GATE Agricultural Engineering (AG):

◆30 Practice Questions

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Here's a set of 30 solved problems for applicants to the GATE Agricultural Engineering (AG) exam. Problems were taken from past question papers and a carefully researched assortment of textbooks. All problems are solved step by step. Enjoy! ■

PROBLEMS

Problem 1. A hollow-cone nozzle is being used for application of pesticide in a crop field. The nozzle is designed for an application rate of 225 L/ha. The sprayer speed is 8 km/h and the nozzle spacing is 60 cm. The 0.9-mm diameter orifice nozzle is rated at 0.88 L/min and 260-kPa pressure. In order to produce the desired nozzle flow, the pressure must be raised to:

(A) 405 kPa
(B) 615 kPa
(C) 802 kPa
(D) 1090 kPa

Problem 2. A 2-stroke, 4-cylinder engine with 80 mm bore and stroke consumes 12 kg of fuel per hour at 2100 rpm. If the air-fuel ratio is 12:1 and the ambient air has constant density 1.23 kg/m^3, the volumetric efficiency of the engine equals:

(A) 60%
(B) 70%
(C) 80%
(D) 85%

Problem 3. The kinetic energy available from a tractor engine flywheel rotating at 1800 revolutions per minute is 120 kJ. If the radius of gyration about the axis of rotation equals 0.3 m, the mass of the flywheel is:

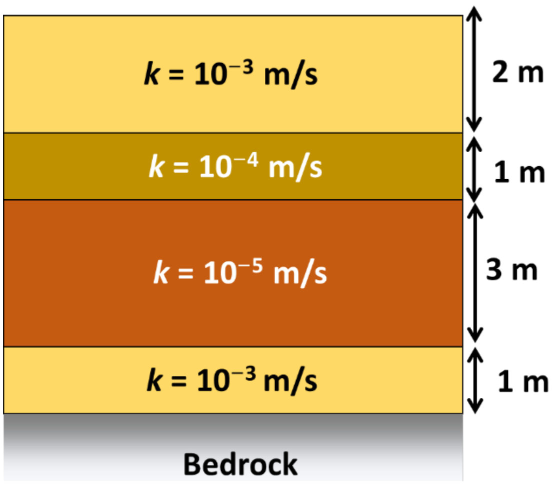
(A) 25 kg
(B) 50 kg
(C) 75 kg
(D) 125 kg

Problem 4. Tractors are prone to overturn during high-speed turns because of their high center of gravity. A certain tractor can turn with an estimated radius of 7 m on concrete without use of wheel brakes. The wheelbase of the tractor is 2.08 m and the distance from the rear axle centerline to the center of gravity of the tractor is 0.66 m. The estimated height of the center of gravity is 1.2 m. The minimum rear tread width is 1.5 m and the maximum rear tread width is 3.2 m. Calculate the critical turning speed at which side tipping would begin with minimum wheel spacing.

(A) 10 km/h
(B) 19.5 km/h
(C) 27.5 km/h
(D) 32 km/h

Problem 5. A sample of saturated clay from a consolidometer test has total mass of 1.5 kg and a dry mass of 1.2 kg. The specific gravity of the solid particles is 2.55. What is the sample's porosity?
(A) 39%
(B) 48%
(C) 54%
(D) 58%

Problem 6. A soil profile consists of four strata with hydraulic conductivities and thicknesses indicated in the following figure. The average coefficient of horizontal permeability for this soil profile is:



(A) 1.2×10^{-4} m/s
(B) 4.5×10^{-4} m/s
(C) 1.2×10^{-3} m/s
(D) 2.4×10^{-3} m/s

Problem 7. A stream channel is built in a rural area. The channel can carry 200 m^3/s, which is the peak flow of the 5-year storm of the watershed in which it was built. What is the probability that the rural area will flood at least once in the next 10 years?
(A) 50%
(B) 72.5%
(C) 77.8%
(D) 89.3%

Problem 8. A basin is monitored by a network of four rain gauges. The annual rainfall registered in these rain gauges are tabulated below. In view of these data, how many additional gauges should be installed for an 8% error in the calculation of mean surface rainfall?

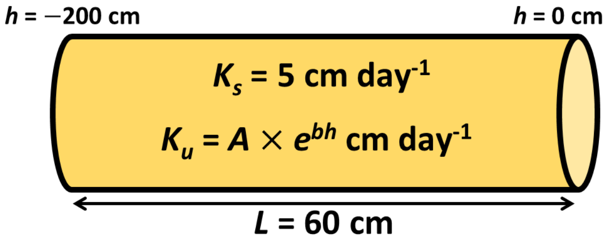
Rain gauge	1	2	3	4
Annual rainfall (cm)	48	74	81	63

(A) One more gauge should be added, totaling 5 gauges.
(B) Two more gauges should be added, totaling 6 gauges.
(C) Three more gauges should be added, totaling 7 gauges.
(D) Four more gauges should be added, totaling 8 gauges.

Problem 9. Find the depth of a most-economical trapezoidal channel carrying a discharge of 20 m^3/s at a bed slope of 0.001, side slope 1:1, and Manning's n equal to 0.013.
(A) 0.8 m
(B) 1.3 m
(C) 2.1 m
(D) 2.9 m

Problems 10 and 11

10. Water is flowing at steady state in a 60-cm long horizontal unsaturated soil column. The soil pressure head (h) is 0 cm at the right end and −200 cm at the left end of the soil column. Both heads are maintained throughout a steady-state experiment. The saturated hydraulic conductivity K_s is 5 cm·day^{-1}, and the unsaturated hydraulic conductivity at a pressure head of −150 cm is one-tenth of K_s. Assuming that the unsaturated hydraulic conductivity $K_u(h)$ is described by an equation of the form $K_u(h) = A \times e^{bh}$, where $h < 0$, calculate coefficient b.



