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Study for Atmospheric Dispersion Factors and Stability in NPP Site

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1. INTRODUCTION

Air pollution models have been studied by the IAEA, NRC, FGR, and EPA [1,2,3]. Air pollution models are useful tools for evaluating emission rates and quantifying adverse pollutant effects in specific regions. The aim of this study is to develop a more efficient methodology of explaining the behavior of the atmosphere using a stability estimation. The atmospheric stability is calculated by determining the turbulence condition using the effect of diffusion and mixing influenced by the methodological phenomena and an air mechanical behavior[1-5].

In this paper the current stability method is modified and improved to select the best estimation.

The new method and best estimation method is introduced by correlation relation.

2. STABILITY METHODS

2.1. Pasquill's Stability

Pasquill's stability class is shown in Tables 1 and 2. The method is dependent on sunlight (cloud stay time at night) and wind velocity. Stability classes describe the impact of atmospheric turbulence in seven categories: A (extremely unstable), B (moderately unstable), C (slightly unstable), D (neutral state), E (slightly stable), F (moderately stable), and G (extremely stable).

Table 1. Stability based on sunlight

Surface Wind Speed (m/sec)	Daytime		
	Strong	Moderate	Slight
2	A	A-B	B
4<U≤2	A-B	B	C
6<U≤4	B	B-C	C
4<U≤6	C	C-D	D
6<U	C	D	D

Table 2. Stability based on Cloudiness

Surface Wind Speed (m/sec)	Night time		
	Thin	Moderate	Heavy
2	E	-	G
4<U≤2	E	-	F
6<U≤4	D	-	E
4<U≤6	D	-	D
6<U	D	-	D

From Tables 1 and 2, the main shortcoming of Pasquill's method is that the stability fluctuation shape is changed into a catastrophic shape close to sunset and at night.

2.1. Wind Fluctuation (CF)

This method is deeply related to the spread distance of air pollutants and strongly affected by atmospheric stability. Using this method, we calculate the vertical wind deviation from the horizontal wind deviation and the wind speed between 10m and 60m height. The method is delineated as follows:

$$(\delta_E) = (\delta_\theta) / \triangle U \quad (1)$$

Where, $\triangle U$ is the wind velocity difference between 10m and 60m height.

2.2. Vertical Temperature and Wind Speed (△ T•U)

Delta T and U (vertical temperature and wind velocity method) uses the temperature difference between two layers of atmosphere and horizontal diffusion by the wind velocity difference between these two layers (height levels 10m and 60m).

2.3. Richardson Number

Equation (2) defines the gradient Richardson number (Rx) and a negative value indicates that the diffusion term by convection is greater than the diffusion term by advection. Generally the Richardson number is expressed as given below:

$$Rx = g(\partial\theta/\partial Z)/[T(\partial u/\partial Z)^2] \quad (2)$$

Where θ is the temperature gradient (K), Z is the layer (height level of atmosphere, m), and g is gravitational acceleration (9.8m/sec). T is the normalized temperature of the atmosphere (K).

Bulk Richardson number method is applied as given below:

$$Rb = [\, g(\partial\theta/\partial Z)/[T(U)^2]]\, Z^2 \quad (3)$$

2.4.. Vertical Temperature (△ T/△ Z: DeltaT/DeltaZ)

This is known as the NRC method. Generally, only the temperature difference between two layers (height levels 10m and 60m) of the atmosphere is used for classifying stability.

2.5.. Horizontal Wind Fluctuation (δ_θ : Sigma Theta)

In Table 3, △ T/△ Z and δ_θ are reflected into Pasquil stability at both levels of 10m and 60m. The basic categories of stability are selected by the NRC method, referenced as R.G.(Regulatory Guide) 1.23 and R.G. 1.145.
These classification methods have greater conservatism than any other methods of classifying atmospheric stability.

Table 3. Stability based on △ T/△ Z and δ_θ

Pasquil Stability	Temperature (△ T/△ Z,℃/100 m)	Wind direction std (δ_θ, angle)
	Range	Range
A	△ T/△ Z≤-1.9	22.5≤δ_θ
B	-1.9<△ T/△ Z≤-1.7	17.5≤δ_θ<22.5
C	-1.7<△ T/△ Z≤-1.5	12.5≤δ_θ<17.5
D	-1.5<△ T/△ Z≤-0.5	7.5≤δ_θ<12.5
E	-0.5<△ T/△ Z≤1.5	3.8≤δ_θ<7.5
F	1.5<△ T/△ Z≤4.0	2.1≤δ_θ<3.8
G	4.0<△ T/△ Z	δ_θ<2.1

3. STUDY STRATEGY

Stability classes describe the impact of atmospheric turbulence in seven categories: A (extremely unstable), B (moderately unstable), C (slightly unstable), D (neutral state), E (slightly stable), F (moderately stable), and G (extremely stable). For the stability calculation, six methods are considered and compared to find the most useful method. Above all, we consider the △ T·U method as the best candidate, because it has the characteristic of a dynamical term of wind speed and a statistic term of △ T.

