

LB/DON/01/2017

# ANALYSIS AND OPTIMIZATION OF CYCLONE SEPARATORS BY USING RANS

Matheskankanamge Shashi Manoj De Silva

(119253H)

LIBRARY  
UNIVERSITY OF MORATUWA, SRI LANKA  
- MORATUWA

Dissertation submitted in partial fulfillment of the requirements for the degree Master of Science in Sustainable Process Development

Department of Chemical and Process Engineering

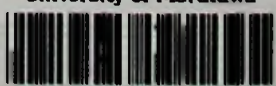
University of Moratuwa

Sri Lanka

January 2016

66"16"  
-----  
66.012 (043)

University of Moratuwa



TH3279

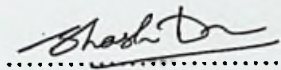
TH3279  
LCD-20M

TH 3279

## DECLARATION OF THE CANDIDATE & SUPERVISOR

"I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works."

  
.....

2016. 10 . 10  
.....

Signature:

Date:

The above candidate has carried out research for the Master Dissertation under my supervision.

  
.....

2016 . 10 . 10  
.....

Signature of the supervisor

Date:

Dr. Mahinsasa Narayana

Senior Lecturer Grade II



## ABSTRACT

Many types of particulate matter collectors are used in the industry to separate particulate matter from the gaseous streams. Among various type of particulate collectors, cyclone separators are one of the most extensively used gas cleaning equipment because of they are inexpensive; easier to fabricate, and could be designed to stand under harsh operating conditions.

Due to this extensive usage in the industry, many theoretical and experimental studies have been carried out and empirical models were developed to predict cyclone separator's most important operational parameters. These models have many limitations of illustrating flow behavior properly due to the complex nature of the cyclone gas-solid flow behavior. Computational Fluid Dynamic (CFD) simulation could be useful to predict cyclone performance as an alternative approach.

This work represents a CFD simulation of a Lapple cyclone separator using OpenFOAM software. Cyclone simulations have been carried out using turbulence models associated with the Reynolds Average Navier Stokes (RANS) equations. Multiphase Particle in Cell (MPPIC) method was used for the particle modeling, in which particle interactions with other particles were represented by models. The perditions of simulations have been compared both mutually and to literature in terms of cyclone pressure drop, gas-solid flow pattern and collection efficiency.

RANS model fairly predict the gas-solid flow pattern of the cyclone. Pressure drop and collection efficiency of cyclone well fitted to the experimental results in the literature.

Optimum values for inlet gas-solid velocity and particulate loading rate for the Lapple cyclone were obtained by RANS analysis. Pressure drop variation with gas-solid inlet velocity which has been obtained by this analysis could be useful to minimize the energy requirement while maintaining the required collection efficiency.

## ACKNOWLEDGMENT

I would like to express my heartiest gratitude to my research supervisor Dr. M. Narayana, a Senior Lecturer of Department of Chemical and Process Engineering of University of Moratuwa, for his enormous encouragement, guidance, dedication and patience throughout the research to make it successful.

My sincere thanks also go to Dr. A Rathnasiri, Head of the Department - Department of Chemical and Process Engineering of University of Moratuwa, for teaching Computational Fluid Dynamics in interesting manner and giving essential basic theoretical background of CFD.

I would like to thank to Dr. S Amarsinghe a Senior Lecturer of Department of Chemical and Process Engineering of University of Moratuwa, for teaching theoretical background of fluid dynamics and encouraging on research work.

My special thanks go to Mr.Suren Watson, Environmental Manager of SGS Lanka (Pvt) Ltd. for encouraging me to select the field of pollution control equipment as my research and for his enormous support given throughout the research to fulfill this work successfully.

I would like to thank IT staff members and non-technical staff members for the support given by providing lab facilities.

My heartiest thanks also go to my loving wife; D. Jayani Chathurika since without the help and support of her, this research could not be completed in to this success.

