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Next >

# 8.2.5 Water emptying from a tank

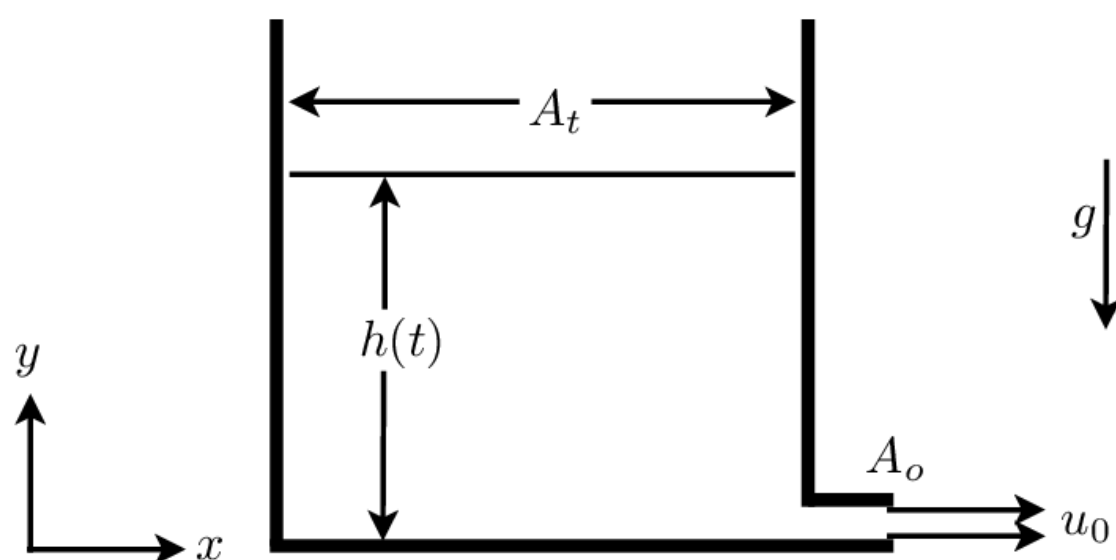
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## MO2.4

Consider a tank holding water with density  $\rho$ . The upper surface of the water is exposed to the atmosphere (i.e. the tank is open on top). The cross-sectional area of the tank is  $A_t$ . The water is emitted from a small orifice at the bottom of the tank. As the water exits through the orifice, the water height  $h(t)$  changes. Let the velocity of the water at this orifice be  $u_o$  and the cross-sectional area of the orifice be  $A_o$  (which we will assume is much smaller than  $A_t$ , i.e.  $A_o/A_t \ll 1$ ). This exit velocity can be estimated assuming idealized flow conditions as

$$u_o = \sqrt{2gh} \quad (8.20)$$

Thus,  $u_o$  decreases as  $h$  decreases.



**Figure 8.5:** Water emptying from a tank

The key principle in deriving this model differential equation known as the conservation of mass and it states that the mass of water in the tank ( $m_w(t)$ ) decreases by the rate at which the water (mass) is emitted at the orifice. Let's call the rate at which mass flows out of the orifice  $\dot{m}_o$ . Then conservation of mass gives,

$$\frac{dm_w}{dt} = -\dot{m}_o \quad (8.21)$$

At any instant, the mass of water in the tank,  $m_w(t)$  is related to the volume of water  $\text{Vol}_w(t)$  and the density  $\rho$  through  $m_w = \rho \text{Vol}_w$ . The water volume is simply  $A_t h$ . Thus,

$$m_w(t) = \rho \text{Vol}_w(t) = \rho A_t h(t) \quad (8.22)$$

The mass flow rate out of the orifice can be shown to be  $\dot{m}_o = \rho A_o u_o$  which upon substitution of Equation (8.20) gives,

$$\dot{m}_o = \rho A_o \sqrt{2gh} \quad (8.23)$$

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2

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experimental results.

### Remark 9.

*The exact solution for the differential model equation (i.e.*