3.1. Methodology and Classification Cases

We consider the following cases to determine the best method:
Case01: Pasquill's methodology
Case02: Wind fluctuation (CF: δ_E, δ_θ)
Case03: Vertical Temperature and wind speed(△T•U)
Case04: Richardson number (Rx) and
Bulk Richardson number (Rb)
Case05: Vertical Temperature (△ T/△ Z)
Case06: Horizontal wind fluctuation (δ_θ)
Fig.1 shows the relation of wind speed (U) and temperature rate (△ T/△ Z) based on the meteorological data base of the YONGGWANG site during three years from 2015 to 2017. Fig.1 is modified from Vogt's correction graph and is used for calculation using modified Vogt's methodology.

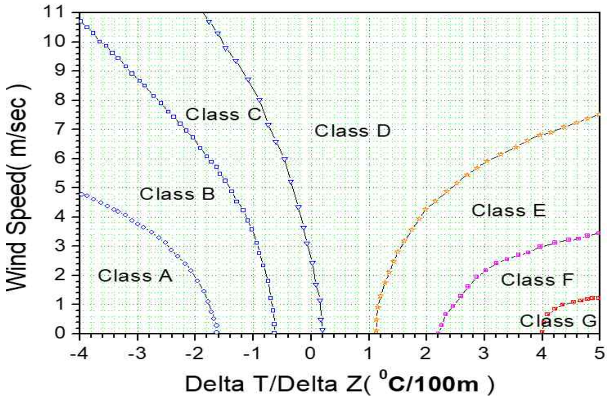


Fig. 1 Wind Speed and Vertical Temperature

3.2. Input Date Base

Table 4 provides a summary of the specifications of the data used in this study. The data set is given below:

Table 4. Site for Atmospheric Stability

Classify	Height	Atmospheric Data			Period
		Wind Direction	Temp.	Other Param.	
Pasquil	60m	-	-	Cloud, Sunlight	2015 ~ 2017
△T/△Z	10m, 60m	-	10m, 60m	-	
△T·U	10m, 69m	-	10m, 60m	Wind Speed (10m, 60m)	
(δ_Θ), angle	60m	60m	60m	-	
(CF: δ_E,δ_Θ)	10m, 60m	60m	60m	Wind Speed (10m, 60m)	
Rb	10m, 60m	-	10m		

4. RESULTS AND DISCUSSIONS

Fig.2 indicates that △ T·U is more similar to the frequency trend of δ_θ than to the frequency trend of △ T/△ Z. The δ_θ is used to explaine the dynamical behavior of atmospheric stability. But △ T/△ Z is used to explain the statistic behavior. In this case, the only similarity between △ T·U and △ T/△ Z is in the range of less than 3m/sec of wind velocity because △ T/△ Z cannot explain the dynamical behavior of the atmosphere.

Table 5 shows that △T·U is in good agreement with △T/△Z in the range of low wind speed of less than 1.5m/sec. But, with strong effects of wind (higher than 1.5m/sec of wind speed), the △T·U method is very similar to δ_θ method.

These results show that the temperature difference between two layers of atmosphere is proportional to seasonal characteristics. But wind speed (wind velocity) is independent of seasonal specification, as seen Figs.3.

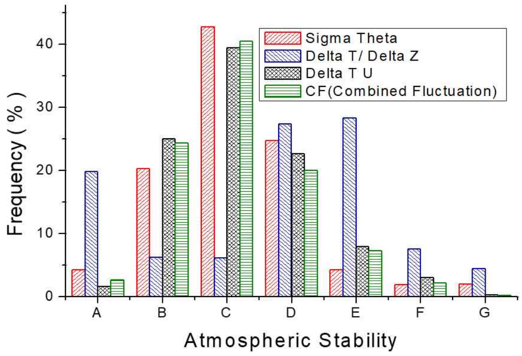
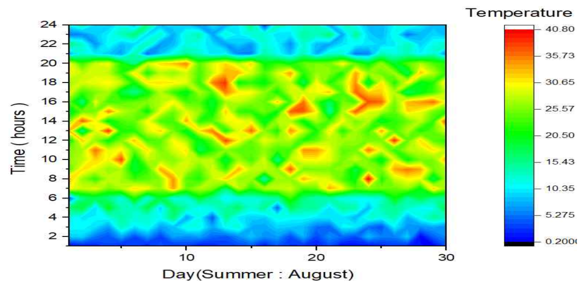
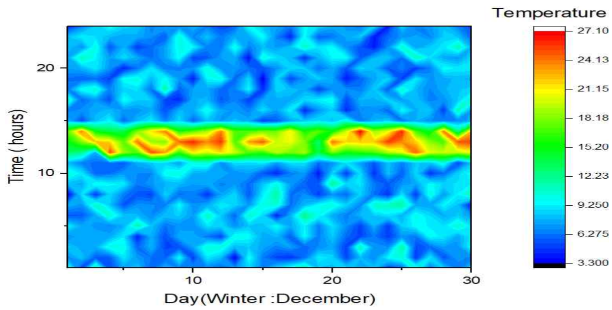


