A Review on the use of Emergency Ventilators for COVID-19

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ABSTRACT – The impact of COVID-19 resulted in a shortage of ventilators as the patients affected by it required breathing assistance. As the number of patients increased, the availability of mechanical ventilators decreased thereby, an alternative approach had to be considered like the use of emergency ventilators. This paper talks about a review of some of the emergency ventilators developed for such conditions. In addition, the paper also gives a brief description of the methodology of a similar emergency ventilator. In our design, we aim to develop and test a low-cost, easy-to-build, non-invasive ventilator that can help with the problem of insufficiency of ventilators. The ventilation is provided by adjusting the pressure of the oxygen supply depending upon the oxygen saturation level in the patient. Most emergency ventilators often fail to indicate any sort of alarm mechanism. This design includes an alarm system and an IoT technology for monitoring the status of a patient from anywhere with the help of smartphones or PCs, this way the constant need of a healthcare provider can be eliminated.

Key Words: emergency ventilator, COVID-19, non-invasive ventilation, oxygen saturation level, alarm mechanism.

1. INTRODUCTION

The novel coronavirus began in China in December 2019 which gradually managed to spread across the world leading to a pandemic [11]. As of May 2021, according to World Health Organization, there have been around 160 million confirmed COVID-19 cases including (approx.) 3 million deaths. It is considered a deadly virus because it affects the immune system of a person by causing acute respiratory distress syndrome (ARDS). The virus has proliferated as it is easily transmissible from person to person. A lot of effort goes into saving lives as it requires tremendous medical assistance and equipment. Due to the inflexible working conditions and exhaustion in supply chains, it becomes difficult to aid the affected masses [12].

Ventilators play a major role in providing breathing assistance for COVID patients, but as the cases increase day-by-day the availability of ventilators reduces. This shortage requires an additional set of ventilators other than the ones that are typically used in ICUs [13]. These devices must have all the basic settings that are present in mechanical ventilators so that they can be used for emergency purposes. The whole and sole reason for such ventilators is to lift the burden off the medical framework. As these ventilators are used in times of emergency, they can be called emergency ventilators. Since emergency ventilators are made portable, they can be used while transporting the patient. Such ventilators often work out cheaper and can hence be manufactured without excess funding.

The development of emergency ventilators solved many problems especially in the areas of cost, availability, and complexity. Various efforts have been made to build such ventilators all over the world. This paper also talks about one such effort to provide a low-cost, easy to use, emergency ventilator that does not require the constant need of a health care provider. This design provides non-invasive ventilation along with an alarm system that detects malfunctions and also the patient's status can be monitored through smartphones.

2. LITERATURE REVIEW

[1] This work presents a low-cost, portable, non-invasive ventilator (NIV) that can be used by patients during the early stages of COVID-19. The design makes use of a high-pressure blower fan for providing non-invasive positive-pressure ventilation like continuous positive airway pressure (CPAP) and bilevel positive airway pressure (BiPAP). One major issue of using CPAP and BiPAP is aerosolization of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). This occurs due to the high pressure used in the device. To avoid this problem, the design introduces a helmet-based NIV. The helmet consists of two virus filters, one on the inlet side and the other on the outlet side so that the exposure of the virus to health care providers can be reduced. The inlet of the helmet is connected to the output of the blower. The ventilator provides 0-20 cm H2O pressure with flow rates of 60-160 Lmin-1. The pressure and flow are monitored by two pressure sensors. The entire device is operated using an Arduino Due microcontroller and it is controlled using a touch-screen display which is mounted on the device. This display can be used to set and monitor clinically important parameters like pressure, breaths per minute (BPM), and inspiratory: expiratory (I: E) ratio. A secure digital (SD) card reader is integrated into the touch-screen for data collection purposes during the treatment of a patient. A magnetic DC buzzer is used as an alarm in case of any system or user faults such as accidental tubing disconnections or pressure leaks. The proposed device has a compact design thereby making it portable and easy-to-use unlike the bulky, heavy, and difficult to assemble bag squeezer ventilators.

[2] The main aim of this paper is to develop a ventilator that can be manufactured and assembled using conventional machines, which also does not require electricity and special equipment to work. To achieve this a gas-driven, automatic pressure-controlled ventilator is used, mainly because the tidal volume is automatically adjusted with respect to the lung compliance, and with the help of frequency adjustment within the provided limits minute volume can be maintained. The device consists of an air interface to which the pressurized air is connected. A patient interface connects the patient to the device and a manometer is used to measure the peak inspiratory pressure (PIP) and positive end-expiratory pressure (PEEP).

