

DEVELOPMENT OF AN AIR HEATING AND HUMIDIFYING SYSTEM FOR MECHANICAL VENTILATION OF INTENSIVE CARE UNIT PATIENTS

E. L. Ferreira ^a,
J. V. C. Vargas ^a,
M. C. Campos ^b,
F. G. Dias ^b,
J. C. Ordonez ^c,
M. L. Brioschi ^a,
and E. F. Botelho ^d

^aUniversidade Federal do Paraná
Programa de Pós-Graduação em Engenharia
Mecânica
CP. 19011, Curitiba, Paraná, Brasil
elianalealf@yahoo.com.br
jvargas@demec.ufpr.br
termometria@yahoo.com.br

^bDepartamento de Engenharia Mecânica,
PGMEC, Universidade Federal do Paraná, C.P.
19011, Curitiba, PR 81531-990, Brazil
mccampos@demec.ufpr.br
gallego@ufpr.br

^cDepartment of Mechanical Engineering and
Center for Advanced Power Systems, Florida
State University, Tallahassee, Florida, 32310,
USA
ordonez@caps.fsu.edu

^dPrefeitura Municipal de Curitiba/Instituto
Curitiba de Saúde, Av Mal Floriano Peixoto,
1895, Rebouças, Curitiba, PR 80230-110,
Brazil
edbotelho@ics.curitiba.pr.gov.br

ABSTRACT

The mechanical ventilators, also named artificial ventilators, are devices used in Intensive Care Units (ICU) for clinically critical patients. The equipment provides artificial breathing for the patient, creating favorable conditions for the patient recovery. It works as a system that is connected to the electric grid and two other networks, one supplies compressed air and the other supplies pure oxygen. Inside the equipment the gases are mixed, and then warmed up and humidified to be finally delivered to the patient. The existing system for treatment of the mixture is not effective, since it delivers the breathing air to the patient out of the normal physiology recommended range, i.e., temperature ~ 32-34°C and relative humidity ~ 80-95%. The objective of this work was to develop a new air heating and humidifying system for mechanical ventilation. First, it was built an air feeding system, composed by a compressor and an electronically controlled valve to simulate an actual mechanical ventilation system in the laboratory. A device for conditioning the air (temperature and humidity) was conceived and built for treating the air feeding system output air. The results of the laboratory measurements show that the developed equipment was capable of making the breathing air to reach the recommended ranges by the normal physiology.

Keywords: Mechanical ventilation, humidifiers, air filter, barrier filter, air relative humidity, temperature

INTRODUCTION

It has long been considered desirable to provide warm and humid inspired gas to mechanically ventilated patients, and various methods to achieve this have been proposed (Chalon et al., 1972; Stone et al., 1981 and Hedley and Allt-Graham, 1994). An artificial air inlet (endotracheal intubation or

tracheostomy) associated with mechanical ventilation does not allow the normal physiologic air heating and humidifying process of inspired gases through the upper airway to happen. As a result, in mechanically ventilated patients, a continuous loss of heat and moisture occurs, which predisposes patients to serious airway damage (Chalon et al., 1972; Stone et al., 1981; Hedley and Allt-Graham, 1994; Chalon et

al., 1979; Forbes, 1973; Forbes, 1974 and Noguchi et al., 1973). In addition, medical gases are dried to avoid condensation damage to valves and regulators in the distribution network.

