So far…

- We've developed a general energy balance
- We've developed a general material balance
- We've only actually looked at systems that are under steady state condition
- Now we are going to do more complicated problems
  - Ones that change with time, or

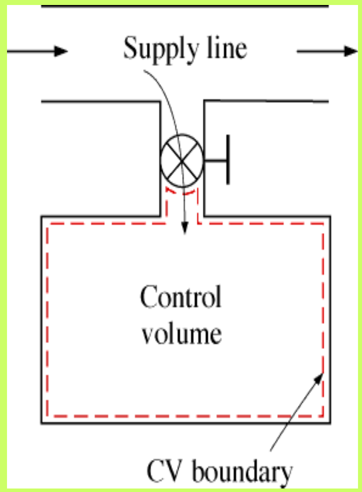
Unsteady (Transient) flow problems

Unsteady flow problems

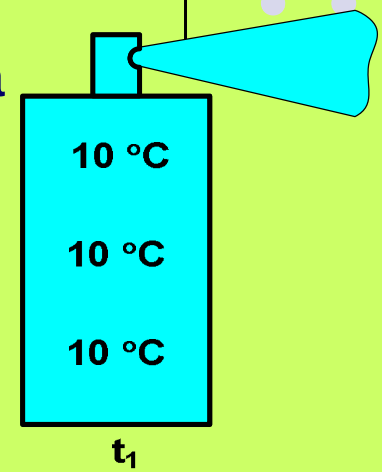
- Unlike steady-flow processes, unsteady-flow process start and end over some finite time period instead of continuing indefinitely.
- Therefore, we deal with change that occur over some time interval Dt instead of the rate of change.

Some familiar *unsteady-flow* processes are (for example)

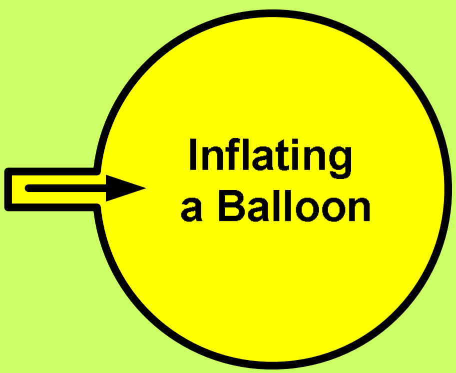
- **the charging of rigid vessels from supply lines.**



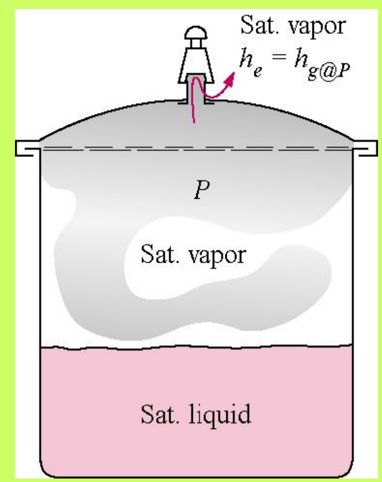
- **discharging a fluid from a pressurized vessel,**



- **inflating tires or balloons.**



- **cooking with an ordinary pressure cooker.**



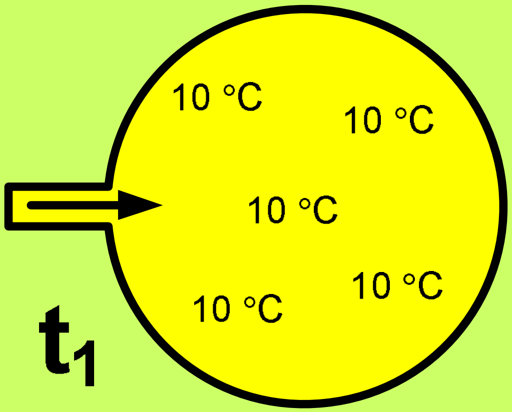
Such problems can be solved by simplified model called..

