STANDARDNA ATMOSFERA

1. Izračunaj stanje standardne atmosfere na visinama:
   a) 4000 m,
   b) 14000 m.

Rješenje: * uvjeti standardne atmosfere na razini mora:

$p_n = 101325$ Pa ; $T_n = 288{,}15$ K ; $\rho_n = 1{,}225$ kg/m^3 ;

* srednji polumjer Zemljine kugle: $R_0 = 6357$ km

a) $h = 4000$ m

$$H = \frac{R_0}{R_0 + h} \cdot h = \frac{6357 \cdot 10^3}{6357 \cdot 10^3 + 4000} \cdot 4000 = 3997{,}5 \text{ m}$$ - geopotencijalna visina

$$T = T_n - \beta \cdot H = 288{,}15 - 6{,}5 \cdot 10^{-3} \cdot 3997{,}5 = 262{,}17 \text{ K}$$

$$p = p_n \cdot (1 - 2{,}256 \cdot 10^{-5} \cdot H)^{5{,}256} = 101325 \cdot (1 - 2{,}256 \cdot 10^{-5} \cdot 3997{,}5)^{5{,}256} = 61656 \text{ Pa}$$

$$\rho = \rho_n \cdot (1 - 2{,}256 \cdot 10^{-5} \cdot H)^{4{,}256} = 1{,}225 \cdot (1 - 2{,}256 \cdot 10^{-5} \cdot 3997{,}5)^{4{,}256} = 0{,}8193 \text{ kg/m}^3$$

$$\mu = 2{,}417 \cdot 10^{-7} \cdot T^{0{,}76} = 2{,}417 \cdot 10^{-7} \cdot 262{,}17^{0{,}76} = 1{,}6649 \cdot 10^{-5} \text{ Pas}$$

$$\nu = \frac{\mu}{\rho} = \frac{1{,}6649 \cdot 10^{-5}}{0{,}8193} = 2{,}0321 \cdot 10^{-5} \text{ m}^2/\text{s}$$

b) $h = 14000$ m

$$H = \frac{R_0}{R_0 + h} \cdot h = \frac{6357 \cdot 10^3}{6357 \cdot 10^3 + 14000} \cdot 14000 = 13969 \text{ m}$$

$$T = T_{11} = 216{,}65 \text{ K}$$

$$p = p_{11} \cdot e^{\left[-1{,}577 \cdot 10^{-4} \cdot (H - 11000)\right]} = 22627 \cdot 2{,}7183^{\left[-1{,}577 \cdot 10^{-4} \cdot (14000 - 11000)\right]} = 14098 \text{ Pa}$$

$$\rho = \rho_{11} \cdot e^{\left[-1{,}577 \cdot 10^{-4} \cdot (H - 11000)\right]} = 0{,}3639 \cdot 2{,}7183^{\left[-1{,}577 \cdot 10^{-4} \cdot (14000 - 11000)\right]} = 0{,}2267 \text{ kg/m}^3$$

$$\mu = 2{,}417 \cdot 10^{-7} \cdot T^{0{,}76} = 2{,}417 \cdot 10^{-7} \cdot 216{,}65^{0{,}76} = 1{,}4403 \cdot 10^{-5} \text{ Pas}$$

$$\nu = \frac{\mu}{\rho} = \frac{1{,}4403 \cdot 10^{-5}}{0{,}2267} = 6{,}3533 \cdot 10^{-5} \text{ m}^2/\text{s}$$

2. Na temelju izmjerene temperature +6 °C i tlaka 83800 Pa, odrediti:
   a) visinu prema temperaturi,
   b) visinu prema tlaku,
   c) visinu prema gustoći.

Rješenje: $t = 6\ ^{\circ}\mathrm{C} \quad \rightarrow \quad T = t + 273{,}15 = 6 + 273{,}15 = 279{,}15\ \mathrm{K}$

