MJFAS Malaysian Journal of Fundamental and Applied Sciences
ISSN:2289-5981 e-ISSN:2289-599X
UTM UNIVERSITI TEKNOLOGI MALAYSIA

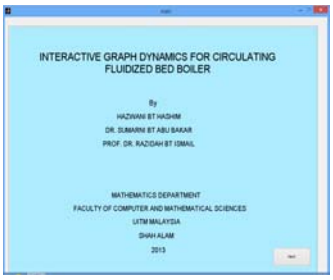
Interactive Graph Dynamics for Fuzzy Autocatalytic Set of Fuzzy Graph of Type-3 for Combustion Process in a Circulating Fluidized Bed Boiler

Hazwani Hashim* and Sumarni Abu Bakar

Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA(UiTM) 40450 Shah Alam, Selangor, Malaysia
**Corresponding Author: wanihashim88@gmail.com*

Article history :
Received 15 September 2014
Accepted 1 March 2015

GRAPHICAL ABSTRACT



ABSTRACT

Dynamical changes of chemical reactions which occurred during combustion process in Circulating Fluidized Bed boiler (CFB) has been modelled using adjacency matrix of Fuzzy Autocatalytic Set (FACS) of fuzzy graph type-3. Analysis of sequence of changes in the reactions at time *t* through Perron-Frobenious eigenvector (PFE) of the matrix in the Graph Dynamic Algorithm (GDA) shows that end-product of the combustion process in the CFB namely Water and Hydrogen is not really potrayed the real process. Therefore, in this study, transition matrix of FACS is utilized to analyse the dynamical changes of the reactions and the GDA is modified and improvised and known as Interactive Graph Dynamics (IGD) is subsequently use to facilitate the analysis. The result shows that by using the transition matrix of FACS, the end-product of the combustion process in CFB is in accordance to the real process. Whilst the IGD is able to reduced computer running time as compared to the existing GDA. This paper describes the development of IGD and the analysis of sequence of changes of chemical reactions during combustion process in CFB by using transition matrix with the helped of MATLAB.

Keywords: Fuzzy Autocatalytic Set, left Perron vector, Transition Matrix, Graph Dynamic Algorithm, Interactive Graph Dynamics, Perron-Frobenius eigenvector (PFE).

http://dx.doi.org/10.11113/mjfas.v11n1.362

1. INTRODUCTION

Circulating Fluidized Bed Boiler (CFB) is a type of boiler used for generating steam under pressure by burning waste solid fuel including coal [1]. Utilization of the boiler for green energy production has become increasingly important issue. It is an evolving technology that is very efficient in generating low-cost electricity with low emission and environment impact. In the past, researches had been conducted to model the combustion process in CFB [2-4]. However little has been done in the field of mathematical modeling of combustion process in CFB [5]. Only recently, a graphical model known as *G(V, E)* has been developed to model the combustion process by utilizing the concept of Autocatalytic Set (ACS) whereby *V* is a set of nodes representing species involved during the process and *E* is a set of edges representing catalytic relationship between species [6,7]. As for the process, eight species which gives significant contribution are identified from chemical reactions that exist during the process namely Coal, Hydrogen (H_2), Oxygen (O_2), Water (H_2O), Carbon (*C*), Nitrogen (N_2), Carbon Dioxide (CO_2), Carbon Monoxide (*CO*), Methane (CH_4), Ethylene (C_2H_4), Hydrogen Sulphide (H_2S), Sulphur (*S*), Sulphur Dioxide (SO_2), Sulphur Trioxide (SO_3) and Pollution. The model in [7] was further refined by exploiting the concept of fuzzy graph [8]. The fuzzy graphical model known as FACS model, G_{FM} (*V*, *E*) provided more information on the strength of connection of its catalytic relationship between species (Refer to Figure 1). The graph which was then represented by adjacency matrix provided information not only about the structure of the graph but also provided information about the dynamic changes of species during the combustion process at any time *t* via its corresponding Perron Frobenious eigenvector (PFE) [8] with the helped of MATLAB.

