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COMPUTER AIDED DESIGN OF HYDROCYCLONES

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Abstract: Extensive literature review on various hydrocyclone design methodologies have been carried out and a generic design procedure for hydrocyclones established from standard design procedures. This generic design procedure for hydrocyclones has been employed to formulate a comprehensive design sequence for computer implementation. The procedure is implemented as a software suite using Microsoft Visual Basic. The software design and implementation involves the following steps; establishing the model equations, designing the database to store data, designing the front-end and formulating the computational algorithm. The structure of the software developed is modular with scope to easily integrate modules for other unit operations. The validity and functional integrity and correctness of the software were also tested and results of design parameters were found to be in agreement with measured values.

Keywords: Hydrocyclone, Computer Aided Design

INTRODUCTION

A hydrocyclone is a device where solid particles or immiscible liquids are separated from liquid (which is usually water (hydro)). Separation is based on density difference between the liquid and the matter to be separated. Hydrocyclones utilize centrifugal force to accelerate the settling rate of particles and one of the most important devices in the minerals industry. They are widely used in closed-circuit grinding operations, clarification of slurry, classification of solids, and separation of two immiscible liquids. Hydrocyclones are versatile, simple and cheap.

The hydrocyclone is divided into two

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major parts, the cylindrical section and the conical section. The cyclone diameter is the dimension, which is referred to when specifying a cyclone size. The cylinder length is simply the length of the straight walls above the cone. Within the cylinder, we find the inlet orifice, the overflow orifice, and the vortex finder. The cone is the portion of the cyclone converging from the cylinder to the underflow orifice. The cone is primarily characterised in two ways; the cone length and the cone angle. Typical designs find optimum performance with cone lengths 4-5 times the cylinder diameter. As a gross generalisation, the longer the cone, the more efficient the hydro cyclone.

The cyclone diameter D_c influences greatly both the separation efficiency and the flow rate - pressure drop relationships. It is a primary design variable to which all other dimensions are usually related. With regard to the effect of the other dimensions of a hydrocyclone, a great deal has been written in the literature (Bradley, 1965, and Reitema, 1961). Hydrocyclones must be properly designed and fabricated to be able to operate efficiently.

Computer Aided Design (CAD) is a widely accepted tool for the design of processes and equipment. Powerful and comprehensive process simulators are available to accurately model any process from single equipment unit to complete process plant. These simulation software packages are usually expensive and not readily affordable in less developed economies like that of Nigeria. Hence this work is undertaken to produce a computer-aided program for the design of hydrocyclones.

DESIGN PROCEDURE

The different designs available in the literature were thoroughly examined and used to formulate the equations that were programmed in the software. These equations are presented elsewhere (Kuye et al, 2005). In this section the key parameters calculated by the software are listed and the computational algorithm is presented.

Cut Size d_{50} models

A total of 8 models for predicting cyclone cut point, d_{50}, were implemented in the software. These models are summarized in Table 1.

Table 1 Models for d_{50}

Model Description
Dahstrom (1954): Small Diameter, Dilute Slurries
Bradley 1960 Empirical Model - Preliminary Calculations
General Model: Scale Up At Low Feed Concentrations
Generalised Model With Effects of Underflow To Throughput Ratio
Plitt (1976); Large Diameter, High Feed Concentration
Mular & Jull (1978); Preliminary Design Purposes. Large Diameter, High Feed Concentration
Krebbs Engineers - Correction for Feed Concentration, Density and Pressure Drop
Massarani 1997: Correction for Feed Concentration and Underflow to Throughput ratio

Efficiency (Recovery) Curve

Three (3) efficiency curve models were implemented in the software to predict the overall efficiency of the cyclone. These are Yoshioka & Hotta (1955), Gerrard & Liddle (1976) and Lynch et. al. (1974)

Particle Distribution in feed

Establishing the overall efficiency of a cyclone requires knowledge of the distribution of the solids particle sizes in both the feed and the underflow, as well as knowledge of the maximum particle size. The program makes provision for the following 3 situations;

- Normal distribution of particles in feed,
- Even distribution of particles in feed and
- Experimental data of particle distribution in feed.

If normal distribution is assumed the user is required to supply the mean and standard deviation of the particles in the feed. The maximum particle size is assumed to be twice the mean. If even distribution of particles is assumed the user is required to supply the maximum particle size. With experimental data on distribution, the user is required to enter the data in tabulated form and the maximum particle size is extracted automatically.

Other parameters calculated are Imperfection, Overall Efficiency, Percentage (%) Solids by weight in feed, Percentage (%) Solids by volume in feed and Cone Angle.

