THE ENERGY OF RAINDROPS

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In soil erosion the precipitation energy is one of the main factors. It is generally expressed as the gravitional energy of the drops, but normally these also have a horizontal movement, i. e. an energy in the wind direction. By means of a simple mathematical model, the velocity of a drop can be calculated approximately and its dependence on wind velocity and wind profile is discussed. When the size distribution of the drops is known, the total precipitation energy can be determined, and it is demonstrated that the total energy is a function of the wind velocity and generally also of the shape of the wind profile.

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Introduction.

In the autumn 1974 the total energy of precipitation as a main factor in soil erosion was discussed in a colloquim at The Geographical Institute. All the papers presented were based upon the idea that the precipitation energy - with identical intensity - was a function of the terminal velocities of the drops. It seemed strange that the wind should have no effect, since increasing wind should increase the horizontal velocities of the drops, and hence the kinetic energy of the precipitation. It was therefore decided to investigate this in greater details, and the present paper presents a simple mathematical model allowing an approximate calculation of velocities as a function of (a) the wind velocity, and (b) different shapes of the wind profile.

Mathematical treatment.

The calculations are based upon a model assuming that all drops, situated above a given height H, have the same horizontal speed as the atmosphere. When the drops have descended the level H, horizontal speed of the drops is presumed to deviate from the horizontal speed of the atmosphere. Finally, it is assumed that no coalescense occurs below the height H.

Over an adequately thick layer, the wind profiles obey the empirical power law

$$u = u_o\,(z/z_o)^n$$

where u is the horizontal wind speed at the height z, u_o the horizontal wind speed at a reference level z_o, and the power n is in particular a function of the stability of the atmosphere, and to a lesser degree of the roughness of the surface.

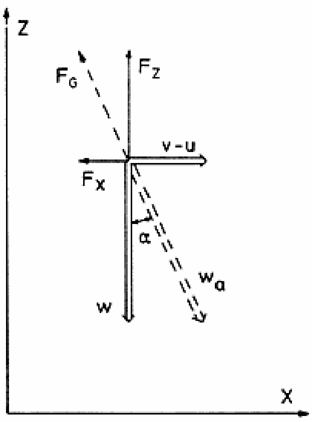
At a drop's relative motion through atmosphere, the frictional drag is determined by

$$F_G = \gamma\,\tfrac{1}{2}\,\rho_L\,w_a^{\,2}\,\tfrac{\pi}{4}\,d^2$$

where γ is some coefficient of resistance, ρ_L the density of the air, w_a the relative (oblique) drop velocity, and d the diameter of the drop.

If the horizontal speed of the drop is v, its relative speed in horizontal direction will be v - u. The vertical speed of the drop being w, the speed w_a relative to the air is given by

$$w_a^{\,2} = w^2 + (v - u)^2$$



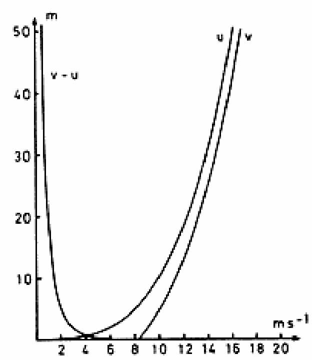


Fig. 1. The frictional resistance is directly opposite the relative velocity w_a, determined by the vertical velocity w and the relative horizontal velocity v−u of the drop. The horizontal component of the frictional resistance is called F_x, the vertikal component F_z.
Fig. 1. Modstanden mod en dråbes bevægelse er modsat rettet den relative hastighed w_a, bestemt ved vertikalfaldhastighed w og relativ horisontal hastighed v−u. Gnidningsmodstandens horisontale og vertikale komposanter er henholdsvis F_x og F_z.

Fig. 2. Velocity profile for the wind and for a water drop.
Fig. 2. Hastighedsprofiler for en vanddråbe og for vinden (d = 3 mm, u_o = 10 ms^{-1} og n = 0.30).

