DESIGN OF INDUSTRIAL BAGHOUSE : COMPUTER SIMULATION TECHNIQUE

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Abstract

The most established model which is notably used in the design of baghouse was developed by Martin Crawford and named as Crawford Mathematical Model. As the model involved a lot of trial and error calculation, attempt was made in this paper to simulate the model on the microcomputer. A program was written in FORTRAN 77 and it was succesfully simulated in the design of baghouse to capture the fly-ash from the typical Malaysia's Palm Oil Mill Boiler. Based on the simulation output three profiles, that include pressure drop, flowrate and weight of dust cake were plotted against the operating time. The graphs generated showed that the length of cleaning cycle is 28.5 minutes if the length of the cleaning process specified is 5 minutes and the maximum pressure drop desired is 4" H_2O. The simulation also deduced that one baghouse with three compartments of 140.6 m^2 each is required in the design of baghouse to capture fly-ash with a loading concentration of 0.0076 kg/m^3 and 3 m^3/s air flow rate.

Introduction

Originating from a variety of sources, but primarily from industrial processes, air particulates exert a significant influence on atmospheric phenomena, plants, property, and human and animal health.

Most of the control devices and physical principles involved in particulate control are uniquely suited to specific applications, and the proper choice of method depends upon careful consideration of several factors such as particle size distribution and concentration, and gas flow rate.

Currently, there are five major groups of control device being practised world wide. These include gravitational settling chamber, centrifugal collector, wet collector, electostatic precipitator and baghouse.

The recent development in air particulate control device found that there has been a fast rising demand in industrial application of baghouse due to its potential of removing fine particles at efficiencies greater than 99+%. Besides, the operating flexibilities posseses by the baghouse which include the wide range of volumetric feed flow rate and type of dust are also the major influences in enhancing the application of such device.

There are three common types of baghouses, classified by the method used for cleanning the dust from the bags, are reverse-air, shaker, and pulse jet baghouses. Both reverse-air and shaker baghouses have been widely use for many years.

Even though the inreasing demand in industrial application of baghouse will be a boost to the baghouses manufacturer, the manufacturer is also facing with a delima of meeting the industrial date-line due to the existing time consumed baghouse design technique. Therefore the needs of the computer application in baghouse design should be given due consideration.

Scope

In this paper, emphasis will be given more on the Crawford Mathematical Model. Effort was made to derive all the equations involved and program was written on FORTRAN 77 based on the equation derived. However program and the flow diagram will not be supplemented in this paper in order to protect its originality. Instead, algorithm involved and the simulation output will be attached as a proof of its validity. Attempt was not made in this paper to revise the basic theory of filtration and complete procedure of designing a baghouse. Finally, it is also worth to note that the written program is only simulating the Crawford Mathematical Model and input required in the program should be calculated earlier.

Theory

Industrial baghouse are constructed with several compartments. The number of compartments chosen during the design depends on the key design parameter which include the total flow to be filtered, the available (desired) maximum pressure drop, the filtration time desired between two cleanings of the same compartment, and the time required to clean one compartment. Selection of the best key design parameters is a matter of experience and common sense. This is due to the fact that all the parameters are related. For instance, the total air flow rate and the maximum allowable pressure drop are interdependent, and are related to the number of compartments, the filtration time, and the cleaning time. Crawford has developed a detailed mathematical model to determine the filtration time and a cleaning cycle when given a maximum pressure drop constraint. As the calculation in Crawford Mathematical Model involves a lot of trial and error which are time consumed, application of computer will be an asset if considered. Detailed algorithm involved in the design of the baghouse is outlined below and assumption was made that the calculation involved in the determination of the design parameter are well understood. In addition, no attempt was made to elaborate each step involved.

Baghouse design algorithm.

1. Specify the average pressure drop, maximum pressure drop, total flow rate, filter resistence coefficient and resistence factor.

2. Calculate the net filtration area required based on assumed filtering velocity.

3. Determine number of compartment and bag required, number of operating compartment, and net filtration area per compartment required.

4. Specify type of baghouse and cleaning time.

5. Specify the cleaning efficiency and calculate the quantity of unremoved dust during the cleaning process.

6. Determine the filtration time and cleaning cycle at specified pressure drop from the Crawford Mathematical Model simulation program.

7. Calculate the average pressure drop.

8. (i) If the calculated average pressure drop greater than assumed average pressure drop then reduce the filtring velocity and repeat all the following steps.
   (ii) If the calculated average pressure drop lesser than assumed average pressure drop then increase the filtring velocity and repeat all the following steps.

(iii) If the calculated average pressure drop more or less same than assumed average pressure drop then stop iteration because design has converged.