COMPUTATIONAL ALGORITHM

1. Select Unit Operation: i.e. Select Cyclone>Hydrocyclone
2. Select Hydrocyclone Geometry
3. Select d_{50} model
4. Input solids density
5. Input liquid density
6. Input Feed pulp density OR Weight % Solids in Feed OR Volumetric % Solids in Feed
7. Input liquid viscosity
8. Input feed pulp viscosity
9. Input Maximum Particle Size, if available
10. Input Minimum Particle Size, if available
11. Select Particle Distribution Type
    a. Enter the mean and standard deviation, if Normal Distribution assumed
    b. Enter maximum particle diameter, if even distribution is assumed
    c. Enter particle distribution data, if measured data is available
12. Select Efficiency Model
13. Select the combination of the design parameters available from (see Table 2)
    a. Feed Rate, Q
    b. Cyclone Diameter, Dc
    c. Set Cut Size, d_{50}
    d. Pressure Drop, ΔP
14. Enter the design parameters based on selection made in 13. This computes the cyclone dimensions and the other design parameters not in the combination (see Table 2)

a. Click Compute Design
b. Compute %Solids by wt in feed
c. Compute %Solids by vol in feed
d. Compute Underflow to throughput ratio (water)
e. Compute Dilution Ratio of feed
f. Compute Water flow rate in feed
g. Compute Solids flow rate in feed
h. Generate Reduced Efficiency Curve
i. Compute Overall Efficiency
j. Compute Reduced Overall Efficiency
k. Compute Imperfection
l. Compute Underflow Density
m. Compute Overflow Density
n. Compute Overall Mass Balance
o. Compute Overall Water Balance
p. Compute Overall Solids Balance
q. Check Mass Balance
r. Display Reduced efficiency curve when prompted.

15. Display Outputs.
16. Print results to a file for future reference

Table2. Possible design parameters combinations

S/N	Design inputs	Design Output
1	Feed rate (Q) and pressure drop (ΔP)	Dc and d_{50}
2	Feed rate (Q) and cyclone diameter (Dc)	ΔP and d_{50}
3	Pressure drop (ΔP) and cyclone diameter (Dc)	d_{50} and Q
4	Cut size (d_{50}) and feed rate (Q)	Dc, ΔP and Ncyclones
5	Cut size (d_{50})and pressure drop (ΔP)	Dc and Q
6	Cut size (d_{50})and pressure drop (ΔP) and Feed Rate (Q)	Dc, Q and Ncyclones

Ncyclones = number of cyclones required for duty

COMPUTER IMPLEMENTATION

Using the Equations presented by Kuye et al (2005), a software for designing hydrocyclone was developed. The platform and tools used were:

Operating System:	Windows 98/2000/XP
Database Platform:	MicrosoftAccess 2000/XP
Program Code:	Microsoft Visual Basic 6.0

Essentially the overall procedure to use the software for design is as follows:

- Select the geometric configuration
- Specify the efficiency model
- Specify design parameters
- Calculate design variables
- Check the design outputs meet constraints
- Save the solution in a file for future reference

The computer program generates the cyclone dimensions from a selected geometric configuration and an acceptable combination of at least 2 or 3 parameters from the 4 design parameters (see Table 2). Efficiency model, cut point model, solids distribution in feed, solids and feed liquid densities, feed and liquid viscosities are all inputs required by the program to compute the various outputs such as overall cyclone efficiency, mass balances and cyclone dimensions. The program automatically generates the cyclone dimensions once enough parameters have been entered to compute the cyclone diameter, Dc.

Another significant feature of the program is that it accepts inputs in any order. The user is not forced through a particular sequence, but must completely specify all the required inputs. The program incorporates a management utility that coordinates the input information in the background and only computes required data when information is complete.

Facilities exist to capture, in the database, new geometric configurations and efficiency models as well as update existing configurations. A list of densities of known solid substances and fluid properties are also available in the database.

The user usually will not need to explicitly specify connection to the database after installation as this is done automatically when you launch the program; except where the database has been moved to another location.

The major dialog boxes of the software are shown in Figs 1 - 9.

RESULTS AND DISCUSSION

To validate the software, 5 problems were used to test the software. The details of the outputs generated for these problems are given by Kuye etal (2005). The problems are summarized in Table 3 and the solutions obtained are shown in Tables 4 to 6.

Table 4 shows that the results agree very well with literature as regards the outputs, that is, cut size and cyclone diameter, thus validating the functional integrity and correctness of the software.

