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NUMERICAL SIMULATION OF CYCLONE EFFICIENCY AND PRESSURE DROP

JOLIUS GIMBUN.

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MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA

2004

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NUMERICAL SIMULATION OF CYCLONE EFFICIENCY AND PRESSURE DROP

By

JOLIUS GIMBUN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Partial Fulfilment of the Requirements for the Degree of Master of Science

May 2004

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Kasarahan kŭŭd kumaä dokoŏu oië Ápä om Ámmä
Robert Gimbun G. & Marry Murinah R.

Sunduan dï pinowoyo nu
Oi tutumatanud do kupusanku

Id kotumbayaan ku'd kumaa'd kinosunduhon'd
Payat dï 'Akï Montuk'

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Abstract of project presented to the Senate of Universiti Putra Malaysia in partial fulfilment of the requirement for the degree of Master of Science in Environmental Engineering.

NUMERICAL SIMULATION OF CYCLONE EFFICIENCY AND PRESSURE DROP

By

JOLIUS GIMBUN

May 2004

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The Department of Environment Malaysia (DOE) has been regulating particulate emission since the 1978. More stringent environmental regulations have resulted in considerable research into ways of reducing harmful and gloomy particulate emissions. Cyclones are probably the most commonly used means of separating dust from gases, controlling pollution, collecting particulate product or recovering catalyst particles from fluidised reactors. Their popularity is due to low maintenance and investment costs. Cyclone design maybe simple but models use to predict the cyclone efficiency and pressure drop are not always accurate. The objective of this study is to carry out simulation via a commercial spreadsheet, MS EXCEL, and CFD code FLUENT 6.1, on cyclone design, efficiency, and pressure drop for particulate emission control.

In this study, CFD code FLUENT and four cyclone collection models earlier developed by other researchers are used for prediction of cyclone efficiency. This study focuses on various operating conditions of cyclone and the simulation result is then verified via experimental data published in the literature. The model with the best prediction on experimental data is then used to evaluate the effects of cyclone configuration, dimension, and variable on its collection efficiency.

The cyclone pressure drop calculations are performed using CFD and empirical models adopted from the literature. These four empirical models and CFD are compared with presented experimental data available in the literature.

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All the modelling and simulation of cyclone efficiency and pressure drop are proved to be satisfactory when compared with the presented experimental data. The CFD simulations and Li and Wang model predict excellently the cyclone cut-off size for all operating conditions with a deviation of 3 and 6% from the experimental data respectively. The CFD simulations also predict excellently the cyclone pressure drop under different temperature and inlet velocity with a maximum deviation of 3% from the experimental data. Specifically, results obtained from the computer modelling exercise have demonstrated that CFD and Li and Wang model is a best method of modelling cyclones collection efficiency and pressure drop.

The result or finding obtained from the research work can be used to develop a cyclone with greater separation efficiency, which is capable of removing up to 99% of PM_5. This cyclone can then be used for particulate pollutant control from industrial factory to the atmosphere.

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Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk Ijazah Master Sains dalam Kejuruteraan Alam Sekitar.

SIMULASI BERANGKA KECEKAPAN DAN KEHILANGAN TEKANAN SIKLON

Oleh

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Jabatan Alam Sekitar Malaysia (JAS) telah mewujudkan peraturan pelepasan habuk semenjak 1978. Dengan Undang undang yang ketat, banyak penyelidikan untuk mengurangkan pelepasan habuk telah dijalankan. Siklon adalah alat pemisah habuk daripada gas yang biasa digunakan dalam kawalan pencemaran, pengumpul partikel atau mendapatkan semula mangkin dari reaktor terbendalir. Ia menjadi pilihan utama disebabkan oleh kos penyelenggaraan dan harganya yang murah. Rekabentu siklon mungkin mudah tetapi model yang digunakan untuk mengira kecekapan siklon tidak selalunya tepat. Objektif penyelidikan ini ialah untuk menjalankan simulasi menggunakan spreadsheet komersial, MS EXCEL, dan kod CFD FLUENT 6.1, dalam rekabentuk, kecekapan, dan kehilangan tekanan siklon untuk kawalan pelepasan partikel.

