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Composition Monitoring of Batch Distillation Column using Adaptive Neuro Fuzzy Inference System Estimator

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Abstract
Batch Distillation is Significant Unit Operation carried over in the adequate forte chemicals, pharmaceuticals, food processing and bio-compatible materials for implants and prosthetics, gels for medical application. So the ultimatum and vagueness in stipulations for these compounds have augmented lately, in seizure which upturns the approbation of the ritual of batch distillation. Batch distillation has always been an important part of the production of seasonal or low capacity and high-purity chemicals. Since a variety of substances found in everyday life have been made with the help of chemicals like manufacturing of inorganic and organic industrial chemicals, ceramics, fuels , fertilizers , plastics, detergents and detergent products (soap, shampoo, cleaning fluids), fragrances and flavors, dietary supplements and pharmaceuticals, food processing, environmental technology. In order to make cost effective of the entire production chain, the monitoring of batch distillation column is through by using ANFIS Design Estimator. In this study, the ANFIS state estimator that surmise the product composition from temperature measurements are tested using a batch distillation column simulation.

Keywords
Batch Distillation, Simulation, Adaptive Neuro - Fuzzy Inference System, State Estimation.

I. Introduction

The Chemical Engineering deals with the process of converting chemicals into more useful form. The batch distillation plays the imperative role in chemical Industries. Batch Distillation is Significant Unit Operation carried over in the adequate forte chemicals, pharmaceuticals, food processing. So the ultimatum and vagueness in stipulations for these compounds have augmented lately, in seizure which upturns the approbation of the ritual of batch distillation. Batch distillation has always been an important part of the production of seasonal or low capacity and high-purity chemicals. Instead of exhausting sundry unceasing column in shackle, multiple compounds can be gotten from a sole batch distillation column.

Around a need of current composition of the column to amenity the process state, the controller will require the unceasing material stream from the column, including the compositions reflux ratio and temperatures. This composition information can be gotten from the standard temperature feedback controllers. Although the temperature measurements are cheapo and have tiny deferments, they are not precise gauges of composition. For the other way inferential estimators gives subordinate temperature measurement. State estimation can be demarcated as the progression of mining gen from facts which encompass valuable gen about a structure and state estimator is the utensil responsible for gathering valued measurements to deduce the anticipated gen. Contemporary estimators besides custom branded relationships in calculating the anticipated gen from erstwhile knowledge of the system the extent of errors, the effects of instabilities and control movements on the system. The methods of minimization illustrate the method of estimation and the use of minimization makes the estimate of mined information “ideal”.

Nevertheless, the ample input-output gen is bred from the progression, ways and means in artificial intelligence methods that use this collected information to design a state estimator. ANFIS pattern is one in which a fuzzy inference system is instigated exhausting adaptive networks. It hypotheses input-output mapping centered both human knowledge (fuzzy if-then rules) and on bred input output data duos exhausting a hybrid algorithm that is the combination of the gradient descent and least square estimates.

In this study, the aim is to design state estimators that deduce the constituent concentrations of the batch distillation column from the measured tray temperatures. The designed estimator is further tested using a rigorous column simulation to find its performance. The ANFIS is centered on the linear dynamic model of the process. ANFIS estimator is premeditated by the data cliques which comprise temperature values and consistent composition values obtained from the rigorous model. The performances of the developed estimators are tested by using the rigorous column simulation and discrete measurements of the top product compositions.

A. Industrial fractionating columns

In a conformist batch distillation, a liquid mixture is charged into a vessel and heat is added to produce vapor fed into a rectifying column. A concentration of the lightest component increases in the upper trays sequentially in the column and a concentration of a subsequent heavy component increases in a still pot. As the concentration of the lightest component in the distillate reaches its specified purity level or the unit in total reflux operation is taken to a steady state, the distillate product withdrawal is then begun. The operation of a batch column is divided into a number of stages as in the order of realization; start-up period, distillation at total-reflux, withdrawal of the lightest product, removal of a slop-cut, withdrawal of the next heaviest product, removal of a second slop-cut and so on.

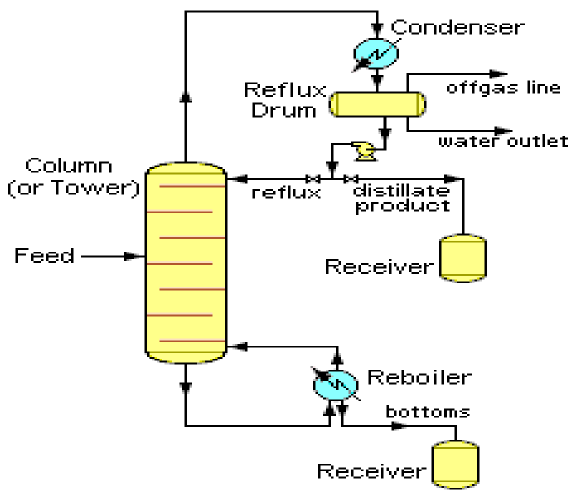

Fig.1: Shows the schematic of a continuous fractionating column.

