Assessment and Modeling of the Effective Stack Height for Different Types of Atmospheric Stability Class

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ABSTRACT

During the operation of any nuclear facility, the Pollutants get released to the ambient atmosphere within stack .The estimation of concentrations of radioactivity due to this effluent using dispersion modals is an important component of the regulatory safety assessment. This model should be used the effective stack height as input parameter, so the aim of this work is the assessment the effective stack height .To achieve this purpose different FORTRAN program have been developed to calculate wind speed at release height, buoyancy flux parameters, momentum flux parameters and the effective stack height for different stability class under buoyancy and momentum conditions. The analysis of the results showed that the high value of effective stack height was obtained in unstable condition for buoyancy than momentum condition with values 194m and 98 m respectively and the concentration of pollutants decreasing by increasing the effective stack height. Finally, the effect of stack gas temperature, stack exit velocity and ambient temperature on effective stack was studied.

Keywords: *Actual stack height/ Stack exit velocity/ Buoyancy flux/ Momentum flux/ Wind speed / Stability Class.*

INTRODUCTION

The effective stack height is very important for studying the atmospheric dispersion,[1] where the dispersion estimates are determined by Gaussian Distribution equation given by formula (1)[2],which calculate the pollutant concentrations at a point of interest [3] ,where the concentration depending on the ways in which s y and sz [4] given by equations (2,3) and requires the calculation of effective stack height, where effective stack height represent the height of the stack (h_s) plus the plume rise (?h)[3] as shown in figure (1) and the higher the effective stack height, the greater the dispersion, lower the concentration of emitted pollutant at a point of interest [5,6]. Gases are emitted from stacks before starting to disperse according to the Gaussian model, which have momentum as they enter the atmosphere and mix with ambient air. The present work is dedicated to the evaluation of the effective stack height of the effluent for different types of stability class and studying the effects of stack exit velocity, stack gas temperature and ambient temperature on effective stack height.
The plume contaminant concentration at a point in space is given by this equation [7]:-

$$X(x,y,z)=\frac{Q}{2p\ \ s_y s_z u} e^{\frac{-1}{2}\left(\frac{y}{s_y}\right)^2} \left\{ e^{\frac{-1}{2}\left[\frac{z-H}{s_z}\right]^2} + e^{\frac{-1}{2}\left[\frac{z+H}{s_z}\right]^2} \right\} \quad \ldots\ldots.(1)$$

, and

The horizontal, vertical dispersion coefficient is given by following equations [8]:-

$$s_y = a\ x^b \ldots\ldots\ldots \quad ..(2)$$

$$s_z = c\ x^d \ldots\ldots\ldots \quad ..(3)$$

Where:

X (x,y,z)= ground level pollutant concentration , g/m^3

Q = mass emitted per unit time, g/s

s_y=horizontal dispersion coefficient (standard deviation), m

s_z =vertical dispersion coefficient (standard deviation), m

u = average wind speed at effective stack height ,m/s

x= distance directly downwind,m

y= horizontal distance from the plume centerline ,m

z= vertical distance , from the plume centerline ,m

H=effective stack height, m

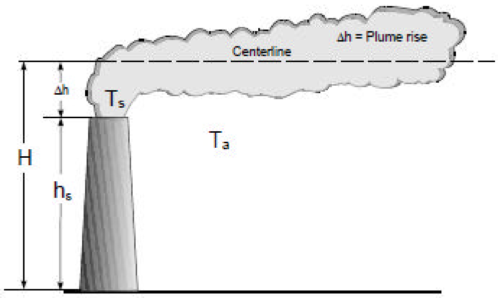

Figure (1): Plume rise

MATERIAL AND METHODS

The effective stack height of the effluent due to buoyancy and momentum conditions [9] determined with a developed computer programs and used data such as wind speed gathered from National Ocean Atmospheric Administration (NOAA) [10] for January month , 2011 year of the north western part from Egypt and hypothetical data used for models such as physical stack height ,stack exit velocity , top inside stack diameter ,stack gas temperature, ambient temperature as shown in below program .

- For buoyancy rise the effective stack height in neutral and unstable stability classe are estimated by Briggs, 1971 ,which given by the equations (4, 5) [11] while in stable stability class is estimated by Briggs, 1975 , which given by the equation (6) [12].

$$H = h_s + \Delta h_{plume\ rise} = h_s + \frac{21.425\ f_b^{0.75}}{\bar{u}} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

($f_b < 55\ m^4/s^3$)

(in neutral case)

$$H = h_s + \Delta h_{plume\ rise} = h_s + \frac{38.71\ f_b^{0.6}}{\bar{u}} \quad \ldots\ldots\ldots\ldots (5)$$

($f_b > 55\ m^4/s^3$)