Dalam kajian ini kod CFD FLUENT dan koleksi model-model siklon yang telah dirumuskan oleh penyelidik – penyelidik terdahulu digunakan dalam simulasi kecekapan siklon. Kajian tertumpu kepada operasi siklon pada keadaan yang berbeza dan keputusan simulasi akan dibuktikan kesahihannya menggunakan data eksperimen. Model yang menunjukkan pengiraan yang paling hampir dengan nilai eksperimen kemudian diggunakan dalam kajian terhadap kesan konfigurasi, dimensi, dan pemboleh ubah siklon kepada kecekapannya.

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Kehilangan tekanan dalam siklon dikira menggunakan CFD dan model - model empirikal yang diperolehi daripada bahan - bahan rujukan. Kiraan keempat-empat model dan CFD kemudian dibandingkan dengan data experimen.

Keseluruhannya, semua keputusan simulasi tekanan dan kecekapan siklon terbukti memuaskan jika dibandingkan dengan data eksperimen. Simulasi dengan menggunakan CFD dan Model Li dan Wang memberikan kiraan yang tepat untuk saiz kritikal atau 'cut-off size' silkon dalam semua keadaan dengan penyimpangan 3 dan 6% daripada data eksperimen. Simulasi CFD juga mampu membuat perkiraan yang baik untuk kehilangan tekanan dalam siklon dengan penyimpangan maksimum 3% daripada data eksperimen. Secara spesifiknya, keputusan daripada simulasi berkomputer menunjukkan CFD adalah cara terbaik untuk mensimulasikan kecekapan dan kehilangan tekanan siklon.

Keputusan dan penemuan kajian dapat diggunakan untuk merekabentuk siklon berkecekapan tinggi, dengan kemampuan untuk menyingkirkan sehingga 99% daripada PM_5. Siklon ini kemudian akan digunakan sebagai alat kawalan pencemaran habuk dari kilang atau lain lain industri.

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It was a dark & stormy night...

Joe 2003

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LIST OF SYMBOLS AND ABBREVIATIONS

L = natural length (m)
a = cyclone inlet height (m)
b = cyclone inlet width (m)
D = cyclone body diameter (m)
D_e = cyclone gas outlet diameter (m)
H = cyclone height (m)
h = cyclone cylinder height (m)
S = cyclone gas outlet duct length (m)
B = cyclone dust outlet diameter (m)
c_0, c_1 = particle inlet and outlet concentration (kg/m^3)
d = particle diameter (m)
D_r = radial turbulent diffusion coefficient
d_{pc} = cut particle diameter collected with 50% efficiency (m)
n = cyclone vortex exponent ($0.5 < n < 1$)
Q = volumetric gas flow rate (m^3/s)
r = radial dimension, $r_w = D/2$ and $r_n = D_e/2$ (m)
R = radius (m)
T = absolute temperature (K)
w = radial particle velocity (rad/s)
w_n, w_w = radial particle velocity at $r = r_n$ and $r = r_w$
α = particle bounce or re-entrainment coefficient
λ = characteristic value
η = efficiency
ρ_g = gas density (kg/m^3)
ρ_p = particle mass density (kg/m^3)
μ = Dynamic gas viscosity (m^2/s)
θ = angular coordinate
d_{pi} = diameter of particle in size range i (m)
g = gravity acceleration (m/s^2)
G = cyclone configuration factor
τ = relaxation time
η_i = grade efficiency of particle size at mid-point of internal i (%)
i = subscript donates interval n particles size range
K_a = a/D
K_b = b/D
K_c = cyclone volume constant
N_e = gas spins through a number of revolutions N_e in the outer vortex
v_i = inlet velocity (m/s)
K = cyclone configuration and operating condition constant
β = slope parameter
z_c = core length (m)
d_c = core diameter (m)
$v_{t\,max}$ = maximum tangential velocity (m/s)
α = velocity head, pressure drop coefficient (m)
v_i = inlet velocity (m/s)
ΔP = cyclone pressure drop (Pa)
G_ϕ = Flux of angular momentum (kgm^2/s^2)
G_x = Flux of linear momentum (kgm/s^2)
p = Pressure (Pa)
k = Turbulent kinetic energy (m^2/s^2)
Re = Reynolds number
ε = Turbulent dissipation rate (m^2/s^3)
S = Swirl number
U, V, W = Velocity (m/s)
u', v', w' = Velocity fluctuation (m/s)
ti = Turbulent intensity

