Department of Electronic & Telecommunication Engineering,
University of Moratuwa,
Sri Lanka.

Simulation of Respiratory Mechanics

210218M Herath HMSI

Submitted in partial fulfillment of the requirements for the module
BM 2102 Modelling and Analysis of Physiological Systems

Date: 2023.03.03

Contents

1 Introduction

The human respiratory system is a complex mechanism that involves multiple physiological components. Understanding the dynamics of this system under various conditions is important for diagnosing and treating respiratory diseases.

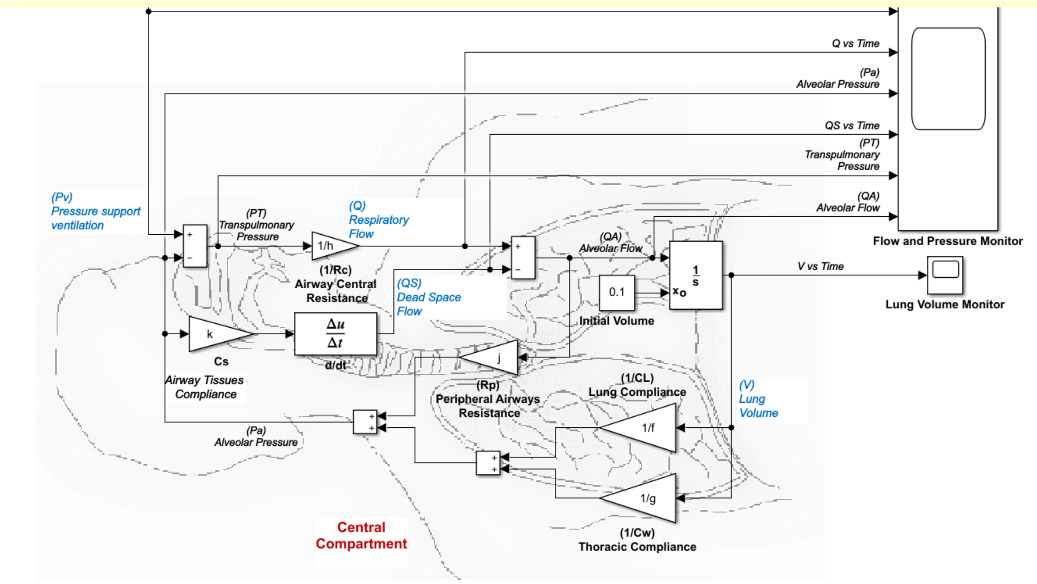

Figure 1: Simulink model which used to simulate the respiratory system

This report presents the simulation of respiratory mechanics under three different conditions: a normal adult, an adult with a restrictive pulmonary disease, and an adult with an obstructive pulmonary disease using the simulator developed by Leonardo Rodriguez and Acevedo Guerrero (2020). This simulink model allows for the visualization of the respiratory mechanics under different conditions. The aim of this report is to analyze and discuss the differences in minute ventilation for the same setting of the ventilator under the three different conditions. The findings of this report could provide valuable insights into the effects of different pulmonary diseases on respiratory mechanics.

2 Normal Person

Approximated values for a normal adult are used to simulate the respiratory mechanics. The following parameters are used for the simulation.[1] :

1. Central airway resistance(Rc) = 3 $H_2O/(L/s)$
2. Pheripheral airway resistance(Rp) = 0.5 $H_2O/(L/s)$
3. Compliance of lungs and chest wall(Cl and Cw) = 0.1 L/cm H_2O
4. Shunt compliance = 0.005 L/cm H_2O

For the first section the following values are used as parameters for the ventilator settings