If α is the angle between w and w_a (see Fig. 1), the following two equations are obtained for the determination of the acceleration of the drop, A_h and A_v, in the horizontal and the vertical direction, respectively

$$-\gamma \tfrac{1}{2} \rho_L w_a^2 \tfrac{\pi}{4} d^2 \sin\alpha = \tfrac{\pi}{6} d^3 \rho_w A_h \qquad (1)$$

$$\gamma \tfrac{1}{2} \rho_L w_a^2 \tfrac{\pi}{4} d^2 \cos\alpha = -\tfrac{\pi}{6} d^3 \rho_w A_v + \tfrac{\pi}{6} d^3 (\rho_w - \rho_L) g \qquad (2)$$

where ρ_w is the density of the drop, g the acceleration of the drop due to gravity, and

$$\operatorname{tg}\alpha = (v - u)/w \qquad (3)$$

The second part of equation (2) represents gravity minus buoyancy at the position of the drop.

Using a first order approximation A_v is zero, hence the left side of equation (2) is (nearly) constant. During the fall of the drop w_a increases, but α must decrease in such a manner that $w_a^2 \cos\alpha$ is (nearly) constant:

$$\gamma \tfrac{1}{2} \rho_L w_a^2 \tfrac{\pi}{4} d^2 \cos\alpha \cong \tfrac{\pi}{6} d^3 (\rho_w - \rho_L) g \qquad (4)$$

At the starting level H the equation can be written

$$\gamma_o \tfrac{1}{2} \rho_L w_o \tfrac{\pi}{4} d^2 \cong \tfrac{\pi}{6} d^3 (\rho_w - \rho_L) g \qquad (5)$$

where γ_o is the coefficient of resistance, w_o the vertical speed of the drop when falling in still air.

Since

$$w = -\frac{dz}{dt} \qquad (6)$$

the equations (1), (3), (4), (5), and (6) may be combined to give

$$\frac{dv}{dz} = D_o (v - u), \text{ where } D_o = \frac{3\gamma_o \rho_L}{4 d \rho_w} \qquad (7)$$

The coefficient of resistance, γ_o, may be calculated by means of equation (5) knowing the terminal velocities of waterdrops in still air. Using the value $\rho_L/\rho_w = 1.196 \cdot 10^{-3}$ some calculations of ρ_o and D_o have been made, and the results are given in Table 1.

Numerical solutions.

The horizontal speed of a drop is determined by equation (7), which can be solved by numerical integration. Calculation start at the starting level H, where $v - u = 0$. Assuming u to be a function of z given by the power law, the value of the drop velocity v for decreasing levels can be calculated successively. Down to 20 m over the plane surface the calculation is made for every meter, from 20 to 5 for every half meter, and from 5 and down to the surface for every 10 cm.

Calculations are made for drop diameters from 1 to 5 mm for each value of the speed u_o (assumed to be determined at the reference level z_o = 10 m) and for each value of the power n.

Tabel 1.

Diameter diameter d mm	Terminal-hastighed terminal velocity w_o m s^{-1}	Modstands-koefficient drag coefficient γ_o	D_o m^{-1}
1	4.03	0.672	0.603
2	6.49	0.518	0.233
3	8.06	0.504	0.151
4	8.83	0.560	0.126
5	9.09	0.661	0.118

Tabel 1. Terminalhastighed w_o, modstandskoefficient γ_o og proportionalitetsfaktor D_o for forskellige dråbediametre ved fald i stillestående luft.

Table 1. Terminal velocities w_o, drag coefficient λ_o and factor D_o (see the text) for water drops falling in still air.

In solving equation (7) the initial condition is that $v - u = 0$ at the starting level H. In practice this assumption is not valid since a drop moves faster than the air. It is shown that the selected initial condition has no influence on the terminal horizontal velocity of the drop at the surface by comparing the calculated values of the terminal velocity obtained for starting levels H equal to 200 m and 100 m, respectively.

Tabel 2.

Diameter diameter d mm	Indsvingningsdistance (m) distance δ = 0.005 cm s^{-1}	 δ = 0.05 cm s^{-1}	 δ = 0.5 cm s^{-1}
1	13	9	5
2	37	27	17
3	59	44	29
4	74	54	36
5	77	58	39

Tabel 2. Indsvingningsdistance for forskellige dråbediametre som funktion af de valgte krav om hastighedsoverensstemmelse (δ).

Table 2. The distance, a drop has to move-according to the model-before obtaining the same velocity (difference δ) as a free falling drop of the same size.

The vertical distance a drop starting at the initial level H = 100 m has to fall, before it reaches the same velocity -at some level above the surface-as a drop starting at the initial level H = 200 m (apart from a small difference δ) is given in Tabel 2. The following starting conditions were selected: u_0 = 10 m s^{-1}, z_0 = 10 m, and n = 0.30.