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B = Body force
μ = Molecular viscosity
ξ = Bulk viscosity
H = Total enthalpy
λ = Thermal conductivity
Γ = Diffusion coefficient
I = Unit tensor
Φ = Reynold average quantities or Pressure strain correlation
P = Shear production
G = Buoyancy stress production tensor
τ_v = Particle response time
Re_r = Relative Reynold number

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CHAPTER I

INTRODUCTION

1.0 Air Pollution

Air pollution is defined as the presence in the outdoor atmosphere of one or more contaminants (pollutants) in quantities and the duration that can harm human, plant, or animal life or property (materials) or which unreasonably interferes with the enjoyment of life or the conduction of business. Examples of traditional contaminants include sulfur dioxide, nitrogen oxides, carbon monoxide, hydrocarbons, volatile organic compounds (VOCs), hydrogen sulfide, particulate matters, smokes, and hazes. This list of air pollutants following World War II, and ozone has become a major world wide air pollutant concern.

Malaysia possesses a great potential market for industrial gas cleaning technology. The country has made great strides in economic development during the last two decades. It is endowed with rich natural resources, such as oil and gas which provide the nation's energy requirements and a feedstock for the development in manufacturing industry. Although Malaysia can be considered as one of the least polluted urban environments in Asia, rapid urbanisation and sustained economic growth have contributed towards air pollution issues. There is a rapid increase of pollutants and waste with the shift in the nation's strategy from agriculture towards manufacturing and heavy industries which will result in the deterioration of air and water quality. The goal of the country is to achieve the status of industrial country by

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the year 2020 and the associated industrial and urban expansion will further strain the environment in Malaysia.

This section is focused on the air pollution issue in Malaysia. The issue of air pollution is particularly critical in urban industrial areas like Klang Valley (Wan Ramli, 1996). The deteriorating state of air quality in this area has been due to the presence of suspended particulates or dusts generated by disposal of industrial, municipal and agricultural waste through open burning. Apart from these, the problem is also worsened by the emission from the power generation plants and by industrial combustion.

Table 1.1 shows some potentially significant air pollution sources published by Department of Environment, (DOE) Malaysia in 1996. The major air pollutants measured under this air quality monitoring programme include suspended particulates, sulphur dioxide, carbon monoxide, nitrogen oxides, hydrocarbons, ozone and lead. The five year statistical data shows the increment for all potentially significant air pollution sources which lead to the emission of large amount of air pollutants.

Table 1.1: Potentially Significant Air Pollution Sources in Malaysia, (DOE, 1996)

Type of sources	**Number of Sources**				
	1990	**1991**	**1992**	**1993**	**1994**
a. Chemical Industries					
- Pesticides and Fertilizer	5	5	5	91	80
- Chemical Manufacturing	192	194	175	98	124
- Plastic and Resin	90	91	142	54	53
- Soup and Detergents	9	9	24	69	32

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Table 1.1: Potentially Significant Air Pollution Sources in Malaysia, 1996 (DOE, 1996) *Cont'd*