Crawford Mathematical Model

In this section, Crawford equations are derived to determine the cleaning interval for a multi-compartment shake and air reverse baghouses. These computations are mainly for design purpose; in practice the baghouse will be cleaned according to a set sequence whenever the presure drop across the filter reaches a certain preset value.

Derivation of Crawford's equations

Consider a baghouse with a total flow rate Q distributed among n_c identical compartments. During the cleaning part of the cycle, n_c-1 compartments are active. The pressure drop ΔP, and its maximum value is ΔPm; this value is to be reached just as the newly cleaned compartment is activated. The weight of dust calculated on each filter is given by Cmai, where subscript i represents the ith. compartment. The flow rate through ith. compartment is Qi; and the filter area in each compartment is Afi, which is the same for all compartments. The analysis begin at the time when compartment 1 has just been clean and is reactivated. Let t_1 be the length of the cleaning cycle, that is, the time period between the start of one cleaning process and the start of the next cleaning process. Also, let Δt_c be length of the cleaning process.

From the basic theory of filtration, the equation may be written for each compartment as

$$\Delta P = (K_1 + K_2 C_{ma_i}) \frac{Q_i}{A_{fi}} \quad (1)$$

$$C_{ma_i} = \frac{Q_i C_{mi} t}{A_{fi}} \quad (2)$$

The total flow rate is equal to the sum of the flow rates through each compartment can be expressed by the following equations:

$$Q = \sum_{i=1}^{n_c} Q_i \qquad 0 < t < t_1 - \Delta t_c \quad (3)$$

$$Q = \sum_{i=1}^{n_c - 1} Q_i \qquad t_1 - \Delta t_c < t < t_1 \quad (4)$$

The weight of dust cake on the filters of the ith comaprtment is given by the integral of Eq. (2) :

$$C_{ma_i} = C_{ma_{i0}} + \int_0^t \frac{Q_i C_{mr}}{A_{fi}}\, dt \qquad (5)$$

Taking the derivative of Eq. (5) and using Eq. (1)

$$\frac{dC_{ma_i}}{dt} = \frac{C_{mr}}{A_{fi}} Q_i = \frac{C_{mr}\,\Delta P}{K_1 + K_2 C_{ma_i}} \qquad (6)$$

Eq. (6) may be integrated and rewritten as

$$K_1(C_{ma_i} - C_{ma_{i0}}) + \frac{K_2}{2}(C_{ma_i}{}^2 - C_{ma_{i0}}{}^2) = C_{mr}\int_0^t \Delta P\, dt \qquad (7)$$

Eq. (7) can be solved for Cmai; the positive sign is used in the quadratic equation, and in addition, the quantity Ø is defined as

$$\phi = \frac{2K_2 C_{mr}}{K_1{}^2}\int_0^t \Delta P\, dt \qquad (8)$$

The resulting equations for Cmai is

$$C_{ma_i} = \frac{K_1}{K_2}\left[-1 + \left[\left(1 + \frac{K_2}{K_1} C_{ma_{i0}}\right)^2 + \phi\right]^{1/2}\right] \qquad (9)$$

Eq. (9) may be written as

$$(K_1 + K_2 C_{ma_i})^2 = K_1{}^2\left[\left(1 + \frac{K_2}{K_1} C_{ma_{i0}}\right)^2 + \phi\right] \qquad (10)$$

If we define $Ø_1$ as the value of Ø by Eq. (8) when t is equal to t_1, the time at the completion of the cleaning cycle, then this equation becomes

$$(K_1 + K_2 C_{ma_{i1}})^2 = K_1{}^2\left[\left(1 + \frac{K_2}{K_1} C_{ma_{i0}}\right)^2 + \phi_1\right] \qquad (11)$$

At the start of the new cleaning cycle, the state of cleanliness of the compartments has shifted cyclicly by one position, so that compartment 1 occupies the position of comprtment 2 at the beginning of the previous cycle, and so forth, as expressed by the following relations when t = t_1 :

$$C_{ma_{i1}} = C_{ma_{i+1,0}} \qquad i = 1, 2, \ldots, n_c - 1 \qquad (12)$$
$$C_{ma,n_c1} = C_{ma_{1,0}} = 0$$

in which we have assumed that compartment 1 starts out with no dust cake on the filter element in the ith compartment at the end of the cleaning cycle. Combining Eqs. 11 and 12 gives

$$(K_1 + K_2 C_{ma_{i+1},o})^2 = (K_1 + K_2 C_{ma_i,o})^2 + K_1^2 \phi_1 \tag{13}$$

which may be expanded as follows:

$$(K_1 + K_2 C_{ma_1,o})^2 = K_1^2 + K_1^2 \phi_1$$
$$(K_1 + K_2 C_{ma_2,o})^2 = (K_1 + K_2 C_{ma_1,o})^2 + K_1^2 \phi_1 = K_1^2 + 2K_1^2 \phi_1$$

