2	72	72	0.20234	0.20
3	57.5	57.5	0.16806	0.16
4	57.5	57.5	0.040125	0.04
5	43	43	0.24506	0.24
6	33	33	0.055649	0.05
65	33	33	0.13418	0.13
66	27	27	0.044505	0.04
67	21	21	0.034615	0.03
68	15	15	0.040385	0.04
Floor 2				
1	24.5	24.5	0.07512	0.07
2	24.5	24.5	0.068853	0.06
3	11.5	11.5	0.033612	0.03
4	11.5	11.5	0.008025	0.01
5	11.5	11.5	0.065539	0.06
6	0	0	0	0
61	0	0	0	0
62	0	0	0	0
Riser	126.5	126.5	0.0752	0.07
Total	126.5	126.5	1.5414	1.54

Table 10: Result comparison for Anesthesia gas

	Flowrate result		Pressure Drop result	
Pipe	MATLAB	Manual	MATLAB	Manual
Floor 1				
1	820	820	2.0114	2.01
2	660	660	1.8548	1.85
3	520	520	1.5198	1.52
4	410	410	0.28611	0.28
5	410	410	2.3366	2.33
6	320	320	0.53962	0.54
65	320	320	1.3011	1.30
66	240	240	0.3956	0.39
67	160	160	0.26374	0.26
68	80	80	0.21538	0.21
Floor 2				
1	550	550	1.6557	1.65
2	330	330	0.92741	0.92
3	210	210	0.61378	0.61
4	100	100	0.069783	0.07
5	100	100	0.5699	0.57
6	0	0	0	0
61	0	0	0	0
62	0	0	0	0
Riser	1360	1360	1.6557	1.65
Total	1360	1360	14.2165	14.2

Generally, the following table shows the total amount of required flow rate of the pipeline and its pressure drop for all types of gases.

Table 11: Flowrate of the pipeline and its pressure drop result

	Gas Type	Q (l/min)	ΔP_T (Kpa)	ΔP_{Design} (Kpa)
1	Oxygen (O_2)	565.75	6.2783	15
2	Medical Vacuum (MV)	1405	4.7184	15
3	Medical Air (MA)	865	9.3833	15
4	Surgical Air (SA)	1575	20.0008	26.25
5	Nitrous Oxide (N2O)	126.5	1.5414	2
6	Anesthetic Gas (AG)	1360	16.2165	20

As shown on the above table, the total medical gases flowrate and their pressure drop with pipe sizing (see Appendix 12-17) is calculated based on the HTM 02 – 01 design standard.

The system design analysis is very optimized which primarily focused on the safety of the system and the cost of the pipeline sizing. So, considering the major (longitudinal) and minor (fittings) pipeline pressure loss is lower than 3.75% of the start pressure with the standardized pipe sizing designing parameters.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

In this chapter a summary of the research question, new findings, recommendations and future research areas in MGPDS is presented.

5.1 Summary

The medical gas pipeline distribution system design follows a complex and conservative designing standard. Thus, rather than using a customized and unofficial Excel spreadsheet templates, which's a very rigid, vulnerable to fraud, susceptible to human error, a tedious, time, energy consuming to design & even to made a slight design modification of the system etc. hence a more powerful and explanatory open source MATLAB program for a perfect optimized design of the system. Therefore, the selected Health Technical Memorandum (HTM 02-01) standard handbook implemented on the MATLAB programming language to solve a medical gas parameter. The thesis provides the safe and reliable design platform using MATLAB software for 6 major & frequently used medical gases. Following this, the system design analysis solves the pipeline distribution layout name coding for the main pipes and its sub branches, flow rate analysis, determination of the most remote pipeline and its pressure drop analysis and also a manual system design analysis is also introduced and compared with the MATLAB analysis result for the sample two floors building. Therefore, the MATLAB program can analyze any number of floors with unlimited number of pipe arrangements in a well-organized design procedure. Therefore, it's a generalized design platform for designing the medical gas pipeline distribution system for any healthcare centers.

5.2 Conclusion

To conclude, based on the MATLAB analysis, the total load of the building is 565.75 l/min for oxygen, 1405 l/min for Medical Vacuum, 865 l/min for Medical air, 1575 l/min for Surgical Air, 126.5 l/min for Nitrous Oxide and 1360 l/min for Anesthetic Gas and it has also a maximum pressure drop of 6.2783 kpa, 4.7184, 9.3833 kpa, 20kpa, 1.5414 kpa, 16.2165 kpa respectively. The end diameter of the hard pipe has 12mm (1/2”) nominal size and the remaining pipeline distribution layout has an increasing order depending on the pressure drop requirement.

Therefore, the MATLAB analysis can be used as a generalized designing platform for any types of gases with the given distribution layout.

5.2 RECOMMENDATION

The recommendations are the following

- The detail pipeline distribution system must be done as per standards
- Take a careful pipeline name coding
- Precise data encoding to the Excel spreadsheet is needed

5.3 FUTURE WORK

Using the output of this research thesis the following researches can be made in the future.

- ✦ Optimized medical gas pipeline distribution design using Graphical User Interface (GUI) format in MATLAB SIMULINK, which's an easier and user-friendly approach.

References

[1] Department of Health, "Medical Gases Health Technical Memorandum (HTM 02-01," *Medical Gas Pipeline*, 2006.

[2] Bermúdez A, González-Díaz J, González-Diéguez FJ, González-Rueda ÁM, Fernández De Córdoba MP, "Simulation and optimization models of steady-state gas transmission networks," 2015.

[3] M. EA, "“A pipe flow network model with incorporation of a junction pressure loss model," 2005.

[4] P, Salah M, "“Medical Gases Systems," 2007.

[5] Fire N., "Medical Gas Cylinder Storage," 2018.

[6] P. M. InterMed, "“World Standards for Medical Gas Systems," 2017.

[7] S. S. Hartikainen J, "Optimal filtering with Kalman filters and smoothers – a Manual," 2008.

[8] Gerald W. Recktenwald, "Pipe Flow Analysis with Matlab," 2007.

[9] Dr Keffer D, "Pipe networking using MATLAB program," 1999.

[10] W. Z. Xiaojing L, "Transient À ow simulation of municipal gas pipelines and," 2011.

[11] "Solutions to improve the quality management of medical gas pipeline systems in china", 2011.

[12] J. Szoplik, "changes in gas in the pipeline depending on the network foundation in," 2017.

[13] C. James Taylor, " Introduction to MATLAB / SIMULINK," 2012.

[14] D. Kuncicky, "“MATLAB programming," 2000.

[15] G.A. Gregory K. Aziz, " calculation of pressure and temperature profiles in multiphase," 2011.

[16] G. W. Recktenwald, " Matlab Programming," 2000.

[17] G. W. Recktenwald, "Optimal filtering with Kalman filters and smoothers – a Manual," 2008.

[18] I. 7396-1, "“Medical gas pipeline systems," 2006.

[19] O. T. Memorandum HT, "HTM 2022: Medical Gas Pipeline Systems," 1997.

[20] NFPA. 99, "Standard for Health Care Facilities," 2005.

[21] NHS, "“Medical Gas and Medical Gas Pipeline Systems (MGPS) Policy," 2016.

[22] Province of Kwazulu-Natal department of health, Standard specification and drawings for," 2001.

[23] SA Health Policy Committee, "“Medical Gas System Policy Directive," 2017.

[24] Sita Bhaskaran and Franz J. M. Salzborn. 1978.

APPENDIXES

Appendix 1 - Glass flow – flows required at terminal units [1]

Service	Location	Nominal pressure (kPa)	Design flow (L/min)	Typical flow required (L/min)	Test flow (L/min)
Oxygen	Operating rooms and rooms in which N_2O is provided for anaesthetic purposes	400	100$^{(1)}$	20	100
	All other areas	400	10	6	40
Nitrous oxide	All areas	400	15	6	40
Nitrous oxide/ oxygen mixture	LDRP (labour, delivery, recovery, post-partum) rooms	310$^{(2)}$	275	20	275
	All other areas	400	20	15	40
Medical air 400 kPa	Operating rooms	400	40$^{(3)}$	40	80
	Critical care areas, neonatal, high dependency units	400	80$^{(3)}$	80	80
	Other areas	400	20	10$^{(3)}$	80
Surgical air/ nitrogen	Orthopaedic and neurosurgical operating rooms	700	350$^{(4)}$	350	350
Vacuum	All areas	40 (300 mm Hg below atmospheric pressure)	40	40 maximum, further diversities apply	40
Helium/oxygen mixture	Critical care areas	400	100	40	80

Notes:

1. During oxygen flush in operating and anesthetic rooms.
2. Minimum pressure at 275 L/min.
3. These flows are for certain types of gas-driven ventilator under specific operating conditions, and nebulizers etc.
4. Surgical air is also used as a power source for tourniquets.

Appendix 2 - Oxygen: design and diversified flows [1]

Department	Design flow for each terminal unit (L/min)	Diversified flow Q (L/min)
In-patient accommodation (ward units):		
Single 4-bed rooms and treatment room	10	$Q_w = 10 + [(n-1)6/4]$
Ward block/department	10	$Q_d = Q_w[1 + (nW-1)/2]$
Accident & emergency:		
Resuscitation room, per trolley space	100	$Q = 100 + [(n-1)6/4]$
Major treatment/plaster room, per trolley space	10	$Q = 10 + [(n-1)6/4]$
Post-anaesthesia recovery, per trolley space	10	$Q = 10 + [(n-1)6/8]$
Treatment room/cubicle	10	$Q = 10 + [(n-1)6/10]$
Operating:		
Anaesthetic rooms	100	Q = no addition made
Operating rooms	100	$Q = 100 + (nT-1)10$
Post-anaesthesia recovery		$Q = 10 + (n-1)6$
Maternity:		
LDRP rooms:		
Mother	10	$Q = 10 + [(n-1)6/4]$
Baby	10	$Q = 10 + [(n-1)3/2]$
Operating suites:		
Anaesthetist	100	$Q = 100 + (nS-1)6$
Paediatrician	10	$Q = 10 + (n-1)3$
Post-anaesthesia recovery	10	$Q = 10 + [(n-1)3/4]$
In-patient accommodation:		
Single/multi-bed wards	10	$Q = 10 + [(n-1)6/6]$
Nursery, per cot space	10	$Q = 10 + [(n-1)3/2]$
Special care baby unit	10	$Q = 10 + (n-1)6$
Radiological: All anaesthetic and procedures rooms	100	$Q = 10 + [(n-1)6/3]$
Critical care areas	10	$Q = 10 + [(n-1)6]3/4$
Coronary care unit (CCU)	10	$Q = 10 + [(n-1)6]3/4$
High-dependency unit (HDU)	10	$Q = 10 + [(n-1)6]3/4$
Renal	10	$Q = 10 + [(n-1)6/4]$
CPAP ventilation	75	$Q = 75n \times 75\%$
Adult mental illness accommodation:		
Electro-convulsive therapy (ECT) room	10	$Q = 10 + [(n-1)6/4]$
Post-anaesthesia, per bed space	10	$Q = 10 + [(n-1)6/4]$
Adult acute day care accommodation:		
Treatment rooms	10	$Q = 10 + [(n-1)6/4]$
Post-anaesthesia recovery per bed space	10	$Q = 10 + [(n-1)6/4]$
Day patient accommodation (as "In-patient accommodation")		As "In-patient accommodation"
Oral surgery/orthodontic:		
Consulting rooms, type 1	10	$Q = 10 + [(n-1)6/2]$
Consulting rooms, types 2 & 3	10	$Q = 10 + [(n-1)6/3]$
Recovery room, per bed space	10	$Q = 10 + [(n-1)6/6]$
Out-patient:		
Treatment rooms	10	$Q = 10 + [(n-1)6/4]$
Equipment service rooms, sterile services etc	100	Residual capacity will be adequate without an additional allowance

Appendix 3 – Vacuum: design and diversified flows [1]

Department	Design flow for each terminal unit (L/min)	Diversified flow Q (L/min)
In-patient accommodation:		
Ward unit	40	$Q = 40$
Multiple ward units	40	$Q_d = 40 + [(n - 1)40/4]$
Accident & emergency:		
Resuscitation room, per trolley space	40	$Q = 40 + [(n - 1)40/4]$
Major treatment/plaster room, per trolley space	40	$Q = 40 + [(n - 1)40/4]$
Post-anaesthesia recovery, per trolley space	40	$Q = 40 + [(n - 1)40/4]$
Treatment room/cubicle	40	$Q = 40 + [(n - 1)40/8]$
Operating:		
Anaesthetic rooms	40	No additional flow included
Operating rooms:		
Anaesthetist	40	$Q = 40$
Surgeon	40	$Q = 40$
Operating suites	40	$Q_s = 80 + [(nS - 1)80/2]$
Post-anaesthesia recovery	40	$Q = 40 + [(n - 1)40/4]$
Maternity:		
LDRP rooms:		
Mother	40	$Q = 40 + [(n - 1)40]/4$
Baby	40	No additional flow included
Operating suites:		
Anaesthetist	40	$Q = 40$
Obstetrician	40	$Q = 40$
Operating suites		$Q_s = 80 + [(nS - 1)80/2]$
Post-anaesthesia recovery	40	$Q = 40 + [(n - 1)40/4]$
In-patient accommodation:		
Ward unit comprising single, multi-bed and treatment room	40	$Q = 40$
Multi-ward units	40	$Q = 40 + [(n - 1)40/2]$
Nursery, per cot space	40	No additional to be included
SCBU	40	$Q = 40 + [(n - 1)40/4]$
Radiology/diagnostic departments:		
All anaesthetic and procedures rooms	40	$Q = 40 + [(n - 1)40/8]$
Critical care areas	40	$Q = 40 + [(n - 1)40/4]$
High-dependency units	40	$Q = 40 + [(n - 1)40/4]$
Renal	40	$Q_d = 40 + [(n - 1)40/4]$
Adult mental illness accommodation:		
ECT room	40	$Q = 40 + [(n - 1)40/4]$
Post-anaesthesia, per bed space	40	$Q = 40 + [(n - 1)40/4]$
Adult acute day care accommodation:		
Treatment rooms	40	$Q = 40 + [(n - 1)40/4]$
Post-anaesthesia recovery per bed space	40	$Q = 40 + [(n - 1)40/8]$
Day patient accommodation (as "In-patient accommodation")		As "In-patient accommodation"
Oral surgery/orthodontic:		
Consulting rooms, type 1	40	Dental vacuum only
Consulting rooms, types 2 & 3	40	Dental vacuum only
Recovery room, per bed space	40	$Q = 40 + [(n - 1)40/8]$
Out-patient:		
Treatment rooms	40	$Q = 40 + [(n - 1)40/8]$
Equipment service rooms, sterile services etc	40	Residual capacity will be adequate without an additional allowance

Appendix 4 - Medical air: design and diversified flows [1]

Department	Design flow for each terminal unit (L/min)	Diversified flow Q (L/min)
In-patient accommodation (ward units):		
Single/multi-bed and treatment rooms(1)	20	$Q_w = 20 + [(n-1)10/4]$
Ward block/department	20	$Q_d = Q_w[1 + (nW-1)/2]$
Accident & emergency:		
Resuscitation room, per trolley space	40	$Q = 40 + [(n-1)20/4]$
Major treatment/plaster room, per trolley space	40	$Q = 40 + [(n-1)20/4]$
Post-anaesthesia recovery, per trolley space	40	$Q = 40 + [(n-1)40/4]$
Operating:		
Anaesthetic rooms	40	No additional flow included
Operating rooms	40	$Q = 40 + [(nT-1)40/4]$
Post-anaesthesia recovery	40	$Q = 40 + [(n-1)10/4]$
Maternity:		
LDRP rooms:	40	$Q = 40 + [(n-1)40/4]$
Baby(2)	40	$Q = 40 + [(n-1)40/4]$
Operating suites:		
Anaesthetist	40	$Q = 40 + [(nS-1)10/4]$
Post-anaesthesia recovery	40	$Q = 40 + [(n-1)40/4]$
Neonatal unit (SCBU)	40	$Q = 40n$
Radiological:		
All anaesthetic and procedures rooms	40	$Q = 40 + [(n-1)40/4]$
Critical care areas(3)	80	$Q = 80 + [(n-1)80/2]$
High-dependency units	80	$Q = 80 + [(n-1)80/2]$
Renal	20	$Q = 20 + [(n-1)10/4]$
Oral surgery/orthodontic:		
Major dental/oral surgery rooms	40	$Q = 40 + [(n-1)40/2]$
All other departments	40	No additional flow allowance to be made
Equipment service rooms	40	No additional flow included

Appendix 5 - Surgical air 700 kPa – design and diversified flows [1]

Department	Design flow for each terminal unit (L/min)	Diversified flow Q (L/min)
Operating room (orthopaedic and neurosurgical operating rooms only): <4 operating rooms >4 operating rooms	 350 350	 $Q = 350 + [(n-1)350/2]$ $Q = 350 + [(n-1)350/4]$
Other departments, eg equipment workshops, fracture clinic	350	$Q = 350$
Equipment service rooms	350	No additional flow required

Appendix 6 - Nitrous oxide: design and diversified flows [1]

Department	Design flow for each terminal unit (L/min)	Diversified flow Q (L/min)
Accident & emergency: resuscitation room, per trolley space	10	$Q = 10 + [(n-1)6/4]$
Operating	15	$Q = 15 + (nT - 1)6$
Maternity: operating suites	15	$Q = 15 + (nS - 1)6$
Radiological: all anaesthetic and procedures rooms	15	$Q = 10 + [(n-1)6/4]$
Critical care areas	15	$Q = 10 + [(n-1)6/4]$
Oral surgery/orthodontic: consulting rooms, type 1	10	$Q = 10 + [(n-1)6/4]$
Other departments	10	No additional flow included
Equipment service rooms	15	No additional flow included
Maternity: <12 LDRP room(s), mother >12 LDRP rooms	 275	 $Q = 275 + [(n-1)6/2]$ $Q = 275 \times 2 + [(n-1)6/2]$
Other areas	20	$Q = 20 + [(n-1)10/4]$
Equipment service rooms	275	No additional flow included

Appendix 7 - Anesthetic gas scavenging systems: design and diversified flows [1]

Department	Design flow for each terminal unit (L/min)	Diversified flow Q (L/min)
Accident & emergency resuscitation room (per trolley space)	$V^{(1)}$	$Q = V + [(n-1)V/4]$
Operating departments	V	$Q = V + (nT - 1)V$
Maternity operating suites	V	$Q = V + (nS - 1)V$
Radiodiagnostic (all anaesthetic and procedures room)	V	$Q = V + [(n-1)V/4]$
Oral surgery/orthodontic consulting rooms (type 1)	V	$Q = V + [(n-1)V/4]$
Other departments	V	$Q = V + [(n-1)V/8]$

Note: For the purpose of sizing the AGS disposal system pump, V is taken as either 130 L/min or 80 L/min.

