Dynamic Simulation of Distillation Sequences in Dew Pointing Unit of South Pars Gas Refinery

Mobina Khodadoost *[1] **and Jafar Sadeghi** [1]
[1] Department of Chemical Engineering, University of Sistan and Baluchestan,
Zahedan, Iran

(Received 29 June 2011, Accepted 20 December 2011)

Abstract

The understanding of the dynamic behavior of distillation columns has received considerable attention because distillation is one of the most widely used unit operations in chemical process industries. This paper reports a dynamic simulation study of the possible distillation columns sequences of Dew pointing unit in the second phase of South Pars Gas Refinery. In this unit, three columns are used for separating the feed of normal paraffin, from methane to n-Decane into the four mixtures of products; so five different simple columns sequences are possible. In this work, we made use of linking between Aspen dynamic and MATLAB Simulink software's for achieving our purpose. At first, simulation and design of the distillation sequences were performed in steady state by using the process simulators Aspen Plus 2006. After steady state simulation, the parameters required for the dynamic simulation were entered and the files were exported to ASPEN Dynamics. PI and PID controller as basic controllers were automatically added and were tuned by the conservative Tyreus–Luyben tuning method. Then the model which connects MATLAB to Aspen Dynamic was created in Simulink and the behavior of the five different sequences in dynamic regime was observed after changing the flow rate of the feed steam by $\pm 5\%$. The results show that the steady state simulation is suitable for the start point, but it is better to use dynamic simulation to design and simulate the chemical process industries because in dynamic simulator there are nonlinear models for calculating the equations of state and simulating the chemical process. In addition, in dynamic simulation we are faced with real condition of process so the obtained results will be close to the real ones. After dynamic investigation, it were found that the sequences-2, sequences-4 and sequences-5 have suitable dynamic behavior for controlling because of auto-rejection of the disturbances, but the sequences-1 and sequences-3 have complex dynamic response and they are found to be hard to control.

Keywords: Dynamic behavior, Aspen dynamic, Simulation, MATLAB, Control, Distillation, Columns sequences, Chemical process

Introduction

The chemical industries are faced with an increasingly competitive environment, ever-changing market conditions, and government regulations; yet, they still must increase productivity and profitability. Dynamic plant studying is a powerful tool which helps managers and engineers to link business operations to process operations, thus enabling true process lifecycle management [1]. To understand the dynamic behavior of a complex chemical process, process manufacturers require a dynamic process simulator [2]. Aspen Dynamic is a state-of-the-art solution designed specifically for dynamic process simulation. Aspen Dynamic is tightly integrated with Aspen Plus (AspenTech's steady state simulator for the chemical process industries); this can be loaded into MATLAB and are used with the Simulink Interface for analyzing the dynamic behavior of chemical process and designing the process control systems [3].

Systematic synthesis of multi-component separation sequences is an important process design problem in chemical industry. It is concerned for the selection of a separation method and choosing the best sequence of separators to split a multi-component mixture into several products of relatively pure species [4]. For solving the separation's problems in chemical industry, distillation columns are widely employed as separators. Their advantages include simple operation and ability to separate various kinds of mixtures into their components.

---

* Corresponding author: Tel: +98- 541-2514341 Email: m.khodadoost@mail.usb.ac.ir

Distillation sequences can be specified by using different methods: heuristic, evolutionary or algorithmic [5].

The number of possible sequences for the separation of an N-component system using simple sharp distillation columns is given by King's formula [6]:

$$N_n = \frac{(2(N-1))!}{N!(N-1)!} \tag{1}$$

Where N_n is the number of possible sequences.

The determination of feasible sequences of multiple distillation columns has been the subject of academic and industrial investigation for many years. The Large researches have been published determining the best sequence of distillation columns [7-9]. Most of these works investigated the sequences in steady state and there were a few researches on dynamic behavior of distillation columns sequence. In addition, dynamic investigations are difficult and need such a long time. We use this application for the first time in simulating the chemical industry of Iran. We will show that the dynamic simulation is better than steady state simulation for designing and simulating the chemical process.