....

$$(K_1 + K_2 C_{ma_{n_c},0})^2 = K_1^2 + (n_c - 1) K_1^2 \phi_1 \quad .$$

Then we see that for ith. compartment

$$K_1 + K_2 C_{ma_i,o} = K_1 \sqrt{1 + (i-1)\phi_1}$$

Solving for Cmaio,

$$C_{ma_i,o} = -\frac{K_1}{K_2} + \frac{K_1}{K_2}\sqrt{1 + (i-1)\phi_1} \tag{14}$$

Substituting Eq. (14) into Eq. (15) gives for Cmai

$$C_{ma_i} = \frac{K_1}{K_2}\left[\sqrt{1 + \phi + (i-1)\phi_1} - 1\right] \tag{15}$$

We substitute Eq. (15) into Eq. (1), giving

$$Q_i = \frac{A_{fi}\,\Delta P}{K_1\sqrt{1 + \phi + (i-1)\phi_1}} \tag{16}$$

Then substituting Eq. (16) into Eqs. (3) and (4) gives

$$Q = \sum_{i=1}^{n_c} \frac{A_{fi}\,\Delta P}{K_1\sqrt{1 + \phi + (i-1)\phi_1}} \qquad 0 < t < t_1 - \Delta t_c$$
$$Q = \sum_{i=1}^{n_c - 1} \frac{A_{fi}\,\Delta P}{K_1\sqrt{1 + \phi + (i-1)\phi_1}} \qquad t_1 - \Delta t_c < t < t_1 \tag{17}$$

Evaluating the second of Eqs. (17) when $t = t_1$, $\phi = \phi_1$, and $\Delta P = \Delta P_m$, we have

$$\frac{Q K_1}{A_{fi}\,\Delta P_m} = \sum_{i=1}^{n_c - 1} \frac{1}{\sqrt{1 + i\phi_1}} \tag{18}$$

Eq. (8) may be solved for ΔP by differentiation, giving

$$\Delta P = \frac{K_1^2}{2K_2 C_{mv}} \frac{d\phi}{dt}$$

Eq. (17) may be integrated, giving

$$Q_t = \frac{A_{fi}}{K_1} \sum_{i=1}^{n_c} \int_0^t \frac{\Delta P\, dt}{\sqrt{1 + \phi + (i-1)\phi_1}}$$

$$Q(t - t_1 + \Delta t_c) = \frac{A_{fi}}{K_1} \sum_{i=1}^{n_c - 1} \int_{t_1 - \Delta t_c}^{t_1} \frac{\Delta P\, dt}{\sqrt{1 + \phi + (i-1)\phi_1}}$$

When Eq. (20) is substituted into these equations, the result is

$$t = \frac{A_{fi} K_1}{2K_2 C_{mr} Q} \sum_{i=1}^{n_c} \int_0^{\phi} \frac{d\phi}{\sqrt{1 + \phi + (i-1)\phi_1}} \qquad 0 < \phi < \phi_1' \tag{21}$$

$$t = t_1 - \Delta t_c + \frac{A_{fi} K_1}{2K_2 C_{mr} Q} \sum_{i=1}^{n_c - 1} \int_{\phi_1'}^{\phi} \frac{d\phi}{\sqrt{1 + \phi + (i-1)\phi_1}} \qquad \phi_1' < \phi < \phi_1 \tag{22}$$

When Eqs. (21) and (22) have been integrated, the result is

$$t = \frac{A_{fi} K_1}{K_2 C_{mr} Q} \sum_{i=1}^{n_c} [\sqrt{1 + \phi + (i-1)\phi_1} - \sqrt{1 + (i-1)\phi_1}] \qquad 0 < \phi < \phi_1' \tag{23}$$

$$t = t_1 - \Delta t_c + \frac{A_{fi} K_1}{K_2 C_{mr} Q} \sum_{i=1}^{n_c - 1} [\sqrt{1 + \phi + (i-1)\phi_1} - \sqrt{1 + \phi_1' + (i-1)\phi_1}] \qquad \phi_1' < \phi < \phi_1 \tag{24}$$

In Eqs. (22) to (24) ϕ_1' is given by

$$\phi_1' = \frac{2K_2 C_{mr}}{K_1^2} \int_0^{t_1 - \Delta t_c} \Delta P\, dt \tag{25}$$