Appendix 8 - Pipeline pressure loss: 400 KPa (4 bar) pipelines [1]

British Standard Size Tube BS EN 1057: R250, Table X		Distance from source (m) at 400 kPa for 7, 14, 21 kPa (1, 2, 3 psi) pressure loss																
Outside Diameter (mm)	Pressure loss (kPa)	8	15	30	61	91	122	152	183	213	244	274	305	335	366	396	427	457
		Free air flow rate (L/min)																
12	7	311	209	141	95	75	64	56	50	46	43	40	37	35	34	32	31	30
	14	455	307	207	139	110	94	82	74	68	63	59	55	52	50	47	45	44
	21	564	382	258	174	138	117	103	93	85	78	73	69	65	62	59	57	55
15	7	579	391	263	177	140	119	105	94	86	80	75	70	66	63	60	58	56
	14	845	572	386	260	207	175	154	139	127	118	110	104	98	93	89	85	82
	21	1038	711	481	325	258	219	192	173	159	147	137	129	122	117	111	107	102
22	7	1677	1135	768	518	411	349	307	277	254	235	220	207	196	186	178	170	164
	14	2441	1656	1123	759	604	513	451	407	373	345	323	304	288	274	262	251	241
	21	3023	2053	1395	945	751	638	562	507	465	431	403	379	359	342	326	313	301
28	7	3363	2283	1547	1047	832	706	622	560	514	476	445	419	397	378	361	346	332
	14	4881	3320	2257	1530	1218	1035	912	823	754	699	653	615	583	555	530	508	488
	21	6034	4109	2800	1901	1514	1287	1135	1024	938	870	814	767	726	691	660	633	609
35	7	6023	4096	2783	1886	1500	1275	1124	1013	928	861	805	758	718	683	653	626	602
	14	8720	5943	4051	2752	2192	1865	1644	1483	1360	1261	1180	1111	1053	1002	957	918	883
	21	10758	7344	5018	3415	2723	2317	2044	1845	1692	1569	1468	1383	1310	1248	1192	1143	1099
42	7	10103	6883	4685	3180	2533	2154	1899	1713	1570	1456	1362	1283	1215	1157	1105	1060	1019
	14	14587	9963	6806	4633	3694	3145	2775	2504	2296	2130	1993	1878	1780	1694	1619	1553	1493
	21	17963	12290	8421	5743	4584	3904	3446	3112	2855	2648	2478	2335	2213	2107	2014	1932	1858
54	7	14974	10588	7487	5294	4323	3743	3348	3056	2830	2647	2496	2368	2257	2161	2076	2001	1933
	14	21176	14974	10588	7487	6113	5294	4735	4323	4002	3743	3529	3348	3192	3056	2937	2830	2734
	21	25935	18339	12968	9169	7487	6484	5799	5294	4901	4585	4323	4101	3910	3743	3597	3466	3348
76	7	37754	26696	18877	13348	10899	9438	8442	7706	7135	6674	6292	5969	5692	5449	5236	5045	4874
	14	53392	37754	26696	18877	15413	13348	11939	10899	10090	9438	8899	8442	8049	7706	7404	7135	6893
	21	65392	46239	32696	23119	18877	16348	14622	13348	12358	11560	10899	10339	9858	9438	9068	8738	8442

Appendix 9 - Pipeline pressure loss: 700 KPa (7 bar) pipelines [1]

British Standard Size Tube BS EN 1057: R250, Table X		Distance from source (m) at 700 kPa for 7, 14, 34 kPa (1, 2, 5 psi) pressure loss																
Outside Diameter (mm)	Pressure loss (kPa)	8	15	30	61	91	122	152	183	213	244	274	305	335	366	396	427	457
		Free air flow rate (L/min)																
12	7	408	276	186	125	99	84	74	67	61	56	53	50	47	45	43	41	39
	14	599	405	274	185	147	124	109	99	90	84	78	74	70	66	63	61	58
	34	979	664	450	304	242	205	181	163	149	138	129	122	115	110	105	100	96
15	7	759	514	347	234	186	158	139	125	114	106	99	93	88	84	80	77	74
	14	1112	754	510	345	274	232	205	184	169	156	146	138	130	124	118	114	109
	34	1811	1231	836	566	450	383	337	304	279	258	242	227	215	205	196	188	180
22	7	2192	1488	1009	682	542	460	406	366	335	310	290	273	259	246	235	225	217
	14	3198	2175	1478	1001	797	677	597	538	493	457	428	403	381	363	347	332	320
	34	5180	3533	2410	1638	1306	1111	980	884	811	752	704	663	628	598	571	548	527
28	7	4387	2984	2027	1374	1093	929	819	739	677	628	587	553	524	498	476	456	439
	14	6382	4351	2963	2013	1604	1364	1203	1086	995	923	863	813	771	734	701	672	646
	34	10290	7038	4816	3283	2620	2232	1970	1779	1632	1514	1417	1335	1266	1205	1152	1105	1063
35	7	7841	5345	3638	2470	1968	1674	1476	1332	1221	1132	1059	998	945	900	860	825	793
	14	11380	7775	5307	3612	2881	2453	2165	1954	1792	1662	1556	1466	1389	1323	1264	1212	1166
	34	18271	12528	8599	5876	4696	4003	3536	3194	2931	2720	2547	2401	2276	2168	2073	1988	1912
42	7	13128	8964	6113	4159	3316	2823	2490	2248	2061	1912	1789	1686	1598	1521	1454	1394	1341
	14	19010	13012	8901	6070	4847	4129	3646	3293	3021	2803	2624	2473	2344	2232	2134	2047	1969
	34	30392	20892	14381	9849	7881	6723	5942	5371	4930	4577	4286	4042	3833	3651	3491	3349	3223

Appendix 10 - Pipeline pressure loss: 1100 kPa (11 bar) pipelines [1]

British Standard Size Tube BS EN 1057: R250, Table X		Distance from source (m) at 1100 kPa for 7, 14, 34 kPa (1, 2, 5 psi) pressure loss																
Outside Diameter (mm)	Pressure loss (kPa)	8	15	30	61	91	122	152	183	213	244	274	305	335	366	396	427	457
		Free air flow rate (L/min)																
12	7	487	356	252	177	144	124	112	102	94	88	84	79	75	72	69	67	65
	14	689	503	355	249	204	177	158	144	133	124	118	111	106	102	98	94	91
	34	1084	791	560	392	321	277	249	227	210	197	185	176	167	161	154	148	143
15	7	867	634	448	314	257	222	199	181	168	157	148	141	134	128	124	119	115
	14	1226	895	633	444	363	314	281	257	238	222	209	199	189	181	174	168	162
	34	1929	1409	996	698	572	494	443	403	373	350	330	313	298	285	275	264	256
22	7	2332	1703	1205	845	692	598	535	487	452	423	399	378	360	345	332	319	309
	14	3294	2405	1701	1193	977	844	755	689	638	597	562	534	509	487	468	451	436
	34	5185	3787	2678	1878	1537	1328	1189	1084	1005	939	886	840	801	767	737	710	686
28	7	4469	3263	2308	1618	1325	1145	1025	935	866	809	764	724	691	660	636	612	591
	14	6311	4608	3259	2286	1872	1616	1448	1320	1223	1143	1078	1022	976	933	897	864	835
	34	9935	7255	5130	3598	2946	2544	2279	2077	1926	1799	1698	1609	1535	1469	1412	1359	1315
35	7	7718	5636	3985	2795	2289	1976	1771	1614	1495	1397	1319	1250	1192	1141	1097	1056	1021
	14	10898	7959	5628	3947	3231	2791	2500	2279	2112	1973	1862	1765	1684	1611	1549	1492	1442
	34	17157	12530	8860	6213	5087	4394	3936	3587	3325	3107	2932	2779	2651	2537	2439	2348	2271
42	7	12550	9166	6481	4545	3721	3214	2879	2624	2432	2272	2144	2033	1940	1855	1784	1718	1661
	14	17724	12944	9152	6418	5255	4538	4066	3706	3435	3209	3029	2871	2739	2620	2519	2426	2345
	34	27902	20377	14409	10104	8273	7145	6401	5834	5407	5052	4768	4519	4312	4125	3966	3819	3692

Appendix 11 - Pipeline pressure loss (vacuum) [1]

British Standard Size Tube BS EN 1057: R250, Table X		Distance from source (m) at 59 kPa (450 mm Hg) for 1.3, 2.6, 3.9, 6.5 kPa (10, 20, 30, 50 mm Hg) pressure loss																
Outside Diameter (mm)	Pressure loss (kPa)	8	15	30	61	91	122	152	183	213	244	274	305	335	366	396	427	457
		Free air flow rate (L/min)																
12	1.3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	2.6	47	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	3.9	60	40	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	6.5	82	55	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
15	1.3	59	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	2.6	89	59	40	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	3.9	113	76	51	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	6.5	153	103	69	46	–	–	–	–	–	–	–	–	–	–	–	–	–
22	1.3	173	116	78	52	41	–	–	–	–	–	–	–	–	–	–	–	–
	2.6	260	174	117	79	62	53	46	42	–	–	–	–	–	–	–	–	–
	3.9	330	222	149	100	79	67	59	53	49	45	42	40	–	–	–	–	–
	6.5	445	301	203	137	108	92	81	73	67	62	57	54	51	49	46	45	43
28	1.3	350	236	159	106	84	71	63	56	51	48	44	42	40	–	–	–	–
	2.6	525	353	238	160	127	107	94	85	78	72	67	63	60	57	54	52	50
	3.9	666	448	303	204	161	137	120	108	99	92	86	81	76	73	69	66	64
	6.5	900	607	412	278	220	187	164	148	135	125	117	110	104	99	95	91	87
35	1.3	637	427	288	193	153	130	114	102	94	87	81	76	72	69	65	63	60
	2.6	947	638	431	290	230	195	171	154	141	131	122	115	109	103	99	95	91
	3.9	1198	808	548	369	293	248	218	197	180	167	156	147	139	132	126	121	116
	6.5	1614	1091	743	503	399	339	298	269	246	228	213	200	190	180	172	165	158
42	1.3	1074	724	488	328	260	220	194	174	160	148	138	130	123	117	111	107	103
	2.6	1598	1079	731	493	391	331	291	262	240	222	208	196	185	176	168	161	155
	3.9	2016	1363	926	626	497	422	371	334	306	283	265	249	236	224	214	205	197
	6.5	2706	1833	1254	851	677	574	506	456	417	387	361	340	322	306	293	280	270
54	1.3	2191	1480	1001	674	535	453	399	359	329	304	284	268	253	241	230	220	212
	2.6	3246	2196	1493	1010	802	681	599	540	494	458	428	403	381	363	346	332	319
	3.9	4083	2766	1889	1281	1019	865	762	687	629	582	545	513	485	462	441	423	406
	6.5	5448	3699	2549	1737	1384	1176	1037	935	856	794	742	699	662	630	601	576	554
76	1.3	5521	3773	2563	1733	1377	1169	1029	927	849	786	735	692	655	623	595	570	548
	2.6	8070	5563	3807	2586	2058	1749	1541	1389	1273	1179	1103	1038	983	936	894	857	823
	3.9	10041	6968	4801	3274	2609	2219	1957	1765	1617	1499	1402	1320	1250	1190	1137	1090	1048
	6.5	13166	9233	6439	4421	3533	3009	2655	2396	2197	2037	1906	1796	1701	1619	1547	1483	1426
108	1.3	12874	9140	6543	4552	3732	3280	2879	2628	2433	2276	1919	2036	1941	1858	1785	1712	1641
	2.6	18207	12874	9235	6578	5274	4552	4071	3716	3441	3219	3035	2879	2745	2628	2525	2422	2325
	3.9	22494	15905	11374	8114	6509	5657	5030	4592	4251	3976	3750	3557	3391	3247	3119	2992	2870
	6.5	29238	20675	14708	10520	8445	7343	6538	5968	5526	5169	4873	4623	4408	4220	4055	3889	3730

Appendix 12 - Pressure during pipeline system tests [1]

Medical gas	Nominal pipeline distribution pressure (kPa)	Test flow (L/min) (measured at terminal unit outlet)	Test location	Min. pressure at design flow measured on the test gauge (kPa)	Plant pressure (kPa)
O_2	400	100 10	Operating rooms (ORs) and anaesthetic rooms (ARs) All other terminal units	380	430–490
N_2O	400	15	All terminal units	380	430–490
Medical air (400 kPa)	400	80 20	Critical care areas, SCBU, HDU, ORs and ARs All other terminal units	380	430–490
Surgical air (700 kPa)	700	350	All terminal units	700 kPa at 350 L/min (max 900 kPa at no flow conditions)[(1)]	See Chapter 4
O_2/N_2O mixtures	400	275 20	LRDP rooms (inhalationary gasps) All other terminal units	310[(2)] 380	430–490
He/O_2	400	80	Critical care areas only	380	430–490
Vacuum	55.3 kPa (400 mm Hg) below standard atmospheric pressure of 101.3 kPa (760 mm Hg)	40	All terminal units	400 kPa (300 mm Hg)	550–650 mm Hg (typical plant operating range)

Notes:

1. Downstream of the local regulator measured at the terminal unit.
2. The peak flow of 275 L/min must be achieved for 5 seconds at a minimum pressure of 310 kPa (310 kPa is the minimum pressure required for the operation of a demand regulator).