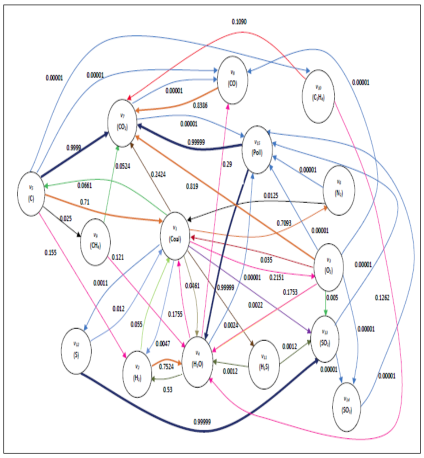


Figure 1. Graphical FACS model G_{FM} (*V*, *E*) of combustion process in CFB

In the study, the dynamic changes of species during the combustion process was determined through dynamic graph of G_{FM} (*V*, *E*) by using PFE of the adjacency matrix embedded in the Graph Dynamic Algorithm (GDA) which was firstly laid in [9]. However, analysis of the dynamics graph of G_{FM} (*V*, *E*) showed that the species left at the end of the process which is Hydrogen (H_2) and Water (H_2O) was not really portrayed the real process. This has motivated further exploration to analyse the dynamical changes of species by using transition matrix of FACS. Subsequently, the GDA is modified and improvised in order to assist the analysis in a sophisticated way. The improvised version of the algorithm is done by modifying the existing pseudo-code in MATLAB and subsequently represented in a form of graphical user interface namely Interactive Graph Dynamics (IGD).

2. TRANSITION MATRIX FOR FACS OF FUZZY GRAPH TYPE-3

FACS of fuzzy graph type-3 is a type of weighted directed graph which having real ordered number of length, θ as its weight [10]. Thus the concept or random walk in an ordinary crisp weighted directed graph is applied and subsequently the following definition is established.

Definition 1: Transition matrix of FACS [10]
The entries of a transition matrix of FACS of fuzzy graph type-3 is P_{ij}^{*}, given by

$$P^{*}{}_{ij} = \begin{cases} \dfrac{\theta_{ij}}{d_{out}(i)} & \text{if} \quad (i, j) \in E \\ \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where the out-degree of i is $d_{out}(i) = \sum \theta_{ij}$ with $\theta_{ij} \in R^{+}$.

This definition has been used in representing FACS model of a clinical waste incineration system [11]. Here, it is exploited once more to represent FACS model of combustion process in the CFB. The transition matrix representing graphical FACS model G_{FM} (V, E) using (1) is as in Figure 2.

Next, the characteristics of the transition matrix are deduced as follows:

i. Since all entries of the matrix P^{*}, $P_{ij}^{*} \geq 0$, therefore the matrix is a nonnegative matrix of order 15 since 15 nodes are considered in the graph.
ii. Entries P_{ij}^{*} represent the probability of node i to move to node j. The higher the value of P_{ij}^{*} the greater the chances to move from node i to node j.
iii. $P_{ij}^{*} = 0$ indicate that there is no link from node i to node j, thus the probability to move from node i to j is zero.
iv. P^{*} is a stochastic matrix since the sum of each row equal to one and no value is less than 0.
v. The diagonal entries are zero. Thus this matrix conformed to the graphical FACS model G_{FM} (V, E) which have no-loop.
vi. P^{*} is a regular transition matrix and also irreducible since for $k = 6, ((P^{*}))_{i,j} > 0, \forall_{i,j} = 1, \ldots, n$.
vii. The largest eigenvalue of P^{*} is $\lambda = 1$. This is also known as right eigenvalue.

