Medicines & Healthcare products Regulatory Agency

MHRA

Rapidly Manufactured Ventilator System (RMVS)

Document RMVS001 - Specification

Issued by MHRA

Version Control

Version	Date Issued	Description
1.0	18/03/2020, 17.31	Initial document plus appendix A
1.1	19/03/2020	Minor formatting changes, Glossary and Corporate logos
2.0	19/03/2020,	Expanding on relevant standards based on clinical engineering advice. Appendix A integrated into 'testing' section
2.1	20/03/2020, 1054	Add explanation of option for volume control ventilation
2.2		Added details to infection control section, added Appendix A: infection control process'
3.0	25/3/20	Added biological safety section, appendix B on indicative testing, refined use of should/could/must to be clearer
3.1	26/3/20	Added appendix C – software safety requirements

Glossary

ARDS – Acute Respiratory Distress Syndrome: a life-threatening form of respiratory failure where the lungs become severely inflamed due to an infection or injury and can't provide the body's vital organs with enough oxygen.

SIMV-PC – Synchronized Intermittent Mandatory Ventilation – Pressure Controlled: a mode of ventilation where the patient is allowed to take spontaneous breaths, the machine will assist the patients breathing when a spontaneous breath is taken. If the patient does not make a pre-set number of breaths a minute (i.e. 10) the machine provides mechanical ventilation to provide the set number.

CMV – Continuous Mandatory Ventilation

PCV – Pressure Controlled Ventilation

VCV – Volume Controlled Ventilation

PRVC – Pressure Regulated Volume Controlled: A mode of ventilation where a set tidal volume is delivered to the patient while maintain the lowest pressure possible in the airway, to avoid trauma.

CPAP: Continuous Positive Airway Pressure a non-invasive ventilation mode that provides a constant steady pressure to keep the lungs expanded

BIPAP – Bilevel Positive Airway Pressure: a non-invasive ventilation mode that provides different levels of pressure when the patient inhales and exhales.

IPPV – Intermittent Positive Pressure Ventilation: a mandatory invasive ventilation mode used to replace a patient's breathing when they cannot for themselves. Can be either volume controlled or pressure controlled. It does not synchronise any patient breathing efforts.

PEEP – Positive End-Expiratory Pressure: The lower pressure applied to the patient's airway to allow them to breathe out, but not too much.

EPAP – Expiatory Positive Airway Pressure: Similar to PEEP, pressure applied to the airway on patient expiration to prevent collapse of the airway.

HMEF – Heat and Moisture Exchange Filter: device fitted to the patient end of the breathing system, contains hydrophobic medium that absorbs heat and moisture from the patients exhaled breath and uses absorbed moisture to humidify inhaled gases. Can also filter bacteria and viruses, this will be used on all patients. WARNING can affect delivered pressure.

RF – Radio Frequency: Many medical devices are sensitive to RF interference. Care should be taken to ensure that this is kept to a minimum.

EM – Electro Magnetic Emissions: Many medical devices are sensitive to EM interference. Care should be taken to ensure that this is kept to a minimum.

Fi02 – Fraction of inspired oxygen: concentration of oxygen in the gas mixture that the patient inhales

AGSS – Anaesthetic gas scavenging system: where anaesthetic agents have been included in the gas mixture, this system is used to collect and remove exhales gas to avoid exposure to health care professionals.

Introduction

This is a specification of the minimally (and some preferred options) clinically acceptable ventilator to be used in UK hospitals during the current COVID-19 pandemic caused by SARS-CoV-2 virus. It sets out the clinical requirements based on the consensus of what is 'minimally acceptable' performance in the opinion of the anaesthesia and intensive care medicine professionals and medical device regulators given the emergency situation. It is for devices, which are most likely to confer therapeutic benefit on a patient requiring invasive ventilation because of respiratory failure caused by SARS-CoV-2, used in the initial care of patients requiring urgent ventilation. A ventilator with lower specifications than this is likely to provide no clinical benefit and might lead to increased harm, which would be unacceptable for clinicians.

Intensive care medicine is a whole system of care and ventilators cannot be safely used on any patient without trained staff and other equipment and medicines. Where these impinge on the specification they are mentioned below.

It is proposed these ventilators would be for short-term stabilisation for a few hours, but this may be extended up to 1-day use for a patient in extremis as the bare minimum function. Ideally it would also be able to function as a broader function ventilator which could support a patient through a number of days, when more advanced ventilatory support becomes necessary.

Must: Defines the minimum viable product clinically acceptable by clinicians

Should: Highly desirable features of considerable benefit for therapeutic use. As time is of the essence if omitting one of these features significantly accelerates development and production it should be considered

Could: Features or options often found in respirators, but are of significantly lower priority in terms of the current need and should not be considered if they delay production and development or the provision of more important features

