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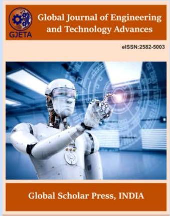

(Research Article)

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Construction of an innovative system for isolating and transporting people with infectious diseases

Valéria Miranda Campos Monteiro [1, 2, *], Sandro Pereira da Silva [2], Joelma Rezende Durão Pereira [2], Evandro Pereira da Silva [3] and Lincoln Cardoso Brandão [4]

[1] *Department of Physiotherapy, University Center of Lavras. Lavras, Minas Gerais, Brazil.*
[2] *Department of Engineering, Federal University of Lavras. Lavras, Minas Gerais, Brazil.*
[3] *Department of Engineering, University Center of Lavras. Lavras, Minas Gerais, Brazil.*
[4] *Department of Mechanical and Industrial Engineering, Federal University of São João Del-Rei. São João Del-Rei, Minas Gerais, Brazil.*

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Abstract

Objective: To propose the construction of an innovative system to isolate and transport people with infectious and contagious diseases with total safety to the physical integrity of both the health professionals involved in this activity and the patient himself. Material and Methods: The product was designed in TopSolid parametric design software, and its structure was manufactured with metallic plates, metalon, acrylic plates and a control system. Every automation system through pneumatics was made using pressure and flow controllers through the use of a PLC (programmable logic controller), thus allowing the insertion of medical protocols. The system allows air to exit the hermetic chamber (whether atmospheric and/or oxygen) sanitized, thus allowing a continuous flow with pressure and flow control without risk of infecting the external environment. Results: The results showed a great innovation that consisted of creating a proof of concept for use in hospitals, SAMUs, ambulances and aircraft, allowing safe isolation and transport for all involved. Conclusion: The innovative system for isolating and transporting people with infectious and contagious diseases proves to be effective for what was proposed, promoting technological innovations in the face of what already exists worldwide.

Keywords: Transport; Isolation; Infectious diseases; Biosecurity; Positive pressure

1. Introduction

An infectious disease is defined as one that is clinically evidenced and results from an infection. The term transmissible is used when the etiologic agent causing the disease is alive and transmissible. Therefore, every contagious disease is an infectious disease whose etiological agents reach healthy individuals through direct or indirect contact with infected individuals. Thus, when there are infectious diseases, sick individuals need to remain isolated during the period of transmissibility of the disease, in places and conditions that prevent direct or indirect transmission of the infectious agent, and, depending on the form of transmission, the diseases will require different types of isolation [1].

During the current COVID-19 pandemic between 2020 and 2021, following guidance to the world's population on the use of face protection masks, hand hygiene, avoiding crowds and closed environments, a slight drop in rates was observed of contamination. However, in addition to this new pandemic scenario, hospitals still need to meet their urgencies/emergencies, overloading the patient care system in the hospital environment.

* Corresponding author: Valéria Miranda Campos Monteiro

The health team involved in the front line of coping with COVID-19 is in a risk group for contamination, and according to Kuldeep et al. (2020) [2], due to the high transmissibility through direct contact or through the air via aerosols, these health professionals must follow a strict protocol of preventive measures with the constant use of personal protective equipment (PPE) to prevent infection. Therefore, Verlee et al. (2014) [3] report that patients requiring isolation in private rooms further negatively impact the system, as the exorbitant use of PPE leads to a high additional cost for the hospital.

Patients with infectious diseases, in addition to this isolation, also require short- or long-distance transport, often even before the treatment is defined or started. According to Schilling et al. (2009) [4], in Europe at that time, the need for a professional conduct that was common, together with an available infrastructure with the maximum support offered to the patient, accessible care and the minimum risk of secondary infections throughout the journey, was already identified of these transports regardless of distance.

In most hospitals, there is no availability of equipment to transport patients in isolation due to the risk of infection. This generates a need to protect other patients hospitalized for other illnesses, in addition to health professionals, especially in circulation areas and wards.

In 2020, Yousuf and collaborators [5] created a protocol for transporting infected patients and mentioned that safe transport is always challenging and dependent on numerous precautions ranging from training the hospital transport team, checklists, availability of suitable transport equipment and the duration of transport. Security is needed for the team involved, the patient himself and even the environment in which the patient was transported at the end of the journey.

