Effect of atmospheric Stability near the Ground On Vertical Entity Transfers

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ABSTRAK

Dalam penelitian tentang fenomena transfer entitas yang dapat berupa transfer momentum panas dan massa dalam sistim Permukaan-Atmosfir, kondisi stabilitas atmosfir dekat permukaan harus diperhitungkan karena pada kenyataan laju transfer entitas turut ditentukan oleh kondisi stabilitas ini.

Kondisi stabilitas dapat berupa kondisi stabil, netral dan tidak stabil. Untuk menentukan kondisi ini dalam praktek, digunakan parameter bilangan Richardson (Ri), yang dapat dihitung dengan mengadakan pengukuran rata-rata kecepatan angin dan suhu udara pada dua ketinggian (z_1, z_2) di atas permukaan.

Kondisi stabilitas memberikan efek terhadap laju transfer entitas. Oleh karena itu dalam menentukan laju transfer dengan metode aerodinamik, sangat perlu untuk memperhitungkan kondisi stabilitas ini. Kekeliruan yang cukup menyolok dapat terjadi bila kondisi stabilitas tidak diperhitungkan. Faktor koreksi pada persamaan-persamaan transfer akan semakin besar dengan semakin tidak stabilnya atmosfir dan akan semakin kecil di bawah nol dengan semakin stabilnya atmosfir. Efek faktor stabilitas terhadap laju transfer biasanya valid dalam kisaran Ri yang mendekati batas -1 dan +1.

1. Introduction

In the subject of environmental physics the system of Surface-Atmosphere is frequently used as a focus of study about physical properties of the system. Some of physics concepts that important are transfer of entity that can be momentum, heat and mass (like O_2, CO_2, and others). The rate of transfer depends on conditions of the atmosphere near the ground. The conditions are usually stated as "stability of atmosphere". In practice, the conditions of the atmosphere near the ground are calculated by using Richardson number (Calder, 1949; Rosenberg et al. 1990),

$$\mathrm{Ri} = \frac{g}{\bar{T}} \frac{(\partial \bar{T}/\partial z + \Gamma)}{(\partial \bar{u}/\partial z)^2} \tag{1}$$

in which g, gravity acceleration; $\bar{T}$, mean of temperature in layer of air above the surface; $\frac{\partial \bar{u}}{\partial z} \mathrm{dan} \frac{\partial \bar{T}}{\partial z}$ are velocity and temperature gradient. Because of important role of stability factor in calculating the rate of entity so that as the first step we have to know the stability condition at the time on which the measurements of the properties were done.

2. The Conditions of Atmosphere Near The Ground

Physically, the conditions of the atmosphere near the ground are detected by looking turbulent motion of the air molecules. In the air, as fluid, the motions of the fluid are investigated by using the concept of "parcel" or "eddy circle". Calder (1949) with complicated steps mathematically stated the rate of mean kinetic energy of the parcel by the equation,

$$\bar{\rho}\frac{\partial \bar{E}}{\partial t} = \bar{\rho} K_M \left(\frac{\partial \bar{u}}{\partial z}\right)^2 - \frac{\bar{\rho} g}{\bar{T}} K_H \left(\frac{\partial \bar{T}}{\partial z} + \Gamma\right) - D - \frac{\partial}{\partial z}\left[\overline{w'(p' + 1/2\bar{\rho}\overline{w'^2})}\right] \tag{2}$$

According to Richardson Calder's equation becomes simple by neglecting a number of terms in the equation (2) those are:

1. the dissipation of energy D by molecular forces.
2. the convective change of E associated with the mean motion (this requires the mean eddying energy to be uniform horizontally).
3. the diffusion of E associated with the eddy motion.

4. the rate of working of the fluctuating gradients of static pressure on the eddying motion.

and is assumed that

5. the vertical heat flux is given by equation,

$$H = - \rho c_p K_H \left(\frac{\partial T}{\partial z} + \Gamma\right)$$

6. $K_H = K_M$

Richardson's fundamental equation is

$$\frac{\partial \bar{E}(z,t)}{\partial t} = K_M(z)\left(\frac{\partial \bar{u}}{\partial z}\right)^2 - \frac{g}{\bar{T}} K_H(z)\left(\frac{\partial \bar{T}}{\partial z} + \Gamma\right) \quad (3)$$

in which

$\frac{\partial \bar{E}(z,t)}{\partial t}$ = rate of increase of the mean turbulent kinetic energy per unit mass of the fluid at height z above the earth's surface.

