Effect of Wind Speed and Stack Height on Plume Rise Using Different Equations

Article · April 2016

DOI: 10.4010/2016.748

Dr. akshey Bhargava

Kalol Institute of Technology & Research Centre

DOI 10.4010/2016.748
ISSN 2321 3361 © 2016 IJESC

Research Article Volume 6 Issue No. 4

Effect of Wind Speed and Stack Height on Plume Rise Using Different Equations

Dr. Akshey Bhargava, Mtech, Ph.D. (Engg.), LL.B
Professor
Department of Civil Engineering
Global Institute of Engineering and Technology, Hyderabad, India
draksheyb@gmail.com

Abstract:
Stack Plume Rise is a conceptual phenomenon which is mainly dependent on two forces, namely, Buoyant and Momentum force. Buoyant forces are governed by temperature, heat emission rate of the stack exit gases whereas Momentum forces are governed by Stack exit gas velocity. Plume Rise is also dependent on various factors like Atmospheric wind speed, Atmospheric stability condition, and Atmospheric turbulence besides some other internal parameters like Stack gas temperature, Heat emission rate, Stack Height and Stack gas exit velocity. The Plume Rise is an important parameter in the overall air pollution control mechanism which directly interferes the dispersion of pollutant over a period of time and space, the more is the plume rise, the better would be the dispersion of air pollutants resulting into less ground level concentration of air pollutants. An effort has been made in the present research paper to optimize the Plume Rise using various equations that are employed to estimate the Plume Rise under different stability conditions, and also Effect of changes of Wind Speeds and Stack Heights.

Introduction:

There are different equations used for estimating Plume Rise, the details of which are given here under:

1. Carson and Moses equation:

- Carson equation for unstable condition:

$\square h = 3.47\ vs.\ d/u + 5.15\ Qh^{0.5}/u.$

- Carson equation for neutral condition:

$\square h = 0.35\ Vs.\ /u + 2.64\ Qh^{0.5}/u.$

- Carson equation for stable condition:

$\square h = 1.04\ Vs.\ d/u + 2.64\ Qh^{0.5}/u.$

Where,

- □h = plume rise in meter
- Vs. = exit gas velocity in m/s
- d = Stack diameter in meter
- u = wind speed at stack height in m/s
- Qh= Heat emission rate in KJ/s

2. Holland equation

$\square h = Vs.d/u\ [1.5 + 2.68 * 10^{-3}\ pd\ (Ts - Ta)/Ts]$
Where,
p= Atmosphere pressure in milli bars

3. Briggs formula for Momentum sources (less than 50 ambient above temperature)

$\square h = 1.5(Vs./u).d$
$= 1.5\ Rd$

4. Smith equation Momentum sources (less than 50 ambient above temperature)

$\square h = d\ (Vs/u)^{0.4}$

- Briggs equation and Smith equation :
- Takes into account only momentum dominated plumes and ignores buoyancy dominated character of plumes
- Can be applied where exit velocity of flue gases are high , preferable above 20 m / s , and stack gas temperature below 100 C
- Gives results with reproducibility of 60 to 70 %

5. CONCAWE FORMULA

$\Delta h = 2.71 * (Qh)^{0.5} / (u)^{0.75}$
$Q = m\ \Delta h = \prod (d^2/4)\ vs.\ \rho s\ Cp\ (Ts - Ta)$

6. THOMAS FORMULA

$\Delta h = 4.71\ (Qh)^{0.444} / (u)^{0.694}$

7. BUOYANT SOURCES

7.1 BRIGGS EQUATION FOR UNSTABLE AND NEUTRAL CONDITION

$$\Delta h = 150\ F / u^3$$

7.2 FOR STABLE WITH CALM CONDITION

$$\Delta H = 5.0\ (F)^{0.25} / S^{0.375}$$

- Where :