(A) $b = 0.005$
(B) $b = 0.015$
(C) $b = 0.05$
(D) $b = 0.15$

11. Calculate the absolute value of the flux density for the soil column. Assume a horizontal coordinate $x = 0$ on the left and $x = L = 60$ cm on the right.
(A) 1 cm day^{-1}
(B) 2 cm day^{-1}
(C) 5.2 cm day^{-1}
(D) 10.4 cm day^{-1}

Problems 12 and 13

12. A 40-cm radius well completely penetrates an unconfined aquifer of depth 50 m. After a long period of pumping at a steady rate of 1800 liters per minute, the drawdown in two observation wells located 30 and 60 m away from the pumping well were found to be 2 and 3 m, respectively. Determine the transmissivity of the aquifer.
(A) 3.5×10^{-3} m^2/s
(B) 7.0×10^{-3} m^2/s
(C) 0.035 m^2/s
(D) 0.070 m^2/s

13. What is the drawdown at the pumping well?
(A) 0.85 m
(B) 1.35 m
(C) 1.85 m
(D) 2.3S5 m

Problems 14 and 15

14. A roller crusher required 9 kW of power to crush spherical grains of 20 cm diameter into 8 cm particles at a feeding rate of 4 kg/s. If the coefficient of friction is 0.475, the diameter of the rolls is:
(A) 38 cm
(B) 65 cm
(C) 104 cm
(D) 130 cm

15. Assume now that the capacity is reduced to 3 kg/s, and that the same particles are to be comminuted to 4 cm instead of 8 cm. The corresponding power consumption is:
(A) 10.9 kW
(B) 14.3 kW
(C) 18.1 kW
(D) 21.4 kW

Problem 16. Wheat of mass density 950 kg/m^3 is stored in a circular concrete silo of 4 m internal diameter and a clear height of 10 m. The angle of internal friction for wheat is 25° and the wheat-concrete friction angle may be taken as 19°. Using the Airy equation, find the maximum lateral pressure at the bottom of the bin section.
(A) 5.5 kPa
(B) 6.8 kPa
(C) 8.0 kPa
(D) 9.1 kPa

Problem 17. A slab of porous starch 1.5 cm thick will be air-dried from a moisture content of 75% to 10% (wet basis in both cases). Drying will take place at a temperature of 70°C and the equilibrium moisture content is assumed to be zero. The following table lists typical values of effective moisture diffusivity and energy of activation for diffusion of food materials at 30°C.

Food material	Moisture diffusivity ($\times 10^{-10}$ m^2/s)	Energy of activation for diffusion (kJ/mol)
Porous	10	15
Nonporous starch/sugar	1	40
Nonporous protein/sugar	0.1	50

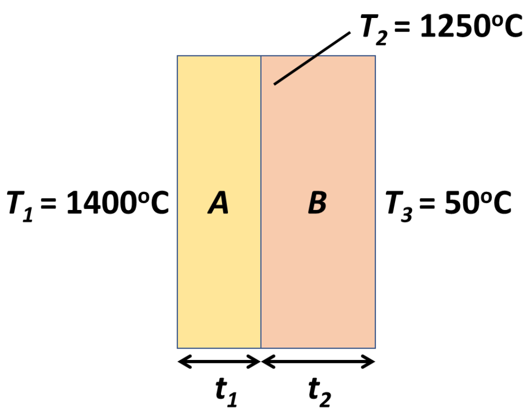
Using the simplified Page equation, find the time required to dry the starch slab.
(A) 1.3 h
(D) 2.6 h
(C) 5.2 h
(D) 10.4 h

Problem 18. A ground beef sample has 10^5 CFUs/g of a Gram-negative psychrotrophic bacterial population. The specific growth rate of the population at 5°C is 0.1. In how many hours will the population reach 10^7 CFUs/g?
(A) 14 h
(B) 25 h
(C) 40 h
(D) 48 h

Problem 19. A lean beef block shaped like a plate of 30 mm thickness is to be frozen from an ambient temperature of −5°C to a final temperature of −30°C. The density and moisture content of this food are 1050 kg/m^3 and 70%, respectively. The thermal conductivity of frozen beef is 1.2 W/m·K and the convective heat transfer coefficient of the surrounding medium is 20 W/m^2·K. The latent heat of fusion may be taken as 333 kJ/kg. Find the freezing time.
(A) 1.2 h
(B) 2.3 h
(C) 5.8 h
(D) 9.6 h

Problem 20. Fruit slices are being dried in a tray dryer of length 0.88 m, subjected to a parallel flow of hot air at 2 m/s and 67°C. The fruit slices remain at a constant temperature of 37°C. Estimate the convection heat transfer coefficient if properties of dry air at a film temperature of 52°C are density ρ = 1.09 kg/m^3, specific heat capacity c_p = 1.0 kJ/kg·K, dynamic viscosity μ = 1.97×10^{-5} Pa·s, and thermal conductivity k = 0.0271 W/m·K.
(A) 1.9 W/m^2·K
(B) 5.7 W/m^2·K
(C) 9.6 W/m^2·K
(D) 18.0 W/m^2·K

Problem 21. The wall of an industrial food heater is made up of two parallel layers (A) and (B) made of different materials; the temperatures are as shown in the sketch. If the ratio of thermal conductivities is K_A/K_B = 3, the ratio of thicknesses t_1/t_2 equals:
(A) 0.188
(B) 0.375
(C) 0.6
(D) 0.75



Problem 22. A non-Newtonian liquid food flows in a straight circular pipe of 4 cm diameter and 5 m length. The food behaves like a power-law fluid with flow index (exponent) 0.4 and rheological constant 2 Pa·s$^{0.4}$. Find the power that must be supplied to maintain a steady flow at average velocity equal to 1.8 m/s in the pipe.