Fig.2 Comparison of stability methods



Summer (August) (A of Fig.3)



Winter (December) (B of Fig.3)

Fig.3. Temperature gradient during annual season

In Table5 and Table6, the matching test of the atmospheric stability classify is carried out using the correlation factors in seven stability (A, B, C, D, E, F, G). In all cases, standard is delta T• U method.

The vertical temperature method is in good agreement with very low wind velocity as correlation factor 0.98.

The horizontal wind fluctuation (δ_θ) is in good agreement with very high wind velocity as correlation factor 0.99.

In other wind velocity, the correlation factors are ranged from 0.26 to 0.8.

Table5. Correction on △T/△Z, δ_θ and △T·U

Wind Speed (m/sec)	(△T/△Z) vs (△T·U) Correlation coefficient	δ_θ vs (△T·U) Correlation coefficient
1～1.5	0.98	0.34
1.5～3	0.80	0.47
3～5	0.41	0.76
5～8	0.30	0.98
8～	0.26	0.99

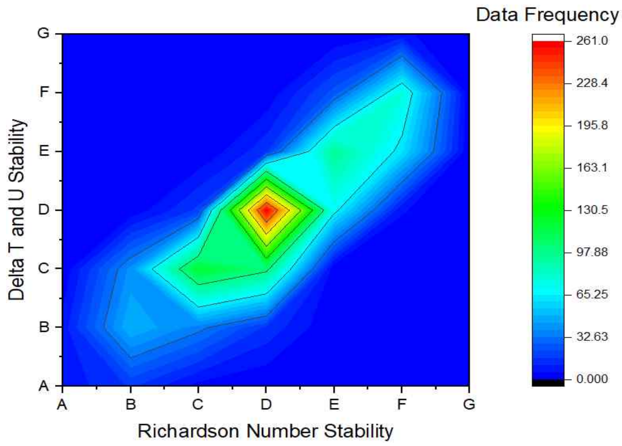
Table 6. Correction on Rb, CF (δ_θ, δ_E) and △T·U

Wind Speed (m/sec)	Rb vs (ΔT·U) Correlation coefficient	CF vs (ΔT·U) Correlation coefficient
1～1.5	0.86	0.93
1.5～3	0.78	0.95
3～5	0.85	0.90
5～8	0.81	0.88
8～	0.95	0.99

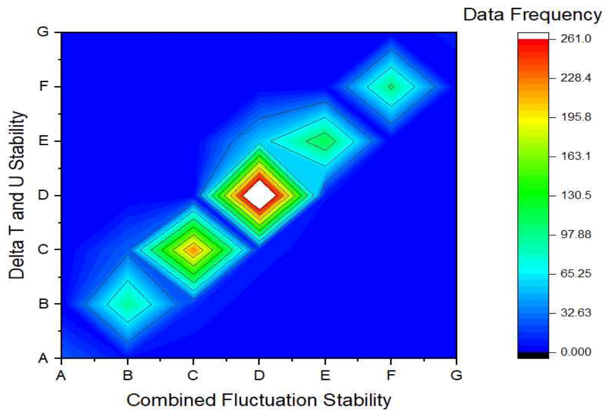
In Fig.4, the equivalent data frequency compared in each category of seven stability (A, B, C, D, E, F, G) are shown in gradient graph. In these graphs, each stability classify is to show the matching characteristic in each stability regions.

In comparison between ΔT·U and vertical temperature, the correlation coefficient of E, F, and G stabilities is 0.98. In the case of horizontal wind fluctuation, the correlation coefficient of A, B, and C is 0.95. In Pasquil's method, the correlation coefficient of D is 0.89.

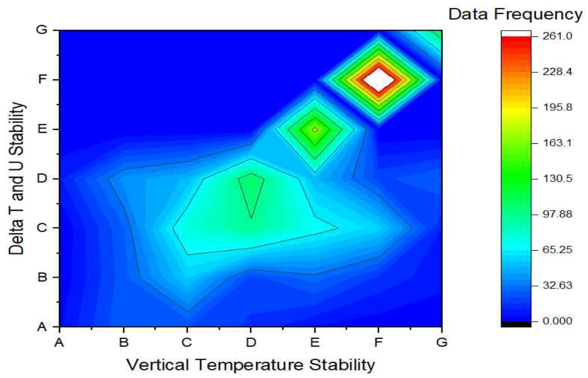
From these results, in the methods of ΔT·U, Rb, and CF, the total correlation coefficient (r) is calculated by root square fitting method. In this study, the total correlation coefficient (r) is 0.901. These results are based on the the comparison between ΔT·U and CF and the comparison between ΔT·U and Rb presented in Fig. 4(See Fig.4, Comparison of Stability Methods).