# TABLE OF CONTENTS

DECLARATION OF THE CANDIDATE & SUPERVISOR .....	i
ABSTRACT .....	ii
ACKNOWLEDGMENT .....	iii
LIST OF FIGURES .....	vi
LIST OF TABLES .....	vii
LIST OF ABBREVIATIONS .....	viii
LIST OF APPENDICES .....	xi
1 INTRODUCTION .....	1
2 LITERATURE SURVEY .....	2
2.1 Overview of Particulate Collectors .....	2
2.2 Cyclone Separator .....	3
2.2.1 Principals of cyclonic separation .....	3
2.2.2 Advantages and disadvantages of cyclone separators.....	5
2.2.3 Typical industrial applications .....	5
2.3 Cyclone Gas Solid Flow Behavior and Collection Efficiency .....	6
2.3.1 Tangential gas velocity .....	6
2.3.2 Axial and radial gas velocity.....	8
2.3.3 Pressure distribution.....	8
2.3.4 Pressure drop.....	9
2.3.5 Collection efficiency .....	10
2.4 Design of Cyclone .....	12
2.4.1 Standard designs .....	12
2.4.2 Factors affecting the cyclone performance .....	14
2.5 The Computational Fluid Dynamics Approach for Cyclone Gas-Solid Flow Simulation .....	14
3 MATHEMATICAL MODEL .....	16
3.1 The Governing Equations for the Gas Phase.....	16
3.1.1 Reynolds Averaged Navier Stokes (RANS) Approach .....	18
3.2 Modeling the Particle Phase .....	19

3.2.1	Governing equations of Multiphase Particle in Cell (MPPIC) method	19
4	COMPUTATIONAL FLUID DYNAMIC MODEL (OPENFOAM)	21
4.1	Geometry and Mesh Preparations	21
4.2	Boundary conditions	22
4.3	Particle injection models	23
4.3.1	Based model	23
5	RESULTS AND DISCUSSION	24
5.1	RANS Simulation Results and Discussion	24
5.1.1	Overall flow pattern	24
5.1.2	Gas velocity profile	25
5.1.3	Tangential gas velocity profile obtained using RANS model	27
5.1.4	Axial and radial gas velocity profiles obtained using RANS model	30
5.1.5	Pressure distribution	32
5.1.6	Pressure drop	33
5.1.7	Collection efficiency of cyclone	34
6	CONCLUSION	37
6.1	Gas flow field simulation	37
6.2	Particle collection and optimization	37
6.3	Suggestions for future work	37
	REFERENCE LIST	38

## LIST OF FIGURES

Figure 2.1 : Flow pattern of the reverse-flow cyclone .....	3
Figure 2.2 : Multicyclone .....	4
Figure 2.3 : Variation of tangential gas velocity and radial velocity in the cyclone....	7
Figure 2.4 : Variation of axial velocity component in the cyclone.....	8
Figure 2.5 : Static pressure (-) and Total pressure (--) variation through the cyclone.	9
Figure 2.6 : Lapple cyclone separator proportions.....	13
Figure 4.1: Lapple cyclone.....	21
Figure 4.2 : 3D view of a) Cyclone geometry and b) CFD mesh of cyclone.....	22
Figure 5.1 : Gas flow path generated by RANS simulation.....	24
Figure 5.2: Velocity profile of cyclone obtained using RANS simulation (at 20 m/s inlet gas velocity .....	25
Figure 5.3: Tangential velocity profile of cyclone obtained using RANS simulation (at 20 m/s inlet gas velocity) .....	27
Figure 5.4 : Averaged tangential gas velocity compared with the experiments .....	28
Figure 5.5 : Gas velocity magnitude pattern at different time instance of the cross section B-B (figure 5.2) of RANS simulation.....	29
Figure 5.6: Axial (Left side figure) and Radial (Right side figure) velocity profile of cyclone separator obtained using RANS simulation.....	30
Figure 5.7: Axial( $U_z$ ), radial( $U_y$ ) and tangential ( $U_x$ ) gas velocities at the cross section B-B (figure 5.2) of RANS simulation.....	31
Figure 5.8 : Pressure profile of cyclone relative to the atmosphere pressure obtain using RANS simulation .....	32
Figure 5.9 : Variation of cyclone pressure drop with inlet gas-solid flow velocity... 33	
Figure 5.10: Particle simulation of Lapple cyclone obtain using RANS simulation. 34	
Figure 5.11 : Cyclone collection efficiency variation with inlet gas-solid flow velocity.....	35
Figure 5.12 : Cyclone collection efficiency variation with inlet particulate loading. 36	