(A) 6 W

(B) 12 W

(C) 24 W

(D) 48 W

Problem 23. A certain crop is grown in an area of 4000 hectares which is fed by a canal system. The hydrological data for this crop are summarized below.

Field capacity of soil	28%
Optimum moisture	13%
Permanent wilting point	9%
Effective depth of root zone	84 cm
Specific gravity of soil	1.5

If the irrigation operation lasts 12 days and all irrigation efficiency metrics are 100%, the water discharge needed in the canal is ________ (◆ m^3/s, *rounded to two decimal places*).

Problem 24. An engine consumes diesel fuel at a rate of 75 L/h. The density of the fuel is 0.835 kg/L and its heating value is 45,000 kJ/kg. The fuel equivalent power in metric hp units is _______ (◆ hp, *no decimal places*).

Problem 25. The normal annual rainfall at stations *A*, *B*, *C*, and *D* in a basin are 81.2, 68.0, 75.4, and 92.0 cm respectively. In the year 2022, station *D* was inoperative whereas stations *A*, *B*, and *C* recorded annual precipitations of 93.5, 74.8, and 69.4 cm, respectively. The missing annual precipitation at station *D* can be determined to be _________ (◆ cm, *rounded to two decimal places*).

Problem 26. The following data pertain to a pumping application.

Flow rate	13 m^3/s
Total dynamic head	180 m
Motor efficiency	85%
Brake horsepower	55 hp
Pump efficiency	60%
Electrical energy cost	₹6/kWh

If the pump is online 20 hours per day and 360 days per year, the annual energy cost to operate the pump is _______ (◆ million ₹/year, *rounded to one decimal place*).

Problem 27. The internal angle of friction of a certain kind of cohesionless soil particles is 32°. The ratio of the coefficient of passive earth pressure to the coefficient of active earth pressure for this soil is ________ (◆ dimensionless, *rounded to one decimal place*).

Problem 28. A fat particle of spherical shape and 12 μm diameter is being suspended in milk of density 1050 kg/m^3 and viscosity 1.8 cP. Taking the density of fat as 950 kg/m^3, the rate at which the fat particle will rise when suspended in this milk sample is _________ (◆ mm/hour, *rounded to one decimal place*).

Problem 29. (Long Problem) An inclined blade tillage tool 32 cm wide and 10 cm long is operating at 32 cm depth in cohesionless soil with density equal to 1.8 g/cm^3 and angle of internal friction equal to 30°. The tool speed is 6 km/h and the soil-metal friction is to be taken as 0.27. Assuming a negligible cutting resistance, determine the horizontal force acting on the tillage tool.

(A) 1390 N

(B) 1510 N

(C) 1730 N

(D) 1940 N

Problem 30. (Long Problem) The following data describe a 90-minute rainstorm over a catchment covered by a homogeneous loess soil. Determine the Wischmeyer erosivity index, here defined as the product of total kinetic energy and maximum 30-minute intensity. Assume that storm kinetic energy KE is related to rainfall intensity by $KE = 0.012 + 0.09 log_{10} I$, with KE given in MJ/ha/mm and I given in in mm/h.

Time from start of storm (min)	Rainfall (mm)	Intensity (mm/h)
0 → 14	1.5	7.10
15 → 29	14.0	60.0
30 → 44	27.5	110.5
45 → 59	32.0	135.0
60 → 74	8.5	32.5
75 → 89	0.95	2.15

(A) 1340 MJ mm ha^{-1} h^{-1}
(B) 1870 MJ mm ha^{-1} h^{-1}
(C) 2120 MJ mm ha^{-1} h^{-1}
(D) 2340 MJ mm ha^{-1} h^{-1}

ANSWER KEY

Problem	Answer	Problem	Answer
1	D	16	A
2	B	17	D
3	C	18	D
4	B	19	B
5	A	20	B
6	B	21	B
7	D	22	C
8	D	23	7.29
9	C	24	1065
10	B	25	97.27
11	C	26	2.1
12	A	27	10.6
13	A	28	15.7
14	C	29	C
15	B	30	B

SOLUTIONS

1 ➡ D

For an application rate A_R = 225 L/ha, a nozzle spacing d_n = 0.6 m, and a sprayer speed u = 8 km/h, the required nozzle flow rate Q_n in L/min can be determined with the formula

$$Q_n = \frac{A_R d_n u}{600} = \frac{225 \times 0.6 \times 8}{600} = 1.8 \text{ L/min}$$

Comparing this with the rated nozzle flow rate Q_r = 0.88 L/min and the rated nozzle pressure p_r = 260 kPa, we have

$$p = \left(\frac{Q_n}{Q_r}\right)^2 p_r = \left(\frac{1.8}{0.88}\right)^2 \times 260 = \boxed{1090 \text{ kPa}}$$

