An inverse control of the extraction column

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Abstract— In this paper inverse modelling method was investigated. In order to perform the state prediction necessary to the future system behavior, an inverse system is developed based on input/output data. Much of work deals with dynamics of processes, system identification, state variable estimation, disturbance estimation, filtering and smoothing. Identification and control system to the variation of the state variables over time in multistage process unit were investigated. A liquid-liquid extraction column was used. Several models were built. Inverse control methods reverse the process finding the response of a system to a particular form of input or disturbance for a given set of initial conditions, and attempt to find the control inputs required to achieve a particular response. With inverse dynamic modelling the control variables, in order to make the plant output, follow the desired set-point. The control system was developed based on input/output data. Numerical simulation was performed. The obtained results show improving products quality control, determine optimum set points, and a troubleshooting day to day operating problem.

Keywords— Control model, dynamic response, inverse method, extraction process, multistage unit.

I. INTRODUCTION

This paper provides information for concept for inverse modelling. Inverse modelling method reverse the process finding the response of a system to a particular form of input of disturbance for a given set of initial conditions and attempt to find a inputs required to achieve a particular response. This article outlines the models for inverse control and introduced some relatively novel approaches which are believed to have some advantages for applications involving inverse system performance investigations. Discussion of possible problems encountered when using these models and more fundamental issues associated with the dynamic properties of inverse control.

In recent years the study of systems learning has successfully elucidated some basic techniques for generalizing concrete examples to more abstract descriptions. These include heuristics for generalizing particular data types, candidate elimination algorithms, methods for generating decision trees and rule sets, back propagation of constraints through an explanation tree, function induction, and synthesis of procedures from execution traces [1],[2]. Learning methods have been reported that claim to learn by analogy, being told, debugging, discovery, doing, examples, experimentation, exploration, imitation, instruction, observation, rote and taking advice. The apparent richness and variety of these approaches may give a misleading impression of a field teeming with fruitful techniques, with a selection of well defined methods for tacking and given problem.

The impact of process control managing in providing enhanced understanding about the dynamic properties of the system under investigation is emphasized.

In general, inverse control systems may have better system performance. It is true that the control factors are functions of both the parameters of the plant under control and the performance index of the closed loop system. These rules and formula are helpful in eliminating the most time consuming trial and error procedures in the synthesis and design of control systems.

In the design method based on gain and phase margins, it is also important to select a suitable equivalent gain/ phase margin contour so as to obtain appreciable performance. In previous studies it was found that is difficult to select such as a contour, and the improper allocation of the equivalent contour will degrade the system's performance [1].

At the inverse dynamics the control variables, in order to make plant output, follow the desired set-point. These inputs can be randomly generated, but they must preferable cover all the input domain. The plant input and output are recorded during the simulation.

This paper outlines the models for inverse control and introduced some relatively novel approaches which are believed to have some advantages for applications involving inverse control system performance investigations. Discussion of possible problems encountered when using these models and more fundamental issues associated with the dynamic properties of inverse control. The impact of process control managing in providing enhanced understanding about the dynamic properties of the system under investigation is emphasized.

II. INVERSE MODELLING METHOD

Functional expressions include many natural laws, as well as relationships between quantities and parameters. Functional representations are appropriate for nested and recursive numeric or non-numeric expressions. Any functional relationship f(x) can be represented in logic and this is no surprise since the two forms are expressively equivalent. Any inverse functional relationship has deductive expression.

But in a framework for induction, it is preferable to treat functional expressions separately and omit explicit quantifiers. An important difference is that functional representations of concepts must be single valued, while logical expressions do not need to be this greatly affects the search space involved.

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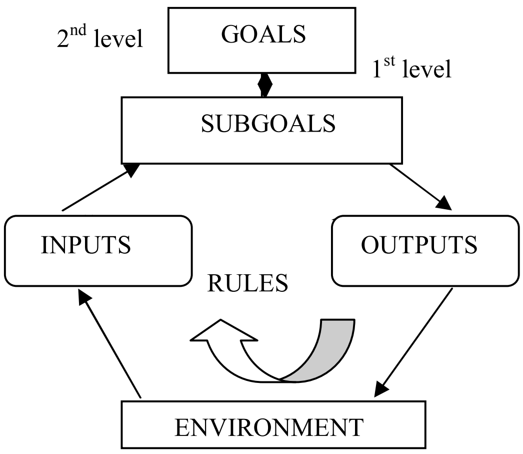

Fig.1 The inverse modelling goal based

When expressed in hierarchical form the relationship that exist between goals and subgoals provide a basis for relating overall goal based system performance to specific assumptions about the variability and contribution of the supporting subgoals. In this form, the belief system is a full expression of some control theory in that the system's relationship with the environment, as expressed in a set of feasible state conditions, can be related either in overall system performance measures to be relationships and the subgoals that support them.

The relationship of the goal relating to state conditions may be inverse expressed. That is very useful to rich unknown parameters. Regression and correlation analysis, when used judiciously, can give correct curves as to the relationships between process variables and optimum conditions.

