DEPARTMENT OF ELECTRONIC AND TELECOMMUNICATION ENGINEERING

UNIVERSITY OF MORATUWA

BM2101

Modeling and Analysis of Physiological Systems

Simulation of Respiratory Mechanics

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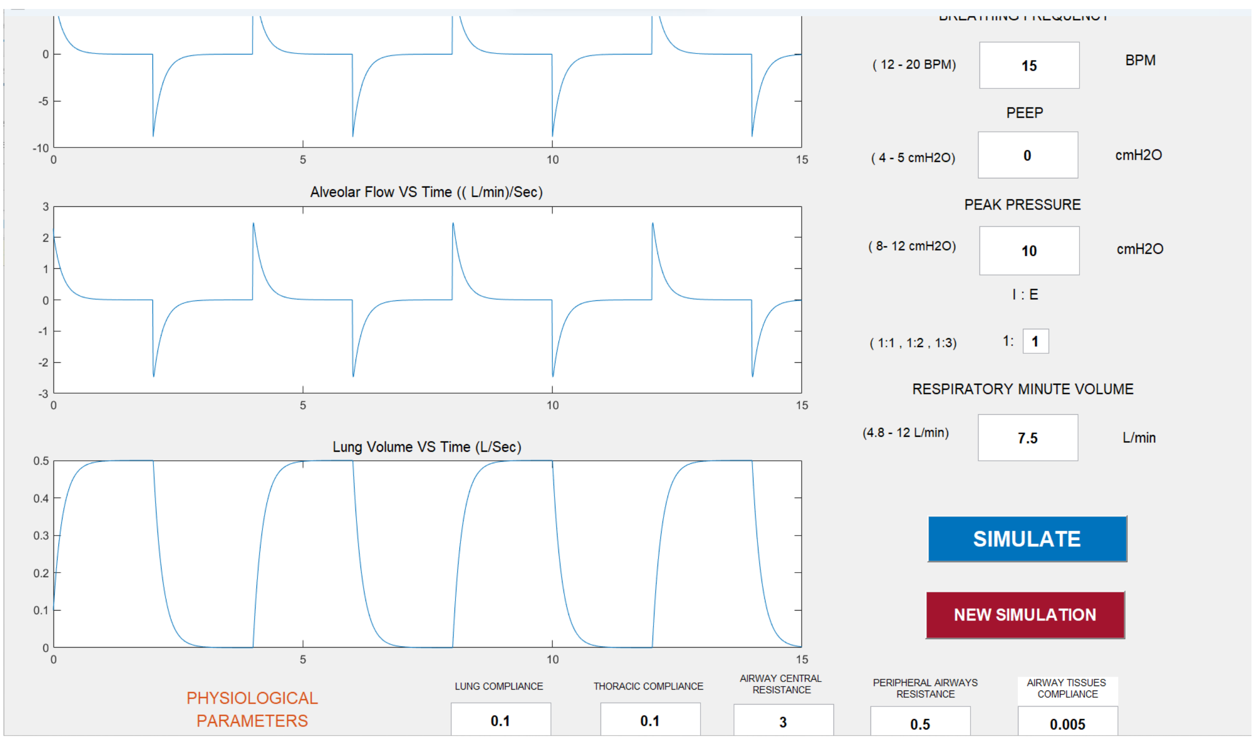
1. A normal person

A normal person has the following values for lung compliance, thoracic compliance, airway central resistance, peripheral airway resistance, and airway tissue compliance:

- Lung compliance = 0.1 L/cmH_2O
- Thoracic compliance = 0.1 L/cmH_2O
- Airway central resistance = 3 cmH_2O/(L/s)
- Peripheral airway resistance = 0.5 cmH_2O/(L/s)
- Airway tissue compliance = 0.005 L/cmH_2O

When this person is connected to a ventilator with the following settings:

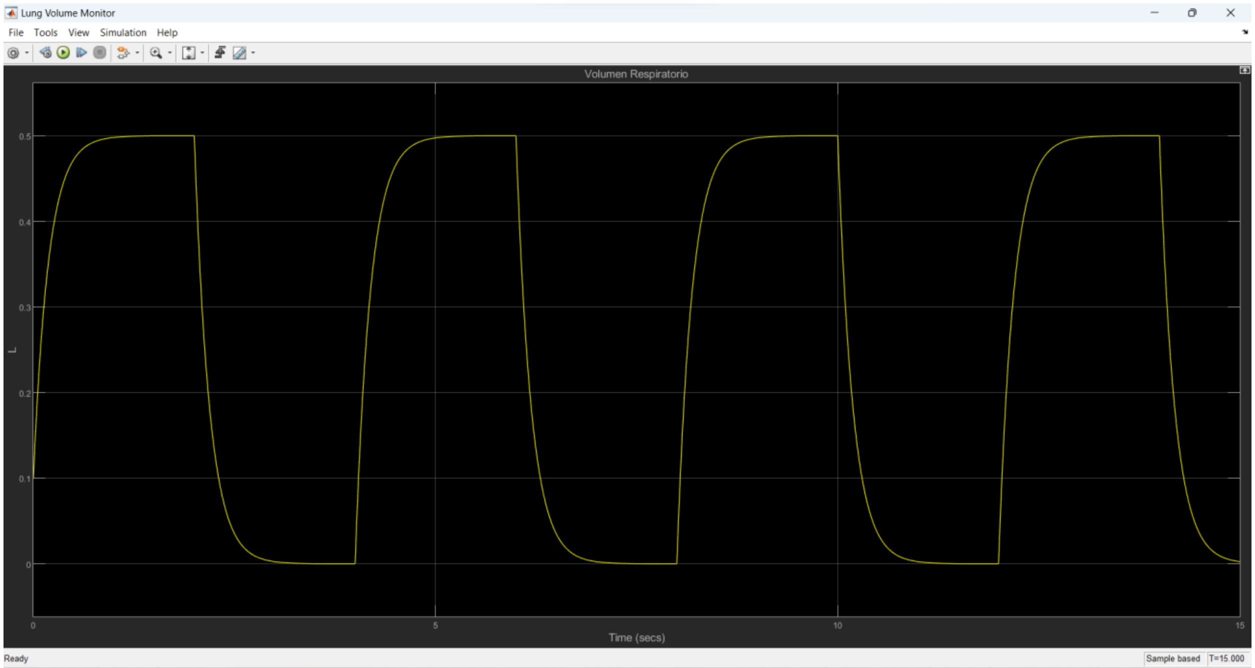
- Breathing frequency = 15 breaths/min
- PEEP = 0 cmH_2O
- Peak pressure = 10 cmH_2O