2 ➡ B

Given the air-fuel ratio A/F = 12/1, the fuel consumption F = 12/60 = 0.2 kg/min, the density of ambient air ρ_a = 1.23 kg/m^3, the cylinder volume $LA = \pi \times 0.08^3/4 = 3.31\times10^{-4}$ m^3, the number of cylinders n = 4, and the rate N = 2100 rpm, we obtain

$$\eta = \frac{(A/F)F/\rho_a}{LAnN} = \frac{12\times 0.2/1.23}{\left(3.31\times 10^{-4}\right)\times 4\times 2100} = 0.702$$

$$\therefore \boxed{\eta = 70.2\%}$$

3 ➡ C

Note first that the kinetic energy for rotational motion is

$$K.E. = \frac{1}{2}I\omega^2$$

where I is the mass moment of inertia and ω is the angular velocity. Denoting the mass of the flywheel as m, the radius of gyration as R and the number of revolutions in one minute as N, we may restate the above equation as

$$K.E. = \frac{1}{2}I\omega^2 \ \rightarrow \ 120{,}000 = \frac{1}{2}\times mR^2 \times \left(\frac{2\pi N}{60}\right)^2$$

$$\therefore 120{,}000 = \frac{1}{2}\times m\times 0.3^2 \times \left(\frac{2\pi\times 1800}{60}\right)^2$$

$$\therefore 120{,}000 = 1600m$$

$$\therefore m = \frac{120{,}000}{1600} = \boxed{75\text{ kg}}$$

4 ➡ B

The first step is to find the distance *y* from the tractor center of gravity to the tipping axis; given the minimum rear tread width *RTW* = 1.5 m, the wheelbase *WB* = 2.08 m, and the distance from rear axle centerline to center of gravity X_{cg} = 0.66 m, we may write

$$y = \frac{RTW\times\left(WB - X_{\text{cg}}\right)}{2WB} = \frac{1.5\times(2.08-0.66)}{2\times 2.08} = 0.512\text{ m}$$

Then, the critical speed is given by

$$S_c = \sqrt{\frac{gry}{h}} = \sqrt{\frac{9.81\times 7.0\times 0.512}{1.2}} = 5.41\text{ m/s}$$

or, equivalently, 19.5 km/h.

5 ➡ A

Firstly, the water content of the soil sample is given by the ratio of water mass to the mass of solids:

$$w = \frac{m_w}{m_s} = \frac{1.5-1.2}{1.2} = 25\%$$

Then, the voids ratio is given by the usual formula

$$e = \frac{wG_s}{S} = \frac{0.25\times 2.55}{1} = 0.638$$

Lastly, we have the porosity n:

$$n = \frac{e}{1+e} = \frac{0.638}{1+0.638} = \boxed{39.0\%}$$

6 ➡ B

This is a straightforward application of the equivalent horizontal permeability formula for a stratified soil:

$$\overline{K} = \frac{K_1Z_1 + K_2Z_2 + K_3Z_3 + K_4Z_4}{Z_1+Z_2+Z_3+Z_4}$$

$$\therefore \overline{K} = \frac{10^{-3}\times 2.0 + 10^{-4}\times 1.0 + 10^{-5}\times 3.0 + 10^{-3}\times 1.0}{2.0+1.0+3.0+1.0} = \boxed{4.47\times 10^{-4}\text{ m/s}}$$

7 ➡ D

This is a straightforward application of the risk formula

$$\text{Risk} = 1 - \left(1 - \frac{1}{T}\right)^n = 1 - \left(1 - \frac{1}{5}\right)^{10} = \boxed{0.893}$$

8 ➡ D

The first step is to compute the mean annual rainfall:

$$\overline{P} = \frac{1}{5}(48 + 74 + 81 + 63) = 66.5 \text{ cm}$$

Then, we compute the standard deviation S:

$$S = \sqrt{\sum_{i=1}^{m} \frac{(P_i - \overline{P})^2}{m-1}} = \sqrt{\frac{1}{3}\left[\begin{array}{l}(48-66.5)^2 + (74-66.5)^2 \\ +(81-66.5)^2 + (63-66.5)^2\end{array}\right]} = 14.39 \text{ cm}$$

The variation coefficient C_u is determined as

$$C_u = \frac{100S}{\overline{P}} = \frac{100 \times 14.39}{66.5} = 21.64$$

The optimum number of rain gauges for an allowed percentage of error ε = 8% follows as

$$N = \left(\frac{C_u}{\varepsilon}\right)^2 = \left(\frac{21.64}{8}\right)^2 = 7.32$$

The ceiling of this result is 8; accordingly, four more gauges should be added to the existing four to maintain the abovementioned percentage of error.

9 ➡ C

For a most-economical trapezoidal channel section, the bottom width b, the flow depth y, and the side slope angle θ are related as

$$b = 2y \tan(\theta/2)$$

But θ = 45° for a side slope of 1:1, so

$$b = 2y \tan(45^\circ/2) = 0.828y$$

Now, the cross-sectional area of a trapezoidal section is

$$A = by + zy^2 = 0.828y \times y + 1 \times y^2 = 1.828y^2 \quad \text{(I)}$$

Appealing to the Manning formula and noting that hydraulic radius $R = y/2$,

$$V = \frac{1}{n} R^{2/3} S^{1/2} = \frac{1}{0.013} \times \left(\frac{y}{2}\right)^{2/3} \times 0.001^{1/2} = 1.532y^{2/3} \quad \text{(II)}$$

The product of velocity as given by (II) and cross-sectional area as given by (I) should yield the discharge, which we know to be 20 m^3/s; accordingly,

$$Q = VA \rightarrow 20 = 1.532y^{2/3} \times 1.828y^2$$

$$\therefore 20 = 2.801y^{8/3}$$

$$\therefore y = \left(\frac{20}{2.801}\right)^{\frac{3}{8}} = \boxed{2.09 \text{ m}}$$