When Eq. (23) is evaluated at $t_1 - \Delta t_c$, for which $\phi = \phi_1$, the final equation is

$$t_1 = \frac{A_{fi} K_1}{K_2 C_{mr} Q} [\sqrt{1 + \phi_1' + (n_c - 1)\phi_1} - 1] \tag{26}$$

The quantity ϕ_1' must still be determined. If Eq. (24) is evaluated when $t = t_1$ and $\phi = \phi_1$, the result is

$$\frac{K_2 C_{mr} Q\, \Delta t_c}{A_{fi} K_1} = \sum_{i=1}^{n_c - 1} \{(1 + i\phi_1)^{1/2} - [1 + i\phi_1 - (\phi_1 - \phi_1')]^{1/2}\}$$

The second radical in the preceding equation may be expanded binomial theorem and higher terms neglected, giving

$$\frac{K_2 C_{mr} Q\, \Delta t_c}{A_{fi} K_1} \approx \frac{1}{2} (\phi_1 - \phi_1') \sum_{i=1}^{n_c - 1} (1 + i\phi_1)^{-1/2}$$

Combining this equation with (18) gives

$$\phi_1' \approx \phi_1 - \frac{2K_2 C_{mc} \Delta P_m \Delta t_c}{K_1^{\,2}} \qquad (27)$$

When Eqs. (23) and (24) are substituted into Eq. (20), the following equations for pressure drop are obtained :

$$\Delta P = \frac{K_1 Q/A_{fi}}{\sum_{i=1}^{n_c} [1 + \phi + (i-1)\phi_1]^{-1/2}} \qquad 0 < \phi < \phi_1'$$

$$\Delta P = \frac{K_1 Q/A_{fi}}{\sum_{i=1}^{n_c-1} [1 + \phi + (i-1)\phi_1]^{-1/2}} \qquad \phi_1' < \phi < \phi_1 \qquad (28)$$

Crawford Mathematical Model Simulation Program Algorithm

1. Program read data required; n_c, Q, Cmv, ΔPm, Δt_c, Afi
2. ϕ_1 will be evaluated according to Eq. (18). Program will solve the equation iteratively.
3. Solved ϕ_1 will be printed.
4. ϕ_1' will be computed based on Eq. (27).
5. ϕ_1' will be printed.
6. Program will calculate the length of cleaning cycle, t_1 for the baghouse from Eq. (26).
7. t_1 will be printed.
8. Evaluation of the initial weight of dust cake, Cmao for each compartment according to Eq. (14).
9. Cmao for each compartment will be printed.
10. Program read data required; increment value (D) of ϕ for condition $0 < \phi < \phi_1'$ and increment value (D_1) of 0 for condition $\phi_1' < \phi < \phi_1$.
11. Computer will evaluate t, ΔP, Cma, and Q from the Eqs. (23), (28), (15), and (16) consecutively for each compartment at $\phi = 0$.
12. t, ΔP, Cma, and Q will be printed.
13. Computer will increase ϕ by increment of D and step 11 and step 12 will be repeated for all $\phi < \phi_1'$.

14. If $\phi > \phi_1'$, computer will evaluate $t_1, \Delta P$, Cma, and Q from Eqs. (24), (28), (15), and (16) consecutively for each compartment at $0 = 0_1'$.

15. $t, \Delta P$, Cma, and Q will be printed.

16. Computer will increase ϕ by increment of D_1 and step 14 and step 15 will be repeated for all $\phi_1' < \phi < \phi_1$.

17. If $\phi > \phi_1$, program stop.

Result

Based on data of fly-ash from Palm Oil Mill Boiler furnished by PORIM, design of baghouse was done according to the baghouse design algorithm outlined earlier. Converged results of the design are listed below :-

$Q = 300\ m^3/min.$ (PORIM Spec.)
$Cmv = 0.0076\ kg/m^3$ (PORIM Spec.)
$n_c = 3$ compartments
$Afi = 140.6\ m^2$
$\Delta Pm = 4$ in. H_2O
$\Delta t_c = 300$ seconds
$t_1 = 1711.57$ seconds

The output file (FILE NAME : BEG ANS) of the Crawford Mathematical Model simulation program is attached in this paper. Based on the simulation output, three graph were generated :

i. Fig. 1 : Pressure drop versus operating time
ii. Fig. 2 : Flow rate versus operating time for each compartment
iii. Fig. 3 : Weight of dust cake versus operating time for each filter

Discussion

Fig. 1 potrays the time variation of pressure drop in an operating baghouse design during a time. Note that when one compartment is taken off-line for cleaning, all the gas must then flow through the remaining compartments. Consequently, the total pressure drop increases suddenly. Just as the pressure drop reaches its maximum allowable value, the cleaned compartment is returned to service, and the pressure drop decrease suddenly.

