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Central Medical Vacuum Systems for Corona Treating Hospitals

V Vasudeva Rao[1*], Manuel Seger[2], Sumeet Thakur[3]& V Vanisri[4]
1 Cryogenic Engineering Centre, Indian Institute of Technology, Kharagpur, India
2 Busch Vacuum (Shanghai) Co., Ltd, China
3 Busch Vacuum India Pvt Ltd., Gurgaon, India
4 Dentist, Kharagpur, India

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ABSTRACT:

Central Medical Vacuum System (CMVS) is considered as a Critical Care Life Support equipment in modern hospitals. It helps in scavenging the ambience and provides suction to safely remove various biological, microbial and chemical fluids without any contamination. Vacuum pumps and pipes need to be optimally designed along with efficient bacteria-filter for safe sucking and disposing biological impurities in hospital rooms. The present paper describes the design concepts of CMVS located in modern hospitals.

KEY WORDS: Corona, vacuum pump, Bacteria filter, exhaust pipe, CMVS

I. INTRODUCTION TO CENTRAL MEDICAL VACUUM SYSTEMS

Today, Vacuum technology is used extensively in many facets of medical industry. Medical vacuum combines provision of fresh medical air, scavenging of contaminated ambience and driving of tools for surgical suction of fluids. The density of corona affected patients in ICU and clinical wards is expected to be very high due to rapid pandemic growth. It is expected that the ambience gets progressively richer in dangerous virus nuclei [1]. This accumulation could be dangerous to the patients as well as attending doctors and nurses [2].We cannot exhaust the corona infected air in the hospital through exhaust fans outside. Instead, a controlled vacuum-suction outlet through a bacterial filter in association with a filtered fresh air purging at inlet of room can minimize the ambience contamination [3]. However, during this process, the room pressure should be maintained nearer to ambient pressure at the altitude location of the hospital.

It is also essential that hospitals and healthcare facilities are provided with safe and large capacityvacuum suction equipment with sufficient wall-mounted vacuum ports in ICU and other critical rooms for surgical suction of fluids. To meet these health care aspects, Central Medical Vacuum Systems are installed in modern hospitals. Centralized Medical vacuum systems (CMVS) are most cost effective and convenient than multiple vacuum systems [4-6]. Further, use of CMVS systems consumes lesser electricity, thereby contributing in cutting down the electrical expenses of the hospital.In addition, the same CMVS could also be used as vacuum cleaners and dehumidifiers in hospital building, thereby reducing the expenditure in purchasing and maintaining alternative expensive equipment. Automation protocols can be integrated with the central monitoring system based on AI software to reduce the human effort.

The present paper provides a conceptual design for installing such central medical vacuum systems in a modern hospital environment.

II. DESIGN OF COMPONENTS FOR CENTRAL MEDICAL VACUUM SYSTEMS

Central Medical Vacuum System(CMVS) is an integral part of hospitals, where vacuum is used for surgical suction, thoracic drainage, gastric suction, laproscopic suction and depletion of bacterial contamination in ICU. Both centralized and decentralized vacuum systems are under consideration for hospitals at the typical vacuum level of 200 to 350 mbara(- 800 to -650mbarg) and a flow range of 25 to 1000 m^3/h at an average vacuum level of 300 mbar. This is equivalent to 8 to 350 Nm^3/h at 1 atm (i.e. 1000 mbara).

The gas flow regions in CMVS are mostly laminar.Further, the throughputs (Q) are quite high, demanding assembly of large capacity vacuum pumps capable of withstanding high operating temperatures (>80°C). The modern multi-claw pumps may offer suitable solutions. In addition, estimation of flow conductances, pressure drops across long vacuum piping and effective pumping speeds at various suction ports is important for designing the CMVS [7]. Vacuum conductance of a pipe (dia D, length L) in laminar flow (common at 300 mbara) is computed by Hagen-Poiseuille's law, given below:

$$C_{pipe} = \frac{\pi D^4 P_{av}}{128 \mu L} \qquad (1)$$

where µ is the dynamic viscosity of the flowing fluid at the average pressure (P_{av}). Theeffective pumping speed (S_{eff}) at the suction port in the hospital building is related to the specified maximum pumping speed of connected pump ($S_{\max}$) and C_{pipe}given as

$$\frac{1}{S_{eff}} = \frac{1}{S_{\max}} + \frac{1}{C_{pipe}} . \qquad (2)$$

The throughput (Q) at the suction port is related to S_{eff} and the vacuum level at the suction port (P_{suc}) through Eq 3.

