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Comparative Study between ADMS and CFD in Modeling Dust Dispersion from a Blasting Events in Quarry

Wahyu Rinaldi*, Teuku Mukhriza

Jurusan Teknik Kimia, Fakultas Teknik Unsyiah, Universitas Syiah Kuala
Jl. Syech Abdurrauf no.7, Darussalam Banda Aceh
*E-mail: wahyu_rinaldi@unsyiah.ac.id

Abstract

Two frequently used methods in atmospheric dispersion modeling (ADMS and CFD) were compared in this study to predict pit retention within an open quarry. Conventional Gaussian plume models developed by CERC, ADMS 3 and ADMS 4, were used to predict the pit retention. This study mimicked Fluent CFD modeling of dust dispersion of a blasting event in Old Moor Quarry. A single blast event that liberated a typical 25,000 tons of rock released 1,900 kg of Total Suspended Particle (TSP). The emission source geometry was defined as a three dimensional block volume source of 70 m normal to the face, 80 m in width and 20 m in height. It was also assumed the TSP liberated over one hour had an emission rate of 4.71×10^{-3} g/m^3/s. The four particle sizes were defined as 2.5, 10, 30 and 75 μm at mass fractions of 0.05, 0.45, 0.3 and 0.2 respectively and the particles were assumed have uniform limestone density of 2600 kg/m^3. The results indicated that ADMS and model based on CFD indicates similar trend, that is, pit retention is proportional to distance from source to pit edge along wind direction and proportional to inverse quarry gradient.

Keywords: dust dispersion, blasting, ADMS, CFD, pit retention

1. Introduction

One of the major environmental impacts from the extractive industry is the generation and emission of dusts. The impacts increase when the operations are adjacent to sensitive receptors such as, populated areas, national parks, areas of outstanding natural beauty, etc. (Petavratzi *et al*., 2005). The impacts become worse if the quarries operate in dry or windy environments. Consequently, because of dust problem, the extractive industries face two major problems that are linked to the occupational health and the air quality issue around the quarries. Moreover, safety and productivity might also be influenced by high concentration of dust and dust properties (Petavratzi *et al.,* 2007).

Levels of pollutant concentrations in the atmosphere are a combination of pollutant emissions, chemical and physical processes in the atmosphere, earth surface properties and geometry (Karatzas and Kaltsatos, 2007). In order to maintain air quality at reasonable levels many nations have air quality standards that are allowed by regulation to be exceeded only rarely. Furthermore, before starting to construct a new facility, it is always necessary to obtain a construction permit from the government. Part of the permit application is to show that the new facility completed, and operating will not violate the air quality standard for each regulated pollutant. Air quality dispersion modeling is about the only way to estimate this future impact (Turner, 1994). Moreover, Corani (2005) argued a system that has the ability to predict pollutant concentrations with sufficient anticipation and can provide Public Authorities with the time required to manage the emergency, for instance, by planning an increase in the public transports in the case of an incoming traffic block, or by issuing early warnings. In particular, dust dispersion model of blasting event can give guidance to operators about location, mass handling, and the right time to perform blasting.

Old moor and Tunstead quarry (Figure 1) is located near Buxton, within the Peak District Area, in Derbyshire. The combined Old Moor and Tunstead quarry was the largest quarry in Britain and remains the most complex. Extensive deposits of regularly bedded and consistent high purity limestone were found at Tunstead. By 1949, the complex annual output approached 2 million tonnes of limestone. By 1957, the complex was closed. Proposal to open up Old Moor quarry to maintain supplies into the 21st century was eventually approved in 1980. Currently, Tunstead and Old Moor quarry is owned by Anglo American Plc (British Geological Survey, 2003).

Atmospheric Dispersion Modelling System (ADMS) is a conventional atmospheric dispersion model developed by Cambridge Environmental Research Consultants Ltd. ADMS can simulate a wide range of buoyant and passive releases to the atmosphere from either single or multiple sources. Instead using Pasquill-Gifford stability class, ADMS describe the atmospheric boundary layer using the boundary layer height (h) and the Monin-Obukhov length (L_{MO}). Skewed Gaussian concentration distribution is used to calculate dispersion under convective conditions. ADMS is applicable for distance up to 60 km downwind of the source and provides useful information for distance up to 100 km (CERC, 2007). The model includes algorithms which take into account effects of main site building, complex terrain, wet deposition, gravitational settling and dry deposition, short term fluctuations in concentration, chemical reactions, radioactive decay, plume rise as a function of distance, jets and directional releases, averaging time ranging from very short to annual, condensed plume visibility, meteorological pre-processor (U.S. Environmental Protection Agency, 2006).