(in unstable case)

$$H = h_s + \Delta h_{plume\ rise} = h_s + 2.6\left(\frac{f_b}{\bar{u}\ s}\right)^{0.33} \quad .....(6)$$

(in stable case)

Where:
H= effective stack height, m
h_s = physical stack height ,m
v_s = stack exit velocity , m/s
d = top inside stack diameter, m
T_s = stack gas temperature,k°
T_a = ambient temperature, k°
g= gravity, 9.8 m/s^2
f_b= buoyancy flux term, m^4/s^3
s= stability parameter
$\bar{u}$ = wind speed at release height, m/s

The value of the Briggs buoyancy flux parameter f_b (m^4/s^3), is given by the following equation (7)[12].

$$f_b = \frac{g\ v_s\ d^2 (T_s - T_a)}{4T_s} \quad .... (7)$$

The value of stability parameter (s) is calculated from the equation (8)[11].

$$s = \frac{g\left(\frac{dq}{dz}\right)}{T_a} \quad .... (8)$$

Where:

$\frac{dq}{dz}$ =0.020 k/m (stability class E) [13] , $\frac{dq}{dz}$ =0.035 k/m (stability class F) [6].

- For momentum rise the effective stack height due to actual stack height and plume rise in neutral , unstable stability classes are determined by Briggs, 1969 ,which given by equation (9) and stable stability class is determined by determined by Briggs, 1969 , which given by the equation (10) [13].

$$H = h_s + \Delta h_{plume\ rise} = h_s + 3d_s \frac{v_s}{\bar{u}} \quad .... (9)$$

For $\frac{v_s}{\bar{u}} > 4$

$$H = h_s + \Delta h_{plume\ rise} = h_s + 1.5\left(\frac{f_m}{\bar{u}\sqrt{s}}\right)^{0.33} . \quad .... (10)$$

Where:
f_m= momentum flux term, m^4/s^3

The value of the briggs momentum flux parameter f_m (m^4/s^3), is given by the following equation (11) [12].

$$f_m = \frac{v_s^2 d_s^{\ 2} (T_a)}{4T_s} \quad ....(11)$$

The value of wind speed parameter $\bar{u}$ (m/s) at release height, is given by the following equation (12) [7].

$$\bar{u} = u_0 \left[\frac{h}{h_0} \right]^n \text{ ....(12)}$$

Where:

$\bar{u}$ =wind speed at release height ,m/s
u_0=weather station wind speed ,m/s
h=height ,m
h_0= weather station height ,m
n=Exponents are shown in table(1)[14]

Table (1) Exponents for Power Low Wind Velocity Profile Equation.

Stability Class	Pasquil Stability Class	Rural Exponent	Urban Exponent
1	A	0.07	0.1
2	B	0.07	0.15
3	C	0.10	0.20
4	D	0.15	0.25
5	E	0.35	0.25
6	F	0.55	0.30

A FORTRAN PROGRM TO CALCULATE THE EFFECTIVE STACK HEIGHT FOR NPP

```
REAL us
C  Effective stack HEIGHT
      vs= 19.
      ds=3.
      ts=400.
      g=9.81
      ta=283.
      E= 0.02
    F=0.035
      hs=67.

      OPEN(5,FILE='11.DAT',STATUS='OLD')
      OPEN(7,FILE='Height11.OUT')
500   READ(5,1,END=100)us
                  IF(us.LE.0.0) us=0.5
      TERM1= ts-ta
                  us1=us*(hs/10.0)**0.25
```

```
                    us2=us*(hs/10.0)**0.30
                    usA=us*(hs/10.0)**0.1
                    usB=us*(hs/10.0)**0.15
                    usC=us*(hs/10.0)**0.20
                    TERMS=4.*ts
      TERM2= (g*vs*ds**2*term1) / TERMS
      TERM3= g*E /370.
                    TERM4= g*F / 370.
                    TERM5= vs**2*ds**2*ta / TERMS
                    TERM6=(TERM2/(us1*TERM3))**0.33
                    TERM7=(TERM2/(us2*TERM4))**0.33
                    TERM8=(TERM5/(us1*sqrt(TERM3)))**0.33
                    TERM9=(TERM5/(us2*sqrt(TERM4)))**0.33
      TERMHN=hs + (21.425*(term2**0.75)/ us1 )
                    TERMHUNA=hs + (38.71*(term2**0.6) / usA )
                    TERMHUNB=hs + (38.71*(term2**0.6) / usB )
                    TERMHUNC=hs + (38.71*(term2**0.6) / usC )
                    TERMHSE= hs + (2.6*TERM6)
                    TERMHSF= hs + (2.6*TERM7)
                    TERMUNNM= hs + ((3.0*ds*vs )/ us1 )
                    TERMUNNMA= hs + ((3.0*ds*vs )/ usA )
                    TERMUNNMB= hs + ((3.0*ds*vs )/ usB )
                    TERMUNNMC= hs + ((3.0*ds*vs )/ usC )
TERMSEM=hs + (1.5*term8)
TERMSFM=hs + (1.5*term9)
         WRITE(*,2)us1,us2,usA,usB,usC,term2,term3,TERMHN, TERMHUNA,
                    *TERMHUNB,TERMHUNC,TERMHSE,TERMHSF,TERMUNNM,TERMUNNM
A,TERMUNNMB,*TERMUNNMC,TERMSEM,TERMSFM
      WRITE(7,2)us1,us2,usA,usB,usC,term2,term3,TERMHN,
TERMHUNA,TERMHUNB,TERMHUNC,
*TERMHSE,TERMHSF,TERMUNNM,TERMUNNMA,TERMUNNMB,TERMUNNMC,TERMSE
M,
     *TERMSFM
      GOTO 500
```

```
    1    FORMAT(F5.2)
2    FORMAT(1X,'us1=',f5.2,1X,'us2=',f5.2,1X,'usA=',f5.2,1X,
    *'usB=',f5.2,1X,'usC=',f5.2,1X,'TERM2=',f7.3,1X,'TERM3=',f7.5,1X,
    *'TERMHN=',f7.3,1X,
    *'TERMHUNA=',f7.2,1X,'TERMHUNB=',f7.2,1X,'TERMHUNC=',f7.2,1X,
    *'TERMHSE=',f9.5,1X,'TERMHSF=',f9.5,1X,'TERMUNNM=',f7.3,1X,
    *'TERMUNNMA=',f7.3,1X,
    *'TERMUNNMB=',f7.3,1X,'TERMUNNMC=',f7.3,1X,'TERMSEM=',f7.3,1X,
    *'TERMSfM=',f7.3)
100   WRITE(*,*)' End of data file'
     STOP
     END
```