The main result of these calculations is that the assumption v − u = 0 at the starting level H has no influence on the resultant terminal velocity of the drop, as long as the starting level is at least 100 m above the surface. In other words, as long as the cloud base is 100 m ore more aloft, drops of a given size will reach a terminal horizontal velocity that depends on drop size and wind profile but not on the starting level of the drop.

The horizontal velocity of the raindrops.

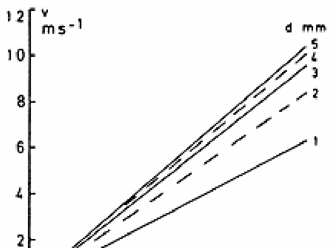
In making the numerical calculations of the terminal velocities (i. e. the velocities at the surface of the earth) a starting height of H = 200 m is chosen. Table 3 shows the results of the calculations using a value of n = 0.30 (approximately the average stability).

Tabel 3.

Diameter diameter d mm	Vindhastighed i 10 m højde wind speed at 10 meters u_0 m s^{-1} 2	4	6	8	10	12
1	1.05	2.10	3.14	4.19	5.24	6.29
2	1.39	2.79	4.18	5.58	6.97	8.36
3	1.59	3.17	4.76	6.35	7.94	9.52
4	1.68	3.35	5.03	6.71	8.32	10.06
5	1.71	3.41	5.12	6.82	8.53	10.23

Tabel 3. Dråbers horisontale terminalhastighed v_{ht} (n = 0.30).
Table 3. The horizontal terminal velocities of raindrops (n = 0.30).

From the table it is seen, that for a given drop diameter the horizontal terminal velocity of the drops is proportional to the wind speed at a height of 10 m (cf. Fig. 3).



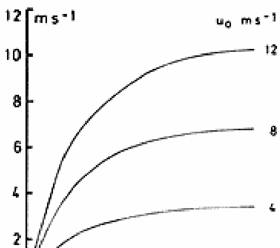


Fig. 3. Horizontal terminal velocity of the drops at different wind speeds at reference level 10 m.
Fig. 3. Horisontal terminalhastighed som funktion af vindhastigheden u_0 i referencehøjden z_0 = 10 m (n = 0.30).
Fig. 4. Horizontal terminal velocity vs. diameter of the drops.
Fig. 4. Horisontal terminalhastighed som funktion af dråbediameter (n = 0.30).

From the table it is also seen, that for a given wind speed the horizontal velocity of the drops increase with increasing drop diameter, but the relationship is far from linear, since the increase in horizontal velocity per mm increase in drop diameter diminishes as the drop diameter grows bigger (Fig. 4).

Tabel 4.

n	Diameter diameter d mm	Vindhastighed i 10 m højde wind speed at 10 meters u_0 m s^{-1} 4	8	12
	1	2.57	5.13	7.70
0.20	3	3.38	6.77	10.15
	5	3.55	7.10	10.65
	1	2.31	4.63	6.94
0.25	3	3.27	6.54	9.82
	5	3.48	6.95	10.43
	1	1.90	3.80	5.70
0.35	3	3.09	6.18	9.26
	5	3.36	6.72	10.08
	1	1.73	3.46	5.19
0.40	3	3.01	6.02	9.04
	5	3.32	6.63	9.95

Tabel 4. Dråbers horisontale terminalhastighed v_{ht} for n = 0.20, 0.25, 0.35 og 0.40.
Table 4. The horizontal terminal velocities of rain drops for n = 0.20, o.25, 0.35 and 0.40.

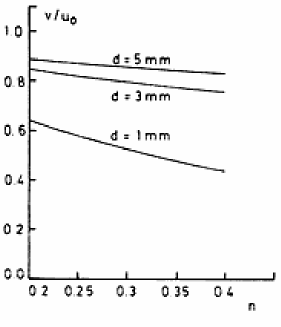
The results of the numerical calculations of the horizontal terminal velocity made for various values of the exponent n are shown in Table 4. From the table it is seen, that for fixed values of n and drop diameter, the horizontal terminal velocity v_{ht} of the drop is proportional to the velocity of the wind u_0.