The mechanical ventilators, also called artificial breathing machines, are instruments built to aid clinically unstable patients or that do not have conditions to breath by themselves. So, there are means to aid the health recovery of those patients. The functioning of most of these machines can basically be described as a system that connects to the power line to two gas lines, which are: I) compressed air – which is responsible for keeping the pressure flow of the machine to the respiratory system of the patient, and II) oxygen – responsible for keeping the oxygenation of the organs and tissues of the patient. Inside of this machine it occurs the mixture of the gases in the blender, which are then passed to the patient, after the gases are treated by another system coupled to the machine. This coupled system works on heating and humidification of the inspired air, or technically speaking, the insufflated air fraction to the patient's lung interior. The insufflated air fraction depends on the ventilation mode: i) VCV – volume controlled ventilation; ii) VCAV – volume controlled assisted ventilation; iii) PCV – pressure controlled ventilation; iv) PAV – pressure controlled assisted ventilation; v) SIMV – synchronized intermittent mandatory ventilation; vi) VCV – pressure supported ventilation; vii) PAV – proportionally assisted ventilation. Those systems basically differ from one another on the type of utilized mechanism to create the air mass flow rate to the patient's lungs. After that, an inspiratory valve triggers and cycles the flow. The final stage is the insufflated air heating and humidification which is performed by humidifiers coupled to the mechanical ventilator. This is accomplished in a pre-determined time, according to the pathology being treated. It is specifically about this system of treatment of the insufflated air in the patient that this article analyzes and develops a study, since the existing systems feed air with low temperature (~ 22°C) and low relative humidity (under 60%).

Some systems are available in the market that have been created with the purpose of heating the air, or filter it of germs and bacteria (general impurities). Nevertheless, none of them show a reading system capable of informing the amount of water in the insufflated air (relative humidity), the value of the internal temperature and the heat that is being lost to the environment. So, there is a necessity of a specific thermodynamic study for this system, which allows, after applying the energy balance (first law of thermodynamics), the development and improvement of the system of conditioning of the insufflated air that comes out of the mechanical ventilation system.

This work has the following objectives: i) to develop an equipment capable of improving the current mechanical ventilation systems, and ii) to

insure the air supply in the conditions established by the medical protocol: 32 °C to 34°C of temperature, and 80% to 95% of relative humidity. The new equipment to be coupled to the mechanical ventilation system is expected to meet the required air conditions for the intubated patient.

MATERIALS AND METHODS

In the period between January 2005 and December 2005, measurements were performed of temperature and relative humidity of the input and output air of a test lung, during procedures of simulation and mechanical ventilation which normally is made on patients on ICU. To do this simulation, first it was built in the laboratory an air feeding system, composed by one compressor and one valve for opening and closing the insufflating air flow, which was electronically controlled to simulate an actual ventilation system.

A prototype of an equipment for conditioning the air to be insufflated in patients (temperature and humidity) was idealized and built for air treatment in the output of the air feeding system. The criteria of selection of the materials idealized for the composition of the experimental prototype were the following:

I – selection of the adequate instrumentation which makes possible the adequate registration and controlling of the temperature and air relative humidity;

II – availability of an air compressor, for air flow generation, with pressure and flow enough to expand-fill the test lung, of the same model used in the calibration of the mechanical ventilators used in the ICU;

III – availability of a data acquisition system, which makes possible the generation of a data bank, for the numerical and graphical evaluation of the acquired data;

IV – utilization of acrylic transparent material for the manufacturing of the system, with the purpose of visualization of the process and to provide the necessary rigidity;

V – utilization of thermistors of high precision, of the type YSI4404 (2250 Ω @25 °C) made by the company YSI Incorporated, USA, for the measurement of temperature;

VI – utilization of relative humidity sensors of the type SC-500, made by the company Ohmic Instruments Co., USA, for the measurement of the air relative humidity;

VII – utilization of a regular thermostat with a scale of 0 to 40 °C, for controlling of a resistance for air heating;

VIII – utilization of a mechanical hygostat, made by the company Lufft, Germany, for the control of a water jet pump for the humidification of the air, and

IX - utilization of a system for air heating and humidification, interconnected, with simultaneous control, to reach the values established by medical protocol.

For all the equipments tests were made for calibration, until the final configuration of the equipment was achieved. The experiments were conducted integrally at the Hydraulic Machines Laboratory, at the Department of Mechanical Engineering of Universidade Federal do Paraná, UFPR.

RESULTS AND DISCUSSION

The following graphs present the experimental measurements made in the laboratory, using the data acquisition system. The measured data was converted in numerical values of temperature and relative humidity of the air in the input and output of the system.