Uniform State Uniform Flow model

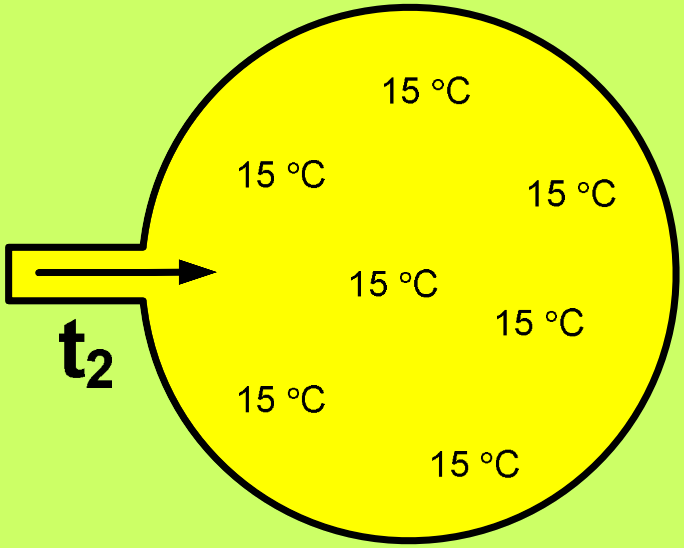
There are 2 main assumptions in this model..

Assumption 1: Uniform State over the CV

- **The state of the mass within the CV may change with time but in a uniform manner.**
- **Uniform means that the fluid properties do not change over the control volume.**

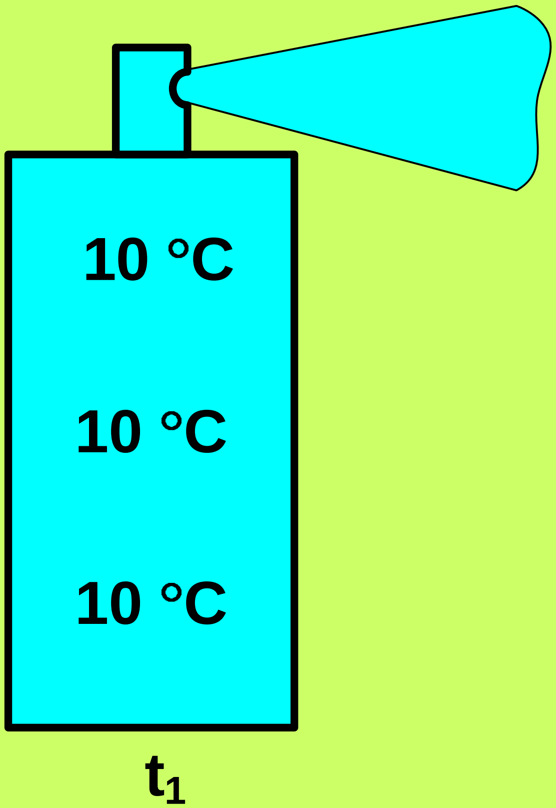


Balloon at t= t_1



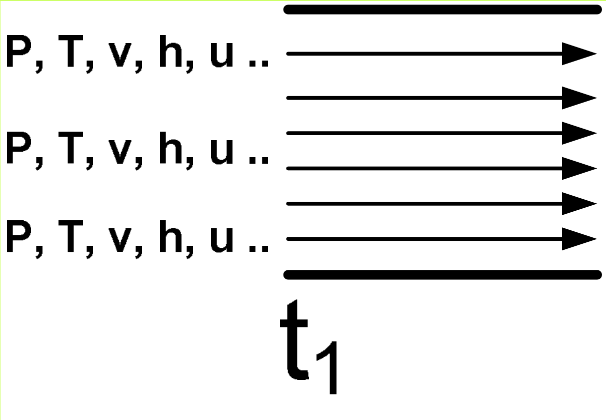
Balloon at t= t_2

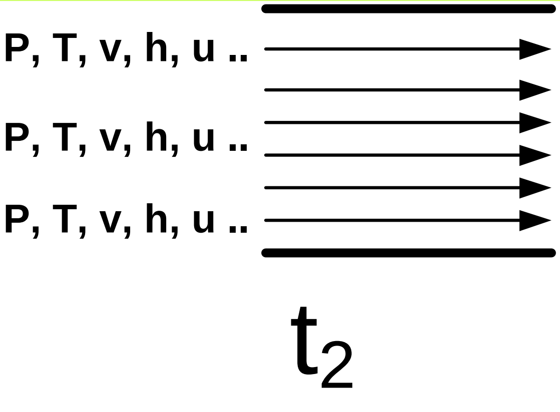
Another example..
Discharging a pressurized can.