In the both cases, the mathematical model is a response function which connects the optimization parameter which describes the outcome of an experiment to the variables which the experimentator manipulates in conducting the experiment.

For both inductive and deductive concept the formalism above suggests representing concepts in an appropriately powerful form of logic. However, although formal logic provides a sufficient basis for deduction, as a foundation for induction it is at once too narrow and too powerful.

The distinction between deductive and inductive concept can be viewed as a modern reincarnation of the long philosophical tradition of distinguishing necessary from contingent truths.

It can be indicated two possible approaches to complex contains modelling. The first, identified with structural knowledge, follows a deductive reasoning approach in which one tries to deduce from an existing theory model relationships for a given problem. The second, identified with a posterior empirical knowledge, follows an inductive approach in which one tries to develop a model from the sampled data. Ideally, these two approaches act as complementary stages of the modelling process. One follows all steps with model calibration and model validation serving as an empirical test bed for a prior model as a learning tool. Yet, in some situations characterized by difficulties in obtaining empirical data due to a budget and time constraints or peliminary scope of the analysis, the model specification may be reduced to the a priori stage.

On the other hand, logic is too powerful because the need to acquire knowledge automatically from environment and integrate it with what is already knows means that only the simplest representations are used. Any one representation will not encompass the broad application of concept modelling, procedures or expressions composed of functions. These reflect fundamental formulations of computing that have been realized in logic, functional and imperative programming styles. Although equivalent in expressive power, the different representations are more or less appropriate for particular concept modelling problems, depending on the nature of the examples, background knowledge, the way the complexity of concepts are measured, and the style of interaction with the environment. For example, decision three are naturally represented as logic expressions, polynomials as functions and tasks as procedures. Functional representations incorporate the powerful mathematics available for numbers. Procedures embody the notions of sequencing, side effects and determinism normally required in sequential, real word tasks.

There is an obvious overlap between logical and non-numerical function representations. For example, the concept of appending lists can equally well be written in logical and functional styles. The difference is that the logical form expression a pure relation without distinguishing input and output, while the functional representation acts on the input list to construct the output.

Objects are characterized by their attributes. Moreover, pair wise relations may exist between them. This means that variables must be introduced to stand for objects in various relations. Such relations can be described by predicates which, like attributes, may be normal linear or tree structured. Objects and concepts are characterized by combinations of predicates.

Attribute vectors, propositional calculus are not powerful enough to describe situations where each example comprises a scene containing several objects.

The two areas of model development and analysis are addressed through the discussion of generic simulation environment. The knowledge based simulation environment is an expression of some control law or cognitive theory. To the extent that the rule base is derived from set of assumptions about the environment and performance expectations, it is a belief system. However, in the existing form, the goals are not expressed and the underlying assumptions are not evident.

In the analysis and synthesis of engineering systems, simulation is a major technique. The traditional simulation techniques are algorithm based. They are often inflexible and provide limited means to the user. In fact, such techniques can not clearly simulate the dynamic behavior of the real processes. The segregation of the database, knowledge base and inference engine in the expert system allows us to organize the different models and domain expertise efficiently because each of these components can be designed and modified separately.

III. INVERSE CONTROL MODEL

With the inverse dynamics modeling the control variables, in order to make the plant output, follow the desired set-point. These inputs can be randomly generated, but they must preferable cover all the input domain. The plant input and output can be considered during the simulation.

The inputs in an inverse control system are shown in Fig.2.

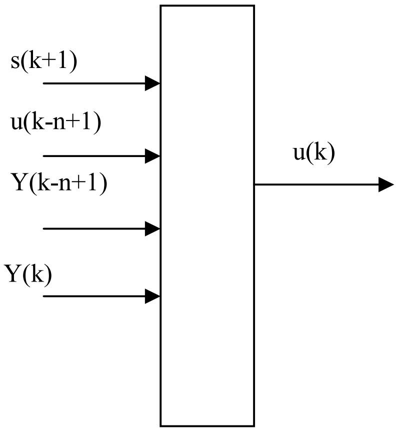

Fig.2 Inverse control model

For a manipulative variable u(k) and controlled variable Y(k), and s(k+1) as desired point value, a control system is shown in Fig.2 and control function is given by Eq.(1).

The inverse dynamics is modeled by applied the input from the initial state of the stage and the final state of the stage such as follow:

$$u(k) = f\{Y(k), Y(k-n+1), s(k+1), u(k-n+1)\} \quad (1)$$

IV. AN EXTRACTION LIQUID-LIQUID MULTISTAGE CONTROL VARIABLE DEFINITION

Separation of two liquid phases, immiscible or partially miscible liquids, is a common requirement in the process industries. For example, in the unit operation of liquid-liquid extraction the liquid contacting step must be followed by a separation stage.

The most commonly used method for the separation and purification of miscible liquids are distillation, solvent extraction and, for a few special applications, adsorption.