Two tests were performed in this work. The graphs show the behavior of the temperature and air relative humidity in three points of the system. The first selected point was the air input of the new system, which corresponds to the air output of the traditional mechanical ventilator. The second selected point was the air output of the new system, i.e., after the air was treated by the new system. The ambient temperature was also measured. The main objective was to verify if the proposed system is capable of producing the desirable effects, i.e., conditioning the air insufflated to the patient within the levels recommended by medical protocol. Both tests were conducted in the period of 3600 seconds (1 hour).

The graphs for test 01 (Figs. 1 and 2) show that the input temperature of the system was at 23 °C and the relative humidity was at 40%, in the beginning of the experiment. Figure 1 shows that it took 1800 seconds (30 minutes) for the air to reach the temperature of 34 °C in the output of the system (which is the lower point in the range established by the medical protocol). The system response for the relative humidity is quite faster, since that right in the beginning of the experiment it reached 66% as shown in Fig. 2. After 3600 seconds (1 hour), the air in the output of the system, which is delivered to the patient, was at 34 °C, and the relative humidity at 77%. The ambient temperature remained at 21°C during the experiment.

Test 02 was performed in the following day of test 01. The results of Figs. 3 and 4 are quite similar to test 01. The idea of performing several tests is to demonstrate that the system repeats its results under different conditions. For test 02, the input temperature in the system was 24 °C and the relative humidity was 46% in the beginning of the experiment. Similarly to the first test, the air took

about 1800 seconds (30 minutes) to reach the conditions established by medical protocol, i.e., 34 °C in the system output. The response of the relative humidity was quite faster again, i.e., in the beginning of the experiment it reached 69%. After 3600 seconds (1 hour), the air in the output of the system, which is delivered to the patient, was at 35 °C, and the relative humidity at 80%. The ambient temperature remained at 21°C during the experiment.

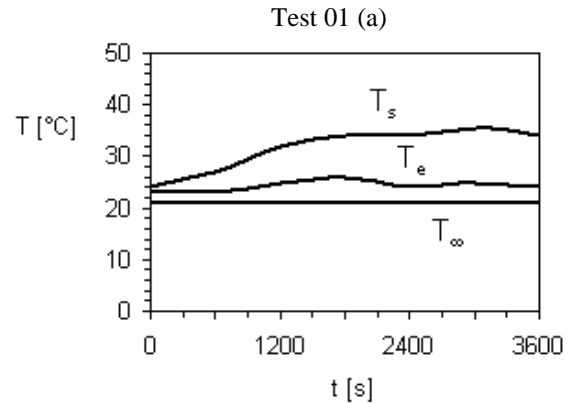


Figure 1. The three temperatures behavior during test 01, where T is the temperature, t the time, T_s, T_e, T_∞ output, input and ambient temperatures, respectively.

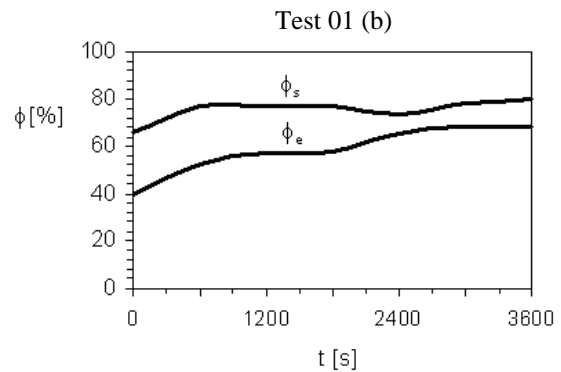


Figure 2. The two relative humidities (ϕ_s and ϕ_e at the output and input, respectively) behavior during test 01.

CONCLUSIONS

In this research, a new system for conditioning the output air of mechanical ventilators was developed and a prototype was built and patented (Ferreira *et al.*, 2006), with the main objective of minimizing the problems caused to the intubated patients in the ICU by the existing systems, such as hypothermia, hyperthermia and water condensation in the system. This leads to great proliferation of germs and bacteria, and delays the treatment of the critical ICU patient.