Appendix 13 - Oxygen gas pipeline distribution layout properties

Floor 1

Pipe	n	Ø	l	L	q	Q	p	DP	Room
1	0	28	1200	1500	0	2283	7	0	a
2	0	22	925	3000	0	768	7	0	a
3	0	22	962	3000	0	768	7	0	a
4	0	22	315	6100	0	518	7	0	a
5	0	22	3045	9100	0	411	7	0	a
6	0	22	901	9100	0	411	7	0	a
11	1	15	647	1500	0	391	7	0	sr
12	1	15	540	1500	0	391	7	0	sr
21	4	15	838	3000	0	263	7	0	em
22	3	15	230	3000	0	263	7	0	em
23	2	15	215	3000	0	263	7	0	em
24	1	15	490	3000	0	263	7	0	em
25	6	15	640	3000	0	263	7	0	rc
26	5	15	200	3000	0	263	7	0	rc
27	4	15	300	6100	0	177	7	0	rc
28	3	15	280	6100	0	177	7	0	rc
29	2	15	90	6100	0	177	7	0	rc
210	1	15	400	6100	0	177	7	0	rc
31	4	15	830	6100	0	177	7	0	ex
32	3	15	180	6100	0	177	7	0	ex
33	2	15	300	6100	0	177	7	0	ex
34	1	15	500	6100	0	177	7	0	ex
41	4	15	730	6100	0	177	7	0	ic
42	3	15	200	6100	0	177	7	0	ic
43	2	15	210	6100	0	177	7	0	ic
44	1	15	490	6100	0	177	7	0	ic
51	2	15	857	9100	0	140	7	0	ot
52	1	15	230	9100	0	140	7	0	ot
53	6	15	330	9100	0	140	7	0	ch
54	5	15	250	9100	0	140	7	0	ch
55	4	15	80	9100	0	140	7	0	ch
56	3	15	785	9100	0	140	7	0	ch
57	2	15	80	9100	0	140	7	0	ch
58	1	15	450	9100	0	140	7	0	ch
61	4	15	742	9100	0	140	7	0	mr
62	3	15	345	9100	0	140	7	0	mr
63	2	15	300	9100	0	140	7	0	mr
64	1	15	300	9100	0	140	7	0	mr
65	4	15	740	9100	0	140	7	0	mo
66	3	15	300	9100	0	140	7	0	mo
67	2	15	300	9100	0	140	7	0	mo
68	1	15	490	9100	0	140	7	0	mo

Floor 2

Pipe	n	Ø	l	L	q	Q	p	DP	Room
1	0	28	1500	1500	0	2283	7	0	a
2	0	22	925	3000	0	768	7	0	a
3	0	22	962	3000	0	768	7	0	a
4	0	22	315	6100	0	518	7	0	a
5	0	22	3045	9100	0	411	7	0	a
6	0	22	901	9100	0	411	7	0	a
11	4	15	800	3000	0	263	7	0	ot
12	3	15	540	3000	0	263	7	0	ot
13	2	15	300	6100	0	177	7	0	ot
14	1	15	300	6100	0	177	7	0	ot
15	4	15	747	3000	0	263	7	0	ot
16	3	15	280	3000	0	263	7	0	ot
17	2	15	300	3000	0	263	7	0	ot
18	1	15	300	6100	0	177	7	0	ot
21	3	15	800	3000	0	263	7	0	or
22	2	15	300	3000	0	263	7	0	or
23	1	15	300	3000	0	263	7	0	or
24	6	15	768	3000	0	263	7	0	ip
25	5	15	100	3000	0	263	7	0	ip
26	4	15	200	6100	0	177	7	0	ip
27	3	15	300	6100	0	177	7	0	ip
28	2	15	220	6100	0	177	7	0	ip
29	1	15	300	6100	0	177	7	0	ip
31	4	15	830	6100	0	177	7	0	ot
32	3	15	180	6100	0	177	7	0	ot
33	2	15	300	6100	0	177	7	0	ot
34	1	15	500	6100	0	177	7	0	ot
41	4	15	730	6100	0	177	7	0	ip
42	3	15	200	6100	0	177	7	0	ip
43	2	15	210	6100	0	177	7	0	ip
44	1	15	490	6100	0	177	7	0	ip
51	2	15	857	9100	0	140	7	0	rd
52	1	15	600	9100	0	140	7	0	ot
53	3	15	950	9100	0	140	7	0	ot
54	2	15	300	9100	0	140	7	0	ot
55	1	15	300	9100	0	140	7	0	ot
61	2	15	1030	9100	0	140	7	0	ot
62	1	15	345	9100	0	140	7	0	ot
63	3	15	300	9100	0	140	7	0	ot
64	2	15	300	9100	0	140	7	0	ot
65	1	15	740	9100	0	140	7	0	ot

Appendix 14 - Medical Vacuum pipeline distribution layout properties

Floor 1

Pipe	n	Ø	l	L	q	Q	p	DP	Room
1	0	54	1200	1500	0	1480	1.3	0	a
2	0	42	925	3000	0	488	1.3	0	a
3	0	42	962	3000	0	488	1.3	0	a
4	0	42	315	6100	0	328	1.3	0	a
5	0	42	3045	9100	0	260	1.3	0	a
6	0	42	901	9100	0	260	1.3	0	a
11	1	42	647	1500	0	724	1.3	0	sr
12	1	42	540	1500	0	724	1.3	0	sr
21	4	42	838	3000	0	488	1.3	0	em
22	3	42	230	3000	0	488	1.3	0	em
23	2	42	215	3000	0	488	1.3	0	em
24	1	42	490	3000	0	488	1.3	0	em
25	6	42	640	3000	0	488	1.3	0	rc
26	5	42	200	3000	0	488	1.3	0	rc
27	4	42	300	6100	0	328	1.3	0	rc
28	3	42	280	6100	0	328	1.3	0	rc
29	2	42	90	6100	0	328	1.3	0	rc
210	1	42	400	6100	0	328	1.3	0	rc
31	4	42	830	6100	0	328	1.3	0	ex
32	3	42	180	6100	0	328	1.3	0	ex
33	2	42	300	6100	0	328	1.3	0	ex
34	1	42	500	6100	0	328	1.3	0	ex
41	4	42	730	6100	0	328	1.3	0	ic
42	3	42	200	6100	0	328	1.3	0	ic
43	2	42	210	6100	0	328	1.3	0	ic
44	1	42	490	6100	0	328	1.3	0	ic
51	2	42	857	9100	0	260	1.3	0	ot
52	1	42	230	9100	0	260	1.3	0	ot
53	6	42	330	9100	0	260	1.3	0	ch
54	5	42	250	9100	0	260	1.3	0	ch
55	4	42	80	9100	0	260	1.3	0	ch
56	3	42	785	9100	0	260	1.3	0	ch
57	2	42	80	9100	0	260	1.3	0	ch
58	1	42	450	9100	0	260	1.3	0	ch
61	4	42	742	9100	0	260	1.3	0	mr
62	3	42	345	9100	0	260	1.3	0	mr
63	2	42	300	9100	0	260	1.3	0	mr
64	1	42	300	9100	0	260	1.3	0	mr
65	4	42	740	9100	0	260	1.3	0	mo
66	3	42	300	9100	0	260	1.3	0	mo
67	2	42	300	9100	0	260	1.3	0	mo
68	1	42	490	9100	0	260	1.3	0	mo

Floor 2

Pipe	n	Ø	l	L	q	Q	p	DP	Room
1	0	54	1500	1500	0	1480	1.3	0	a
2	0	42	925	3000	0	488	1.3	0	a
3	0	42	962	3000	0	488	1.3	0	a
4	0	42	315	6100	0	488	1.3	0	a
5	0	42	3045	9100	0	260	1.3	0	a
6	0	42	901	9100	0	260	1.3	0	a
11	4	42	800	3000	0	488	1.3	0	ot
12	3	42	540	3000	0	488	1.3	0	ot
13	2	42	300	6100	0	328	1.3	0	ot
14	1	42	300	6100	0	328	1.3	0	ot
15	4	42	747	3000	0	488	1.3	0	ot
16	3	42	280	3000	0	488	1.3	0	ot
17	2	42	300	3000	0	488	1.3	0	ot
18	1	42	300	6100	0	488	1.3	0	ot
21	3	42	800	3000	0	488	1.3	0	or
22	2	42	300	3000	0	488	1.3	0	or
23	1	42	300	3000	0	488	1.3	0	or
24	6	42	768	3000	0	488	1.3	0	ip
25	5	42	100	3000	0	488	1.3	0	ip
26	4	42	200	6100	0	488	1.3	0	ip
27	3	42	300	6100	0	488	1.3	0	ip
28	2	42	220	6100	0	488	1.3	0	ip
29	1	42	300	6100	0	488	1.3	0	ip
31	4	42	830	6100	0	488	1.3	0	ot
32	3	42	180	6100	0	488	1.3	0	ot
33	2	42	300	6100	0	488	1.3	0	ot
34	1	42	500	6100	0	488	1.3	0	ot
41	4	42	730	6100	0	488	1.3	0	ip
42	3	42	200	6100	0	488	1.3	0	ip
43	2	42	210	6100	0	488	1.3	0	ip
44	1	42	490	6100	0	488	1.3	0	ip
51	2	42	857	9100	0	260	1.3	0	rd
52	1	42	600	9100	0	260	1.3	0	ot
53	3	42	950	9100	0	260	1.3	0	ot
54	2	42	300	9100	0	260	1.3	0	ot
55	1	42	300	9100	0	260	1.3	0	ot
61	2	42	1030	9100	0	260	1.3	0	ot
62	1	42	345	9100	0	260	1.3	0	ot
63	3	42	300	9100	0	260	1.3	0	ot
64	2	42	300	9100	0	260	1.3	0	ot
	1	42	740	9100	0	260	1.3	0	ot

Appendix 15 – Medical air pipeline distribution layout properties

Floor 1

Pipe	n	Ø	l	L	q	Q	p	DP	Room
1	0	28	1200	1500	0	2283	7	0	a
2	0	22	925	3000	0	768	7	0	a
3	0	22	962	3000	0	768	7	0	a
4	0	22	315	6100	0	518	7	0	a
5	0	22	3045	9100	0	411	7	0	a
6	0	22	901	9100	0	411	7	0	a
11	1	15	647	1500	0	391	7	0	sr
12	1	15	540	1500	0	391	7	0	sr
21	4	15	838	3000	0	263	7	0	em
22	3	15	230	3000	0	263	7	0	em
23	2	15	215	3000	0	263	7	0	em
24	1	15	490	3000	0	263	7	0	em
25	6	15	640	3000	0	263	7	0	rc
26	5	15	200	3000	0	263	7	0	rc
27	4	15	300	6100	0	177	7	0	rc
28	3	15	280	6100	0	177	7	0	rc
29	2	15	90	6100	0	177	7	0	rc
210	1	15	400	6100	0	177	7	0	rc
31	4	15	830	6100	0	177	7	0	ex
32	3	15	180	6100	0	177	7	0	ex
33	2	15	300	6100	0	177	7	0	ex
34	1	15	500	6100	0	177	7	0	ex
41	4	15	730	6100	0	177	7	0	ic
42	3	15	200	6100	0	177	7	0	ic
43	2	15	210	6100	0	177	7	0	ic
44	1	15	490	6100	0	177	7	0	ic
51	2	15	857	9100	0	140	7	0	ot
52	1	15	230	9100	0	140	7	0	ot
53	6	15	330	9100	0	140	7	0	ch
54	5	15	250	9100	0	140	7	0	ch
55	4	15	80	9100	0	140	7	0	ch
56	3	15	785	9100	0	140	7	0	ch
57	2	15	80	9100	0	140	7	0	ch
58	1	15	450	9100	0	140	7	0	ch
61	4	15	742	9100	0	140	7	0	mr
62	3	15	345	9100	0	140	7	0	mr
63	2	15	300	9100	0	140	7	0	mr
64	1	15	300	9100	0	140	7	0	mr
65	4	15	740	9100	0	140	7	0	mo
66	3	15	300	9100	0	140	7	0	mo
67	2	15	300	9100	0	140	7	0	mo
68	1	15	490	9100	0	140	7	0	mo

Floor 2

Pipe	n	Ø	l	L	q	Q	p	DP	Room
1	0	28	1500	1500	0	2283	7	0	a
2	0	22	925	3000	0	768	7	0	a
3	0	22	962	3000	0	768	7	0	a
4	0	22	315	6100	0	518	7	0	a
5	0	22	3045	9100	0	411	7	0	a
6	0	22	901	9100	0	411	7	0	a
11	4	15	800	3000	0	263	7	0	no
12	3	15	540	3000	0	263	7	0	no
13	2	15	300	6100	0	177	7	0	no
14	1	15	300	6100	0	177	7	0	no
15	4	15	747	3000	0	263	7	0	no
16	3	15	280	3000	0	263	7	0	no
17	2	15	300	3000	0	263	7	0	no
18	1	15	300	6100	0	177	7	0	no
21	3	15	800	3000	0	263	7	0	or
22	2	15	300	3000	0	263	7	0	or
23	1	15	300	3000	0	263	7	0	or
24	6	15	768	3000	0	263	7	0	ip
25	5	15	100	3000	0	263	7	0	ip
26	4	15	200	6100	0	177	7	0	ip
27	3	15	300	6100	0	177	7	0	ip
28	2	15	220	6100	0	177	7	0	ip
29	1	15	300	6100	0	177	7	0	ip
31	4	15	830	6100	0	177	7	0	no
32	3	15	180	6100	0	177	7	0	no
33	2	15	300	6100	0	177	7	0	no
34	1	15	500	6100	0	177	7	0	no
41	4	15	730	6100	0	177	7	0	ip
42	3	15	200	6100	0	177	7	0	ip
43	2	15	210	6100	0	177	7	0	ip
44	1	15	490	6100	0	177	7	0	ip
51	2	15	857	9100	0	140	7	0	rd
52	1	15	600	9100	0	140	7	0	no
53	3	15	950	9100	0	140	7	0	no
54	2	15	300	9100	0	140	7	0	no
55	1	15	300	9100	0	140	7	0	no
61	2	15	1030	9100	0	140	7	0	no
62	1	15	345	9100	0	140	7	0	no
63	3	15	300	9100	0	140	7	0	no
64	2	15	300	9100	0	140	7	0	no
65	1	15	740	9100	0	140	7	0	no

Appendix 16 – Surgical air pipeline distribution layout properties

Floor 1

Pipe	n	Ø	l	L	q	Q	p	DP	Room
1	0	28	1200	1500	0	2984	7	0	a
2	0	22	925	3000	0	1009	7	0	a
3	0	22	962	3000	0	1009	7	0	a
4	0	22	315	6100	0	682	7	0	a
5	0	22	3045	9100	0	542	7	0	a
6	0	22	901	9100	0	542	7	0	a
11	1	15	647	3000	0	347	7	0	sr
12	1	15	540	3000	0	347	7	0	sr
21	4	15	838	6100	0	234	7	0	em
22	3	15	230	6100	0	234	7	0	em
23	2	15	215	3000	0	347	7	0	em
24	1	15	490	3000	0	347	7	0	em
25	6	15	640	3000	0	347	7	0	rc
26	5	15	200	6100	0	234	7	0	rc
27	4	15	300	3000	0	347	7	0	rc
28	3	15	280	3000	0	347	7	0	rc
29	2	15	90	3000	0	347	7	0	rc
210	1	15	400	3000	0	347	7	0	rc
31	4	15	830	3000	0	347	7	0	ex
32	3	15	180	6100	0	234	7	0	ex
33	2	15	300	6100	0	234	7	0	ex
34	1	15	500	6100	0	234	7	0	ex
41	4	15	730	6100	0	234	7	0	ic
42	3	15	200	6100	0	234	7	0	ic
43	2	15	210	6100	0	234	7	0	ic
44	1	15	490	6100	0	234	7	0	ic
51	2	15	857	6100	0	234	7	0	no
52	1	15	230	6100	0	234	7	0	no
53	6	15	330	6100	0	234	7	0	ch
54	5	15	250	6100	0	234	7	0	ch
55	4	15	80	6100	0	234	7	0	ch
56	3	15	785	9100	0	186	7	0	ch
57	2	15	80	9100	0	186	7	0	ch
58	1	15	450	9100	0	186	7	0	ch
61	4	15	742	9100	0	186	7	0	mr
62	3	15	345	9100	0	186	7	0	mr
63	2	15	300	9100	0	186	7	0	mr
64	1	15	300	9100	0	186	7	0	mr
65	4	15	740	9100	0	186	7	0	mo
66	3	15	300	9100	0	186	7	0	mo
67	2	15	300	9100	0	186	7	0	mo
68	1	15	490	9100	0	186	7	0	mo