Distillation is one of the most common and energy intensive separation processes. In a typical chemical plant, it accounts for about 40% of the total energy consumption. Industrial distillation is typically performed in large, vertical cylindrical columns known as "distillation towers" or "distillation columns" with diameters ranging from about 65 centimeters to 6 meters and heights ranging from about 6 meters to 60 meters or more. Industrial distillation towers are usually operated at a continuous steady state. Unless disturbed by changes in feed, heat, ambient temperature, or condensing, the amount of feed being added normally equals the amount of product being removed. It should also be noted that the amount of heat entering the column from the reboiler and with the feed must equal the amount heat removed by the overhead condenser and with the products.
However, many industrial fractionating columns have outlets at intervals up the column so that multiple products having different boiling ranges may be withdrawn from a column distilling a multi-component feed stream. The "lightest" products with the lowest boiling points exit from the top of the columns and the "heaviest" products with the highest boiling points exit from the bottom. Industrial fractionating columns use external reflux to achieve better separation of products. Reflux refers to the portion of the condensed overhead liquid product that returns to the upper part of the fractionating column. Inside the column, the down flowing reflux liquid provides cooling and condensation of up flowing vapors thereby increasing the efficacy of the distillation tower. The more reflux and/or more trays provided, the better is the tower's separation of lower boiling materials from higher boiling materials.
The design and operation of a fractionating column depends on the composition of the feed and as well as the composition of the desired products. Given a simple, binary component feed, analytical methods such as the McCabe-Thiele method or the Fenske equation can be used. For a multi-component feed, simulation models are used both for design, operation and construction. Bubble-cap "trays" or "plates" are one of the types of physical devices which are used to provide good contact between the up flowing vapor and the down flowing liquid inside an industrial fractionating column. The efficiency of a tray or plate is typically lower than that of a theoretical 100% efficient equilibrium stage. Hence, a fractionating column almost always needs more actual, physical plates than the required number of theoretical vapor-liquid equilibrium stages.

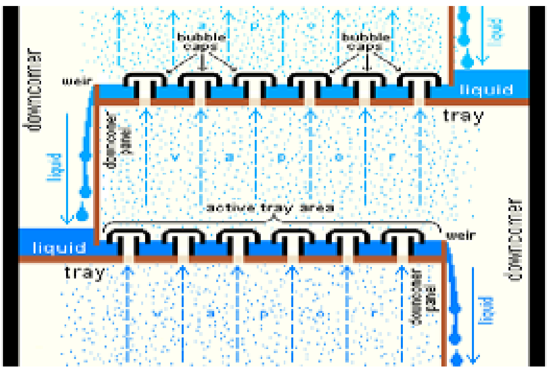

Fig. 2 : Section of fractionating tower of a Pair of trays with bubble caps.

In industrial uses, sometimes a packing material is used in the column instead of trays, especially when low pressure drops across the column are required, as when operating under vacuum. This packing material can either be random dumped packing (1–3" wide) such as Raschig rings or structured sheet metal. Liquids tend to wet the surface of the packing and the vapors pass across this wetted surface, where mass transfer takes place. Differently shaped packing's have different surface areas and void space between packing's. Both of these factors affect packing performance.

B. The Boiling Point Diagram

The boiling point diagram shows how the equilibrium compositions of the components in a liquid mixture vary with temperature at a fixed pressure.
Consider an example of a liquid mixture containing 2 components (A and B) - a binary mixture.
This has the following boiling point diagram. The boiling point of A is that at which the mole fraction of A is 1. The boiling point of B is that at which the mole fraction of A is 0. In this example, A is the more volatile component and therefore has a lower boiling point than B. The upper curve in the diagram is called the dew-point curve while the lower one is called the bubble-point curve.

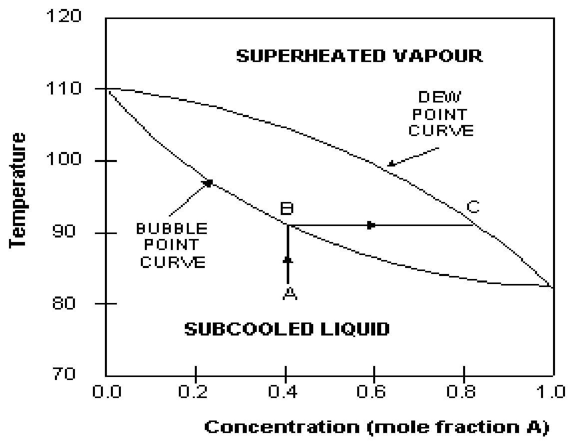

Fig. 3 : Boiling Point Diagram

For example, when a sub cooled liquid with mole fraction of A=0.4 (point A) is heated, its concentration remains constant until it reaches the bubble-point (point B), when it starts to boil. The vapour evolved during the boiling has the equilibrium composition given by point C, approximately 0.8 m ole fraction A. This is approximately 50% richer in A than the original liquid.
C. Difference between liquid and vapour compositions is the basis for distillation operations.
Relative volatility is a measure of the differences in volatility between 2 components, and hence their boiling points. It indicates how easy or difficult a particular separation will be. The relative volatility of component 'i' with respect to component 'j' is defined as

