Thermodynamics and Heat Transfer Assignment Week 1
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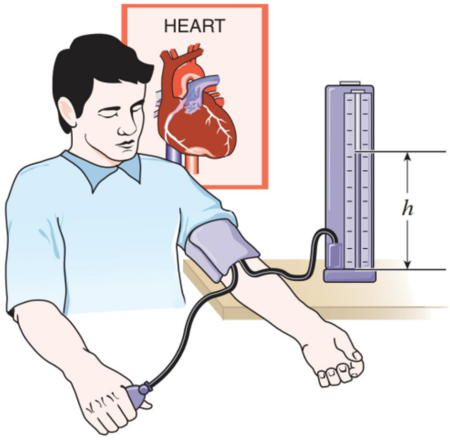
1. The maximum blood pressure in the upper arm of a healthy person is about 120 mmHg. If a vertical tube open to the atmosphere is connected to the vein in the arm of the person, determine how high the blood will rise in the tube. Take the density of the blood to be 1050 kg/m3. **(15 Points)**



Exercise 1:

$P_{max\ blood} = 120\ mm\ Hg = 15998\ Pa$

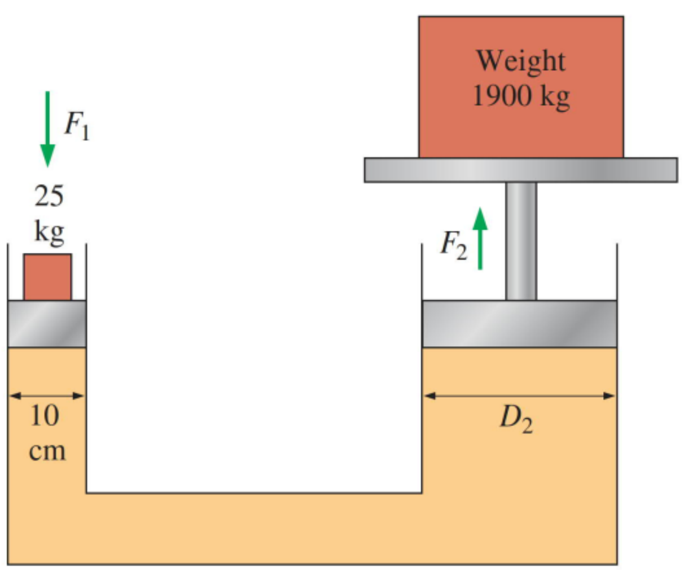
$P_{atm} = 101.3\ Pa$, $\rho_{blood} = 1050\ kg/m^3$

Manometer pressure: $P_{max\ blood} = P_{atm} + (\rho_{blood}\, g\, h_{blood})$

$\Rightarrow 15998\ Pa = 101.3\ Pa + 1050 \times 9.81 \times h_{blood}$

$\Rightarrow h_{blood} = \dfrac{15998 - 101.3}{1050 \times 9.81} = 1.543\ (m)$ (answer)

2. A hydraulic lift is to be used to lift a 1900-kg weight by putting a weight of 25 kg on a piston with a diameter of 10 cm. Determine the diameter of the piston on which the weight is to be placed.? **(15 Points)**



Exercise 2:

$m_1 = 25\ kg$, $m_2 = 1900\ kg$, $D_1 = 10\ cm \Rightarrow D_2 = ?\ cm$

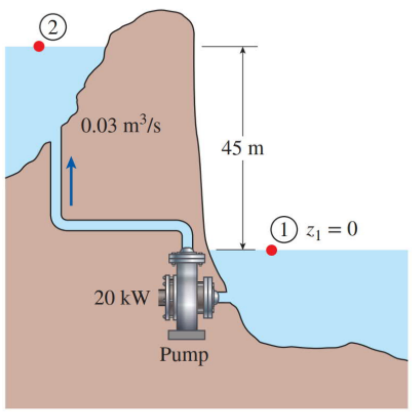
Hydrostatic pressure equation : $P_1 + \rho g h - \rho g h = P_2$

$$\Rightarrow P_1 = P_2 \Rightarrow \frac{F_1}{A_1} = \frac{F_2}{A_2} = \frac{m_1 g}{\frac{\pi D_1^2}{4}} = \frac{m_2 g}{\frac{\pi D_2^2}{4}} \Rightarrow \frac{m_1}{D_1^2} = \frac{m_2}{D_2^2}$$

$$\Rightarrow D_2^2 = \frac{D_1^2 m_2}{m_1} = \frac{(0.1m)^2 1900kg}{25kg} = 0.76m$$

$$\Rightarrow D_2 = \sqrt{0.76} = 0.872m = 87.2\ cm \text{ (answer)}$$

3. Water is pumped from a lower reservoir to a higher reservoir by a pump that provides 20 kW of shaft power. The free surface of the upper reservoir is 45 m higher than that of the lower reservoir. If the flow rate of water is measured to be 0.03 m3/s, determine mechanical power that is converted to thermal energy during this process due to frictional effects. (Assume that the water levels of the both reservoirs don't change during water delivering). **(20 Points)**