Appendix 17 –Nitrous oxide pipeline distribution layout properties

Floor 1

Pipe	n	Ø	l	L	q	Q	p	ΔΠ	Room
1	0	28	1200	1500	0	2283	7	0	a
2	0	22	925	3000	0	768	7	0	a
3	0	22	962	3000	0	768	7	0	a
4	0	22	315	6100	0	518	7	0	a
5	0	22	3045	9100	0	411	7	0	a
6	0	22	901	9100	0	411	7	0	a
11	1	15	647	1500	0	391	7	0	sr
12	1	15	540	1500	0	391	7	0	sr
21	4	15	838	3000	0	263	7	0	em
22	3	15	230	3000	0	263	7	0	em
23	2	15	215	3000	0	263	7	0	em
24	1	15	490	3000	0	263	7	0	em
25	6	15	640	3000	0	263	7	0	rc
26	5	15	200	3000	0	263	7	0	rc
27	4	15	300	6100	0	177	7	0	rc
28	3	15	280	6100	0	177	7	0	rc
29	2	15	90	6100	0	177	7	0	rc
210	1	15	400	6100	0	177	7	0	rc
31	4	15	830	6100	0	177	7	0	ex
32	3	15	180	6100	0	177	7	0	ex
33	2	15	300	6100	0	177	7	0	ex
34	1	15	500	6100	0	177	7	0	ex
41	4	15	730	6100	0	177	7	0	ic
42	3	15	200	6100	0	177	7	0	ic
43	2	15	210	6100	0	177	7	0	ic
44	1	15	490	6100	0	177	7	0	ic
51	2	15	857	9100	0	140	7	0	ot
52	1	15	230	9100	0	140	7	0	ot
53	6	15	330	9100	0	140	7	0	ch
54	5	15	250	9100	0	140	7	0	ch
55	4	15	80	9100	0	140	7	0	ch
56	3	15	785	9100	0	140	7	0	ch
57	2	15	80	9100	0	140	7	0	ch
58	1	15	450	9100	0	140	7	0	ch
61	4	15	742	9100	0	140	7	0	mr
62	3	15	345	9100	0	140	7	0	mr
63	2	15	300	9100	0	140	7	0	mr
64	1	15	300	9100	0	140	7	0	mr
65	4	15	740	9100	0	140	7	0	mo
66	3	15	300	9100	0	140	7	0	mo
67	2	15	300	9100	0	140	7	0	mo
68	1	15	490	9100	0	140	7	0	mo

Floor 2

Pipe	n	Ø	l	L	q	Q	p	ΔΠ	Room
1	0	28	1500	1500	0	2283	7	0	a
2	0	22	925	3000	0	768	7	0	a
3	0	22	962	3000	0	768	7	0	a
4	0	22	315	6100	0	518	7	0	a
5	0	22	3045	9100	0	411	7	0	a
6	0	22	901	9100	0	411	7	0	a
11	4	15	800	3000	0	263	7	0	no
12	3	15	540	3000	0	263	7	0	no
13	2	15	300	6100	0	177	7	0	no
14	1	15	300	6100	0	177	7	0	no
15	4	15	747	3000	0	263	7	0	no
16	3	15	280	3000	0	263	7	0	no
17	2	15	300	3000	0	263	7	0	no
18	1	15	300	6100	0	177	7	0	no
21	3	15	800	3000	0	263	7	0	or
22	2	15	300	3000	0	263	7	0	or
23	1	15	300	3000	0	263	7	0	or
24	6	15	768	3000	0	263	7	0	ip
25	5	15	100	3000	0	263	7	0	ip
26	4	15	200	6100	0	177	7	0	ip
27	3	15	300	6100	0	177	7	0	ip
28	2	15	220	6100	0	177	7	0	ip
29	1	15	300	6100	0	177	7	0	ip
31	4	15	830	6100	0	177	7	0	no
32	3	15	180	6100	0	177	7	0	no
33	2	15	300	6100	0	177	7	0	no
34	1	15	500	6100	0	177	7	0	no
41	4	15	730	6100	0	177	7	0	ip
42	3	15	200	6100	0	177	7	0	ip
43	2	15	210	6100	0	177	7	0	ip
44	1	15	490	6100	0	177	7	0	ip
51	2	15	857	9100	0	140	7	0	rd
52	1	15	600	9100	0	140	7	0	no
53	3	15	950	9100	0	140	7	0	no
54	2	15	300	9100	0	140	7	0	no
55	1	15	300	9100	0	140	7	0	no
61	2	15	1030	9100	0	140	7	0	no
62	1	15	345	9100	0	140	7	0	no
63	3	15	300	9100	0	140	7	0	no
64	2	15	300	9100	0	140	7	0	no
65	1	15	740	9100	0	140	7	0	no

Appendix 18 – Anesthetic gas pipeline distribution layout properties

Floor 1

Pipe	n	Ø	l	L	q	Q	p	DP	Room
1	0	28	1200	1500	0	2283	7	0	a
2	0	22	925	3000	0	768	7	0	a
3	0	22	962	3000	0	768	7	0	a
4	0	22	315	6100	0	518	7	0	a
5	0	22	3045	9100	0	411	7	0	a
6	0	22	901	9100	0	411	7	0	a
11	1	15	647	1500	0	391	7	0	sr
12	1	15	540	1500	0	391	7	0	sr
21	4	15	838	3000	0	263	7	0	em
22	3	15	230	3000	0	263	7	0	em
23	2	15	215	3000	0	263	7	0	em
24	1	15	490	3000	0	263	7	0	em
25	6	15	640	3000	0	263	7	0	rc
26	5	15	200	3000	0	263	7	0	rc
27	4	15	300	6100	0	177	7	0	rc
28	3	15	280	6100	0	177	7	0	rc
29	2	15	90	6100	0	177	7	0	rc
210	1	15	400	6100	0	177	7	0	rc
31	4	15	830	6100	0	177	7	0	ex
32	3	15	180	6100	0	177	7	0	ex
33	2	15	300	6100	0	177	7	0	ex
34	1	15	500	6100	0	177	7	0	ex
41	4	15	730	6100	0	177	7	0	ic
42	3	15	200	6100	0	177	7	0	ic
43	2	15	210	6100	0	177	7	0	ic
44	1	15	490	6100	0	177	7	0	ic
51	2	15	857	9100	0	140	7	0	ot
52	1	15	230	9100	0	140	7	0	ot
53	6	15	330	9100	0	140	7	0	ch
54	5	15	250	9100	0	140	7	0	ch
55	4	15	80	9100	0	140	7	0	ch
56	3	15	785	9100	0	140	7	0	ch
57	2	15	80	9100	0	140	7	0	ch
58	1	15	450	9100	0	140	7	0	ch
61	4	15	742	9100	0	140	7	0	mr
62	3	15	345	9100	0	140	7	0	mr
63	2	15	300	9100	0	140	7	0	mr
64	1	15	300	9100	0	140	7	0	mr
65	4	15	740	9100	0	140	7	0	mo
66	3	15	300	9100	0	140	7	0	mo
67	2	15	300	9100	0	140	7	0	mo
68	1	15	490	9100	0	140	7	0	mo

Floor 2

Pipe	n	Ø	l	L	q	Q	p	DP	Room
1	0	28	1500	1500	0	2283	7	0	a
2	0	22	925	3000	0	768	7	0	a
3	0	22	962	3000	0	768	7	0	a
4	0	22	315	6100	0	518	7	0	a
5	0	22	3045	9100	0	411	7	0	a
6	0	22	901	9100	0	411	7	0	a
11	4	15	800	3000	0	263	7	0	ot
12	3	15	540	3000	0	263	7	0	ot
13	2	15	300	6100	0	177	7	0	ot
14	1	15	300	6100	0	177	7	0	ot
15	4	15	747	3000	0	263	7	0	ot
16	3	15	280	3000	0	263	7	0	ot
17	2	15	300	3000	0	263	7	0	ot
18	1	15	300	6100	0	177	7	0	ot
21	3	15	800	3000	0	263	7	0	or
22	2	15	300	3000	0	263	7	0	or
23	1	15	300	3000	0	263	7	0	or
24	6	15	768	3000	0	263	7	0	ip
25	5	15	100	3000	0	263	7	0	ip
26	4	15	200	6100	0	177	7	0	ip
27	3	15	300	6100	0	177	7	0	ip
28	2	15	220	6100	0	177	7	0	ip
29	1	15	300	6100	0	177	7	0	ip
31	4	15	830	6100	0	177	7	0	ot
32	3	15	180	6100	0	177	7	0	ot
33	2	15	300	6100	0	177	7	0	ot
34	1	15	500	6100	0	177	7	0	ot
41	4	15	730	6100	0	177	7	0	ip
42	3	15	200	6100	0	177	7	0	ip
43	2	15	210	6100	0	177	7	0	ip
44	1	15	490	6100	0	177	7	0	ip
51	2	15	857	9100	0	140	7	0	rd
52	1	15	600	9100	0	140	7	0	no
53	3	15	950	9100	0	140	7	0	no
54	2	15	300	9100	0	140	7	0	no
55	1	15	300	9100	0	140	7	0	no
61	2	15	1030	9100	0	140	7	0	no
62	1	15	345	9100	0	140	7	0	no
63	3	15	300	9100	0	140	7	0	no
64	2	15	300	9100	0	140	7	0	no
65	1	15	740	9100	0	140	7	0	no

Appendix 19 - Manual design analysis for Medical vacuum

 # Floor 1: Flowrate calculation

Main pipe 6

Maternity room, [Q = 80 + (n - 1) 40]

[68], n=1, Q = 80 + (1 - 1) 40 = 80

[67], n=2, Q = 80 + (2 - 1) 40 = 120

[66], n=3, Q = 80 + (3 - 1) 40 = 160

[65], n=4, Q = 80 + (4 - 1) 40 = **200**

Post Anesthesia Maternity recovery room, [Q = 10 + (n - 1) 10]

[64], n=1, Q = 40 + (1 - 1) 10 = 40

[63], n=2, Q = 40 + (2 - 1) 10 = 50

[62], n=3, Q = 40 + (3 - 1) 10 = 60

[61], n=4, Q = 40 + (4 - 1) 10 = **70**

Total flow rate for main pipe 6 = 118 + 12.25 = **270**

Main pipe 5

Children's inpatient room, [Q = 40]

[58], n=1, Q = 40

[57], n=2, Q = 40

[56], n=3, Q = 40

[55], n=4, Q = 40

[54], n=5, Q = 40

[53], n=6, Q = **40**

Physiotherapy room, [Q = 40]

[52], n=1, Q = 40

[51], n=2, Q = **40**

Total flow rate for main pipe 5 = 270 + 40 + 40 = **360**

Main pipe 4

Internal Care unit (ICU room), [Q = 40 + (n - 1)10]

[44], n=1, Q = 40 + (1 - 1) 10 = 40

[43], n=2, Q = 40 + (2 - 1) 10 = 50

[42], n=3, Q = 40 + (3 - 1) 10 = 60

[41], n=4, Q = 40 + (4 - 1) 10 = **70**

Total flow rate for main pipe 4 = 360 + 70 = **430**

Main pipe 3

Examination room, [Q = 40]

[34], n=1, Q = 40

[33], n=2, Q = 40

[32], n=3, Q = 40

[31], n=4, Q = **40**

Total flow rate for main pipe 3 = 430 + 40 = **470**

Main pipe 2

Post Anesthesia recovery room, [Q = 40 + (n - 1) 10]

[210], n=1, Q = 40 + (1 - 1) 10 = 40

[29], n=2, Q = 40 + (2 - 1) 10 = 50

[28], n=3, Q = 40 + (3 - 1) 10 = 60

[27], n=4, Q = 40 + (4 - 1) 10 = 70

[26], n=5, Q = 40 + (5 - 1) 10 = 80

[25], n=6, Q = 40 + (6 - 1) 10 = **90**

Emergency room, [Q = 40 + (n - 1) 10]

[24], n=1, Q = 40 + (1 - 1) 10 = 40

[23], n=2, Q = 40 + (2 - 1) 10 = 50

[22], n=3, Q = 40 + (3 - 1) 10 = 60

[21], n=4, Q = 40 + (4 - 1) 10 = **70**

Total flow rate for main pipe 2 = 470 + 90 + 70 = **630**

Main pipe 1

Surgery rooms: [Q = 80 + (n - 1) 40]

[11], n = 1, Q = 80 + (1 - 1)40 = **80**

[12], n = 1, Q = 80 + (1 - 1)40 = **80**

Total flow rate for main pipe 1 = 630 + 80 + 80 = **790**

 # Floor 2: Flowrate calculation

Main pipe 6

Oncology room, [Q = 40 + (n - 1)10]

[65], n=1, Q = 40 + (1 - 1)10 = 10

[64], n=2, Q = 40 + (2 - 1)10 = 50

[63], n=3, Q = 40 + (3 - 1)10 = **60**

CT Scan & ENT room, [Q = 40 + (n - 1)10]

[62], n=1, Q = 40 + (1 - 1)10 = 40

[61], n=2, Q = 40 + (2 - 1)10 = **50**

Total flow rate for main pipe 6 = 10 + 10 = **110**

Main pipe 5

Hematology room, [Q = 40 + (n - 1) 10]

[55], n=1, Q = 40 + (1 - 1) 10 = 40

[54], n=2, Q = 40 + (2 - 1)10 = 50

[53], n=3, Q = 40 + (3 - 1)10 = **60**

Radiography & MRI room, [Q = 40 + (n - 1)5]

[52], n=1, Q = 40 + (1 - 1)5 = 40

[51], n=2, Q = 40 + (2 - 1)5 = **45**

Total flow rate for main pipe 5 = 110 + 60 + 45 = **215**

Main pipe 4

Inpatient room, [Q = 40 + (n - 1)10]

[44], n=1, Q = 40 + (1 - 1) 10 = 40

[43], n=2, Q = 40 + (2 - 1) 10 = 50

[42], n=3, Q = 40 + (3 - 1) 10 = 60

[41], n=4, Q = 40 + (4 - 1) 10 = **70**

Total flow rate for main pipe 4 = 215 + 70 = **285**

Main pipe 3

Pediatric room, [Q = 40 + (n - 1) 10]

[34], n=1, Q = 40 + (n - 1) 10 = 40

[33], n=2, Q = 40 + (n - 1) 10 = 50

[32], n=3, Q = 40 + (n - 1) 10 = 60

[31], n=4, Q = 40 + (n - 1) 10 = **70**

Total flow rate for main pipe 3 = 285 + 70 = **355**

Main pipe 2

Inpatient room, [Q = 40 + (n - 1) 10]

[29], n=1, Q = 40 + (1 - 1) 10 = 40

[28], n=2, Q = 40 + (2 - 1) 10 = 50

[27], n=3, Q = 40 + (3 - 1) 10 = 60

[26], n=4, Q = 40 + (4 - 1) 10 = 70

[25], n=5, Q = 40 + (5 - 1) 10 = 80

[24], n=6, Q = 40 + (6 - 1) 10 = **90**

Orthodontic room, [Q = 40]

[23], n=1, Q = 40

[22], n=2, Q = 40

[21], n=3, Q = **40**

Total flow rate for main pipe 2 = 355 + 90 + 40 = **485**

Main pipe 1

Urology rooms: [Q = 40 + (n - 1) 10]

[18], n=1, Q = 40 + (1 - 1) 10 = 40

[17], n=2, Q = 40 + (2 - 1) 10 = 50

[16], n=3, Q = 40 + (3 - 1) 10 = 60

[15], n=4, Q = 40 + (4 - 1) 10 **= 70**

Neurology rooms: [Q = 40 + (n - 1) 10]

[14], n=1, Q = 40 + (1 - 1) 10 = 40

[13], n=2, Q = 40 + (2 - 1) 10 = 50

[12], n=3, Q = 40 + (3 - 1) 10 = 60

[11], n=4, Q = 40 + (4 - 1) 10 **= 70**

Total flow rate for main pipe 1 = 485 + 70 + 70 = **615**

The total diversified flowrate is the sum of individual floors flowrate

$Q_{Total} = Q_1 + Q_2$

$= 790 + 615$

$\mathbf{Q_{Total} = 1405}$

Riser flowrate

$Q_{Riser} = Q_{Total} = 1405$

<u># Floor 1: pressure loss calculation</u>

[1], l=1200, L=1500, q=790, Q=2283, p=1.3

$$\Delta P = \left[\frac{1200}{1500}\right]\left[\frac{790}{2283}\right]^2 [1.3] = 0.55514$$

[2], l=925, L=3000, q=630, Q=738, p=1.3

$$\Delta P = \left[\frac{925}{3000}\right]\left[\frac{630}{738}\right]^2 [1.3] = 0.51747$$

[3], l=962, L=3000, q=470, Q=768, p=1.3

$$\Delta P = \left[\frac{962}{3000}\right]\left[\frac{470}{768}\right]^2 [1.3] = 0.40149$$

[4], l=315, L=6100, q=430, Q=518, p=1.3

$$\Delta P = \left[\frac{315}{6100}\right]\left[\frac{430}{518}\right]^2 [1.3] = 0.088007$$

[5], l=3045, L=9100, q=360, Q=411, p=1.3

$\Delta P = \left[\frac{3045}{9100}\right]\left[\frac{360}{411}\right]^2 [1.3] = 0.60231$