$\frac{\partial \bar{u}}{\partial z}$ dan $\frac{\partial \bar{T}}{\partial z}$ = mean velocity and temperature gradient.

$K_M(z)$, $K_H(z)$ = coefficients of turbulent diffusion for momentum and heat respectively (i.e. the eddy viscosity and eddy conductivity)

Γ = dry adiabatic lapse rate.

g = acceleration due to gravity

Equation (3) can be rearranged as

$$\frac{\partial \bar{E}(z,t)}{\partial t} = K_M(z)\left(\frac{\partial \bar{u}}{\partial z}\right)^2 \left\{ \frac{K_M}{K_H} - \frac{g}{\bar{T}} \frac{(\partial \bar{T}/\partial z + \Gamma)}{(\partial \bar{u}/\partial z)^2} \right\} \quad (4)$$

Since $K_H(z)$ $(\partial u/\partial z)^2$ is essentially positive and different from zero (except it the trivial case u = constant), the sign of $\frac{\partial \bar{E}(z,t)}{\partial t}$ depends on the non-dimensional quantity

$$Ri = \frac{g}{\bar{T}} \frac{(\partial \bar{T}/\partial z + \Gamma)}{(\partial \bar{u}/\partial z)^2}$$

called Richardson number (Ri). On the assumption that $K_M(z) = K_H(z)$, whether turbulence will increase or decrease will depend on the non-dimensional quantity, Ri.

In the latter development Richardson number has became the principal criterion to detect the condition of the atmosphere near the ground. Based on many investigations about characteristic of fluid motion Thom (1975) and Oke (1978) had described the relation between Richardson number and stability regimes in relation to regimes of convection as can be seen in the figure 1 above. From the figure we also

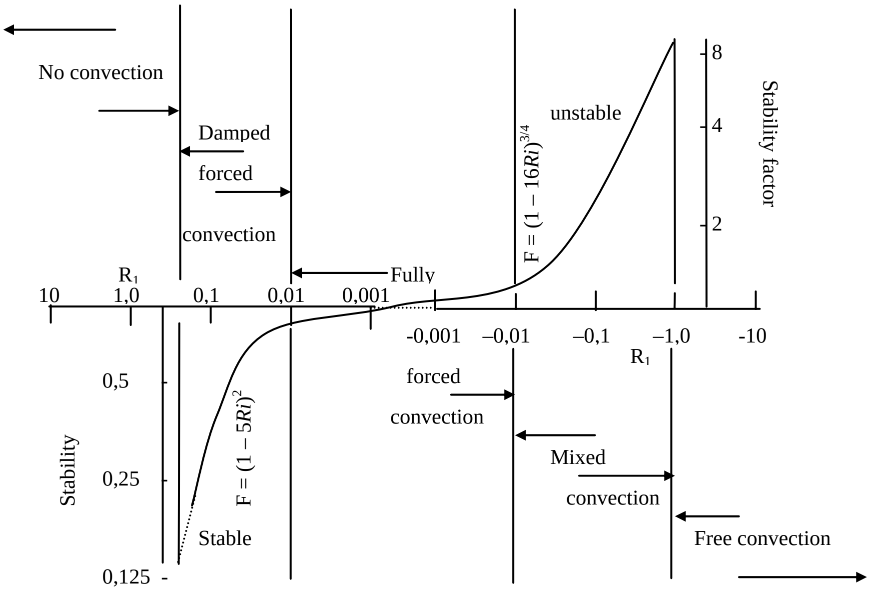

Figure 1. Non-dimensional 'stability factor' $(\phi_V \phi_P)^{-1}$ plotted logarithmically against the Richardson number stability parameter. Flux calculated in non-neutral conditions using flux-gradient equations valid for neutral conditions must be multiplied by this factor. Also showing the characteristic flow regimes at different stability (Oke, 1978; Thom, 1975).

can detect the regime of convection of air motion.

3. The Effect of Stability on Entity transfer.

The effect of stability on entity transfer like momentum, heat and masses in the Surface-Atmosphere system can be seen to the equations of transfer below (Monteith and Unsworth 1990; Palilingan 2003), frequently called aerodynamic method.