Exercise 3:

$z_2 = 45m$, $\dot{V} = 0.03\ m^3/s$

$z_1 = 0$, $\dot{W}_{pump} = 20\ kW = 20000\ W$

The water at (1) and (2) has no change in velocity and has the same atmospheric pressure $\Rightarrow$ change in mechanical energy of water is the change in potential energy

$$\Rightarrow \Delta \dot{E}_{mech} = \dot{m} g \Delta z = \dot{m} g z_2 = \rho \dot{V} g z_2 = 1000 \times 0.03 \times 9.81 \times 45$$

$$\Rightarrow \Delta \dot{E}_{mech} = 13243.5\ W$$

There fore, mechanical power converted to thermal energy due to friction is:

$$\dot{W}_{friction} = \dot{W}_{pump} - \Delta \dot{E}_{mech} = 20000 - 13243.5 = 6756.5\ W$$

(answer)

4. A wind turbine is rotating at 15 rpm under steady winds flowing through the turbine at a rate of 42,000 kg/s. The tip velocity of the turbine blade is measured to be 250 km/h. If 180 kW power is produced by the turbine, determine

(a) the average velocity of the air

(b) the conversion efficiency of the turbine.

Take the density of air to be 1.31 kg/m3. **(15 Points)**

Exercise 4:

$\omega = 15 \text{ rpm}$, $V_{tip} = 250 \text{ km/h}$, $\dot{m}_{air} = 42000 \text{ kg/s}$, $\rho_{air} = 1.31 \text{ kg/m}^3$

We have: $\omega = 15 \text{ rpm} = 0.25 \text{ rps}$ $\quad \dot{W} = 180 \text{ kW}$

Blade span diameter: $D = \dfrac{V_{tip}}{\pi \omega} = \dfrac{(250 \text{ km/h})\left(\frac{1}{3.6}\right)}{\pi \cdot 0.25} = 88.42 \text{ m}$

Blade span area: $A = \dfrac{\pi D^2}{4} = \dfrac{\pi (88.42)^2}{4} = 6140.32 \text{ m}^2$

a) Average air velocity through the wind turbine:

$$V = \frac{\dot{m}}{\rho A} = \frac{42000 \text{ kg/s}}{(1.31 \text{ kg/m3})(6140.32 \text{ m}^2)} = 5.22 \text{ m/s (answer)}$$

b) Kinetic energy of air: $\dot{KE} = 1/2\, \dot{m} V^2 = 1/2 \times 42000 \times 5.22^2 = 572216 \text{ J}$

$\Rightarrow$ Conversion ~~energy~~ efficiency of the turbine: $\eta = \dfrac{\dot{W}}{\dot{KE}} = \dfrac{180 \times 10^3}{572216} = 31.45\,\%$ (answer)

5. As a future engineer, you need to find a solution for a clean energy source to replace the current carbon-based energy sources. Please review the advanced clean energy technologies and select one of them for discussion. Write an essay (400-500 words) to explain your solutions. **(30 Points)**