[6], l=901, L=9100, q=270, Q=411, p=1.3

$\Delta P = \left[\frac{901}{9100}\right]\left[\frac{270}{411}\right]^2 [1.3] = 0.13366$

[65], l=740, L=9100, q=200, Q=140, p=1.3

$\Delta P = \left[\frac{740}{9100}\right]\left[\frac{200}{140}\right]^2 [1.3] = 0.081319$

[66], l=300, L=9100, q=160, Q=140, p=1.3

$\Delta P = \left[\frac{300}{9100}\right]\left[\frac{160}{140}\right]^2 [1.3] = 0.026374$

[67], l=300, L=9100, q=120, Q=140, p=1.3

$\Delta P = \left[\frac{300}{9100}\right]\left[\frac{120}{140}\right]^2 [1.3] = 0.01978$

[68], l=490, L=9100, q=80, Q=140, p=1.3

$\Delta P = \left[\frac{490}{9100}\right]\left[\frac{80}{140}\right]^2 [1.3] = 0.021538$

ΔP^1_{total} = 0.55514 + 0.51747 + 0.40149 + 0.088007 + 0.60231 + 0.13366 + 0.081319 + 0.026374 + 0.01978 + 0.021538

= **2.4471**

<u># Floor 2: pressure loss calculation</u>

[1], l=1500, L=1500, q=615, Q=2283, p=1.3

$\Delta P = \left[\frac{1200}{1500}\right]\left[\frac{615}{2283}\right]^2 [1.3] = 0.5402$

[2], l=925, L=3000, q=485, Q=738, p=1.3

$\Delta P = \left[\frac{925}{3000}\right]\left[\frac{485}{738}\right]^2 [1.3] = 0.39837$

[3], l=962, L=3000, q=355, Q=768, p=1.3

$\Delta P = \left[\frac{962}{3000}\right]\left[\frac{355}{768}\right]^2 [1.3] = 0.30325$

[4], l=315, L=6100, q=285, Q=518, p=1.3

$\Delta P = \left[\frac{315}{6100}\right]\left[\frac{285}{518}\right]^2 [1.3] = 0.039206$

[5], l=3045, L=9100, q=215, Q=411, p=1.3

$\Delta P = \left[\frac{3045}{9100}\right]\left[\frac{285}{411}\right]^2 [1.3] = 0.35971$

[6], l=901, L=9100, q=110, Q=411, p=1.3

$\Delta P = \left[\frac{901}{9100}\right]\left[\frac{110}{411}\right]^2 [1.3] = 0.054456$

[61], l=1030, L=9100, q=50, Q=140, p=1.3

$\Delta P = \left[\frac{1030}{9100}\right]\left[\frac{50}{140}\right]^2 [1.3] = 0.028297$

[62], l=345, L=9100, q=40, Q=140, p=1.3

$\Delta P = \left[\frac{345}{9100}\right]\left[\frac{40}{140}\right]^2 [1.3] = 0.0075824$

ΔP^2_{total} = 0.5402 + 0.39837 + 0.30325 + 0.039206 + 0.35971 + 0.054456 + 0.028297 + 0.0075824

= **1.7311**

Riser flowrate & pressure loss calculation

$Q_{Riser} = Q_{Total} = 1405$

l=1500, L=1500, q=1405, Q=2283, p=1.3

$\Delta P_{Riser} = \left[\frac{1500}{1500}\right]\left[\frac{1405}{2283}\right]^2 [1.3]$

$= 0.5402$

The total pressure loss is the sum of individual floors & riser pressure loss

$\Delta P_{Total} = \Delta P^1_{total} + \Delta P^2_{total} + \Delta P_{Riser}$

$= 2.4471 + 1.7311 + 0.5402$

$\Delta P_{Total} = 4.7184$

The total pressure loss should be less than the allowable design pressure loss ($\Delta P_{All} = 15$)

$\Delta P_{Total} < \Delta P_{All}$; $4.7184 < 15$

Therefore, the design is **SAFE!**

Appendix 20 - Manual design analysis for Medical air

 # Floor 1: Flowrate calculation

Main pipe 6

Maternity room, [Q = 40 + (n - 1) 2.5]

[68], n=1, Q = 40 + (1 - 1) 2.5 = 40

[67], n=2, Q = 40 + (2 - 1) 2.5 = 42.5

[66], n=3, Q = 40 + (3 - 1) 2.5 = 45

[65], n=4, Q = 40 + (4 - 1) 2.5 = 4**7.5**

Post Anesthesia Maternity recovery room, [Q = 40 + (n - 1) 10]

[64], n=1, Q = 40 + (1 - 1) 10 = 40

[63], n=2, Q = 40 + (2 - 1) 10 = 50

[62], n=3, Q = 40 + (3 - 1) 10 = 60

[61], n=4, Q = 40 + (4 - 1) 10 = **70**

Total flow rate for main pipe 6 = 70 + 47.5 = **117.5**

Main pipe 5

Children's inpatient room, [Q = 40 + (n - 1) 10]

[58], n=1, Q = 40 + (1 - 1) 10 = 40

[57], n=2, Q = 40 + (2 - 1) 10 = 50

[56], n=3, Q = 40 + (3 - 1) 10 = 60

[55], n=4, Q = 40 + (4 - 1) 10 = 70

[54], n=5, Q = 40 + (5 - 1) 10 = 80

[53], n=6, Q = 40 + (6 - 1) 10 = **90**

Physiotherapy room, [Q = 40]

[52], n=1, Q = 40

[51], n=2, Q = **40**

Total flow rate for main pipe 5 = 117.5 + 90 + 40 = **247.5**

Main pipe 4

Internal Care unit (ICU room), [Q = 80 + (n - 1)40]

[44], n=1, Q = 80 + (1 - 1) 40 = 80

[43], n=2, Q = 80 + (2 - 1) 40 = 100

[42], n=3, Q = 80 + (3 - 1) 40 = 120

[41], n=4, Q = 80 + (4 - 1) 40 = **200**

Total flow rate for main pipe 4 = 247.5 + 200 = **447.5**

Main pipe 3

Examination room, [Q = 40]

[34], n=1, Q = 40

[33], n=2, Q = 40

[32], n=3, Q = 40

[31], n=4, Q = **40**

Total flow rate for main pipe 3 = 447.5 + 40 = **487.5**

Main pipe 2

Post Anesthesia recovery room, [Q = 40 + (n - 1) 2.5]

[210], n=1, Q = 40 + (1 - 1) 2.5 = 40

[29], n=2, Q = 40 + (2 - 1) 2.5 = 42.5

[28], n=3, Q = 40 + (3 - 1) 2.5 = 45

[27], n=4, Q = 40 + (4 - 1) 2.5 = 47.5

[26], n=5, Q = 40 + (5 - 1) 2.5 = 50

[25], n=6, Q = 40 + (6 - 1) 2.5 = **52.5**

Emergency room, [Q = 40 + (n - 1) 5]

[24], n=1, Q = 40 + (1 - 1) 5 = 40

[23], n=2, Q = 40 + (2 - 1) 5 = 45

[22], n=3, Q = 40 + (3 - 1) 5 = 50

[21], n=4, Q = 40 + (4 - 1) 5 = **55**

Total flow rate for main pipe 2 = 487.5 + 52.5 + 55 = **595**

Main pipe 1

Surgery rooms: [Q = 40 + (n - 1) 10]

[11], n = 1, Q = 40 + (1 - 1)10 = **40**

[12], n = 1, Q = 40 + (1 - 1)10 = **40**

Total flow rate for main pipe 1 = 595 + 40 + 40 = **675**

 # Floor 2: Flowrate calculation

Main pipe 6

Oncology room, [Q = 0]

[65], n=1, Q = 0

[64], n=2, Q = 0

[63], n=3, Q = **0**

CT Scan & ENT room, [Q =0]

[62], n=1, Q = 0

[61], n=2, Q = **0**

Total flow rate for main pipe 6 = 0 + 0 = **0**

Main pipe 5

Hematology room, [Q = 0]

[55], n=1, Q = 0

[54], n=2, Q = 0

[53], n=3, Q = **0**

Radiography & MRI room, [Q = 40 + (n - 1)10]

[52], n=1, Q = 40 + (1 - 1)10 = 40

[51], n=2, Q = 40 + (2 - 1)10 = **50**

Total flow rate for main pipe 5 = 0 + 0 + 50 = **50**

Main pipe 4

Inpatient room, [Q = 20 + (n - 1)10/4]

[44], n=1, Q = 20 + (1 - 1) 10/4 = 20

[43], n=2, Q = 20 + (2 - 1) 10/4 = 22.5

[42], n=3, Q = 20 + (3 - 1) 10/4 = 25

[41], n=4, Q = 20 + (4 - 1) 10/4 = **27.5**

Total flow rate for main pipe 4 = 50 + 27.5 = **77.5**

Main pipe 3

Pediatric room, [Q = 0]

[34], n=1, Q = 0

[33], n=2, Q = 0

[32], n=3, Q = 0

[31], n=4, Q = 0

Total flow rate for main pipe 3 = 77.5 + 0 = **77.5**

Main pipe 2

Inpatient room, [Q = 40 + (n - 1) 10]

[29], n=1, Q = 20 + (1 - 1) 10/4 = 20

[28], n=2, Q = 20 + (2 - 1) 10/4 = 22.5

[27], n=3, Q = 20 + (3 - 1) 10/4 = 25

[26], n=4, Q = 20 + (4 - 1) 10/4 = 27.5

[25], n=1, Q = 20 + (5 - 1) 10/4 = 30

[24], n=2, Q = 20 + (6 - 1) 10/4 = **32.5**

Orthodontic room, [Q = 40 + (n - 1) 20]

[23], n=1, Q = 40 + (n - 1) 20 = 40

[22], n=2, Q = 40 + (n - 1) 20 = 60

[21], n=3, Q = 40 + (n - 1) 20 = **80**

Total flow rate for main pipe 2 = 77.5 + 32.5 + 80 = **190**

Main pipe 1

Urology rooms: [Q = 0]

[18], n=1, Q = 0

[17], n=2, Q = 0

[16], n=3, Q = 0

[15], n=4, Q = **0**

Neurology rooms: [Q = 0]

[14], n=1, Q = 0

[13], n=2, Q = 0

[12], n=3, Q = 0

[11], n=4, Q = **0**

Total flow rate for main pipe 1 = 190 + 0 = **190**

The total diversified flowrate is the sum of individual floors flowrate

$Q_{Total} = Q_1 + Q_2$

$= 675 + 190$

$\mathbf{Q_{Total} = 865}$

Riser flowrate

$Q_{Riser} = Q_{Total} = 865$

<u># Floor 1: pressure loss calculation</u>

[1], l=1200, L=1500, q=675, Q=2283, p=7

$\Delta P = \left[\frac{1200}{1500}\right]\left[\frac{675}{2283}\right]^2 [7] = 1.6557$

[2], l=925, L=3000, q=595, Q=738, p=7

$\Delta P = \left[\frac{925}{3000}\right]\left[\frac{595}{738}\right]^2 [7] = 1.6721$

[3], l=962, L=3000, q=487.5, Q=768, p=7

$\Delta P = \left[\frac{962}{3000}\right]\left[\frac{487.5}{768}\right]^2 [7] = 1.4248$

[4], l=315, L=6100, q=447.5, Q=518, p=7

$\Delta P = \left[\frac{315}{6100}\right]\left[\frac{447.5}{518}\right]^2 [7] = 0.31228$

[5], l=3045, L=9100, q=247.5, Q=411, p=7

$\Delta P = \left[\frac{3045}{9100}\right]\left[\frac{247.5}{411}\right]^2 [7] = 1.4105$

[6], l=901, L=9100, q=117.5, Q=411, p=7

$\Delta P = \left[\frac{901}{9100}\right]\left[\frac{117.5}{411}\right]^2 [7] = 0.19814$

[65], l=740, L=9100, q=47.5, Q=140, p=7

$\Delta P = \left[\frac{740}{9100}\right]\left[\frac{118}{140}\right]^2 [7] = 0.19313$

[66], l=300, L=9100, q=45, Q=140, p=7

$\Delta P = \left[\frac{300}{9100}\right]\left[\frac{112}{140}\right]^2 [7] = 0.074176$

[67], l=300, L=9100, q=42.5, Q=140, p=7

$\Delta P = \left[\frac{300}{9100}\right]\left[\frac{106}{140}\right]^2 [7] = 0.070055$

[68], l=490, L=9100, q=40, Q=140, p=7

$\Delta P = \left[\frac{490}{9100}\right]\left[\frac{100}{140}\right]^2 [7] = 0.10769$

ΔP^1_{total} = 1.6557 + 1.6721 + 1.4248 + 0.31228 + 1.4105 + 0.19814 + 0.19313 + 0.074176 + 0.070055 + 0.10769

= **7.1187**

<u># Floor 2: pressure loss calculation</u>

[1], l=1500, L=1500, q=190, Q=2283, p=7

$\Delta P = \left[\frac{1200}{1500}\right]\left[\frac{190}{2283}\right]^2 [7] = 0.58257$

[2], l=925, L=3000, q=190, Q=738, p=7

$\Delta P = \left[\frac{925}{3000}\right]\left[\frac{190}{738}\right]^2 [7] = 0.53396$

[3], l=962, L=3000, q=77.5, Q=768, p=7

$\Delta P = \left[\frac{962}{3000}\right]\left[\frac{77.5}{768}\right]^2 [7] = 0.22651$

[4], l=315, L=6100, q=77.5, Q=518, p=7

$\Delta P = \left[\frac{315}{6100}\right]\left[\frac{77.5}{518}\right]^2 [7] = 0.054082$

[5], l=3045, L=9100, q=50, Q=411, p=7

$\Delta P = \left[\frac{3045}{9100}\right]\left[\frac{50}{411}\right]^2 [7] = 0.28495$

[6], l=901, L=9100, q=0, Q=411, p=7

$\Delta P = \left[\frac{901}{9100}\right]\left[\frac{0}{411}\right]^2 [7] = 0$

[61], l=1030, L=9100, q=0, Q=140, p=7

$\Delta P = \left[\frac{1030}{9100}\right]\left[\frac{0}{140}\right]^2 [7] = 0$

[62], l=345, L=9100, q=0, Q=140, p=7

$\Delta P = \left[\frac{345}{9100}\right]\left[\frac{0}{140}\right]^2 [7] = 0$

ΔP^2_{total} = 0.58257 + 0.53396 + 0.22651 + 0.054082 + 0.28495 + 0 + 0 + 0

= **1.6821**

Riser flowrate & pressure loss calculation

$Q_{Riser} = Q_{Total} = 865$

l=1500, L=1500, q=865, Q=2283, p=7

$\Delta P_{Riser} = \left[\frac{1500}{1500}\right]\left[\frac{865}{2283}\right]^2 [7]$

$= 0.5825$

The total pressure loss is the sum of individual floors & riser pressure loss

$\Delta P_{Total} = \Delta P^1_{total} + \Delta P^2_{total} + \Delta P_{Riser}$

$= 7.1187 + 1.6821 + 0.5825$

$\boldsymbol{\Delta P_{Total} = 9.3833}$

The total pressure loss should be less than the allowable design pressure loss ($\Delta P_{All} = 15$)

$\Delta P_{Total} < \Delta P_{All}$; $9.3833 < 15$

Therefore, the design is **SAFE!**

Appendix 21 - Manual design analysis for Surgical air

 # Floor 1: Flowrate calculation

Main pipe 6

Maternity room, [Q = 350 + (n - 1) 175]

[68], n=1, Q = 350 + (1 - 1) 175 = 350

[67], n=2, Q = 350 + (2 - 1) 175 = 525

[66], n=3, Q = 350 + (3 - 1) 175 = 700

[65], n=4, Q = 350 + (4 - 1) 175 = **875**

Post Anesthesia Maternity recovery room, [Q = 0]

[64], n=1, Q = 0

[63], n=2, Q = 0

[62], n=3, Q = 0

[61], n=4, Q = 0

Total flow rate for main pipe 6 = 875 + 0 = **875**

Main pipe 5

Children's inpatient room, [Q = 0]

[58], n=1, Q = 0

[57], n=2, Q = 0

[56], n=3, Q = 0

[55], n=4, Q = 0

[54], n=5, Q = 0

[53], n=6, Q = **875**

Physiotherapy room, [Q = 0]

[52], n=1, Q = 0

[51], n=2, Q = **0**

Total flow rate for main pipe 5 = 875 + 0 = **875**

Main pipe 4

Internal Care unit (ICU room), [Q = 0]

[44], n=1, Q = 0

[43], n=2, Q = 0

[42], n=3, Q = 0

[41], n=4, Q = **0**

Total flow rate for main pipe 4 = 875 + 0 = **875**

Main pipe 3

Examination room, [Q = 0]