$F = g\ Vs\ (d/2)^2\ (Ts - Ta) / Ta$

As a function of downwind distance, x

- $\Delta h = 1.6\ (F)^{0.333} * (x)^{0.666} / u$

- $(\rho s - \rho a) / \rho a = (Ta - Ts) / Ta$
- Where :
- ρs = Density of stack gas
  ρa = Density atmospheric air

8. WHALEYS EQUATION

$\Delta h = 262*(Qh)^{0.24} / u$
Where:
Qh = Heat emission in MW

9. LUCAS EQUATION

Unstable and Neutral conditions
$\Delta h = ((60 + 5\ H)/U)*(Qh)^{0.25}$
For average meteorological conditions
$\Delta h = ((275 + 2\ H) / U) * (Qh)^{0.25}$

Where:
Qh = Heat emission in MW

For stable and low wind speeds
$\Delta h = (116* / u) / (Qh)^{0.25}$

For stable and high wind speeds
$\Delta h = (160 / u) * (Qh)\ 0.25$

10. MORTON, TAYLOR, AND TURNER EQUATION

(Stable conditions with little or no winds)

$\Delta h = 5.0\ (F^{0.25}) / (S^{0.375})$
Where:
F = Buoyancy flux parameter
S = Stability parameter

11. BIS SUGGESTED BRIGGS EQUATION

For hot gas with heat release of 10^6 cal/s or more

$\Delta h = 0.84 * (12.4 + 0.09 * H) * (Qh^{0.25}) / U$

Where:
Qh = heat emission rate in cal/s

For momentum dominated, not very hot release

$\Delta h = 3\ Vs.\ d / u$

An effort has been made in the present research paper to analyze the effect of wind speeds and stack heights for a Power Plant of capacity 1000 MW using different Plume Rise equations by considering following variable parameters:

- Stack height(H1)- 100m, 125m, 150m, 175m, 200m, 225m, 250m, 275m, 300m.
- Diameter (d)-5m
- Exit velocity (Vs) - 20m/s
- Stack temperature (Ts)-50C, 75C, 100C, 125C, 140C 150C, 175C. 200C, 225C, 250C.
- Density of particle-1200kg/m3
- Viscosity of gases-1.84*10^-4kg/m2.
- Horizontal wind speed (u1) – 2m/s, 2.5m/s, 3m/s, 3.5m/s, 4m/s, 4.5m/s, 5m/s, 5.5m/s, 6m/s, 6.5m/s, 7m/s, 7.5m/s, 8m/s, 8.5m/s, 9m/s, 9.5m/s, 10m/s, 10.5m/s, 11m/s, 11.5m/s, 12m/s, 12.5m/s,13m/s, 13.5m/s, 14m/s, 14.5m/s, 15m/s.
- Ambient temperature (Ta)-25C
- Heat emission rate (Qh) - 5000K.cal/sec
- Assume adiabatic condition- stable, unstable, neutral.
- Plume rise (ΔH) = (?)