Ventilation

1. Must have at least 1, optionally 2 modes of ventilation
    a. Must have CMV.
    b. The CMV mode must be either
        i. (ideally) Pressure Regulated Volume Control, or
        ii. pressure controlled ventilation (PCV) or
        iii. minimally a volume controlled ventilation (VCV).
    c. PRVC/Pressure Controlled - a set pressure is delivered for the period of inspiration and the volume achieved is measured and displayed. Ideally PRVC, an adaptive mode where the tidal volume is set and the lowest possible pressure is delivered to achieve this volume. PCV where the user has to provide the adaptive control to achieve tidal volume is only acceptable if the tidal volume delivered is clearly displayed and the user can set patient specific upper and lower tidal volume alarms to alert to the need to adjust the pressure.
    d. Volume Control Ventilation– the user sets a tidal volume and respiratory rate. The tidal volume is delivered during the inspiratory period. Acceptable only if additional pressure limiting controls are available, see Inspiratory Pressure section.
    e. Should havea spontaneous breathing pressure support mode for those patients breathing to some extent themselves, e.g. BIPAP or SIMV-PC. The user sets an inspiratory pressure and an expiratory pressure. The ventilator can sense when a patient starts to breathe in and apply the inspiratory pressure, then sense when the patient starts to breathe out and apply the expiratory pressure (this pressure is still positive but lower than the inspiratory pressure).
2. If a pressure support mode is provided the RMVS must failsafe automatically onto mandatory ventilation if the patient stops breathing in this mode.
3. Inspiratory airway pressure, the higher pressure setting that is applied to make the patient breathe in:
    a. Plateau pressure should be adjusted to achieve volume and must be limited to 35 cmH_2O by default. It is acceptable if an option to increase this to 70 cmH_2O in exceptional circumstances is provided. This must require a positive decision and action by the user
    b. Peak pressure should be no more than 2 cmH_2O greater than plateau pressure.
    c. If volume control ventilation is used, the user must be able to set inspiratory airway pressure limit in the range at least 15 – 40 cmH_2O in at least increments of 5 cmH_2O.
    d. There must be a mechanical failsafe valve that opens at 80 cmH_2O.
4. Positive End Expiratory Pressure (PEEP). The pressure maintained in the breathing system during expiration.
    a. RMVS must provide a range 5-20 cm H2O adjustable in 5 cmH_2O increments.

b. The patient breathing system must remain pressurised to at least the PEEP level setting at all times.

5. Inspiratory:Expiratory ratio (I:E). The proportion of each breathing cycle that is spent breathing in compared to breathing out.

   a. RMVS must provide 1:2.0 (i.e. expiration lasts twice as long as inspiration) as the default setting.

   b. RMVS could provide adjustable I:E in the range 1:1 – 1:3.

6. Respiratory Rate. The number of breathing cycles every minute.

   a. RMVS must provide a range 10 – 30 breaths per minute in increments of 2 (only in mandatory mode) that can be set by the user.

7. Tidal Volume (V_t) setting, if provided. The volume of gas flowing into the lungs during one inspiratory cycle

   a. Must have at least one setting of 400ml +/- 10 ml.

   b. Should have 350ml and 450 ml options.

   c. Could have a range 250 – 600 ml in steps of 50ml.

   d. Could have a range up to 800 ml.

Gas and electricity

1. Incoming Gas Supply.

   a. All gas connectors and hoses must comply with BS EN ISO 5359:2014+A1:2017, ISO 5359:2014/AMD 1:2017 and BS 2050: 1978 Electrical Conductivity.

   b. Must connect to wall pipeline oxygen supply via BS 5682:2015 compatible probes (Schrader). If hose not permanently fixed to machine, then must connect with NIST (Non-Interchangeable Screw Thread to ISO 18082:2014/AMD 1:2017). Oxygen pipeline pressure is approximately 3.7 – 4.5 bar.

   c. Oxygen supply from wall outlets outside of ICU and theatres is limited to approximately 6-10 lpm averaged over the outlets within a ward(HTM_02-01_Part_A). As such, RMVS should provide for a gas reservoir to manage peak inspiratory flow rates of up to 100 lpm

   d. Average oxygen consumption must be no more than 6 lpm. This may be allowed to increase as greater certainty is gained over oxygen supply.

   e. If RMVS connects to wall pipeline Medical Air (MA4, NOT SA7) it must be via BS 5682:2015 compatible probes.

   f. If connection to Anaesthetic Gas Scavenging System or an external activated charcoal absorber is provided it must comply to ISO 7396-2:2007 (If inhaled anaesthetic agents are being used).

   g. An RMVS may include an oxygen concentrator as the source of oxygen. Note these will typically be limited to 10 lpm 96% oxygen.

2. Electricity Supply.
    a. If mains powered RMVS must connect to 240V mains via standard UK 3pin plug.
    b. Must be PAT tested to the adapted IEC 60601, IEC 62353 standards
    c. If electricity is required for functioning, RMVS must have a battery backup of at least 20 minutes in case of mains electricity failure.
    d. Could utilise hot swappable batteries so that it can be run on battery supply for an extended period, e.g. 2 hours for within hospital transfer.
    e. Must avoid harmful RF or EM emissions that could interfere with other critical care equipment.
3. Gas supply to patient.
    a. User must be able to control inspired oxygen proportion (FiO_2). The percentage of oxygen in the gas being breathed in by the patient. Room air is 21% oxygen.
    b. Must provide a (50% or 60%) and 100% options
    c. Should provide control variable between 30 – 100 % in 10% steps.
    d. Patient breathing system connections: RMVS must present 22mm outside diameter (OD) 'male' standard connectors to ISO 5356-1:2015 on both outlet and inlet ports for connection to user supplied 22mm 'female' connectors on the breathing system. These must be rigid and robust (not plastic) and separated by a minimum of 10 cm between centres to accommodate filter HMEs.
4. All elements in the gas pathway must meet biological safety and low-pressure oxygen safety standards, especially to minimise risk of fire or contamination of the patient's airway.