(1) Momentum transfer

$$\tau = \rho k^2 (z-d)^2 \left(\frac{\partial u}{\partial z} \right)^2 (\phi_M)^{-2} \qquad (5)$$

(2) Heat transfer

$$H = - \rho c_p k^2 (z-d)^2 \frac{\partial u}{\partial z} \frac{\partial T}{\partial z} (\phi_H \phi_M)^{-1} \qquad (6)$$

(3) Water vapor transfer

$$\lambda E = - \left(\frac{\rho c_p}{\gamma} \right) k^2 (z-d)^2 \frac{\partial u}{\partial z} \frac{\partial e}{\partial z} (\phi_V \phi_M)^{-1} \qquad (7)$$

(4) CO_2 transfer

$$CO_2 = k^2 (z-d)^2 \left(\frac{\partial u}{\partial z} \right) \left(\frac{\partial c}{\partial z} \right) (\phi_C \phi_M)^{-1} \qquad (8)$$

Factor $(\phi_X \phi_M)^{-1}$ indicate stability factor or also describe the effect of atmosphere conditions on the rate of entities transfers. As can be seen to the figure 1 that the stability factor increases in the regime unstable and decreases in stable regime, and in the neutral regime the stability factor nearly unity. Based on many investigations in fields and also in wind tunnel, correction factor written as,

$$(\phi_X \phi_M)^{-1} = (1-Ri)^{3/4} \qquad (9)$$

in unstable conditions and

$$(\phi_X \phi_M)^{-1} = (1-Ri)^2 \qquad (10)$$

in stable conditions, while in neutral conditions

$$(\phi_X \phi_M)^{-1} \approx 1 \qquad (11)$$

So by above theoretical reality can be concluded that the rate of transfer is affected by the atmospheric condition. In unstable condition mixed convection and free convection dominate the mechanism of transfer, in neutral condition dominated by forced convection, while in stable condition by damped forced convection.

As measurement of property observed in two heights z_1 and z_2 and by assuming that d = 0, the transfer equations of entity written as (Oke (1978; Palilingan, 2003),

Momentum transfer

$$\tau = \rho k^2 z^2 \left(\frac{\Delta u}{\Delta z} \right)^2 (\phi_M)^{-2} \qquad (12)$$

Heat transfer

$$H = - \underline{\rho c_p k^2 z^2 \frac{\Delta u}{\Delta z} \frac{\Delta T}{\Delta z}} (\phi_H \phi_M)^{-1} \qquad (13)$$

Water vapor transfer

$$\lambda E = - \left(\frac{\rho c_p}{\gamma} \right) k^2 z^2 \frac{\Delta u}{\Delta z} \frac{\Delta e}{\Delta z} (\phi_V \phi_M)^{-1} \qquad (14)$$

CO_2 transfer

$$CO_2 = k^2 z^2 \left(\frac{\Delta u}{\Delta z} \right) \left(\frac{\Delta c}{\Delta z} \right) (\phi_C \phi_M)^{-1} \qquad (15)$$

where $\Delta u = \bar{u}(z_2) - \bar{u}(z_1)$, $\Delta T = T(z_2) - T(z_1)$, $\Delta e = e(z_2) - e(z_1)$, $\Delta c = c(z_2) - c(z_1)$, And $\Delta z = z_2 - z_1$.

By using equations 12 until 15 the rate of the transfers can be evaluated.

4. Examples of Data and calculating of correction factor in transfer equations

In order to see how the stability affect the rate of transfer of entities, in appendix table 1 given the data observed in Papakelan station of climatology in Tondano observed on 15 until 17 October 1999. Based on this data would be shown the effect of atmospheric stability against the rate of transfers.

As can be seen in the table that the correction factor $(\phi_H \phi_M)^{-1}$ are small in the neutral conditions where the value of the factors are in range $-0{,}01 < R_I < 0{,}01$, and as in figure these are neutral regime. Neutral regime occurred especially in the period 1 until period 4. The correction factors of $(\phi_H \phi_M)^{-1}$ are large in period 5 up to period 10 and counted as unstable conditions.

