Assessment of Mechanical Mixing Height for Unstable Atmospheric Class using Different Mathematical Models

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Abstract:-

The height of mechanical mixing layer is one of the parameter of the safety analysis report of any nuclear facility due to relation to the dispersion factor of pollutants. It can provide information about lower atmospheric dispersion, which is usually used to study the pollutants released from nuclear facility, risk analysis and emergency planning. The height of mixing layer is difficult to be measured; therefore, mathematical methods are introduced to calculate this layer.

Different Fortran Programs have been developed to calculate the Monin – Obukhov length, universal stability function and the friction velocity, these parameters are used to calculate the height of mechanical mixing layer.

The analysis of the results showed that the variation of the height of the mechanical mixing layer for different seasons depends on the degree of unstable condition and wind speed, where the height of the mechanical mixing layer equals 2433 m at wind speed of 14.5m/s, 1952m at wind speed of 13m/s and 1700m at wind speed of 13m/s in case of A, B and C respectively.

Introduction

The region of the atmosphere which governs the vertical and horizontal exchanges of pollutants is called mixed layer (Zelaya-Angel, 2010).The height of the mixed layer determines the vertical extent of dispersion for pollutants releases from nuclear facility and other facility, the greater the vertical extent of the mixed layer, the larger the volume available to dilute pollutant emissions and measure of the effectiveness of energy transfer from the sun to the earth's surface and returned to the lower atmosphere (Stull, 1989). It covers a range from approximately 50m in the night time to 3000m in the day time as shown in fig. (1). From figure (1) the unstable mixing layer is characterized by a deeper and the stable mixing layer is shallower and steeper vertical gradients in wind speed and potential temperature (Bernhard, 2003). The height of mixing layer are not measured on a routine basis. Therefore, indirect methods are introduced to calculate this layer (Antonio, 1997).

The meteorological data such as wind speed and stability class are important for the transport and dispersion of the pollutants in the atmosphere, where atmospheric turbulence, indicates the dispersive ability of the atmosphere (DEC, 2005).The stability classes can be segmented into the following categories (neutral, stable and unstable) (IAEA, 1980) each one of them has a direct impact on the height of mixing layer. For neutral and stable conditions, the height of mixing layer was calculated by Sugiyama and Nasstrom (1999). While in unstable condition during day for each hour there are two separate mixing height (MH) values: a convective, MH_{conv}, and mechanical, MH_{mech} (Georgieva, 2006). Convective turbulence is caused by the rising of air heated at ground level and calculated by Tawfik, et al (2004) and the mechanical turbulence is a function of wind speed and surface roughness (DEC, 2005).

The aim of the work:-

The purpose of this work is concerned for the calculation of mechanical mixing height (MH_{mech}) by several models during unstable conditions because this value is one of the key parameter of the safety analysis report of any nuclear facility and important in the prediction of pollutants concentration released from any nuclear facility and the scaling of turbulence.

Methodology and Theoretical Background

The mechanical mixing height of atmosphere was calculated by Zannetti (1999) and Cost -710 (1998). A computer program was developed using this model to estimate this layer. we have used data gathered with the National Ocean Atmospheric Administration (NOAA) such as wind speed and stability class for three months January , March and May for 2011 of the north western part of Egypt and the user selected the data concerning unstable stability class, which is classifed into A- Extremely unstable , B -Moderately unstable and C- Slightly unstable (IAEA, 1980).The day time mechanical mixing height was determined by applying the following equations (Zannetti, 1999) and (Cost -710, 1998):-

$$h = \frac{0.133\,U^*}{f}$$

$$h = \frac{0.25\,U^*}{f}$$

Where,
h is day time mechanical mixing height,
f is the Coriolis Parameter = $2\Omega\sin(\varphi)$,
Ω is Earth's rotation rate $=7.29 \times 10^{-5}$ rad·s^{-1},
$\pi = 3.14$,
φ is latitude = $31^{o}\,4''$,
The friction velocity (U*) is given by the following equation (Antonio, 1997):

$$U^* = \frac{k\,u_{ref}}{\ln\left(\frac{z_{ref}}{z_0}\right) - \psi_m\left(\frac{z_{ref}}{L}\right) + \psi_m\left(\frac{z_0}{L}\right)}$$

Where,
U* is the friction velocity ,
K is Von Karman's constant =0.4,
U_{ref} is the wind velocity at z_{ref} ,
z_{ref} is the reference height at 10m,
Z_0 is roughness height = 0 .03m (Hanna, 1982)
L is the Monin – Obukhov length calculated using the following equation (Golder D, 1972) and (Liu, 1976).

$$\frac{1}{L} = a\,z_0^{\,b}$$

Monin – Obukhov length Scale L at given .The constants a and b depend on the stability classes

Results and Discussion

To clarify the calculation of mechanical mixing layer (ML) within the months January, March and May using the different mathematical models.