[34], n=1, Q = 0

[33], n=2, Q = 0

[32], n=3, Q = 0

[31], n=4, Q = **0**

Total flow rate for main pipe 3 = 875 + 0 = **875**

Main pipe 2

Post Anesthesia recovery room, [Q = 0]

[210], n=1, Q = 0

[29], n=2, Q = 0

[28], n=3, Q = 0

[27], n=4, Q = 0

[26], n=5, Q = 0

[25], n=6, Q = **0**

Emergency room, [Q = 0]

[24], n=1, Q = 0

[23], n=2, Q = 0

[22], n=3, Q = 0

[21], n=4, Q = **0**

Total flow rate for main pipe 2 = 875 + 0 = **875**

Main pipe 1

Surgery rooms: [Q = 350 + (n - 1) 175]

[11], n = 1, Q = 350 + (1 - 1)175 = **350**

[12], n = 1, Q = 350 + (1 - 1)175 = **350**

Total flow rate for main pipe 1 = 875 + 350 + 350 = **1575**

The total diversified flowrate is the sum of individual floors flowrate

$Q_{Total} = Q_1$

$\mathbf{Q_{Total} = 1575}$

Riser flowrate

$Q_{Riser} = Q_{Total} = 1575$

 # Floor 1: pressure loss calculation

[1], l=1200, L=1500, q=1575, Q=2283, p=7

$\Delta P = \left[\frac{1200}{1500}\right]\left[\frac{1575}{2283}\right]^2 [7] = 2.9558$

[2], l=925, L=3000, q=875, Q=738, p=7

$\Delta P = \left[\frac{925}{3000}\right]\left[\frac{875}{738}\right]^2 [7] = 1.8717$

[3], l=962, L=3000, q=875, Q=768, p=7

$\Delta P = \left[\frac{962}{3000}\right]\left[\frac{875}{768}\right]^2 [7] = 1.9466$

[4], l=315, L=6100, q=875, Q=518, p=7

$\Delta P = \left[\frac{315}{6100}\right]\left[\frac{875}{518}\right]^2 [7] = 0.46377$

[5], l=3045, L=9100, q=875, Q=411, p=7

$\Delta P = \left[\frac{3045}{9100}\right]\left[\frac{875}{411}\right]^2$ [7] = 3.7814

[6], l=901, L=9100, q=875, Q=411, p=7

$\Delta P = \left[\frac{901}{9100}\right]\left[\frac{875}{411}\right]^2$ [7] = 1.1189

[65], l=740, L=9100, q=875, Q=140, p=7

$\Delta P = \left[\frac{740}{9100}\right]\left[\frac{875}{140}\right]^2$ [7] = 2.6778

[66], l=300, L=9100, q=700, Q=140, p=7

$\Delta P = \left[\frac{300}{9100}\right]\left[\frac{700}{140}\right]^2$ [7] = 0.86849

[67], l=300, L=9100, q=525, Q=140, p=7

$\Delta P = \left[\frac{300}{9100}\right]\left[\frac{525}{140}\right]^2$ [7] = 0.65136

[68], l=490, L=9100, q=350, Q=140, p=7

$\Delta P = \left[\frac{490}{9100}\right]\left[\frac{350}{140}\right]^2$ [7] = 0.70926

ΔP^1_{total} = 2.9558 + 1.8717 + 1.9466 + 0.46377 + 3.7814 + 1.1189 + 2.6778 + 0.86849 + 0.65136 + 0.70926

= **17.0450**

Riser flowrate & pressure loss calculation

$Q_{Riser} = Q_{Total} = 865$

l=1500, L=1500, q=1575, Q=2283, p=7

$\Delta P_{Riser} = \left[\frac{1500}{1500}\right]\left[\frac{1575}{2283}\right]^2$ [7]

= 2.9558

The total pressure loss is the sum of individual floors & riser pressure loss

$\Delta P_{Total} = \Delta P^{1}_{total} + \Delta P_{Riser}$

$= 17.0450 + 2.9558$

$\mathbf{\Delta P_{Total} = 20.0008}$

The total pressure loss should be less than the allowable design pressure loss ($\Delta P_{All} = 26.25$)

$\Delta P_{Total} < \Delta P_{All}$; $20.0008 < 26.25$

Therefore, the design is **SAFE!**

Appendix 22 - Manual design analysis for Nitrous Oxide

 # Floor 1: Flowrate calculation

Main pipe 6

Maternity room, [Q = 15 + (n - 1) 6]

[68], n=1, Q = 15 + (1 - 1) 6 = 15

[67], n=2, Q = 15 + (2 - 1) 6 = 21

[66], n=3, Q = 15 + (3 - 1) 6 = 27

[65], n=4, Q = 15 + (4 - 1) 6 = **33**

Post Anesthesia Maternity recovery room, [Q = 0]

[64], n=1, Q = 0

[63], n=2, Q = 0

[62], n=3, Q = 0

[61], n=4, Q = **0**

Total flow rate for main pipe 6 = 33 + 0 = **33**

Main pipe 5

Children's inpatient room, [Q = 0]

[58], n=1, Q = 0

[57], n=2, Q = 0

[56], n=3, Q = 0

[55], n=4, Q = 0

[54], n=5, Q = 0

[53], n=6, Q = **0**

Physiotherapy room, [Q = 10]

[52], n=1, Q = 10 = 10

[51], n=2, Q = 10 = **10**

Total flow rate for main pipe 5 = 33 + 10 = **43**

Main pipe 4

Internal Care unit (ICU room), [Q = 10 + (n - 1)1.5]

[44], n=1, Q = 10 + (1 - 1)1.5 = 10

[43], n=2, Q = 10 + (2 - 1)1.5 = 11.5

[42], n=3, Q = 10 + (3 - 1)1.5 = 13

[41], n=4, Q = 10 + (4 - 1)1.5 = 14.5

Total flow rate for main pipe 4 = 43 + 14.5 = **57.5**

Main pipe 3

Examination room, [Q = 0]

[34], n=1, Q = 0

[33], n=2, Q = 0

[32], n=3, Q = 0

[31], n=4, Q = **0**

Total flow rate for main pipe 3 = 57.5 + 0 = **57.5**

Main pipe 2

Post Anesthesia recovery room, [Q = 0]

[210], n=1, Q = 0

[29], n=2, Q = 0

[28], n=3, Q = 0

[27], n=4, Q = 0

[26], n=5, Q = 0

[25], n=6, Q = **0**

Emergency room, [Q = 10 + (n - 1) 1.5]

[24], n=1, Q = 10 + (1 - 1) 1.5 = 10

[23], n=2, Q = 10 + (2 - 1) 1.5 = 11.5

[22], n=3, Q = 10 + (3 - 1) 1.5 = 13

[21], n=4, Q = 10 + (4 - 1) 1.5 = **14.5**

Total flow rate for main pipe 2 = 57.5 + 14.5 = **72**

Main pipe 1

Surgery rooms: [Q = 15 + (n - 1) 6]

[11], n = 1, Q = 15 + (1 - 1)6 = **15**

[12], n = 1, Q = 15 + (1 - 1)6 = **15**

Total flow rate for main pipe 1 = 72 + 15 + 15 = **102**

 # Floor 2: Flowrate calculation

Main pipe 6

Oncology room, [Q = 0]

[65], n=1, Q = 0

[64], n=2, Q = 0

[63], n=3, Q = **0**

CT Scan & ENT room, [Q =0]

[62], n=1, Q = 0

[61], n=2, Q = **0**

Total flow rate for main pipe 6 = 0 + 0 = **0**

Main pipe 5

Hematology room, [Q = 0]

[55], n=1, Q = 0

[54], n=2, Q = 0

[53], n=3, Q = **0**

Radiography & MRI room, [Q = 10 + (n - 1)6/4]

[52], n=1, Q = 10 + (1 - 1) 6/4 = 10

[51], n=2, Q = 10 + (2 - 1) 6/4 = **11.5**

Total flow rate for main pipe 5 = 0 + 0 + 11.5 = **11.5**

Main pipe 4

Inpatient room, [Q = 0]

[44], n=1, Q = 0

[43], n=2, Q = 0

[42], n=3, Q = 0

[41], n=4, Q = **0**

Total flow rate for main pipe 4 = 11.5 + 0 = **11.5**

Main pipe 3

Pediatric room, [Q = 0]

[34], n=1, Q = 0

[33], n=2, Q = 0

[32], n=3, Q = 0

[31], n=4, Q = **0**

Total flow rate for main pipe 3 = 11.5 + 0 = **11.5**

Main pipe 2

Inpatient room, [Q = 40 + (n - 1) 10]

[29], n=1, Q = 0

[28], n=2, Q = 0

[27], n=3, Q = 0

[26], n=4, Q = 0

[25], n=5, Q = 0

[24], n=6, Q = **0**

Orthodontic room, [Q = 10 + (n - 1) 6/4]

[23], n=1, Q = 10 + (1 - 1) 6/4 = 10

[22], n=2, Q = 10 + (2 - 1) 6/4 = 11.5

[21], n=3, Q = 10 + (3 - 1) 6/4 = **13**

Total flow rate for main pipe 2 = 11.5 + 13 = **24.5**

Main pipe 1

Urology rooms: [Q = 0]

[18], n=1, Q = 0

[17], n=2, Q = 0

[16], n=3, Q = 0

[15], n=4, Q = **0**

Neurology rooms: [Q = 0]

[14], n=1, Q = 0

[13], n=2, Q = 0

[12], n=3, Q = 0

[11], n=4, Q = **0**

Total flow rate for main pipe 1 = 24.5 + 0 = **24.5**

The total diversified flowrate is the sum of individual floors flowrate

$Q_{Total} = Q_1 + Q_2$

$= 102 + 24.5$

$\mathbf{Q_{Total} = 126.5}$

Riser flowrate

$Q_{Riser} = Q_{Total} = 126.5$

<u># Floor 1: pressure loss calculation</u>

[1], l=1200, L=1500, q=102, Q=2283, p=7

$\Delta P = \left[\frac{1200}{1500}\right]\left[\frac{102}{2283}\right]^2 [7] = 0.2502$

[2], l=925, L=3000, q=72, Q=738, p=7

$\Delta P = \left[\frac{925}{3000}\right]\left[\frac{72}{738}\right]^2 [7] = 0.20234$

[3], l=962, L=3000, q=57.5, Q=768, p=7

$\Delta P = \left[\frac{962}{3000}\right]\left[\frac{57.5}{768}\right]^2 [7] = 0.16806$

[4], l=315, L=6100, q=57.5, Q=518, p=7

$\Delta P = \left[\frac{315}{6100}\right]\left[\frac{57.5}{518}\right]^2 [7] = 0.040125$

[5], l=3045, L=9100, q=43, Q=411, p=7

$\Delta P = \left[\frac{3045}{9100}\right]\left[\frac{43}{411}\right]^2 [7] = 0.24506$

[6], l=901, L=9100, q=33, Q=411, p=7

$\Delta P = \left[\frac{901}{9100}\right]\left[\frac{33}{411}\right]^2 [7] = 0.055649$

[65], l=740, L=9100, q=33, Q=140, p=7

$\Delta P = \left[\frac{740}{9100}\right]\left[\frac{33}{140}\right]^2 [7] = 0.13418$

[66], l=300, L=9100, q=27, Q=140, p=7

$\Delta P = \left[\frac{300}{9100}\right]\left[\frac{27}{140}\right]^2 [7] = 0.044505$

[67], l=300, L=9100, q=21, Q=140, p=7

$\Delta P = \left[\frac{300}{9100}\right]\left[\frac{21}{140}\right]^2 [7] = 0.034615$

[68], l=490, L=9100, q=15, Q=140, p=7

$\Delta P = \left[\frac{490}{9100}\right]\left[\frac{15}{140}\right]^2 [7] = 0.040385$

ΔP^1_{total} = 0.250 + 0.20234 + 0.16806 + 0.040125 + 0.24506 + 0.055649 + 0.13418 + 0.044505 + 0.034615 + 0.040385

= **1.2151**

<u># Floor 2: pressure loss calculation</u>

[1], l=1500, L=1500, q=24.5, Q=2283, p=7

$\Delta P = \left[\frac{1200}{1500}\right]\left[\frac{24.5}{2283}\right]^2 [7] = 0.07512$

[2], l=925, L=3000, q=24.5, Q=738, p=7

$\Delta P = \left[\frac{925}{3000}\right]\left[\frac{24.5}{738}\right]^2 [7] = 0.068853$

[3], l=962, L=3000, q=11.5, Q=768, p=7

$\Delta P = \left[\frac{962}{3000}\right]\left[\frac{11.5}{768}\right]^2 [7] = 0.033612$

[4], l=315, L=6100, q=11.5, Q=518, p=7

$\Delta P = \left[\frac{315}{6100}\right]\left[\frac{11.5}{518}\right]^2 [7] = 0.008025$

[5], l=3045, L=9100, q=11.5, Q=411, p=7

$\Delta P = \left[\frac{3045}{9100}\right]\left[\frac{11.5}{411}\right]^2 [7] = 0.065539$

[6], l=901, L=9100, q=0, Q=411, p=7

$\Delta P = \left[\frac{901}{9100}\right]\left[\frac{0}{411}\right]^2 [7] = 0$

[61], l=1030, L=9100, q=0, Q=140, p=7

$\Delta P = \left[\frac{1030}{9100}\right]\left[\frac{0}{140}\right]^2 [7] = 0$

[62], l=345, L=9100, q=0, Q=140, p=7

$\Delta P = \left[\frac{345}{9100}\right]\left[\frac{0}{140}\right]^2 [7] = 0$

ΔP^2_{total} = 0.07512 + 0.068853 + 0.033612 + 0.008025 + 0.065539 + 0 + 0 + 0

= **0.2511**

The total diversified flowrate is the sum of individual floors flowrate

$Q_{Total} = Q_1 + Q_2$

= 102 + 24.5

Q_{Total} = 126.5

Riser flowrate & pressure loss calculation

$Q_{Riser} = Q_{Total} = 126.5$

l=1500, L=1500, q=126.5, Q=2283, p=7

$$\Delta P_{Riser} = \left[\frac{1500}{1500}\right]\left[\frac{126.5}{2283}\right]^2 [7]$$

= 0.0752

The total pressure loss is the sum of individual floors & riser pressure loss

$\Delta P_{Total} = \Delta P^1_{total} + \Delta P^2_{total} + \Delta P_{Riser}$

= 1.2151 + 0.2511 + 0.0752

ΔP_{Total} = 1.5414

The total pressure loss should be less than the allowable design pressure loss ($\Delta P_{All} = 15$)

$\Delta P_{Total} < \Delta P_{All}$; 1.5414 < 15

Therefore, the design is **SAFE!**

Appendix 23 - Manual design analysis for Anesthesia gas

 # Floor 1: Flowrate calculation

Main pipe 6

Maternity room, [Q = 80 + (n - 1) 80]

[68], n=1, Q = 80 + (1 - 1) 80 = 80

[67], n=2, Q = 80 + (2 - 1) 80 = 160

[66], n=3, Q = 80 + (3 - 1) 80 = 240

[65], n=4, Q = 80 + (4 - 1) 80 = **320**

Post Anesthesia Maternity recovery room, [Q = 0]

[64], n=1, Q = 0

[63], n=2, Q = 0

[62], n=3, Q = 0

[61], n=4, Q = **0**

Total flow rate for main pipe 6 = 320 + 0 = **320**

Main pipe 5

Children's inpatient room, [Q = 0]

[58], n=1, Q = 0

[57], n=2, Q = 0

[56], n=3, Q = 0

[55], n=4, Q = 0

[54], n=5, Q = 0

[53], n=6, Q = **0**

Physiotherapy room, [Q = 80 + (n - 1)10]

[52], n=1, Q = 80 + (1 - 1)10 = 80

[51], n=2, Q = 80 + (2 - 1)10 = **90**

Total flow rate for main pipe 5 = 320 + 90 = **410**

Main pipe 4

Internal Care unit (ICU room), [Q = 80 + (n - 1)10]

[44], n=1, Q = 0

[43], n=2, Q = 0

[42], n=3, Q = 0

[41], n=4, Q = **0**

Total flow rate for main pipe 4 = 410 + 0 = **410**

Main pipe 3

Examination room, [Q = 80 + (n - 1)10]

[34], n=1, Q = 80 + (1 - 1)10 = 80

[33], n=2, Q = 80 + (2 - 1)10 = 90

[32], n=3, Q = 80 + (3 - 1)10 = 100

[31], n=4, Q = 80 + (4 - 1)10 = **110**

Total flow rate for main pipe 3 = 410 + 110 = **520**

Main pipe 2

Post Anesthesia recovery room, [Q = 0]