10 ➡ B

The unsaturated hydraulic conductivity is given by $K_u = A \times e^{-bh}$. Since the maximum (saturated) HC for this soil is 5 cm·day^{-1}, the value of constant A must be 5 cm·day^{-1}. In turn, constant b can be found by noting that the unsaturated HC at h = −150 cm is one-tenth of the saturated value, that is, 0.1 × 5 = 0.5 cm·day^{-1}:

$$K_u(h) = 5 \times \exp(bh) \rightarrow 0.5 = 5 \times \exp(-150b)$$

$$\therefore 0.1 = \exp(-150b)$$

$$\therefore \ln(0.1) = -150b$$

$$\therefore b = \frac{\ln(0.1)}{-150} = \boxed{0.0154}$$

11 ➡ C

From Darcy's law, we may write

$$q = -K_u(h)\frac{dh}{dx}$$

so that, separating variables and integrating,

$$q = -K_u(h)\frac{dh}{dx} \rightarrow \int_0^{60} q\,dx = \int_{-200}^{0} K_u(h)\,dh$$

$$\therefore 60q = \int_{-200}^{0} 5\exp(0.0154h)\,dh$$

$$\therefore 60q = \frac{5}{0.0154}\exp(0.0154h)\Big|_{h=-200}^{h=0}$$

$$\therefore 60q = \frac{5}{0.0154}\times(1-0.046)$$

$$\therefore 60q = 310$$

$$\therefore q = \frac{310}{60} = \boxed{5.17\text{ cm day}^{-1}}$$

12 ➡ A

Noting that Q = 1800 liters/min = 0.03 m^3/s, we first find the hydraulic conductivity of the aquifer material:

$$Q = \frac{\pi K\left(h_1^2 - h_2^2\right)}{\ln(r_1/r_2)} \rightarrow 0.03 = \frac{\pi \times K \times \left(48^2 - 47^2\right)}{\ln(30/60)}$$

$$\therefore 0.03 = 431K$$

$$\therefore K = \frac{0.03}{431} = 6.96\times10^{-5}\text{ m/s}$$

The transmissivity T follows as

$$T = Ky = \left(6.96\times10^{-5}\right)\times 50 = \boxed{3.48\times10^{-3}\text{ m}^2/\text{s}}$$

13 ➡ A

Letting h_w and r_w denote the depth and the radius of the well, respectively, we may write

$$Q = \frac{\pi K\left(h_1^2 - h_w^2\right)}{\ln(r_1/r_w)} \rightarrow 0.03 = \frac{\pi\times\left(6.96\times10^{-5}\right)\times\left(48^2 - h_w^2\right)}{\ln(30/0.4)}$$

$$\therefore 0.03 = 5.06\times10^{-5}\left(48^2 - h_w^2\right)$$

$$\therefore 0.03 = 0.117 - 5.06\times10^{-5}h_w^2$$

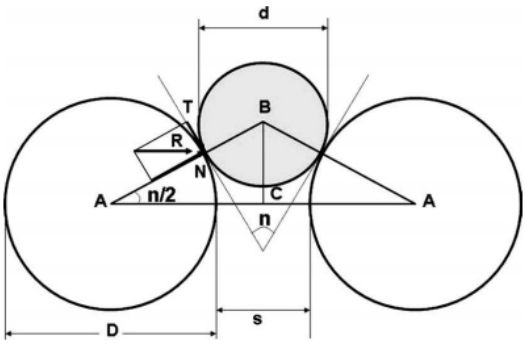
$$\therefore 0.03 - 0.117 = -5.06\times10^{-5}h_w^2$$

$$\therefore h_w = \sqrt{\frac{0.03-0.117}{-5.06\times10^{-5}}} = 41.5\text{ m}$$

Subtracting this from the depth of the well gives

$$\text{Drawdown} = 50 - h_w = \boxed{0.85\text{ m}}$$

14 ➡ A



Refer to the figure on the side. Dimensions *D, s*, and *d* are related as

$$\cos\left(\frac{n}{2}\right)=\frac{D+s}{D+d}\ \ \text{(I)}$$

But angle *n*/2 can be obtained from the coefficient of friction *f*:

$$f=\tan(n/2)=0.475$$

$$\therefore n=2\arctan(0.475)=50.8^{\circ}$$

so that, substituting in (I) and manipulating,

$$\cos\left(\frac{50.8^{\circ}}{2}\right)=\frac{D+8}{D+20}$$

$$\therefore 0.903=\frac{D+8}{D+20}$$

$$\therefore 0.903(D+20)=D+8$$

$$\therefore 0.903D+18.1=D+8$$

$$\therefore D=\frac{10.1}{0.097}=\boxed{104\text{ cm}}$$

15 ➡ A

Applying the Bond equation to the initial conditions gives the Bond work index K_b:

$$\frac{P_1}{f_1}=K_b\left(\frac{1}{\sqrt{D_{P,1}}}-\frac{1}{\sqrt{D_f}}\right)$$

$$\therefore \frac{9}{4}=K_b\left(\frac{1}{\sqrt{8}}-\frac{1}{\sqrt{20}}\right)$$

$$\therefore K_b=17.3\text{ kW}$$

In the second case, the power required to crush grains to 4 cm at a feeding rate of 3 kg/s becomes

$$\frac{P_2}{f_2}=K_b\left(\frac{1}{\sqrt{D_{P,2}}}-\frac{1}{\sqrt{D_f}}\right)$$

$$\therefore \frac{P_2}{3}=17.3\times\left(\frac{1}{\sqrt{4}}-\frac{1}{\sqrt{20}}\right)$$

$$\therefore \boxed{P_2=14.3\text{ kW}}$$

16 ➡ A

Firstly, note that the coefficient of friction for wheat is μ = *tan* 25° = 0.466, while the coefficient of friction for the wheat-concrete interface is μ' = *tan* 19° = 0.344. Also, density ρ = 950 kg/m^3 and height *h* = 10 m. Applying the Airy equation, we obtain

$$P=\rho h\left[\frac{1}{\sqrt{\mu(\mu+\mu')}+\sqrt{1+\mu^2}}\right]=950\times10\times\left[\frac{1}{\sqrt{0.466\times(0.466+0.344)}+\sqrt{1+0.466^2}}\right]$$

