Fuzzy Logic Based Automation and Control of Vacuum Neutralisation and Evaporation for Ammonium Nitrate (NH₄NO₃) Prilling Process: A Simulation Approach

Shivani Gupta¹ and Dinesh Singh Rana²
¹Department of Electrical Engineering
Geeta Institute of Management and Technology, Kanipla, Kurukshetra
²Department of Instrumentation, Kurukshetra University, Kurukshetra
Email: shivanigupta.2988@gmail.com, dineshsrana24@rediffmail.com

Abstract—Ammonium Nitrate (AN) prilling Process is nonlinear and non stationery in nature. Due to uncertainty created by nonlinear conditions like temperature rise due to exothermic reaction in the neutraliser, level in the evaporator, velocity of the cooling air in prilling tower, temperature and moisture content of prills and size of the prills. Due to these difficulties the degree of automation is quite low in such process industries. The fuzzy logic control (FLC) is proven better for such types of processes where process dynamics is complex. In present paper, a fuzzy logic based scheme has been proposed for automation and control of Vacuum neutralisation and evaporation stage for ammonium nitrate (NH₄NO₃) prilling process. The system design starts from identification of inputs, Outputs and the membership function for each condition from normal operation up to emergency operation of ammonium nitrate prilling process.

Index Terms: NH₄NO₃, Membership function, AN prills, P&ID, FLC

I. INTRODUCTION

Your goal is to simulate the usual appearance of papers in Ammonium Nitrate (AN) is made by the reaction between gaseous ammonia and aqueous nitric acid. The product ammonium nitrate solution so formed can be used in various ways. It can be used as a solution or it can be formed into solid ammonium nitrate by prilling. The Ammonium Nitrate production process comprises three main unit operations: Neutralisation, Evaporation, solidification. The exothermic reaction of nitric acid and ammonia gas takes place in the neutraliser. This equipment can operate at a variety of operating pressures, temperatures and concentrations [1]. The reaction of ammonium nitrate is as follows:

Ammonium nitrate formation

\[ \text{NH}_3 (g) + \text{HNO}_3 (aq.) \rightarrow \text{NH}_4\text{NO}_3 (aq.) \]

The evaporation is normally required to remove the majority of the water which is present in the ammonium nitrate solution and produce an ammonium nitrate solution of the required concentration [1]. This melt is sprayed in a prilling tower. Droplets of NH₄NO₃ melt falls in counter-current to cold stream of air and are partially crystallised [1-2]. The AN prills formed are sent to the dryer drums. It is dried in the drums by hot
air flowing in the first part in co-current and second part in counter current with the product. From the outlet of dryer, the product is conveyed to the screen where undersize and oversize particles are separated from the final product [1-2]. Undersized and oversized prills are recycled to AN solution tank where they are dissolved and returned to the prilling section. On size product coming from the screen sent to fluidised bed cooler to be cooled below transition point, it is subsequently cooled with an anti caking agent to avoid that end product picks up moisture in the storage [1-2]. Ammonium Nitrate manufacturing process has been illustrated by the block diagram shown in figure 1.

In present paper, a fuzzy logic based scheme has been proposed for automation and control of Vacuum neutralisation and evaporation stage for ammonium nitrate\(\text{(NH}_4\text{NO}_3\text{)}\) prilling process.

II. METHODOLOGY FOR AUTOMATION OF VACUUM NEUTRALISATION AND EVAPORATION

Most of the chemical processes are nonlinear in nature and also non stationary [3] thus it is difficult to derive and identify an appropriate dynamic model for traditional controllers. The quality of the model which is loss of precision from linearization and/or uncertainties in the system’s parameters negatively influences the quality of the resulting control. In many cases of industrial process control, for example, in chemical industries, the degree of automation is quite low. This change leads to deterioration in the performance of the linear controller. It is very difficult to get an accurate and linearized mathematical model therefore the fuzzy control technology is applied [4-5].

In order to achieve objective of ammonium nitrate prilling process automation and control, first we need to develop the process flow diagram and P& ID of Ammonium Nitrate Prilling process. P&IDs play a significant role in the maintenance and modification of the process that it describes [6]. It is critical to demonstrate the physical sequence of equipment & systems, as well as how these systems connect. During the design stage, the diagram provides the basis for the development of system control schemes, allowing for further safety & operational investigations [7-9]. The whole Prilling plant is divided into three small units and for each unit, fuzzy logic based controller has been developed. In present study we have used fuzzyTECH software 5.5 tools for implementation of automation and control simulation of ammonium nitrate prilling process. fuzzyTECH contain all editors, analyzers and tools to design a complete fuzzy logic system. It supports various fuzzy logic inference methods and algorithms. After the fuzzyTECH software assigns degrees of membership to the linguistic terms, the software processes these terms by making fuzzy logic inferences. It produces crisp output values through the process of defuzzification using standard membership functions like triangular type, trapezoidal type etc. in most practical applications[10-13]. fuzzyTECH offers the following analyzer tools to verify a fuzzy system’s behaviour:
Transfer Plot: It analyzes the static input/output characteristic of a fuzzy logic system as a colour plot. Two input variables and one output variable are always shown in this graph. The two input variables are shown on the horizontal and vertical axis, and the value of the output variable is displayed as the colour of the area spanned by the input variables.

3D Plot: It analyzes the static input/output characteristic of a fuzzy logic system as a scalable rotational 3D Plot. Use the rightmost drop down list box to change the resolution of the 3D Plot. We can select variables for display in the plot by using the drop down list boxes (below the 3D Plot’s toolbar) displaying variable names. The four arrow buttons on the left side of the toolbar rotate the plot in all directions.