Assumption 2: Uniform Flow over inlets and exits

- **The fluid flow at inlets/exits is assumed to be uniform and steady.**
- **Uniform means that the fluid properties do not change over the cross section of the inlet/exit.**
- **Steady means that the fluid properties do not change with time over the cross section of the inlet/exit.**





Mathematical Analysis:

Recall the general mass balance equation

$$\sum m_{in} - \sum m_{exit} = \Delta m_{system} = m_2 - m_1$$

Recall also the general energy balance equation

$$Q - W + \sum m_i \left(h_i + \frac{\vec{V}_i^{\,2}}{2} + g z_i \right) - \sum m_e \left(h_e + \frac{\vec{V}_e^{\,2}}{2} + g z_e \right) = \boxed{\Delta E_{cv}}$$

Let us analyze the right side first then the left side of this equation

$$\Delta E_{CV} = \Delta U + \underbrace{\Delta KE}_{} + \underbrace{\Delta PE}_{}$$

KE of the CV

PE of the CV

Usually, they both equal 0, therefore

$$\Delta E_{CV} = \Delta U = U_2 - U_1 = \overbrace{m_2 u_2}^{E_2} - \overbrace{m_1 u_1}^{E_1}$$

At time 2

At Time 1

$$\Delta E_{CV} = m_2 u_2 - m_1 u_1$$

the left side

$$Q + \sum m_i \left(h_i + \frac{\vec{V}_i^2}{2} + g z_i \right) - W - \sum m_e \left(h_e + \frac{\vec{V}_e^2}{2} + g z_e \right) = \Delta E_{cv}$$

In many cases, we can neglect both the KE and PE of the flowing fluid (ie at inlets/exits)

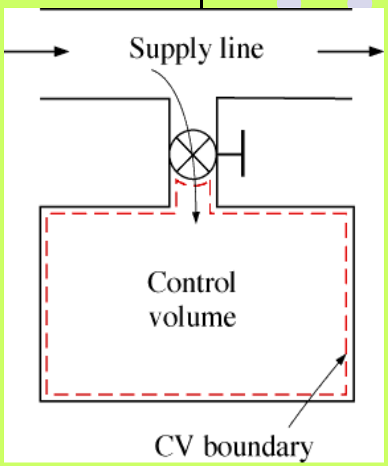
$$Q - W + \underbrace{\sum m_i h_i}_{inlet} - \underbrace{\sum m_e h_e}_{exit} = \underbrace{m_2 u_2}_{time\ 2} - \underbrace{m_1 u_1}_{time\ 1}$$

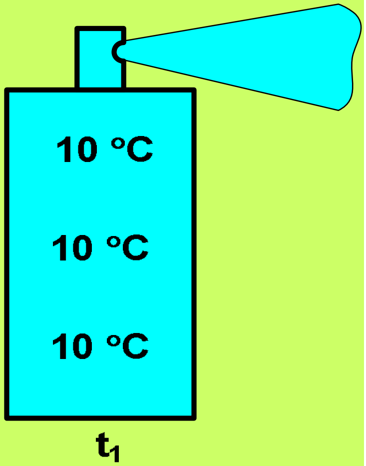
Assuming only a single inlet and a single exit stream

$$Q - W + m_i h_i - m_e h_e = m_2 u_2 - m_1 u_1$$

Charging (discharging) Problems

- Charging (or discharging) vessels is an important engineering application that is modeled as USUF process.
- There is no exit in the charging process and no inlet in the discharging process.
- What happens to the temperature when you fill an empty tank with air?
  - The air gets hot. Why?
- What happens to the temperature when you use a bottle of canned air?
  - The bottle air gets cold. Why?
- We will answer these questions shortly!