$$\alpha_{ij} = \left((y_i|x_i) \middle| (y_j|x_j) \right)$$

xi = mole fraction of component 'i' in the liquid
yi = mole fraction of component 'i' in the Vapour
Thus if the relative volatility between 2 components is very close to one, it is an indication that they have very similar vapour pressure characteristics. This means that they have very similar boiling points and therefore, it will be difficult to separate the two components via distillation.

Distillation columns are designed based on the boiling point properties of the components in the mixtures being separated. Thus the sizes, particularly the height, of distillation columns are determined by the vapour liquid equilibrium (VLE) data for the mixtures.

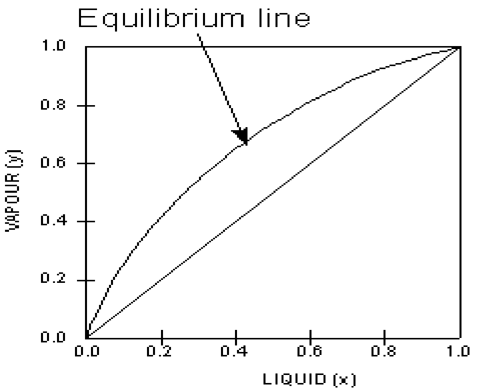

Fig.4 : Equilibrium line

The most intriguing VLE curves are generated by azeotropic systems. In other words azeotropic systems give rise to VLE plots where the equilibrium curves crosses the diagonals.

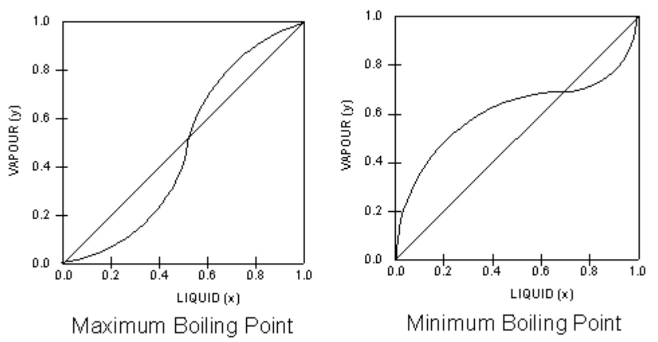

Fig. 5: VLE Curves generated by Azeotropic System

II. Anfis Estimator

Neuro-Fuzzy systems are the systems that neural networks (NN) are incorporated in fuzzy systems, which can use knowledge automatically by learning algorithms of NNs. They can be viewed as a mixture of local experts. Adaptive Neuro-Fuzzy inference system (ANFIS) is one of the examples of Neuro Fuzzy systems in which a fuzzy system is implemented in the framework of adaptive networks. ANFIS constructs an input-output mapping based both on human knowledge (in the form of fuzzy rules) and on generated input-output data pairs. Effective control for distillation systems, which are one of the important unit operations for chemical industries, can be easily designed with the known composition values.

Online measurements of the compositions can be done using direct composition analyzers.

However, online composition measurement is not feasible, since, these analyzer's, like gas chromatographs, involve large measurement delays. As an alternative, compositions can be estimated from temperature measurements. Thus, an online estimator that utilizes temperature measurements can be used to infer the produced compositions. In this study, ANFIS estimators are designed to infer the top and bottom product compositions in a continuous distillation column and to infer the reflux drum compositions in a batch distillation column from the measurable tray temperatures. Simple ANFIS structure is designed and implemented in adaptive closed loop control scheme.

A. ANFIS Architecture

In ANFIS, Takagi-Sugeno type fuzzy inference system is used. The output of each rule can be a linear combination of input variables plus a constant term or can be only a constant term. The final output is the weighted average of each rule's output.

The rule base contains two Takagi-Sugeno if then rules as follows:

Rule1: If x is A1 and y is B1, then 1 1 1 1 f = p x + q y + r

Rule2: If x is 2 A and y is 2 B, then 2 2 2 2 f = p x + q y + r

A fuzzy if-then rule (fuzzy rule, fuzzy implication, or fuzzy conditional statement) is expressed as follow:

If x is A then y is B

Where A and B linguistic values defined by fuzzy sets. "x is A" is called "antecedent" or "premise", while "y is B" is called the "consequence" or "conclusion" (Castillo and Melin 2000).