Liquid-liquid extraction or solvent extraction is a separation which is based on the different distribution of the components to be separated between two liquid phases. It depends on the mass transfer of the component to be extracted from a first liquid phase to a second one.

A distinction has to mark between components liquid streams and phases. Both streams and phases are composed of individual substances the components. Phases are liquid streams that are in equilibrium with each other. Generally, more than three components are involved in an extraction. The feed to a liquid-liquid extraction is the solution that contains the components to be separtaed.

For an extraction prcess system, input variables might include rafinate flow rate and rafinate phase composition as disturbances, and solvent flow as manipulative variable. Output variables might include overhead extract composition, holdup, and flow rate on any or all of the stages and temperature on each stage (Fig.3)[3],[4].

Solvent flow rate S is a manipulated variable u(k), composition of the extract phase at the top x_E is controlled variable y(k) and s(k+1) is desired point value.

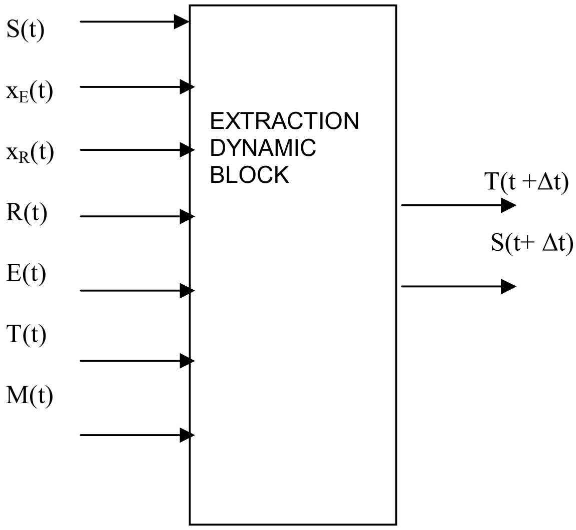

Fig.3 An extraction process unit

One physical stream may be considered to contain many variables its rate, its composition, its temperature, etc.. Their qualitative terms are:

Input variables (low, medium, high).
Output variables (low, medium, high).
Control variables (increasing, normal, decreasing).

The qualitative model for systematic cause-event analysis was made, and variables discrete state were defined[3]-[10].

rafinate flow flow (low, medium, high).
extract flow(low, medium, high).
solvent flow (low, medium, high).
raffinate composition(low, medium, high).
extract composition(low, medium, high).

composition (increasing, slow increasing, normal, slow decreasing , decreasing).

The inverse dynamics of an extraction unit is modeled by applied the input from the initial state of the stage at the final state of the stage.

The extract flow rate control system is shown in Fig.4.

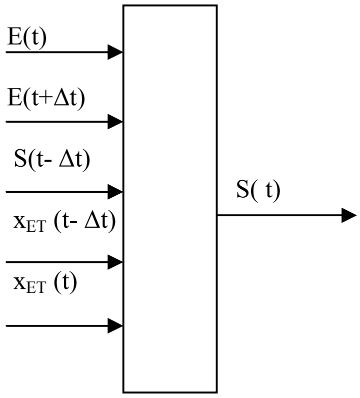

Fig.4 Extract flow rate control system model

Dynamic control function for extract flow rate is:

$$S(t)=f(E(t), E(t+\Delta t), x_E(t-\Delta t), x_E(t), S(t-\Delta t)) \quad (2)$$

Corresponding rules can be generating as shown in section V.

Raffinate flow rate control system is shown in Fig. 5.

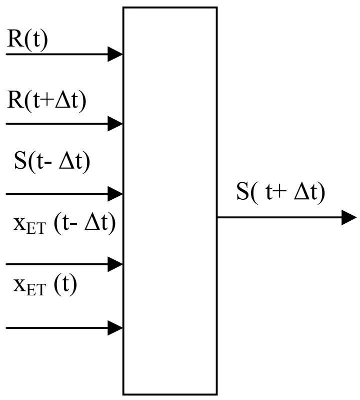

Fig. 5 Raffinate flow rate control model

Dynamic control function for raffinate flow rate is:

$$S(t)=f(R(t), R(t+\Delta t), x_E(t-\Delta t), x_E(t), S(t-\Delta t)) \quad (3)$$

Outlet extract composition control model is shown in Fig.6. Dynamic control function for the extract composition is given by eq. (4).

Control model for extract composition control to raffinate composition disturbance has shown in Fig. 7 and control function has given by eq.(5).

Control model for extract composition control for temperature disturbance is shown in Fig.8 and control function given by eq.(6).

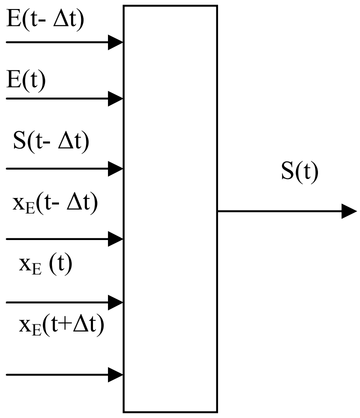

Fig. 6 Outlet extract composition control system model

Dynamic control for outlet extract composition is:

$$S(t)= f(E(t),E(t-\Delta t),x_E(t-\Delta t), x_E(t), x_E(t+\Delta t), S(t-\Delta t)) \quad (4)$$

Corresponding rules is shown in section V.