Fig. 2 shows the flow rates through the different compartments during one cleaning cycle. The flowrate drops through the newly cleaned compartment while increasing through the others. When the third compartment is removed for cleaning, the flow rate increases abruptly through the others. In addition, Fig. 5b also potrays that at any given time, the flow rate through each compartment will differ from the others because each compartment will have a different amount of dust accumulated in it at that time in the cycle. The flow rate through the cleanest compartment will be the greatest, and that through the dirtiest compartment will be the smallest. Furthermore, the relative flow distribution through the compartments changes during the cycle as newly cleaned compartments come on-line.

Fig. 3 indicates how the weight of the dust cake increases during successive cleaning cycles for the different compartments. When the third compartment is removed for cleaning, the weight of the dust cake increases linearly in the other two compartments. In reality, the the weight of the dust cake is not zero in newly cleaned compartment because cleaning efficiency unlikely to be 100%.

Conclusion

The profiles generated from the simulation output of the Crawford Mathematical Model program which have the similarities with the hypotetical profiles proved that the developed program is valid. As a whole, the development of the program is not only to the extent of reducing the time consumed in solving the Crawford Mathematical Model but its also manage to shorten the hours involved in the design of the baghouse.

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Biography

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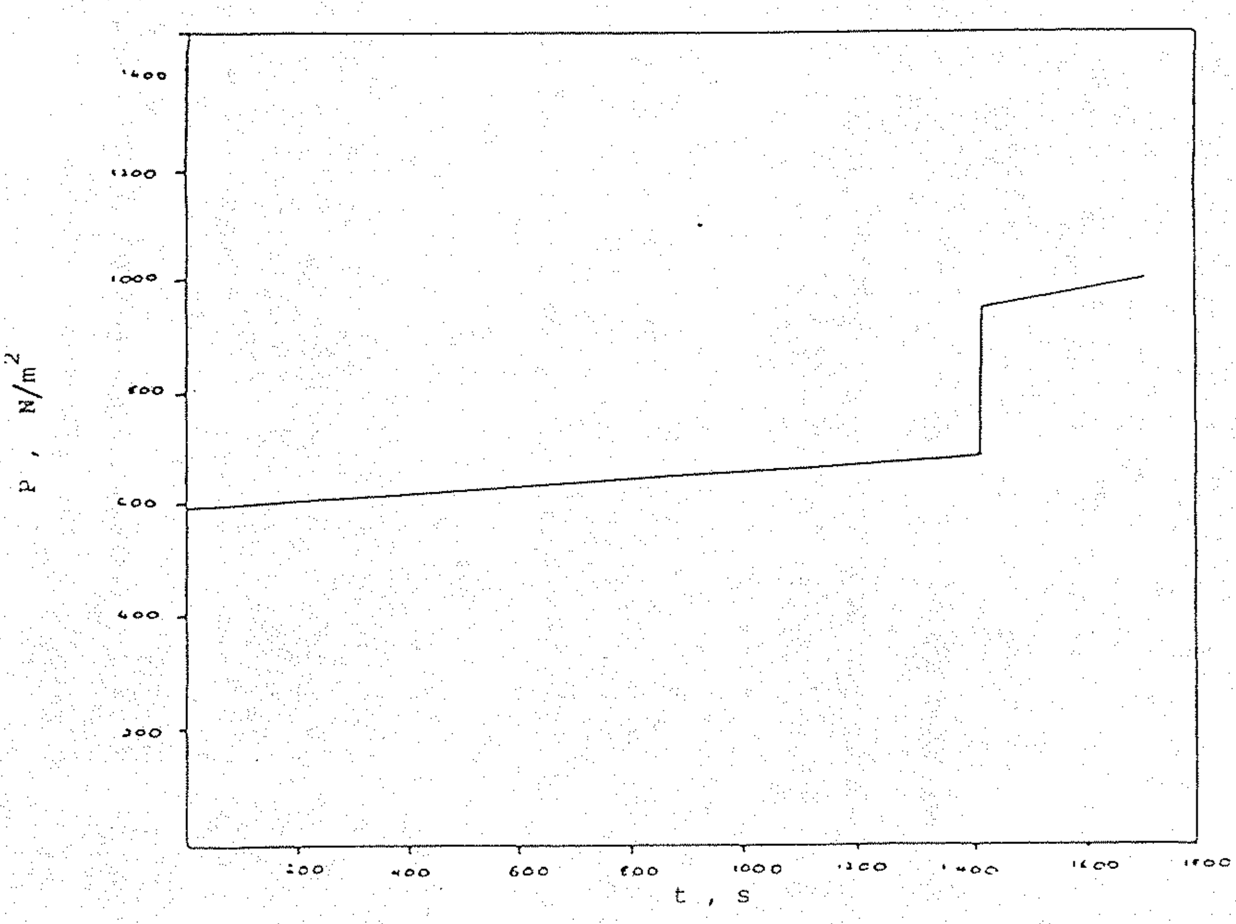