In January, 2011 the determination of mechanical mixing height at stability class (C) class, which dominates in this month shows that the model by Zannetti, and Sire (1999) according to equation (1) gives the best results when (6 m/s ≤ ws < 6 m/s) , whereas mixed layer was observed reaching depths of up to 1438 m on January 27th at ws = 11m/s and up to 719 m on January 5th at Ws =5.5 m/s as shown in Fig.(1) and Table (1) .

In March, 2011 the determination of mechanical mixing height at stability class (A) shows that the model by Zannetti, and Sire (1999) related to equation (1) gives the best results when the wind speed is greater than or equal to 6m/s ,where mixed layer was observed reaching depths of up to 2433 m on March 9th at ws =14.5 m/s due to monsoon winds, while the model by Cost -710, (1998) according to equation (2) gives the best results when the wind speed is less than 6m/s , where mixed layer was observed reaching depths of up to 1730 m on March 9th at ws =5.5 m/s . For class B and C the model by Zannetti, and Sire (1999) related to equation (1) gives the best results when the wind speed is greater than or equal to 6m/s and when the wind speed is less than 6m/s and the mixing depths observed reaching depths of up to 1950 m on March 9th at ws =13 m/s, up to 826m on March 10th at ws =5.5 m/s and up to 1700m on March 8th at ws =13 m/s, up to 719m on March 15th at ws =5.5 m/s respectively.

In May 2011the mechanical mixing height calculated for stability class (C) which dominate in this month shows that the model by Zannetti, and Sire (1999) according to equation (1) gives the best results when the wind speed is greater than or equal to 6m/s and when the wind speed is less than 6m/s , where mixed layer was observed reaching depths of up to 1438 m on May 11th at ws = 11m/s and up to 650 m on May 7th at Ws =5 m/s as shown in Fig.(2 and Table (2) .This results correlate with Simpson, et al (2006) ,Roy, et al (2011),Zelaya- Angel, et al (2010)and Tawfik, et al (2004).

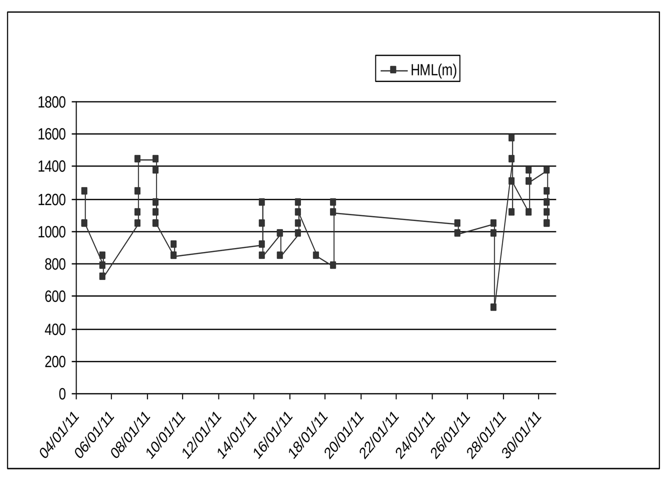

Figure (1). Height of mixed layer within January 2011.

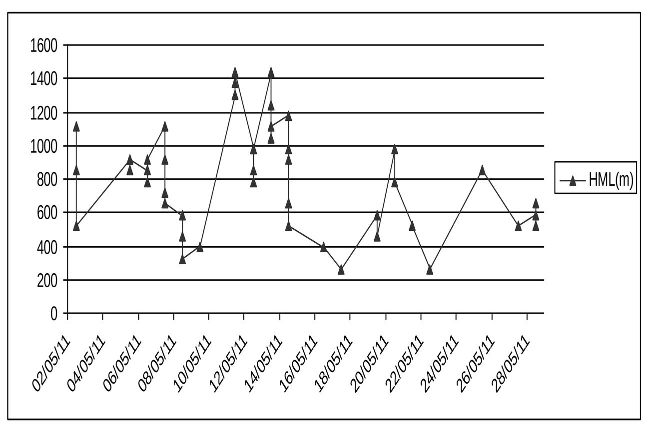

Figure (2). Height of mixed layer within May 2011.

