Implementation of Powered Air-Purifying Respirator (PAPR) in the COVID-19 Pandemic Situation

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When the COVID-19 outbreak arrives in the beginning of 2020, the shortage of PAPRs becomes a critical issue. Many hospitals do not procure the PAPRs because there is usually no need of using it. Demanding of the PAPRs is soaring up urgently, however, the commercial availability is in short.

PAPRs are needed to provide the protection safety for the medical staffs. The paper proposed the principle design concepts of a PAPR, however, with the pandemic situation, many limitations have been imposed. The design has to be simple but is able to accommodate the need of being the personal protection. The design does not intend to replace the commercially available products in the market but must have all the basic features needed for the protection. The limitations of the product are clearly stated.

Safety and reliability are the two critical parts in the design. The necessary tests have also been proposed in this paper. The testing does not only guarantee the quality of the product, but it also creates the confidence for the users.

This design has been implemented and tried by medical staffs. At the time of publishing, 500 sets have been distributed over Thailand where the PAPRs are in need.

Keywords: COVID19, PAPR, Personal Protective Equipment

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Background

Beginning of 2020, the world is facing the COVID-19 outbreak. The virus spreads out quickly. Most medical units are not prepared for this pandemic situation. The shortage of many medical equipment becomes critical. PAPR is one of the personal protective equipment (PPE) that is in the priority list. The unit is to protect the medical staffs. The procurement of such equipment becomes difficult due to the lack of supplies and budgets. Many medical units have to operate without the proper protection equipment for their staffs.

We have proposed a design of PAPR to be used in this circumstance. After gathering the necessary features from the real users, we start the design. Not only from the user-requested features, but also some of the essential foundation from the standard on respiratory protective devices as per the EN12941,[1] have already been analyzed for any possible suitability to adapt. This design is not intended to be comparable to the commercially available products[2,3]. Many features are not prioritized for building the product at this moment. The lack of those features gives the limitation of the product. Prior to use, it is necessary to keep the users informed and understood these limitations clearly for their own safety.

Safety and reliability are the two crucial parts in the design. We also propose the necessary tests needed to be done to guarantee the quality of the end-products.

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Those tests are not intended to substitute the tests in EN12941. Due to time constrain and fast-paced scenarios, the tests we have conducted are designed to expedite the process while still keeping the basic principle of PAPR. The testing is the critical parts as this equipment which is used for the safety of the users. The testing is not only for the quality of the products but is also for the confidence of the end users.

With this pandemic situation, hardware and other supplies are in disruption as well. The shortage of parts is without doubt. Most parts chosen in the design are available locally, Thailand. To increase the reliability of the designed unit and to shorten the testing process of the end product, any components that are available in the market or have been earlier used by other application are mostly picked up. The implementation of the new part or electronic circuit is also avoided. The design is kept simple but is able to accommodate the need of being the personal protection equipment.

Next the overall system design is given. Then the design of each part is given in details. The tests are listed and the test results are given as a reference.

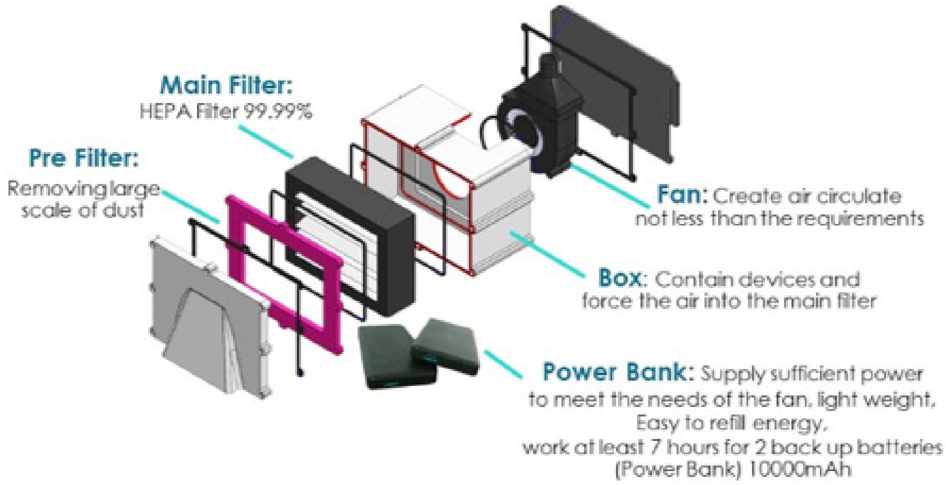
Overall System Design

PAPR composes of three portions: purifier, breathing hose and hood. Inside the purifier, the atmospheric air is drawn through the filter by the suction action of a fan. The filtered air is now clean, then, being pushed out to the air outlet. The clean air is conducted to the hood through the breathing hose. With the high enough air flow and small leak from the hood, the pressure inside the hood can be maintained positive. The positive pressure inside the hood will protect the dirty air from outside the hood to come in.