Garibaldi et al. (2019) [6] state that many factors complicate the operational decision to evacuate patients with communicable diseases and report that the ventilated air in most modern aircraft cabins is sterilized during pressurization, but this does not happen before takeoff, which greatly increases the risk of disease transmission at that time.

The current outbreak caused by SARS-CoV-2 (COVID-19) was already expected by some specialists and, similar to previous outbreaks, should soon be contained, leading to reflection on the real current problem, which is how we are programming ourselves to contain the next epidemic./zoonotic CoV pandemic that is very likely to occur in the next 5 to 10 years or even sooner [2].

Faced with the real need to isolate and transport patients with infectious and contagious diseases, the huge worldwide shortage of isolation beds and the lack of efficient transport systems that seek to reduce the transmission of infection between patients and health professionals who work on the front line, a proof of concept will be built of a system capable of isolating and transporting patients with infectious diseases, having a high relevance for the world population and for the scientific community. Therefore, the objective of the present study is to build a proof of concept of an innovative system for isolating and transporting people with infectious and contagious diseases, aiming to guarantee the safety of the physical integrity of patients, health professionals, and all individuals involved.

2. Materials and methods

The innovative system for isolating and transporting people with infectious and contagious diseases was developed at the Advanced Manufacturing and Manufacturing Laboratories of the School of Engineering/Mechanical Engineering Nucleus of the Federal University of Lavras (UFLA) from June 2020 to November 2021.

Initially, the project was idealized in its conceptual phase by a brainstorm with the entire multidisciplinary team and then the process of creating the proof of concept took place through the segments of the steps planned for product development. As shown in Figure 1, the drawings during the conceptual design were made freehand on a clipboard and later transferred to parametric drawing.

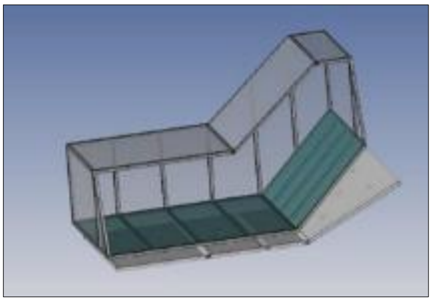

Figure 1 Parametric drawing. Source: From the author

According to Procópio and collaborators in 2021 [7], parametric design is a concept of how to organize a design process strategic in making the connection between the problem and the solution, being a type of open and dynamic representation that allows freedom of expression and your update at any time.

The electrical panel consisted of circuit breakers, 24v DC power supply, connection terminals and a programmable logic controller. Figure 2 shows an overview of the electrical panel.

Figure 2 PLC – programmable logic controller. It is digital electronic equipment with hardware and software compatible with industrial applications. Source: From the author (2021)

To automate all the system procedures, allowing the insertion and alteration of the medical protocols defined by the health team involved, a Schneider PLC - Programmable Logic Controller, model Zélio Sr2b121bd, 24v DC power supply, 8x24 VDC digital inputs, 4 analog inputs and outputs: 4x relay.

For oxygen and atmospheric air supply systems with pressure control and flow rate, pneumatic accessories, industrial and hospital filters and a fluid spray system were used, which will all be described in the figure below.

Figure 3 Industrial Filters. Mix of industrial filters containing SMC Condensate Separator Air Filter, model AMG150C-02BD; SMC 2-stage Submicron Air Filter, model AMH150C-02BD-T. Source: From the author (2021)

To ensure that the atmospheric air supply solution or pure oxygen is safely conditioned to the human being, a HEPA-type hospital filter was added to the end of the air inlet line, the same filter used in surgical and intensive care units. Figure 4 shows the HEPA filter and the fitting interface.

Figure 4 HEPA filter. BECARE brand hospital standard HEPA bacterial filter, dimensions 5x10x7 cm. Source: From the author (2021)

In addition to the pressure switch, a modular pressure controller was used for coarser pressure regulation. This controller was mounted on the input line of the isolation and transport system. As shown in Figure 5.