## LIST OF TABLES

Table 2.1 : Overview of particulate collectors.....	2
Table 2.2 : Standard cyclone dimensions.....	13
Table 4.1 : Dimensions of Lapple cyclone.....	21
Table 4.2 : Functions applied for boundaries of RANS.....	22
Table 5.1 : Cyclone pressure variation with inlet gas-solid flow velocity.....	33
Table 5.2: Variation of collection efficiency with inlet gas-solid flow velocity .....	35
Table 5.3: Variation of collection efficiency with particulate loading rate .....	36



## LIST OF ABBREVIATIONS

Abbreviation	Description
$\beta$	constants
$\delta_{ij}$	Kronecker delta
$\Delta$	lattice spacing constant
$\Delta P$	static pressure drop
$\Delta t$	residence time of gas
$\theta_{cp}$	close pack volume fraction
$\lambda_{mix}$	mixing length of the sub grid scale
$\mu$	viscosity of gas
$\mu_t$	eddy (turbulent) viscosity
$\nu_e$	eddy viscosity
$\varepsilon$	dissipation of turbulent kinetic energy
$\rho$	density
$\rho_g$	density of gas
$\rho_g$	density of gas
$\rho_p$	density of particle
$\tau$	particle stress
$\phi$	a property of a flow
$\Phi$	the mean property
$\Omega_p$	particle volume at position $x$ and time $t$
$\omega_k$	rotational vector
$A$	particle acceleration
$B_c$	cyclone inlet width
$C_\mu$	dimensionless constant
$C_s$	a constant
$D_p$	diameter of the particle
$D, D_c$	diameter of the cyclone

$D_e$	diameter of gas exit
$d_p$	diameter of the particle
$d_{pc}$	diameter of the particle collected with 50% efficiency
$F$	Particle phase and gas phase momentum exchange rate
$H_c$	cyclone inlet height
$H_c$	cyclone inlet height
$H_v$	the pressure drop, which is given in terms of number of inlet velocity heads
$J_c$	diameter of dust outlet
$K$	constant, function of cyclone design and operating parameters
$k$	turbulent kinetic energy
$L_c$	height of cylindrical section
$L_c$	length of cylindrical body
$N_e$	number of effective revolutions in the outer vortex
$n$	vortex exponent
$n_1$	vortex component at 283K
$n_2$	vortex component operating temperature
$P$	total pressure in the cyclone
$P_s$	constant
$R$	radius of the cyclone body
$R_{ij}$	Reynolds stress ( $u'_i u'_j$ )
$r$	radial distance from center axis (m)
$S_c$	length of vortex finder from inlet width
$S^2$	squared resolved deformation rate
$T_1$	283K
$T_2$	operating temperature
$U$	mean velocity of flow
$U_x$	tangential gas velocity
$U_y$	radial gas velocity

$U_z$	axial gas velocity
$u$	three dimensional velocities
$u'$	instantaneous fluctuating velocity component
$u_p$	particle velocity
$V_i$	gas inlet velocity
$V_{ct}$	tangential gas velocity component (m/s)
$V_t$	terminal velocity
$Z_c$	height of conical section
$Z_c$	length of cone

## **LIST OF APPENDICES**

<b>Appendix</b>	<b>Description</b>	<b>page</b>
<b>APPENDIX I</b>	<b>Rosin-Rammler particle distribution</b>	<b>41</b>