

DESIGN OF AIR CYCLONES: Part II – SOFTWARE DEVELOPMENT

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Abstract

Standard design procedures for air cyclones have been employed to formulate a comprehensive design sequence for computer implementation. The procedure is implemented as a software suite, which essentially incorporates a Microsoft Access Database to store data and Microsoft Visual Basic 6.0 front-end modules for user interaction. The software design and implementation involves the following steps: establishing the model equations, designing the database to store data, designing the front-end modules and formulating the computational algorithm. The structure of the software developed is modular with scope to easily integrate modules for other unit operations.

Symbols used

D_c	Cyclone diameter, m
a	Inlet height, m
b	Inlet width, m
D_u	Gas overflow outlet diameter, m
S	Gas underflow outlet diameter, m
h	Cylindrical height of cyclone, m
Z_c	Conical height of cyclone, m
H	Total height of cyclone ($h+Z_c$), m
η	Collection efficiency, %
η_o	Overall collection efficiency
v_i	Inlet velocity, m/s
Q	Feed rate, m ³ /s
S_f	Separation Factor
d_{pc}	Critical particle diameter, microns

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Introduction

In general, cyclones are robust devices used for sizing, classification and screening of particulate materials in mixture with fluids (gases or liquids). In particular, an air cyclone is a commonly used piece of equipment that utilizes centrifugal and gravitational forces to separate particles in gaseous streams [2]. Because they are simple and have low operating costs, they are probably the most widely used dust collectors in the industry. Air cyclones have no moving parts and come in various sizes and shapes. They operate on the simple principle that particles enter the device with the flowing fluid and swirl round the cylindrical part of the device. The particles have too much momentum and cannot turn with the fluid. Therefore, the particles impact and fall (by gravitational action) down the cyclone walls, and are collected.

In recent times, computer-aided design (CAD) has made the designing of processes and equipment much easier. Powerful and comprehensive process simulators are available worldwide to accurately model any process from a single unit to a complete process plant. In less- developed countries like Nigeria, these simulation software are usually very expensive and unaffordable by entrepreneurs who may desire to use them. It has therefore become necessary and timely to develop locally such software by harnessing indigenous technical expertise from both the academia and the industry. This initiative has led to the development of software for the design, optimisation and performance evaluation of air cyclones [1].

Accurate design of air cyclones is a necessary pre-requisite for optimal performance of the equipment in any chemical engineering process. For this to be possible all parameters that affect the performance of the cyclone must be considered. Many models for the design, simulation and optimisation of air cyclone exist. Such models have been reviewed in the first part of this paper [3]. The main objective of this second part is to present a detailed description of the developed software that can be used for the design, simulation and performance evaluation of air cyclones.

Software Development

Design Parameters Specification

The model equations and cyclone configurations used in this work have been described elsewhere [1]. The calculations required in the design of an air cyclone depend on the input variables that are specified. The following parameters can be specified or calculated:

- a. Volumetric flow rate of feed.
- b. Cyclone diameter.
- c. Cut diameter.
- d. Cyclone efficiency.
- e. Pressure drop

Of the five variables listed above, it is required to specify only two or three parameters as inputs for a design problem (and the others are calculated). Thus, given the cyclone geometry and operating conditions (temperature, pressure and

densities of fluid and particulates), there are nine possible combinations of these design parameters for which a design

solution can be calculated. Table I is a matrix of the combination of the variables and Table II explains each combination.

Table I. A matrix of cyclone input variables.

	b	c	D	e	ae
A	1	2	3	4	-
B	-	5	6	-	7
C	-	-	-	8	-
D	-	-	-	-	9

*ae means that volumetric flow rate and pressure drop are specified

Table II. Combinations of Design Parameters.