$Q = S_{eff} * P_{suc}$ (3)

Fig. 1 shows a typical Central Medical Vacuum System(CMVS) located in the basement of hospital with piping connections to the wards. The main components of CMVS are listed below:

1. Vacuum Pumps
2. Digital Electrical Control Panel
3. Bacterial Filter
4. Vacuum Reservoir
5. Non-Return Valves and Connection Pipe

Fig 1: Schematic of Central Medical Vacuum System for Hospital use [8]

The role of each component is briefly explained below.

Vacuum pump and non-return valve

The Vacuum Pump is the heart of the CMVS to supply the required vacuum for different locations in the hospital. Vacuum pump shall have a required capacity in SCFM at a vacuum level of 20"Hg. The Selection and Sizing of vacuum pump for medical application is explained in section 3. All the pumps shall be mounted on vibration isolators. Insertion of a non return valve with stainless steel spring in the pipe between the inlet filter and each pump inlet is mandatory. Such a non-return valve provided at the inlet suction port protects the vacuum from inadvertent pressurization. Further, in case of power failure it helps in retention of vacuum inside the vacuum reservoir.

Vacuum Reservoir

The vacuum reservoir is provided as buffer chamber and is manufactured to meet the requirements of the hospital. According to the pressure level in the vacuum reservoir, the controller will start or stop the vacuum pumps. One or more vacuum vessels are supplied as a part of reservoir. These vessels are galvanized inside and outside, designed, built and tested according to ASME Section VIII, for an external pressure of 15 psig. Further, it should be equipped with Drain valve, Vent valve, Sight glass assembly and a three valve bypass piping.

Bacterial filter

The purpose of Bacterial filter is the separation of biological and cleaning fluids coming to the vacuum pump, so that no pump contamination appears. This part of the plant is located between the vacuum reservoir and the pump. Fig. 2 shows such bacteria filters designed for CMVS [8]. A parallel filter assembly is generally used for better and reliable operation. Bacteria filters, with manual isolating valves enable the selection of Duty and Standby. Each Medical filter must come equipped with removable sterilisable drain flask with isolating valve and direct mounting differential pressure indicator, which indicates when the filter element needs replacement. The medical vacuum filter shall meet the requirements of the D.H.S.S. for infectious disease units (HTM 2022) with complete bacteria removal to 0.0001% penetration, as tested to BS.3928 efficiency.

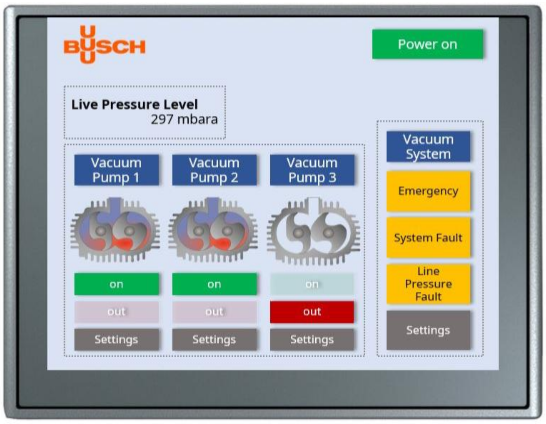
Fig 2: Bacteria filters with drainflask for CMVS [8]

Digital Electrical Control Panel

A typical control panel to operate/monitor all pumps of triplex Pump System is shown in Fig 3 [8].

The control panel shall be of automatic lead/lag type, designed to alternate pumps sequentially and to equalize run time. The vacuum system control panel shall be site-calibrated to the elevation during start-up and initiate pumps based upon the site specific requirements. The selection of Lead and Lag pumps can also be programmed through this panel on day / month / year basis.Reservoir vacuum level can be shown on the panel digitally and also pump's on and off vacuum levels can be programmed from this panel.

One programmable logic controller with analog expansion module provides full-color, graphic, user-friendly touch-screen operator interface trending information for the operational parameters such as: vacuum level, discharge temperature and on/off status of pumps. Ethernet connectivity and embedded web page for remote monitoring (overloading, high discharge temperature) is also included.