RESULTS AND DISCUSSION

1-The results of effective stack height for different types of stability class under buoyancy and momentum condition were presented in figures (2a, 2b), (3) and (4a, 4b, 4c).

Figs (2a) and (2b) show that the results of effective stack height for different degree of stable class for buoyancy and momentum conditions , where figure (2a) show that the value ranged from 126.3 m to 146.7 for case E and the value ranged from 83.4 m to 89 m for case F ,which may be attributed to condition of buoyancy flux and wind speed at release height according to equations (6 ,7 and 12) and figure (2b) show that for case E the value ranged from 114.8 m to 131 m and the value ranged from 81.5m to 86 m for case F , due to momentum flux and wind speed at release height according to equations (10 ,11 and 12)

Figure (3) shows that the results of effective stack height for neutral condition for buoyancy and momentum conditions ranged from 111.6 m to 176 m by Appling equations (4, 7 and 12) and ranged from 76.6 m to 90.6 m by Appling equations (9, 11 and 12) respectively , this results wind speed and material released into atmosphere which is at same temperature as the ambient air but have a lower molecular weight and hence lower density than the ambient air.

Also figs (4a and 4b) show that the results of effective stack height for different degree of unstable classes for buoyancy and momentum condition ,where figure (4a) showed that the values for A , B and C ranged from 119m to 194.4 m , 114.4 m to 182.8 m and 110 m to 172.3 m respectively , this could be imputed to the wind speed at release height according to equations (5,7 and 12) and may be the plumes which are lighter than air because they are at a higher temperature and lower density than the ambient air which surrounds them , figure (4b) show that the values for A , B and C ranged from 79.8 m to 98.4 m , the value ranged from 78.6 m to 95.5 m and the values ranged from 77.6 m to 92.9 m respectively , this may be due to wind speed at release height according to equations (9,11 and 12).

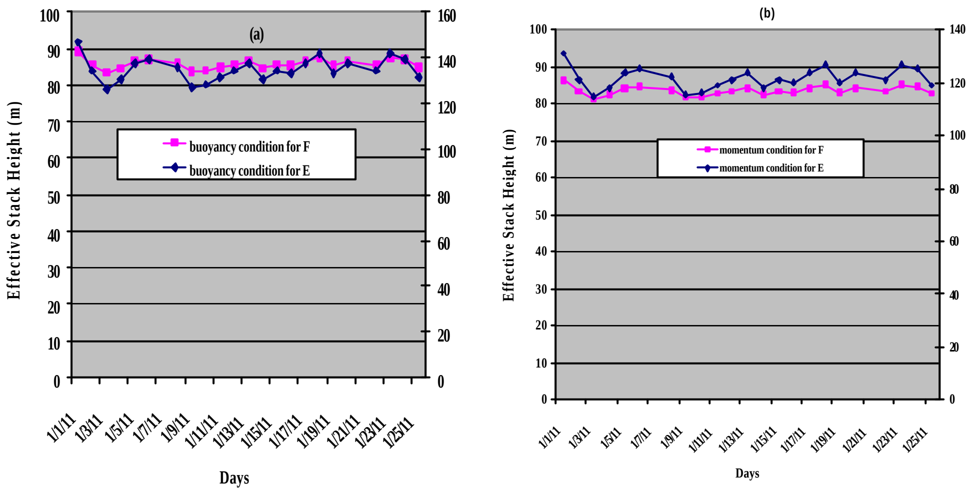

Figure (2) : Effective stack height in January month for different degree of stable condition