1. BPM = 15
2. Positive End Expiratory Pressure = 0
3. Peak Pressure = 10

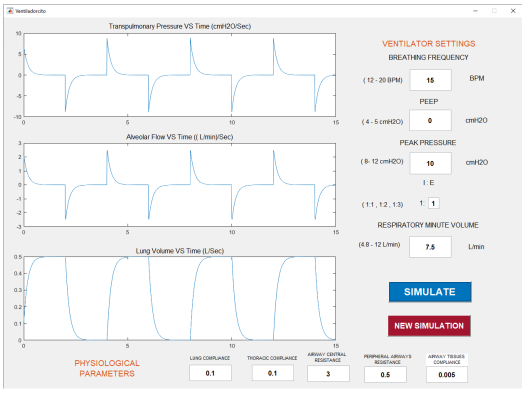

Figure 2: Ventilator settings for a normal person

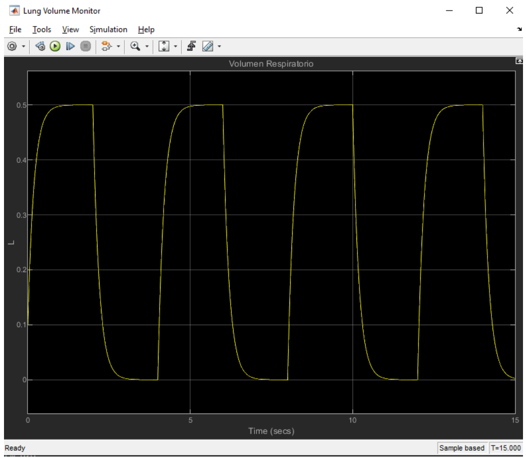

Figure 3: Minute Volume

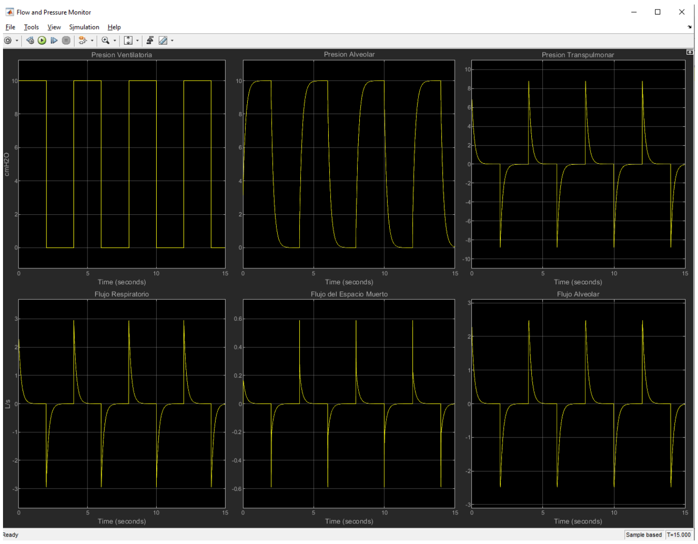

Figure 4: Flow and pressure values for a normal person

3 With a Restrictive Pulmonary Disease

3.1 Disease Conditions: Fibrosis

In a restrictive pulmonary disease usually pulmonary compliance is reduced which is due to reducing the resultant of chest wall compliance and lung compliance. This results in a reduced lung volume and increased work of breathing causing the difficulty in breathing also. It needs more pressure difference to take usual volume of air in to lungs. The following parameters are used for the simulation of a person with a restrictive pulmonary disease.

Fibrosis is a chronic progressive lung disease due to formation of scar tissue in the lung which leads to increase airway resistance and decrease lung compliance making them less capable of expanding and relaxing. For the simulation of a person with fibrosis, the following parameters are used.

1. Central airway resistance(Rc) = 5 $H_2O/(L/s)$
2. Pheripheral airway resistance(Rp) = 0.1 $H_2O/(L/s)$
3. Compliance of lungs(Cw) = 0.05 L/cm H_2O
4. chest wall compliance(Cl) = 0.05 L/cm H_2O
5. Shunt compliance = 0.005 L/cm H_2O

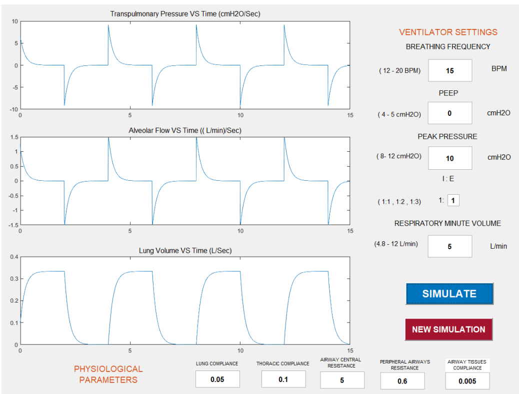

Figure 5: When used normal ventilator settings for a person with restrictive pulmonary disease