Fig. 1 : Pressure drop variation against time

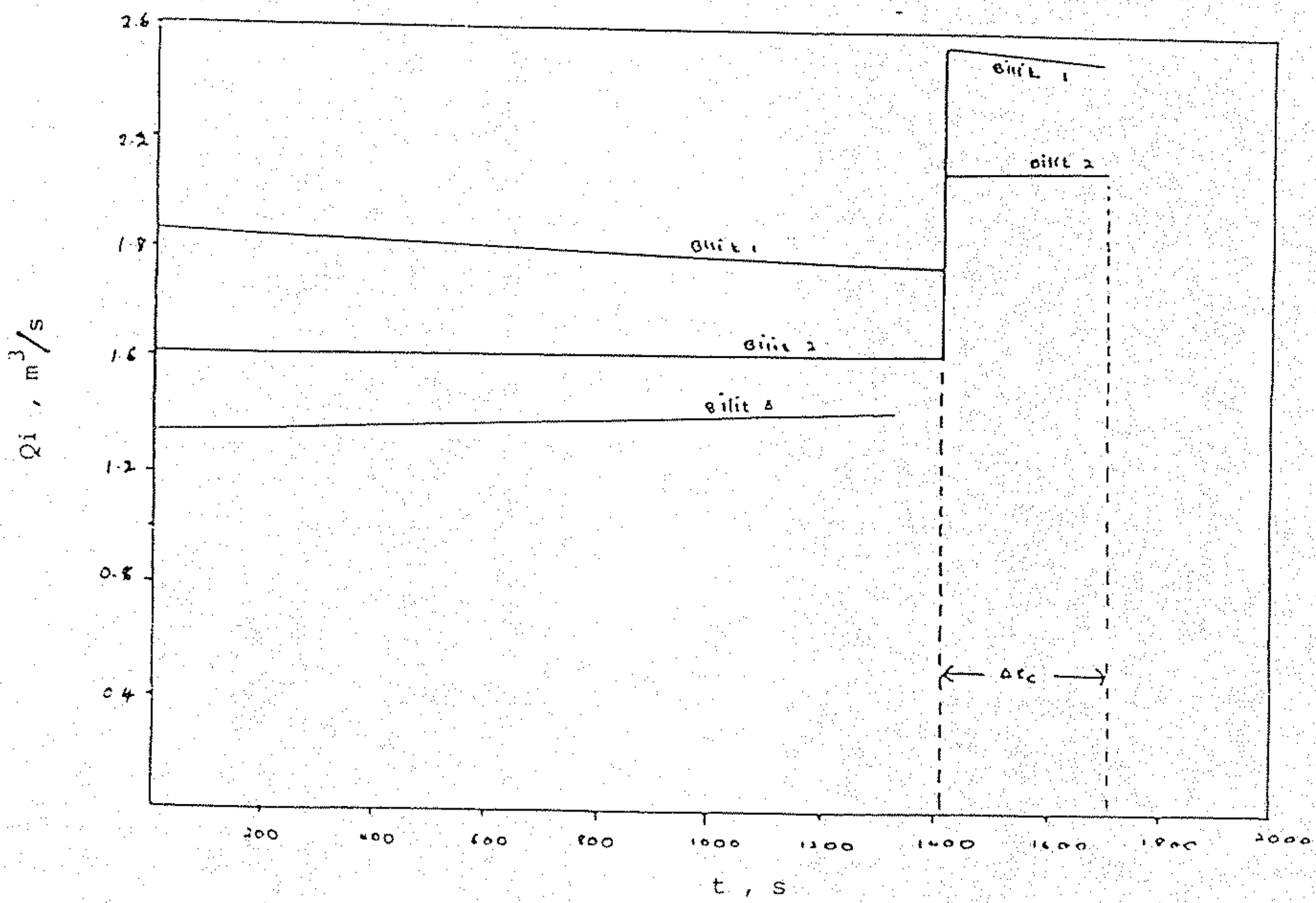

Fig.2 : Flowrate for each compartment against time

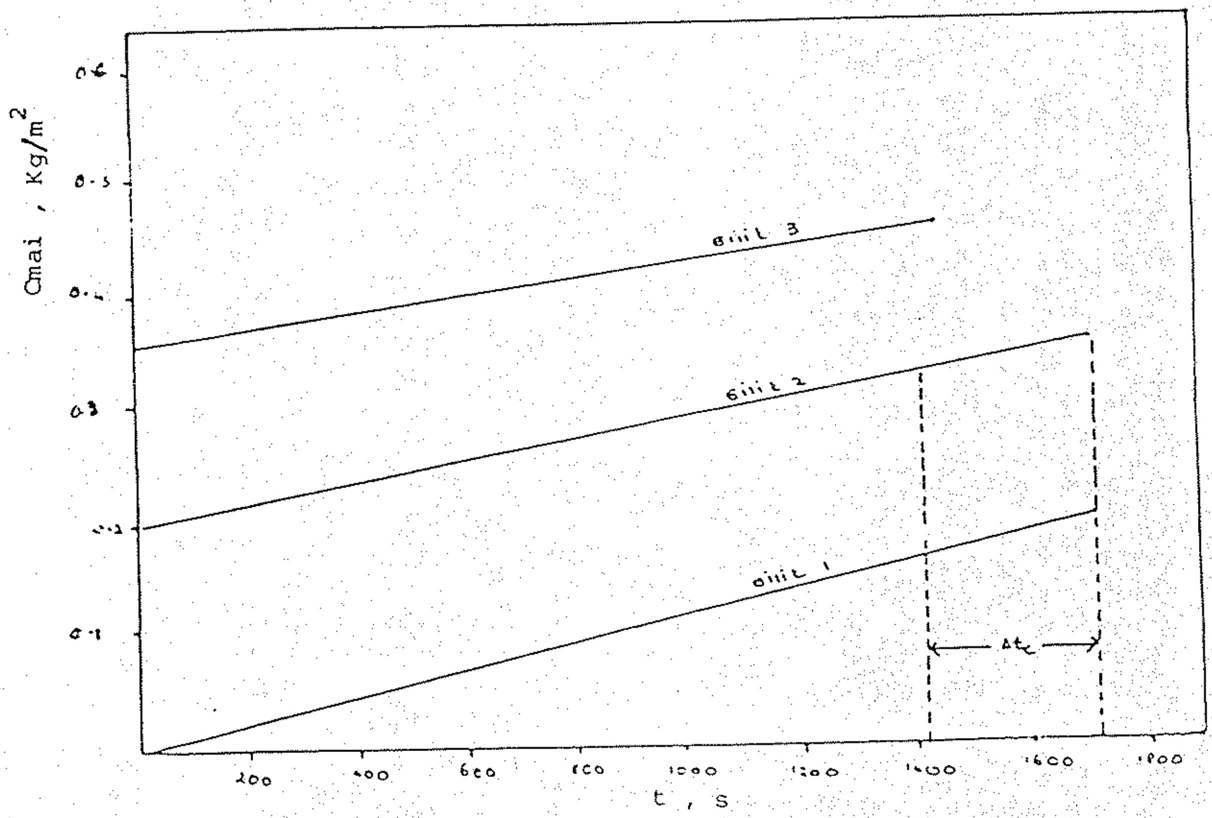

Fig.3 : Dust weight for each compartment against time

SAMPLE OF SIMULATION OUTPUT FILE

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FILE: DEG    ANS    A    INSTITUT SAINS KOMPUTER - UNIVERSITI TEKNOLOGI
                                                                    82
    A =   1.42233372
  PHI1=   0.679999411
  PHI2=   0.508999586
    TI=   1711.57227

 I         CPAIO(KG/M2)
 1          0.000
 2          0.197
 3          0.257

  CPA(1)(KG/M2)=   0.00000
  CPA(2)(KG/M2)=   0.19743
  CPA(3)(KG/M2)=   0.35749
  QI(1)(M3/S)=   2.06402
  QI(2)(M3/S)=   1.59242
  QI(3)(M3/S)=   1.34356