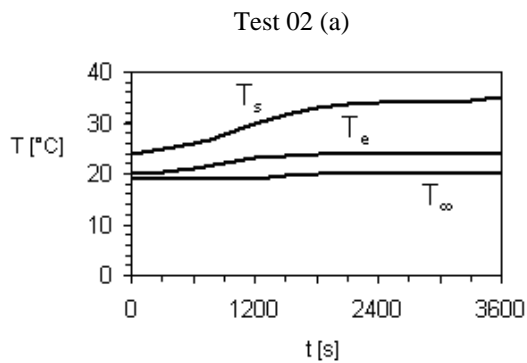


Figure 3. The three temperatures behavior during test 02.

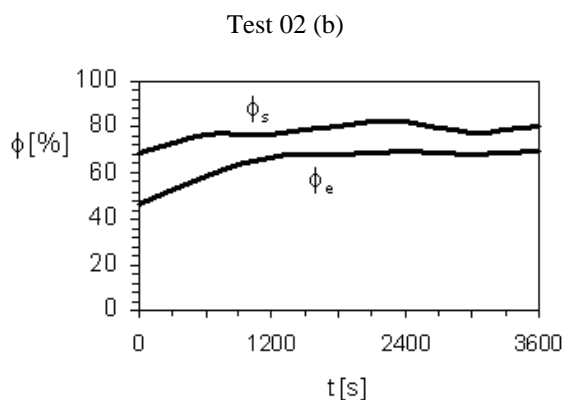


Figure 4. The two relative humidities (RH) behavior during test 02.

According to the results presented in this paper, it is possible to minimize the effects on the respiratory system of intubated patients in the ICU by controlling the temperature and relative humidity of the air in the input of endotracheal tube that conducts the air to the patient. This was demonstrated by connecting a new equipment to the output of a mechanical ventilator, of simple conception, considered in this work, to condition the air to be insufflated to the intubated patient. It is interesting to point out that the new equipment does not take too long to reach the desired temperature and relative humidity conditions, i.e., approximately 30 minutes in the tests performed in this study, mainly if it is considered that without the equipment, the patient would have to breath air out of the recommended conditions by the medical protocol.

Finally, it is important to point out that the need to demonstrate the effectiveness of the new equipment through studies in human beings is crucial, under the ethical and legal points of view. Only after performing such experiments, it will be demonstrated the viability and applicability of the system in human beings.

REFERENCES

- Chalon, J., Loew, D. and Malebranche, J., 1972, Effect of Dry Anesthetic Gases on Tracheobronchial Ciliated Epithelium, *Anesthesiology*, Vol. 37, pp. 338-343.
- Chalon, J., Patel, C., Ali, M., Turndorf, H. and Fischgrund, G. K., 1979, Humidity and the Anesthetized Patient, *Anesthesiology*, Vol. 50, pp. 195-198.
- Ferreira, E. L., Vargas, J. V. C., Campos, M. C., Brioschi, M. L., Alves, J. L. and Ordenez, J. C., 2006, Sistema De Aquecimento e Umidificação de Ar para Ventilação Mecânica de Pacientes de Unidade de Terapia Intensiva, Patente: Privilégio e Inovação. Nr. PI06010687, 31 de Mar (Depósito).
- Forbes, A. R., 1973, Humidification and Mucus Flow in the Intubated Trachea, *Br J Anaesth* Vol. 45, pp. 874-878.
- Forbes, A. R., 1974, Temperature, Humidity and Mucus Flow in the Intubated Trachea, *Br J Anaesth*, Vol. 46, pp. 29-34.
- Hedley, R. M. and Allt-Graham, J., 1994, Heat and Moisture Exchangers and Breathing Filters, *Br J Anaesth*, Vol. 73, pp. 227-236.
- Noguchi, H., Takumi, Y. and Aochi, O., 1973, A Study of Humidification in Tracheostomized Dogs, *Br J Anaesth*, Vol. 45, pp. 844-848.
- Stone, D. R., Downs, J. B., Paul, W. L. and Perkins, H. M., 1981, Adult Body Temperature and Heated Humidification of Anesthetic Gases during General Anesthesia, *Anesth Analg*, Vol. 60, pp. 736-741.

Received: September 24, 2008

Revised: October 24, 2008

Accepted: November 24, 2008