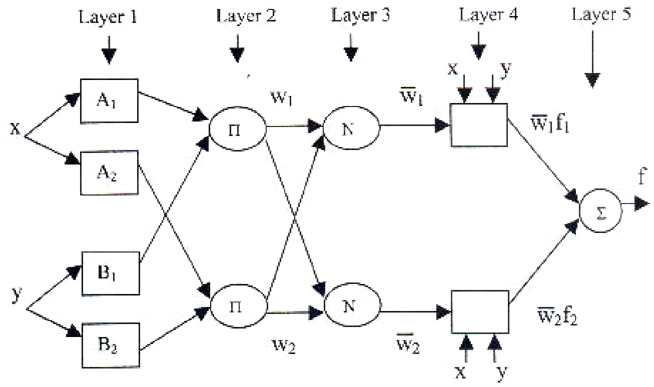

Fig.6 : Basic Structure of ANFIS

B. Basic Structure of ANFIS

The designed ANFIS estimator is used to infer the compositions from measurable tray temperatures in batch and continuous distillation columns. In estimator design process, different ANFISs are constructed and trained to find the architecture that gives the best performance as an estimator. In order to design an estimator, first, training data sets should be generated to train the estimator networks. These data sets consist of estimator inputs and desired output values. They are produced from the process input45 output data. Performances of the trained estimators are evaluated with model simulations and best estimator architecture is obtained. These simulations are made to verify and to generalize the ANFIS structures. Verification is done to show how good the estimator structure learned the given training data. This is carried out by simulating the column models with specific initial process inputs used in obtaining training data sets.

III. Results and Discussion

In this part of the study, it is aimed to investigate the ANFIS structure performances in batch distillation column. In continuous distillation column, since four components were separated, three tray temperatures were used as the estimator's input. It was also seen from the results that three tray temperature measurements were sufficient to estimate the compositions. Training of ANFIS structures Estimations based on simulations for continuous column indicated that, Triangular structures are better than Gaussian structures both in verification and generalization. Therefore, only triangular structure's performances are used in batch distillation studies. These structures are trained with generated training data sets. Thus, number of trainings and test simulations are decreased. The ANFIS estimator design is performed in three phases. First, input process variables which are in operational range are changed and output variables are obtained from rigorous model simulations. Then, training data sets are generated using these input - output data and different ANFIS architectures are trained with these data sets.

Simulation Results

After trained the structures, estimators' verification and generalization capabilities are tested using the rigorous model of the column as a real plant.

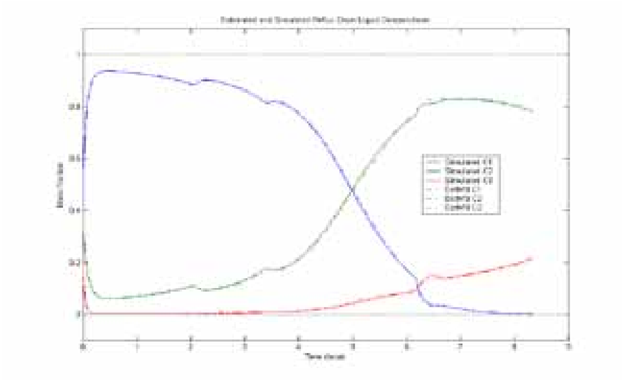

Fig.7 : Simulation Result

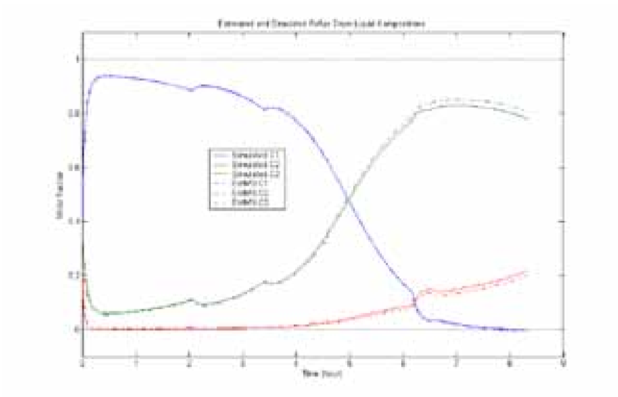

Fig.8 : Simulation Result

IV. Conclusion

The study is aimed to estimate the compositions in the batch distillation column from temperature measurements using ANFIS estimator. It is found that, the input -output data of the rigorous plant simulation ANFIS estimator is trained and from several simulation runs for different architectures of ANFIS estimator the estimator performance is optimized. It is seen that ANFIS estimator performs more accurate estimations of the reflux-drum compositions than the EKF does. The superior performance of the ANFIS is due to having the information directly taken from the input -output data of the simulated plant.

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