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 05 | May - 2021 ISSN: 2582-3930

The key component of this device is a piston, which along with a prestressed spring can control the pressure during inhalation and exhalation of a patient. The volume flow is controlled with the help of a screw present in an outlet provided in the device. The system supports continuous positive airway pressure (CPAP). An overpressure valve is included in case of any dysfunction in the device or the attached tubes. This valve decreases excessive pressure by opening up when the maximum pressure value is reached. Additionally, the device consists of a simple membrane that allows spontaneous breathing where the patient is allowed to inhale at a flow rate higher than that provided by the gas interface. At the time of exhalation, the resistance of the adjustable outlet helps the patient exhale as the membrane is closed. On the whole, the device can be manufactured with components and materials which are locally available. Due to the lack of electronics used and the simplicity in design, it can be easily implemented especially in remote areas of developing countries.

[3] The main objective of this paper is to produce low-cost emergency ventilators for fast deployment. It also aims at using simple fabrication techniques and generic off-the-shelf parts. GlasVent is an affordable and rapidly deployable emergency DIY ventilator that has been designed in such a way that it requires minimal training for operation. The system can work in two levels of operation: a) Manual operation b) Mains or Battery operation. This system makes use of a crank-slider mechanism to compress the BVM that is located in between two pistons. In the first level of operation, the device is designed in such a way that it can be operated manually if the power supply or the battery fails. This level of operation does not make use of any electronic components. In the second level of operation, most of the features are controlled by an Arduino. The breaths per minute provide to the patient through the BVM are controlled with the help of a potentiometer. A pressure sensor is located at the output of the BVM to monitor the pressure. The system also consists of an LED which acts as a warning in case of any malfunctions in the device. The Arduino is connected to a laptop or PC where the current status of the patient concerning the pressure data is displayed. This device can also be operated with a battery which makes it a backup for safe operation and it can be easily portable. It is powered by three Li-ion battery cells which can last up to 4 hours with continuous usage. This battery operation of the device can be used in remote places where the power supply is not available. GlasVent overcomes some features of hospital-grade ventilators for a short period as it allows ventilation powered manually or with battery and software resourcing using tablets, PC’s or smartphones. But it still needs development to meet the regulatory requirements.

[4] This paper focuses on designing a prototype of a mechanical ventilator that can be made with minimum external hardware and readily available hospital equipment. The ventilator consists of inspiratory and expiratory limbs. The tidal volume is generated through the inspiratory limb by regulating the peak inspiratory pressures (PIP), whereas by regulating and monitoring the positive end-expiratory pressure (PEEP) the expiratory limb allows exhalation. The inspiratory limb includes a flow-inflating bag wrapped in a resistive sheath, which is compressed using medical gas from a compressed gas source. The inspiratory pressure rises as there is a sudden release of stored energy to the patient due to the elasticity of the flow-inflating bag. This design consists of a solenoid valve that is programmed by the Arduino Uno microcontroller. The Respiratory rate, inspiratory time, and inspiratory-to-expiratory ratio can be customized by programming the solenoid valve to open with a certain frequency for a specified duration of time. This can be adjusted by the health care provider. A one-way bidirectional splitter is obtained from a self-inflating bag system that is included in the expiratory limb. The flow-inflating bag on the expiratory limb accommodates a reservoir volume in case of malfunctions and allows patient-initiated breaths. Through a drill hole, the flow-inflating bag is placed inside a size 3 soccer ball. The maximal pressure in the reservoir is limited by the pressure relief valve. This pressure relief valve along with the soccer ball, flow-inflating bag, and the gas inflow forms the inspiratory reservoir. The secondary reservoir must have a pressure less than or equal to the pressure set at the PEEP valve. The expiratory port is connected to the spring-loaded PEEP valve and the patient port is connected to the patient’s endotracheal tube. The tidal volume, PIP, PEEP, inspiratory-to-expiratory time ratio, and respiratory rate were measured with each breath. Hence, the proposed device was economically constructed from readily available hospital supplies, has strong ventilatory capability and customizability that can be used in times of emergency with low-resource settings.