Type of sources	Number of Sources				
	1990	**1991**	**1992**	**1993**	**1994**
b. Food and Agriculture					
- Palm Oil Mill	260	258	267	286	286
- Rubber Mill	211	209	184	184	168
- Rubber Product Manufacturing	82	91	322	595	594
c. Metal Industries					
- Aluminium Works	19	19	34	34	39
- Foundries	277	261	314	314	228
- Iron and Steel Mill	24	24	26	26	51
- Lead Smelter and Related Works	11	11	32	32	49
- Tin Smelting	5	5	5	5	8
d. Mineral Products					
- Asbestos Works	5	5	5	8	10
- Cement Products	178	180	185	306	313
- Glass Works	27	27	39	52	219
- Portland Cement Manufacturing	5	5	5	47	47
e. Petroleum Industry					
- Petroleum Refineries	5	5	5	8	46
- Miscellaneous Petroleum Process	28	32	36	36	12
- Gas Processing	24	25	25	30	36
f. Fuel Combustion Sources					
- Thermal Power Station	14	14	14	32	32
- Boiler and Furnaces	2374	2526	2613	2828	2841
- Incinerator	250	279	406	427	448

1.1 Particulate Emission

Particulates represent any dispersed matter, solid or liquid, in which the individual aggregates are larger than single small molecules (about 0.0002 μm in diameter) but smaller than about 500 micrometers (μm) (Hesketh, 1996). The origins of the

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particles determine their sizes and natures. Hesketh (1996) prove the following useful definitions of natural and man-made mixtures of particles and gases: "Smokes are both liquid and solid particles from oxidation processes, while fumes are specifically smokes condensed from metallic vapours. Dust is a dispersion aerosol of particles naturally generated by wind-ground interactions. Mists are liquid droplet suspension and fog is a condensed mists. Hazes are mists and dusts while smog was originally a contraction indicating the presence of both *smoke* and *fog*". However, in the field of air pollution it is common to use the terms "dust" and "particulate" almost interchangeably to describe almost any fine solid material required to be removed from a gas stream.

Particulate air pollution includes solid and liquid particles directly emitted into the air, such as diesel soot, road and agricultural dust, and particles resulting from manufacturing processes. Particles are also produced through photochemical reactions involving pollution gases, such as sulfur and nitrogen oxides, which are by-product of fuel combustion (Ostro and Chestnut, 1998). The emission of particulate matters increases as the increment of potential air pollution sources (Table 1).

Fang *et al.* (2003) found out that health related problem was associated with either the total mass concentration of suspended particles or the mass concentration of particles with aerodynamic diameters smaller than 10 μm (PM_{10}). Epidemiological studies conducted in several countries showed consistent associations of exposure to ambient particulates with adverse health effects including increased mortality, hospitalization for respiratory or cardiovascular disease, and respiratory symptoms and decreased lung function. Based on epidemiological time series studies, dose-response functions were identified between an increase in particulate matter and

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adverse health effects (El-Fadel and Massoud, 2000). Guo *et al.* (1999) revealed that PM_{10} was positively associated with the prevalence of asthma in middle-school students in Taiwan.

1.2 Regulation of Particulate Emission

The Department of Environment (DOE) Malaysia has been regulating particulate emission since the 1978 (EQA 1974, 2001) under the regulation 24, 25 and 29 of Environment Quality (Clean Air) Regulations. Standards A and B in Malaysia Clean Air Act are only enforced to the existing facilities while, Standard C is a requirement for new and future facilities. Any plant or facilities that are built after this regulation is considered as new facilities and need to comply with Standard C in Environment Quality (Clean Air) (Amendment) Regulations 2001 in Table 1.2. The regulation is divided into three main parts, *Solid particles concentration in heating of metals, Portland cement plant* and *Solid particles concentration in other operations*. The measurement of dust, soot, ash, grit and any solid particles concentration must be done before admixture with air, smokes, or other gases.

Table 1.2: Environment Quality (Clean Air) (EQA 1974, 2001)

Standard	Solid particles concentration in heating of metals (g/m^3)	Solid particles concentration in other operations (g/m^3)	Portland cement plant (g/m^3)	
			Klin	Clinker cooler, finishing grinding, etc
A	0.3	0.6	0.4	0.4
B	0.25	0.5	0.2	0.2
C	0.2	0.4	0.2	0.1

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