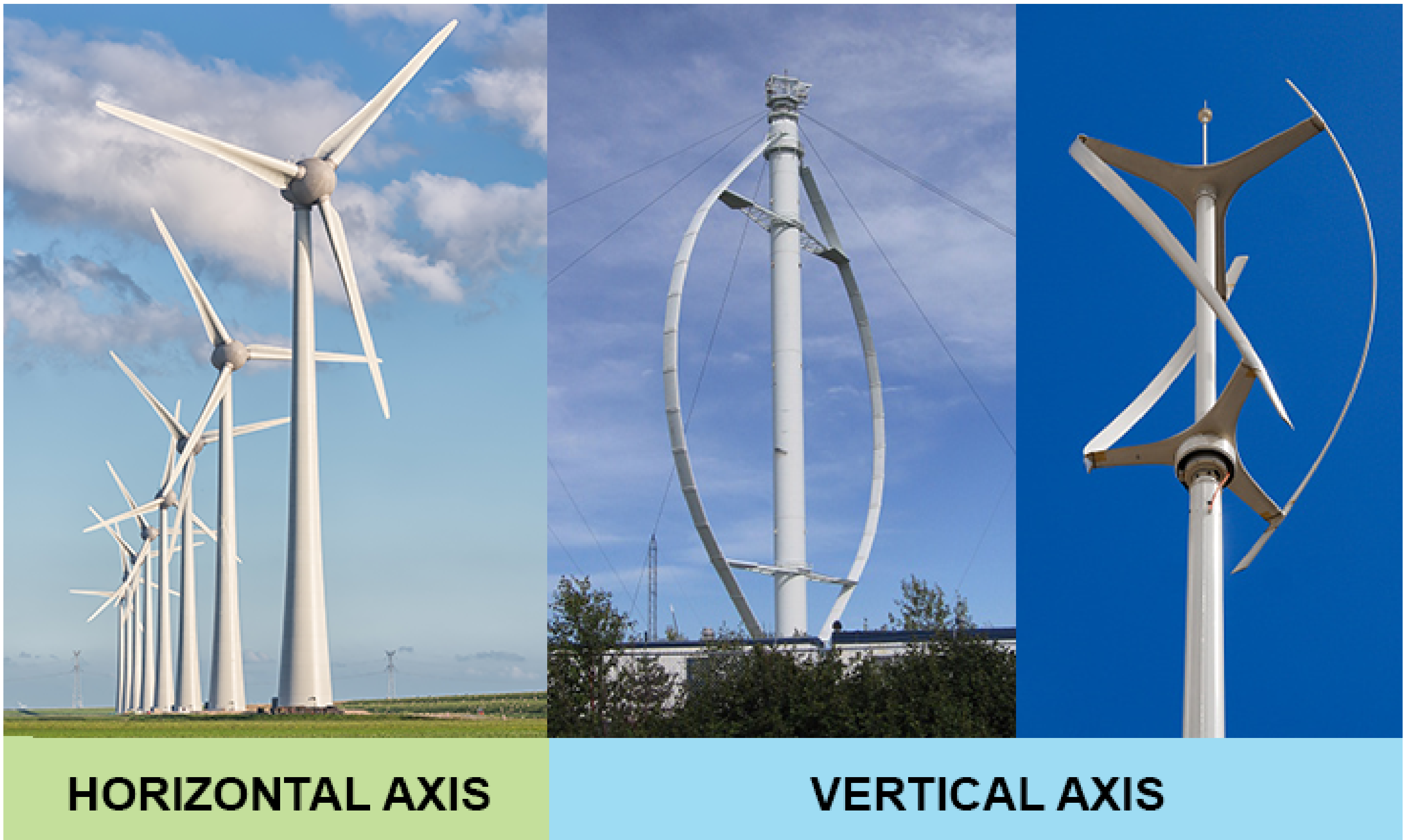
Essay

Clean energy is defined to be renewable and sustainable within a human timescale. Another criteria is that clean energy should cause no or little environmental degradation or pollution, which carbon-based energy sources normally do. The advanced clean energy technology that I will discuss is the modern design of the wind turbine.

In general, wind, which produced around 6 percent of global electricity in 2020, was the second largest renewable energy source after hydropower for power generation [1]. Wind energy sector is growing fast and the wind industry is constantly improving its technology to meet higher demand for power and gradually replace carbon-based fuels. One of the central technologies of wind energy is the design of wind turbines.

Wind turbine design consists of 2 integral parts: the rotor, the direct current (DC) generator or alternating current (AC) alternator. The turbine is normally built high above the ground on a tower. When the wind flows through the turbine, the wind is partly obstructed by the turbine, which makes the wind slow down and the turbine rotate. Therefore, the turbine extracts the kinetic energy from the wind [2]. To extract more kinetic energy from the air current, the wind speed needs to flow faster or the rotor blades span is designed larger. In other words, there is a strong correlation between wind power production and the wind turbine design in their interaction.

Modern advanced turbines generally have two common designs: The horizontal-axis turbines and the vertical-axis turbines. [3] There are certain circumstances where one design is used. The horizontal-axis design resembles propeller airplane engines, which dominates the wind industry. The vertical-axis design resembles egg-beaters that rotates around the axis, which is usually built in small farms because it does not extract as much energy as horizontal design does [3].



Source: https://c03.apogee.net/mvc/home/hes/land/el?utilityname=peco2&spc=kids&id=16214

Since the horizontal-axis design is the most common wind turbine design, there are several factors in consideration.

- Number of blades: First, the blade number should be odd rather than even. Odd number creates imbalance and thus the wind turbines are more likely to rotate [2]. For 1 blade-turbine, there is much empty area and most of the wind flows through it, creating inefficiency. It is proven that higher number of blades create less power while cost of production stays high. Therefore, most horizontal wind turbines nowadays have 3 blades.
- Blade span: It is known that the angular velocity of the blade creates rotational tip speed of the rotor. The longer the turbine blade span, the faster the tip rotation becomes for the same wind speed. However, there is a point where a longer span will decrease efficiency due to heavy weight. Usually three bladed wind turbine designs have a tip speed ratio of between 6 and 8. [2]

There are also disadvantages in the wind turbine design. Constant rotation will cause cyclic fatigue that needs maintenance in the wind turbine. Constant work is also not guaranteed if the wind is light enough, and the sound from the rotating blades can cause mild noise pollution.

[500 words]

References:

[1] Renewable Energy, Center for climate and energy solutions.
Available at https://www.c2es.org/content/renewable-energy/

[2] Wind Turbine Design for Wind Power.
Available at https://www.alternative-energy-tutorials.com/wind-energy/wind-turbine-design.html

[3] Wind explained: Types of wind turbines, U.S. Energy Information Administration
Available at https://www.eia.gov/energyexplained/wind/types-of-wind-turbines.php

6. Your free feedback on the first weeks and time spent on this learning exercise. (This does not affect the grading)

The first week is okay, except that there are problems with Mycourse submission box and some misunderstandings in the exercise. I hope next week will turn out smoothly.

I spent 6 hours on doing this exercise