1. Process simulation

I. Problem definition (Case study)

The problem addressed in this paper can be stated as follows. This research considers an industrial case study. The main object of the research is dynamic design and analyze of the possible distillation columns sequences of Dew pointing unit of the second phase of South Pars Gas Refinery's by using the link of Aspen dynamic and MATLAB Simulink software's.

II. Method

Aspen Dynamics is a state-of-the-art solution designed specifically for dynamic process simulation. Aspen Dynamics is tightly integrated with Aspen Plus, AspenTech's steady state simulator for the chemical process industries.

This integration enables users to use an existing Aspen Plus steady state simulation and quickly create a dynamic simulation.

Aspen Dynamics enables users to gain a detailed understanding of the unique dynamics of their processes. Users can leverage this knowledge during design and operation to optimize safety, operability, and productivity within plants and to minimize capital and operating costs. The Control Design Interface, included in Aspen Dynamics, enables a linear state space model to be extracted from the Aspen Dynamics rigorous non-linear simulation. Aspen Dynamic can be loaded into MATLAB and are used with the Control System Toolbox in designing a process control system. Once the user has designed a control system, the Simulink Interface can be used to test its performance.

The interface enables an Aspen Dynamics process simulation to be used as a block within a Simulink model. This determines that the user can test the controller performance on the full, rigorous, non-linear dynamic model of the process. Without this interface, the control design can only be tested using the linear dynamic model within MATLAB. This leaves uncertainties about how the controller will perform on the real, non-linear process. Using Aspen Dynamics with MATLAB and Simulink helps the user to develop better process control systems, and to be confident that they would effectively work when deployed on the plant [3 and 10]. In addition, this application helps the users to save the time in simulating and expeditiously achieve the results that are very important in chemical industries.

III. Input data for steady state simulation

The feed of 1346 kmol/h of normal paraffin, from methane to n-Decane and the four mixtures of desired products (according to Table1) were considered [11]. For this products number, according to King Relation (Eq-1) 5 different simple column sequences are possible. Figure (1) show all these sequences.

In this unit, there are three distillation columns: Depropaniser, Debutaniser and Dehexaniser. These columns separate the feed into four products. Depropaniser separates the lightest components, Methane to Iso-Butane; Debutaniser separates the middle of components which are Propane to Iso-Pentane and Dehexaniser separates the heaviest components from N-Butane to N-Decane. These columns can set in five sequences; all the sequences were designed and simulated by Aspen Plus 2006 process simulator while considering a desired molar purity for each product mixture (Table 1).

The simplified DSTWU (shortcut distillation design using the Winn-Underwood-Gilliland method) model based on the Winn–Underwood Gilliland method was first used to initialize the rigorous simulations performed with the RadFrac model. The perfect steady state simulation is necessary to achieve the correct dynamic simulation [10].

IV. Dynamic simulation requirements

Before starting dynamic simulation by Aspen Dynamics, a steady state simulation of the system in Aspen Plus should be done. In addition, the pressure units such as valves and pumps, which are not necessary for the steady state simulation, must be specified. The sizing of the equipment is also required for the dynamic simulation.

After simulating the distillation columns sequences in steady state by Aspen Plus and entering the parameters required for the dynamic simulation, the files were exported to Aspen Dynamics. Basic controllers (Base- Level Controller, Feed Flow Controller and Tray Temperature Controller) should be added after importing the file into Aspen Dynamics. Aspen Dynamics provides a number of different types of controllers. The PID Incr. model was used for all controllers in our simulation as the PI and the PID controller and tuned by the conservative Tyreus–Luyben tuning settings [12, 13]. Figure (2) shows the dynamic simulation scheme of possible sequences of distillation columns for this research in Aspen Dynamic.