Infection control

For clinical guidelines on infection control for ventilator equipment see Appendix A

1. All parts coming into contact with the patient's breath must be either disposable or designed to be reusable
2. All working components of the device must be contained within an impermeable casing.
3. All external surfaces must be cleanable in the likely event that they get respiratory secretions or blood splatter on them. Cleaning would be by healthcare workers manually wiping using an approved surface wipe with disinfectant or cloths and approved surface cleaning liquid.
4. There will be a separately sourced HMEF-bacterial-viral filter between the machine and patient which may impact on resistance within the system, which may need to be accounted for with some designs. The pressure being delivered to the patient is the specified pressure. If the filter has a resistance of, say 2 cmH_2O at 30 lpm, the ventilator needs to output 37 cmH_2O to achieve a set 35 cmH_2O at the patient. This will need further detailed consideration. Viral filtering filters may have much higher resistance that may be clinically relevant.

5. Could include facility for hot water humidifier to be included in breathing system.

Monitoring and Alarms

IEC60601-1-8:2006 is the one relevant standard for alarms for RMVS. Alarms, alarm limits, and priorities are complex areas to optimise for human usability. The key is to get enough alarms but not too many and for alarms to be clearly ranked so that more urgent patient safety problems are highlighted more. Early attention to this area is important, and should be built in from the start.

1. Must alarm at:
    a. Gas or electricity supply failure.
    b. Machine switched off while in mandatory ventilation mode.
    c. Inspiratory airway pressure exceeded.
    d. Inspiratory and PEEP pressure not achieved (equivalent to disconnection alarm).
    e. Tidal volume not achieved or exceeded.
2. Monitoring displayed continuously so the user can verify.
    a. Must show the current settings of tidal volume, frequency, PEEP, FiO_2, ventilation mode.
    b. Must show the actual current airway pressure
    c. Should show the achieved tidal volume, breathing rate, PEEP, andFiO_2.
    d. If pressure support mode is provided there must be real time confirmation of each patient breath and an alarm if below acceptable range.
    e. Could provide CO_2 monitoring.

Biological Safety

The authoritative standard covering this area is ISO 18562-1:2017 “Biocompatibility evaluation of breathing gas pathways in healthcare applications. Evaluation and testing within a risk management process”.

1. Materials of Construction (raw materials)
    A) The chosen material must be reasonably pure and simple in nature (minimise the use of additives where possible)
    B) For components requiring flexibility avoid the use of materials requiring plasticisers. Good candidates are those materials that belong to the polyolefin family, examples include polyethylene and polypropylene
    C) For structural components materials such as polycarbonate or Acrylonitrile butadiene styrene (ABS) should be used without additives, although reinforcement with glass fibre would be acceptable
    D) Polyvinyl chloride (PVC) must be avoided in the patient gas pathway
    E) PVC should be avoided elsewhere

2. Manufacturing process (risk from contaminants)

A) Mould release agents used within extrusion or injection moulding techniques may be required in setting up the machine, they should not be needed once a process is in full scale production
B) Approximately, the first 20 or so items in an injection moulding production run should be discarded to minimise risk from contamination with mould release agents
C) Extrusion and moulding techniques are comparatively simple and well controlled; therefore, ventilators will not be required to be manufactured within cleanroom specifications
D) Manufacture in a reasonably clean room and protection of components and products from contamination should suffice
E) If A-D is followed, chemical or particulate testing of the air coming out of the breathing circuit should not be necessary

3. Hazard Mitigation
   A) Particulate matter: solid particles suspended in a gas- Particulate matter emissions are not of significant concern if the manufacturing process is adequately controlled as per the above criteria
   B) Volatile organic compound (VOC): organic compound whose boiling point is in the range of 50ºC to 260ºC- Risk of exposure to VOCs can be minimised through the appropriate choice of materials as set out in section 1
   C) Leachable substances (in condensate): chemical removed from the medical device by the action of water, other liquids or other gases related to the use of the medical device- insure a HME filter is used between the ventilator and breathing system.

Software Safety

Software in a high-risk device like RMVS will almost certainly have the capability to cause serious injury or death if risk control measures are not adequately implemented. See appendix C for details of minimal necessary risk control measures.

Miscellaneous

1. Must be reliable. RMVS must be capable of continuous operation (100% duty cycle) for 14 days.
2. Should be capable of operation continuously for more than 14 days. The expected durability must be specified.
3. Could be floor standing.
4. Could be small and light enough to mount on patient bed with orientation independent functioning.
5. Should be as robust as possible. For example, it may be dropped from bed height to floor.
6. It must be intuitive to use for qualified medical personnel, but these may not be specialists in ventilator use.
   a. Must not require more than 30 minutes training for a doctor with some experience of ventilator use.
   b. Must include Instructions for Use.

c. Instructions for use should be built into the labelling of the ventilator, e.g. with ‘connect this to wall’ etc.

d. Must include clear labelling of all critical functions and controls using standard terms, pictograms and colours that will be readily recognised by UK healthcare staff.

7. Must have transparent design, supply chain, manufacture, quality assurance and testing processes that are of sufficient quality to enable MHRA officials to deem appropriate for usage in exceptional circumstances.

8. Must not be excessively cumbersome so that it would impede hospital operations or prevent easy movement within hospital premises.

9. Must be made from materials and parts readily available in the UK supply chain (anticipating increasing global restrictions on freight movement).