Figure 5 AR-B Series Modular Pressure Regulator - AR20-01BG-B and Flow Meter. ISE30A-01-N-LD series high precision digital pressure switch. Source: From the author (2021)

The supply of air, be it atmospheric, oxygen or a mixture of both, passes through a high-precision pressure controller.

For the adduction of pure oxygen, a high precision flow controller was considered in the pneumatic system. Figure 6 shows the flow switch and a set of redundantly connected ON/OFF valves.

Figure 6 Flow controller. PF2A series flow switch - PF2A710-01-67 supplied by SMC company, with high precision adjustments in the range of 0.1 l/min. ON/OFF electric valves. Process Directional Valves VX2 - VX210BA manufactured by SMC supplier, with ON/OFF type relay contact activation. This type of control valve was chosen so that the system could operate automatically and autonomously. Source: From the author (2021)

The air outlet system, in this case, potentially contaminated air that was inside the isolation and transport system, goes through a cleaning cycle composed of an ON/OFF valve and a flushing mixer of air and glycerin alcohol.

The two pneumatic components work in series, considering the control of the air output of the isolation system, passing first through the ON/OFF valve. In this case, to ensure always positive pressure inside the system and after its opening, the air flow passes through the mixer, considering microparticles of glycerinated alcohol in spraying to clean the air that will be expelled again into the atmosphere.

3. Results and discussion

In this context, the result of the project was the construction of the proof of concept of the innovative system for isolating and transporting people with infectious and contagious diseases capable of maintaining an internal atmosphere with flow and pressure control, continuous flow and exit of sanitized air to the external environment.

3.1. Building the proof of concept.

The construction process was first carried out using Metalon bars 30x30 mm with a thickness of 2 mm, as shown in Figure 7.

Figure 7 Initial construction: metal bars and metal sheets. Source: From the author (2021)

Because it is made of carbon steel, Metalon is highly resistant and easy to cut. The bars were structurally positioned, forming the skeleton of the insulation and transport system, with no joints. The connecting elements of the Metalon bars were executed by TIG welding (tungsten inert gas welding) to eliminate individual connectors, facilitating the sealing of the insulation and transport system, which will thus manage to remain hermetic. According to Geary in 2013 [8], the weld known as TIG is widely used in the industry precisely because it results in an extremely strong weld, free of defects, clean and with a great finish.

Then, with the use of metal plates, the lower part was closed, forming a permanent joint corresponding to the front of the patient's feet. At this moment of closing, a 45° angle of inclination of the head of the isolation system was also formed, which, according to medical protocols as mentioned by Jerre et al. and his collaborators in 2007 [9], is very important for good positioning of the patient, facilitating lung expansion and preventing worsening of the respiratory condition.

As shown in figures 8 and 9, the dimensions of the isolation and transport system for people with infectious diseases were validated.