Case	Design Parameters	Values to calculate from parameters
1	Q, D_c	Compute V_i from $Q/(ab)$
2	Q, d_{pc}	Compute D_c from d_{pc} , Compute V_i from $Q/(ab)$
3	Q, η	Compute d_{pc} from η , D_c from d_{pc} , V_i from $Q/(ab)$
4	$Q, \Delta P$	Compute V_i from ΔP , D_c from Q and V_i
5	D_c, d_{pc}	Compute Q from d_{pc} and D_c , V_i from $Q/(ab)$
6	D_c, η	Compute d_{pc} from η , Q from d_{pc} and D_c , V_i from $Q/(ab)$
7	$D_c, Q, \Delta P$	Compute V_i from Q & D_c , Use ΔP as design validation
8	$d_{pc}, \Delta P$	Compute V_i from ΔP , D_c from d_{pc} and V_i (Q)
9	$\eta, Q, \Delta P$	Compute d_{pc} from η , D_c from d_{pc} , V_i from $Q/(ab)$

The various combinations shown in Table II were implemented in the developed software.

Computational Algorithm

The computational algorithm around which the software is programmed is given below:

1. Select the Geometric Configuration for the Gas Cyclone Design required
2. Select Efficiency Model
3. Get the Cyclone Dimensional Ratios.
4. Specify Operating Temperature; Compute Fluid Density and Fluid Viscosity
5. Specify Operating Pressure.
6. Specify Inlet Feed Rate Q .
7. Select Particles Category and extract Particle Density
8. Specify Particle Distribution.
9. Specify Set Cut Size
10. Specify Number of Cyclones in parallel Or Number of Cyclones in series
11. Specify one of the design parameter combinations listed in Table II
12. Compute the following in the order given
 - a. Cyclone Natural Lengths
 - b. Diameter of Central Core at Vortex
 - c. Cyclone Volume At Natural Length
 - d. Cyclone Volume Below Exit Duct
 - e. Vortex Exponent

- f. Relaxation Time
- g. Cyclone Volume Constant
- h. Cyclone Configuration Factor
- i. Cyclone Grade Efficiency
- j. No of Inlet Velocity Heads
- k. Cyclone Surface Area
- l. Compute Inlet Velocity

For each cyclone in series, compute the following:

- Pressure Drop
- Friction Loss
- Saltation Velocity
- Velocity Ratio
- Critical Particle Diameter
- Critical Particle Diameter At 50 % Efficiency
- Ratio of set Cut Size and Critical Particle Size
- Ratio of set Cut Size and Critical Particle Size as 50 % Efficiency
- Separation Factor
- Collection Efficiency
- Compute Overall Collection Efficiency
- Compute Outlet Velocity
- Set Inlet Velocity to the Outlet Velocity

Repeat for the next cyclone

13. If Overall Collection Efficiency not satisfactory, iterate from step 10.
14. Check design through constraints.
15. If 13 not satisfied, iterate from step 11.

Software Implementation

The software was developed using Visual Basic 6.0. The program automatically generates the cyclone dimensions once enough design parameters have been entered. The user is not forced through a formal data input sequence since it coordinates input information in the background and computes required data when information is complete. The full description of the software is given elsewhere [1].

The various components of the main dialog box for the developed software are shown in Figures 1-6. As can be seen from the figures, the interface has several tabs through which inputs can be specified: General, Design Parameters, Geometry and Model, Operating Conditions and Dust Specifications.

The first interface the user sees on entering is the one with the Operating Conditions tab (Figure 1) on which you specify the operating temperature, operating pressure and the fluid type (usually air).