From the characteristics listed above, the main characteristic of transition matrix for FACS for G_{FM} (V, E) are stochastic, irreducible and have right eigenvalue $\lambda = 1$ which are found to be similar to the characteristics of transition matrix of FACS in [11]. Thus, further analysis on the dynamical changes of species during combustion process in the CFB by using transition matrix of FACS is adopted from [11]. The analysis is successfully assisted with the help of GDA.

$$P^{*} = \begin{pmatrix}
0 & \frac{0.0047}{1.2894} & \frac{0.2151}{1.2894} & \frac{0.0461}{1.2894} & \frac{0.0661}{1.2894} & \frac{0.7093}{1.2894} & \frac{0.2424}{1.2894} & 0 & 0 & 0 & \frac{0.0024}{1.2894} & \frac{0.0011}{1.2894} & \frac{0.0022}{1.2894} & 0 & 0 \\
\frac{0.055}{0.8074} & 0 & 0 & \frac{0.7524}{0.8074} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{0.035}{1.03502} & 0 & 0 & \frac{0.1753}{1.03502} & 0 & 0 & \frac{0.8195}{1.03502} & \frac{0.00001}{1.03502} & 0 & 0 & 0 & 0 & \frac{0.00519}{1.03502} & \frac{0.00001}{1.03502} & \frac{0.00001}{1.03502} \\
\frac{0.1755}{0.99551} & \frac{0.53}{0.99551} & 0 & 0 & 0 & 0 & 0 & \frac{0.29}{0.99551} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{0.00001}{0.99551} \\
\frac{0.71}{1.89001} & \frac{0.155}{1.89001} & 0 & 0 & 0 & 0 & \frac{0.99999}{1.89001} & \frac{0.00001}{1.89001} & \frac{0.025}{1.89001} & \frac{0.00001}{1.89001} & 0 & 0 & 0 & 0 & 0 \\
\frac{0.0125}{0.01251} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{0.00001}{0.01251} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{0.00001}{0.00002} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{0.00001}{0.00002} \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{0.8386}{0.8386} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{0.1214}{0.1738} & 0 & 0 & \frac{0.0524}{0.1738} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{0.1262}{0.2352} & 0 & 0 & \frac{0.109}{0.2352} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{0.0012}{0.0024} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{0.0012}{0.0024} & 0 & 0 \\
\frac{0.012}{1.01199} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{0.99999}{1.01199} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{0.00001}{0.00002} & \frac{0.00001}{0.00002} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{0.00001}{0.00001} \\
0 & 0 & 0 & \frac{0.99999}{1.99998} & 0 & 0 & \frac{0.99999}{1.99998} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{pmatrix}$$

Figure 2. Transition matrix of FACS for G_{FM} (V, E) of combustion process in CFB

3. GRAPH DYNAMIC ALGORITHM

Graph Dynamic Algorithm (GDA) was firstly developed in [9] in the analysis of the dynamical behaviour of species involved in clinical waste incineration system. The algorithm was constructed using MATLAB as a platform and the main key element that play vital role in the algorithm is the utilization of PFE of adjacency matrix of FACS namely matrix A in determining insignificant species at any time t. Subsequently, the algorithm is modified to assist the analysis of the dynamical behaviour of the same system by using PFE of transition matrix of FACS. The algorithm is as follows:

Graph Dynamics Algorithm:

Input: Given a transition matrix P.
Output: Compute left Perron vector and reduce the dimension of matrix P.
Begin
    read input matrix $P_{n\times n}$
    while $n > 2$
        find left Perron vector,X
        if $x_i < 0$
        $\text{LPF} = -1 \times X$
        else $\text{LPF} = X$
        find min x_i and delete row and column i of matrix P
return $P_{n-1\times n-1}$
end

repeat until $P_{2\times 2}$

The algorithm is once again implemented to analyse the dynamical behaviour of species during combustion process in the CFB. However it is not efficient enough since it involves a larger dimension of matrix. Thus takes a longer running time. Motivated by this, further modification on the pseudo-code and arrangement of information of the result from the analysis is explored.

4. DEVELOPMENT OF IGD

The Graphical User Interface (GUI) is a way of arranging information on a computer screen that is easy to understand and use because it uses icons, menus and a mouse rather than only text and programs written in high level language which is often not much handy for others except for programmers [13]. Therefore the existing GDA is improved by using GUI. The graphical user interface should be attractive so that the user is interested to utilize the program. The Interactive Graph Dynamics (IGD) is a GUI application to facilitate the analysis of dynamics graph of FACS in the CFB. Flowchart depicted in Figure 3 represents basic steps in the development of the IGD.