$$\therefore P=5530\text{ Pa}=\boxed{5.53\text{ kPa}}$$

17 ➡ D

The moisture diffusivity of a porous material at 30°C is 10×10^{-10} m^2/s. Since drying is being performed at a temperature of 70°C, we must first update the diffusivity to this temperature using the Arrhenius-like equation

$$\ln\left(\frac{D}{D_0}\right) = -\frac{E_D}{R}\left(\frac{1}{T}-\frac{1}{T_0}\right)$$

$$\therefore \ln\left(\frac{D}{D_0}\right) = -\frac{15{,}000}{8.314}\times\left(\frac{1}{343}-\frac{1}{303}\right) = 0.694$$

$$\therefore D = D_0 \exp(0.694)$$

$$\therefore D = \left(10\times 10^{-10}\right)\times\exp(0.694) = 20.0\times 10^{-10}\ \text{m}^2/\text{s}$$

We proceed to compute the drying constant K:

$$-K = \frac{\pi^2 D}{L^2} = \frac{\pi^2\times\left(20.0\times 10^{-10}\right)}{0.015^2} = 8.77\times 10^{-5}\ \text{s}^{-1}$$

$$\therefore -K = 0.316\ \text{h}^{-1}$$

The moisture content of the food material before and after drying will be X_o = 75/(100 – 75) = 3.0 and X = 10/(100 – 10) = 0.111 kg/kg, respectively. Now, the drying time is given by the simplified Page equation:

$$\ln\left(\frac{X-X_e}{X_0-X_e}\right) = -Kt$$

$$\therefore \ln\left(\frac{0.111-0}{3.0-0}\right) = -0.316\times t$$

$$\therefore -3.30 = -0.316\times t$$

$$\therefore t = \frac{3.30}{0.316} = \boxed{10.4\ \text{h}}$$

18 ➡ D

The evolution of this microbial population may be described with the exponential law

$$C(t) = 10^5\times(1.1)^t$$

To find the time t_0 at which the population reaches 10^7 CFUs/g, we write

$$10^7 = 10^5\times(1.1)^{t_0}$$

$$\therefore \frac{10^7}{10^5} = (1.1)^{t_0}$$

$$\therefore 100 = (1.1)^{t_0}$$

$$\therefore \log_{10}100 = t_0\times\log_{10}1.1$$

$$\therefore 2 = t_0\times 0.0414$$

$$\therefore t_0 = \frac{2}{0.0414} = \boxed{48.3\ \text{h}}$$

The bacterial population will reach 10^7 CFUs/g within approximately two days.

19 ➡ B

This is a straightforward application of Plank's equation:

$$t_f = \frac{\rho L_f}{T_\infty - T_F}\left(\frac{a}{2h_c}+\frac{a^2}{8k}\right)$$

$$\therefore t_f = \frac{1050\times(333\times 0.7\times 1000)}{-5-(-30)}\left(\frac{0.03}{2\times 20}+\frac{0.03^2}{8\times 1.2}\right) = 8260\ \text{s}$$

$$\therefore \boxed{t_f = 2.29\ \text{h}}$$

20 ➡ B

The convective heat transfer coefficient can be extracted from the Nusselt number Nu, which in the case of parallel flow over a flat plate may be obtained with the Dittus-Boelter correlation:

$$\mathrm{Nu} = 0.664\,\mathrm{Re}_L^{1/2}\,\mathrm{Pr}^{1/3} \quad \text{(I)}$$

The Reynolds number Re_L is such that

$$\mathrm{Re}_L = \frac{\rho VL}{\mu} = \frac{1.09\times 2.0\times 0.88}{1.97\times 10^{-5}} = 97{,}400$$

while the Prandtl number Pr becomes

$$\mathrm{Pr} = \frac{c_p\mu}{k} = \frac{1000\times\left(1.97\times 10^{-5}\right)}{0.0271} = 0.727$$

Substituting in (I),

$$\mathrm{Nu} = 0.664\times 97{,}400^{1/2}\times 0.727^{1/3} = 186$$

Finally, from the definition of Nusselt number,

$$\mathrm{Nu} = \frac{hL}{k} \;\rightarrow\; h = \frac{k\times\mathrm{Nu}}{L}$$

$$\therefore h = \frac{0.0271\times 186}{0.88} = \boxed{5.73\ \mathrm{W/m^2\cdot K}}$$

21 ➡ B

Per Fourier's law, the heat flux must be the same in both layers; accordingly,

$$\dot{q}_1'' = \dot{q}_2'' \;\rightarrow\; \frac{K_A\left(T_1 - T_2\right)}{t_1} = \frac{K_B\left(T_2 - T_3\right)}{t_2}$$

$$\therefore \frac{t_1}{t_2} = \frac{K_A\left(T_1 - T_2\right)}{K_B\left(T_2 - T_3\right)}$$

$$\therefore \frac{t_1}{t_2} = 3\times\frac{\left(T_1 - T_2\right)}{\left(T_2 - T_3\right)}$$

$$\therefore \frac{t_1}{t_2} = 3\times\frac{(1400-1250)}{(1250-50)} = \boxed{0.375}$$

22 ➡ C

The power Π is given by the product of flow rate and pressure drop:

$$\Pi = Q\Delta p \quad \text{(I)}$$

Here, Q can be determined as

$$Q = \frac{\pi d^2}{4}\times u = \frac{\pi\times 0.04^2}{4}\times 1.8 = 0.00226\ \mathrm{m^3/s}$$

while Δp can be determined from Poiseuille's equation for power-law fluids:

$$\Delta p = K\left(\frac{4L}{d}\right)\left(\frac{8u}{d}\right)^n = 2\times\left(\frac{4\times 5.0}{0.04}\right)\times\left(\frac{8\times 1.8}{0.04}\right)^{0.4} = 10{,}530\ \mathrm{Pa}$$