Mass balance in Charging Problems

Recall

$$\sum m_{in} - \sum m_{exit} = m_2 - m_1$$

Is there mass exiting? No

Is there mass at initial state? No

For one inlet, we have:

$$m_i = m_2$$

Energy balance in Charging Problems

Recall

$$Q - W + m_i h_i - m_e h_e = m_2 u_2 - m_1 u_1$$

Is there heat transfer?	No
Is there work?	No
Is there energy transferred out by mass?	No
Was there an energy at time 1?	No

Energy balance in Charging Problems (continued..)

Therefore

$$m_i h_i = m_2 u_2$$

But from mass balance: $m_i = m_2$

$$\therefore h_i = u_2$$

$$u_i + P_i v_i = u_2$$

That means the temperature in the tank is higher than the inlet temperature

$$\therefore u_2 > u_i$$

It takes energy to push the air into the tank (flow work). That energy is converted into internal energy.

Mass and Energy balance in discharging Problems

$$m_e = m_1$$

$$m_e h_e = m_1 u_1$$

$$\therefore h_e = u_1$$

That means the temperature in the tank is lower than the exit temperature

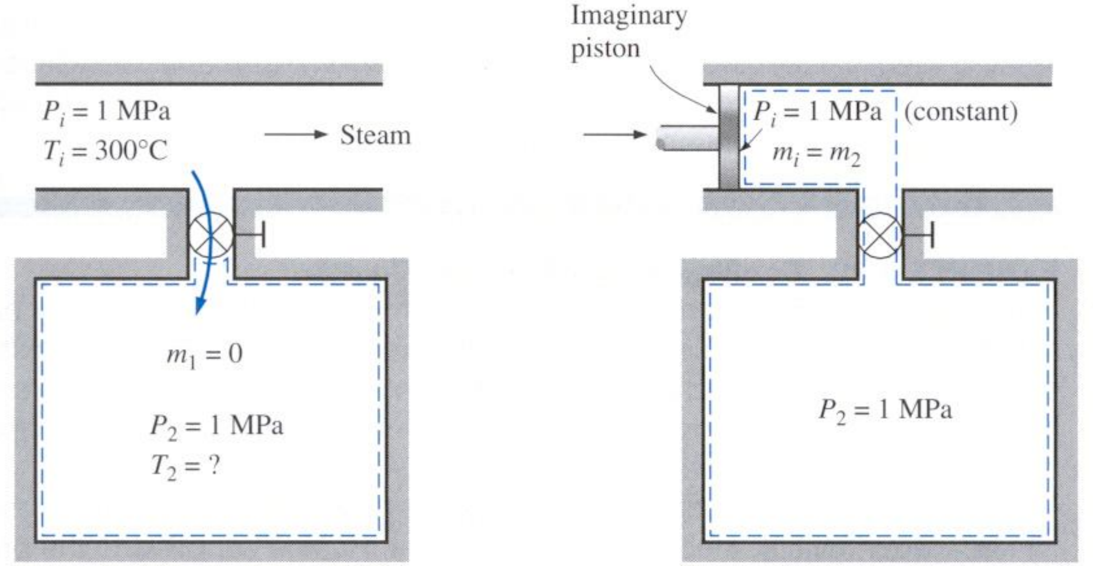
$$u_e + P_e v_e = u_1$$

It takes energy to push the air out of the can (flow work).
That energy comes from the energy of the air that remains in the can.

$$\therefore u_1 > u_e$$

Example(4-17): Charging of a Rigid Tank by Steam

A rigid, insulated tank that is initially evacuated is connected through a valve to a supply line that carries steam at 1 MPa and 300°C. Now the valve is opened, and steam is allowed to flow slowly into the tank until the pressure reaches 1 MPa, at which point the valve is closed. Determine the final temperature of the steam in the tank.