Tabel 5.

	n 0.20	0.25	0.30	0.35	0.40
f_0	1.0358	1.0162	1.0000	0.9873	0.9774
a	0.4733	0.2183	0.0000	−0.1862	−0.3487
b mm^{-1}	0.9184	0.8993	-	0.8486	0.8336

Tabel 5. Konstanterne f_0, a og b i ligningen $f = f_0 + a\ exp(-b \cdot d_{gs})$, hvor $f = v_{ht}(n)/v_{ht}$ (0.30).
Table 5. The factors f_0, a and b from the equation $f = f_0 + a\exp(-b \cdot d_{gs})$, where $f = v_{ht}(n)/v_{ht}(0.30)$.

The horizontal terminal velocity as a function of n is illustrated by plotting $\beta = v_{ht}/u_0$ against n (Fig. 5). It is seen that in the case of small drops there is a distinct decrease in β, and consequently in v_{ht}, for increasing values of n, while β for larger drops decreases very little with increasing n. From Fig. 6, which shows β as a function of drop diameter for various values of n, it appears that the smaller the n value (i. e. the less stable



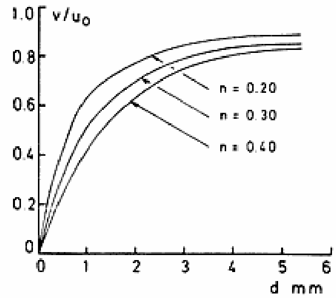


Fig. 5. $\beta = v_{ht}/u_0$ vs. n for d = 1, 3 and 5 mm.
Fig. 5. $\beta = v_{ht}/u_0$ *som funktion af n for d = 1, 3 og 5 mm.*
Fig. 6. $\beta = v_{ht}/u_0$ vs. diameter for n = 0.20, 0.30 and 0.40
Fig. 6. $\beta = v_{ht}/u_0$ *som funktion af dråbediameter for n = 0.20, 0.30 og 0.40.*

Tabel 6.

Interval interval d mm	Diameter diameter d_{gs} mm	Relativ fordeling distribution ψ
0.00–0.25	0.157	0.001
0.25–0.50	0.388	0.007
0.50–0.75	0.633	0.018
0.75–1.00	0.881	0.039
1.00–1.25	1.130	0.076
1.25–1.50	1.379	0.110
1.50–1.75	1.628	0.135
1.75–2.00	1.878	0.141
2.00–2.25	2.127	0.113
2.25–2.50	2.377	0.096
2.50–2.75	2.627	0.077
2.75–3.00	2.877	0.059
3.00–3.25	3.127	0.042
3.25–3.50	3.377	0.026
3.50–3.75	3.626	0.017
3.75–4.00	3.876	0.013
4.00–4.25	4.126	0.010
4.25–4.50	4.376	0.008
4.50–4.75	4.626	0.004
4.75–5.00	4.876	0.004
5.00–5.25	5.126	0.002
5.25–5.50	5.376	0.002
5.50–5.75	5.626	0.000
5.75–6.00	5.876	0.000

Tabel 6. Dråbefordeling (efter Laws og Parsons) ved en nedbørsintensitet på ca. 12.5 mmh^{-1}.
Table 6. The size distribution (after Laws and Parsons) at an intensity of 0.5 in h^{-1}.

the atmosphere) the greater the horizontal terminal velocity will be.

Method used in calculating the energy of precipitation.

When the distribution of the drops in the precipitation (rain) and the terminal velocities of the drops both in horizontal and vertical direction are known, it is possible to calculate the total kinetic energy of a shower.

The calculations are based on the size distribution found by Laws and Parsons at an intensity of 0.5 in h^{-1} (cf. Table 6) and the calculated horizontal component of the terminal velocities. The approach used in making the calculations of the energy of the precipitation is as follows:

a) For every interval in drop size, the drop diameter d_{gs}, matching the average mass of drops in the interval, is calculated.
b) For every value of d_{gs}, the vertical terminal velocity is obtained graphically from curves giving the terminal velocity as a function of drop diameter.
c) For every value of d_{gs}, the horizontal terminal velocity v_{ht} is obtained from parabolic interpolation based upon the calculated horizontal velocities for drop diameters of 1, 2, 3, 4, and 5 mm applying the exponent value n = 0.30.
The values of the horizontal terminal velocities for $d_{gs} > 5$ mm are obtained by extrapolation. This might seem doubtful, but v_{ht} increases only slowly for increasing d_{gs} and in this case even relatively large errors would only affect the energy of the total shower to a small extent, since large drops are relatively rare.
d) For other values of n the horizontal terminal velocity $v_{ht}(n)$ is obtained from