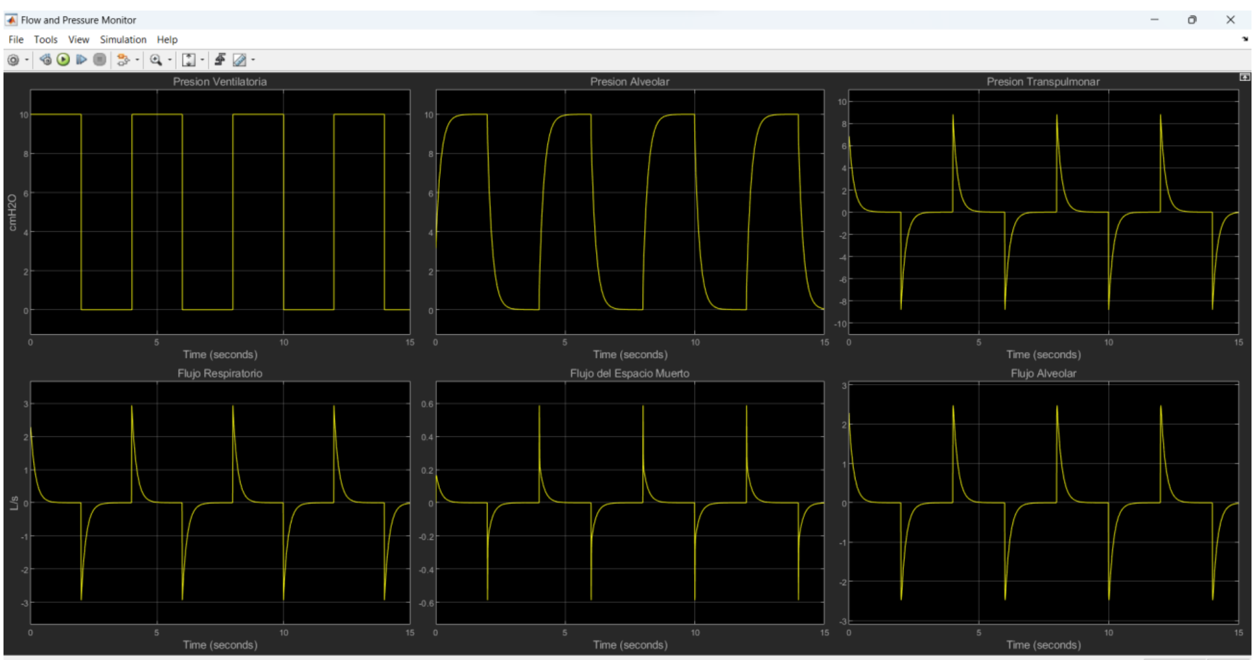


Here we can see the minute ventilation (MV) is 7,500 mL/min.

Minute ventilation is the volume of air that enters the lungs per minute. It is calculated as the product of respiratory rate (RR) and tidal volume (VT). In this case, the RR is 15 breaths/min and the VT is 500 mL, so the MV is 7,500 mL/min.

The following graphs are shown for further explanations.