Live Pressure Level
297 mbara

Fig 3: Digital control panel for CMVS

III. SIZING OF CENTRAL MEDICAL VACUUM SUPPLY SYSTEM – AN EXAMPLE PROJECT

As an example, a large hospital expansion/renovation project in a city Calgary (Canada) located at 3500 ft. above sea level executed by Busch is taken up. The project includes the addition of 600 new vacuum outlets spread over 40 new emergency examination rooms, 100 patient rooms, 10 new operating rooms, 6 preparation rooms, 4 endoscopy rooms, 15 recovery rooms, 2 scrub rooms and 1 sterile corridor stretcher location.A schematic layout of the hospital is given in Figure 4and the details of suction ports and flows are listed in Table 1.

Table 1: Details of suction ports & flows

Device/ Application	Typical flow in SCFM for port	Number of suction ports	Total suction (SCFM)	Nominal vacuum level (mbara)
Tracheal suction	1	5	5	Average 300mbara
Surgical suction	3.5	20	70	
Wound drainage	0.04 - 0.4	100	4	
Gastric drainage	0.04 – 0.4			
Thoracic drainage	0.04 – 0.4			
Total			79	

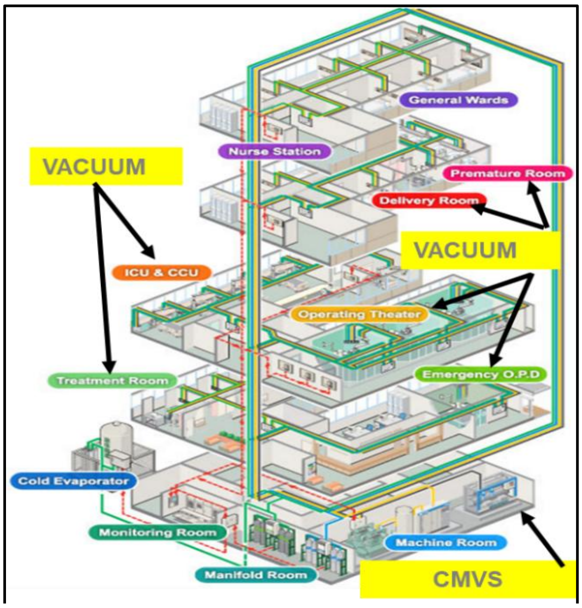


Fig 4: Hospital layout with CMVS at basement

Planning of suitable central medical vacuum system(CMVS) is done in the following 4 steps.

Step-1: Data Collection

- All outlets are accounted per room and per occupancy.
- A list of all medical equipment that require vacuum is also compiled.

Step- 2: Capacity Calculation

- Using the typical flows listed in Table 1, the required capacity is estimated at 79 SCFM.

The project location is at approx. 1,067 m or 3,500 ft of elevation. Hence an altitude correction factor (as shown in Figure 5) is applied for suction speed calculation taking care of the reduced barometric pressure, i.e. 79 SCFM x 1.14 = 90 SCFM @ 300 mbara at 3,500ft. This is 14% larger capacity compared to the plant capacity at sea level.

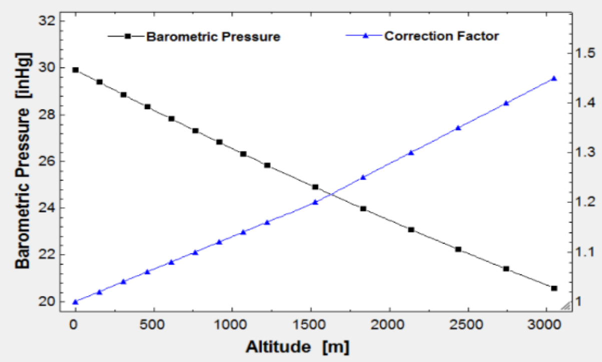


Fig 5: Vacuum level and correction factor as a function of altitude

Step 3- Technology Selection

Currently, 4 main technologies are being offered on the market today for medical vacuum systems

- Dry rotary claw pumps
- Liquid ring vacuum pumps
- Oil-Lubricated rotary vane pumps
- Dry rotary vane vacuum pumps

In order to minimize maintenance and cost of ownership, Dry Claw Vacuum Pump (MINK series pump of Busch) is selected as the standard of acceptance for the project. These pumps operate seamlessly which leads to an almost maintenance-free operation. The rotary claw operation principle reduces their energy consumption considerably in comparison with other conventional vacuum pumps in rough vacuum. A medical vacuum pumping system must meet DIN EN ISO 7396-1, DIN EN 737-3, NFPA99, HTM 02-01 design standards. Medical Vacuum systems can be duplex or triplex systems depending upon the requirement.The final combination of pumping systems chosen for the present case is given below, taking maximum flow rate into consideration.

