The Human Ventilator

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The human ventilator as equipment for pressure energy transfer: the risk of not taking in account Engineering aspects in such a complex problem. A short essay regarding Engineering issues regarding the human ventilators and comments on available data.

Human ventilator | Pressure energy | Coronavirus pandemic | Brazil demographic data | Analysis of available data | Momentum transport

1. Introduction

In this essay, I invite the readers to reflect on a very serious problem that I have noticed during the last months: there is a current tendency of reducing complex and multidisciplinary problems to a single sphere of knowledge. This is particularly complicated when we are facing problems that affect all of the global society.

2. The human ventilator as equipment for pressure energy transfer: the risk of not taking in account Engineering aspects in such a complex problem

Firstly, I give you a simple personal example about the time when our research group started a project regarding the development of optical fiber sensors for the monitoring of biochemical systems, especially fermentation. By that time, we noticed that many biologists and biotechnology professionals needed a solution for the assessment of such systems. In many cases, though, their formation made it particularly difficult to find a solution. This is a problem that is present in almost every knowledge field. In a PhD lecturer, the great Prof. Dr. R. Maciel Filho (one of the greatest Brazilian authorities on the energetic and fermentation sectors) mentioned how important it was that engineers, chemists, and biologists discussed with each other. The group of Prof. Maciel Filho wished to make it viable to operate a biorefinery, but the Monod kinetic parameters that would make the operation economically feasible were unreal. However, talking to a biologist colleague, Prof. Maciel learned that there was a particular *Clostridium* lineage which could be genetically modified to obtain fermentation parameters close to what they needed. That showed him the importance of discussing and collaborating with everyone, since he learned something that, in principle, he did not even imagine.

Since the end of February 2020, there is an intense public discussion about the importance of the human ventilators. They are many times seen as the solution for the problem of coronavirus emergency, what would justify enormous investments spent on their acquisition. The basic technology that bases this class of equipment is, in reality, known for decades. We are talking about systems for transfer of pressure energy: pumps, ventilators, blowers, compressors, etc [1][2]. Such systems are extensively studied by Chemical and Mechanical Engineers during their formation, since one of their common attributions is their project and dimensioning. It is important to emphasize here that I am specifically discussing the project of dimensions and mechanical parts, not the electric and electronic projects, or the quality control restrictions required for medical use. These restrictions usually constitute the "*bottleneck*" and the greatest cost difficulties. There are also widely known assessment systems for equipment of *momentum* transfer. One example of monitoring device that may be used is the mass flow meter, which presents applications to different Engineering and Biomedical fields, like yeast fermentation, where it is applied to control the entrance of oxygen that feeds a bioreactor.

By April 22, 2020, the world was facing one of the most critical moments of the so-called first wave of coronavirus disease. People in USA and in Europe were particularly affected, and it was one of the moments of the pandemic when more people were submitted to ventilation treatments. Regrettably, the available data indicated that 88% of the patients died in the ventilators [3][4]. In the following day (April 23), a very interesting article from Thomson Reuters [5] (disclosed by the Newsletter Nature Briefing of 24 April, 2020) discussed this topic. Different medical doctors were interviewed regarding the so-called "*rush to ventilate*", and they were already arguing that this approach could actually be a huge mistake.

This Reuters' article was based on data gathered from many cities of the world. Despite of any possible conflict of interest or of any transparency issue, the information reported from Wuhan (China) authorities indicated a death rate of 86% for the ventilated patients [5]. This rate is quite similar to the one reported by the government and by hospitals of New York City (NY, USA): ~90% of NY ventilated patients died [3][4]. Thomson Reuters also elaborated very interesting graphics showing a compendium of data from hospitals and explaining how invasive the ventilation process is. In fact, this process requires the sedation of the patient (induced coma) [6].

Discussing with some Engineering colleagues possible reasons for such high mortality (~90% in New York City), the most important conclusion that we achieved was that at least one Chemical or Mechanical Engineer should have been consulted. That is because this engineer would be capable of argue something that is actually quite simple: every system destined to transport pressure energy is projected for operating under a specific head loss condition (basically, a specific friction condition). If the head losses (i.e., losses by friction, vortex formation, changes of direction of the fluid, etc) are lower than the projected value, we have an over dimensioned equipment. It causes the fluid to reach the end of the process line excessively pressurized. The opposite situation is the under dimension (i.e., actual head losses are higher than the projected values). It results in a fluid with low velocity or that may be even incapable of reaching the end of the line [1][2].

If the process line presents a filter, the pressure conditions are more restrictive. That is because the head losses in filters are high, as can be noticed by analyzing the widely known equations of *Ergun* and *Hagen-Poiseuille*.