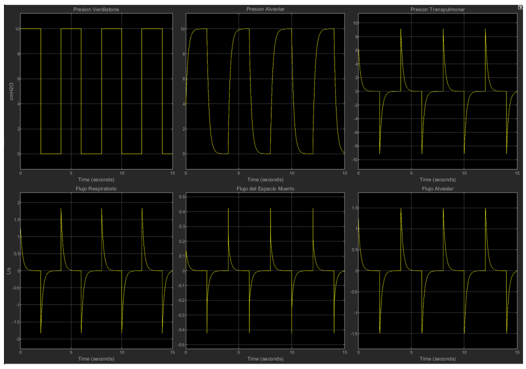

Figure 6: Flow and pressure values for a diseased person

In a restrictive pulmonary disease factors like central and pheripheral airway resistance, are leastly affected which cause to increase the real part of the impedance of the respiratory system.

3.2 Ventilator settings related to facilitate breathing

We can observe that the lung volume decreases due to the reduction of compliance. It causes the difficulty of expanding and relaxing of lungs leading to reduction of minute volume due to reduction of tidal volume. To accomodate normal oxygen flow for the patient peak pressure of the ventilator should be increased. Suggested values are,

1. BPM = 15

2. Positive End Expiratory Pressure = 2 - For reducing the work of breathing
3. Peak Pressure = 14 - To increase the pressure difference to take usual volume of air in to lungs
4. I:E ratio = 1:1

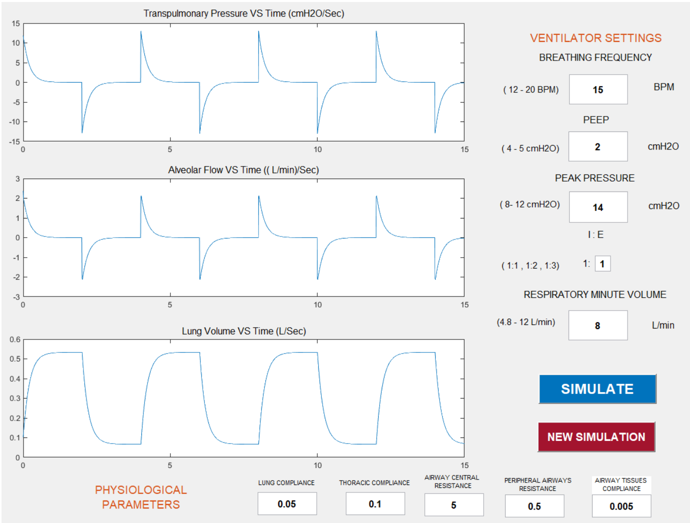

Figure 7: After adjusting ventilator settings for a person with obstructive pulmonary disease

4 With a Obstructive Pulmonary Disease

4.1 Disease Conditions: Pulmonary Emphysema

In obstructive pulmonary diseases, the airways are narrowed increasing the resistance to the flow or the lung compliance increases, which makes it difficult to exhale air from the lungs. In such a condition we can observe real part of the impedance of the respiratory system increases comparitive to the imaginary part.

The disease condition we are going to simulate is Pulmonary Emphysema which causes to enlargement of the air sacs (alveoli) in the lungs, leading to decreased elasticity and increased compliance of lungs. Minute volume is increased in this condition. The following parameters are used for the simulation of a person with a restrictive pulmonary disease.

1. Central airway resistance(Rc) = 3 cm $H_2O/(L/s)$
2. Pheripheral airway resistance(Rp) = 0.5 cm $H_2O/(L/s)$
3. Chest wall compliance(Cw) = 0.1 L/cm H_2O
4. Compliance of lungs(Cl) = 0.3 L/cm H_2O[1]
5. Shunt compliance = 0.005 L/cm H_2O

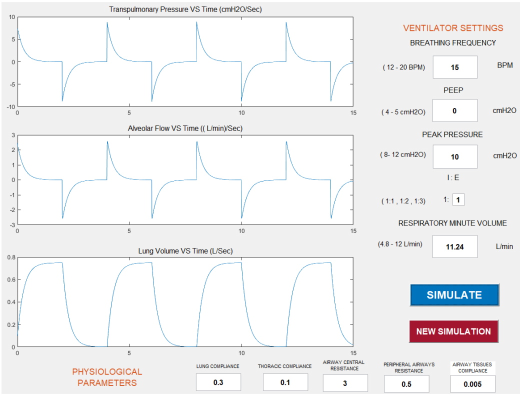

Figure 8: When used normal ventilator settings for a person with obstructive pulmonary disease