Days	Ws (m)	Stability Class	HML (m)	Days	Ws (m)	Stability Class	HML (m)	Days	Ws (m)	Stability Class	HML (m)
04/01/11	9.5	C	1242.33	09/01/11	6.5	C	850.02	27/01/11	8	C	1046.18
04/01/11	8	C	1046.18	14/01/11	7	C	915.4	27/01/11	7.5	C	980.79
04/01/11	8	C	1046.18	14/01/11	9	C	1176.95	27/01/11	4	C	523.09
05/01/11	6	C	784.63	14/01/11	8	C	1046.18	28/01/11	11	C	1438.49
05/01/11	6.5	C	850.02	14/01/11	6.5	C	850.02	28/01/11	12	C	1569.26
05/01/11	5.5	C	719.25	15/01/11	7.5	C	980.79	28/01/11	8.5	C	1111.56
07/01/11	8	C	1046.18	15/01/11	7.5	C	980.79	28/01/11	10	C	1307.72
07/01/11	8.5	C	1111.56	15/01/11	6.5	C	850.02	29/01/11	8.5	C	1111.56
07/01/11	9.5	C	1242.33	16/01/11	7.5	C	980.79	29/01/11	10	C	1307.72
07/01/11	11	C	1438.49	16/01/11	9	C	1176.95	29/01/11	10.5	C	1373.1
08/01/11	11	C	1438.49	16/01/11	8	C	1046.18	29/01/11	10	C	1307.72
08/01/11	10.5	C	1373.1	16/01/11	8.5	C	1111.56	30/01/11	10.5	C	1373.1
08/01/11	8.5	C	1111.56	17/01/11	6.5	C	850.02	30/01/11	9	C	1176.95
08/01/11	9	C	1176.95	18/01/11	6	C	784.63	30/01/11	9.5	C	1242.33
08/01/11	8	C	1046.18	18/01/11	9	C	1176.95	30/01/11	8.5	C	1111.56
08/01/11	8	C	1046.18	18/01/11	8.5	C	1111.56	30/01/11	8	C	1046.18
09/01/11	6.5	C	850.02	25/01/11	8	C	1046.18	30/01/11	8	C	1046.18
09/01/11	7	C	915.4	25/01/11	7.5	C	980.79	30/01/11	8	C	1046.18

Table (1) : Height of Mixed Layer (HML) at Different Wind Speeds and Stability Classes within January 2011.

Days	Ws (m)	Stability Class	HML (m)	Days	Ws (m)	Stability Class	HML (m)
02/05/11	8.5	C	1111.56	13/05/11	11	C	1438.49
02/05/11	6.5	C	850.02	13/05/11	9.5	C	1242.33
02/05/11	4	C	523.09	13/05/11	8	C	1046.18
05/05/11	7	C	915.4	13/05/11	8.5	C	1111.56
05/05/11	6.5	C	850.02	14/05/11	9	C	1176.95
05/05/11	7	C	915.4	14/05/11	7.5	C	980.79
06/05/11	6.5	C	850.02	14/05/11	7	C	915.4
06/05/11	6.5	C	850.02	14/05/11	5	C	653.86
06/05/11	6	C	784.63	14/05/11	5	C	653.86
06/05/11	7	C	915.4	14/05/11	5	C	653.86
07/05/11	8.5	C	1111.56	14/05/11	4	C	523.09
07/05/11	7	C	915.4	16/05/11	3	C	392.32
07/05/11	5.5	C	719.25	17/05/11	2	C	261.54
07/05/11	5	C	653.86	19/05/11	4.5	C	588.47
08/05/11	4.5	C	588.47	19/05/11	3.5	C	457.7
08/05/11	3.5	C	457.7	20/05/11	7.5	C	980.79
08/05/11	2.5	C	326.93	20/05/11	6	C	784.63
09/05/11	3	C	392.32	21/05/11	4	C	523.09
11/05/11	10	C	1307.72	21/05/11	4	C	523.09
11/05/11	10.5	C	1373.1	22/05/11	2	C	261.54
11/05/11	11	C	1438.49	25/05/11	6.5	C	850.02
12/05/11	7.5	C	980.79	27/05/11	4	C	523.09
12/05/11	6	C	784.63	28/05/11	4.5	C	588.47
12/05/11	6.5	C	850.02	28/05/11	4	C	523.09
12/05/11	7.5	C	980.79	28/05/11	5	C	653.86

Table (2) : Height of Mixed Layer (HML) at Different Wind Speed and Stability Class within May 2011.

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