Triplex (3 pumps) Medical Vacuum System or Quad (4 pumps) Medical Vacuum System with a flow rate of 102 SCFM per pump at 3500ft altitude are selected.To minimize space requirement, the stack mounted pump configuration as shown in Fig 6, is selected to match the requirement of different volumes at different floors of the hospital.

Fig 6: Assembly of CMVS [8]

Step 4- Location and length of exhaust pipe

The placement of vacuum exhausts at various locations of the hospital building is determined carefully; respecting all the standard codes maintaining minimum distances aboveground, from air intakes, operable windows and doors. The pumping speed calculations are done considering the bends and extensions in the piping network.

The exhaust location in the building should be carefully chosen to meet the following requirements.

- The exhaust outlet shall be located at least 10m (30ft) away from any door or operable window,15m (50ft) from any mechanical air intake and a minimum of 3m (10ft) above ground. The end of the exhaust shall be turned downward and screened.
- The exhaust outlet shall be protected against weather and the entry of vermin. It shall be accessible to the authorized personnel for cleaning, inspection and servicing.
- The exhaust line shall be provided with a drain at its lowest point.
- The distances given are minimums only. The intent is to prevent vacuum exhaust gases from being drawn into air-intakes or allowed to enter

healthcare facility through openings such as doors and windows. Consideration should be given to prevent freezing of the outdoor sections of the exhaust(s) due to the effects of prevailing cold winds or accumulated snow on them.

Equivalent exhaust pipe length has to be designed taking into account for all the required elbows, tees and valves using a chart of equivalent pipe lengths. If such a chart is not available, for rough calculation purposes, simply add 30% to the linear pipe length (or even more if large number of elbows are required). However, the piping should be designed minimising the use of elbows and tees.

Step 5- Selection of exhaust pipe diameter

- Once the equivalent exhaust pipe length is determined, one can select the appropriate pipe diameter using the table 2.

Table 2- Exhaust pipe diameter selection

System capacity SCFM @ 300 mbara	Equivalent pipe Length (feet)						
	50	100	150	200	300	400	500
	Exhaust pipe size (inches)						
10	2	2	2	2	2	2	2
50	2	2.5	3	3	3	3	3
100	3	3	3	4	4	5	5
150	3	4	4	4	5	5	5
200	4	4	4	5	5	5	5
300	5	5	5	5	6	6	6
400	5	5	6	6	6	8	8
500	5	6	6	6	8	8	8
600	6	6	8	8	8	10	10

IV. CENTRAL MEDICAL VACUUM SYSTEMS SUITABLE TO FIGHT COVID-19

In the fight against Corona Virus, hospitals are using Central Medical Vacuum System (CMVS) to suck the body secretions or breathing air in operating and treatmentrooms, where the feared virus may be present. Fig. 7 shows one such CMVS, equipped with Busch MINK Rotary Claw Vacuum Pumps, supplied to an emergency hospital in Wuhan, China treating COVID-19 patients [9]. They are equipped with special filters which prevent the viruses from passing through. In addition, the claw pumps used in CMVS pumps do not require operating fluids such as water or oil, which could be contaminated with the viruses.

Fig 7: CMVS equipped with MINK Rotary Claw Vacuum Pumps by Busch at Wuhan, China [9]

The major benefit of using Rotary Claw Vacuum Pumps is that it raises the gas temperature by 80 to 90°C during internal compression and therefore most likely deactivating the effect of COVID-19 viruses, before exhausting.State of the art analyses show that temperatures have a serious effect in inactivating SARS-CoV-2 structures in short time - especially when exposing the process gas to temperatures above 100°C. Further, Rotary Claw vacuum system have a guaranteed oil-free, non-contacting, non-wearing operation, which means any media sucked will not mix with any of the pump fluids and get retained, making it much safer to operate and maintain.

Further, the CMVS are planned with a scope for expansion, in order to cope with an expected further rush of intensive care patients, with corona virus complications.

V. CONCLUSIONS

The global rise in infectious diseases and exposure of medical professionals to medically hazardous substances in hospitals, is necessitating the inclusion of Central Medical Vacuum System(CMVS) in modern hospitals. The design aspects of such CMVS are elaborated in this paper along with few live examples.

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Conflict of Interest- None