The main page of Interactive Graph Dynamics for the CFB is shown in Figure 5. The interface is divided into multiple sections. The steps begin by running *main.m* file in the MATLAB environment. The main page is subsequently appear and user has to click *next* button to lead to second interface as shown in Figure 6 where it illustrates the schematic diagram of CFB and its brief information.

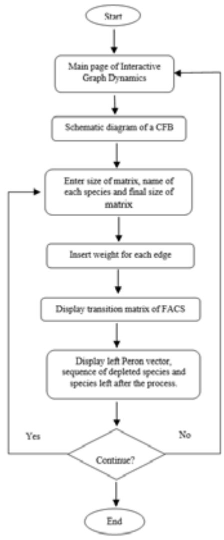


Figure 3. Flowchart of IGD

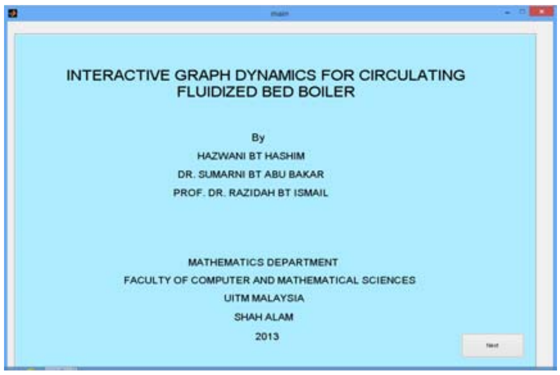


Figure 5. Main page of Interactive Graph Dynamics for CFB

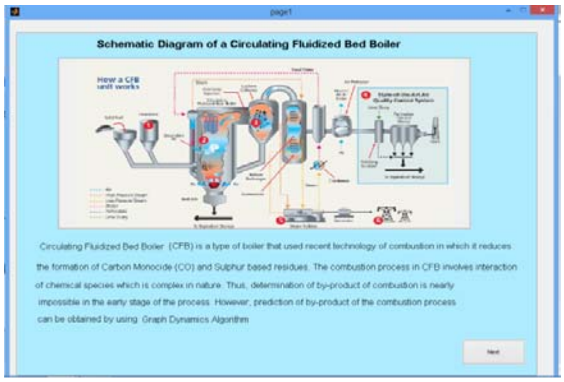


Figure 6. Schematic Diagram of a Circulating Fluidized Bed Boiler

In Figure 7, the interface contains mainly three parts. The user is required to key in matrix size, n and note that the size of the matrix is equal to the number of species involved in the combustion process of CFB. Next, the name for each species is inserted and *insert names* button has to be clicked in order to save the name of the species. Finally, final size of matrix has to be entered and *next* button is clicked to save and completed the process.

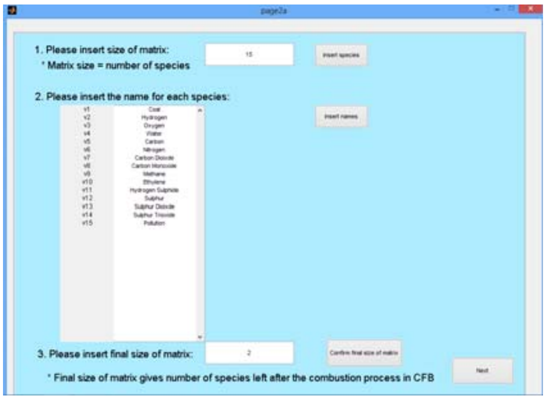


Figure 7. Input Page of Interactive Graph Dynamics

The weight of each edge for the graph in Figure 1 is represented in a form of weighted matrix as in Figure 8. This screen requires the user to key in the weight of the edge in the matrix. The *next* button is subsequently clicked to complete the process.