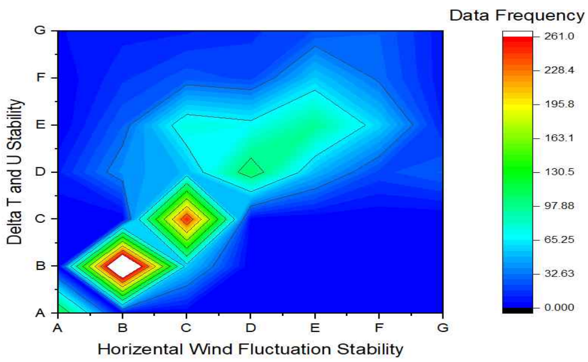
Richardson Number (A of Fig. 4)



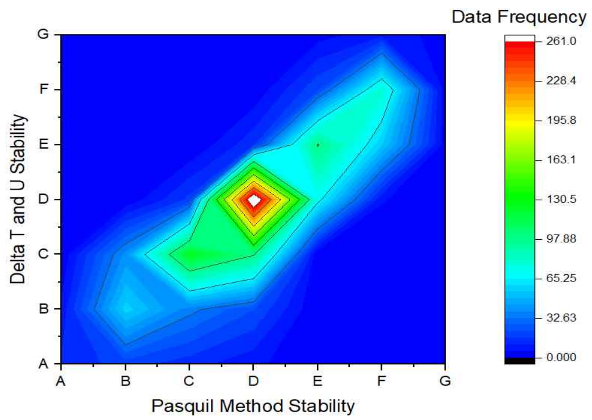
Combined Fluctuation (B of Fig. 4)



Verrtical Temperature (C of Fig. 4)



Horizental Wind Fluctuation (D of Fig. 4)



Pasquil's Method (E of Fig. 4)

Fig. 4 Atmospheric Stability in every conditions

5. CONCLUSIONS

In this study, various methods to determine the stability of the atmosphere are reviewed. In particular, the IAEA methodology ($\Delta T \cdot U$) is discussed and compared with other methods. The $\Delta T \cdot U$ methodology is very reasonable in terms of both dynamic and static stability. Comparison results and conclusions are as follows:

(1) For wind speed higher than 5.0 m/sec, $\Delta T \cdot U$ is similar to δ_θ.
(2) For wind speed less than 3.0 m/sec, $\Delta T \cdot U$ is in good agreement with $\Delta T/\Delta Z$.
(3) Stability of atmosphere is generally impacted by wind speed.
(4) Stability frequency has the similar trends in comparison between $\Delta T \cdot U$ and Combined Fluctuation (CF).
(5) $\Delta T \cdot U$ method is very efficient to explain atmospheric behavior and stability character.
(6) $\Delta T \cdot U$ is in good agreement with Rb comparing with trends.
(7) E, F, G stabilities, D stability, and A, B, C stabilities are equivalent to vertical temperature, Pasquil, wind fluctuation, respectively.
(8) From this study, $\Delta T \cdot U$ method is very similar to Rb and CF.
(9) Correlation coefficient $\Delta T \cdot U$ method is ranged from 0.34 to 0.99.
(10) In the methods of $\Delta T \cdot U$, Rb, and CF, total correlation coefficient (r) is calculated by root square fitting method. In this study, the total correlation coefficient (r) is 0.901.

ACKNOWDGEMENT

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REFERENCES

[1] ICRP, 2007. The 2007 Recommendations of ICRP. ICRP Publication 103. Ann. ICRP 37(2–4). "IAEA Safety Guideline 50-SG-3S: Atmospheric dispersion in nuclear power plant siting.*" IAEA, Vienna*, **97pp**,(1980).

[2] Vogt, R. J. et al., *FRG Report*, **Jul-807-ST**,(1971).

[3] U.S. Nuclear Regulatory Commission, "Atmospheric dispersion models for potential accident consequence assessments at nuclear power plants.,"*Reg. Guide 1.145, USNRC*, Wash., DC, **20555**,(1982).

[4] Pasquill, F., "The estimation of the dispersion of wind bone material,*" Meteorological Magazine*, **No. 4**, 50-55,(1961).

[5] Pasquill, F., "Atmospheric dispersion parameters in Gaussian plume modeling.," *Part II. Possible requirements for change in the Turner workbook values*., **EPA-600/4-76-030 B**.,(1976).