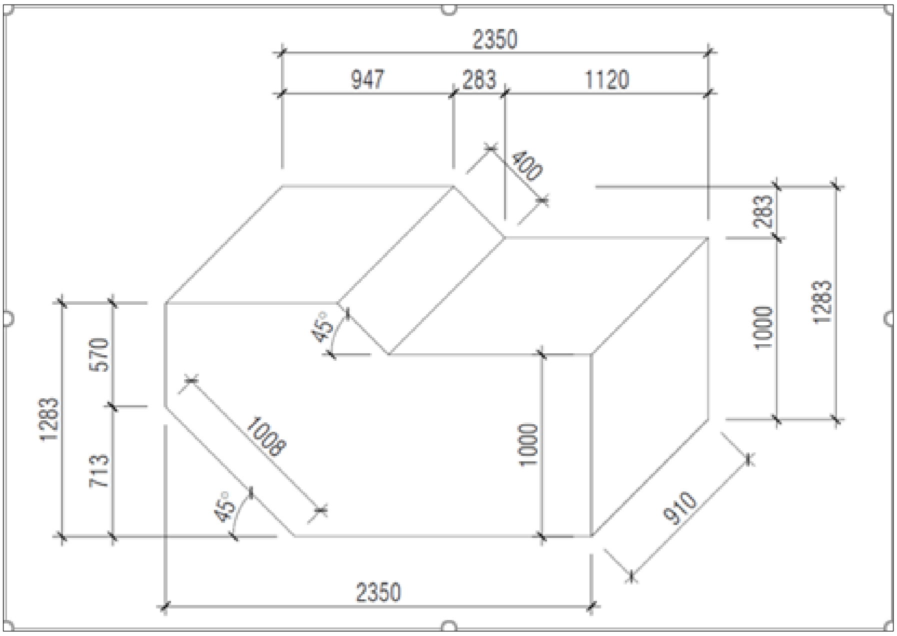

Figure 8 CAD design and dimensions of the insulation system. Source: From the author (2021)

Figure 9 Validation of the dimensions of the insulation system. Source: From the author (2021)

In this validation phase, the parameters that were determined using the Top Solid Software provided by the company Missler were confirmed.

The insulation system was built with sealing rubbers, as shown in Figure 10.

Figure 10 View of the acrylic and rubber sealing plates. Door view of the innovative insulation and transport system. Source: From the author (2021)

In this prototype phase, transparent acrylic plates were used, which fit perfectly, but it is suggested later to use polycarbonate, which has greater and better mechanical resistance. The transparent acrylic plates are on both the right and left sides and on the upper part of the system, and the acrylic seal was made with EVA rubber glued with a metal plate. EVA rubber was added to the entire edge of the side of the system that allows opening and was also located next to the door.

In the isolation and transport system for people with infectious diseases, sealing latches are installed. The locks are positioned close to the main areas where there are angles/curves and together in the same location in the system are the Ga 100 Folded Zinc-plated Tensor Fastening Clamp locks that, when closed, are compressed with the EVA fixed in the system, thus providing a perfect seal. This type of closure with latches makes it possible and provides the conditions for quickly opening the door to handle emergency cases such as cardiorespiratory arrest, for example, where you have to quickly access the patient.

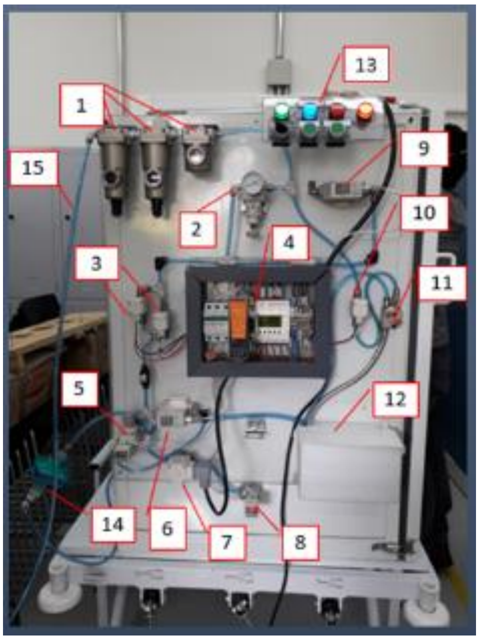

Figure 11 Detail of the control panel, where 1. Industrial standard filters (redundant and coalescing). 2. First pressure controller manometer. 3. Redundant ON/OFF valves. 4. PLC - Programmable logic controller, source, circuit breakers and connection terminals. 5. Second high precision pressure controller manometer. 6. High precision flow meter. 7. ON/OFF valve. 8. Pressure controller. 9. Flow controller. 10. ON/OFF valve. 11. Whirling system. 12. Container with 70% glycerinated alcohol. 13. Buttons that turn on/off and luminous identification of faults in the system. 14. Hepa filter (hospital standard). 15. Microtube

The isolation and transport system, developed hermetically, has a control panel in its lower part positioned for inserting and changing medical protocols when necessary. According to Rozenfeld et al. in 2006 [10], in the conceptual design phase, it is necessary to develop solutions for the function of the product, bringing functionality and making it easier for the user. The control panel items were detailed as shown in Figure 11.

3.2. System operation

The irrigation system represented through the typology, the flowchart and the pneumatic control circuit applied to the isolation and transport system for people with infectious diseases, as shown in Figures 12, 13 and 14, will be explained below.