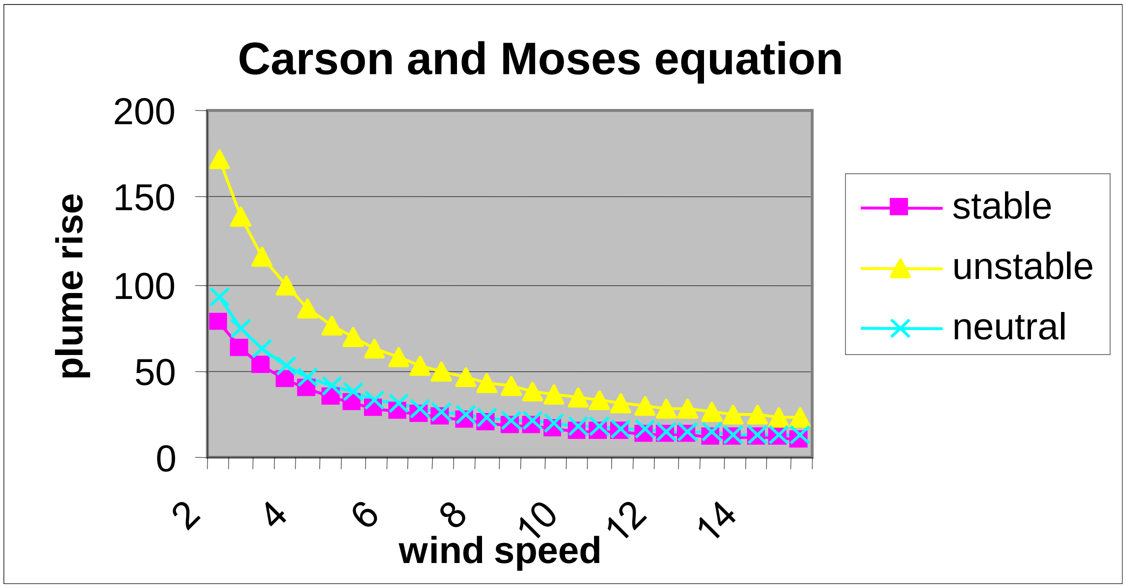
Effect of wind velocity on plume rise

- Wind velocity(u1): 2m/s to 15m/s with an interval of 0.5m/s
- Constants

- Exit velocity(Vs.): 20m/s
- Fixed stack height(H1): 100meters
- Stack gas temperature(Ts): 140C
- Plume rise (ΔH) = (?)

Effect of different Wind velocity on Plume Rise in Carson and Moses equation

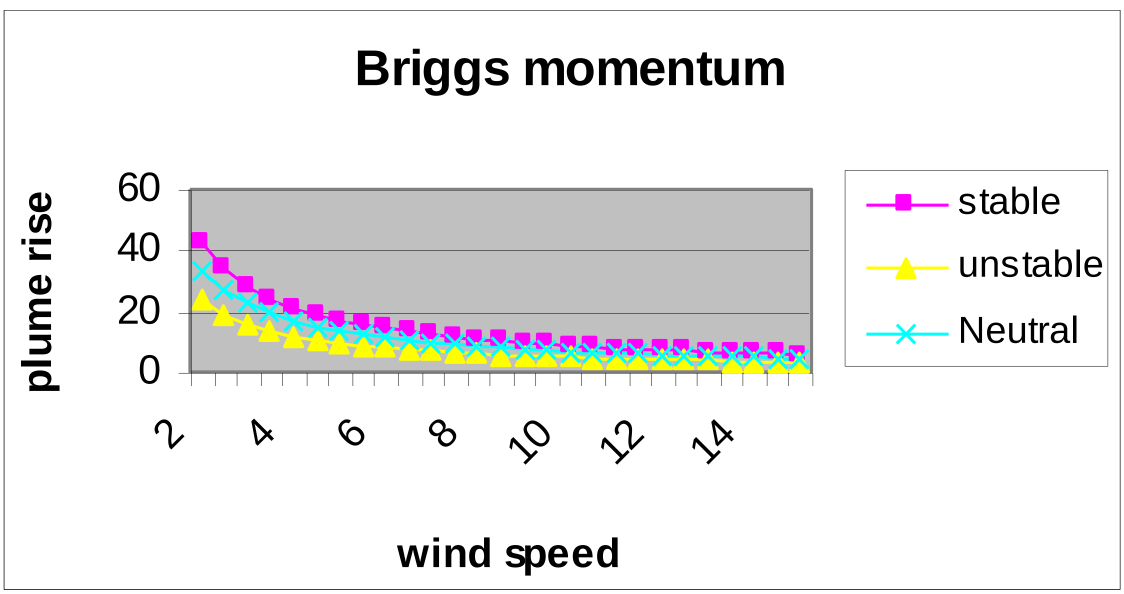
Graph: 1 Plume rise vs. wind velocity



Plume rise decreases 5.212, 11.51and 6.21 meters for every 1m/s increase of wind speed `under stable, unstable and neutral condition respectively.