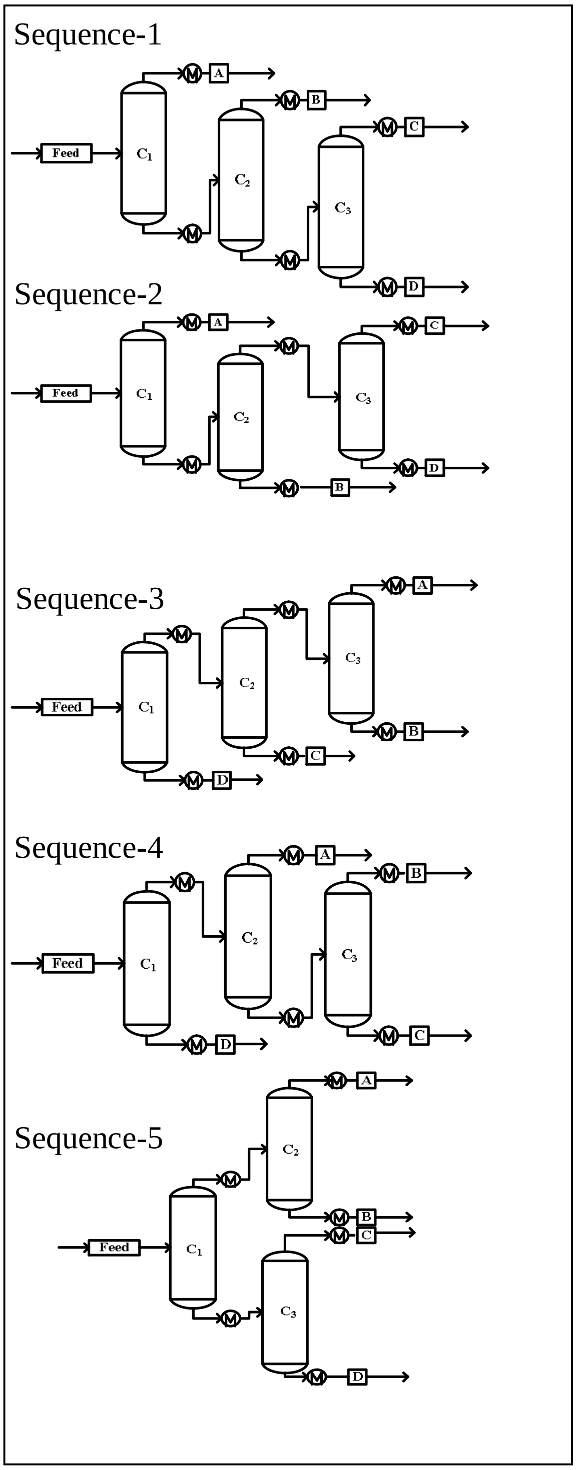

Figure1: Different sequences for the separation

Table 1: Product compositions

Product Name	A	B	C	D
Components	Methane Ethane Propane Iso-Butane	Propane Iso-Butane N-Butane Iso-Pentane	N-Butane Iso-Pentane N- Pentane N-Hexane N-Heptane	Hexane Heptane Octane Nonane N-Decane
Molar Flow (kmol/hr)	402 157 220 1	5 70 115 2	7 3 31 23 5	1 104 115 38 16

V. Loaded Aspen Dynamic into MATLAB

After dynamic simulation by Aspen Dynamics, the model which connects MATLAB to Aspen Dynamic is created in Simulink and the behavior of the 5 different sequences in dynamic regime is observed after changing the feed composition by ±5%. We decided to use this disturbance due to the fact that the majority of petroleum refinery and chemical industries are faced with this problem; as their initial food is prepared from different sources and there is a little difference in its composition in various seasons. We try to identify the best sequences that has suitable dynamic for controlling. If some sequences can remove disturbance automatically and rapidly, they will be easily controlled.

2. Results and discussion

The dynamic analysis was organized in the following way. In 5 different sequences, essential controllers were used and their tests with single control loops were precedently carried out; then Aspen Dynamic and Simulink was linked together and responses to disturbances in the feed composition were considered.