   CELP(N/M2)=    527.144043        T(S)=  0.00000000E+00   PHI=  0.00000000E+00

  CPA(1)(KG/M2)=   0.00663
  CPA(2)(KG/M2)=   0.20255
  CPA(3)(KG/M2)=   0.36182
  QI(1)(M3/S)=   2.05825
  QI(2)(M3/S)=   1.59431
  QI(3)(M3/S)=   1.34744
   CELP(N/M2)=    531.329344        T(S)=  57.5451050       PHI=  0.15555555E-01

  CPA(1)(KG/M2)=   0.01320
  CPA(2)(KG/M2)=   0.20765
  CPA(3)(KG/M2)=   0.36613
  QI(1)(M3/S)=   2.05265
  QI(2)(M3/S)=   1.59613
  QI(3)(M3/S)=   1.35123
   CELP(N/M2)=    535.676[illegible]     T(S)=  115.0[illegible]       PHI=  [illegible]
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CMA(1)(KG/M2)=  0.06969
CMA(2)(KG/M2)=  0.25227
CMA(3)(KG/M2)=  0.40416
QI(1)(M3/S)=  2.00886
QI(2)(M3/S)=  1.60973
QI(3)(M3/S)=  1.30140
 DELP(N/M2)=   631.192871      T(S)=   633.504883      PHI=  0.219999850