[210], n=1, Q = 0

[29], n=2, Q = 0

[28], n=3, Q = 0

[27], n=4, Q = 0

[26], n=5, Q = 0

[25], n=6, Q = **0**

Emergency room, [Q = 80 + (n - 1) 20]

[24], n=1, Q = 80 + (1 - 1) 20 = 80

[23], n=2, Q = 80 + (2 - 1) 20 = 100

[22], n=3, Q = 80 + (3 - 1) 20 = 120

[21], n=4, Q = 80 + (4 - 1) 20 = **140**

Total flow rate for main pipe 2 = 520 + 140 = **660**

Main pipe 1

Surgery rooms: [Q = 80 + (n - 1) 80]

[11], n = 1, Q = 80 + (1 - 1)80 = **80**

[12], n = 1, Q = 80 + (1 - 1)80 = **80**

Total flow rate for main pipe 1 = 660 + 80 + 80 = **820**

 # Floor 2: Flowrate calculation

Main pipe 6

Oncology room, [Q = 0]

[65], n=1, Q = 0

[64], n=2, Q = 0

[63], n=3, Q = **0**

CT Scan & ENT room, [Q =0]

[62], n=1, Q = 0

[61], n=2, Q = **0**

Total flow rate for main pipe 6 = 0 + 0 = **0**

Main pipe 5

Hematology room, [Q = 0]

[55], n=1, Q = 0

[54], n=2, Q = 0

[53], n=3, Q = **0**

Radiography & MRI room, [Q = 80 + (n - 1)20]

[52], n=1, Q = 80 + (1 - 1)20 = 80

[51], n=2, Q = 80 + (2 - 1)20 = **100**

Total flow rate for main pipe 5 = 0 + 0 + 100 = **100**

Main pipe 4

Inpatient room, [Q = 0]

[44], n=1, Q = 0

[43], n=2, Q = 0

[42], n=3, Q = 0

[41], n=4, Q = **0**

Total flow rate for main pipe 4 = 100 + 0 = **100**

Main pipe 3

Pediatric room, [Q = 80 + (n - 1) 10]

[34], n=1, Q = 80 + (1 - 1) 10 = 80

[33], n=2, Q = 80 + (2 - 1) 10 = 90

[32], n=3, Q = 80 + (3 - 1) 10 = 100

[31], n=4, Q = 80 + (4 - 1) 10 = **110**

Total flow rate for main pipe 3 = 100 + 110 = **210**

Main pipe 2

Inpatient room, [Q = 40 + (n - 1) 10]

[29], n=1, Q = 0

[28], n=2, Q = 0

[27], n=3, Q = 0

[26], n=4, Q = 0

[25], n=1, Q = 0

[24], n=2, Q = **0**

Orthodontic room, [Q = 80 + (n - 1) 20]

[23], n=1, Q = 80 + (n - 1) 20 = 80

[22], n=2, Q = 80 + (n - 1) 20 = 100

[21], n=3, Q = 80 + (n - 1) 20 = **120**

Total flow rate for main pipe 2 = 210 + 0 + 120 = **330**

Main pipe 1

Urology rooms: [Q = 80 + (n - 1) 10]

[18], n=1, Q = 80 + (1 - 1) 10 = 80

[17], n=2, Q = 80 + (2 - 1) 10 = 90

[16], n=3, Q = 80 + (3 - 1) 10 = 100

[15], n=4, Q = 80 + (4 - 1) 10 = **110**

Neurology rooms: [Q = 80 + (n - 1) 10]

[14], n=1, Q = 80 + (1 - 1) 10 = 80

[13], n=2, Q = 80 + (2 - 1) 10 = 90

[12], n=3, Q = 80 + (3 - 1) 10 = 100

[11], n=4, Q = 80 + (4 - 1) 10 = **110**

Total flow rate for main pipe 1 = 330 + 110 + 110= **550**

The total diversified flowrate is the sum of individual floors flowrate

$Q_{Total} = Q_1 + Q_2$

$= 820 + 540$

$\mathbf{Q_{Total} = 1360}$

Riser flowrate

$Q_{Riser} = Q_{Total} = 1360$

 # Floor 1: pressure loss calculation

[1], l=1200, L=1500, q=820, Q=2283, p=7

$$\Delta P = \left[\frac{1200}{1500}\right]\left[\frac{820}{2283}\right]^2 [7] = 2.0114$$

[2], l=925, L=3000, q=660, Q=738, p=7

$$\Delta P = \left[\frac{925}{3000}\right]\left[\frac{660}{738}\right]^2 [7] = 1.8548$$

[3], l=962, L=3000, q=520, Q=768, p=7

$$\Delta P = \left[\frac{962}{3000}\right]\left[\frac{520}{768}\right]^2 [7] = 1.5198$$

[4], l=315, L=6100, q=410, Q=518, p=7

$$\Delta P = \left[\frac{315}{6100}\right]\left[\frac{410}{518}\right]^2 [7] = 0.28611$$

[5], l=3045, L=9100, q=410, Q=411, p=7

$\Delta P = \left[\frac{3045}{9100}\right]\left[\frac{410}{411}\right]^2 [7] = 2.3366$

[6], l=901, L=9100, q=320, Q=411, p=7

$\Delta P = \left[\frac{901}{9100}\right]\left[\frac{320}{411}\right]^2 [7] = 0.53962$

[65], l=740, L=9100, q=320, Q=140, p=7

$\Delta P = \left[\frac{740}{9100}\right]\left[\frac{320}{140}\right]^2 [7] = 1.3011$

[66], l=300, L=9100, q=240, Q=140, p=7

$\Delta P = \left[\frac{300}{9100}\right]\left[\frac{240}{140}\right]^2 [7] = 0.3956$

[67], l=300, L=9100, q=160, Q=140, p=7

$\Delta P = \left[\frac{300}{9100}\right]\left[\frac{160}{140}\right]^2 [7] = 0.26374$

[68], l=490, L=9100, q=80, Q=140, p=7

$\Delta P = \left[\frac{490}{9100}\right]\left[\frac{80}{140}\right]^2 [7] = 0.21538$

ΔP^1_{total} = 2.0114 + 1.6721 + 1.8548 + 0.28611 + 2.3366 + 0.53962 + 1.3011 + 0.3956 + 0.26374 + 0.21538

= **10.7242**

 # Floor 2: pressure loss calculation

[1], l=1500, L=1500, q=540, Q=2283, p=7

$\Delta P = \left[\frac{1200}{1500}\right]\left[\frac{540}{2283}\right]^2 [7] = 1.6557$

[2], l=925, L=3000, q=330, Q=738, p=7

$\Delta P = \left[\frac{925}{3000}\right]\left[\frac{330}{738}\right]^2 [7] = 0.92741$

[3], l=962, L=3000, q=210, Q=768, p=7

$\Delta P = \left[\frac{962}{3000}\right]\left[\frac{210}{768}\right]^2 [7] = 0.61378$

[4], l=315, L=6100, q=100, Q=518, p=7

$\Delta P = \left[\frac{315}{6100}\right]\left[\frac{100}{518}\right]^2 [7] = 0.069783$

[5], l=3045, L=9100, q=100, Q=411, p=7

$\Delta P = \left[\frac{3045}{9100}\right]\left[\frac{100}{411}\right]^2 [7] = 0.5699$

[6], l=901, L=9100, q=0, Q=411, p=7

$\Delta P = \left[\frac{901}{9100}\right]\left[\frac{0}{411}\right]^2 [7] = 0$

[61], l=1030, L=9100, q=0, Q=140, p=7

$\Delta P = \left[\frac{1030}{9100}\right]\left[\frac{0}{140}\right]^2 [7] = 0$

[62], l=345, L=9100, q=0, Q=140, p=7

$\Delta P = \left[\frac{345}{9100}\right]\left[\frac{0}{140}\right]^2 [7] = 0$

ΔP^2_{total} = 1.6557 + 0.92741 + 0.61378 + 0.069783 + 0.5699 + 0 + 0 + 0

= **3.8366**

Riser flowrate & pressure loss calculation

$Q_{Riser} = Q_{Total} = 1360$

l=1500, L=1500, q=1360, Q=2283, p=7

$\Delta P_{Riser} = \left[\frac{1500}{1500}\right]\left[\frac{1360}{2283}\right]^2 [7]$

= 1.6557

The total pressure loss is the sum of individual floors & riser pressure loss

$\Delta P_{Total} = \Delta P^{1}_{total} + \Delta P^{2}_{total} + \Delta P_{Riser}$

$= 10.7242 + 3.8366 + 0.6557$

$\mathbf{\Delta P_{Total} = 14.2165}$

The total pressure loss should be less than the allowable design pressure loss ($\Delta P_{All} = 15$)

$\Delta P_{Total} < \Delta P_{All}$; $14.2165 < 15$

Therefore, the design is **SAFE!**

Appendix 24 - MATLAB analysis for Medical Gas Pipeline Distribution System

```
.
 % Load the data from the Excel spreedsheet file
%data = xlsread('Medical Vacuum.xlsx');

% data is for storing the numeric data
% s is for storing the txt data along with the headings
% r is the combined raw data

[status,sheets] = xlsfinfo('Anesthetic Gas.xlsx');

floors = length(sheets);

floor_flowRates = zeros(1,floors);
floor_Pressures = zeros(1,floors);

%gas = "oxygen";
gas = input('Enter the gas type\n');

for fl=1:floors

    disp("Floor "+fl);
    [data,s,r] = xlsread('Anesthetic Gas.xlsx',fl);
    C = string(s(2:end,10));  % convert the cellarray data to
string stored in s
    % Extract the size or the numeric data matrix
    [m,n] = size(data);
    base = 10;
```

```
.

    %%
    % count the number of main pipes
    for i=2:m   % start from the second row of data

                continue;
            end
        end
    end
    %%
    % Display the number of Main pippes
```

```
    disp("No of Main Pipes = "+numOfMainPipes);
```

.

```
    %Identify the number and side of the branch pipes of each
main pipe
    numOfBranches = zeros(1,numOfMainPipes);

    k = 1;
    for j=i:m  % Start from the row located after the last main
pipe i.e. i
        % check the most significant digit using the msb
function
        % if the msb of data(j,1) is equal to main pipe number
then it is a
        % branch pipe thus % increment the no of branch pipes

            else
                numOfBranches(1,k) = numOfBranches(1,k)+1;
            end
        end
    end

    % Display the number of branch pipes of each main pipe
    disp("Number of branch pipes");
    numOfBranches
```

.

```
%%
    %%%%%%%%%%%%  Flow Rate Calculation
    % % Backward tracing
    offset = 0;   % used to decrement or jump accordingly
    a = 0;
    f = 0;
    mainPipeFlow = zeros(1,numOfMainPipes);
    for q=numOfMainPipes:-1:1  % start from the last
        if q==numOfMainPipes
            offset = 0;
        else
            offset = offset+numOfBranches(1,q+1);
        end
        start = m-offset;

        for x=start:-1:start-numOfBranches(1,q)+1
```

```
            %disp(data(x,4));
            % Flow Rate Calculation
            if data(x-1,2)
                mainPipeFlow(1,q) = mainPipeFlow(1,q)+data(x,6);

            end
        end

        %disp("Pipe  "+q+"  "+mainPipeFlow(1,q));
        if q==numOfMainPipes
            data(q,6) = mainPipeFlow(1,q);
        else
            mainPipeFlow(1,q) =

        disp("Pipe  "+q+"  "+mainPipeFlow(1,q));
    end

    floor_flowRates(1,fl) = mainPipeFlow(1,1)
```

.

```
%%
    % Locating the lonest pipe
    % The following two loops locate the longest
    jump = 0;

       if data(b,2)==1
          %data(b,4) = lengths(2,p);
          side = 0;

        end
    end

    for g=1:numOfMainPipes
        r = g;
        while r>=1
        r = r-1;
        end
    end

    lengths
    % use its column representation to find the value and index
of the largest
    % element
```

```
    [M,I] = max(lengths(:));
    % Now, use the ind2sub function to extract the row and
column indices of
    % lengths corresponding to the largest element
    [I_row, I_col] = ind2sub(size(lengths),I);
    % This index will then be used to locate the actual branch
index by using
```

.

```
%%
    % track the path of the longest pipe ending
    mainPipeEnd = msb(data(idx,1));
    % store the pressure of this farthest branch as a starting
point of the
    % pressure values
    pressure =
(data(idx,4)/data(idx,5))*rssq(data(idx,6)/data(idx,7))*data(idx
,8);
    disp("Branch "+idx+" Diameter "+data(idx,3)+" Length
"+data(idx,4)+" Pressure "+pressure);
    % start the counting one minus the farthest point since it
is accounted for
    % by the previous line of code calculation
    temp =
(data(count,4)/data(count,5))*rssq(data(count,6)/data(count,7))*
data(count,8);
        pressure = pressure+temp;
        disp("Branch "+count+" Diameter "+data(count,3)+" Length
"+data(count,4)+" Pressure "+temp);
        count = count-1;
    end

    % add the main pipe pressures to the sum starting from the
main pipe of the
    % assumed farthest pipe to the first main pipe.
    temp2 =
(data(z,4)/data(z,5))*rssq(data(z,6)/data(z,7))*data(z,8);
        pressure = pressure+temp2;
        disp("Branch "+z+" Diameter "+data(z,3)+" Length
"+data(z,4)+" Pressure "+temp2);
    end
```

.

```
 %%
%Raiser calculation

raiserFlowRate = sum(floor_flowRates)
raiserPressure =
(data(1,4)/data(1,5))*rssq(data(1,6)/data(1,7))*data(1,8)

pressure = sum(floor_Pressures) + raiserPressure

if gas=="Oxygen Gas"&&pressure>15
    disp('High pressure drop for Oxygen Gas');
elseif gas=="Medical Air"&&pressure>15
    disp('High pressure drop for Medical Air');
elseif gas=="Nitrous Oxide Gas"&&pressure>2
    disp('High pressure drop for Nitrous Oxide Gas');
elseif gas=="Medical Vacuum"&&pressure>15
    disp('High pressure drop for Medical Vacuum');
elseif gas=="Surgical Air"&&pressure>26.25
    disp('High pressure drop for Surgical Air');
elseif gas=="Anesthetic Gas"&&pressure>20
    disp('High pressure drop for Anesthetic Gas');
end
```

.