$$v_{ht}(n) = f \cdot v_{ht}(0.30)$$

where $v_{ht}(0.30)$ is the horizontal terminal velocity of the drop concerned for n = 0.30 at the given speed of wind. The factor f is obtained from the empirically based relation

$$f = f_o + a \cdot e^{-b \cdot d_{gs}}$$

where e is the base of the natural logarithms, and where f_o, a, and b are constants.
The terminal velocities for drop diameters of 1, 3, and 5 mm may be used to calculate f_o, a, and b
e) The precipitational energy is expressed per mm precipitation (i. e. per kg m^{-2}).
Laws and Parson's precipitational distribution factor ψ expresses the amount of precipitation (in kg m^{-2}) in the interval of drop size considered.

In order to obtain the total energy of precipitation (per m^2), the value found for the precipitational energy is multiplied by the total amount of precipitation (per m^2).

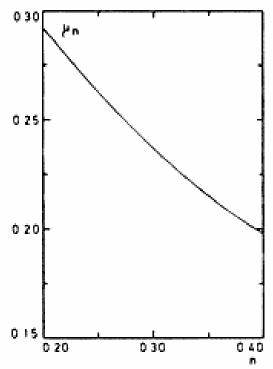
f) For a given value of u_0, the total energy per mm rain may be stated as

$$E = \Sigma \tfrac{1}{2} \psi_i (w_i^2 + v_i^2)$$

where ψ_i is the amount of precipitation in drop size interval number i, and where w_i and v_i are the vertical and horizontal terminal velocities, respectively, for the drop diameter d_{gs} in the i'th interval.
Since $\beta_i = v_i/u_o$ is only a function of drop size (Fig. 6) for a given value of n, it can be shown that

$$E = \tfrac{1}{2} \Sigma \psi_i w_i^2 + \tfrac{1}{2} \Sigma \psi_i (\beta_i u_0)^2$$
$$= E_0 + \mu_n u_0^2$$

where $E_o = \tfrac{1}{2} \Sigma \psi_i w_i^2$ is the total energy of the drops in calm weather, and where $\mu_n = \tfrac{1}{2} \Sigma \psi_i \beta_i^2$ is a quantity dependant on the stability index n. It is seen that the total energy is a parabolic function of wind speed, when the size distribution and wind profile are kept constant.



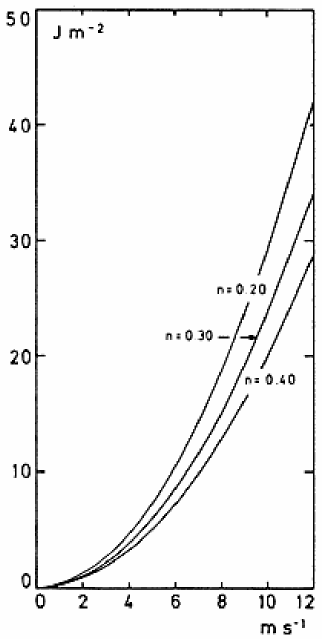


Fig. 7. The factor μ_n vs. n.
Fig. 7. Proportionalitetsfaktoren μ_n i ligningen for nedbørenergien $E = E_o + \mu_n \cdot u_o^2$ som funktion af n.
Fig. 8. The horizontal energy per mm rain at an intensity of 0.5 in h^{-1}.
Fig. 8. Nedbørens horisontalenergi pr. mm regn ved en nedbørintensitet på ca. 12.5 mm h^{-1}.

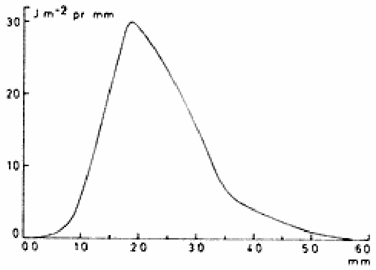
Results from calculation of the energy of prepicitation.

The resulting E_o and μ_n values obtained from the selected size distribution and wind profile are shown in Table 7. The graph of μ_n versus n is shown in Fig. 7. μ_n appears to be a non-linear decreasing function of n. The calculations show that for a given wind speed, at the reference level z_o = 10 m, the total energy of precipitation is larger in unstable conditions of the atmosphere (n small) than in stable conditions (n large).