Table 5 shows that the results for Krebs and Massarani Scale-up Model for all concentrations agree with the base case while Bradley, Dahlstrom, Plitt and Mullar & Jull models are not in agreement. These confirm that Krebbs and Massrani models are valid for the low feed concentration (1% vol) used while the other models are not. The values of Q_{max} for Dahlstrom and Plitt also appear rather too low which again makes the two models odd for the problem. It may be pointed out that Plitt model is based on empirical results for large diameter cyclones and high feed concentrations. Although the Dahlstrom model is for small diameter cyclones and dilute slurries but the exact ranges are not specified.

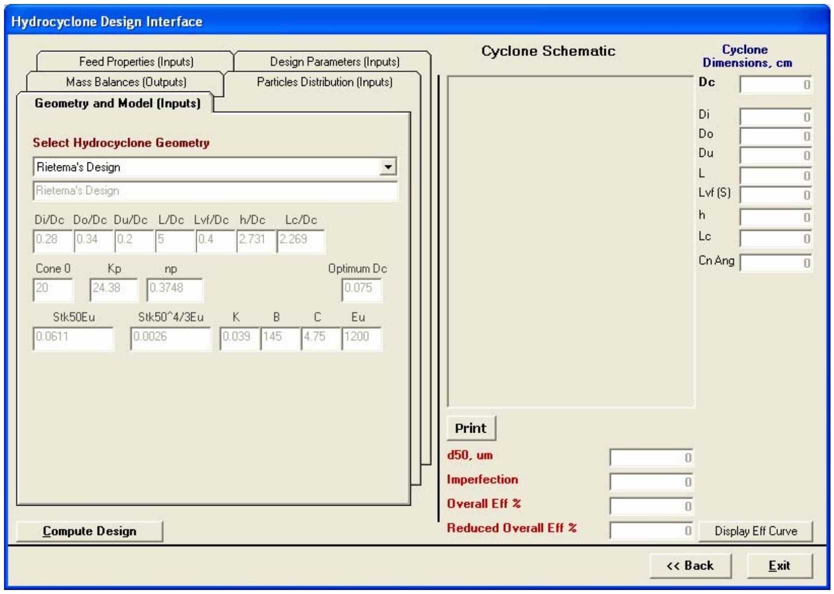

Fig.1: Hydrocyclone Design

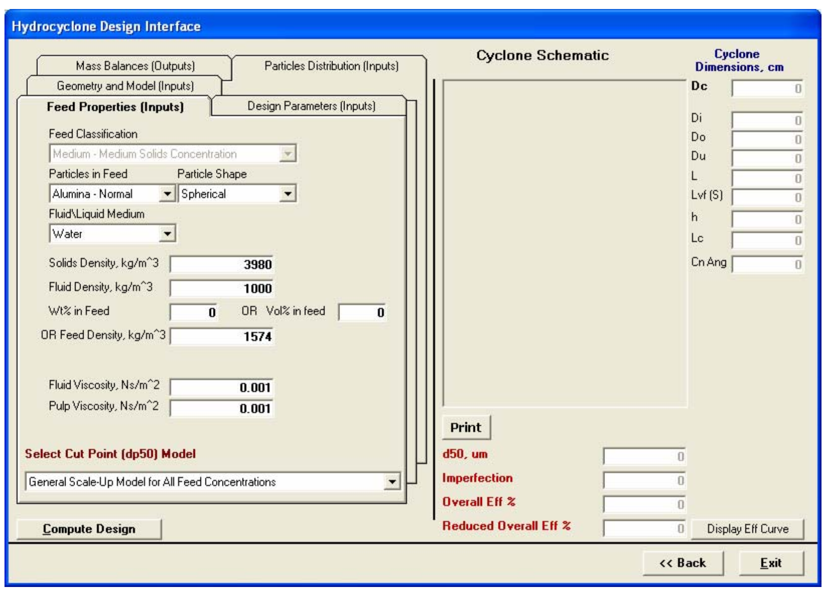

Fig. 2: Feed Properties Input

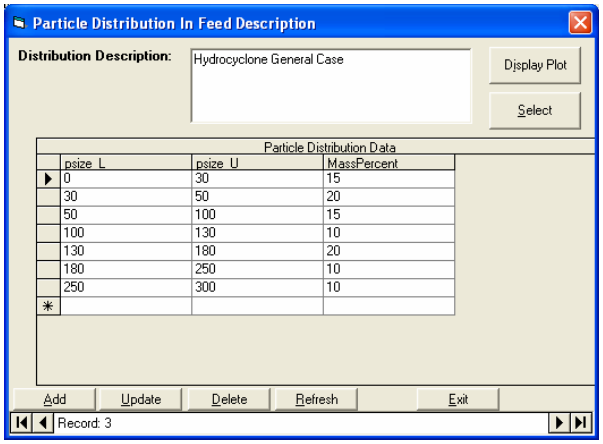

Fig. 4: Particle Distribution

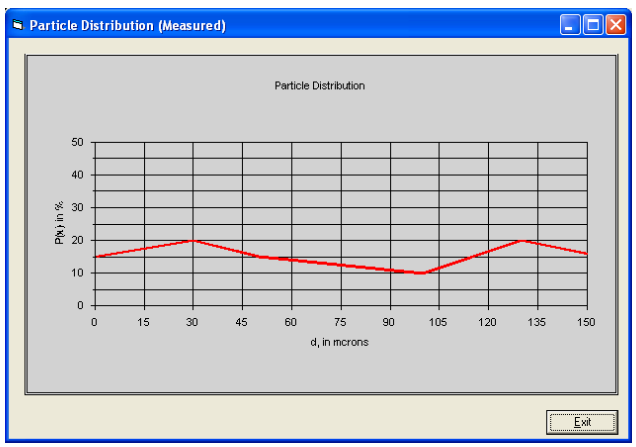

Fig. 5: Particle Distribution plot

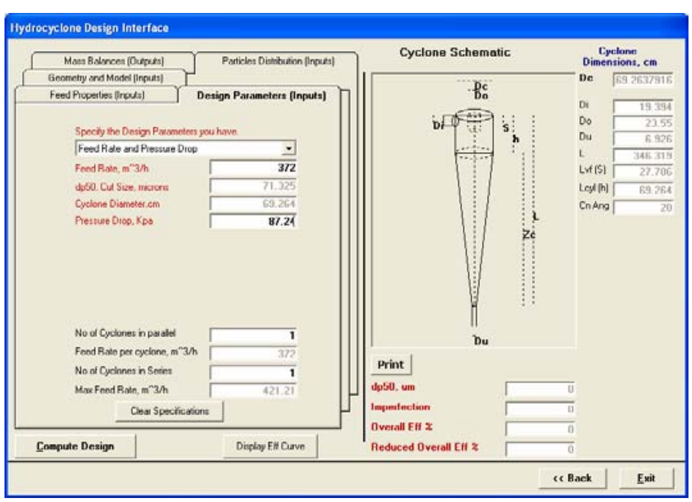

Fig.6: Design Parameter Tab

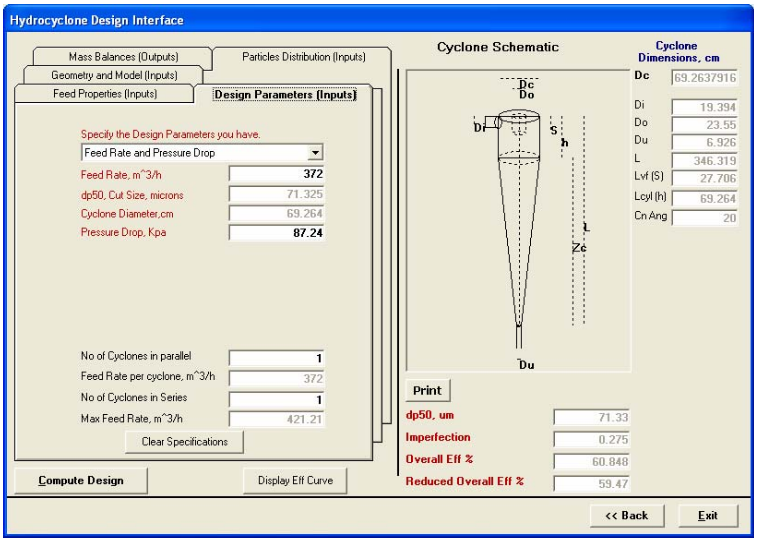

Fig. 7:Typical Design Output

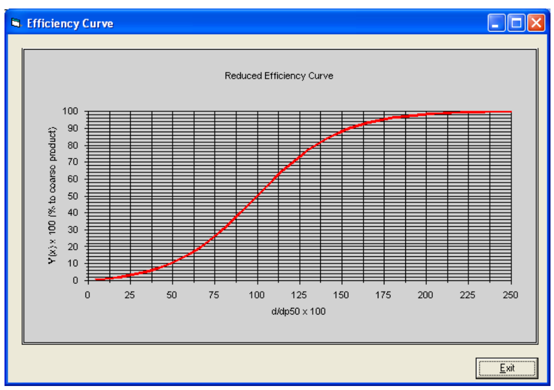

Fig. 8: Efficiency plot interface

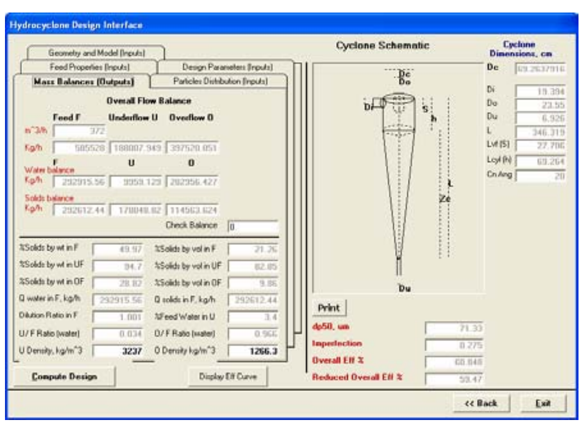

Fig. 9: Mass flow Balance Interface

