# THE MODEL OF THE RESPIRATORY SYSTEM AS AN EDUCATIONAL DEVICE FOR SIMULATION OF THE VENTILATORY PARAMETERS EFFECT UPON THE INTRAPULMONARY CONDITIONS

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### *Summary*
*The aim of the work was to design a simulator of the human respiratory system consuming oxygen and producing carbon dioxide. The respiratory quotient, tidal volume, mechanical parameters of the system and other parameters should be similar to the physiological ones, so that the simulator could be used for simulation of artificial ventilation of a real patient. The model consists of a high-volume plastic box assuring the desired lung compliance, a propane-butane burner equipped with a water-based cooling system, oxygen and $CO_2$ analyzers of the "intrapulmonary" gases and a control system. The simulator is an educational device suitable for testing of the influence of the ventilatory parameters upon the intrapulmonary conditions similarly as during artificial lung ventilation of a human patient.*



### *Keywords*
*artificial lung ventilation, ventilatory parameters, model, simulator, respiration*


## Introduction

Despite the recent technology development in critical care, acute respiratory failure has still a very high mortality, which approaches 40 % in patients suffering from adult respiratory distress syndrome [1]. New ventilatory regimens (characterized by new or unusual ventilatory parameters) and new artificial ventilators are being introduced. Therefore, a lung simulator is a useful tool for both testing the ventilators and training students.

The aim of the work is to design a model of the lung that performs similarly as the real respiratory system. The model should simulate real mechanical parameters of the respiratory system, real metabolic rate-consumption of oxygen and real respiratory quotient-and, finally, it should behave as an adult patient for training students in ventilatory setting and respiratory care.

## Methods

Design of the model (simulator) should comply with the basic requirement that should assure that properties of the simulator and its behavior during artificial lung ventilation are very similar to those during artificial lung ventilation of a real adult patient. There are three main parts of the model. The first part is responsible for simulation of gas exchange in the organism, i.e. it simulates metabolism. The second part simulates real mechanical properties of the respiratory system. The third part is represented by an advanced monitoring of ventilation and intrapulmonary conditions.

The overall scheme of the model is presented in Fig. 1. The model comprises a high-volume plastic box assuring the desired lung compliance, a propane-butane burner equipped with a water-based cooling system assuring oxygen consumption and carbon dioxide production, oxygen and carbon dioxide analysers of the "intrapulmonary" gases and a control system.

### Simulation of metabolism

A device simulating metabolism encompasses a propane-butane burner equipped with a water-based cooling system. This device, referred to as metabolic unit, has several important properties.

The burner consumes oxygen from the internal space of the simulator (intrapulmonary or alveolar space) and it produces carbon dioxide, water vapour and heat. In the living organisms, the ratio between carbon dioxide production and oxygen consumption is referred to as the respiratory quotient. The fuel is a mixture of propane and butane