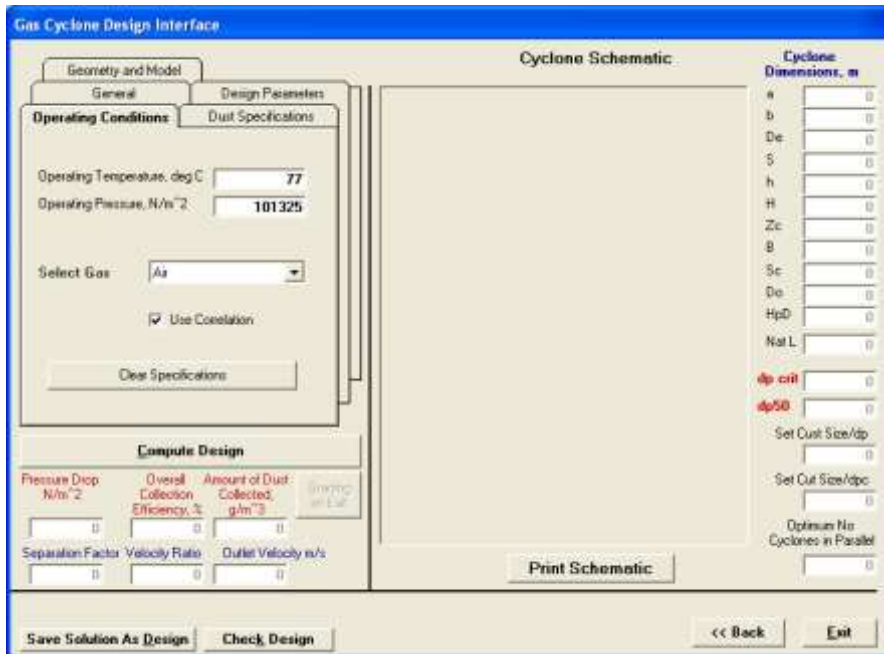


Fig.1: Main dialog box – Operating Conditions tab.

The Dust Specifications tab (fig. 2) is where the dust type in the gas/air stream is specified. These include the dust loading in the feed, maximum and minimum particle size and the particle size distribution. To input the particle size distribution in inlet feed, two approaches were included in the software. In the first approach, the distribution was assumed to be lognormal, and the user is expected to specify the mass median diameter and geometric standard deviation of the particles. In the second approach, the actual distribution data is available and is supplied as input.

The Geometry and Model tab is re-illustrated in fig. 3. A number of standard cyclone configurations and the efficiency models are included in the software; the user is expected to specify the particular

configuration and the model that should be used.

The design parameters are specified via the Design Parameters tab (fig. 4). This is where the desired combination of the design parameters (see Table I) is specified. On completion, the cyclone dimensions and size will be computed and its schematic diagram will be shown on the interface. The General tab (fig. 5) simply shows fluid density, fluid viscosity, and parameters specific to the cyclone configuration. The efficiency, the pressure drop of the cyclone and other process outputs such as critical particle sizes and velocity, are calculated and displayed when Compute Design button is clicked (fig. 6). Clicking Check Design button displays an interface (fig. 7), which shows the design

constraints, and on clicking the appropriate button (Click to Perform check on solution)

the program shows if the solution meets the various design criteria.

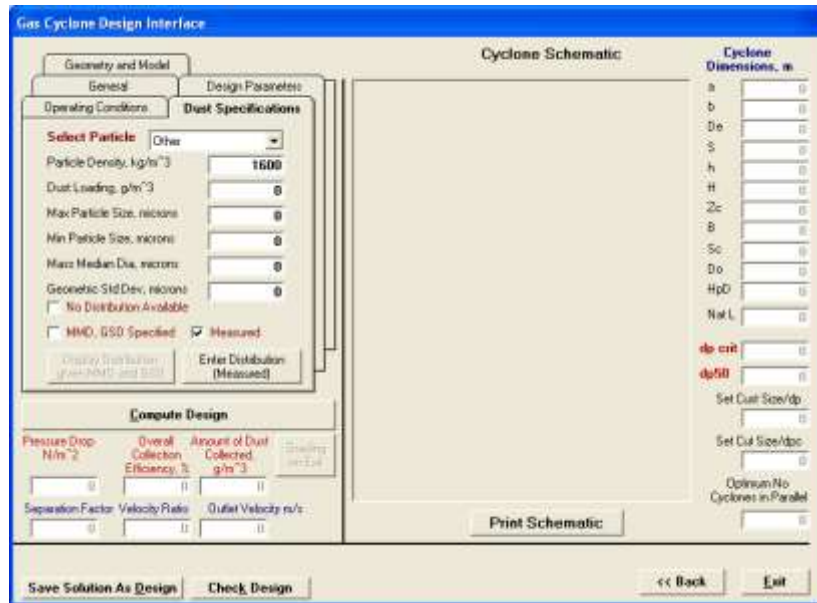


Fig. 2: Main dialog box – Dust Specifications tab.