$p = 83800\ \mathrm{Pa}$

a) $T = T_n - \beta \cdot H \quad \rightarrow \quad H = \dfrac{T_n - T}{\beta} = \dfrac{288{,}15 - 279{,}15}{6{,}5 \cdot 10^{-3}} = 1384{,}6\ \mathrm{m}$

$$h = \frac{R_0}{R_0 - H} \cdot H = \frac{6357 \cdot 10^3}{6357 \cdot 10^3 - 1384{,}6} \cdot 1384{,}6 = 1384{,}9\ \mathrm{m}$$

b) $p = p_n \cdot (1 - 2{,}256 \cdot 10^{-5} \cdot H)^{5{,}256}$

$$\left(\frac{p}{p_n}\right)^{\frac{1}{5{,}256}} = 1 - 2{,}256 \cdot 10^{-5} \cdot H$$

$$H = \frac{1}{2{,}256 \cdot 10^{-5}} \cdot \left[1 - \left(\frac{p}{p_n}\right)^{\frac{1}{5{,}256}}\right] = \frac{1}{2{,}256 \cdot 10^{-5}} \cdot \left[1 - \left(\frac{83800}{101325}\right)^{\frac{1}{5{,}256}}\right] = 1572{,}9\ \mathrm{m}$$

$$h = \frac{R_0}{R_0 - H} \cdot H = \frac{6357 \cdot 10^3}{6357 \cdot 10^3 - 1572{,}9} \cdot 1572{,}9 = 1573{,}3\ \mathrm{m}$$

c) $p = \rho \cdot R \cdot T \quad \rightarrow \quad \rho = \dfrac{p}{R \cdot T} = \dfrac{83800}{287{,}053 \cdot 279{,}15} = 1{,}0458\ \mathrm{kg/m^3}$

$\rho = \rho_n \cdot (1 - 2{,}256 \cdot 10^{-5} \cdot H)^{4{,}256}$

$$\left(\frac{\rho}{\rho_n}\right)^{\frac{1}{4{,}256}} = 1 - 2{,}256 \cdot 10^{-5} \cdot H$$

$$H = \frac{1}{2{,}256 \cdot 10^{-5}} \cdot \left[1 - \left(\frac{\rho}{\rho_n}\right)^{\frac{1}{4{,}256}}\right] = \frac{1}{2{,}256 \cdot 10^{-5}} \cdot \left[1 - \left(\frac{1{,}0458}{1{,}225}\right)^{\frac{1}{4{,}256}}\right] = 1617{,}0\ \mathrm{m}$$

$$h = \frac{R_0}{R_0 - H} \cdot H = \frac{6357 \cdot 10^3}{6357 \cdot 10^3 - 1617{,}0} \cdot 1617{,}0 = 1617{,}4\ \mathrm{m}$$

3. Za koliko je veća gustoća suhog zraka u odnosu na zrak potpuno zasićen vodenom parom pri tlaku p = 101325 Pa i temperaturi t = 20 °C. Parcijalni tlak vodene pare u potpuno zasićenom zraku iznosi p_{para} = 2337 Pa.

Rješenje:

p = 101325 Pa
t = 20 °C $\rightarrow$ $T = t + 273{,}15 = 20 + 273{,}15 = 293{,}15$ K
p_{para} = 2337 Pa
R_{zrak} = 287,053 J/kgK
R_{para} = 461,6 J/kgK

* suhi zrak: $\rho_{SZ} = \dfrac{p}{R_{zrak} \cdot T} = \dfrac{101325}{287{,}053 \cdot 293{,}15} = 1{,}20411\ \text{kg/m}^3$

* vlažni zrak: $p = p_{zrak} + p_{para} \rightarrow p_{zrak} = p - p_{para} = 101325 - 2337 = 98988$ Pa

$\rho_{zrak} = \dfrac{p_{zrak}}{R_{zrak} \cdot T} = \dfrac{98988}{287{,}053 \cdot 293{,}15} = 1{,}17633\ \text{kg/m}^3$ – gustoća suhog zraka u smjesi vlažnog zraka

$\rho_{para} = \dfrac{p_{para}}{R_{para} \cdot T} = \dfrac{2337}{461{,}6 \cdot 293{,}15} = 0{,}01727\ \text{kg/m}^3$ – gustoća vodene pare u smjesi vlažnog zraka

$\rho_{VZ} = \rho_{zrak} + \rho_{para} = 1{,}17633 + 0{,}01727 = 1{,}19360\ \text{kg/m}^3$ – gustoća vlažnog zraka

* razlika gustoća: $\Delta\rho = \rho_{SZ} - \rho_{VZ} = 1{,}20411 - 1{,}19360 = 0{,}01051\ \text{kg/m}^3$

$$\Delta\rho[\%] = \frac{\Delta\rho}{\rho_{VZ}} \cdot 100 = \frac{0{,}01051}{1{,}20411} \cdot 100 = 0{,}873\ \%$$

* $F_Z \propto \rho \rightarrow$ smanjenje gustoće zraka uzrokuje smanjenje sile uzgona