Many other systems were designed for control. One of them is shown in Fig.7 and Fig.8.

Control function for extract composition control for raffinate composition disturbance is:

$$S(t+\Delta t)=f(E(t), E(t+\Delta t), x_E(t), y_E(t+\Delta t), x_R(t), x_R(t+\Delta t), S(t-\Delta t), S(t),M(t)) \quad (5)$$

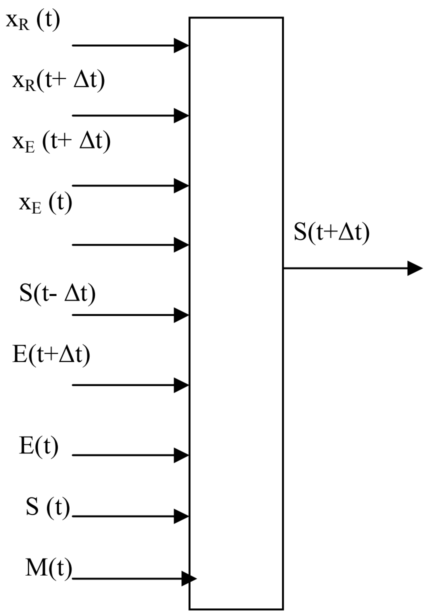

Fig.7 An inverse extract control model incorporating inlet raffinate phase composition changes

Control function for extract composition control for temperature disturbance is:

$$S(t+\Delta t)=f(T(t),T(t+\Delta t),E(t+\Delta t), x_E(t), y_E(t+\Delta t), x_R(t), x_R(t+\Delta t), S(t-\Delta t), S(t),M(t)) \quad (6)$$

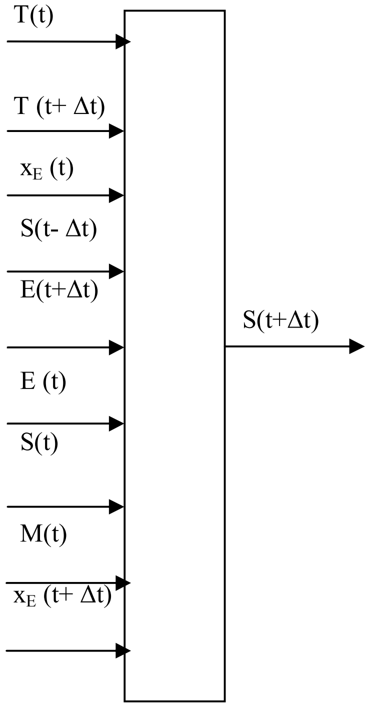

Fig.8 Dynamic control of the extract composition to solvent flow rate disturbance

V. RULES STE FOR STAGE UNIT

A control system was generating using a many rules. Some of them follow:

Rule set number 1:
IF S(t) is low THEN E(t+Δt) is decreasing .
IF S(t) is high THEN E(t+Δt) is increasing .

Rule set number 2:
IF S(t) is high AND E(t) is medium THEN x_E(t+Δt) is increasing.
IF S(t) is low AND E(t) high THEN x_E(t+Δt) is increasing.

Rule set number 3:
IF x_R(t) is high AND R(t) is high THEN S(t+Δt) is high.
IF x_R(t) is low AND R(t) is low THEN S(t+Δt) is low.

Rule set number 4:
IF S(t) is high THEN x_E(t) is increasing .
IF S(t) is low THEN x_E(t) is decreasing.

VI. THE COUNTER-CURRENT LIQUID-LIQUID EXTRACTION COLUMN

The basic principles of liquid-liquid extraction are covered with several extraction equipment. Stage wise contactors, in which the liquids are alternately contacted, mixed and then separated in a series of stages. Differential contactors, in which the phases are continuously in contact in the extractor and are only separated at the exits, for example, in packed column extractors.

The number of stages required, the throughputs, the settings characteristics of the phases, and the available floor area and head room need to be taken into consideration when selecting an extractor for a particular application.

The key component of this liquid phase, the phase from which the solute is extracted, is called A, the transfered substance, the solute B. The extraction solvent is the liquid added to the process to extract the substance B from the feed. The solvent can be pure component, S but usually contains small quantities of B and A. The solvent phase leaving the extractor is the extract. The extract contains mainly S and extracted component B but also small quantities of A. The raffinate is the liquid phase left from the feed after being contacted by the extraction solvent, it is composed mainly of A, but generally small quantities of the extracted component B and solvent S.

Liquid-liquid extraction is primarily applied where direct separation methods such as distillation and crystalization can not be used or are too costly. Liquid-liquid extraction is also emloyed when the components to be separated are heat sensitive (antibiotics) or relatively nonvolatile (mineral salts), similar boiling points, high boiling points, in azeotrope mixture and recovery nuclear fuels.