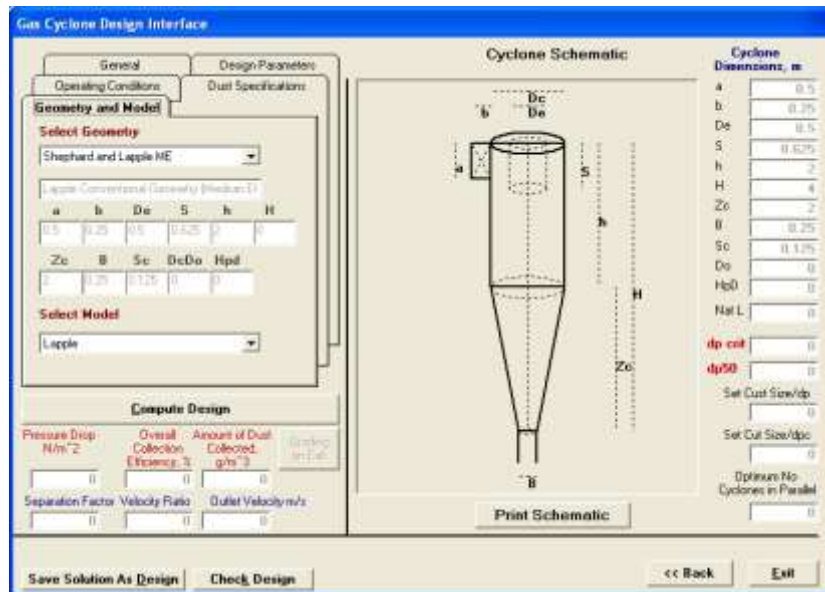


Fig. 3: Main dialog box – Operating Conditions tab.

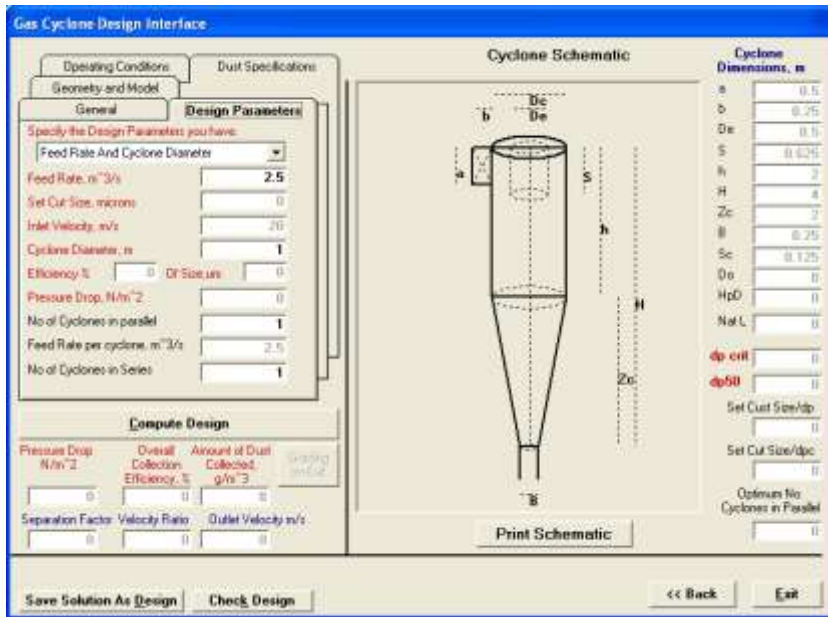


Fig. 4: Main dialog box – Design Parameters tab.