Picture 1 The components of PAPR.

The required air flowrate in most documents is at least 170 liter per minute. The hood has to fit the body, especially around the neck or the face, such that the amount of leak is minimum, but not air-tight. Pressure inside the hood is supposed to keep relatively positive comparing to the ambient at all time regardless of the wearer's breathing pattern.

The purifier composes of 5 main components: case, fan, main filter, pre-filter and power supply. The fan builds up the air pressure to be high enough to force the air to flow from outside the case passing through both filters before sending out the clean air to the breathing hose. The case plays the critical part of the design. It is not only fitting all components together, but also forcing the air to properly flow in the designated path.



Picture 2 The components of the purifier.

Components

3.1 Main filter

The main filter is the HEPA filter. The filter is commercially available in the market for clean room applications. We request the manufacturer customize the size to fit in our portable unit.

We are choosing the H14-class filter for a reasonable air purifying capability. At the designed flowrate, the filter filters out the 0.3μm particle out by 99.995%. The filtering capability depends on the flowrate. The higher the flow, the more particle penetration. The chosen filter has the physical dimensions of 160*120*45 mm^3 giving the filter media surface around 0.33 m^2. It has the guaranteed filtering efficiency of 99.995% up to 340 liter per minutes (twice the required flowrate). To improve margin of error, more than enough air flow rate is opted since we do not incorporate the flow sensor feedback system to automatically adjust the flowrate. Adding the flow sensor and the electronic controller would definitely require more time-to-market due to the part acquisition and reliability test. In certain conditions, the flowrate can be increased when there is lower air resistant in the downstream route i.e. chamber (case), the breathing hose and the hood.

If the flowrate is higher than 340 liter/minute, the particle penetration will increase. The filtering efficiency drops a bit and is guaranteed at 99.99%, till the flow rate reaches up to 450 liter/min. Beyond that, till 850 liter/min, the efficiency maintains at 99.9%.

The life-time of this filter depends on the quality of the ambient air the unit has been used. We expect it to be more than 6 months with the proper pre-filter. We recommend the user replace the main filter every 3 months because there is no filter replacement indicator. Having the filter replacement indicator would require additional electronic circuit which we try to avoid.

3.2 Pre-Filter

The pre-filter is a thin layer of coarse filter to sieve out big particles and is situated upstream to the main filter. Preventing debris burden to the main filter by the action of pre-filter, in a long term, increases the life-span of the main filter.

This pre-filter will be changed or cleaned more often than the main filter. We recommend user clean it every day or replace it every week.