a- Buoyancy condition **b-Momentum condition**

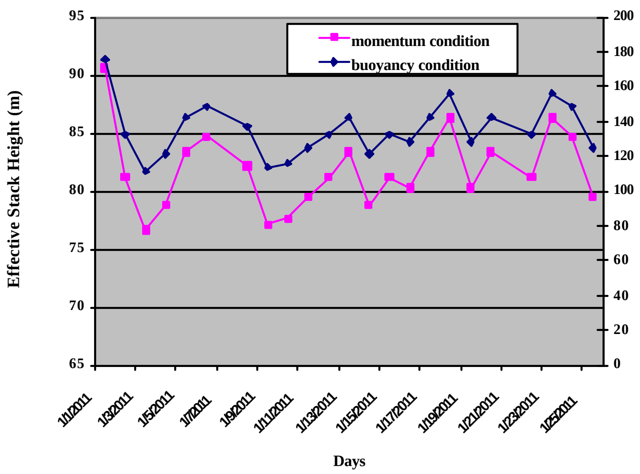

Figure (3): Effective stack height for January month in neutral condition

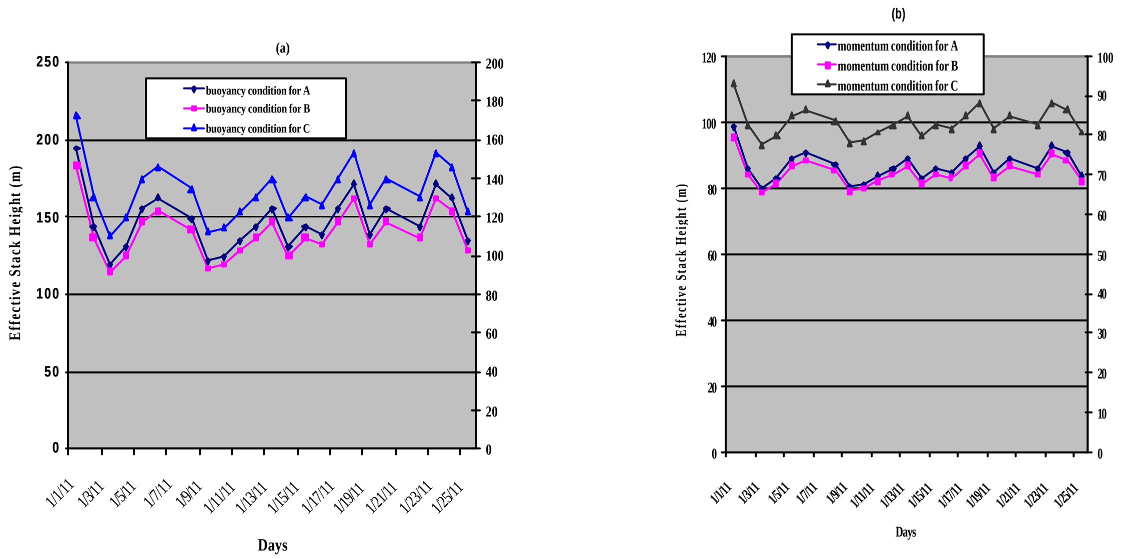

Figure (4) : Effective stack height in January month for different degree of unstable condition

a-Buoyancy condition **b-Momentum condition**

2- The calculated values of concentrations of emitted pollutant from stack for different degree of stability class as shown in figure (5), from fig(5) , we notice that the concentration decreasing by increasing the effective stack height with values 2.79E-08 g/m^3 to 4.64E-025 g/m^3 at effective stack height of 50 m and 100m respectively according to equation(1),which may be attributed to higher dispersion of pollutant results lower the concentration ,this agree with Essa, et al [(15)] .

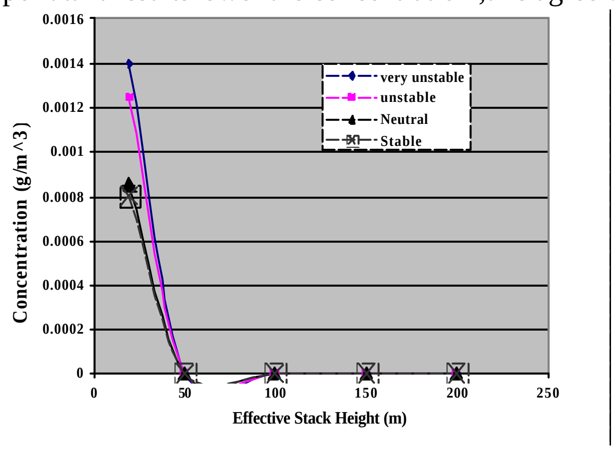

Figure (5): Variation of ground concentration with effective stack height.