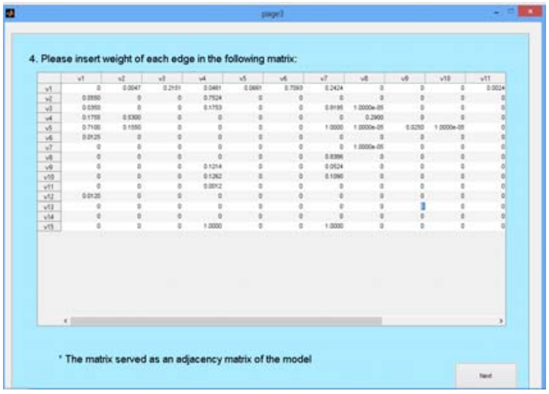


Figure. 8. The Weighted Matrix of Each Edge

5. WORKING WITH OUTPUT SCREEN

Once the entire weighted matrix is inserted, subsequently the *display the FACS matrix* button is clicked to display the transition matrix of FACS as shown in Figure 9. The transition matrix is a stochastic matrix since the sum for each row is equal to one. The *next* button is for user to proceed to the next output.

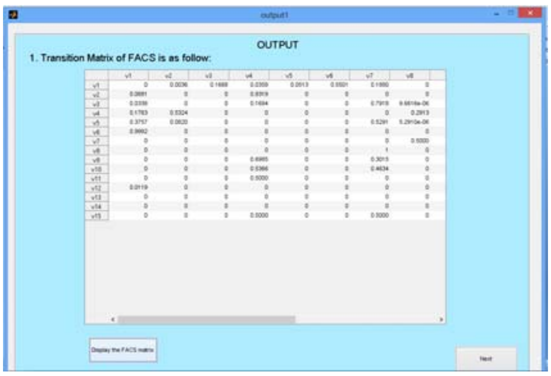


Figure 9. The Output for Transition Matrix of FACS

The final screen of Interactive Graph Dynamics displayed left Perron vector for every update as well as the species remained or the by-product of the combustion process as shown in Figure 10. The species left at the end of the process is based on the final size of matrix that the user keyed in. Two options is given in the page where the user can either clicked the *continue* or *exit* button. If the user chooses the *continue* button, input page in Figure 7 is appeared. Meanwhile if the user clicked on to the *exit* button, the process is completed and the main page appeared. The detailed output which is appeared in the notepad is as shown in Figure 11

6. RESULT AND DISCUSSION

This section discusses two main results, namely about the performance of the improvised IGD and result from the analysis of the graph dynamics obtained from the IGD. As in Figure 10, sequence of depleted species during combustion process is obtained through the IGD with the helped of MATLAB-R2009b. The running time taken for the process to complete is 0.0521 second. Table 1 below shows time taken for the process to complete by using GDA and IGD.

Table 1: Computer Running Time

Model	Existing GDA	Improvised GDA
$G_{FM}(V, E)$	1.663 seconds	0.0521 seconds

Table 1 represents the difference of running time taken for both algorithm in finding the sequence of depleted species and eventually end product of combustion process in the CFB. It shows that the IGD algorithm can complete the process faster as compared to the existing GDA. It is because pseudo-code in the IGD algorithm has been improvised and is shorter as compared to the existing pseudo-code in GDA [11].

The IGD algorithm is also implemented to the graph of FACS of clinical waste incineration process [11]. The running time taken is then compared to the existing GDA as in Table 2.

Table 2: Computer Running Time

Model	Existing GDA	Improvised GDA
$G_{FT3}(V, E)$	0.2553 seconds	0.0096 seconds

From both Table 1 and 2 and by looking at the computer running time, it is clear that the IGD algorithm is not only well performed to the FACS with small number of nodes as in $G_{FT3}(V, E)$ but also large number of nodes as in $G_{FM}(V, E)$ which eventually could handle a sparse graph. Subsequently the graphical user interface which developed with stand alone application gives an advantage to the user whereby it can be performed without MATLAB installed and is able to protect the code from being duplicated or copied.

Next, by looking at the sequence of depleted species in Figure 9, it is shown that Ethylene (C_2H_4) is the first species depleted in the combustion process, followed by Methane (CH_4), Sulphur (S), Sulphur

Trioxide (SO_3), Hydrogen Sulphide (H_2S), Sulphur Dioxide (SO_2), Carbon (C), Oxygen (O_2), Nitrogen (N_2), Coal, Hydrogen (H_2), Water (H_2O) and Carbon Monoxide (CO) and species left at the end of the process are Carbon Dioxide (CO_2) and Pollution which are also known as by-product of the combustion process. The by-product obtained by using transition matrix of FACS in this study shown to be in accordance to any other combustion process of any other system since CO_2 is among significant production of any combustion [14]. According to Sabariah [9], H_2O is also considered as by-product of the combustion process. However the percentage of the amount of H_2O is small as compared to the emission of CO_2 [14]. Therefore, it shows that graph dynamics using transition matrix of FACS could better interpret the real combustion process in the CFB.