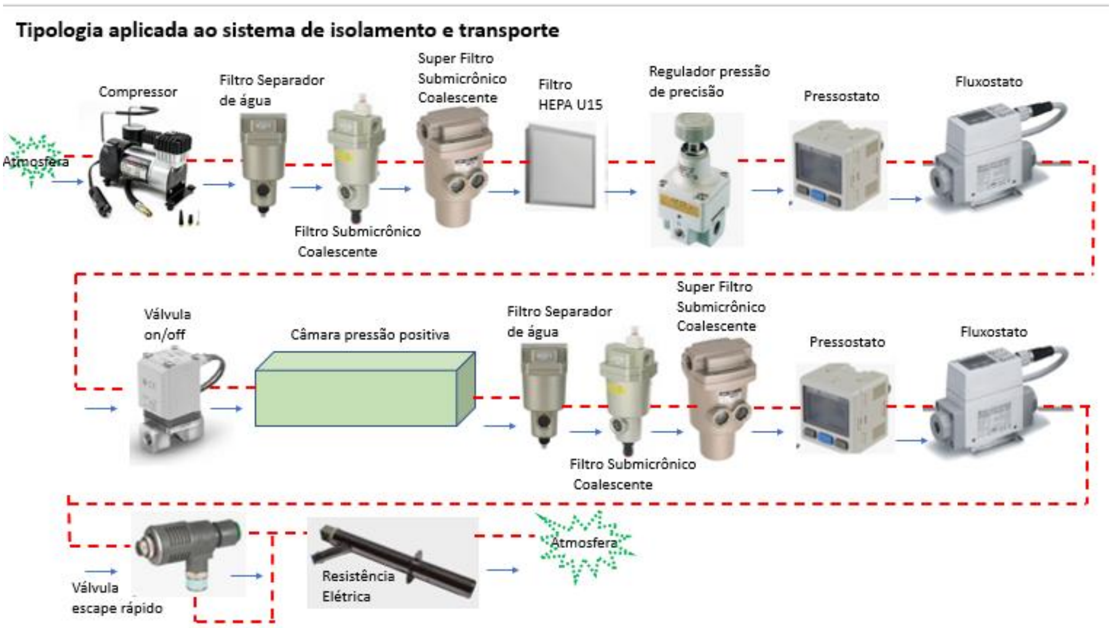

Figure 12 Type of pneumatic control of the enclosure system. Source: From the author (2021)