An extraction column for counter current multistage extraction methanol from water by ethyl-acetate, which has shown in Fig. 9, was used. Let consider the stripping of component B from A+B freed mixture using solvent S. The main state variables characterizing of the process are extract flow rate E, extract composition of the extract stream in inlet (pure solvent), extract composition at the outlet of the column, raffinate flow rate, raffinate composition in inlet and temperature of the liquid phases. Distribution coefficient $k_{L/L}$ =0.0589. Methanol and ethyl-acetate have built azeotrope at the 0.917 mole fraction of methanol and 0.083 mole fraction of ethyl-acetate [11-[15].

The steady state parameters for examined process are given in Table 1.

A dynamic model for the extraction column control can be obtained using of the first principle modelling approach.

Material balance arraund the bottom of the cascade,

$$R_{j+1} + E_{J+1} - R_J - E_J = \frac{dm_J}{dt} \qquad (7)$$

where E_{J+1} is mass flow rate of fresh solvent does not contain either A or B, R_J is flow rate of the stripped rafinate phase, E_J is extract leaving stage J. R_{j+1} is raffinate entering stage j, and m is hold up.

Table1. The steady state parameters

Extract flow rate E, mole/h	5.0
Solvent S, mole /h	4.0
Inlet extract methanol composition $x_{E,j}$, mole/mole	0.000
Outlet extract methanol composition $y_{E,j+1}$, mole/mole	0.035
Rafinate flow rate R, mole/h	10.00
Inlet rafinate methanol composition $x_{R,1}$, mole/mole	0.450
Outlet rafinate methanol composition, x_{RJ}, mole/mole	0.2
Liquid temperature T_j , ˚C	25.0
Hold up, kg	0.6
Pressure, bar	1.00

Material balance for stage j,

$$R_{j-1} + E_{j+1} - R_j - E_j = \frac{dm_j}{dt} \quad (8)$$

or

$$R_{j-1} + E_{j+1} - R_j - E_j - L_j = \frac{dm_j}{dt}$$

if takes into account the net downward flow L of A+B which the same for every stage j.
Total energy balance,

$$R_{j-1}h_{j-1} + E_{j+1}H_{j+1} - R_j h_j - E_j H_j = \frac{du_j}{dt} \quad (9)$$

or

$$R_{j-1}\rho c_P T_{j-1} + E_{j+1}\rho c_P T_{j+1} - R_j \rho c_P T_j - E_j \rho c_P T_j - = \rho c_P \frac{du_j}{dt} \quad (10)$$

were h is enthaply of the raffinate stream, H is enthalpy of the extract stream, u is energy accumulation, T is temperature, ρ is density, c_P is heat capacity.

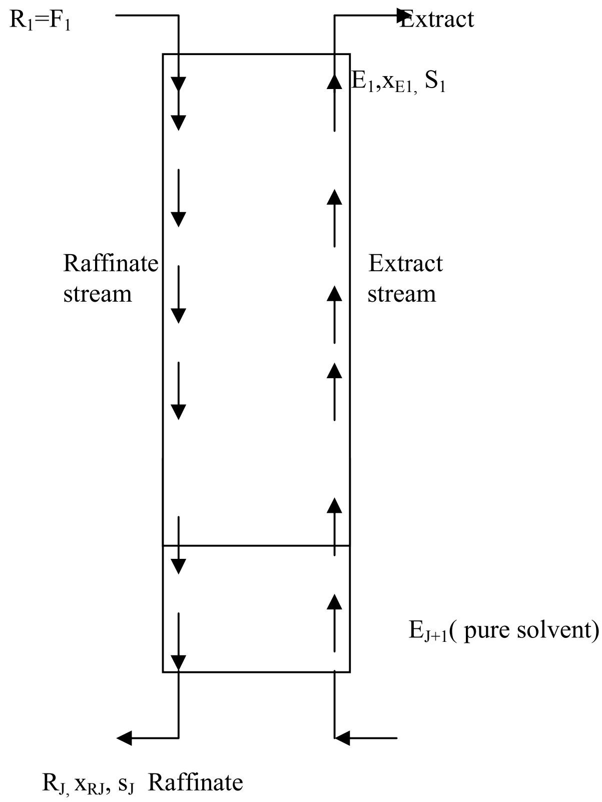

Fig.9 The extraction column scheme

Material balance for the solvent:

$$R_{j-1}s_{j-1} + E_{j+1}S_{j+1} - R_j s_j - E_j S_j = \frac{dm_j}{dt} \quad (11)$$

or

$$R_{j-1}s_{j-1} + E_{j+1}S_{j+1} - R_j s_j - E_j S_j - L s_L = \frac{dm_j}{dt} \quad (12)$$

where S and s are defined by

$$S \; or \; s = \frac{Solvent}{A + B}$$

For the component B:

$$R_{j-1}x_{R\,j-1} + E_{j+1}x_{E\,j+1} - R_j x_{R\,j} - E_j x_{E\,j} = \frac{dm_j}{dt} \quad (13)$$

or

$$R_{j-1}x_{R\,j-1} + E_{j+1}x_{E\,j+1} - R_j x_{R\,j} - E_j x_{E\,j} - Lx_L = \frac{dm_j}{dt} \quad (14)$$

where

$$x_R = \frac{B}{A+B}, \text{ and } \quad x_E = \frac{B}{A+B}$$

$x_R(t)$ is raffinate phase composition, $x_E(t)$ is the extract phase composition. If the fresh solvent fed to the bottom stage is pure $x_L = x_{EJ}$.