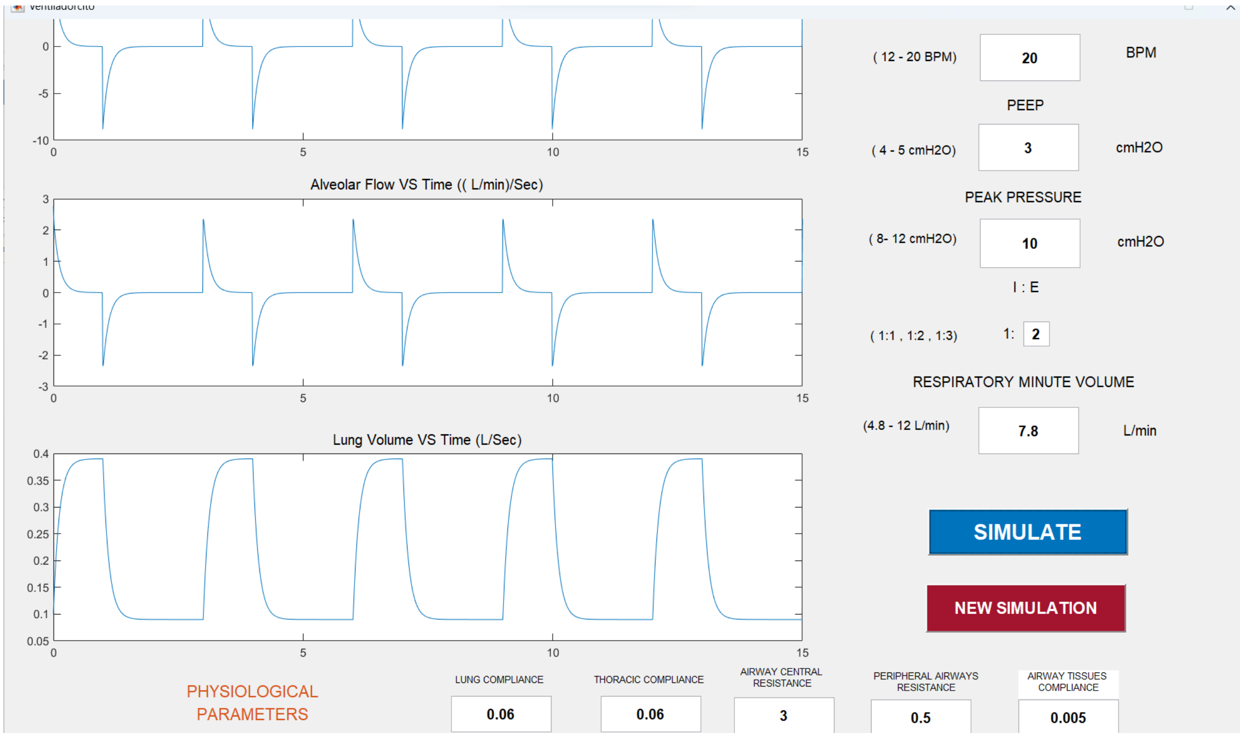
2. **Restrictive pulmonary disease**

- Lung compliance and thoracic compliance are decreased. This means that it takes more pressure to inflate the lungs, which will reduce the tidal volume and minute ventilation.
- Airway central resistance, peripheral airway resistance, and airway tissue compliance are not affected.

  Therefore, Let's take the following values.

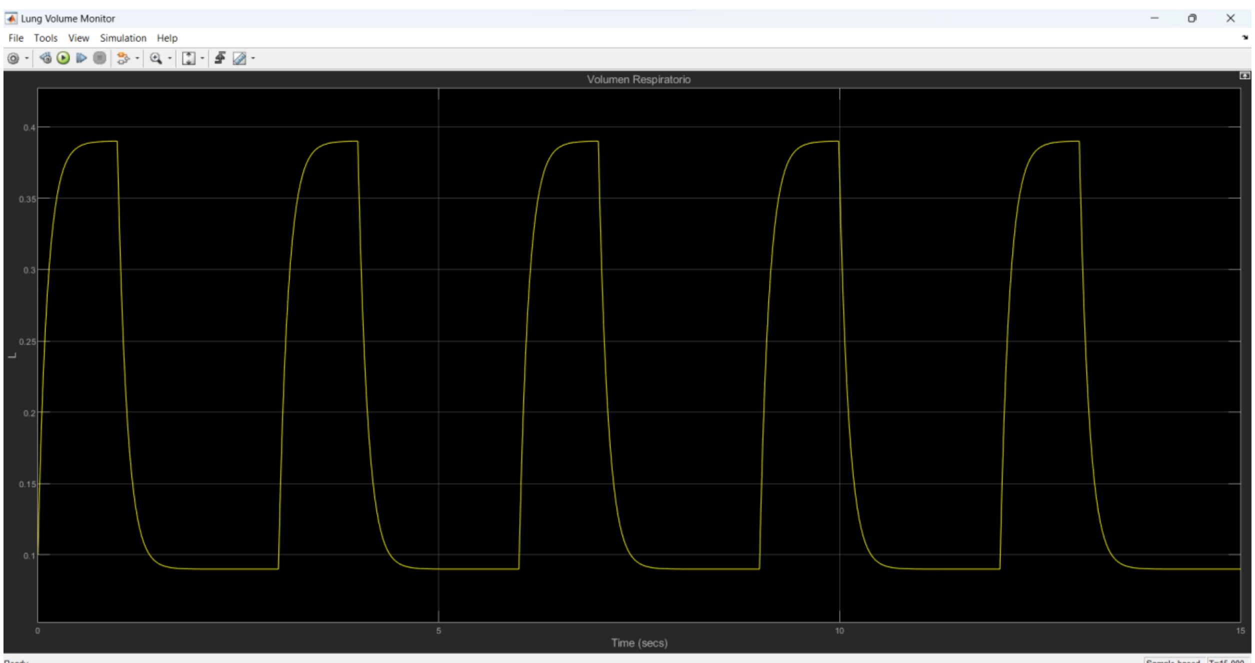
  - Lung compliance = 0.06 L/cmH_2O
  - Thoracic compliance = 0.06 L/cmH_2O
  - Airway central resistance = 3 cmH_2O/(L/s)
  - Peripheral airway resistance = 0.5 cmH_2O/(L/s)
  - Airway tissue compliance = 0.005 L/cmH_2O