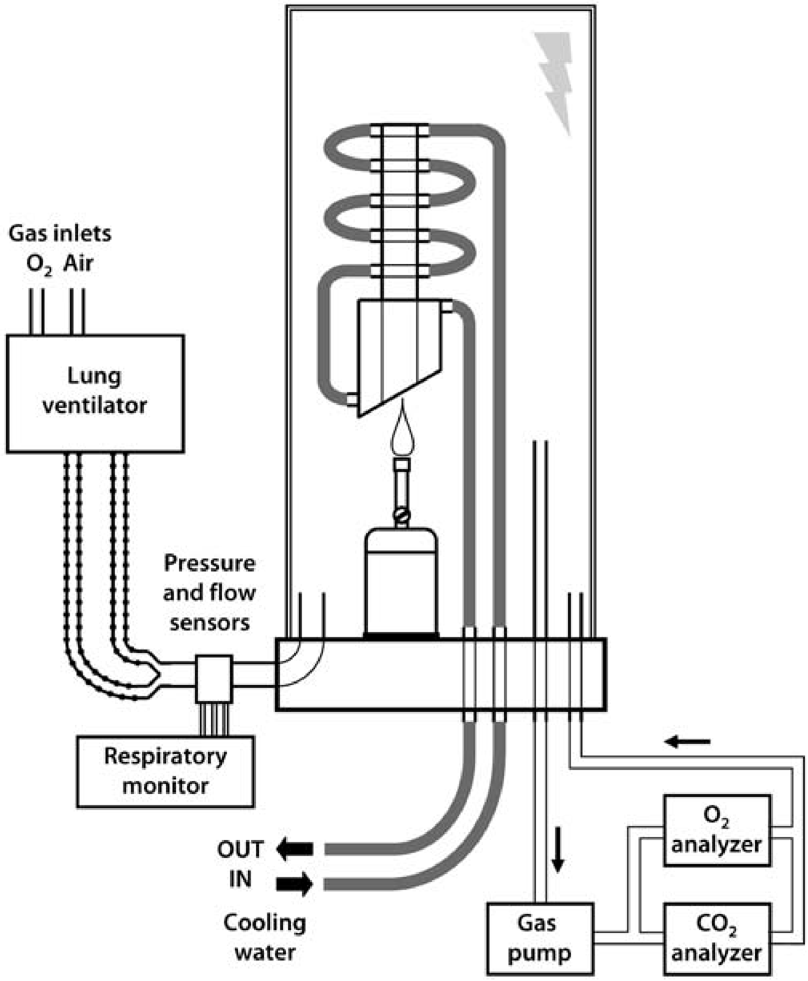


*Fig. 1: The overall scheme of the lung model.*

in a certain ratio depending on the gas cylinder producer. From the chemical equations describing propane and butane burning:

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O + \text{heat} \qquad \text{for propane,} \quad (1)$$

$$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O + \text{heat} \quad \text{for butane,} \quad (2)$$

the corresponding respiratory quotients for propane and butane are 3/5 = 0.6 and 8/13 = 0.615 respectively. As there is a very small difference between them, the total respiratory quotient is approximately 0.6 regardless of the actual propane/butane ratio in the cylinder. This ratio is suitable for the simulator, because respiratory quotient varies between 0.3 and 0.7 when lipids are metabolised, it is 0.8 for proteins and 1 for carbohydrates [2].

The amount of consumed oxygen and produced carbon dioxide is possible to set by adjusting propane-butane flow through the burner and consequently calculated from the above stated chemical equations (1) and (2).

The water cooler has two functions: firstly, it cools the flue-gas to a temperature similar to the temperature of the cooling water, and, secondly, the cooler assures the water vapour condensation. Considering the very low partial pressure of water vapour at the temperature of the cold water, nearly all water vapour from the flue-gas condensates in the cooler and therefore it does not affect the volume and/or compositions of the alveolar gas.

**The respiratory system model**

The model of the respiratory system is designed so that it simulates mechanical parameters of the respiratory system of an adult patient. As the most important parameter is


*Fig. 2: The realized lung model. The model is connected to Veolar (Hamilton Medical) ventilator.*

lung compliance, the inner volume of the model chamber is 137 liters. This volume represents – when the walls are rigid – a value of the corresponding adiabatic compliance equal to 0.966 L/kPa. The compliance of the respiratory system of an adult patient is approximately 1 L/kPa. The airway resistance can be changed using a set of exchangeable pneumatic resistors.

**The measurement and monitoring**

In order to assure the detailed monitoring of the ventilation and monitoring of the intrapulmonary conditions, two monitoring units have been introduced.

The first monitor is a monitor of ventilation, which consists of pressure and airflow sensors connected between the ventilator and the model (see Fig. 1) and the hardware of the monitor. The monitor provides values of the basic ventilatory parameters, it computes airway resistance and lung compliance in real time [3, 4] and it also records the pressure and airflow curves and provides some other information about the ventilatory regimen used.

The second monitoring unit consists of an oxygen analyzer, carbon dioxide analyzer and a pump that forces the alveolar gas to flow through the analyzers and then back to the alveolar space again. Two sampling pipes leading into the alveolar space allow these connections.

## Results

The designed and constructed model (Fig. 2), when connected to an artificial lung ventilator (Veolar, Hamilton Medical in Fig. 2), behaves as a real patient. Its mechanical parameters are similar to mechanical parameters of the respiratory system of an adult patient ($C_{RS\ model}$ = 0.966 L/kPa in model vs. $C_{RS}$ =1 L/kPa approximately in an adult). Concerning the simulation of metabolism, after adjustment of the propane-butane gas flow, the metabolic unit consumes approximately the same amount of oxygen as an adult patient. It results in those composition of the alveolar gas ($pO_2$ = 15–16 kPa) that is similar to alveolar gas inside the real lungs ($pO_{2\ model}$ = 13–14 kPa) when a standard ventilatory parameters are adjusted on the ventilator: tidal volume $V_T$ = 500 mL, ventilatory frequency $f$ = 20 bpm and oxygen fraction $F_IO_2$ = 0.21 in the inspiratory gas.

## Conclusion

The designed simulator is suitable for training in respiratory care, because it reacts to changes of the ventilatory regimen and ventilatory parameters correspondingly as an adult patient. The simulator is an educational device suitable for testing of the influence of the ventilatory parameters upon the intrapulmonary conditions similarly as during artificial lung ventilation of a human patient. Furthermore, the model is suitable for testing of ventilators as it has well-defined mechanical parameters and suitable monitoring capabilities.

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