The output values for various disturbance to the inputs are obtained by simulation.

VI. RESULTS AND DISCUSSION

A random disturbance were used for control response. The investigation is carried out during a time period from 0 to 2400s. The process inputs and outputs are considered during the simulation. The sampling interval was 10s.

In Fig.10 the disturbance with varying amplitude to the raffinate stream flow rate is shown. In Fig.11 the disturbance with varying amplitude in inlet raffinate composition has shown. The obtained control results are shown in Fig.12-Fig.15.

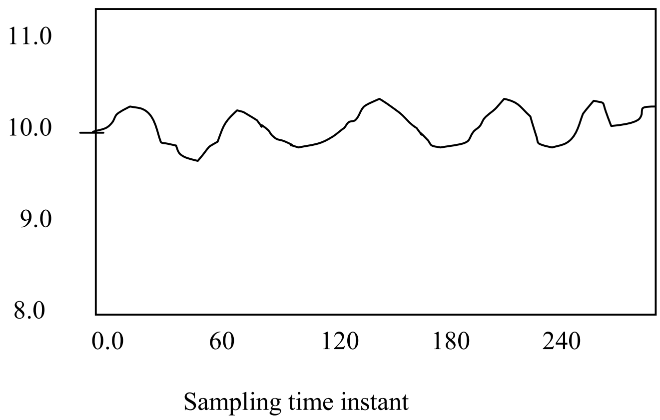

Fig.10 Disturbance with varying amplitude in the raffinate flow rate

Dynamic response of the outlet extract composition to disturbance in the raffinate flow rate is shown in Fig.12. Dynamic response of the solvent flow rate to disturbance in inlet raffinate composition is shown in Fig.13. The response of the extract outlet composition to the disturbance in the inlet raffinate composition is shown in Fig.14.

The temperature changing on the disturbance in inlet raffinate flow rate is shown in Fig.15. The temperature response has shown very stable.

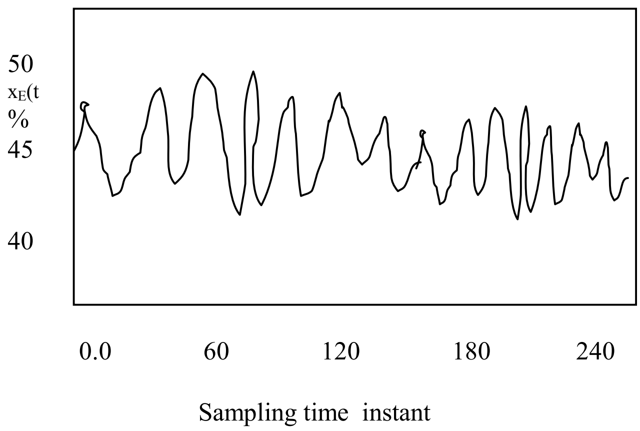

Fig.11Disturbance with varying amplitude in the inlet raffinate composition

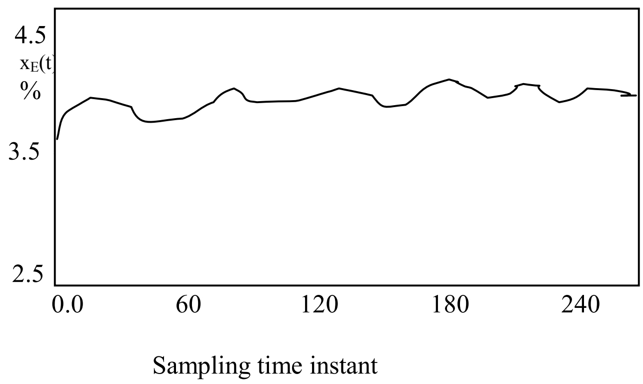

Fig.12 Dynamic response of the outlet extract composition to disturbance with varying amplitude in the inlet raffinate flow rate