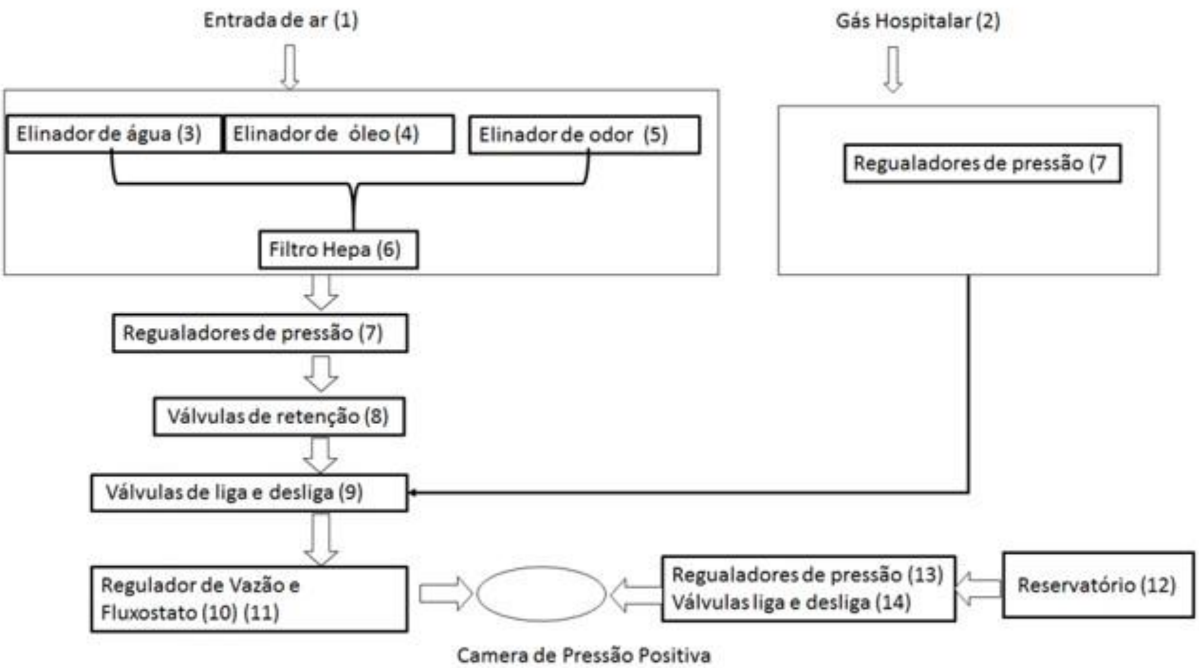

Figure 13 Flowchart of the pneumatic control of the enclosure system. Source: From the author (2021)

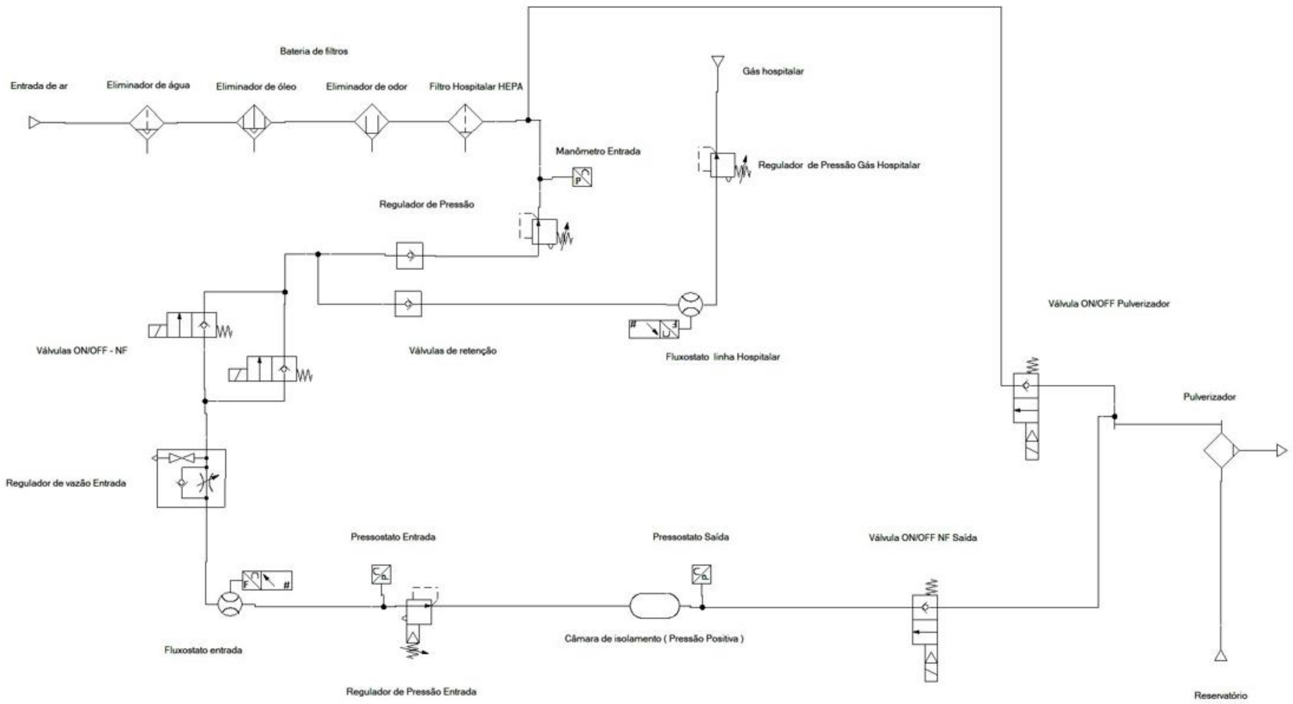

Figure 14 Circuit of the pneumatic control of the enclosure system. Source: From the author (2021)

With a focus on maintaining a positive pressure environment, the system has differential pressure control where there are air inlets that take place through a high precision pressure regulator of 0.05 MPa, both atmospheric air and oxygen or the mixing of the two when necessary, which happens at the top of the system, as shown in Figure 15, exemplifying the air flow inside the system.