Figure 1. Aerial view of Tunstead Quarry (A) and Old Moor Quarry (B) (Google earth, 2008)

This study was carried out to compare the conventional Gaussian plume model and modeling techniques that are used really often recently in atmospheric dispersion research, Computational Fluid Dynamic (CFD). The conventional Gaussian plume models used in this study are ADMS 3 and ADMS 4, which are developed by Cambridge Environmental Research Consultants (CERC). The ADMS 3 and ADMS 4 models output then were compared to Fluent CFD model output studied by Lowndes *et al.* (2008). The objectives of this research was to compare the two different models (ADMS and CFD model) outputs of dust dispersion from rock blasting events in Old Moor quarry in term of pit retention.

2. Methodology

A comparative analysis between ADMS, and model dust dispersion of a blasting event in Old Moor Quarry, and Computational Fluid Dynamics (CFD) model by Lowndes *et al.* (2008) was done. Pollutant source properties given by Silvester *et al.* (2006) were used. A single blast event liberated a typical 25,000 tons of rock released 1,900 kg of Total Suspended Particle (TSP). The emission source geometry was defined as a three dimensional block volume source of 70 m normal to the face, 80 m in width and 20 m in height. It was also assumed the TSP liberated over one hour has an emission rate of 4.71×10^{-3} $g/m^3/s$. The four particle sizes were defined as 2.5, 10, 30 and 75μm at mass fractions of 0.05, 0.45, 0.3 and 0.2 respectively and the particles were assumed have uniform limestone density of 2600 kg/m^3.

This study mimicked Fluent CFD modeling by Lowndes *et al.* (2008). However, in this study ADMS 3 and ADMS 4 were used instead using Fluent®. Furthermore, horizontal cross-section of volume source that entered into pollutant geometry screen was an irregular pentagon shape to accommodate the convex shape required by ADMS 4. Rectangular shape was used for ADMS 3.

Pollutant source parameter:

a. Particle size and size fraction:
   - 2.5 μm = 0.05
   - 10 μm = 0.45
   - 30 μm = 0.3
   - 75 μm = 0.2

b. Limestone density : 2600 kg/m^3

c. Emission rate : 4.71×10^{-3} $g(m^3/s)$

d. Vertical extent of source (L1) : 20 m

e. Source height : 10 m

Meteorological parameter:

a. Boundary layer height : 800 m

b. Surface heat flux : 0

c. Reference speed : 4.5 m/s

d. Reference height : 2 m (The reference height in the CFD analysis is measured from the far edges of the domain which is assigned as the 0 datum) (72 m was used for ADMS)

e. Wind direction : 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°

Coordinate X,Y and deposition rate ($\mu g/(m^2/s)$) from model output file were extracted from .gst file to calculate the amount of dust deposited inside the quarry boundary in one hour. Each black nodes in Figure 2. represent coordinate X,Y from the model output file. It was assumed that all location inside the thick box had the same deposition rate with the black node surrounded by the box. The box area is $\Delta x \times \Delta y$. Dust deposition then was given by

$$dust\ deposition\,(g/h) = \frac{dep.rate\,(\mu g/m^2/s)}{10^6\,\mu g/g} \times \frac{3600\,s}{1h} \times area\,(m^2)$$

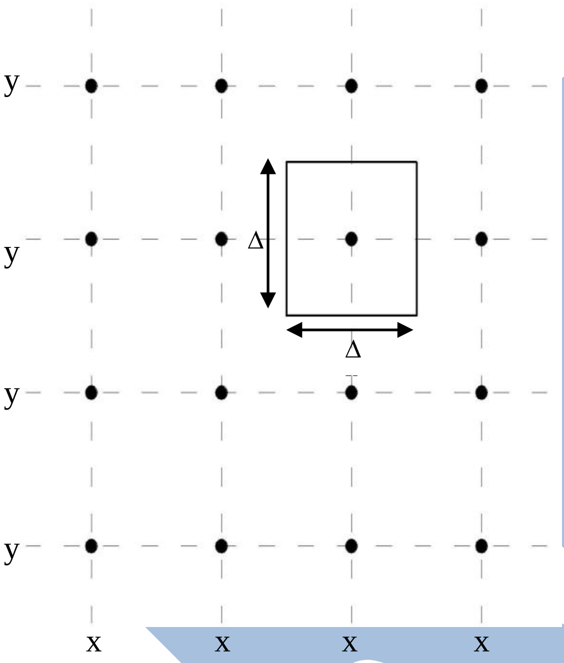

Figure 2. Calculation grid used to determine the amount of dust deposited within quarry

3. Result and Discussion

Modeling of dust dispersion from limestone rock blasting in Old Moor quarry using ADMS 3 and ADMS 4 were compared with modeling based on CFD in this study. While the technology of precise blasting has developed over time to increase the effectiveness of rock blasting process, however, there were only few information about the aftermaths of explosion in quarrying operation especially dust dispersion. Environmental regulation regarding to dust emission has brought this study become important especially in the case of Old Moor quarry located closed to residential area and a national park. Proximity of these sensitive receptors to the quarry is the driven for this modeling study.