Substituting in (I),

$$\Pi = Q\Delta p = 0.00226\times 10{,}530 = \boxed{23.8\ \mathrm{W}}$$

23 ➡ 7.29

Given specific gravity S_g = 1.5, effective depth of root zone d = 84 cm, field capacity F_c = 0.28, and optimum moisture m_0 = 0.13, the depth of stored moisture d_w is determined as

$$d_w = S_g\times d\times\left(F_c - m_0\right) = 1.5\times 84\times(0.28-0.13) = 18.9\ \mathrm{cm}$$

Multiplying this by the crop area gives the volume of water needed:

$$\forall = 0.189\ \mathrm{m}\times 4000\ \mathrm{ha}\times 10{,}000\ \frac{\mathrm{m^2}}{\mathrm{ha}} = 7.56\times 10^6\ \mathrm{m^3}$$

Finally, for a 12-day irrigation operation, the discharge supplied by the canal becomes

$$Q = \frac{7.56\times10^6}{12\times24\times3600} = \boxed{7.29\ \text{m}^3/\text{s}}$$

24 ➡ 1065

On a mass basis, the fuel consumption rate is

$$\dot{m} = 75\ \frac{\text{L}}{\text{h}}\times0.835\ \frac{\text{kg}}{\text{L}} = 62.6\ \text{kg/h}$$

Then, the fuel equivalent power is obtained if we multiply the mass flow by the heating value of the fuel:

$$Q = 62.6\ \frac{\text{kg}}{\text{h}}\times\frac{1}{3600}\ \frac{\text{h}}{\text{s}}\times45{,}000\ \frac{\text{kJ}}{\text{kg}} = 783\ \text{kW}$$

Finally, noting that 1 metric hp = 735.5 W, we write

$$Q = 783{,}000\ \text{W}\times\frac{1}{735.5}\ \frac{\text{hp}}{\text{W}} = \boxed{1065\ \text{hp}}$$

25 ➡ 97.27

This is a straightforward application of the formula

$$P_x = \frac{N_x}{M}\left(\frac{P_1}{N_1}+\frac{P_2}{N_2}+\ldots+\frac{P_m}{N_m}\right)$$

where *N* denotes normal annual precipitations, *P* denotes observed annual precipitations at a given year, and *M* is the number of stations for which data is available. In the problem at hand, we have

$$P_D = \frac{N_D}{M}\left(\frac{P_A}{N_A}+\frac{P_B}{N_B}+\frac{P_C}{N_C}\right)$$

$$\therefore P_D = \frac{92.0}{3}\times\left(\frac{93.5}{81.2}+\frac{74.8}{68.0}+\frac{69.4}{75.4}\right) = \boxed{97.27\ \text{cm}}$$

26 ➡ 2.1

The annual cost is

$$AC = \left(\frac{55\ \text{hp}}{0.85}\right)\times\left(0.746\ \frac{\text{kW}}{\text{hp}}\right)\times\left(6\ \frac{\text{rupee}}{\text{kWh}}\right)\times\left(20\ \frac{\text{hr}}{\text{d}}\right)\times\left(360\ \frac{\text{d}}{\text{year}}\right)$$

$$\therefore AC = 2.09\times10^6 \approx \boxed{2.1\ \text{million rupees/year}}$$

27 ➡ 10.6

Knowing that the coefficient of passive earth pressure is

$$K_p = \tan^2\left(45^\circ+\frac{\phi'}{2}\right) = \tan^2\left(45^\circ+16^\circ\right) = \tan^2\left(61^\circ\right)$$

whereas that of active earth pressure is

$$K_a = \tan^2\left(45^\circ-\frac{\phi'}{2}\right) = \tan^2\left(45^\circ-16^\circ\right) = \tan^2\left(29^\circ\right)$$

the ratio we're looking for then becomes

$$\frac{K_p}{K_a} = \left[\frac{\tan 61^\circ}{\tan 29^\circ}\right]^2 = \boxed{10.6}$$

28 ➡ 15.7

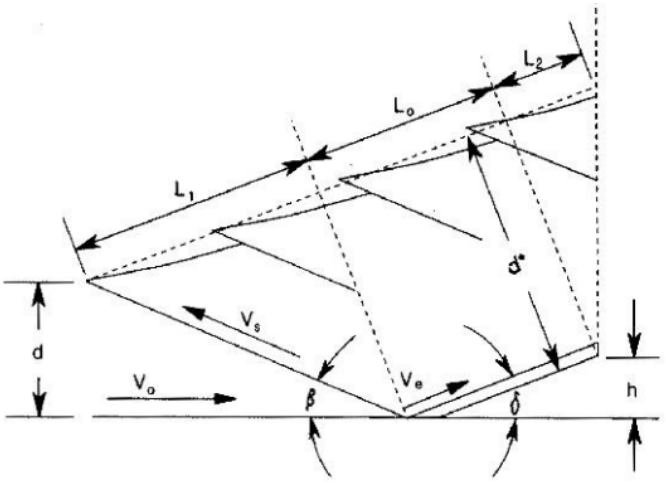
Noting that μ = 1.8 cP = 1.8×10^{-3} Pa·s, the velocity of the suspended fat particle can be found with Stokes' law:

$$V = \frac{D_p^2\left(\rho_{\text{milk}}-\rho_{\text{fat}}\right)g}{18\mu} = \frac{\left(12\times10^{-6}\right)^2\times\left(1050-950\right)\times9.81}{18\times\left(1.8\times10^{-3}\right)} = 4.36\times10^{-6}\ \text{m/s}$$

$$\therefore V = 4.36\times10^{-6}\ \frac{\text{m}}{\text{s}}\times3600\frac{\text{s}}{\text{hr}}\times1000\frac{\text{mm}}{\text{m}} = \boxed{15.7\ \text{mm/hr}}$$

29 ➡ C

The figure on the next page illustrates a segment of soil on the plane tillage tool.