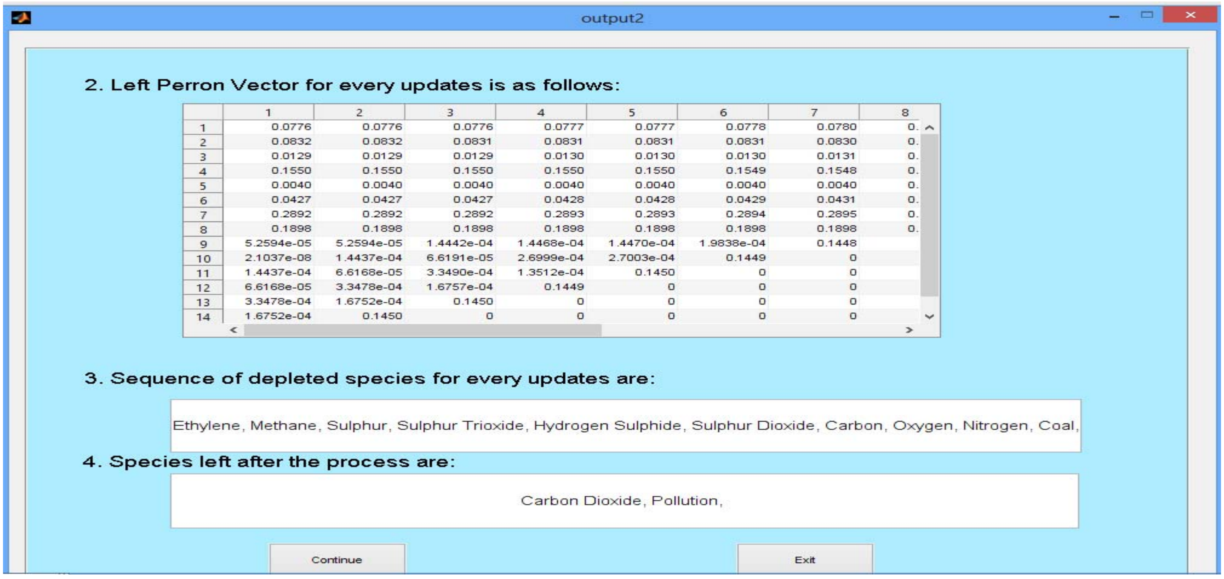


Figure 10. Left Perron Vector for Every Update

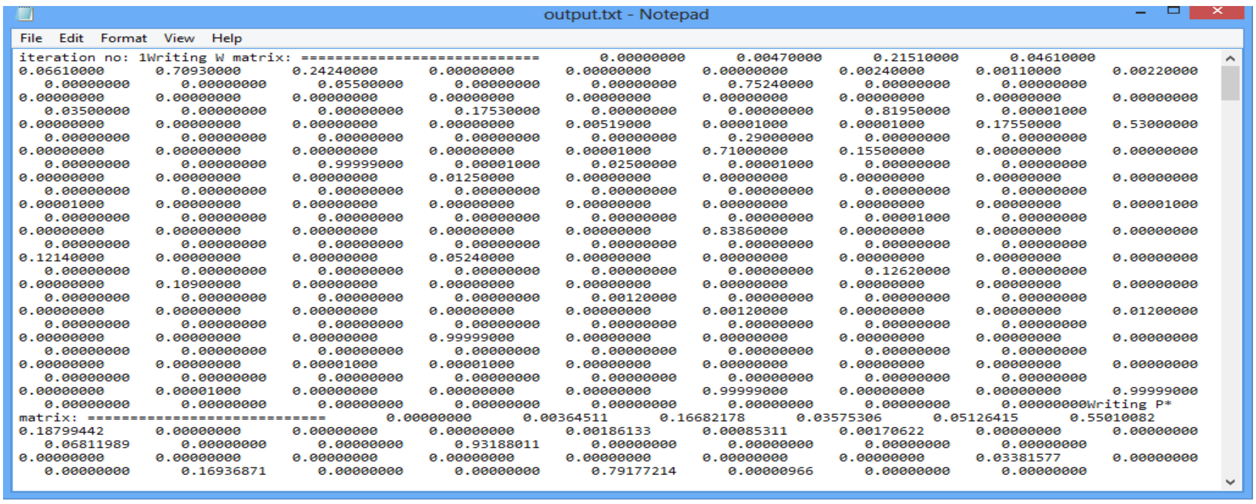


Figure 11. Detail Output for IGD

7. CONCLUSION

The Interactive Graph Dynamics (IGD) is an interface that provides an efficient computation for analysis of Graph Dynamics of combustion process in the CFB where dynamical behaviour of the species is investigated through left Perron vector as an indicator for the existence of which species is insignificant at time, *t*. The graph dynamics result using transition matrix of FACS shows that by-product of the combustion process in CFB is more consistent to the real process as compared to the by-product obtained by using adjacency matrix. Meanwhile, the IGD works well in deleting any species according to its insignificant contribution to the process after certain time *t* and able to reduce computer running time as compared to the existing GDA. Therefore it creates additional advantages when dealing with sparse graph. This interface will enhance the development of new tools in the analysis of Graph Dynamics. However, the GUI embedded in the IGD can be improved so that it becomes more users friendly.

ACKNOWLEDGEMENT

The authors would like to thank the Research Management Institute, UiTM Malaysia for the financial support through the FRGS Grant Scheme NO: 600-RMI/FRGS 5/3 (8/2013). Their gratitude is also extended to anonymous reviewers for their valuable comments and suggestion.

References

[1] P. Chattopadhyay, Boiler Operation Engineering: Question and Answer, 2nd ed., New Delhi, India: Tata Mc Graw Hill, 2000.