Tabel 7.

n	μ_n J s^2 m^{-4} mm^{-1}
0.20	0.291_3
0.25	0.261_5
0.30	0.236_5
0.35	0.215_6
0.40	0.198_1
$E_o = 21.2_7$ J m^{-2} mm^{-1}	

Tabel 7. Konstanten E_o og proportionalitetsfaktor μ_n (ligningen for nedbørenergi: $E = E_o + \mu_n u_o^2$) for forskellige værdier af n.
Table 7. The constant energy E_o and the factor μ_n, determining the energy of precipitation: $E = E_o + \mu_n u_o^2$.



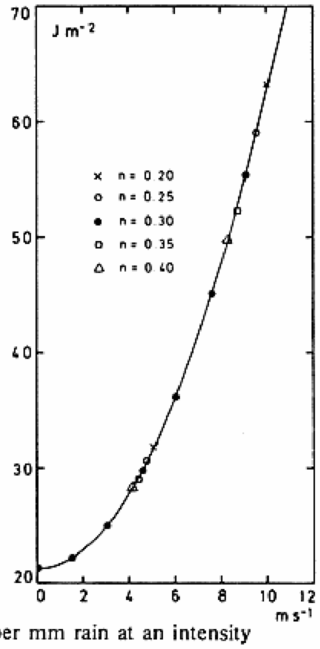


Fig. 9. The distribution of the energy per mm rain at an intensity of 0.5 in h^{-1}.
The area beneath the curve represents the total energy of the rainfall per mm rain.
Fig.9. Nedbørens energifordeling pr. mm regn ved en intensitet på ca. 12.5 mm h^{-1} (u_o = 12 m s^{-1}, n = 0.30).
Arealet under kurven repræsenterer den samlede energi pr. mm regn.
Fig. 10. The total energy per mm rain at an intensity of 0.5 in h^{-1} vs. wind speed at reference level 4 m.
Fig. 10. Nedbørenergi pr. mm regn ved en nedbørintensitet på ca. 12.5 mm h^{-1} som funktion af vindhastigheden i referencehøjden z_o = 4 m.

Fig. 8 depicts the »horizontal« energy ($\mu_n \cdot u_o^2$) per mm rain at the precipitation intensity considered (about 12.5 mm $\cdot$ h^{-1}) as a function of wind speed at the 10 m level for 3 different values of the exponent n. It is noted that the »horizontal« energy of the rain is a significant part of the total energy at wind velocities greater than 6 m $\cdot$ s^{-1}.

The graph depicting precipitational energy per mm rain at an intensity of 0.5 in$\cdot h^{-1}$ as a function of drop size is shown in Fig. 9 for a wind velocity of 12 m$\cdot s^{-1}$ at the 10 m level and n = 0.30. It is seen that for drop sizes less than 1 mm and larger than 5 mm the energy is quite insignificant.

Finally, Fig. 10 shows that by selecting an appropriate reference level at which to measure the wind speed u_o, it is possible to obtain a relation between precipitational energy and wind speed at reference level, which is independant of the stability index n. For the rain intensity selected and the related size distribution, it is found that the appropriate reference level is z_o = 4 m. In this case the total energy of the precipitation is given by

$$E = E_o + \mu_o (u_o[z_o = 4m])^2$$

where $E_o = 21.27\ J\ m^{-2}\ mm^{-1}$, $\mu_o = 0.412\ J\ s^2\ m^{-4}\ mm^{-1}$, and $u_o(z_o = 4\ m)$ is the wind speed at the 4 m level.

RESUME

Ved anvendelse af en simpel matematisk model for vanddråbers fald gennem luften kan dråbernes horisontalhastighed approksimativt bestemmes ved numerisk integration af en differentialligning. Ved løsningen af ligningen forudsættes det

1) at vindhastighed og horisontal dråbehastighed er den samme i et øvre udgangsniveau H,
2) at dråben kan betragtes som en kugle,
3) at der ikke optræder koalescens i atmosfæren i lag under højden H,
4) at vindprofilen kan beskrives ved en potenslov.

Beregningerne viser, at den første antagelse ikke medfører fejl ved beregningen af dråbernes horisontale terminalhastighed, når blot udgangshøjden H er større end 100 m over jordoverfladen.