[5] This paper discusses the development of an alarm system for pressure cycled ventilators. The device will indicate useful clinical metrics like peak inspiratory pressure (PIP), positive end-expiratory pressure (PEEP), and respiratory rate (RR). In case of any malfunctions with respect to these metrics, an alarm goes off. The alarm design consists of a key component that is an electronic pressure sensor that gives a signal and this pressure signal is monitored with the help of a pair of nonlinear recursive envelope trackers. The algorithm used is based on low-complexity signal processing which is similar to the one used in hearing aids. This algorithm requires little memory and performs very few calculations so it can almost run on any microcontroller. The electronic pressure sensor is connected to the patient airway by a standard respiratory tubing adapter. The ventilator here is a pressure-cycled pneumatic ventilator, where pressurized gas is given to the patient airway and with a pressure-switching mechanism, this pressurized gas will cycle between inhalation and exhalation. High-pressure gas flows from the ventilator to the patient’s lungs during inhalation, where the airway pressure increases till it reaches a maximum pressure threshold (PIP) that can be adjusted by the user. The airway pressure slowly drops below the positive end-expiratory pressure (PEEP) during exhalation. The designed alarm system consists of a microcontroller, a four-character seven-segment display, three pushbuttons, a buzzer, and a pressure sensor. The display module displays the PIP, PEEP, and RR values in cycles every few seconds. The pushbuttons are provided for enabling, disabling, and adjusting the alarm settings. A piezoresistive pressure sensor is used which has a pressure range of about 0 to 100 cm H_2O. Thus, the developed device is of low cost and it is easy to produce using few electronic components.

[6] The article addresses the design and development of a human breathing assist machine (ventilator) prototype for use by qualified medical professionals in the emergency room, as

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 05 | May - 2021 ISSN: 2582-3930

well as in other locations, where a regular ventilator machine cannot be made available. This paper aims to describe a quick construction of a low-cost ventilator to ventilate patients on oxygenated air mixture through an endotracheal tube, for the most severe hypoxemic phase of the COVID-19 disease, also known as a severe acute respiratory syndrome (SARS) or acute respiratory distress syndrome (ARDS). The popular crank-rocker mechanism has been used to meet some of the vital design requirements of the emergency ventilator. In this volume-controlled ventilation (VCV), the user sets a tidal volume and controls the pressure limits. The recommended tidal volumes for ARDS are 4–6 ml/ kg body weight during one inspiratory cycle. In the present design, inspiratory and expiratory time are different and are vital features. Achieving a different time for inspiration and expiration using a pneumatic drive increases the complexity of the pneumatic circuit, as well as increases the cost. Hence, a motor-based design had to be finalized. A quickly constructible ventilator design with user-controlled tidal volume at 1:2 (I: E ratio) has been achieved by a six-bar planar linkage. Metallic links of the desired length, manufactured in the workshop, will be used instead of flexible acrylic links to reduce any error in the time ratio, in a later version. Attempts are currently made to incorporate an in-line slider and variable time ratio. It is noted that the current design is not intended for permanent use, but as an emergency, measure to overcome the expected acute shortage of ventilators as a result of the currently existing worldwide outbreak of SARS-CoV2.

[7] A novel design for a simple, low-cost, easy-to-operate emergency use ventilator (EUV) that can be mass-produced to address future shortages for the treatment of patients with ARDS due to pandemic viral illness. The ventilator is designed to operate with a common, disposable, single-limb patient circuit. The device weighed 4 kg and measured 8 cm × 30 cm × 40 cm as tested, allowing for use on a bedside table or movable stand. To operate the ventilator, one standard medical air and one medical oxygen flowmeter are connected to respective supply outlets. The single-limb ventilator circuit is attached to the front of the unit and the unit is plugged into 120 V AC electrical power. A power switch at the back of the ventilator turns the device on, as indicated by the LCD screen display. Desired total flow and FiO2 are set and the patient limb circuit is attached to the endotracheal or tracheostomy tube. The PEEP can be adjusted by rotating the corresponding control knob to the desired level. Before starting ventilation, the desired inspiratory time and breath rate are selected via knobs attached to potentiometers. The LOCK/UNLOCK button is then pressed to confirm and lock the desired settings, and the START/STOP button is pressed to initiate ventilation. Breath rate and inspiratory time can be changed at any time by depressing the LOCK/UNLOCK button, setting knob inputs, and initiating these settings by depressing the LOCK/UNLOCK button again. This device delivers volume control ventilation via a simple design with user inputs of inspiratory time, flow rate, PEEP, and breath rate. Despite its low cost, essential safety features are built into the device, making it safe and easy to use for a broad range of health care personnel.