10. Standards – there are many standards that exist in this area. Below is a list of the most relevant ones. They are not formal regulatory requirements, but many are harmonised against regulatory requirements. Consider them as helpful advisory standards for now. MHRA will lead an exercise to define which can be ‘safely’ relaxed for this emergency situation.

a. BS EN 794-3:1998 +A2:2009 Particular requirements for emergency and transport ventilators

b. ISO 10651-3:1997 Lung Ventilators for Medical Use - Emergency and Transport

c. BS ISO 80601-2-84:2018 Medical electrical equipment. Part 2-84. Particular requirements for basic safety and essential performance of emergency and transport ventilators – especially the parts on ‘patient gas pathway’ safety (very similar to IEC 60601)

d. ISO 80601-2-12:2020 Medical electrical equipment — Part 2-12: Particular requirements for basic safety and essential performance of critical care ventilators

e. BS ISO 19223:2019 Lung ventilators and related equipment. Vocabulary and semantics

Testing

1. It is accepted that full demonstration of compliance to ISO 80601-2-12:2020 is unrealistic in the time frame required for development. Nevertheless, compliance with the essential safety standards must be demonstrated for patient safety.

2. It is not anticipated that devices will be CE marked and approval by the MHRA will be through the “Exceptional use of non-CE marked medical devices” route (https://www.gov.uk/guidance/exceptional-use-of-non-ce-marked-medical-devices)

3. When the current emergency has passed these devices will NOT be usable for routine care unless they have been CE marked through the Medical Device Regulations. The device must display a prominent indelible label to this effect.

4. Usability testing at both prototype and final production stages will be required. This should be done as a short Formative Usability Test to ISO62366 (this can be done in a day) in a realistic environment if possible. The user will be wearing complex protective clothing which includes: Eye goggles (in addition to spectacles if worn), Face shield, Plastic apron, Surgical gown, Two layers of gloves, usually nitrile non-handed small, medium, large variants, Gloves are donned in layers and sticky taped onto sleeves of gown in between layers

5. The user must be able to instantly see the settings selected and be able to easily operate all controls while dressed in protective gear. They may be required to remain so clothed and operating the ventilator for a number of hours without breaks.

Unknown Issues

1. How much oxygen is consumed by RVMS. Preference is given to designs consuming the least oxygen, but a mixture of designs is needed, and some designs fundamentally limit the minimum oxygen flow.
    a. Absolute minimum oxygen requirement is the human consumption of about 250 ml/min in a healthy person but upto 500 ml/min in severe sepsis. However, achieving this is only possible if certain breathing system designs are used and 'driving' gas is air.
        i. Specifically, would have to use circle breathing system with active CO_2 absorption. Is sufficient soda lime available?
    b. If consumption in the range 1-6 l/min is acceptable then a wider range of designs is possible, but some very basic designs are not.
    c. If consumption in the range 10l/min is acceptable then any possible design can be considered.
2. Is there any need to consider running from only low-pressure oxygen e.g. from a concentrator? This makes design more complex.
3. How plentiful is the supply of syringe drivers and drugs for sedation?
    a. If limited, then a vaporiser could be used to vaporise Isoflurane for sedation.
    b. This would need certain breathing system designs, mandatory AGSS and a supply of vaporisers.
4. If monitoring can be done by another machine it could be left out of the ventilator, but essential parameters must be available to the clinician.

Appendix A:

Clinical guidelines for infection control of ventilator

This appendix is intended to guide developers on the likely clinical guidance that users will be working to. It is not actual guidance for users of such equipment.

Ventilator equipment is kept in close proximity to patients, and while the ventilator itself does not come into direct or invasive contact with the patient, it will be physically connected to equipment that does. Therefore, it is important that all proposed ventilators can be thoroughly decontaminated by health care professionals in the health care setting. The process for how this is carried out and guidance on design factors to be considered are detailed below.

Where possible the process for cleaning devices should be intuitive, however documentation for the correct method of decontamination should be detailed in the instructions for use. Preferably all components into direct contact with the patient's breath will be disposable, where this is not possible the process for sterilising reusable components should be detailed in the instructions for use. All information in the instructions for use should be presented as described in ISO 17664:2017 Processing of health care products.

The external surfaces surface of the device will need to be regularly decontaminated, once every 24 hours minimum for multi day single patient use, and between each individual patient use. This decontamination will be carried out by a nurse or other health care professional, using either a single use disinfectant wipe or a liquid disinfectant applied with a disposable cloth. All external surfaces of the device will be cleaned, including screens, buttons and, control switches. For this reason, it is important that all devices are designed in a way to prevent the ingress of fluid through the casing. All screens should also be made of a material that that will not cloud or smear after disinfection.

To prevent contamination of the patient gas pathway, and internal components, the device should be designed to use separately sourced HMEF-bacterial-viral filter between the machine and patient. These filters will be place at the exhalation and inspiration ports of the device I.E. ports for breath in and out. The filters are bulky, measuring approximately 10CM each on average and designs should be made with adequate spacing for both filters on dual port devices.

To prevent dust and other contaminates from entering the internal components of the device, all inlets and outlets to room air should also have a filter in place. Instructions on the method of changing these filters, as well as the frequency that change is required, should be detailed in the device's instructions for use.

If the option of using a hot water humidifier is also included in the design, methods of preventing fluid ingress through inhalation and exhalation ports should be considered.

Appendix B

Testing protocol for final validation of safety and performance of RVMS.

This testing protocol will be used by the independent testing facility advising MHRA on the suitability of RVMS. The protocol may have to be varied at the discretion of the tester. It is here for advisory purposes to explain the likely testing that RVMS will undergo.