In the literature problem 5 was solved with the Mullar and Jull model. Problem 5 was solved using this model and other d_{50} models. Table 6 shows that the software output for the Mullar and Jull model agrees very well with the literature solution. The Plitt and Bradley models also agree fairly well with the literature values although the configuration would be more expensive (larger diameter in the case of Bradley and more cyclones in the case of Plitt). As expected the Dahlstrom and Scale Up for low concentrations models gave results that are not feasible since these models are for dilute slurries. The Krebs model gave a slightly higher diameter than the literature value.

Table 3. Data on problems for software validation.

Input parameters	Problem No 1	2	3	4	5
Q (m^3/h)	18	18	30	Same as	102.4
ΔP (kPa)	100	100	304.24	problem 3	82.74
ρ_s (kg/m^3)	3000	3000	2600	but with	3700
ρ (kg/m^3)	1000	1000	1000	different	1000
V (%)	1	1	1	efficiency	21.67
μ_l (Ns/m^2)	0.001	0.001	0.001	models	0.001
d_{50} (μm)			8		74
$d_{50, mean}$ (μm)	15	15	15		110
s (standard deviation, μm)	3	3	3		3
Hydrocyclone type	Rietema opt	Bradley			Rietema opt

Table 4: Solution to Problems 1 to 3

	Problem 1		Problem 2		Problem 3	
	Calculated	Literature	Calculated	Literature	Calculated	Literature
D_c; in cm	12.971	12.970	22.330	22.330	8.838	9.100
D_{50}; in μm	11.617	11.620	11.939	11.930		
Reduced Efficiency %, E'_T	72.194		71.556		96.283	
No of cyclones	1	1	1	1	2	2
Qmax	15.816		46.861		14.204	

Table 5: Solution to Problem 4