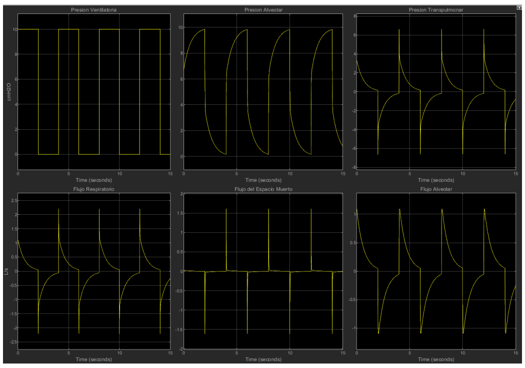

Figure 9: Flow and pressure values for a diseased person

4.2 Ventilator settings related to facilitate breathing

We can observe that the lung volume increases but transpulmonary pressure falls which causes for a lesser flow of air leading to breathing difficulties.This leads to reduction of oxygen in lungs So, to accomodate normal oxygen flow for the patient peak pressure of the ventilator should be increased. To keep alveoli open positive end expiratory volume should also needed to increase. Suggested values are,

1. BPM = 15
2. Positive End Expiratory Pressure = 3 - For keeping alveoli open and preventing them from collapsing
3. Peak Pressure = 12 - As increased airway resistance leads to expiratory flow limitation
4. I:E ratio = 1:3 - to prevent hyperinflation and allowing to take oxygenated air in

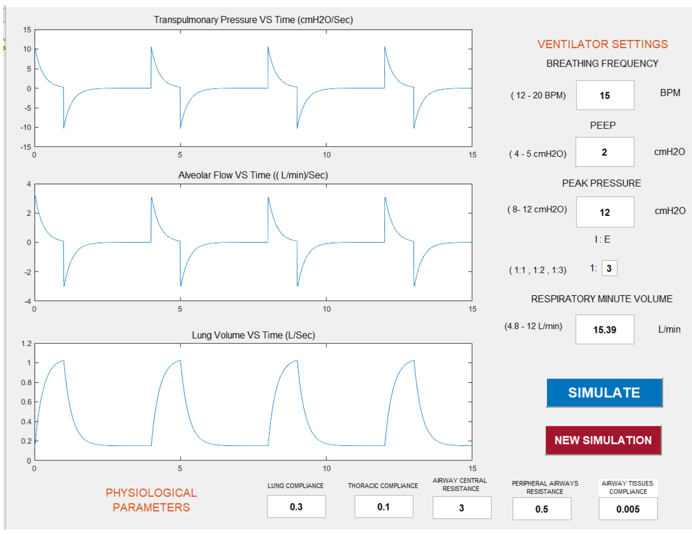

Figure 10: After adjusting ventilator settings for a person with obstructive pulmonary disease

5 Differences in Minute Ventilation for the Same Setting of the Ventilator

$$\text{Minute Volume} = \text{Tidal Volume} \times \text{Respiratory Rate} \tag{1}$$

The minute ventilation is the volume of air breathed in one minute. It is calculated by multiplying the tidal volume by the respiratory rate. Although we used the same setting of the ventilator for different conditions, minute volume can vary due to various factors such as,

- **Patient's disease conditions:** As we seen in the above changing of pulmonary impedances cause to change the minute volume. Person with obstructive lung disease tend to have increased minute volume than the normal person while a person with restrictive lung disease tend to have decreased minute volume than the normal person.
- **Anatomical parameters of the patient:** The physical parameters of the patient such as height, weight causes to change the lung capacity(tidal volume) which causes to show different minute volumes for two healthy persons.
- **Patient's effort:** The patient's effort to breath also causes to change the minute volume. If the patient is in a relaxed state, the minute volume will be less than the patient who tries to breath deeply.

References

[1] Simulation of Respiratory Mechanics on Simulink with GUI, available at `https://www.mathworks.com/matlabcentral/fileexchange/75335-simulation-of-respiratory-mechanics-on-simulink-with-gui`