3.3 Case

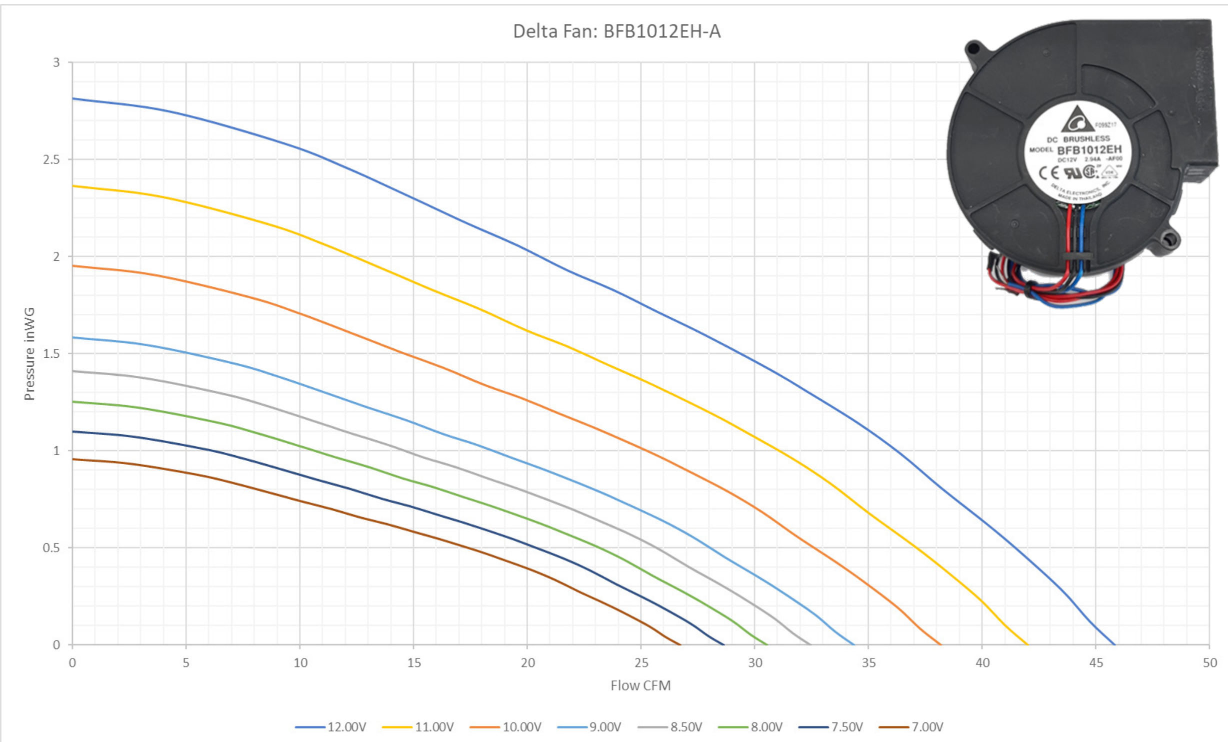
The case holds all components of the purifier together. It is also the component to control the direction of the airflow. It is a critical part of the design. It guarantees the atmospheric air to be only the air that passes thru the main filter. The case has to block any leak from the unwanted incoming air to mix with the clean air. The incoming (upstream to the fan) portion has to be securely sealed, that means, airtight is absolutely required. Leaking from the outgoing portion (downstream to the fan) is less critical because the air pressure is relatively positive to the ambient. Even there are some leaks in the outgoing portion, the air will leak out. There is no dirty air getting into the system.

The case is also directing the airflow from the open area on the back to the air outlet that fits with the breathing hose. This directing causes an amount of pressure drop. The design of the case, then, guides the fan selection.

3.4 Fan

The fan is a battery-powered electro-mechanical device to force the air flow from the open area on the back of the purifier to the hood. The centrifugal fan is suitable for this application. The expected flow rate is at least 170 liter per minute. We select the fan Model# BFB1012EH-A from Delta Electronics (Thailand) PCL. who has the manufacturing plant in Thailand. The model has been used in many electronic equipment, so the reliability of the fan is guaranteed.

In order to achieve the determined flow rate and to maintain high enough pressure to compensate pressure drop within other components, the fan has to be selected properly based on the fan characteristic curve. The pressure drop can be found in any place where there is resistance for example, in the filter, the shape of the case and in the breathing hose.



Picture 3 The fan characteristic curve.

The fan characteristics curve from the datasheet [4] is estimated for different supply voltages. The permissible supply voltage of the fan ranges from 7.0V to 12.6V. We can adjust the voltage to control the proper operating condition i.e. the flowrate and the pressure.

3.5 Power Supply

The power supply must contain enough energy to provide at least 4 hours continuous operation. The unit consumes approximately 7W-12W of power. The fan requires the voltage in the range of 7V to 12V. The voltage on the implementation is around 7.5V.

There is not only the limitation of the available batteries in the market, but the battery management system and the charging system are also required. Both battery management system and the charging system need extra time to establish, to test and to produce.

We decide to use the power bank which is widely available in the market and the end-users would be familiar with. Most power banks come with the built-in battery management system. By choosing the power bank as the power source, the charger is easily found. The disadvantage is the inability to directly check the battery capacity from our unit but this reduces the development-production time and allows the users to use something they have and are used to.

Most of the power banks provide only 5V 1A. To supply enough voltage to the unit, we prefer to use two power banks together in series to obtain 10V 1A power supply. Diodes are used to adjust the voltage to fit the requirement, thus certain amount of heat production is expected. With this design, two power banks of 10,000mA each would provide more than 7 hours of continuous operation.

3.6 Breathing hose

The breathing hose is the component to conduct the clean air from the purifier to the hood. Under normal usage, the hose has to resist collapse, kink resistance. Couplings, connecting the hose with the hood and the hose with the purifier, have to be chosen such that the air leak is minimal. The couplings have to be strong enough to guarantee the secured connection to prevent inadvertent dislodging during the operation of the unit.