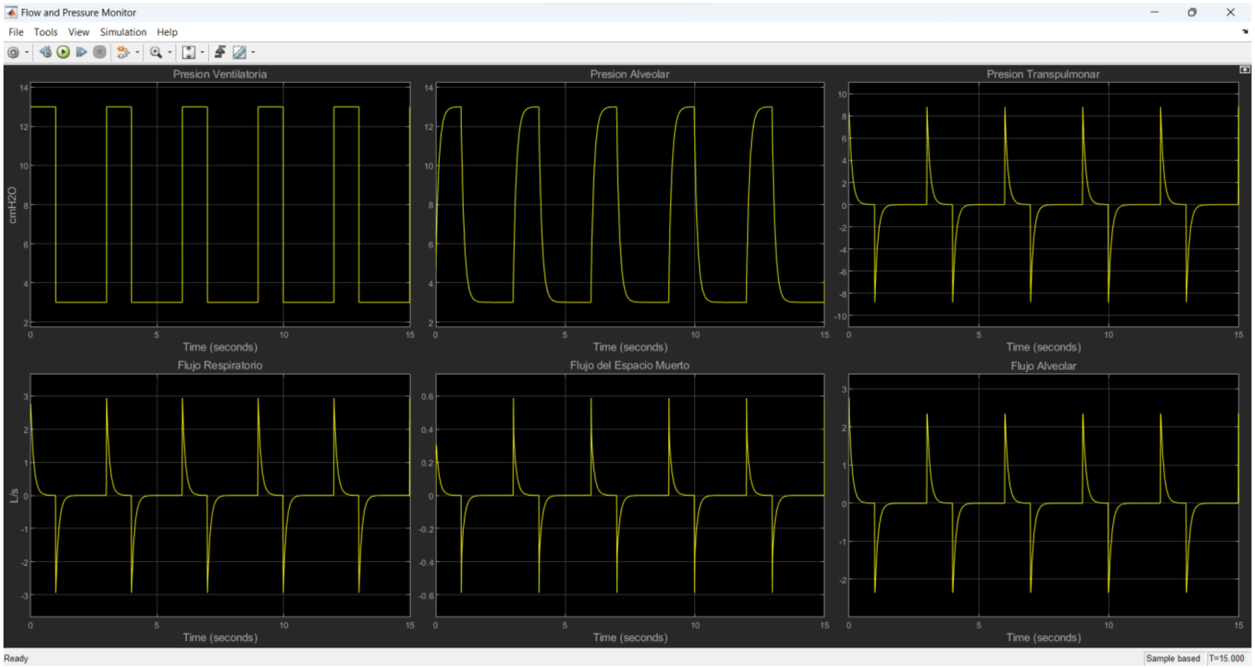
- The ventilator settings need to be adjusted. The peak pressure needs to be increased to ensure that the lungs are adequately inflated. The PEEP (positive end-expiratory pressure) also needs to be increased to help keep the alveoli open at the end of expiration. The breathing frequency may also need to be increased.
- Here are the adjusted ventilator settings:
  - Breathing frequency = 20 breaths/min
  - PEEP = 3 cmH_2O
  - Peak pressure = 10 cmH_2O
  - I:E ratio = 1:2



Here we can see the minute ventilation (MV) is 7,800 mL/min. It is in an acceptable range.

The following graphs show this in more detail.