Moreover, in these cases there is another important and fundamental operation parameter related to the filter, which is its mechanical resistance. This factor is particularly important for sleeve filters, which finds applications in industries that work with particulate materials (e.g. industries of ore processing), food industries, and even in domestic use, where they are used for straining the coffee. An oversized system, then, presents high risk of causing mechanical damages on filters [1][2].

An even more dramatic situation is noticed in membranes, especially the polymeric ones. Personally, I could observe this situation when performing an internship in the outstanding laboratory of materials characterization of the Membrane Research Centre (Straž pod Ralskem, Czech Republic), coordinated at that moment by Drs. M. Novotnà and Z. Marušák [7]. The pressure restrictions imposed by the maximum allowable transmembrane pressure (TMP) and by the possibility of clogging and fouling (caused by the presence of dispersed particulate material) commonly make it impeditive to position some membranes in a direction perpendicular to the fluid streamlines. Therefore, the membranes must be maintained positioned parallel to the streamlines to reduce the transverse mechanical pressure. As consequence, a substantial amount of the transport results not from *momentum* transfer mechanisms, but from processes of mass convection or diffusion, which may be less efficient. Many membranes may also present anisotropy: the mechanical resistance in the transverse axis is different from the resistance in longitudinal axis, a characteristic that must be taken in account when projecting the transport system [7][8].

Biomembranes are obviously even more sensitive. Many of them are part of a class of materials known as "*Soft Matter*", as well as hydrogels and many of the biopolymers (and many biomembranes are actually hydrogels). The reader is referred to the excellent Royal Society of Chemistry's journal called "Soft Matter" for more information and for the latest research in this field [9].

Now we can finally reach the central bullet of this essay: pulmonary alveoli are extremely fragile membranes that allow the passage of gases [10][11]. Then, what may be inferred about the mechanical resistance of inflamed alveoli? It is probably much reduced.

These days, we often read and hear people claiming a new political "*mantra*": they respect and follow the Science (took as a faceless and nameless entity, what is almost a dogmatic posture), in opposition to each one who does not agree with them. These people seem to ignore that there are still many open scientific questions. For instance, are there any studies, mathematical modeling, or estimations of the effects of inflammations over the maximum transmembrane pressure that the alveoli may support without suffering rupture? Once the alveoli get more fragile, the TMP is probably reduced.

As long as I know, these studies were not performed so far, but they would be very relevant to evaluate: if a patient can be submitted to the ventilation treatment; which is the maximum ventilation pressure that may be imposed to a given patient; and also what is the actual technical and economic return brought by the elevated budget invested in human ventilators. Another fair question: do medical doctors have the competence to calculate the TMP, which is a fundamental parameter when deciding the flow of gases that will be ventilated into the lungs? We must remember that it requires technical knowledge on fluid mechanics and on the analysis of transport equipment. Therefore, I believe this is actually a highly complex multidisciplinary problem that involves engineering applied to the human biological system.

One that deliberately ignores the multidisciplinary nature of this problem assumes the risk of imposing an intense transverse mechanical pressure to membranes (pulmonary alveoli) that are already compromised due to the inflammation. Depending on the personal characteristics of the patient (e.g. if the person is a smoker, or if the person does not practice physical exercises) this pressure could be higher than the maximum that could be supported even if that person was not ill. Moreover, any biological system (like a yeast or animal population) shows substantial variations of size, resistance, metabolism, etc. between the individual cells or organisms that constitutes that system [10][11].

If we not take in account specific physiological and physiotherapeutic details, we may conclude that the ventilators are, at least in theory, capable of causing irreversible mechanical damage (or even capable of causing a “explosion”) to the patients’ lungs due to the excessive pressure. Such phenomenon may be observed in any filter or membrane [1][2][7][8]. It is noticed, for example, in very prosaic situations: when one that is pressurizing the car’s or bicycle’s tires keeps the compressor working for too long, so that the tires blow; or when a party balloon that is being filled suddenly explodes due to overpressure. A similar, but more complicated and less familiar example comes from our research group. When operating a microfermentor, the setting of the pump controller at high flow rates results in leakage of the culture media from the microchannels. Again, the reason is quite simple: the excess energy must be transferred out, and any fluid flows from the point of higher to the point of lower pressure [12].

The human ventilator is often seen as the solution for the coronavirus crisis, and that is one reason why so many governments have purchased a significant amount of such equipment. However, the above discussion leads me to the humble (engineer) opinion (or conclusion) that the ventilators may be actually killing some of the patients. In its turn, it is known that the induced coma (in many cases of 30 or more days) combined to the presence of an invasive equipment that literally drives the respiration process resulted in atrophy of multiple muscles of some ventilated patients, including the muscles involved in the breathing process. As consequence, many of those patients had to be submitted to numerous exhaustive sections of physiotherapy to relearn some basic functions of the organism, like walking and breathing. Sadly, many of them died after being cured from the disease [3][4][5][6].