3- The results of effect of ambient temperature stack gas temperature and stack exit velocity on effective stack height were shown in figs (6-12).

I- Effect of ambient temperature:

In stable class, figure (6a)show that the value of effective stack height decrease from 215 m , 208 m to 194 m as the ambient temperature increase as 50 K$^?$, 100 K$^?$ to 183 K$^\circ$ respectively for buoyancy condition according to equations (6,7) and figure (6b) show that the value increase from 84 m , 85 m to 93 m as the ambient temperature increase from 50 K$^\circ$, 100 K$^\circ$ to 183 K$^\circ$ respectively for momentum condition according to equations (10,11). In neutral class, figure (7) show that the value of effective stack height decrease from 811 m , 730 m to 587 m as the ambient temperature increase as 50 $K^?$, 100 $K^?$ to183 $K^?$ respectively for buoyancy condition according to equations (4,7). In unstable class, figure (8) show that the value of effective stack height decrease from 740 m , 680 m to 572 m as the ambient temperature increase as 50 $K^?$, 100 $K^?$ to 183 $K^?$ respectively for buoyancy condition according to equations (5,7).

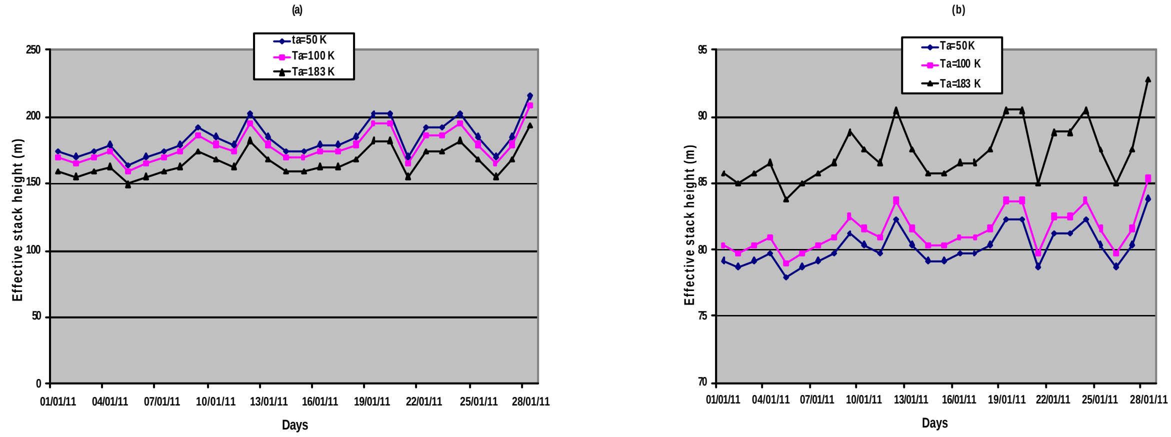

Figure (6) Effective Stack height for Stable condition at different ambient temperature.

a:- In buoyancy case **b:- In momentum case**

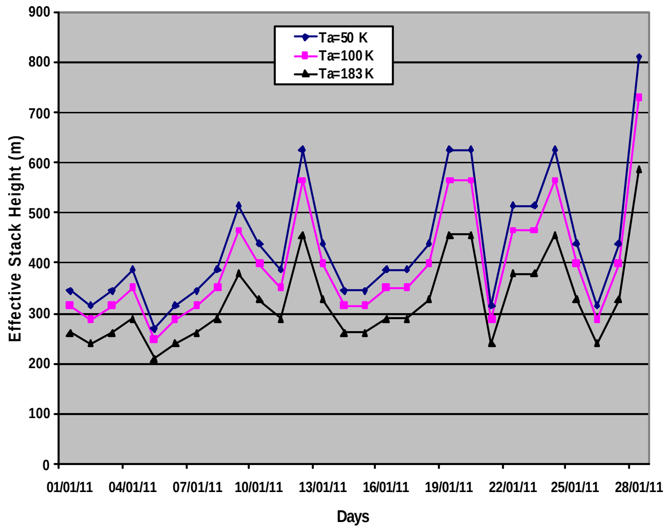

Figure (7) Effective Stack height for neutral condition under buoyancy case at different ambient temperature.