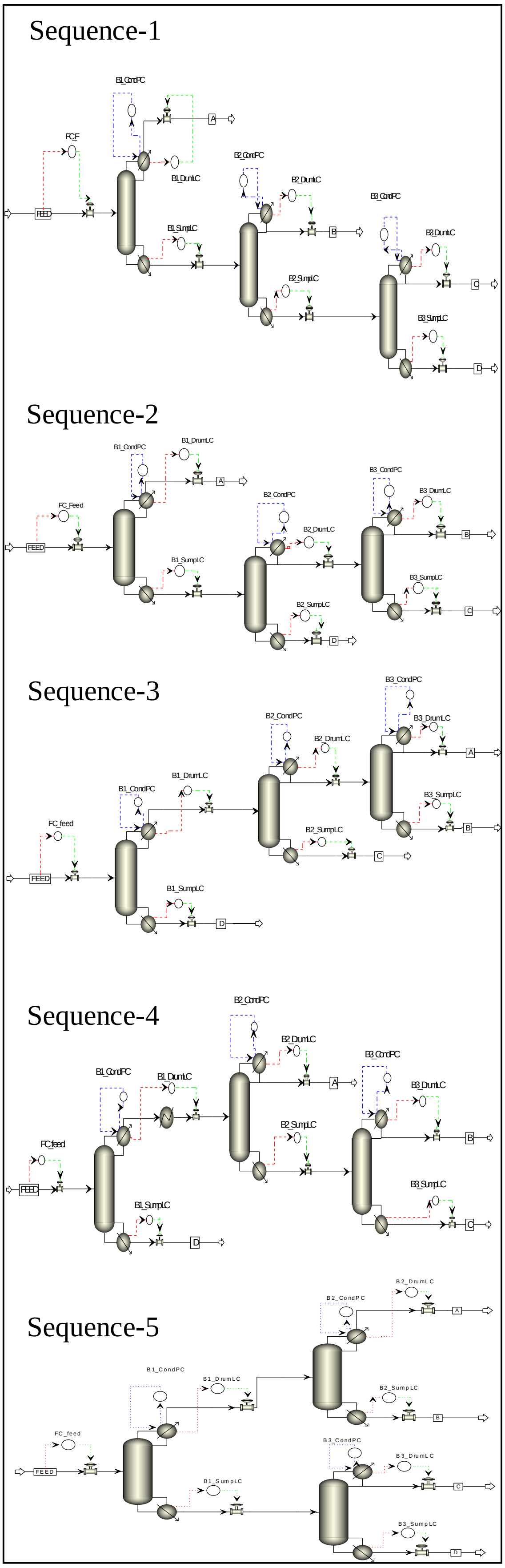

Figure2: Dynamic simulation scheme of possible sequences

Since there is no previous work reported on the dynamic properties of the sequences for this case and the above-mentioned component mixture, an initial study on the SISO control of each product stream was carried out. Table (2) gives the values of the controller parameters that were obtained after the tuning procedure.

As a first results, it can be mentioned that the steady state simulation is suitable for the start point, and it is better to use dynamic simulation to design and simulate the chemical process industries. It is in view of the fact that in dynamic simulator there are nonlinear models for calculating the equations of state and simulating the chemical process and the pressure profile of all equipments and streams have been calculated by the simulator's software so the results and observations will be closed to real case. On the other hand, if we use dynamic simulation, we will be able to design and verify the process control schemes, safety studies, relief valve sizing, failure analysis, and development of startup, shutdown, rate-change, and grade transition policies.

The response to a disturbance in feed composition was analyzed. To implement this scenario, the composition of feed's components was equally increased while total feed flowrate was just changed about ±5%. Figure (3) shows the dynamic performance of all product streams (A, B, C and D) under such a disturbance. It were observed the three sequences (2, 4 and 5) can cope with the effect of the disturbance by adjusting the product composition to its original design value and have suitable dynamic behavior to control because of auto-rejection of the disturbances. It can be observed that the sequences-1 and 3 have complex dynamic response because they could not remove disturbance. They are hard to control. It also illustrates that the conventional sequence (sequence-1), which exists in real plant, is more noticeably affected by the disturbance and has a complex dynamic, therefore if some disturbances are been in feed, it will be difficult and costly to remove it and keep the purity of products.