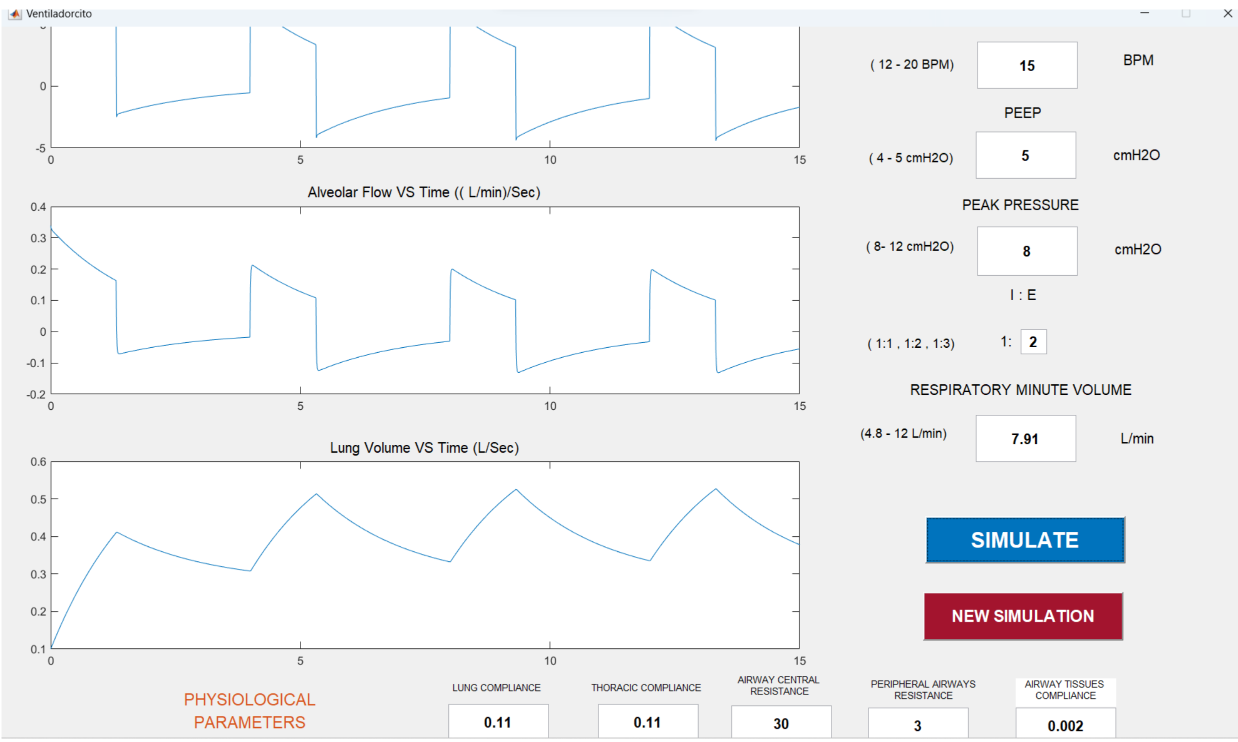
3. Obstructive pulmonary disease

- Lung compliance and thoracic compliance are increased. This means that it takes less pressure to inflate the lungs, but the airways are narrowed, which makes it difficult to exhale.
- Airway central resistance, peripheral airway resistance, and airway tissue compliance are affected. The airway central resistance and peripheral airway resistance are increased, which makes it more difficult to exhale. The airway tissue compliance is decreased, which makes the lungs more rigid and difficult to inflate.

  Therefore, Let's take the following values.