By using the equation 13 for heat transfer, for example, obtained the rates like in the last column of the appendix table. The wrong is done as the correction factor is neglected. As can be seen in period 9 and 10 the correction factors can reach the value 17.888 and 15.336. So these values can not be neglected in calculating the rate of transfer. Of course, beside the atmospheric stability, the rate of transfer determined by driving force as well. Driving force for momentum, heat, and mass (water vapor CO_2) transfer are Δu, ΔT and Δe and Δc. The driving force is large more and more then the rate of transfer is large more and more.

The others conclusion that are important in relation to the rate of entities transfer are: in unstable condition mixed convection and free convection dominate transfer mechanism, forced convection in neutral condition and damped forced convection in stable condition.

From the value of the correction factor $(\phi_H\phi_M)^{-1}$ in every period and compared with the figure 1, the effect of atmospheric stability against the rate of transfer can be summarized in table 1.

Table 1. Summarizing qualitatively effect of atmospheric stability against the correction factor in calculating the rate of transfers.

Condition	**Ri**	$(\phi_H\phi_M)^{-1}$
Stable	Ri>0,01	< 1
Neutral	-0,01<Ri<0,01	≈ 1
Unstable	Ri<-0,01	>>>1

5. Conclusion

By discussing this paper there are some conclusions that can be taken here those are:

1. In investigating physical properties of the atmosphere near the ground especially on the rate of entities transfers, the conditions of the atmosphere usually stated with stability must be taken into account
2. The effect of atmosphere conditions on the rate of entity transfers can be summarized as follows: The correction factor in the transfer equations become large in unstable condition so in calculating the rate of transfer this factor can not be neglected. In other word, we have to use the complete form of transfer equations that take into consideration the correction factor.

6. References

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Table 1. Examples of data and calculating of correction factor in transfer equations. Data observed in 14 periods of observation. In every period data observed per 5 minute. Location of observation is Papakelan Tondano. Period 1 until period 4 observed on 15-17 October 1999 while period 5 until period 10 observed on 16-18 February 1999.

Time Period of observation	**Temp. (K)**	**T(K)**	**Z (m)**	**u(m/det)**	**Ri**	**Stability**	**T2-T1**	**u2-u1**	**$(\phi_H \phi_M)^{-1}$**	**The rate of heat transfer (Wm^{-2})**
1	298.7	297.8	0.5	170.500	-0.0000035	Neutral	-1.90	-164.7	1.000	28051.27
(07.00-07.25)	296.8		2	5.830						
2	298.3	297.7	0.5	38.830	-0.0000118	Neutral	-1.25	72.34	1.000	8108.05
(07.30-07.55)	297.1		2	111.170						
3	299.0	297.7	0.5	10.000	-0.0002456	Neutral	-2.67	23.17	1.003	5562.64
(08.00-08.25)	296.3		2	33.170						
4	300.0	298.4	0.5	6.830	-0.0004049	Neutral	-3.18	19.67	1.005	5635.09
(08.30-08.55)	296.8		2	26.500						
5	300.4	300.0	0.5	0.413	-0.0562229	Unstable	-0.80	0.835	1.618	96.09
13.30-13.55	299.6		2	1.248						
6	299.6	299.2	0.5	0.384	-0.0853112	Unstable	-0.90	0.72	1.907	110.79
14.00-14.25	298.7		2	1.104						
7	299.8	299.4	0.5	0.351	-0.1393049	Unstable	-0.80	0.531	2.409	91.74
14.30-14.55	299.0		2	0.882						
8	297.8	297.5	0.5	0.242	-0.2053120	Unstable	-0.60	0.38	2.978	60.88
15.00-15.25	297.2		2	0.622						
9	298.5	298.3	0.5	0.099	-2.8613296	Unstable	-0.40	0.083	17.888	53.24
15.30-15.55	298.1		2	0.182						
10	298.5	298.2	0.5	0.078	-2.3187872	Unstable	-0.70	0.122	15.336	117.41
16.00-16.25	297.8		2	0.200						

Notes: the density of air (ρ) and the constant pressure heat capacity (c_p) on temperature average (the third column) calculated by using equations:

- $\rho = \frac{pM}{RT} = \frac{1{,}013 \, x \, 10^5 \, x29}{8{,}31x10^3 T}$ and
- $c_p = 6{,}713 + 0{,}4697x10^{-3}T + 1{,}147x10^{-6}T^2 - 0{,}4696x10^{-9}T^3$ (cal/gr-mol K)
- 1 cal/gr-mol K = $4.186x10^3$ Joule/kg-mol K.