(a) Flow of steam into an evacuated tank (b) The closed-system equivalence

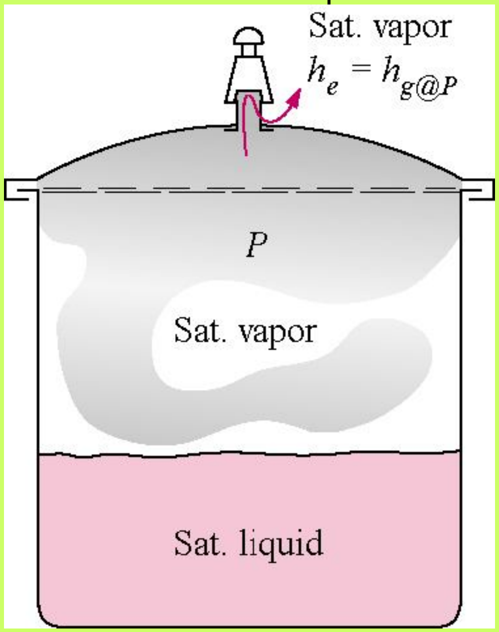
<Answer: 456.2°C>

Example (4-18): Cooking with a Pressure Cooker

A certain pressure cooker has a volume of 6 L and operating pressure of 75 kPa gage. Assuming an atmospheric pressure of 100 kPa. Initially, it contains 1 kg of water. Heat is supplied to the pressure cooker at a rate of 500 W for 30 min after the operating pressure is reached. Determine:

(a) the temperature at which cooking takes place and

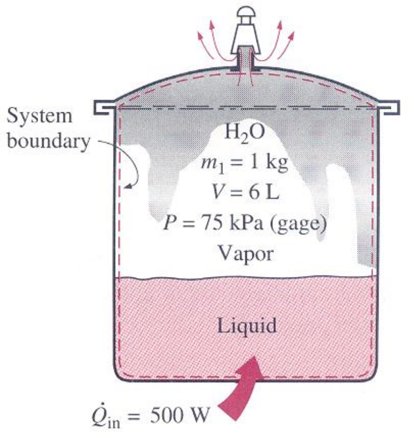
(b) the amount of water left in the pressure cooker at the end of the process.



***<Answer: (a) 116.1^{o}C, (b) 0.6 kg*.**

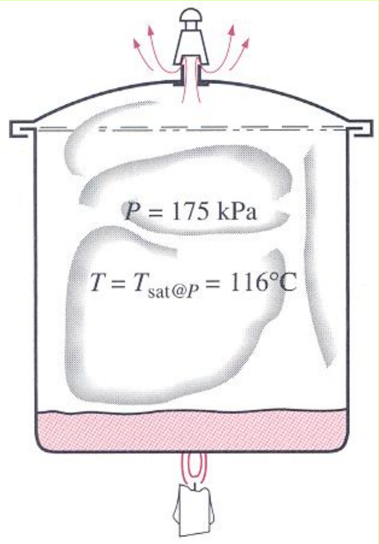
Solution:

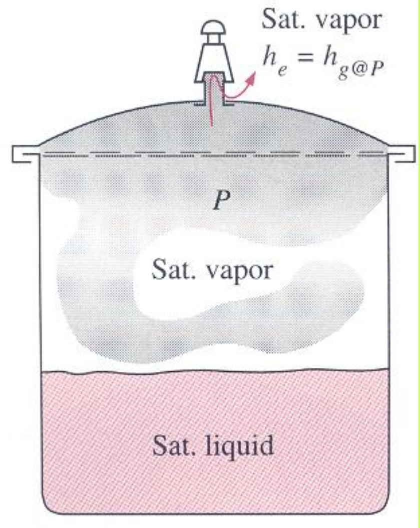
(1) This is a discharging problem.



(3) The steam leaving the cooker will be saturated vapor.

(2) As long as there is a liquid, the phase will be sat. mixture and the temperature will be sat. temperature at the cooking pressure.





Time-dependent inlet/exit conditions

- We assumed that the flow into or out of the CV is steady.
- How would we handle inlet or exit conditions that change with time?
- The best we can do at this point is to take the time average.
- to see this approximation, see next slide….

- Consider air coming out of a can. It gets colder with time.
- That means the exit conditions are not constant since T_e is decreasing with time.
- So, how can we deal with the 1st low

$$h_{ave} = \frac{h_2 + h_1}{2}$$

$$Q - W + m_i h_i - m_e h_e = m_2 u_2 - m_1 u_1$$

What conditions should you use for h_e?