Effect of different wind velocity on plume rise in Briggs equation (momentum sources) Less than 50F above ambient

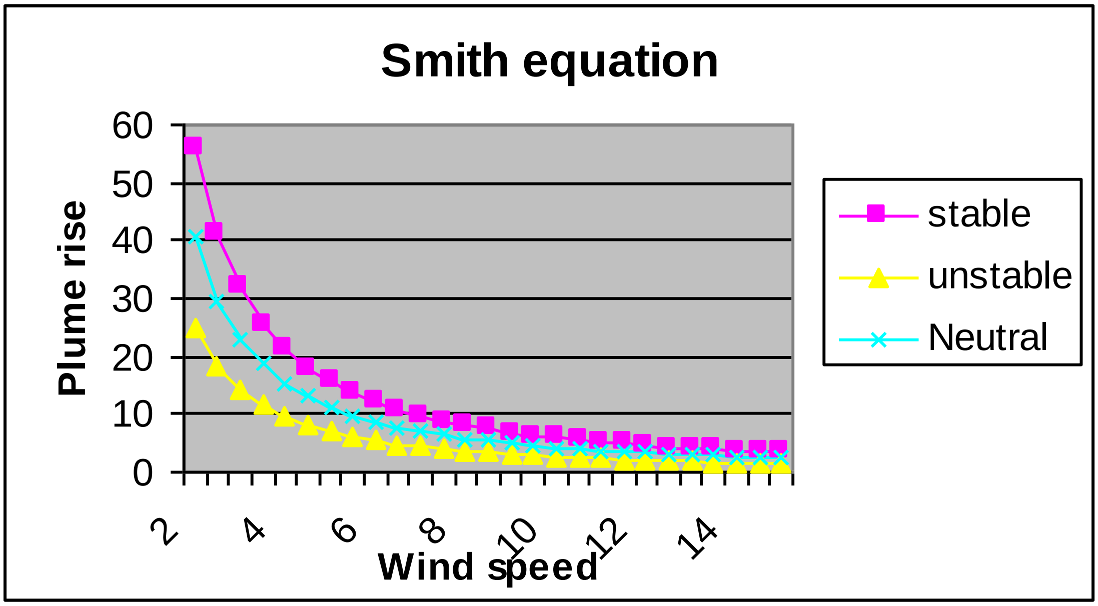
Graph: 2 Plume rise vs. stack height



Plume rise decreases 2.81, 1.58 and 2.23 meters for every 1m/s increase of wind speed `under Stable, Unstable and Neutral conditions respectively.