[8] The ventilator under the proposed design was being developed using wooden pieces with a weight of 6 kg and has a volume of 14 x 7 x 9 inches. It functions without a human operator as it delivers breaths through the compression of an orthodox bag-valve-mask. It satisfies its energy needs from an electric motor having a battery power of 12 volts DC. Different functions need to be performed for ventilation i.e. pressure and required number of breaths per minute is managed by an easy-to-use input board comprising of buttons. A functional model of the machine was constructed and was tested on an artificial lung. The model mechanism was operated by the medical representative responsible for breath rate and tidal volume, inclusively an assistance-controlled arm, and a low battery alarm. This machine requires a lesser amount of power, running for 2.15 hours on one battery charge. It shows the status on an LCD. Improvements in its functionalities are in the pipeline. These provisions will be based upon the results of the outcome incurred by the tests and experiments of the prototype. Investigations are also proposed to examine the outcomes resulted by using a different motor. Further induction of features is also proposed including a PEEP valve, a humidity exchanger, and a blow-off valve. BVMs are easily accessible in the market, therefore induction of them is also having a positive charge for further proceedings. In the Final stage, tests will be enforced for the sake of testing the ventilator on a lung model to come up with the standards set for the ventilator to make the product able to compete with the market.

[9] This paper designs a Portsmouth Ventilator with the following criteria: standard components that are accessible to the public, "open-source" compatibility to allow anyone to easily recreate the system, ability to ventilate in acute respiratory distress syndrome, and lowest possible cost to provide adequate oxygenation and ventilation. It incorporates three solenoid valves controlled by a simple microcontroller-driven electronics circuit. The ventilator connects to the pipeline gas supply to both air and oxygen. The ventilator delivers a hybrid form of pneumatic, assist-control ventilation, with predicted tidal volumes of 300–800mL, positive end-expiratory pressure 0–20cm H2O, and Fio2 21–100%. Using a Boyle law relationship (P1 V1 = P2 V2), the chamber volume at high pressure is discharged into the breathing circuit, and the patient lungs at a lower pressure and a higher volume. A pressure transducer continuously monitors airway pressure and displays a green light-emitting diode (LED) for airway pressures from 0 to 20cm H2O, an amber LED for airway pressures from 20 to 30cm H2O, and a red LED for airway pressures for greater than 30cm H2O. If a prolonged period of "red" pressure is identified, the ventilator delivers a prolonged expiratory phase. The ventilator will not deliver additional breaths if the airway pressure remains high and will alarm. Alternatively, if the ventilator detects a prolonged period of low airway pressures, it will generate an alarm that indicates either a loss of fresh gas supply or circuit disconnect. The Portsmouth Ventilator has limitations compared with modern ventilators; however, it is believed to provide a safe, effective, and rapidly scalable alternative ventilation solution.

[10] This paper aims at designing a portable ventilator model which can be used for measuring the respiration status of humans. The ventilator is associated with a PC with handles and catches that are constrained by a medical caretaker, or specialist. It has tubes that are associated with the individual through a breathing cylinder. The breathing cylinder is put in the patient's mouth or an opening in the neck into the windpipe (trachea). In this model the atmospheric air/compressed air is

given into the tube of 6mm which is connected to the regulator, then the regulator is adjusted at 1 bar through the connection of the gauge in the regulator. This 6mm tube which is extended from the compressor and regulator is connected to the solenoid valve, which is processed by the Arduino board that acts as on and off condition, thereby controlling the flow of air through the condition of atmospheric air/compressor. After attachment of the 6mm tube to the flow control valve, the tubing connection has upgraded from 6mm to 8mm for the connection of the patient circuit with a green adapter. This device is provided with a very basic design and reliable structure that is easily acceptable by the patient. The main focus of this paper is to minimize the components and increase the efficiency of the device so that while using this device to the patient, they should feel as comfortable as the normal ventilator. This research has led to the development of a lab model ventilator.

3. PROPOSED METHODOLOGY

As we know emergency ventilators are playing a very important role in providing ventilation during the shortage of ventilators available in hospitals. Most emergency ventilators that are available do not have some of the advanced features found in hospital ventilators. They are often manually operated which has to be done by a health care provider. This research aims to build a low-cost, user-friendly, non-invasive ventilator that is built using off-the-shelf components.