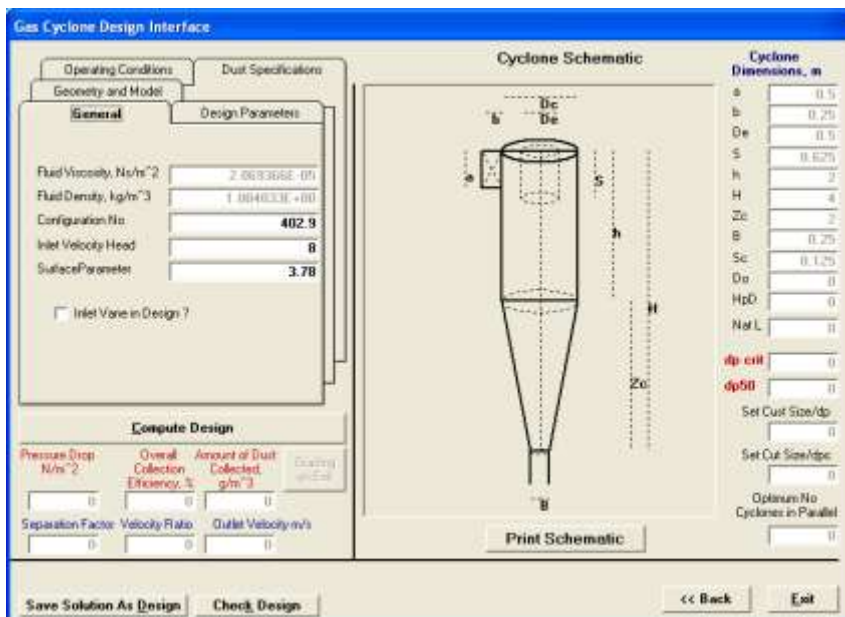


Fig. 5: Main dialog box – General tab.

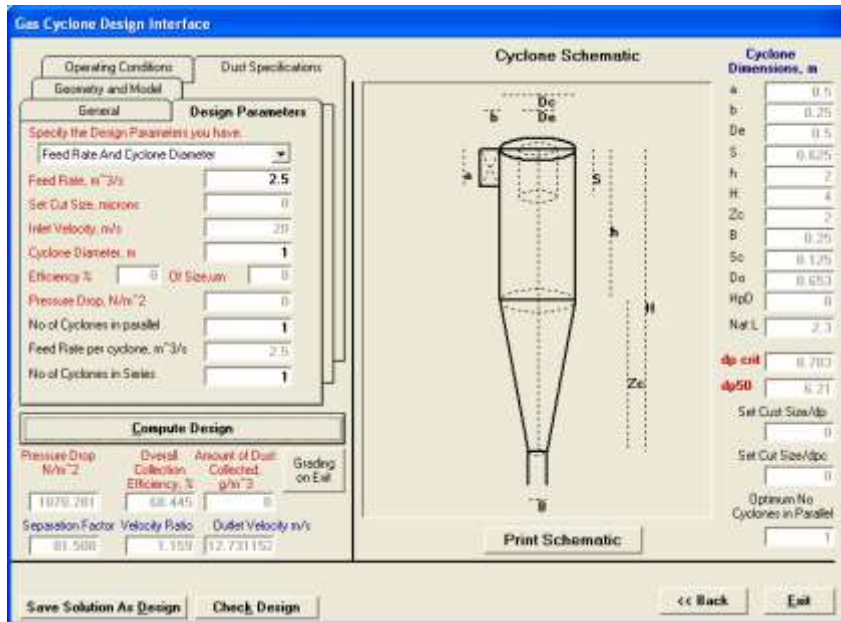


Fig. 6: Main dialog box – Design Parameters tab after calculation performed.