General

- Enclosures of ventilators shall provide at least an IP22 degree of protection to the harmful ingress of water. It must experience no harmful effects when the enclosure is tilted at an angle up to 15^{o} from its normal position and exposed to dripping water for a duration of 10 minutes and a water flow equivalent to 3mm rainfall per minute.
- All external surfaces must be cleanable in the likely event that they get respiratory secretions or blood splatter on them. Cleaning would be by healthcare workers manually wiping using an approved surface wipe with disinfectant or cloths and approved surface cleaning liquid.
- Mains powered ventilators must be 240V and PAT tested to the adapted IEC 60601, IEC 62353 standards and have an alarm that sounds when power fails.
- Ventilators which rely on mains power for operation must have 20 minutes back up battery power available in case of mains electricity failure.
- All parts of the breathing system which can, or could, come into contact with the patient's expired gas must be either single patient use only and labelled with an ISO 7000-1051 mark or the words "Do not re-use". Or must be able to be decontaminated between patients.
- All components of the gas pathways in the breathing system must use materials which have been evaluated for biocompatibility according to ISO 18562-1:2017 and shall not contain phthalates or other substances, which are classified as endocrine disrupting, carcinogenic, mutagenic or toxic to reproduction, in a concentration that is above 0,1 % weight by weight of any article
- A ventilator and its parts, including applicable accessories shall have adequate mechanical strength when subjected to mechanical stress caused by normal use, pushing, impact, dropping and rough handling.
- If a connector is provided for the gas exhaust port, it shall be a 30 mm connector conforming with ISO 5356-1:2015.

Labelling

A clearly visible permanent label must be attached with the words "Follow Instructions for Use" accompanied by the following ISO 7010 compatible permanent labels: M002, M004, M009, M013 and M016.

A clearly visible permanent label with the words "Restricted device for use during COVID-19 pandemic, only to be used for emergency ventilation – any adverse incidents must be reported to MHRA." The size and font of the text on the labels should be appropriate to the size of the device.

Must include clear labelling of all critical functions and controls using standard terms, pictograms and colours that will be readily recognised by UK healthcare staff.

Breathing system inlets and outlets must be clearly marked with direction arrows. A clearly visible permanent label with the words “Manual Back Up Ventilation Must Be Available” in a minimum of 50 point text.

Must include clear marks or labels to indicate the default settings of 90-100% oxygen, 400mls tidal volume and / or inspiratory plateau pressure 35 cmH2O, 15 cmH2O PEEP, rate 20 breaths min^{-1}.

Pressurised gas input operated ventilators- Oxygen and / or Air

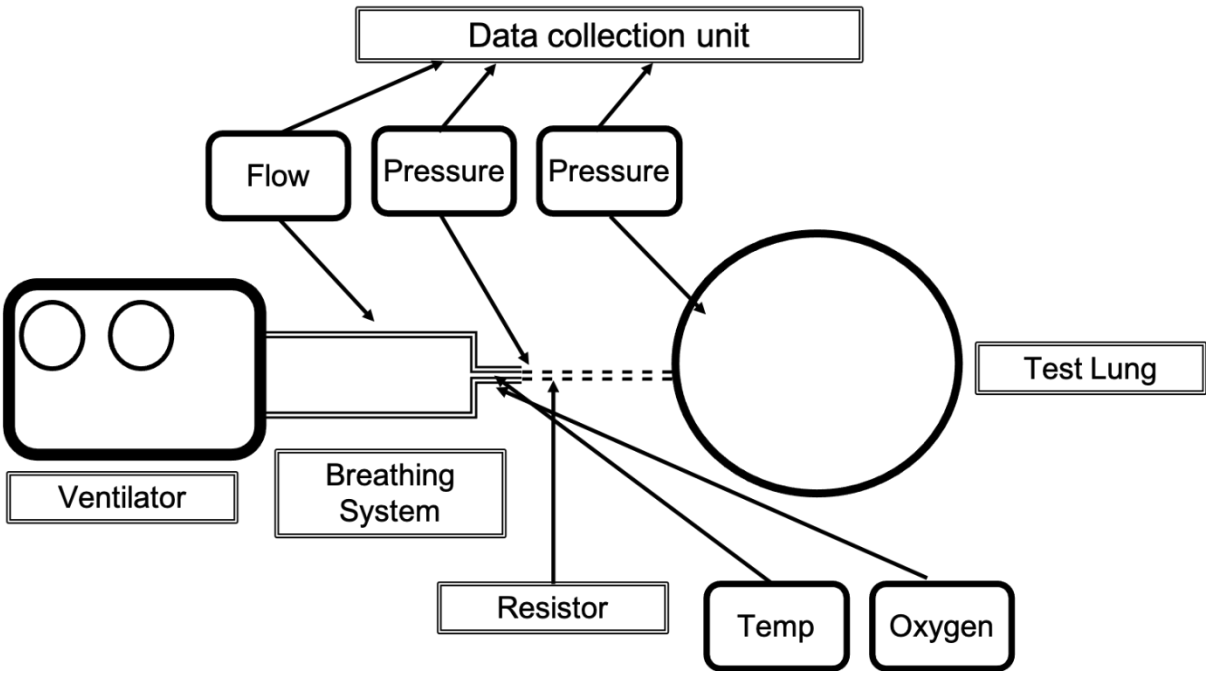
- If the ventilator is intended to be connected to a 4bar medical gas pipeline system using BS 5682:2015 compatible probes, then:
    - Oxygen consumption used to drive the ventilator shall not exceed 6 lpm averaged over 1 minute
    - Any transient input flowrate shall not exceed 200 lpm averaged over 3 s
    - Both measured at maximum tidal volume / inspiratory flow and rate settings
    - If transient high-flows (50 – 200 lpm) are used to drive the ventilator it should be marked as a “High-Flow Device”
    - It should only be connected to a pipeline installation designed using a diversity factor that allows for the indicated high flow at a specified number of terminal outlets, in order to avoid exceeding the pipeline design flow, thereby minimising the risk that the ventilator interferes with the operation of adjacent equipment
    - The inlets for pressurised gases into the ventilator must be marked with the gas name or chemical symbol and the rated gas pressure
    - For a ventilator with two or more high-pressure input ports (oxygen and medical air), a means shall be provided to limit reverse gas flowrate (leakage) and cross leakage from gas intake ports into the supply system of the same gas to a flowrate less than 100 ml/min in normal condition or single fault condition.
    - Each high-pressure input port shall be provided with a filter having a pore size less than or equal to 100 µm.