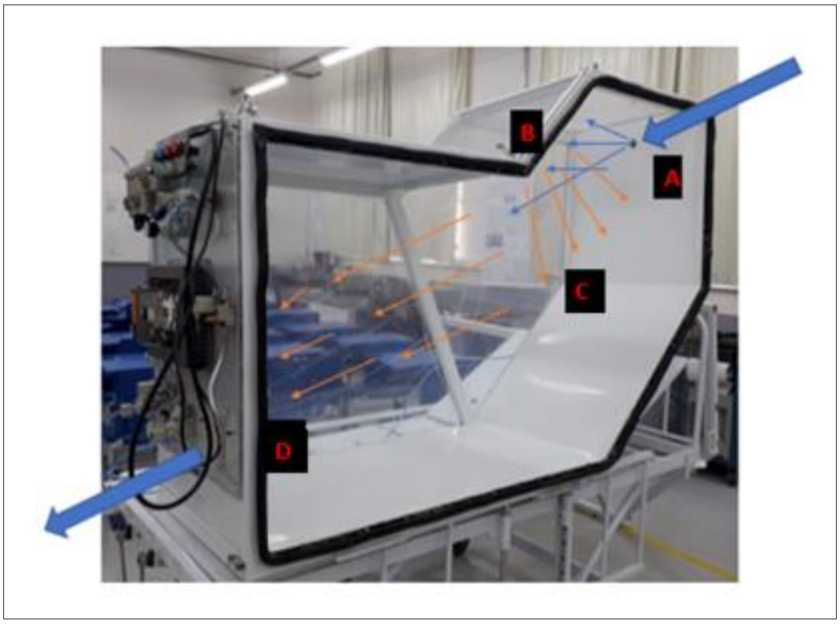

Figure 15 Air flow inside the system. Source: From the author (2021)

The location represented in the figure above by the letter A is the only point of entry of air into the system; this point is strategic, as it is the region that is close to the patient's head. The air flow will be directed toward the ramp that is in front of the system user, and a straight air flow will hit the inclined plane represented by the blue arrows and the letter B. Part of it will dissipate toward the exit represented by the orange arrows and the letter D, and the other part of it will go to the frontal/facial region of the patient represented by the orange arrows and the letter C. This volume of air creates a positive atmosphere inside the system that is completely closed and hermetic. This positive atmosphere is only possible when there is control of air flow and air pressure, controlling pressure and flow. The only air outlet is located near the patient's feet represented by the letter D, and this outlet also occurs through a high-precision pressure controller, resolution from 0.01 to 0.4 MPa. Then, the entry and exit of air from the system is controlled. Two high precision pressure flow controllers were used to enable the air volume to generate positive pressure within the innovative insulation system.

The vast majority of models of positive pressure insulation systems existing worldwide thus far work with volumetric air overload and do not have air exchange [6,11]. In this project, the air is released, so the flow is continuous, and the air is completely recycled when it reaches the pressure and does not have the saturation of atmospheric air or oxygen. This is a very significant technological innovation since medical protocols, as in the guidelines of the AMIB and SBPT (2013) [12], indicate a positive atmosphere for better ventilation of the patient, preventing the worsening of the breathing pattern and thus avoiding the need to intubate the patient for the use of invasive mechanical ventilation.

3.3. Adduction of atmospheric air

The supply of air to the isolation and transport system requires control of the number of particles that is allowed in hospital environments and is similar where it is necessary to maintain biosecurity; for this, the HEPA filter is the most indicated due to its high filtration efficiency [13]. The adduction of atmospheric air into the system takes place as follows: there are 3 batteries of filters, 1 coalescent, and 2 redundant filters (hydrocyclone filtration systems where the air flow enters, rotates and throws the particulate to the filter walls that comes out through the exhaust valves), and from these filters, which have industrial characteristics 1 HEPA-type filter was added, aiming to have a mix of industrial filters and 1 hospital filter. The particulate existing in the atmospheric air (type of waste) is filtered at a rate of 3 microns (the maximum particulate that will pass from now on in the system is a size below 3 microns). Thus, the treatment of atmospheric air was carried out (promoting air conditioning).