[2] C. K. Park, and P. Basu, Chemical Engineering Science, 2 (1997) 3499.

[3] X. S. Wang, B. M. Gibbs, M. J. Rhodes, Fuel, 73 (1994) 1120.

[4] J. Adanez, L. F. Diego, P. Gayan, L. Armesto, A. Cabanillas, Fuel, 74 (1995) 1049.

[5] L. Huilin, Z. Guangbo, B. Rushan, C. Yongjin, and D. Gidaspow, Fuel, 79 (2000) 165.

[6] A.B. Sumarni, H. Ainy, H. O. Fatin, I. Shafawati and A.M. Fudzla, "Autocatalytic set of chemical reactions of fluidized bed boiler" IEEEXplore, 2012, 1-6.

[7] Y. Nurul, A.B. Sumarni, I. Razidah, Symposium Kebangsaan Sains Matematik ke-21, 1605, 70 (2014).

[8] I. Razidah, A.B Sumarni, Y. Nurul Syazwani, Proceeding of Gulf International Conference on Applied Mathematics, 87(2014), 267-274.

[9] B. Sabariah, Modelling of Clinical Waste Incinerator Process Using Novel Fuzzy Autocatalytic Set: Manifestation of Mathematical Thinking, PhD Thesis, Universiti Teknologi Malaysia, 2005.

[10] A.B. Sumarni, On the Structure of Fuzzy Autocatalytic Set of Fuzzy Graph Type-3.Phd Thesis ,2013.

[11] A.B Sumarni, A. Tahir, B. Sabariah, Journal of Fundamental Sciences, 6 (2012) 9.

[12] A.B. Nasziruzzaman, Using MATLAB to develop standalone graphical user interface (gui) software packages for educational purposes (2010). Retrieved November 23, 2013, from http://www.intechopen.com.

[13] Biarnes, M., Freed, B. & Esteves, J. Combustion. Retrieved December 22, 2013, from http://www.e-inst.com.

[14] Epa. gov. Carbon Dioxide Emissions (2013). Retrieved November 23, 2013, from http://www.epa.gov.