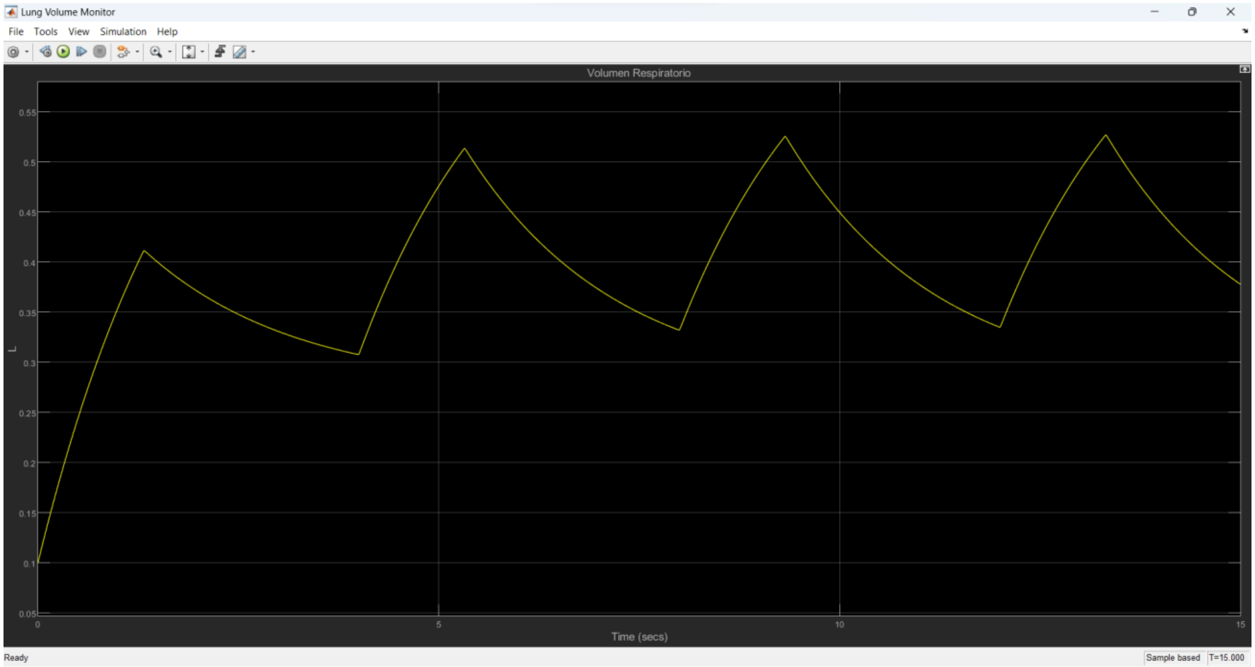
  - Lung compliance = 0.11 L/cmH_2O
  - Thoracic compliance = 0.11 L/cmH_2O
  - Airway central resistance = 30 cmH_2O/(L/s)
  - Peripheral airway resistance = 3 cmH_2O/(L/s)
  - Airway tissue compliance = 0.002 L/cmH_2O

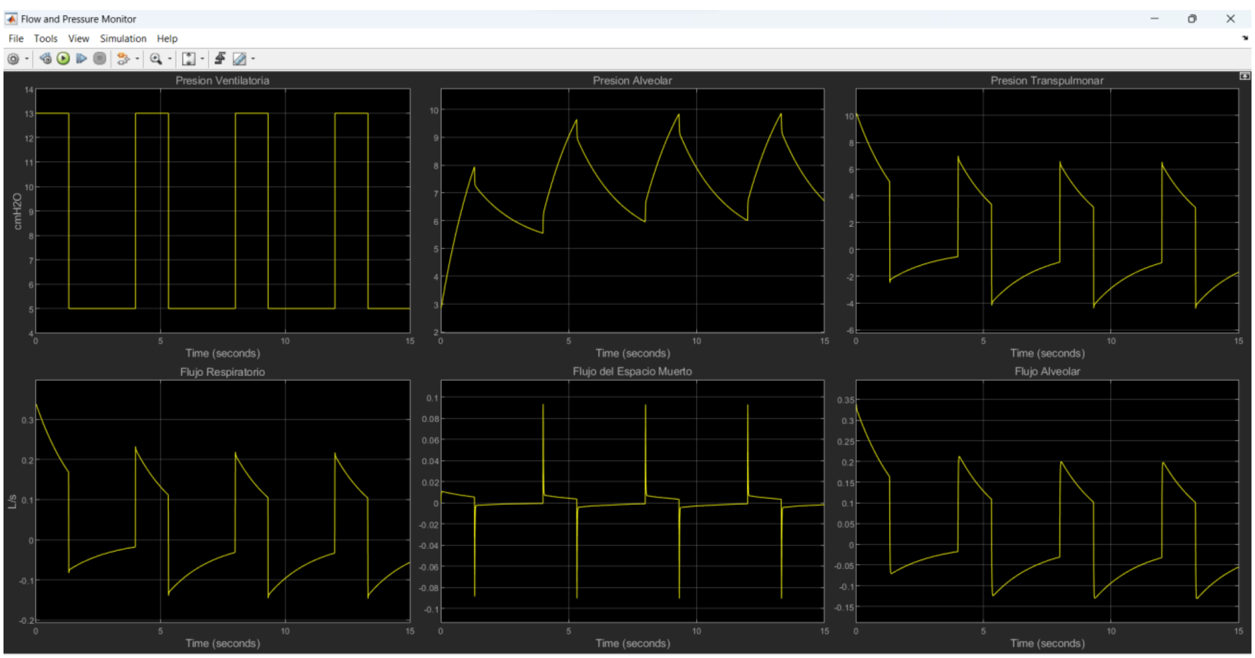
- The ventilator settings need to be adjusted. The peak pressure needs to be decreased to prevent barotrauma. The PEEP (positive end-expiratory pressure) also needs to be increased to help keep the alveoli open at the end of expiration. The breathing frequency may also need to be increased.
- Here are the adjusted ventilator settings:
    - Breathing frequency = 15 breaths/min
    - PEEP = 5 cmH_2O
    - Peak pressure = 8 cmH_2O
    - I:E ratio = 1:2