Appendix 25 - MATLAB analysis result for Oxygen Gas Pipeline Distribution System

```
>> Code_floors
Enter the gas type
"Oxygen Gas"
Floor 1
No of Main Pipes = 6
Number of branch pipes

numOfBranches =

  Columns 1 through 5

     2    10     4     4     8

  Column 6

     8

Pipe  6  130.25
Pipe  5  155.25
Pipe  4  178.75
Pipe  3  193.25
Pipe  2  247.75
Pipe  1  447.75

floor_flowRates =

  447.75000         0


lengths =

  Columns 1 through 2

        1847        3898
        1740        4035

  Columns 3 through 4

        4897        5032
           0           0
```

```
  Columns 5 through 6

        7534        9035
        8422        9178

Branch 38 Diameter 15 Length 345 Pressure 0.018956
Branch 37 Diameter 15 Length 1030 Pressure 0.056593
Branch 6 Diameter 22 Length 901 Pressure 0.033726
Branch 5 Diameter 22 Length 3045 Pressure 0.23936
Branch 4 Diameter 22 Length 315 Pressure 0.039427
Branch 3 Diameter 22 Length 962 Pressure 0.19436
Branch 2 Diameter 22 Length 925 Pressure 0.27541
Branch 1 Diameter 28 Length 1500 Pressure 0.3618

floor_Pressures =

    4.6969         0

Floor 2
No of Main Pipes = 6
Number of branch pipes

numOfBranches =

  Columns 1 through 5

     8     9     4     4     5

  Column 6

     5

Pipe  6  20
Pipe  5  42
Pipe  4  56.5
Pipe  3  66.5
Pipe  2  98
Pipe  1  118

floor_flowRates =

  447.75000  118.0000
```

```
lengths =

  Columns 1 through 2

        3440        3825
        3127        4313

  Columns 3 through 4

        5197        5332
           0           0

  Columns 5 through 6

        8204        9023
        8297        8988

Branch 38 Diameter 15 Length 345 Pressure 0.018956
Branch 37 Diameter 15 Length 1030 Pressure 0.056593
Branch 6 Diameter 22 Length 901 Pressure 0.033726
Branch 5 Diameter 22 Length 3045 Pressure 0.23936
Branch 4 Diameter 22 Length 315 Pressure 0.039427
Branch 3 Diameter 22 Length 962 Pressure 0.19436
Branch 2 Diameter 22 Length 925 Pressure 0.27541
Branch 1 Diameter 28 Length 1500 Pressure 0.3618

floor_Pressures =

    4.6969    1.2196


raiserFlowRate =

  565.75000


raiserPressure =

    0.3618


pressure =

    6.2784
```

Appendix 26 - MATLAB analysis result for Medical Vacuum Pipeline Distribution System

```
>> Code_floors
Enter the gas type
"Medical Vacuum"
Floor 1
No of Main Pipes = 6
Number of branch pipes

numOfBranches =

  Columns 1 through 5

     2    10     4     4     8

  Column 6

     8

Pipe  6  270
Pipe  5  360
Pipe  4  430
Pipe  3  470
Pipe  2  630
Pipe  1  790

floor_flowRates =

   790     0


lengths =

  Columns 1 through 2

        1847        3898
        1740        4035

  Columns 3 through 4

        4897        5032
           0           0
```

```
  Columns 5 through 6

        7534        9035
        8422        9178

Branch 42 Diameter 42 Length 490 Pressure 0.021538
Branch 41 Diameter 42 Length 300 Pressure 0.01978
Branch 40 Diameter 42 Length 300 Pressure 0.026374
Branch 39 Diameter 42 Length 740 Pressure 0.081319
Branch 6 Diameter 42 Length 901 Pressure 0.13366
Branch 5 Diameter 42 Length 3045 Pressure 0.60231
Branch 4 Diameter 42 Length 315 Pressure 0.088007
Branch 3 Diameter 42 Length 962 Pressure 0.40149
Branch 2 Diameter 42 Length 925 Pressure 0.51747
Branch 1 Diameter 54 Length 1200 Pressure 0.55514

floor_Pressures =

    2.4471         0

Floor 2
No of Main Pipes = 6
Number of branch pipes

numOfBranches =

  Columns 1 through 5

     8     9     4     4     5

  Column 6

     5

Pipe  6  110
Pipe  5  215
Pipe  4  285
Pipe  3  355
Pipe  2  485
Pipe  1  615

floor_flowRates =

   790   615
```

```
lengths =

  Columns 1 through 2

        3440        3825
        3127        4313

  Columns 3 through 4

        5197        5332
           0           0

  Columns 5 through 6

        8204        9023
        8297        8988

Branch 38 Diameter 42 Length 345 Pressure 0.0075824
Branch 37 Diameter 42 Length 1030 Pressure 0.028297
Branch 6 Diameter 42 Length 901 Pressure 0.054456
Branch 5 Diameter 42 Length 3045 Pressure 0.35971
Branch 4 Diameter 42 Length 315 Pressure 0.039206
Branch 3 Diameter 42 Length 962 Pressure 0.30325
Branch 2 Diameter 42 Length 925 Pressure 0.39837
Branch 1 Diameter 54 Length 1500 Pressure 0.5402

floor_Pressures =

    2.4471    1.7311


raiserFlowRate =

        1405


raiserPressure =

    0.5402


pressure =

    4.7184
```

Appendix 27 - MATLAB analysis result for Medical Air Pipeline Distribution System

```
>> Code_floors
Enter the gas type
"Medical Air"
Floor 1
No of Main Pipes = 6
Number of branch pipes

numOfBranches =


  Columns 1 through 5


     2    10      4      4      8


  Column 6
     8


Pipe  6  117.5
Pipe  5  247.5
Pipe  4  447.5
Pipe  3  487.5
Pipe  2  595
Pipe  1  675


floor_flowRates =
   675     0


lengths =
  Columns 1 through 2
```

```
        1847         3898
        1740         4035

  Columns 3 through 4
        4897         5032
           0            0

  Columns 5 through 6
        7534         9035
        8422         9178

Branch 42 Diameter 15 Length 490 Pressure 0.10769
Branch 41 Diameter 15 Length 300 Pressure 0.070055
Branch 40 Diameter 15 Length 300 Pressure 0.074176
Branch 39 Diameter 15 Length 740 Pressure 0.19313
Branch 6 Diameter 22 Length 901 Pressure 0.19814
Branch 5 Diameter 22 Length 3045 Pressure 1.4105
Branch 4 Diameter 22 Length 315 Pressure 0.31228
Branch 3 Diameter 22 Length 962 Pressure 1.4248
Branch 2 Diameter 22 Length 925 Pressure 1.6721
Branch 1 Diameter 28 Length 1200 Pressure 1.6557

floor_Pressures =

    7.1187         0

Floor 2
No of Main Pipes = 6
Number of branch pipes
```

```
numOfBranches =
  Columns 1 through 5
     8     9     4     4     5

  Column 6
     5

Pipe  6  0
Pipe  5  50
Pipe  4  77.5
Pipe  3  77.5
Pipe  2  190
Pipe  1  190

floor_flowRates =

   675   190

lengths =

  Columns 1 through 2

        3440        3825
        3127        4313

  Columns 3 through 4

        5197        5332
           0           0
```

```
  Columns 5 through 6

        8204        9023
        8297        8988

Branch 38 Diameter 15 Length 345 Pressure 0
Branch 37 Diameter 15 Length 1030 Pressure 0
Branch 6 Diameter 22 Length 901 Pressure 0
Branch 5 Diameter 22 Length 3045 Pressure 0.28495
Branch 4 Diameter 22 Length 315 Pressure 0.054082
Branch 3 Diameter 22 Length 962 Pressure 0.22651
Branch 2 Diameter 22 Length 925 Pressure 0.53396
Branch 1 Diameter 28 Length 1500 Pressure 0.58257

floor_Pressures =

    7.1187    1.6821
raiserFlowRate =

   865

raiserPressure =

    0.5826

pressure =

    9.3833
```

Appendix 28 - MATLAB analysis result for Surgical Air Pipeline Distribution System

```
>> Code_floors
Enter the gas type
"Surgical Air"
Floor 1
No of Main Pipes = 6
Number of branch pipes

numOfBranches =

  Columns 1 through 5

     2    10     4     4     8

  Column 6

     8

Pipe  6  875
Pipe  5  875
Pipe  4  875
Pipe  3  875
Pipe  2  875
Pipe  1  1575

floor_flowRates =

        1575
```

```
lengths =

  Columns 1 through 2

        1847        3898
        1740        4035

  Columns 3 through 4

        4897        5032
           0           0

  Columns 5 through 6

        7534        9035
        8422        9178

Branch 42 Diameter 15 Length 490 Pressure 0.70926
Branch 41 Diameter 15 Length 300 Pressure 0.65136
Branch 40 Diameter 15 Length 300 Pressure 0.86849
Branch 39 Diameter 15 Length 740 Pressure 2.6778
Branch 6 Diameter 22 Length 901 Pressure 1.1189
Branch 5 Diameter 22 Length 3045 Pressure 3.7814
Branch 4 Diameter 22 Length 315 Pressure 0.46377
Branch 3 Diameter 22 Length 962 Pressure 1.9466
Branch 2 Diameter 22 Length 925 Pressure 1.8717
Branch 1 Diameter 28 Length 1200 Pressure 2.9558
```

```
floor_Pressures =

   17.0450


raiserFlowRate =

        1575


raiserPressure =

    2.9558


pressure =

   20.0008
```

Appendix 29 - MATLAB analysis result for Nitrous Oxide Pipeline Distribution System

```
>> Code_floors
Enter the gas type
"Nitrous Oxide Gas"
Floor 1
No of Main Pipes = 6
Number of branch pipes

numOfBranches =

  Columns 1 through 5

     2    10      4      4      8

  Column 6

     8

Pipe  6  33
Pipe  5  43
Pipe  4  57.5
Pipe  3  57.5
Pipe  2  72
Pipe  1  102

floor_flowRates =

   102     0
```

```
lengths =

  Columns 1 through 2

        1847        3898
        1740        4035

  Columns 3 through 4

        4897        5032
           0           0

  Columns 5 through 6

        7534        9035
        8422        9178

Branch 42 Diameter 15 Length 490 Pressure 0.040385
Branch 41 Diameter 15 Length 300 Pressure 0.034615
Branch 40 Diameter 15 Length 300 Pressure 0.044505
Branch 39 Diameter 15 Length 740 Pressure 0.13418
Branch 6 Diameter 22 Length 901 Pressure 0.055649
Branch 5 Diameter 22 Length 3045 Pressure 0.24506
Branch 4 Diameter 22 Length 315 Pressure 0.040125
Branch 3 Diameter 22 Length 962 Pressure 0.16806
Branch 2 Diameter 22 Length 925 Pressure 0.20234
Branch 1 Diameter 28 Length 1200 Pressure 0.2502
```

```
floor_Pressures =

    1.2151         0

Floor 2
No of Main Pipes = 6
Number of branch pipes

numOfBranches =

  Columns 1 through 5

     8     9     4     4     5

  Column 6

     5

Pipe  6  0
Pipe  5  11.5
Pipe  4  11.5
Pipe  3  11.5
Pipe  2  24.5
Pipe  1  24.5

floor_flowRates =

  102.0000   24.5000
```

```
lengths =

  Columns 1 through 2

        3440        3825
        3127        4313

  Columns 3 through 4

        5197        5332
           0           0

  Columns 5 through 6

        8204        9023
        8297        8988

Branch 38 Diameter 15 Length 345 Pressure 0
Branch 37 Diameter 15 Length 1030 Pressure 0
Branch 6 Diameter 22 Length 901 Pressure 0
Branch 5 Diameter 22 Length 3045 Pressure 0.065539
Branch 4 Diameter 22 Length 315 Pressure 0.008025
Branch 3 Diameter 22 Length 962 Pressure 0.033612
Branch 2 Diameter 22 Length 925 Pressure 0.068853
Branch 1 Diameter 28 Length 1500 Pressure 0.07512

floor_Pressures =

    1.2151    0.2511
```

```
raiserFlowRate =

  126.5000


raiserPressure =

    0.0751


pressure =

    1.5414
```

Appendix 30 - MATLAB analysis result for Anesthesia Gas Pipeline Distribution System

```
>> Code_floors
Enter the gas type
"Anesthetic Gas"
Floor 1
No of Main Pipes = 6
Number of branch pipes

numOfBranches =

  Columns 1 through 5

     2    10     4     4     8

  Column 6

     8

Pipe  6  320
Pipe  5  410
Pipe  4  410
Pipe  3  520
Pipe  2  660
Pipe  1  820

floor_flowRates =

   820     0
```

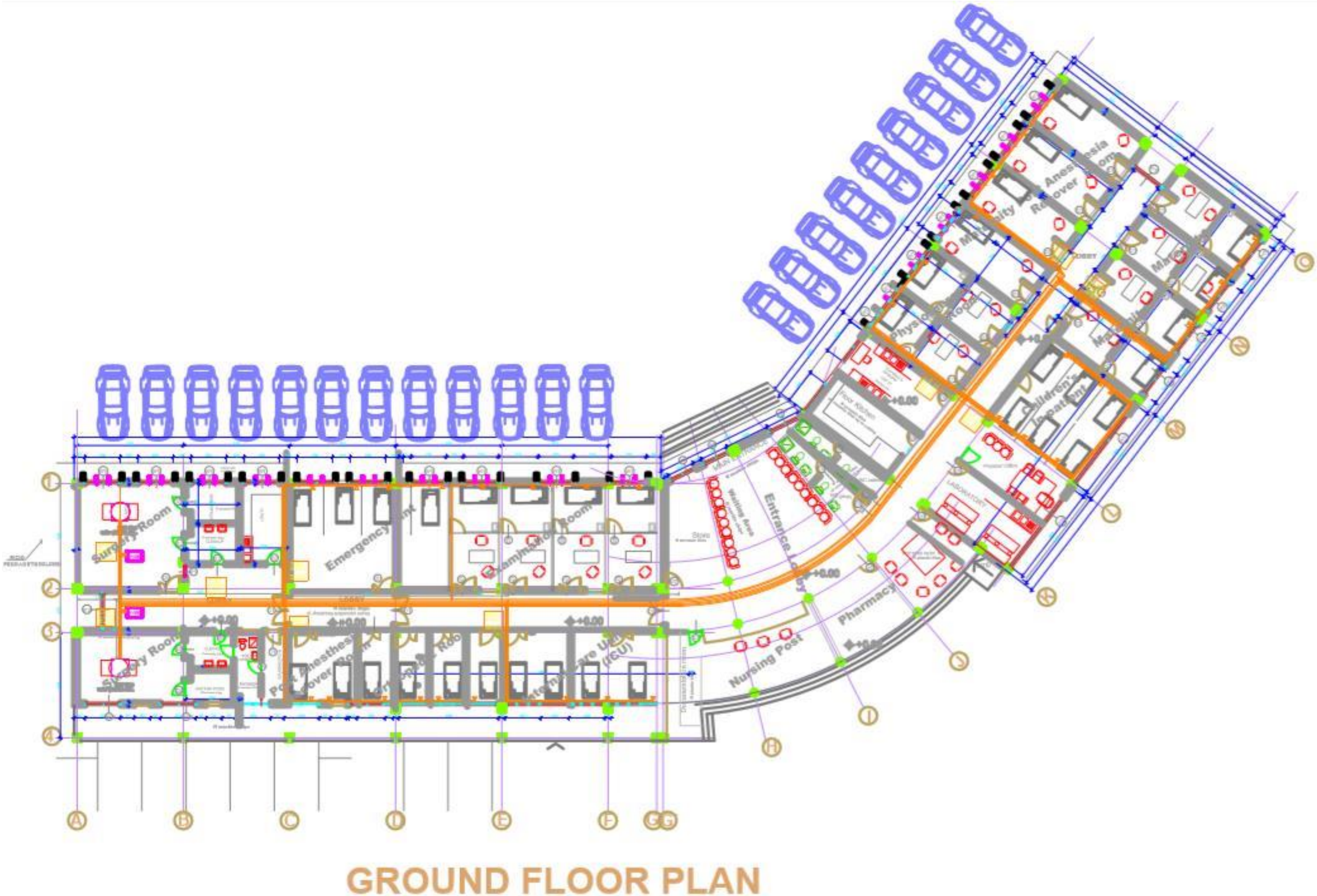
```
lengths =

  Columns 1 through 2

        1847         3898
        1740         4035

  Columns 3 through 4

        4897         5032
           0            0

  Columns 5 through 6

        7534         9035
        8422         9178

Branch 42 Diameter 15 Length 490 Pressure 0.21538
Branch 41 Diameter 15 Length 300 Pressure 0.26374
Branch 40 Diameter 15 Length 300 Pressure 0.3956
Branch 39 Diameter 15 Length 740 Pressure 1.3011
Branch 6 Diameter 22 Length 901 Pressure 0.53962
Branch 5 Diameter 22 Length 3045 Pressure 2.3366
Branch 4 Diameter 22 Length 315 Pressure 0.28611
Branch 3 Diameter 22 Length 962 Pressure 1.5198
Branch 2 Diameter 22 Length 925 Pressure 1.8548
Branch 1 Diameter 28 Length 1200 Pressure 2.0114
```

```
floor_Pressures =

   10.7242         0

Floor 2
No of Main Pipes = 6
Number of branch pipes

numOfBranches =

  Columns 1 through 5

     8     9     4     4     5

  Column 6

     5

Pipe  6  0
Pipe  5  100
Pipe  4  100
Pipe  3  210
Pipe  2  330
Pipe  1  540

floor_flowRates =

   820   540
```

```
lengths =

  Columns 1 through 2

        3440        3825
        3127        4313

  Columns 3 through 4

        5197        5332
           0           0

  Columns 5 through 6

        8204        9023
        8297        8988

Branch 38 Diameter 15 Length 345 Pressure 0
Branch 37 Diameter 15 Length 1030 Pressure 0
Branch 6 Diameter 22 Length 901 Pressure 0
Branch 5 Diameter 22 Length 3045 Pressure 0.5699
Branch 4 Diameter 22 Length 315 Pressure 0.069783
Branch 3 Diameter 22 Length 962 Pressure 0.61378
Branch 2 Diameter 22 Length 925 Pressure 0.92741
Branch 1 Diameter 28 Length 1500 Pressure 1.6557

floor_Pressures =

   10.7242    3.8366
```

```
raiserFlowRate =

        1360


raiserPressure =

    1.6557

pressure =

   16.2165
```

Appendix 31 – Sample hospital plan layout for MGDS - Ground floor (Floor 1)



Appendix 32 – Sample hospital plan layout for MGDS - First floor (Floor