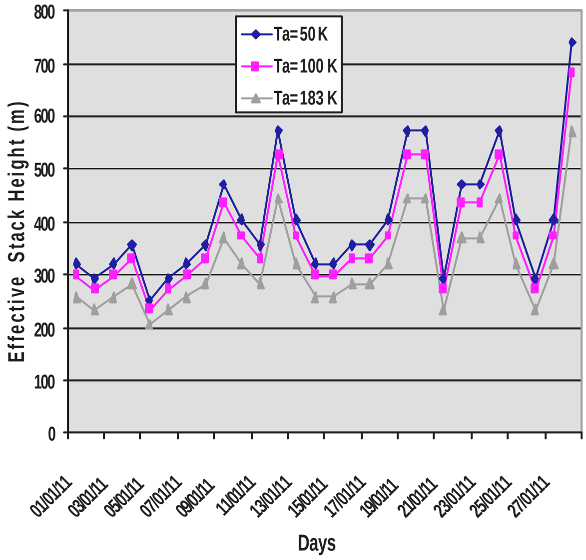

Figure (8) Effective Stack height for unstable condition under buoyancy case at different ambient temperature.

II- Effect of stack gas temperature:

In stable class, figure (9a) show that the value of effective stack height increase from 128 m to 193 m as the stack gas temperature increase from 300 K° to 600 K° respectively for buoyancy condition according to equations (6,7) and figure (9b) show that the value decrease from 99 m to 93 m as the stack gas temperature increase from 300 K°to 600 K° respectively for momentum condition according to equations (10,11).

In neutral class, figure (10) show that the value of effective stack height increase from 163 m to 577 m as the stack gas temperature increase from 300 K° to 600 K° respectively for buoyancy condition according to equations (4,7). In unstable class, figure (11) show that the value of effective stack height increase from 198 m to 377 m as the ambient temperature increase from 300K° to 600 K° respectively for buoyancy condition according to equations (5,7).

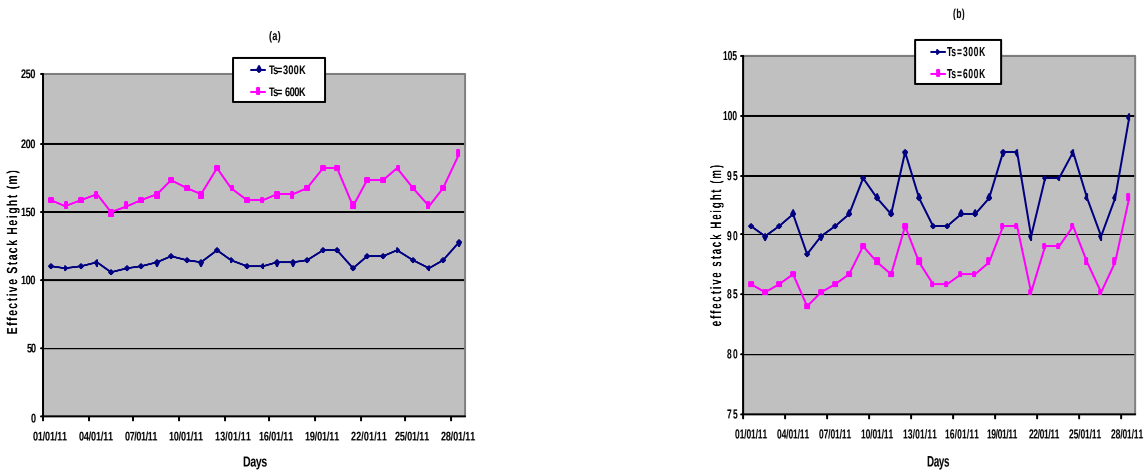

Figure (9) Effective Stack height for Stable condition at different stack gas temperature.

a:- In buoyancy case **b:- In momentum case**

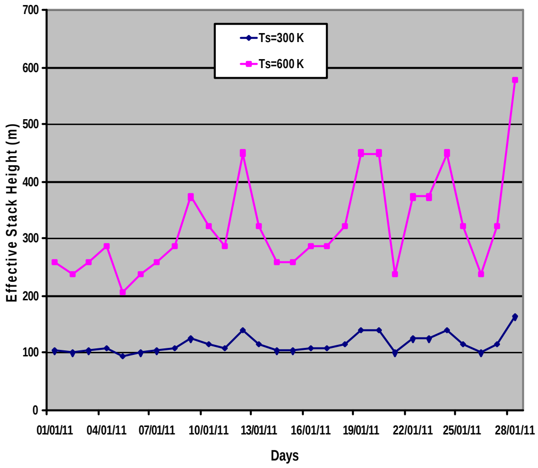

Figure (10) Effective Stack height for neutral condition under buoyancy case at different stack gas temperature.