CMA(1)(KG/M2)=  0.07570
CMA(2)(KG/M2)=  0.25709
CMA(3)(KG/M2)=  0.40830
QI(1)(M3/S)=  2.00462
QI(2)(M3/S)=  1.61099
QI(3)(M3/S)=  1.33439
 DELP(N/M2)=   635.002197      T(S)=   689.927979      PHI=  0.239999831

CMA(1)(KG/M2)=  0.08166
CMA(2)(KG/M2)=  0.26199
CMA(3)(KG/M2)=  0.41243
QI(1)(M3/S)=  2.00049
QI(2)(M3/S)=  1.61221
QI(3)(M3/S)=  1.33730
 DELP(N/M2)=   633.792715      T(S)=   744.017334      PHI=  0.259999812

CMA(1)(KG/M2)=  0.08758
CMA(2)(KG/M2)=  0.26667
CMA(3)(KG/M2)=  0.41654
QI(1)(M3/S)=  1.99646
QI(2)(M3/S)=  1.61338
QI(3)(M3/S)=  1.35016
 DELP(N/M2)=   [illegible].535400      T(S)=   799.706621      PHI=  0.279999793
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FILE: EEG      ANS      A    INSTITUT SAINS KOMPUTER - UNIVERSITI TEKNOLOGI
                                                                      86

 CMA(2)(KG/M2)=  0.30858
 CMA(3)(KG/M2)=  0.45286
 QI(1)(M3/S)=  1.96424
 QI(2)(M3/S)=  1.62242
 QI(3)(M3/S)=  1.41334
  DELP(N/M2)=    675.153320      T(S)=   1278.07176      PHI=  0.459999621

 CMA(1)(KG/M2)=  0.14437
 CMA(2)(KG/M2)=  0.31313
 CMA(3)(KG/M2)=  0.45692
 QI(1)(M3/S)=  1.95105
 QI(2)(M3/S)=  1.62328
 QI(3)(M3/S)=  1.41567
  DELP(N/M2)=    678.655180      T(S)=   1329.50722      PHI=  0.479999692

 CMA(1)(KG/M2)=  0.14993
 CMA(2)(KG/M2)=  0.31755
 CMA(3)(KG/M2)=  0.46077
 QI(1)(M3/S)=  1.95794
 QI(2)(M3/S)=  1.62411
 QI(3)(M3/S)=  1.41795
  DELP(N/M2)=    682.143555      T(S)=   1381.47461      PHI=  0.499999583

 CMA(1)(KG/M2)=  0.15525
 CMA(2)(KG/M2)=  0.32216
 QI(1)(M3/S)=  2.13044
 QI(2)(M3/S)=  2.25956
  DELP(N/M2)=    557.502[illegible]      T(S)=   1431.75537      PHI=  0.519999[illegible]

 CMA(1)(KG/M2)=  0.15795
 CMA(2)(KG/M2)=  0.32460
 QI(1)(M3/S)=  [illegible]
 QI(2)(M3/S)=  [illegible]
  DELP(N/M2)=    [illegible]      T(S)=   1455.06[illegible]      PHI=  [illegible]
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CMA(1)(KG/M2)=  0.18709
CMA(2)(KG/M2)=  0.34877
QI(1)(M3/S)=  2.71625
QI(2)(M3/S)=  2.28375
 DELP(N/M2)=   989.517578      T(S)=  1647.99756      PHI=  0.639999449

CMA(1)(KG/M2)=  0.18968
CMA(2)(KG/M2)=  0.35096
QI(1)(M3/S)=  2.71515
QI(2)(M3/S)=  2.28485
 DELP(N/M2)=   992.126953      T(S)=  1665.70337      PHI=  0.649999440

CMA(1)(KG/M2)=  0.19227
CMA(2)(KG/M2)=  0.35314
QI(1)(M3/S)=  2.71405
QI(2)(M3/S)=  2.28594
 DELP(N/M2)=   994.729760      T(S)=  1683.36230      PHI=  0.659999420

CMA(1)(KG/M2)=  0.19486
CMA(2)(KG/M2)=  0.35531
QI(1)(M3/S)=  2.71298
QI(2)(M3/S)=  2.29702
 DELP(N/M2)=   997.322998      T(S)=  1700.97632      PHI=  0.669999421
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