Five pollutant sources in different location inside the quarry were modeled for eight wind directions. The modeling results show in average 60% and 49% of dust emitted from the blasting events is deposited inside the quarry for ADMS 3 and ADMS 4 respectively. For CFD modeling (Lowndes *et al*, 2008), 58% of dust is trapped inside the quarry.

ADMS 3 ability to model pollutant dispersion in complex terrain like Old Moor Quarry was not totally reliable. Ninety percent simulations showed FLOWSTAR warning with message "*WARNING: An attempt was made to access data outside the FLOWSTAR grid*" in ADMS 3 while ADMS 4 had only twenty five percent.

Table 1. The maximum and the minimum pit retention comparison

Modelling technique		Pit Retention	Distance between centroid and pit edge (m)	Gradient
CFD	Min	0.075	41	0.427
	Max	0.842	853	0.021
ADMS 3	Min	0.222	123	0.305
	Max	1.034	717	0.052
ADMS 4	Min	0.167	41	0.427
	Max	0.851	682	0.083

Table 1 shows the comparison of the minimum and the maximum pit retention among the three modeling techniques. All models show that pit retention is proportional to distance between centroid and pit edge and inversely proportional to gradient. However, ADMS 3 overestimate pit retention for the maximum value of over 100%.

In case of the mass fraction of dust retained inside the quarry versus distance from source to the downwind quarry edge, ADMS and CFD show analogous trend. Figure 3, 4 and 5 show that pit retention increase proportional to the distance. However, the pit retention tendency is proportional to logarithmic of distance for CFD model, while it is linear to distance for ADMS.

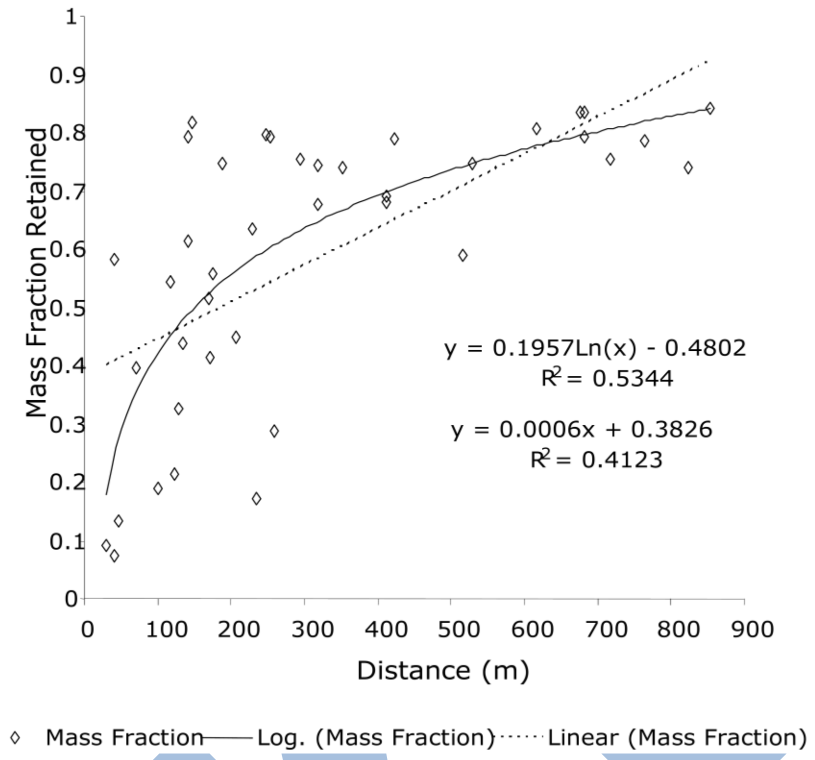

Figure 3. Pit deposition as a function of distance between emission centroid and pit edge along wind vector modeled with CFD.