Ventilator test conditions

- Connected to gas supplies as specified for normal use
- Industrial grade oxygen and air may be substituted for the equivalent medical gas, as appropriate, unless otherwise stated.
- When using substitute gases, care should be taken to ensure that the test gases are oil-free and appropriately dry.
- If air can be used instead of oxygen without affecting performance this should be done to conserve medical oxygen supplies.
- Gas flowrate, volume and leakage are expressed as STPD apart from the breathing system which are expressed as BTPS.

Test Set Up

- Attach the ventilator via the intended breathing system to an adult test lung with variable compliance and resistance with an electronic ventilator tester.
- Attach pressure sensor at the connection of the breathing system and the test lung with a 10-90% rise time of ≤ 10 ms.
- Attach pressure sensor to the test lung after the adjustable flow resistor with a 10-90% rise time of ≤ 10 ms. (to measure PEEP)
- Attach a flow sensor between the breathing system and the test lung with a 10-90% rise time of ≤ 10 ms.
- Place an oxygen sensor (0-100 % ± 1%) in the inspiratory limb of the breathing system.
- (Optional) Place a temperature sensor between the breathing system and the test lung (0-50 oC ± 0.5 oC
- Data acquisition from sensors to be ≥ 200 samples s-1.



Volume Controlled Ventilation Test (Compliance)

Test No	Test Lung Compliance ml/cmH_2O ± 10%	Test Lung Resistance cmH_2O/l/s ± 10%	Tidal Volume mls	Rate Min $^{-1}$	I:E	O_2 %	PEEP
1	50	5	500	20	1:2	50-60	5
2	50	5	500	20	1:2	90-100	5
3	50	5	500	12	1:2	50-60	5
4	50	5	500	12	1:2	90-100	5
5	50	5	500	20	1:2	50-60	10
6	50	5	500	20	1:2	90-100	10
7	50	5	500	12	1:2	50-60	10
8	50	5	500	12	1:2	90-100	10
9	50	5	500	20	1:2	50-60	15
10	50	5	500	20	1:2	90-100	15
11	50	5	500	12	1:2	50-60	15
12	50	5	500	12	1:2	90-100	15
13	20	5	500	20	1:2	50-60	5
14	20	5	500	20	1:2	90-100	5
15	20	5	500	12	1:2	50-60	5
16	20	5	500	12	1:2	90-100	5
17	20	5	500	20	1:2	50-60	10
18	20	5	500	20	1:2	90-100	10
19	20	5	500	12	1:2	50-60	10
20	20	5	500	20	1:2	50-60	10
21	20	5	500	20	1:2	50-60	15
22	20	5	500	20	1:2	90-100	15
23	20	5	500	12	1:2	50-60	15
24	20	5	500	20	1:2	50-60	15
25	10	5	500	20	1:2	50-60	5
26	10	5	500	20	1:2	90-100	5
27	10	5	500	12	1:2	50-60	5
28	10	5	500	12	1:2	90-100	5
29	10	5	500	20	1:2	50-60	10
30	10	5	500	20	1:2	90-100	10
31	10	5	500	12	1:2	50-60	10
32	10	5	500	20	1:2	50-60	10
33	10	5	500	20	1:2	50-60	15
34	10	5	500	20	1:2	90-100	15
35	10	5	500	12	1:2	50-60	15
36	10	5	500	20	1:2	50-60	15

Volume Controlled Ventilation Test (Resistance)

Test No	Test Lung Compliance ml/cmH_2O ± 10%	Test Lung Resistance cmH_2O/l/s ± 10%	Tidal Volume mls	Rate Min $^{-1}$	I:E	O_2 %	PEEP
1	50	5	500	20	1:2	50-60	5
2	50	5	500	20	1:2	90-100	5
3	50	5	500	12	1:2	50-60	5
4	50	5	500	12	1:2	90-100	5
5	50	5	500	20	1:2	50-60	10
6	50	5	500	20	1:2	90-100	10
7	50	5	500	12	1:2	50-60	10
8	50	5	500	12	1:2	90-100	10
9	50	5	500	20	1:2	50-60	15
10	50	5	500	20	1:2	90-100	15
11	50	5	500	12	1:2	50-60	15
12	50	5	500	12	1:2	90-100	15
13	20	20	500	20	1:2	50-60	5
14	20	20	500	20	1:2	90-100	5
15	20	20	500	12	1:2	50-60	5
16	20	20	500	12	1:2	90-100	5
17	20	20	500	20	1:2	50-60	10
18	20	20	500	20	1:2	90-100	10
19	20	20	500	12	1:2	50-60	10
20	20	20	500	20	1:2	50-60	10
21	20	20	500	20	1:2	50-60	15
22	20	20	500	20	1:2	90-100	15
23	20	20	500	12	1:2	50-60	15
24	20	20	500	20	1:2	50-60	15
25	10	50	500	20	1:2	50-60	5
26	10	50	500	20	1:2	90-100	5
27	10	50	500	12	1:2	50-60	5
28	10	50	500	12	1:2	90-100	5
29	10	50	500	20	1:2	50-60	10
30	10	50	500	20	1:2	90-100	10
31	10	50	500	12	1:2	50-60	10
32	10	50	500	20	1:2	50-60	10
33	10	50	500	20	1:2	50-60	15
34	10	50	500	20	1:2	90-100	15
35	10	50	500	12	1:2	50-60	15
36	10	50	500	20	1:2	50-60	15