Time Plot: It analyzes the time response characteristic of a fuzzy logic system.

Rule Analyzer: It analyzes which rules had influence on the value of an output or an intermediate variable.

Statistics: It controls the use of fuzzy rules by a statistics column in the Spreadsheet Rule Editor.

Trace: It traces the dynamic input/output characteristic of a fuzzy logic system. The traced data can be saved. The File Recorder Debug mode allows us to replay, step through, visualize and analyze the trace.

A. Steps for creating a fuzzy system

1. Go to fuzzy design wizard, create a new system.
2. Define no. of input and output variables. These variables are further divided into linguistic terms.
3. Each variable possess a given value that is assigned in variable dialog box.
4. A rule box is defined which holds the inference with the product values and connects systems output to systems inputs.
5. A rule can be changed by changing its DOS (Degree of support) value from 0 to 1.
6. Evaluate the IF-THEN conditions for various inputs and outputs.
7. It can be analyzed using various plots: Time plot, Transfer plot and 3D plot.

The P&ID diagram for Vacuum neutralisation and evaporation stage of Ammonium nitrate prilling process has been shown in figure 2. In this stage, concentration of NH₄NO₃ solution, pressure, temperature at which neutralizer operates, level in the evaporator, pH of solution after evaporation, and pressure of steam in evaporator are the parameters which requires to monitor and control for best performance and yield of plant/process.

![Diagram of Vacuum Neutralization and Evaporation Process](image)

Figure 2: Process Equipment and Instrumentation lay out of Vacuum Neutralization and Evaporation
B. Control loop for Vacuum Neutralization and Evaporation stage of prilling process

The Fuzzy logic control of the vacuum neutralisation and evaporation process is illustrated in figure 3. The IF-THEN rules for step 1 are:

- IF conc. NH3gas AND conc.HNO3 AND pressure AND Temp THEN conc.NH4NO3sol AND Flow.NH4NO3 AND Heat AND pH.sol.NH4NO3
- IF Flow.NH4NO3sol AND Process_conden THEN Steam_pressure AND Steam.Temp AND To_valveV2
- IF Coolinwater AND Steam_pressure AND Steam.Temp THEN Clean_condenst
- IF Level AND pressure_steam AND To_valveV2 THEN conc.of melt AND pH_after evaporation AND Temp.melt AND To_vaporseprtr2
- IF Process_conden AND To_vaporseprtr2 THEN AN.melt AND Tempsteamout
- IF Coolinwater AND Tempsteamout THEN condensate

Figure 3: Fuzzy logic controller for Vacuum Neutralization and Evaporation stage of prilling process

Figure 4 shows the membership function for Concentration C1 of HNO3; figure 5 shows the membership function for Concentration C2 of NH3, figure 6 shows the membership function for Temperature T1 at which reaction takes place in the neutraliser and figure 7 shows the membership function for Pressure P1. Figure 8 shows the membership function for Concentration C3 of NH4NO3.
Figure 4: Membership function of Concentration $C_1$

Figure 5: Membership function of Concentration $C_2$

Figure 6: Membership function of Temperature $T_1$

Figure 7: Membership function of Pressure $P_1$
The AN solution from Vapour Separator is fed to the Evaporator through Valve V2. The Level L1 and the Pressure P3 are the inputs. The outputs are Concentration of melt C4, Temperature of melt T3 and pH2 after evaporation. Figure 9 shows the membership function of pressure of steam to evaporator P3. Figure 10 shows the membership function of Level L1 of solution in the Evaporator. Figure 11 shows the membership function of Temperature of melt T3. Figure 12 shows membership function of Concentration of melt C4.

III. RESULTS & DISCUSSIONS

The fuzzy logic system for Vacuum Neutralization and Evaporation stage of prilling process is made for formation of concentrated ammonium nitrate solution after neutralisation and evaporation. Here the concentration of NH4NO3, temperature of the neutraliser and level of evaporator and the concentration of the resulting AN melt were controlled. Figure 13 shows the Time Plot of AN Neutraliser plotted between concentration of HNO3, and concentration of NH3 as input and concentration of NH4NO3 as output.
It is inferred from the time plot that IF conc. of HNO$_3$ is high and conc. of NH$_3$ is medium THEN conc. of NH$_4$NO is medium. Figure 14 shows the 3D Plot of AN Neutraliser plotted between pressure and temperature of the neutraliser at the time of reaction as input and concentration of NH$_4$NO$_3$ as output. It is inferred from the time plot that IF pressure is low and temperature is medium THEN conc. of NH$_4$NO$_3$ is medium.

Figure 15 shows the 3D Plot of Evaporator plotted between level in the evaporator and pressure of the steam as input and concentration of melt as output. It is inferred from the time plot that IF level is high and pressure of steam is medium THEN conc. of melt is high.
IV. CONCLUSIONS

The Whole plant of Ammonium Nitrate Prilling process has been divided into three parts and Process Flow Diagram and P&ID has been designed for Vacuum Neutralization and Evaporation. A complete automation of Vacuum Neutralization and Evaporation stage of NH₄NO₃ prilling process has been developed with loop identification at each part of the plant using fuzzy logic. Detail analysis of each control loop has been carried out. The major outcome of our study is that fuzzy logic controller has proven better than conventional controller for controlling non-linear process such as NH₄NO₃ prilling process in present case. Fuzzy logic based automation of ammonium nitrate prilling process may achieves better yield of the ANprills.

REFERENCES

[10] Intelligent systems and controls, Principles and applications by Laxmidhar Behera and Indrani Kar, Published in India by Oxford University Press (2009)