Effect of different wind velocity on plume rise in Smith equation

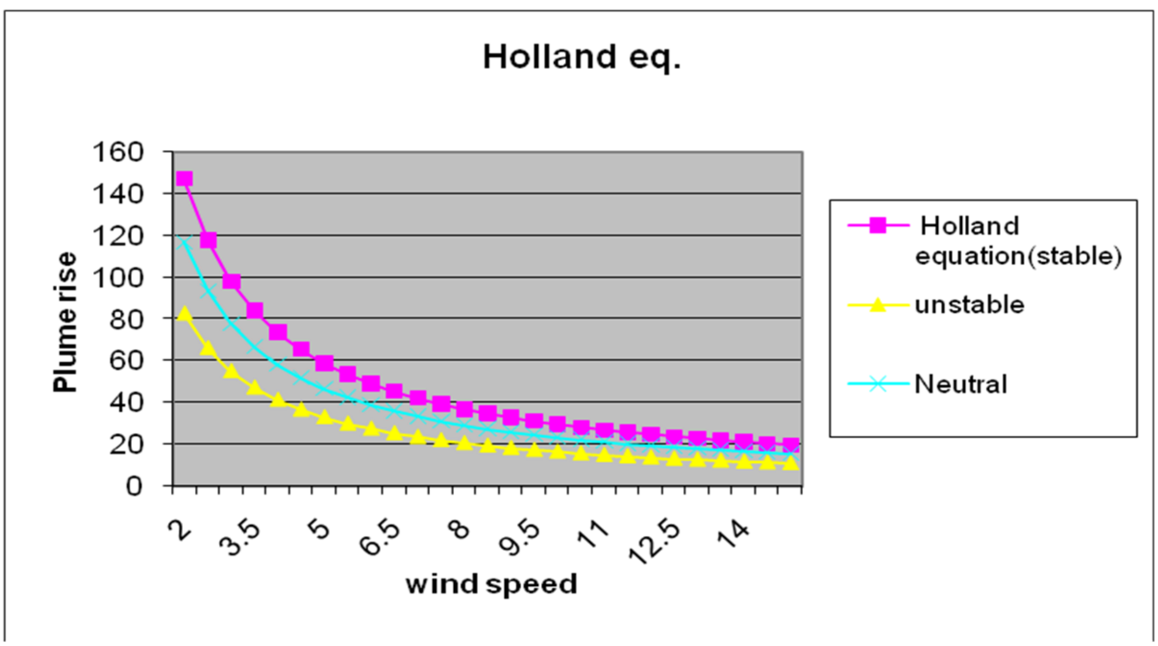
Graph: 3 Plume rise vs. stack height



Plume rise decreases 4.07, 1.81 and 2.94 meters for every 1m/s increase of wind speed `under stable, unstable and neutral condition respectively

Effect of different wind velocity on plume rise in Holland equation

Graph: 4 Plume rise vs. stack height

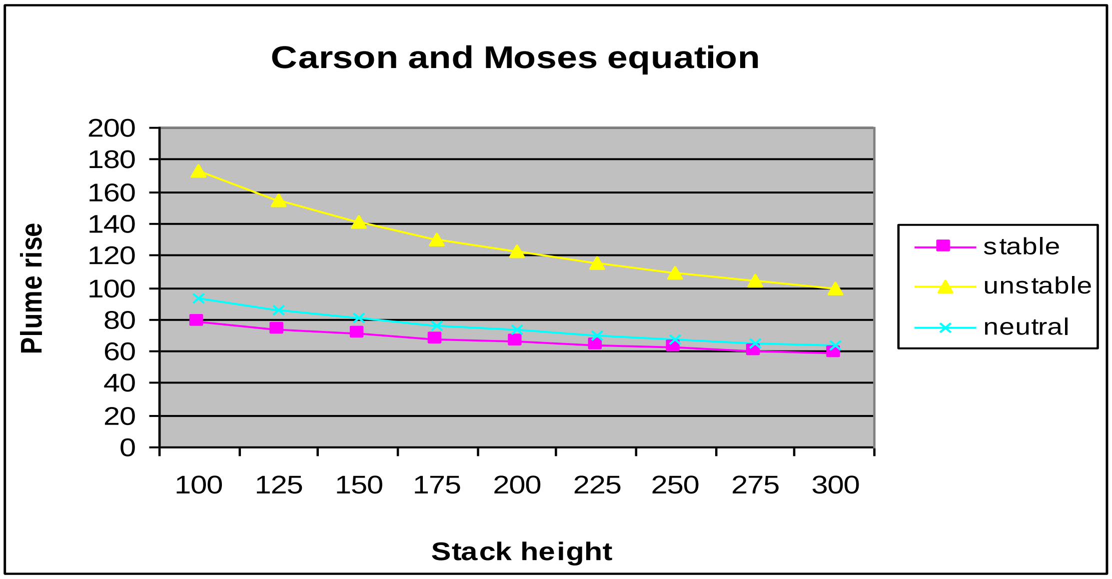


•Similarly effect of different Stack Heights have also been analyzed on Plume Rise using different equations by considering following variable parameters :

- Stack height: 100m t0 300m with an interval of 25m
- Constants
- Exit velocity: 20m/s
- Wind velocity: 100meters
- Stack gas temperature: 140C
- Plume rise=?