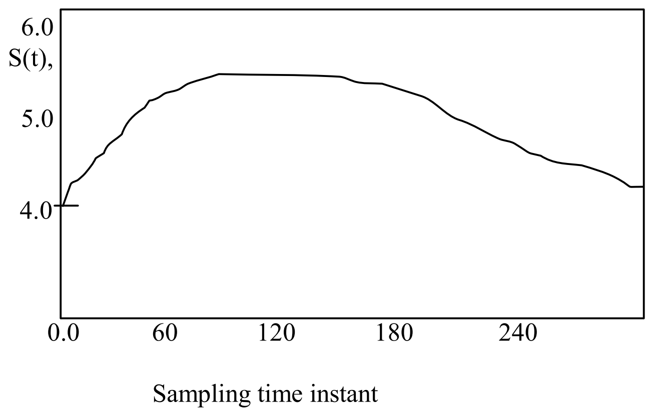

Fig.13 Dynamic response of the solvent flow to the disturbance in the inlet raffinate composition as shown in Fig.11

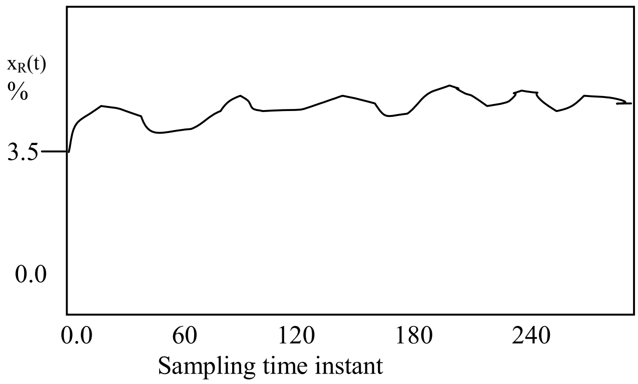

Fig.14 Dynamic response of the outlet extract composition to the disturbance with varying amplitude in inlet raffinate composition

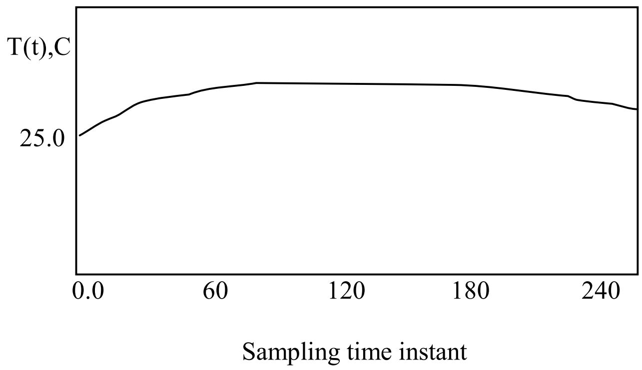

Fig.15 Temperature response to the disturbance with varying amplitude in inlet raffinate flow rate

The disturbance with fixed amplitude in the raffinate flow rate has shown in Fig. 16.

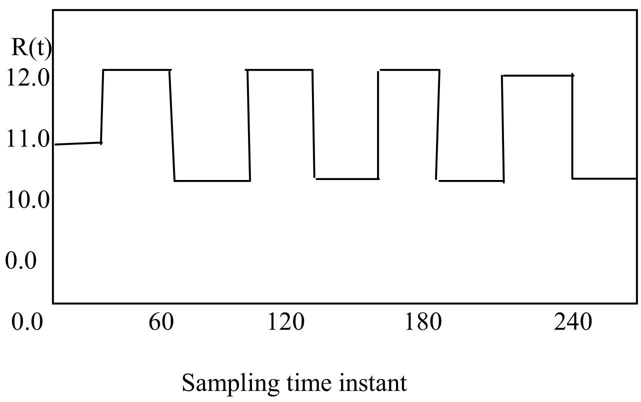

Fig.16 The disturbance in the raffinate flow rate with fixed amplitude

The disturbance in the raffinate composition with fixed amplitude is shown in Fig. 17.

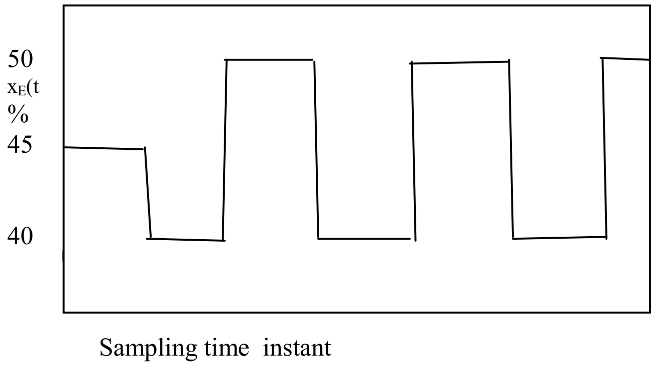

Fig.17 Disturbance with fixed amplitude in the inlet raffinate composition

Dynamic response of the outlet raffinate composition to the disturbance with constant amplitude in the raffinate flow rate is shown in Fig.18. Dynamic response of the solvent flow to disturbance with fixed amplitude in inlet composition is shown in Fig.19. The response of the raffinate outlet composition to the disturbance with fixed amplitude in the inlet raffinate composition is shown in Fig.20.