The features of this design include an alarm system in case of any malfunctions, an oxygen level sensor to read the oxygen saturation level of the patient along with a pressure sensor that can read the pressure value, and with the help of a motor, the pressure can be controlled according to the oxygen saturation level of the patient. In addition to this, a monitoring system is also included to eliminate the constant need for a health care provider. Here the pressure values and oxygen values can be displayed on smartphones as well as PCs. This data can be collected for future references. The basic block diagram of this design is as shown in Fig-1.

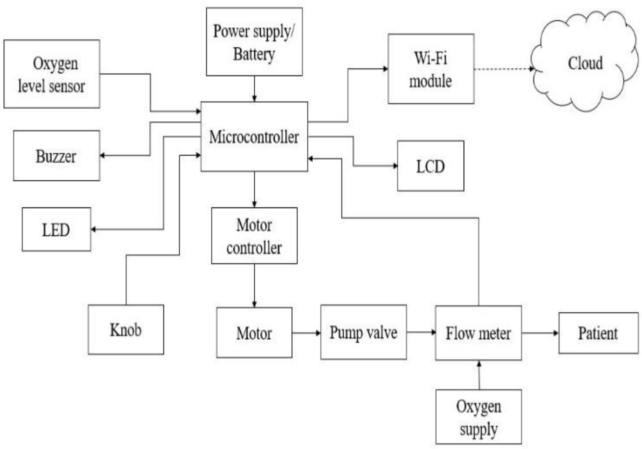

Fig -1: Block Diagram of Emergency Ventilator

The simple working of this device is that, when the patient's oxygen level is read by the oxygen level sensor, it is checked if the value is above the minimum percentage (90%), the supply of oxygen is normal and a green LED is used to indicate this condition. In case the patient's oxygen level goes below the minimum value, the pressure at which the oxygen is supplied will vary accordingly to increase the oxygen level of the patient. In this condition, when the oxygen level is low, the buzzer is turned ON as an indication and the red LED glows. The pressure is varied with the help of a motor whose speed is manipulated by a motor controller. This way the patient is provided with the right amount of oxygen through non-invasive ventilation. This working methodology can be represented with the help of a flow chart as shown in Fig- 2.

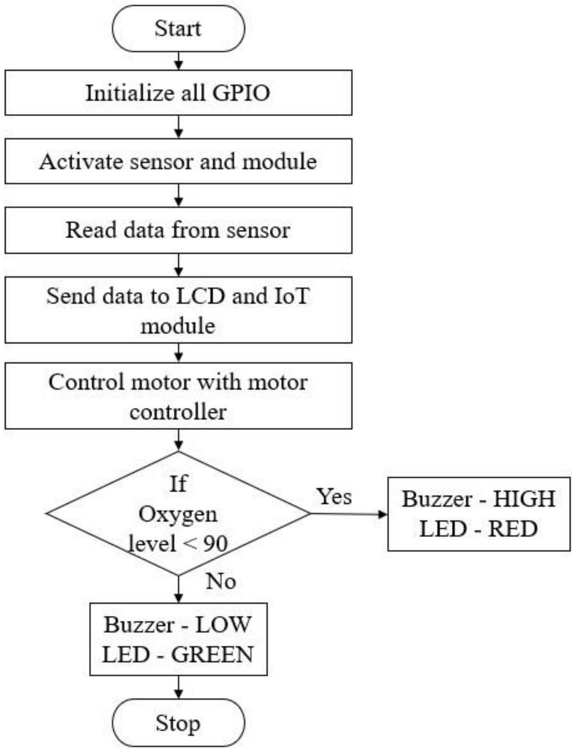

Fig -2: Flow Chart of the proposed system

4. CONCLUSION

In response to the COVID-19 pandemic, we designed a low-cost, easy-to-build, non-invasive emergency ventilator. After analyzing several pieces of research, the design was made to reduce the complexity that goes into general ventilators but at the same time, meeting all the requirements of providing proper ventilation. The simplicity of the design makes it user-friendly due to which medical experts do not have to be present constantly. In case of any emergency where the patient is suffering from insufficient oxygen, the alarm system included in the design will indicate this with the help of a buzzer. During this situation, the pressure is automatically adjusted, therefore providing sufficient oxygen to the patient. The inclusion of the Wi-Fi module enables real-time monitoring of the patient along with data collection for future reference.

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