De horisontale terminalhastigheder viser sig ved beregningerne at være en funktion af vindhastigheden u_o i referenceniveauet (z_o = 10 m) og af eksponenten n i den potenslov, der gengiver vindprofilen (fig. 3-6).

For nedbørenergien vises det, at for samme dråbefordeling i nedbøren og for samme værdi af eksponenten i potensloven er den totale energi en parabolsk funktion af vindhastigheden i referenceniveauet. På grundlag af den dråbefordeling, der er fundet af Laws og Parsons, er nedbørens energi i horisontal retning beregnet som funktion af vindhastigheden i referenceniveauet 10 m og for 3 forskellige værdier af eksponenten (u= 0.20, 0.30 og 0.40), fig 7-8.

Ved passende valg af referenceniveau z_o for vindhastigheden u_o kan man opnå en praktisk talt entydig sammenhæng mellem nedbørenergien og vindhastigheden uafhængigt af eksponenten n. For den angivne dråbefordeling finder man, at referenceniveauet skal være $z_o \cong 4$ m, fig 10.

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Fig. 8 depicts the »horizontal« energy ($\mu_n \cdot u_o^2$) per mm rain at the precipitation intensity considered (about 12.5 mm $\cdot$ h^{-1}) as a function of wind speed at the 10 m level for 3 different values of the exponent n. It is noted that the »horizontal« energy of the rain is a significant part of the total energy at wind velocities greater than 6 m $\cdot$ s^{-1}.

The graph depicting precipitational energy per mm rain at an intensity of 0.5 in$\cdot$h^{-1} as a function of drop size is shown in Fig. 9 for a wind velocity of 12 m$\cdot$s^{-1} at the 10 m level and n = 0.30. It is seen that for drop sizes less than 1 mm and larger than 5 mm the energy is quite insignificant.

Finally, Fig. 10 shows that by selecting an appropriate reference level at which to measure the wind speed u_o, it is possible to obtain a relation between precipitational energy and wind speed at reference level, which is independant of the stability index n. For the rain intensity selected and the related size distribution, it is found that the appropriate reference level is z_o = 4 m. In this case the total energy of the precipitation is given by

$$E = E_o + \mu_o (u_o[z_o = 4m])^2$$

where $E_o = 21.27$ J m^{-2} mm^{-1}, $\mu_o = 0.412$ J s^2 m^{-4} mm^{-1}, and $u_o(z_o$ =4 m) is the wind speed at the 4 m level.

RESUME

Ved anvendelse af en simpel matematisk model for vanddråbers fald gennem luften kan dråbernes horisontalhastighed approksimativt bestemmes ved numerisk integration af en differentialligning. Ved løsningen af ligningen forudsættes det

1) at vindhastighed og horisontal dråbehastighed er den samme i et øvre udgangsniveau H,
2) at dråben kan betragtes som en kugle,
3) at der ikke optræder koalescens i atmosfæren i lag under højden H,
4) at vindprofilen kan beskrives ved en potenslov.

Beregningerne viser, at den første antagelse ikke medfører fejl ved beregningen af dråbernes horisontale terminalhastighed, når blot udgangshøjden H er større end 100 m over jordoverfladen.

De horisontale terminalhastigheder viser sig ved beregningerne at være en funktion af vindhastigheden u_o i referenceniveauet (z_o = 10 m) og af eksponenten n i den potenslov, der gengiver vindprofilen (fig. 3-6).

For nedbørenergien vises det, at for samme dråbefordeling i nedbøren og for samme værdi af eksponenten i potensloven er den totale energi en parabolsk funktion af vindhastigheden i referenceniveauet. På grundlag af den dråbefordeling, der er fundet af Laws og Parsons, er nedbørens energi i horisontal retning beregnet som funktion af vindhastigheden i referenceniveauet 10 m og for 3 forskellige værdier af eksponenten (u= 0.20, 0.30 og 0.40), fig 7-8.

Ved passende valg af referenceniveau z_o for vindhastigheden u_o kan man opnå en praktisk talt entydig sammenhæng mellem nedbørenergien og vindhastigheden uafhængigt af eksponenten n. For den angivne dråbefordeling finder man, at referenceniveauet skal være $z_o \cong 4$ m, fig 10.

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