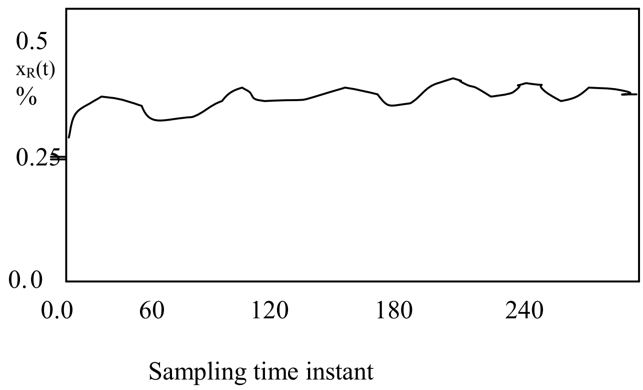

Fig.18 Dynamic response of the outlet raffinate composition to disturbance with fixed amplitude in the inlet raffinate flow rate

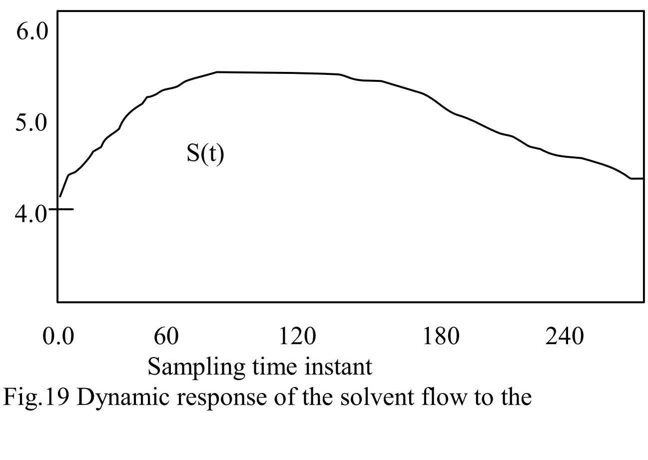

Fig.19 Dynamic response of the solvent flow to the

disturbance with fixed amplitude in the inlet raffinate composition

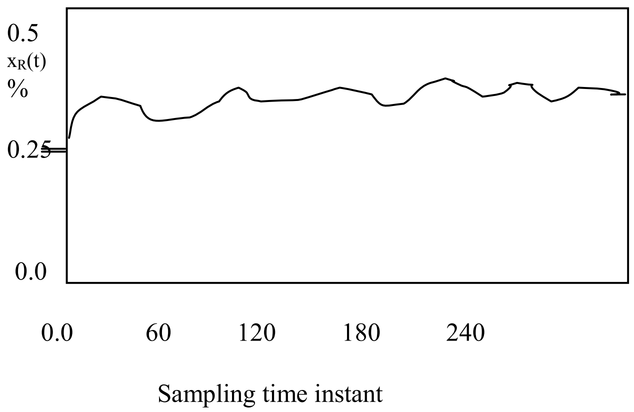

Fig.20 Dynamic response of the outlet raffinate composition to the disturbance with fixed amplitude in inlet raffinate composition

The extract composition response to the temperature disturbance with constant amplitude ia shown in Fig.21.

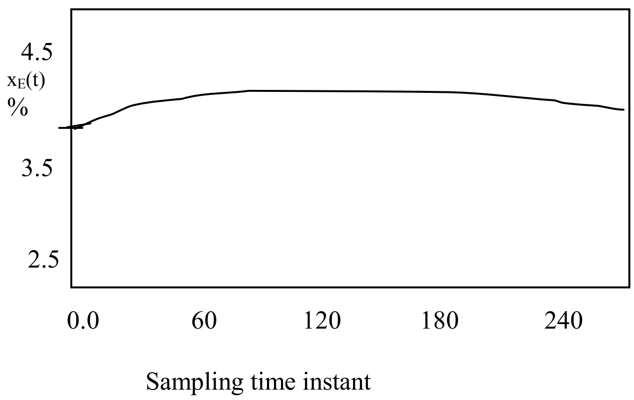

Fig.21 Extract composition response to the temperature disturbance with fixed amplitude

VII. CONCLUSION

Dynamic response of the liquid-liquid extraction time in multistage process unit was investigated. The counter-current extraction column was examined.

The dynamic responses of the flow rate and composition control loops to a random disturbance with varying amplitude and with constant amplitude were examined. Inverse modelling method was applied. Numerical simulation was presented to show validity of the proposed method.

The obtained results are shown the system reaches the set point faster with less overshoot, hence the settling time is the shortest, especially for unstable regions.

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Notation
A-water
B-methanol
E-extract stream flow rate, mole/h
H-extract stream enthalpy, J/mole
h- raffinate stream enthalpy, J/mole
R-raffinate flow rate, mole/h
M-total holdup, mole
m- holdup on stage, kg
S-solvent flow rate, mole/h
s-set point
T- temperature, ^{0}C
u-energy, J
u-manipulated variable
x_R-raffinate strean composition, mole/mole
x_E-extract stream composition, mole/mole
Y-control variable

Index
E-extract
j – any stage
i- any component
R-raffinate
S-solvent
0-inlet

Greek symbol
Δt-sampling interval

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