Effect of different Stack height on plume rise in Carson and Moses equation

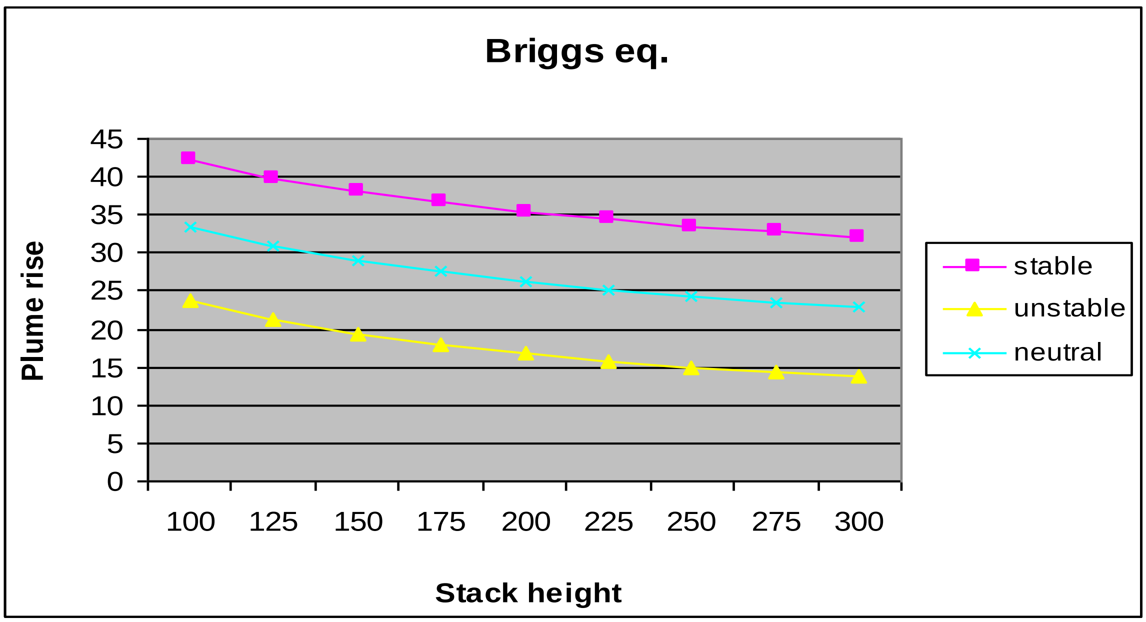
Graph: 5 Plume rise vs. stack height



Plume rise decreases 0.094, 0.36 and 0.148 meters for every 1m
Increase of stack height `under stable, unstable and neutral condition
Respectively

Effect of different Stack height on plume rise in Briggs equation (momentum sources) Less than 50F above ambient