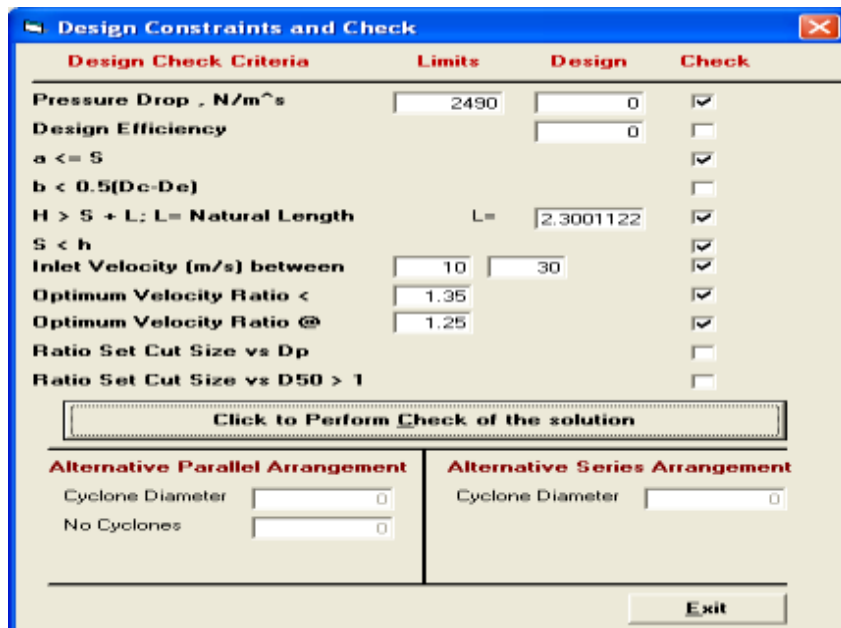


Fig. 7: Check Design Computations.

Validation of Software Results

To validate the software, 17 problems were used. The details of the outputs generated for these problems were given

in Kuye et. al. [1]. In this paper results from two of the problems are shown in Tables III and IV; Problem 1 is from Cooper and Alley [4], while problem 2 is from Sinnott [5].

Table III: Cyclone Configurations for sample problems

Dimension	Problem 1 Ratio to Dc	Problem 2 Ratio to Dc
A	0.50	0.50
B	0.25	0.19
De	0.50	0.50
S	0.63	0.50
H	2.0	1.5
Zc	2.0	2.5
H	4.0	4.0
B	0.25	0.38

Table IV - Verification of Cyclone Efficiency using Lapple Model

Variable	Problem 1		Problem 2	
	Literature	CAPED Software	Literature	CAPED Software
Gas	Air	Air	Nitrogen	Nitrogen
Configuration	Shephard & Lapple	Shephard & Lapple		From Example
Efficiency Model	Lapple	Lapple		Lapple
Pressure Drop Model	Not Specified	Stairmand	Stairmand	Stairmand
No Cyclones in parallel	1	1	4	4
Q*	2.5 m ³ /s	2.5 m ³ /s	1.11 m ³ /s	1.11 m ³ /s
D _c *	1 m	1 m	0.42 m	0.42 m
T	77 °C	77 °C	150 °C	150 °C
P	1.01325x10 ⁵ N/m ²	1.01325x10 ⁵ N/m ²	1.01325x10 ⁵ N/m ²	1.01325x10 ⁵ N/m ²
V _i	20 m/s	20 m/s	16.5 m/s	16.589 m/s
d _p critical		8.78 μm		4.779 μm
d _{pc} (cut size)	6.3 (μm)	6.21 μm		3.393 μm
ΔP		1070.281 N/m ²		541.267 N/m ²
ρ _p	1600 kg/m ³	1600 kg/m ³	2500 kg/m ³	2500 kg/m ³
ρ _f	1.01 kg/m ³	1.004 kg/m ³	0.81 kg/m ³	0.81 kg/m ³
μ _p	2.0833x10 ⁻⁵ N.s/m ²	2.06936x10 ⁻⁵ N.s/m ²	2.3 x 10 ⁻⁵ N.s/m ²	2.3x10 ⁻⁵ N.s/m ²
V _o		12.73 m/s		0.953
η _{overall}	67.60 %	68.45 %	88.70 %	88.42 %

The results agreed well on the following performance outputs; pressure drop, cut size and overall collections efficiency. The variances with the results for problem 1, for example, can be explained to be due to implementation of variation of density and viscosity of air with temperature in the software, while the literature data assumed constant values.

Conclusion

The software is modular in design, interactive and user-friendly and can be extended to handle dust-laden gases. Design information, cyclone configurations

and profiles are captured in the database with facility for updating as new information is gathered. Various tests-runs provide confidence that the outputs of the software can be used as specification data for fabrication of an intended cyclone.

Acknowledgement

The authors are grateful to the Raw Material Research and Development Council (RMRDC), Abuja, Nigeria for financing the Design Project that produced the results used in developing this paper.

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