Here we can see the ventilator settings are helping the patient to breathe adequately. The minute ventilation (MV) is 7,910 mL/min.

The following graphs show this in more detail.





Differences in minute ventilation for the same setting of the ventilator

Differences in minute ventilation for the same setting of the ventilator refers to the variations in the volume of air entering the lungs per minute (minute ventilation or MV) for different individuals, even when they are set on the same ventilator settings.

This phenomenon occurs due to various factors that can influence a person's respiratory mechanics and demand for ventilation.

1. Underlying Condition: Patients with different underlying respiratory conditions may have distinct respiratory rates and tidal volumes, even when placed on the same ventilator settings. For instance, a patient with pneumonia may have a higher respiratory rate and lower tidal volume compared to a patient with asthma.
2. Patient Size and Lung Capacity: Individual patients may have varying lung capacities and body sizes. Larger patients typically have larger lungs and may require higher minute ventilation compared to smaller individuals.
3. Ventilator Model and Algorithm: Different ventilator models may use different algorithms for calculating minute ventilation based on the input parameters. As a result, the same set of ventilator settings on two different ventilators might produce slightly different minute ventilation values.
4. Patient Effort: Patients who are actively engaged in breathing efforts while on a ventilator may influence minute ventilation. In contrast, patients who are sedated or lack respiratory drive might show variations in minute ventilation.

Monitoring minute ventilation is crucial in ventilator management to ensure patients receive an appropriate amount of ventilation. If minute ventilation is too low, it may lead to inadequate oxygenation and ventilation. On the other hand, if minute ventilation is too high, the patient may be at risk of complications such as barotrauma, which is a lung injury caused by excessive pressure.

This is an example for this.

Assume two patients, Patient A and Patient B, both require respiratory support and are placed on the same ventilator model with the following settings:

- Respiratory Rate (RR): 20 breaths per minute
- Tidal Volume (VT): 500 mL

According to the provided ventilator settings, the calculated minute ventilation for both patients would be:

Minute Ventilation (MV) = RR (breaths per minute) × VT (mL) MV = 20 breaths/min × 500 mL/breath = 10,000 mL/min

Now let's consider the influence of individual factors that can lead to differences in minute ventilation between Patient A and Patient B:

Patient A: Patient A has pneumonia, which can lead to increased respiratory rate and shallow breathing due to compromised lung function. As a result, Patient A exhibits the following parameters:

- RR: 25 breaths per minute
- VT: 400 mL

For Patient A, the calculated minute ventilation would be:

MV = 25 breaths/min × 400 mL/breath = 10,000 mL/min

Despite having the same ventilator settings as Patient B, Patient A achieves the same minute ventilation due to the higher respiratory rate compensating for the reduced tidal volume.

Patient B: Patient B has asthma, which may cause the airways to constrict, resulting in difficulty exhaling. Consequently, Patient B demonstrates the following parameters:

- RR: 18 breaths per minute
- VT: 600 mL

For Patient B, the calculated minute ventilation would be:

MV = 18 breaths/min × 600 mL/breath = 10,800 mL/min

Although the ventilator settings are identical for both patients, Patient B achieves a higher minute ventilation compared to Patient A due to the larger tidal volume compensating for the lower respiratory rate.