In Soehne's model of soil tillage, the specific draft force *D** is expressed as

$$D^* = \frac{W}{z} + \frac{cA_1 + B}{z\left(\sin\beta + \mu\cos\beta\right)}$$

where *W* is the soil weight, *z* is the geometric factor, *c* is the soil cohesion, A_1 is the area of forward failure surface, *B* is the soil acceleration force, β is the angle of the forward failure surface, and μ is the coefficient of internal soil friction. The first step is to compute the acceleration force *B*, which is given by

$$B = \rho_s b d v_o^2 \frac{\sin\delta}{\sin\left(\delta + \beta\right)}$$

Here, density ρ_s = 1.8 g/cm^3, width *b* = 0.32 m, depth *d* = 0.32 m, velocity v_o = 6 km/h = 1.67 m/s, tool angle δ = 45° (as tool width and depth have the same value), and β = (90° – ϕ)/2 = 29°, giving

$$B = 1800 \times 0.32 \times 0.32 \times \left(6/3.6\right) \times \frac{\sin 45^\circ}{\sin\left(45^\circ + 29^\circ\right)} = 226 \text{ N}$$

Then, the shear plane area A_1 is given by

$$A_1 = \frac{bd}{\sin\beta} = \frac{0.32 \times 0.32}{\sin\left(29^\circ\right)} = 0.211 \text{ m}^2$$

The weight of soil *W* is such that

$$W = \gamma b d^* \left(L_o + \frac{L_1 + L_2}{2} \right)$$

where length L_o = 0.10 m and

$$d^* = d\frac{\sin\left(\delta + \beta\right)}{\sin\beta} = 0.32 \times \frac{\sin\left(45^\circ + 29^\circ\right)}{\sin\left(29^\circ\right)} = 0.632 \text{ m}$$

$$L_1 = d\frac{\cos\left(\delta + \beta\right)}{\sin\beta} = 0.32 \times \frac{\cos\left(45^\circ + 29^\circ\right)}{\sin\left(29^\circ\right)} = 0.182 \text{ m}$$

$$L_2 = d^* \tan\delta = 0.632 \times \tan\left(45^\circ\right) = 0.632 \text{ m}$$

so that

$$W = \left(9.81 \times 1800\right) \times 0.32 \times 0.632 \times \left(0.10 + \frac{0.182 + 0.632}{2} \right) = 1810 \text{ N}$$

Noting that the coefficient of soil-metal friction μ' = 0.27 and coefficient of soil internal friction $\mu = \tan\phi = \tan(30^\circ) = 0.577$, we proceed to compute the geometric factor *z*:

$$z = \left(\frac{\cos\delta - \mu'\sin\delta}{\sin\delta + \mu'\cos\delta} + \frac{\cos\beta - \mu\sin\beta}{\sin\beta + \mu\cos\beta} \right)$$

$$\therefore z = \left(\frac{\cos 45^\circ - 0.27 \times \sin 45^\circ}{\sin 45^\circ + 0.27 \times \cos 45^\circ} + \frac{\cos 29^\circ - 0.577 \times \sin 29^\circ}{\sin 29^\circ + 0.577 \times \cos 29^\circ} \right) = 1.18$$

Finally, noting that $c = 0$ for a cohesionless soil, the draft force D^* is calculated to be

$$D^* = \frac{W}{z} + \frac{cA_1 + B}{z(\sin\beta + \mu\cos\beta)} = \frac{1810}{1.18} + \frac{0 \times 0.211 + 226}{1.18 \times (\sin 29^\circ + 0.577 \times \cos 29^\circ)} = \boxed{1730 \text{ N}}$$

30 ➡ B

Inspecting the table, it is easy to see that the storm registered maximum intensity values in the 30-minute interval from 30 to 59 minutes from the beginning the storm. The maximum 30-minute intensity is then (27.5 + 32.0)/0.5 = 119 mm/h. We also need the kinetic energy of the storm. The *KE* is related to intensity by the relationship we were given, namely

$$KE = 0.012 + 0.09\log_{10} I$$

For the interval 0 → 14 min, for example, I = 7.10 mm/h and *KE* = 0.089 MJ/ha/mm; we then multiply this value of *KE* by the rainfall depth to obtain the *total* kinetic energy; for the example interval at hand, the total *KE* is 0.089 × 1.5 = 0.134 MJ/ha. The full calculations are summarized below.

Time from start of storm (min)	Rainfall (mm)	Intensity (mm/h)	Kinetic energy (MJ/ha/mm)	Total kinetic energy (MJ/ha) (Col. 2 x Col. 4)
0 - 14	1.5	7.1	0.089	0.133
15 - 29	14	60	0.172	2.408
30 - 44	27.5	110.5	0.196	5.387
45 - 59	32	135	0.204	6.519
60 - 74	8.5	32.5	0.148	1.259
75 - 89	0.95	2.15	0.042	0.040
			Total =	15.746

As shown, the total kinetic energy equals 15.746 MJ/ha. Multiplying this by the maximum 30-minute intensity gives the Wischmeyer erosivity index:

$$E \times I_{30} = 119 \times 15.746 = \boxed{1870 \text{ MJ mm ha}^{-1} \text{ h}^{-1}}$$

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