After the air has been treated, it will pass through the 1st pressure control gauge where it will adjust to the inlet pressure (roughly) passing through a system of redundant valves (if one fails the other works) which has the function to open and close, then a PLC (Programmable Logic Controller), with digital and analog inputs and outputs that will emit a warning signal, an alarm. All this reinforcement is so that there is no risk of blocking the entry of air into the system since the patient is inside and the system is closed. Then, the atmospheric air passes through a high precision flow meter, Fluxostat, with digital and analog outputs with a scale from 0 to 10 L/min, to control and adjust the flow. At that moment, a new, more refined pressure calibration is performed through the 2nd pressure control manometer, which is of high precision, with a resolution from 0.01 to 0.4 MPa.

After going through the flow and pressure control, the air goes into the isolation and transport system for people with infectious diseases.

3.4. Oxygen adduction

The adduction of oxygen into the system occurs as follows: the oxygen cylinder that is already in the hospital environment stores purified air and can come into direct contact with the patient, presenting pressure control in the cylinder itself, without the need for the use of filters. From that point on, the oxygen that enters the system has only flow control. There is a valve that opens and closes and releases only oxygen or oxygen together with atmospheric air when there is a need to mix the two, according to the medical protocol adopted by the health professional. Leaving the valve, the flow will go to the 2nd high-precision manometer, where the pressure will be controlled to ensure a positive atmosphere inside the system. Again, it is emphasized that for positive pressure to exist within the system, there must be flow and pressure control and the use of noninvasive positive pressure helps so that patients with COVID-19 do not develop severe forms of the disease [14].

3.5. Adduction of atmospheric air and oxygen

If there is a need for both atmospheric air and oxygen inputs, the two systems will work together. After determining which volume will be needed, the PLC (programmable logic controller) will work on opening and closing these valves, and the two will reach the pressure controller that will adjust the positive pressure and will proceed to the only air inlet in the system being directed toward the patient's head as previously described.

Voltage and current data, for adequacy of the atmospheric air and/or oxygen rate are managed and processed by the programmable logic controller and the hardware operates outside the Windows® platform; therefore, the processing of the received information occurs at a rate of 3 to 5 ms, almost in real time, ensuring system efficiency.

3.6. System air outlet

The system's air output occurs as follows: the system is pressurized and allows air to exit from a single exit point, as already mentioned, located near the patient's feet. There is a pressure controller that when reaching the pressure that was set, the valve will open and will discharge this contaminated air to a turbulence system. This whirling system will supply the contaminated air flow (this system is closed), and this same system will also suction the glycerin alcohol that will be inside a reservoir and thus mix with the contaminated air flow occurring a whirlpool with micro spraying and the particulate is deposited again in the box where there is an air outlet that will go to the sanitized atmosphere, a great technological innovation. We consider continuous flow, and to be continuous flow, we have to sanitize the air outlet.

4. Conclusion

According to the information presented in this work, the following can be concluded:

- It was possible to develop a hermetic chamber that provides safety and isolation by contact and aerosol, considering a continuous flow and a positive atmosphere through pressure control and differential flow where they were regulated with a high precision of up to 0.4 MPa.
- The system allowed the use of atmospheric air, oxygen and even the mixture of the two when necessary through intelligent control using a programmable logic controller that accepts the inclusion and alteration of medical protocols according to the decision of the health team involved.
- In validating the dimensions determined in the Top Solid software, which are essential for safe air, land and intrahospital transport, the system is efficient.
- Provided the exit of sanitized air to the external environment through a flushing system together with glycerin alcohol.

Therefore, the proof of concept of the innovative system for isolating and transporting people with infectious and contagious diseases proves to be effective for what was proposed, promoting technological innovations in the face of what already exists worldwide.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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