D_{50} Model	D_c; in cm	No of Cyclones	Reduced Efficiency %, E'_T	Qmax, m^3/h
Reitema (Base case)	8.838	2	96.283	14.204
Bradley 1960	15.924	1	96.283	25.408
Dahlstrom	3.094	19	96.399	1.572
Scale Up For All Concentrations	7.567	3	96.271	10.671
Plitt	2.444	42	96.049	0.722
Mullar & Jull	12.445	1	96.303	25.436
Krebs	8.394	3	96.283	13.470

Table 6: Solution to Problem 5

D_{50} Model	D_c; in cm	No Cyclones	Reduced Efficiency %, E'_T	Qmax, m^3/h
Mullar & Jull (Literature)	66	3	-	372.5
Software				
Mullar & Jull	66.223	3	86.428	374.981
Plitt	64.446	7	85.911	153.437
Bradley 1960	116.223	3	86.119	374.565
Dahlstrom	3880.678	1	87.442	1287658.95
Scale Up For Low Concs	1320.926	1	87.192	83086.57
Scale Up For All Concs	340.716	1	86.91	6845.96
Krebs	71.611	1	87.192	4504.34

CONCLUSIONS

The software developed has been tested with some problems taken from the literature. Generally there was good agreement between the software output and the corresponding literature values. It was also shown that the software output is dependent on the d_{50} models that were used. The choice of the appropriate d_{50} model is dependent on the concentration of the slurry. However, based on the data used for validation, it is not possible at this stage to define explicitly what constitute a low concentration or otherwise. The software can be used to predict key hydrocyclone parameters such as cyclone diameter and efficiency.

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