Results showed the suitable separation of components is sensitized to the sequence of distillation columns. When the lightest and heaviest components are consecutively separated, sequence-1 and sequence-3; we are faced with some problems. These sequences disperse the disturbance to the whole of the plant and the operating conditions of columns are changed, therefore the purity of products is lost. It means that the separation of lightest and heaviest component in first column is not a good choice in respect of controlling. However sequence-1 is the best choice in order to saving energy and cost [9] but it has a complex dynamic behavior. In addition, we can realize that if we use conventional sequence (sequence-1) to separate a feed in petroleum refinery or other plant, we will be careful about the control systems that will be used. These control system must be very sensitive to changes.

Table 2: Controller parameters for the SISO control tests

Controller	Column 1		Column 2		Column 3	
	K_c	τ_I (min)	K_c	τ_I (min)	K_c	τ_I (min)
Pressure	**20**	**12**	**25**	**16**	**25**	**12**
Level	**10**	**1000**	**15**	**1000**	**10**	**1000**
Feed's flowrate	**0.5**	**0.3**	--	--	--	--

3. Conclusion

Dynamic plant simulation is a powerful tool that helps managers and engineers link business operations to process operations, thus enables true Process Lifecycle Management. In this paper we analyzed the dynamic behavior of distillation columns sequences to the fact that in chemical and petrochemical industries, distillation is the most widely applied separation technology. Dynamic simulation is difficult but results show the dynamic simulation is better than the steady state simulation. It seems the steady state simulation is suitable as a start point in simulation and process design. In dynamic simulator there are nonlinear model for calculation and simulation. In dynamic simulation we are faced with real condition of process so the results have been obtained will be near the real results. After dynamic analyses by changing the flow rate of the feed in 5 different sequences, we found out that, the sequences-2, 4 and 5 have suitable dynamic behavior but the sequences-1 and 3 have complex dynamic response and they are hard to control. In general, all sequences were able to cope with the feed disturbance implemented. But some of them need time for removing it and time is wasted and. During this process products will be lost or will not have desired purity. At the end, it must be noted; if we use dynamic simulation, we will be able to solve such problems by designing a suitable control system.

4. Acknowledgements

The authors wish to acknowledge financial support from the Iranian Gas National Company, for the development of this project