Volume Controlled Ventilation Test (Tidal Volume)

Test No	Test Lung Compliance ml/cmH_2O ± 10%	Test Lung Resistance cmH_2O/l/s ± 10%	Tidal Volume mls	Rate Min $^{-1}$	I:E	O_2 %	PEEP
1	50	5	300	20	1:2	50-60	5
2	50	5	300	20	1:2	90-100	5
3	50	5	300	12	1:2	50-60	5
4	50	5	300	12	1:2	90-100	5
5	50	5	300	20	1:2	50-60	10
6	50	5	300	20	1:2	90-100	10
7	50	5	300	12	1:2	50-60	10
8	50	5	300	12	1:2	90-100	10
9	50	5	300	20	1:2	50-60	15
10	50	5	300	20	1:2	90-100	15
11	50	5	300	12	1:2	50-60	15
12	50	5	300	12	1:2	90-100	15
13	20	20	300	20	1:2	50-60	5
14	20	20	300	20	1:2	90-100	5
15	20	20	300	12	1:2	50-60	5
16	20	20	300	12	1:2	90-100	5
17	20	20	300	20	1:2	50-60	10
18	20	20	300	20	1:2	90-100	10
19	20	20	300	12	1:2	50-60	10
20	20	20	300	20	1:2	50-60	10
21	20	20	300	20	1:2	50-60	15
22	20	20	300	20	1:2	90-100	15
23	20	20	300	12	1:2	50-60	15
24	20	20	300	20	1:2	50-60	15
25	10	50	300	20	1:2	50-60	5
26	10	50	300	20	1:2	90-100	5
27	10	50	300	12	1:2	50-60	5
28	10	50	300	12	1:2	90-100	5
29	10	50	300	20	1:2	50-60	10
30	10	50	300	20	1:2	90-100	10
31	10	50	300	12	1:2	50-60	10
32	10	50	300	20	1:2	50-60	10
33	10	50	300	20	1:2	50-60	15
34	10	50	300	20	1:2	90-100	15
35	10	50	300	12	1:2	50-60	15
36	10	50	300	20	1:2	50-60	15

Pressure Controlled Ventilation Test (15 cmH2O)

Test No	Test Lung Compliance ml/cmH_2O ± 10%	Test Lung Resistance cmH_2O/l/s ± 10%	Plateau Pressure cmH_2O	Rate Min $^{-1}$	I:E	O_2 %	PEEP
1	50	5	15	20	1:2	50-60	5
2	50	5	15	20	1:2	90-100	5
3	50	5	15	12	1:2	50-60	5
4	50	5	15	12	1:2	90-100	5
5	50	5	15	20	1:2	50-60	10
6	50	5	15	20	1:2	90-100	10
7	50	5	15	12	1:2	50-60	10
8	50	5	15	12	1:2	90-100	10
9	50	5	15	20	1:2	50-60	15
10	50	5	15	20	1:2	90-100	15
11	50	5	15	12	1:2	50-60	15
12	50	5	15	12	1:2	90-100	15
13	20	20	15	20	1:2	50-60	5
14	20	20	15	20	1:2	90-100	5
15	20	20	15	12	1:2	50-60	5
16	20	20	15	12	1:2	90-100	5
17	20	20	15	20	1:2	50-60	10
18	20	20	15	20	1:2	90-100	10
19	20	20	15	12	1:2	50-60	10
20	20	20	15	20	1:2	50-60	10
21	20	20	15	20	1:2	50-60	15
22	20	20	15	20	1:2	90-100	15
23	20	20	15	12	1:2	50-60	15
24	20	20	15	20	1:2	50-60	15
25	10	50	15	20	1:2	50-60	5
26	10	50	15	20	1:2	90-100	5
27	10	50	15	12	1:2	50-60	5
28	10	50	15	12	1:2	90-100	5
29	10	50	15	20	1:2	50-60	10

30	10	50	15	20	1:2	90-100	10
31	10	50	15	12	1:2	50-60	10
32	10	50	15	20	1:2	50-60	10
33	10	50	15	20	1:2	50-60	15
34	10	50	15	20	1:2	90-100	15
35	10	50	15	12	1:2	50-60	15
36	10	50	15	20	1:2	50-60	15

Pressure Controlled Ventilation Test (30 cmH2O)

Test No	Test Lung Compliance ml/cmH_2O ± 10%	Test Lung Resistance cmH_2O/l/s ± 10%	Plateau Pressure cmH_2O	Rate Min $^{-1}$	I:E	O_2 %	PEEP
1	50	5	30	20	1:2	50-60	5
2	50	5	30	20	1:2	90-100	5
3	50	5	30	12	1:2	50-60	5
4	50	5	30	12	1:2	90-100	5
5	50	5	30	20	1:2	50-60	10
6	50	5	30	20	1:2	90-100	10
7	50	5	30	12	1:2	50-60	10
8	50	5	30	12	1:2	90-100	10
9	50	5	30	20	1:2	50-60	15
10	50	5	30	20	1:2	90-100	15
11	50	5	30	12	1:2	50-60	15
12	50	5	30	12	1:2	90-100	15
13	20	20	30	20	1:2	50-60	5
14	20	20	30	20	1:2	90-100	5
15	20	20	30	12	1:2	50-60	5
16	20	20	30	12	1:2	90-100	5
17	20	20	30	20	1:2	50-60	10
18	20	20	30	20	1:2	90-100	10
19	20	20	30	12	1:2	50-60	10
20	20	20	30	20	1:2	50-60	10
21	20	20	30	20	1:2	50-60	15
22	20	20	30	20	1:2	90-100	15
23	20	20	30	12	1:2	50-60	15
24	20	20	30	20	1:2	50-60	15
25	10	50	30	20	1:2	50-60	5
26	10	50	30	20	1:2	90-100	5
27	10	50	30	12	1:2	50-60	5
28	10	50	30	12	1:2	90-100	5
29	10	50	30	20	1:2	50-60	10