3.7 Hood

The hood has to be light-weighted and the materials are of the medical requirement for protective clothing. The distal end of the breathing hose is connecting to the hood near the top, making the airflow blowing around at the front area. Multiple requests from the users to tailor made some characteristics to meet their specific needs have been raised and this has been contributed to major changes of the product since its prototype. For example, the front cover needs to be clear without distortion and glaring for better optical quality, whereas scratch resistance is another property to be considered. Joining of pieces of the material need to be properly sealed seam. The hood internal space is somewhat to be spacious enough to accommodate the wearer's optical gears.

The air leak out of the hood through the neck region is common and expected, however, to keep inside pressure constant, the amount of leak can be controlled by tightening the hood collar to the body. If the leak is too high, the pressure inside the hood drops. Users should test the pressure to guarantee the optimal positive pressure at all time specially when they breathe in.

Tests

The nature of producing and using the safety equipment is to have proper testing. The tests described in this section are primarily necessary to guarantee the operation of the unit to fit the usage. The tests are designed based on the requirement of the unit. There are three groups of testing: manufacturer test, third-party test and end-user test.

The manufacturer test is the set of tests that are required according to the specification of the product.

1) Flow Test is to check the flowrate generated by the unit. The flowrate indicates the amount of clean air transferred to the wearer. The higher flowrate would give comfort environment inside the hood. The flowrate is tested at the end of the breathing hose before connecting to hood. The minimum flow rate is 170 liter per minute. Our unit has been passed the requirement.

2) Pressure Test is to check the static pressure inside the hood while being worn by a wearer. The objective of having PAPR is to have positive pressure

inside the hood, so the dirty air outside the hood cannot get in. The pressure is crucial for PAPR utilization. The goal is to sustain positive pressure even the user breathes in.

3) Breathing Hose and Coupling Test is to guarantee the quality of the breathing hose and the couplings. The breathing hose has to be strong enough such that it will not collapse under the operation.

The third-party test is the set of tests to meet the requirement and to make the user be confident in using the unit. These tests are representing the critical features that directly impact the users. Using the third-parties intent to guarantee the users of the test results.

1) Leak Test is to guarantee that the air, delivered to the user, is clean enough. The atmospheric air has to pass thru the main filter to filter out unpleasant dirt. The leak of the dirty air will give the negative impact to the user. Regarding the purifier, since it is assembled from multiple pieces, air tight enclosure is seriously justified. When conducting the test, the whole purifier should be placed inside a testing environment as per the quality measurement standard. The Q&E International Co., Ltd., a clean room performance testing company in Thailand, is responsible for testing and verifying. We send all preliminary units (7 units) to have PAO (poly alpha olefin) test and all of them passes the test with the average of less than 0.01% leakage. Depicted in Picture 4.

Picture 4 The leak test on our first unit.

2) Filter Test is to guarantee the quality of the filter. The quality of the filter is the amount of dirt particle can be trapped inside the filter. Because we are using a standard HEPA filter. The filter manufacturer has obtained the certification to guarantee the quality of the filter.

3) Hood Test is checking the quality of the hood has enough protection against biological agents. This has been done by the manufacturer of the hood.

4) Other Test by the regulation of each region has to be done before deployment of the units. Each region has its own regulation on how to handle with this type of medical devices. Addition tests may be done to increase the confident of the user. Our unit has been verified by the Faculty of Medical Technology, Mahidol University (Viral spray test).

The end-user tests are considered simple for users to do prior to use. Wearers need to do these right before gearing it up.

1) Physical Check is to check physical appearance of the unit. In case there is any crack or break on the unit, the unit can easily be exposed to dirt air or cause a significant drop of the flowrate.

2) Pressure Check is to check the pressure inside the hood during wearing it on. There is a pressure gauge giving for the user to check the pressure. The pressure has to be positive even when the user is breathing. If the pressure is too low, there might be too much leak out of the hood. The hood needs to be tightened.

Conclusion

A simple design of the PAPR has been proposed. The design is to make the protecting equipment for medical staff. Due to the pandemic situation, the design is kept as simple as possible while maintaining the basic features of the PAPR. The availability of parts has been taken into account. The limitation of the design has been issued. At the time of publishing, there are 100 units being deployed. The next milestone is to deploy 4,000 units throughout the country.

We are now making the second generation. The hood has been improved to give comfort to the wearer. Some electronics are added to have the battery built-in.

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