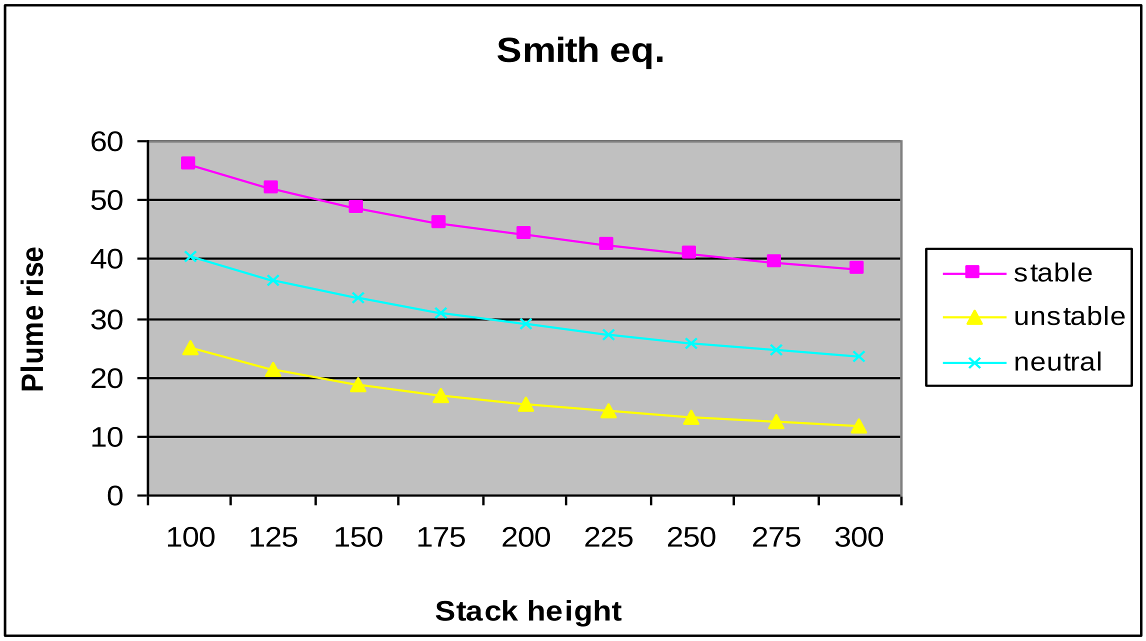
Graph: 6 Plume rise Qh vs. stack height



Plume rise decreases 0.05, 0.05 and 0.053 meters for every 1m
Increase of stack height `under stable, unstable and neutral condition
Respectively

Effect of different Stack height on plume rise in Smith equation.

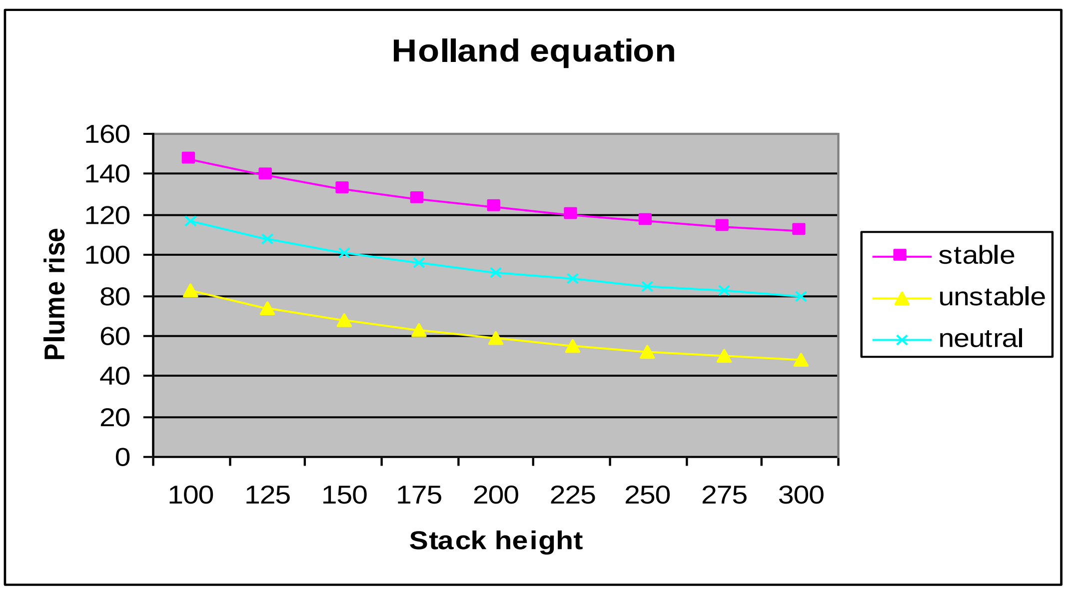
Graph: 7 Plume rise vs. stack height



Plume rise decreases 0.089, 0.067 and 0.084 meters for every 1m Increase of stack height `under stable, unstable and neutral condition Respectively

Effect of different Stack height on plume rise in Holland equation

Graph: 8 Plume rise Qh vs. stack height



Plume rise decreases 0.176, 0.174 and 0.186 meters for every 1m Increase of stack height `under stable, unstable and neutral condition Respectively

Conclusions:

The present study concludes the fact that with the increase of horizontal Wind velocity and Stack height, Plume Rise decreases under all stability conditions and as such needs to be planned and considered at the initial stages of plant set up in order to have minimum ground level concentrations of Air Pollutants from such plants.

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