30	10	50	30	20	1:2	90-100	10
31	10	50	30	12	1:2	50-60	10
32	10	50	30	20	1:2	50-60	10
33	10	50	30	20	1:2	50-60	15
34	10	50	30	20	1:2	90-100	15
35	10	50	30	12	1:2	50-60	15
36	10	50	30	20	1:2	50-60	15

Acceptable Performance

- Under steady-state conditions, the indicated airway pressure shall be accurate to within ±(2 +(4 % of the actual reading)) cmH2O.
- The accuracy of measurement of expired volumes greater than 50 ml shall be within ±(4,0 +(15 % of the actual volume expired through the patient-connection port)) ml.
- Oxygen concentrations will be ± 5 % of the set value.
- Disconnect alarm will sound within 3 seconds of disconnection

Pressure Relief Tests

- Set ventilator to 250 – 300 mls tidal volume or 30 cmH2O Inspiratory pressure with 10 cmH2O PEEP at a rate of 10 min -1.
- Set maximum pressure level and alarm to 35 cmH20.
- Compress test lung until pressure alarms and ventilator stoops inflating and alarms
- Record maximum pressure reached.
- Set pressure to maximum value or 70 cmH20, whichever is lower.
- Detach test lung and occlude patient end of breathing system.
- Confirm that pressure in system does not exceed 80 cmH2O and that alarm is activated.

Closed Suctioning Test

- Set ventilator to 250 – 300 mls tidal volume or 30 cmH2O Inspiratory pressure with 10 cmH2O PEEP at a rate of 10 min -1.
- Attach intended breathing system to ventilator.
- Set maximum vacuum to -200 cmH20 when inlet occluded.
- Open suction flow control to a free suction flow of 30 lpm.
- Attach a closed suction system with a 14 Fr catheter fully retracted (important in some systems to produce a gas tight seal)
- Attach a test lung with a compliance of 10ml / cmH2O (+/- 10%) to the patient connection port of the closed suction system
- Advance suction catheter into test lung
- Operate suction control on closed suction system for 3 seconds whilst withdrawing
- Confirm PEEP does not drop below 5 cmH2O
- Retract suction catheter fully. Repeat 5 times
- Repeat but increase suction time to 30 seconds, (PEEP will be lost, and alarms may sound)
- Confirm ventilator returns to default settings when suction is stopped

EMC Testing (TBC)

- Must comply with IEC 60601-1-2:2014, Medical electrical equipment — Part 1-2: General requirements for basic safety and essential performance — Collateral Standard: Electromagnetic disturbances — Requirements and tests

Sound Levels

- TBC

Appendix C

Software development requirements for a Rapidly Manufactured Ventilator System.

The authoritative standards for the development of software for medical devices are BS EN 62304:2006+A1:2015 Medical device software — Software life-cycle processes and BS EN ISO 14971:2012 Medical Devices – Application of risk management to medical devices. Where possible software for a Rapidly Manufactured Ventilator System should be developed in a facility that has experience of developing software using these standards.

A Rapidly Manufactured Ventilator System incorporating software is likely to be a high-risk device that will almost certainly, before the implementation of software risk control measures (RCMs), have the capability to cause serious injury or death. Because it is likely that the software will be developed to an accelerated life cycle it is essential that the following principles are adhered to:

1. The software is developed under strict process control using a quality management system, ideally BS EN ISO 13485 or BS EN ISO 9001.
2. A process is followed to determine the risks arising from the operation of the software and to mitigate those risks. This is most easily done by the application of BS EN ISO 14971.
3. A software development process is followed to achieve a low probability of failure of the software in use. This is most easily done by the appropriate application of BS EN 62304 based on the risk management process in 2 above.
4. Less emphasis need be placed on the requirements of BS EN ISO 62304 software post-production monitoring and maintenance processes.

The minimum steps that must be adhered to are as follows.

1. The software development must be planned
2. The system requirements specifications must be translated into software requirements specifications.
3. There must be enough software architecture and software design to enable the risks arising from the use of the software to be determined.
4. The risks arising from the operation of the software must be determined and the risk control measures (RCMs) for these risks must be translated into software requirements. Special attention must be paid to any software of unknown provenance or commercial off the shelf software incorporated into the device.
5. The implementation and effectiveness of the RCMs must be verified and validated.
6. The verification and validation of the software must be planned and reported on.
7. The outputs of the software must be reviewed against the software requirements prior to the release of the software for clinical use.

MHRA will review that the software has been developed under satisfactory control and is safe and effective before use. At least the following artefacts should be produced to aid this review:

1. Software Development plan.
2. System and software requirements specifications.
3. Appropriate software architecture and software design documents.
4. A risk management plan and report.
5. Software verification and validation plans and reports.
6. A software release note.