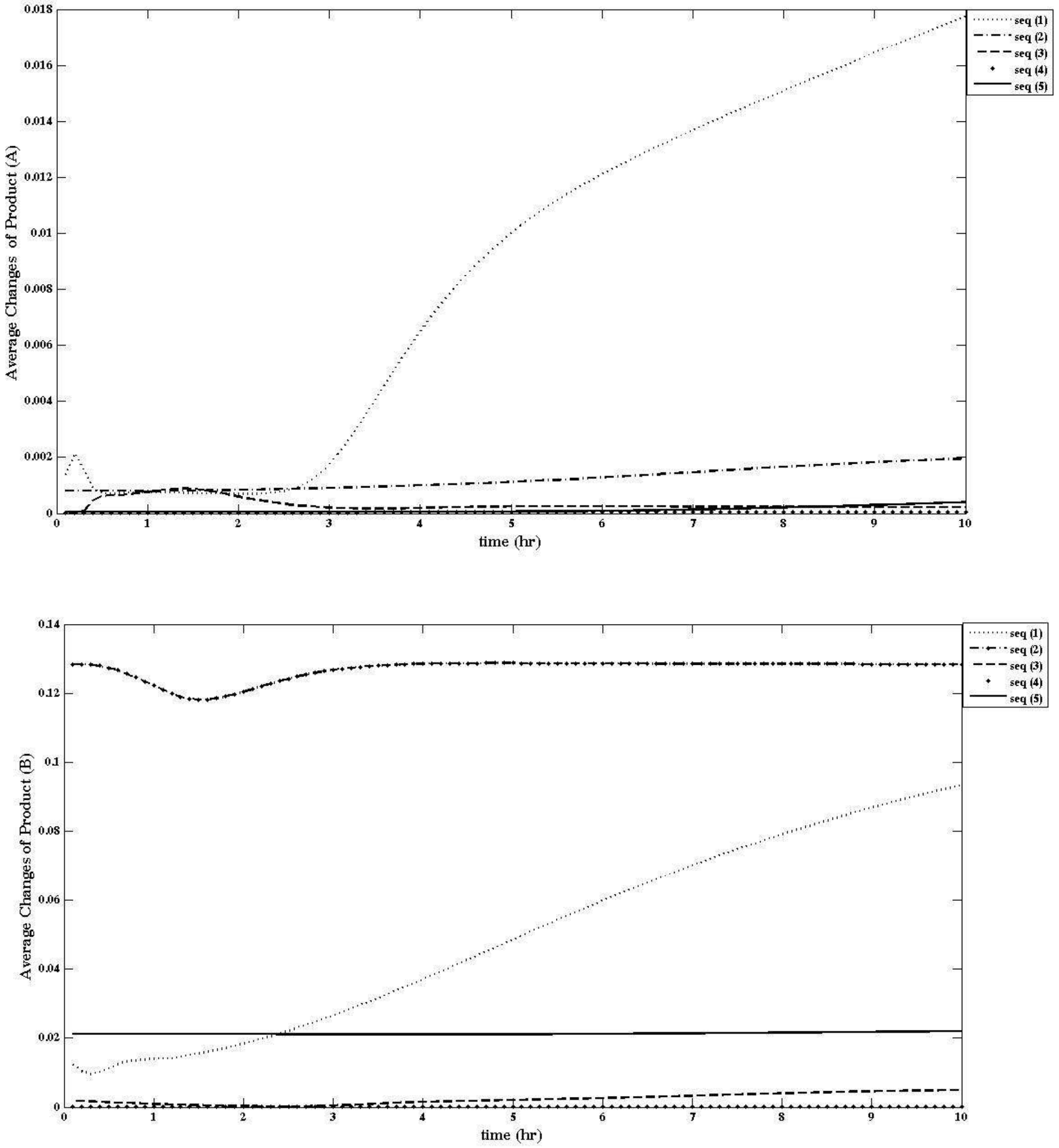

Figure3: Dynamic performance of all product streams in possible sequenses

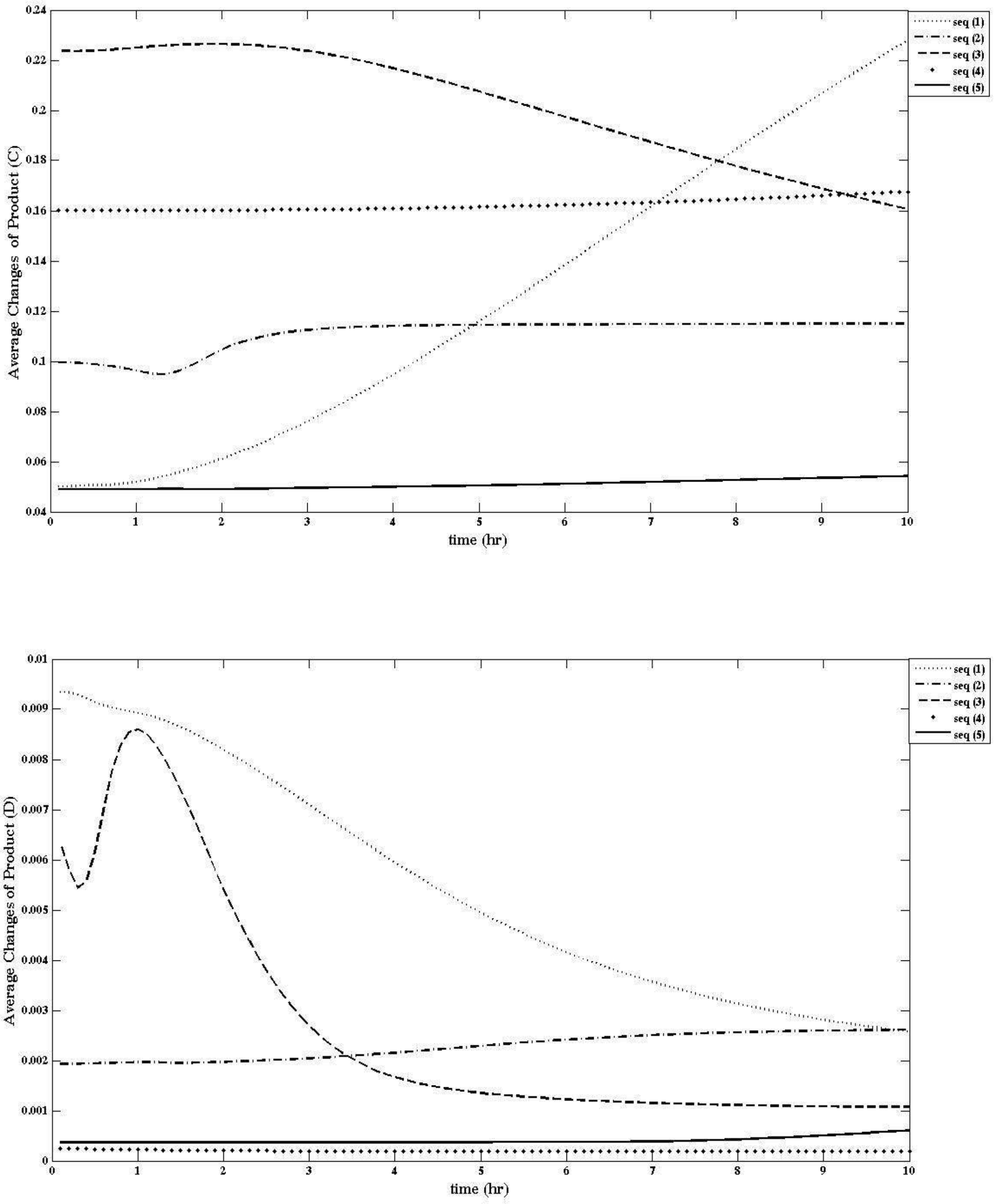

Figure3 (cont^{d}): Dynamic performance of all product streams in possible sequenses

References:

1- Grossmann, I.E. (2004). "Challenges in the new millennium: product discovery and design, enterprise and supply chain optimization, global life cycle assessment." *Computers & Chem. Eng,* Vol. 29, PP. 29-39.

2- Bequette, B. W. (1998). “Process Dynamics Modeling, Analysis and Simulation.” Prentice Hall PTR, New Jersey.

3- Aspen Tech Company (atesupport@Aspentech.com (Engineering Suite).

4- Yeomans, H. and Grossmann, I. E. (2000). “Disjunctive programming models for the optimal design of distillation columns and separation sequences.” *Ind. Eng. Chem. Res*, Vol. 39, PP. 1637-1648.

5- Westerberg, A. W. (1981). “The synthesis of distillation based separation systems.” *Comp. Chem. Eng.*, Vol. 9, PP .421-429.

6- King, C. J. (1980). “Separation Processes,” McGraw-Hill Publishing Company, New York, Second Edition.

7- Leboreiro, J. and Joaquin, A. (2004). “Processes synthesis and design of distillation sequences using modular simulators: A genetic algorithm framework.” *Com. Chem. Eng*. Vol. 28, PP. 1223–1236.

8- Lucia, A. and McCallum, B. R. (2009). “Energy targeting and minimum energy distillation column sequences.” *Com. Chem. Eng.* Vol. 34, PP. 1–12.

9- Errico, M., Tola, G., Rong, B. G., Demurtas, D. and Turunen, I. (2009). “Energy saving and capital cost evaluation in distillation column sequences with a divided wall column.” *Ind. Eng. Chem. Res.* Vol .87, PP. 1649–1657.

10- Luyben, W. L. (2006). “Distillation Design and Control Using Aspen Simulation.” second ed, John Wiley and Sons, Inc, Hoboken, New Jersey.

11- South Pars Field Development (Phase Two & Three), “Operating Manual, Unit 105, Dew Pointing and Mercaptans Removal.”

12- Shinskey, F. G. (1984). “Distillation Control”, second ed. McGraw-Hill, New York.

13- Luyben, W.L. (1999). “Process Modeling, Simulation, and Control for Chemical Engineers,” McGraw-Hill Publishing Company, New York, Second Edition.