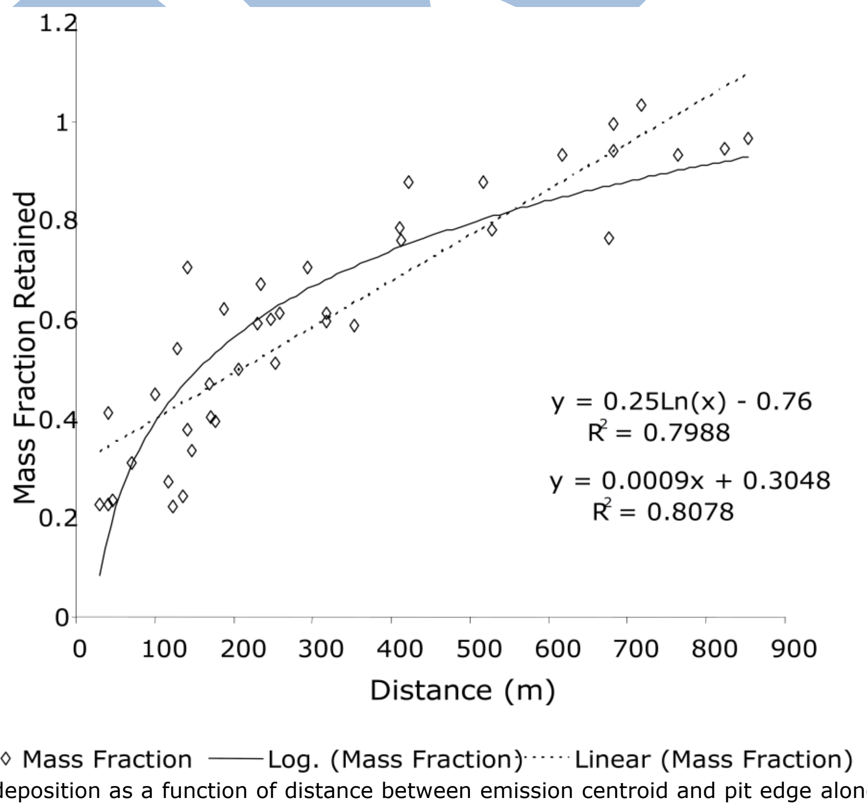

Figure 4. Pit deposition as a function of distance between emission centroid and pit edge along wind vector modeled with ADMS 3.

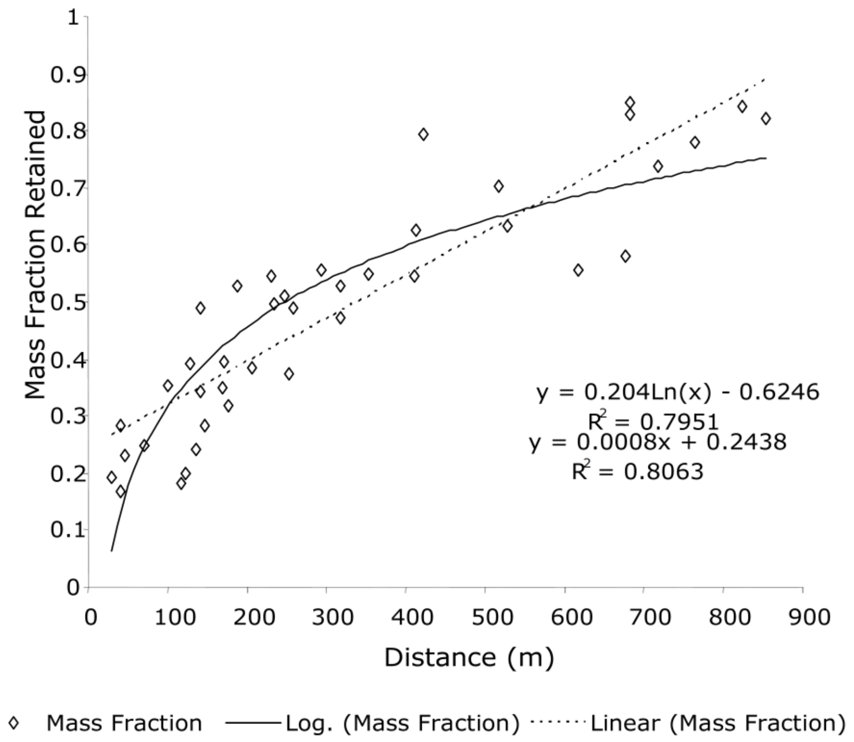

Figure 5. Pit deposition as a function of distance between emission centroid and pit edge along wind vector modeled with ADMS 4

4. Conclusions

Both ADMS and CFD model show similar trend where the pit retention will increase with increasing of distance from source to the pit edge. Both ADMS and CFD model show that pit retention will decrease with increasing of quarry gradient. The maximum pit retention for Old Moor Quarry modeled with CFD and ADMS 4 are 0.842 and 0.851 respectively. The minimmum pit retention for Old Moor Quarry modeled with CFD , ADMS 3 and ADMS 4 are 0.427, 0.222 and 0.167, respectively.

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