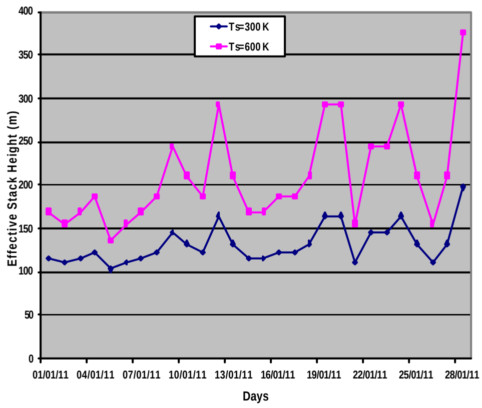

Figure (11) Effective Stack height for unstable condition under buoyancy case at different stack gas temperature.

III- Effect of stack exit velocity:

In stable class, figs (12a) (12b) shows that the value of effective stack height increase from 96m , 134m ,151 m to 163 m as the stack exit velocity increase from 0.4m/s , 5m/s , 10m/s to 15 m/s respectively according to equations (6,7) for buoyancy condition and the value increase from 69 m , 79m , 87 to 93 m as the stack exit velocity increase from 0.4m/s , 5 m/s , 10 m/s to 15 m/s respectively according to equations (10,11) for momentum condition. In neutral class, figs (13a) (13b) shows that the value of effective stack height increase from 85m ,187m ,270 m to 341 m as the stack exit velocity increase from 0.4 m/s, 5 m/s, 10 m/s to 15 m/s respectively according to equations (6,7) for buoyancy condition and the value increase from 68m ,85m , 104m and 123 m as the stack exit velocity increase 0.4 m/s , 5m/s , 10m/s to 15 m/s according to equations (10,11) respectively and momentum condition. In unstable class, figs (14a) (14b) shows that the value of effective stack height increase from 101m ,223m ,304 m to 370 m as the stack exit velocity increase from 0.4 m/s , 5 m/s , 10 m/s to 15 m/s respectively for buoyancy according to equations (6,7) and the value increase from 69m,89m, 112m to 135 m as the stack exit velocity increase from 0.4 m/s , 5m/s , 10m/s to 15 m/s respectively for momentum condition according to equations (10,11) .

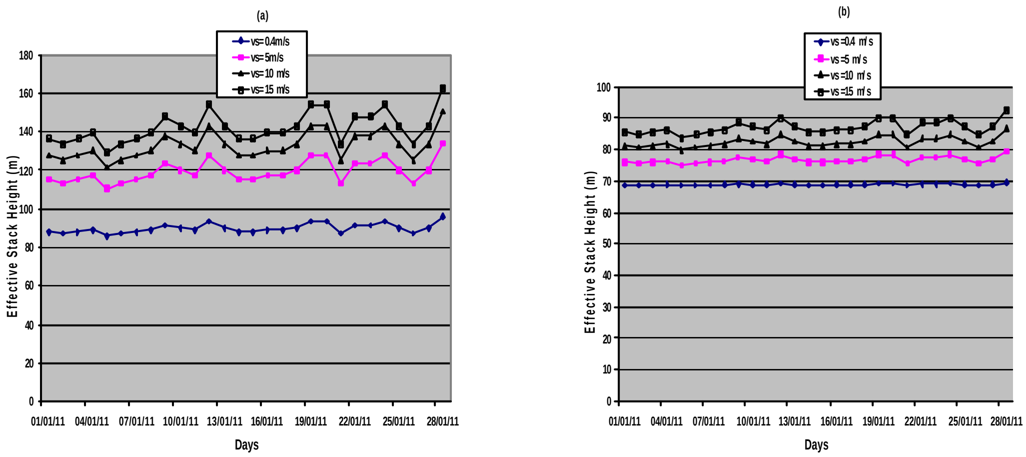

Figure (12) Effective Stack height for stable class at different stack exit velocity.

a:- Buoyancy case **b:- Momentum case**

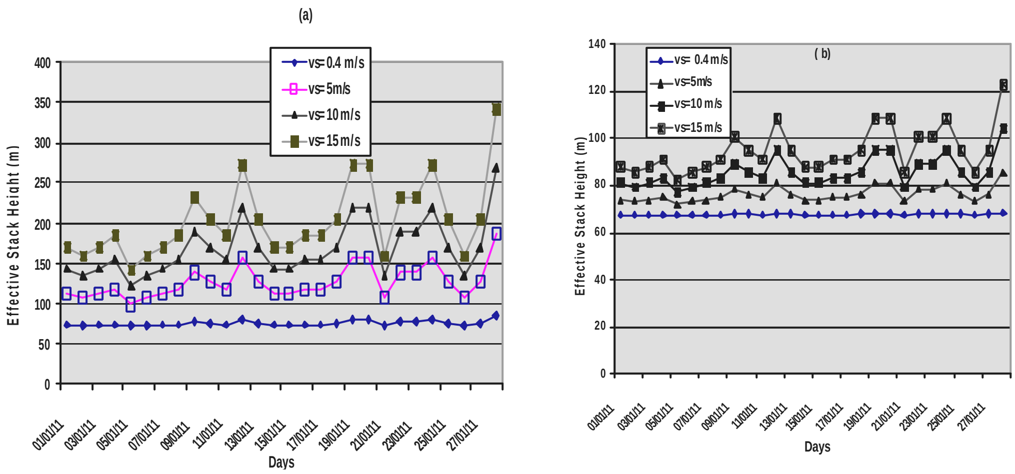

Figure (13) Effective Stack height for neutral class at different stack exit velocity.