From the beginning of 2020, many of us in the entire world have also observed or have been submitted to procedures that may be considered at least invasive. Many times, there is lack of theoretical basis, but the procedures are adopted as medical answers, with no possibility of being questioned. Many of the procedures, though, should be submitted to the evaluation of independent instrumentation experts, for example. A situation common in many Brazilian cities: there is a systematic use of infrared (IR) thermometers to assess the bodies’ temperatures. A first problem is that the human body presents thermal profiles: there are temperature differences between different regions, like the differences between the heart and the extremities of the body. The temperature also varies during the day. If you practice exercises in a gym; if the day is too sunny or too hot; or if you got nervous, or frightened, then your temperature may rise significantly. Other problem is that many IR thermometers were originally designed to assess very high temperatures (e.g. in metallurgical furnaces) where the conditions are dangerous for an operator to be close to, or where it may be impossible to use a thermocouple. In these cases, the maximum sensitivities of the thermometers occur for high temperatures, so the resolution is reduced for temperatures lower than 100 ºC. IR thermometers are generally based on Stefan-Boltzmann Law, which states that the power irradiated from a body is proportional to the difference between the fourth power of the body’s temperature and the fourth power of the reference temperature (a body that is usually in a distance infinitely high, where there is no irradiation) [13].

Even with all of these issues, the IR thermometers have been imposed to Brazilians as an effective methodology for temperature evaluation and for control of the coronavirus. However, it is not informed to the public neither the resolution nor the error inherent to the evaluation with those instruments. For example: are they capable of effectively detecting variations of 2 ºC for temperatures below 40 ºC? If the error is equal or greater than 2 ºC, readings from 34 to 38 could be observed when assessing a same body with temperature of 36 ºC. No analyses of the assessment systems (the famous Gage R&R study) are provided, and no one independently verifies the operators’ and instruments’ errors involved in the procedure. In the entrance of a local market, I could see the security evaluating the temperatures: a person which had body temperature higher than 37.2 ºC was prohibited to enter in the store. I thought that was unreal, since the instrument did not seen to have the capability of verifying a difference of only 0.2 ºC. In fact, one person was allowed to enter because the equipment measured 34 ºC (i.e., it was a person with severe hypothermia).

I believe that the most regrettable, however, is the misinformation that naturally comes with a terror campaign. In a country like Brazil (population of more than 211.7 million people) which shows high indices of analphabetism (the analphabets represented 6.6% of the population in 2019); and of people that does not have access to sanitation (in 2019, 15.6% of the households did not have access to garbage collection and waste management; 14.5% did not have access to safe drinking water; and 31.7% of did not have access to sanitary sewer); where 13.3 million people were unemployed in the second trimester of 2020; and where the average income of the population is of only 2398 BRL/month (~447 USD/month, data regarding the second trimester of 2020) [14][15]; the misinformation may become a devastating problem. I have already met people who actually believe that there is no infection if there is no fever (or, in other words, if you are infected, you must be in fever). Then, for those people, even systems with considerable uncertainty may be taken as a guarantee of safety: if the IR sensor says nobody is in fever, they believe that there are no risks, and so people are being kept safe. No one explains them that the information shown by the thermometer may have no practical value if the equipment’s resolution is too low, but seems that there is no problem at all with this situation. I have particular doubts that the range for maximum sensitivity is even checked prior to acquiring one of those thermometers, but there are no voices questioning that. In fact, we have been watching a passive behavior of the population, with people stating that they do not have the right to question anything that looks like a medical issue (even when many medical doctors do not agree with each other).

There are many bullets for being discussed regarding the coronavirus pandemic. As in every complex problem, I believe that there may be several treatments and solutions. But, due to the presented discussion, I believe that early interventions prior to the inflammatory phase should be tried. That is not an opinion with no scientific basis: in Reference [16], we may find an index of more than 100 peer-reviewed papers published in important journals reporting good results when early applying retroviral or antibody cocktails to the treatment of the coronavirus disease.

In emerging and developing countries, there are also important economic restrictions for a given solution, what brings the need for improvement and optimization of the use of the resources. Complex problems usually offer the possibility of an infinite number of solutions, and many times none of them is correct. We must, then, choose the optimal or the best solution. Actually, every real world problem challenges us with three main groups of restrictions: (i) technical restrictions, the ones which are related to the technical and scientific resources available; economic restrictions, basically the available funds (budget); (iii) and the most complex and, maybe, the most important ones: the human restrictions, which include: the resistance that people may represent when one is trying to implement a change or a decision; how they see and what they think about this change or decision; and what they are actually willing to do regarding the change or decision.

No decision should be made before performing a detailed analysis of each restriction. More complex problems and with a higher number of human restrictions, in turn, demand every opinion to be taken in account. This is especially important when not only the problem itself, but also the solutions that we may propose have potential to affect each member of a heterogeneous population in many different ways.

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