a:- Buoyancy case **b:- Momentum case**

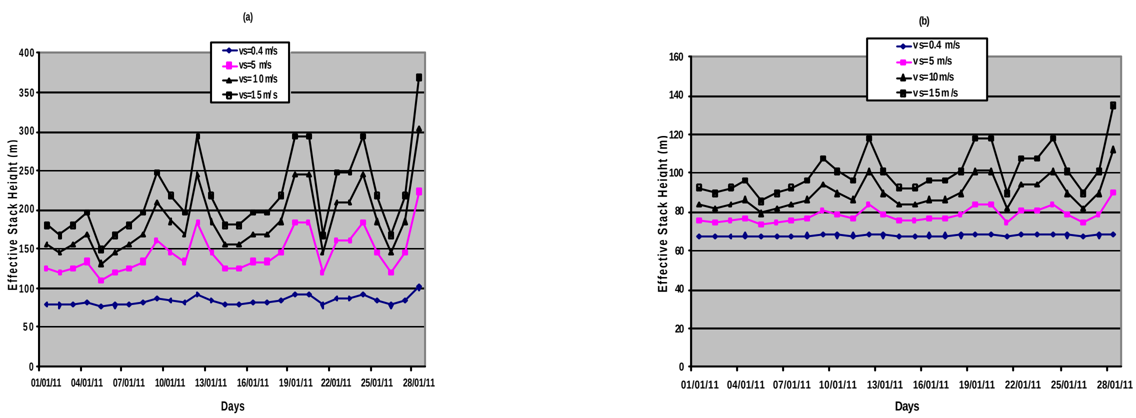

Figure (14) Effective Stack height for unstable class at different stack exit velocity.

a:- Buoyancy case **b:- Momentum case**

CONCLUSION

It can conclude that:-

- In buoyancy condition, the value of effective stack height is higher than in case of momentum condition.
- The concentration of emitted pollutant decreases with increasing the value of effective stack height.
- In buoyancy condition, the increase the value of ambient temperature with the decrease the value of the effective stack height while in momentum condition, the increase the value of ambient temperature with increase the value of the effective stack height.
- In buoyancy condition, the increase the value of stack gas temperature with the increase the value of the effective stack height while in momentum condition, the increase the value of stack gas temperature with the decrease the value of the effective stack height.
- The value of effective stack height increases with increase the value of the effluent gas velocity.

REFRENCES

(1) N. Kozarev, N. Ilieva ; Journal of the University of Chemical Technology and Metallurgy; 46, 3 (2011).
(2) IAEA, Atmospheric dispersion in nuclear power plant siting. S.S., IAEA-Vienna; 50 (1980).
(3) yosemite.epa.gov/oaqps/eogtrain.../Lesson%206.pdf
(4)Faw R.E., Shultis KJ., Radiological assessment, sources and exposures. Englewood Cliffs, NJ: PTR Prentice-Hall; (1993).
(5) www.iyte.edu.tr/~cemilsofuoglu/Lecture7.pdf
(6) Schnelle KB Jr, Dey PR, Atmospheric dispersion modeling compliance guide. New York: McGraw-Hill; (2000).
(7) P. Aarne Vesilind, J. Jeffrey Peirce and Ruth F. Weiner. Environmental Engineering. Butterworth Heinemann. 3rd ed; (1994).
(8)Curtiss PS, Rabl A., Impacts of air pollution: General relationships and site dependence. Atmos. Environ.; 30(19), 3331–3347 (1994).
(9) James E. Carson and Harry Moses ; Journal of the Air Pollution Control Association; 19, 11(1969).
(10)www.arl.noaa.gov/ready
(11) www.weblakes.com/guides/iscst3/.../6_1_4.html
(12) Briggs, G.A, plume rise predictions. Atmospheric turbulence and Diffusion Laboratory report, ATDL concentration file; 75, 15 (1975).
(13) G.A. Briggs, Plume rise .USAEC critical Review Series,TID, NTIS; 25,75 (1969).
(14) Irwin J.S. A theoretical variation of the wind profilepower law exponent as a function of, surface roughnessand stability. Atmos. Environ.; 13, 191–194 (1979b).
(15) K. S. M. Essa, F. Mubarak, and S. E. M. Elsaid ; Meteorol. Atmos. Phys.; 93, 247–253 (2006).