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Design and Development Aspects of Process Instrumentation for a Newly Developed Technology

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Abstract*—Process development is a multidisciplinary field involving experts from various branches of engineering such as chemical, instrumentation, mechanical, electrical and electronics engineering. The role of an instrumentation engineer increases as we move from bench level project to a pilot scale level, and then to a commercial scale level. To design a process and its control effectively, it is necessary to understand the process thoroughly. The main role of an instrumentation engineer involves design, commissioning and maintenance of the instruments and also control of the processes. This paper is based on the authors experience in the design of such systems. The detailed description about the role of an instrumentation engineer in the development of a process and the steps involved in the designing of a chemical process is explained. The general rules to be followed while designing a process are explained in detail with reference to a vacuum distillation process. The design considerations in the vacuum distillation process, control loops and basic instrumentation applied for the equipment and the process lines are explained. These designs and data sheets are used for commissioning and automation of the process plant. Using these data sheets, one can determine the type of instrument to be used for measuring a particular physical parameter, number of instruments required, alarms and interlocks used in the plant and to easily locate any instrument during the maintenance of the plant.
Keywords*— Chemical process designing, applied instrumentation, Instrumentation scale-up, P&ID design, Vacuum distillation process.

I. INTRODUCTION

Process development can be defined as the study of development of a process from a laboratory to a commercial scale. It is not an independent field in chemical engineering, but contains and integrates all fields in process technology such as the basic field's physical transport phenomena, kinetics, thermodynamics, and the applied field's chemical reaction engineering, physical/chemical separations, and equipment design [1]. The starting point generally consists of laboratory results that concern a chemical reaction whose translation into a commercial plant appears viable. To go directly from a laboratory scale to an industrial scale is rarely feasible. As a rule, one or more additional experiments are necessary to reproduce the laboratory results on a larger scale. The main goal of process development is to find out which steps in the process may be expected to present difficulties and which additional research needs to be performed to solve these problems at minimum cost and as quickly as possible. It is here that the methodology of process development, and hence of scale-up, becomes decisive for the success of the operation. Because most operations are scale-dependent, scale modification is an essential part of the work of the process engineer. By studying processes, the so called scaling rules can be defined. Scaling rules allows us to apply knowledge and experience from small laboratory equipment to a large industrial unit.

II. OVERVIEW

The role of an instrumentation engineer in developing a chemical process can be described as follows: for developing a large process industry, the inception comes from an idea based on the needs and requirements. This comes from the involvement of a chemist. Based on the idea, a theory is developed on how the process can be setup by the chemist along with the help of a chemical engineer. Now a lab scale experiment is conducted to check the working of the process. If this experiment is successful, the same process is developed in a bench level which will have more production and requires local measurement and control instruments. Bench level process is carried out by a chemical engineer with little involvement of an instrumentation engineer. Once the bench scale process is successful, before setting up an industry, a pilot scale plant is developed in order to check the productivity and the efficiency of the process on a larger scale [2]. This plant will contain all the measurement, controls, automation and some energy conservation measures. An instrumentation engineer plays a major role in commissioning and maintenance of this plant with the

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help of chemical, mechanical and electrical engineers. Once the pilot scale level runs successfully, a commercial plant is setup which contains all aspects mentioned in a pilot plant with more importance given to the energy conservative measures and the safety aspects of the plant [3]. This will include complete involvement of the electrical, mechanical and an instrumentation engineer. During the production stage there is always a chance of making slight changes in the process in order to run the plant effectively to get better results.

III. THE STAGES OF DESIGN

A. Block Flow Diagram (BFD)

This gives basic information of what is happening in the process or steps involved in the process. The block or rectangles are used to represent a unit operation. The blocks are connected by straight lines which represent the process flow streams which flow between the units. These process flow streams may be mixtures of liquids, gases and solids flowing in pipes or ducts, or solids being carried on a conveyor belt. Flow streams should be numbered sequentially in a logical order. Unit operations (i.e., blocks) should be labeled. Where possible, the diagram should be arranged so that the process material flows from left to right, with upstream units on the left and downstream units on the right.

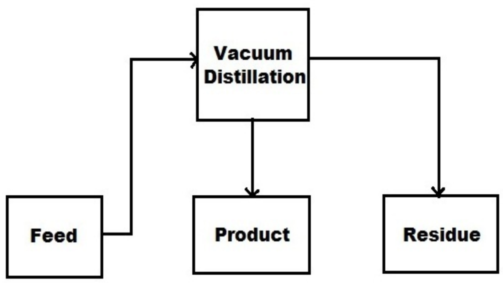

Fig. 1 Block Flow Diagram of vacuum distillation process

An example of a simple vacuum distillation process is considered in order to explain the step by step procedure followed in designing a process. The block flow diagram of this process is shown in Fig. 1. Vacuum distillation process is generally used for compounds having high boiling points. This is because, at vacuum, the boiling point of the compounds decreases and the evaporation takes place easily. Feed is given at the upstream side of the distillation tower. The bottom product is taken as the final product and the top product is the residue which will be sent to an effluent treatment plant for recycle. This diagram gives a brief overview of the process.

B. Process Flow Diagram (PFD)

A Process Flow Diagram-PFD (or System Flow Diagram-SFD) shows the relationships between the major components in the system. PFD also tabulates process design values for the components in different operating modes, typical minimum, normal and maximum. A PFD does not show minor components, piping systems, piping ratings and designations. Fig. 2 is the process flow diagram of the vacuum distillation process described in the BFD. This diagram gives the details of the basic equipment used and the flow of the process. ST-105a, b are the storage tanks for feed. This feed is pumped to the distillation tower T-103 with the help of the feed pumps P-103a, b. Rb-103 is the kettle type reboiler connected to the tower. The top product from the tower is cooled using condensers E-105, 106 using cooling water and chilled water respectively as the utilities. The process in reflux line is collected in reflux drum RD-102 and finally collected in the storage tanks ST-107a, b. The vacuum in the tower and the reflux line is maintained using vacuum pump VP-103. The bottom product from the reboiler is collected in the storage tanks ST-104a, b which is sent for recycle. Some local instrumentation is also provided in this drawing for level and temperature indications and also for the feed flow control.

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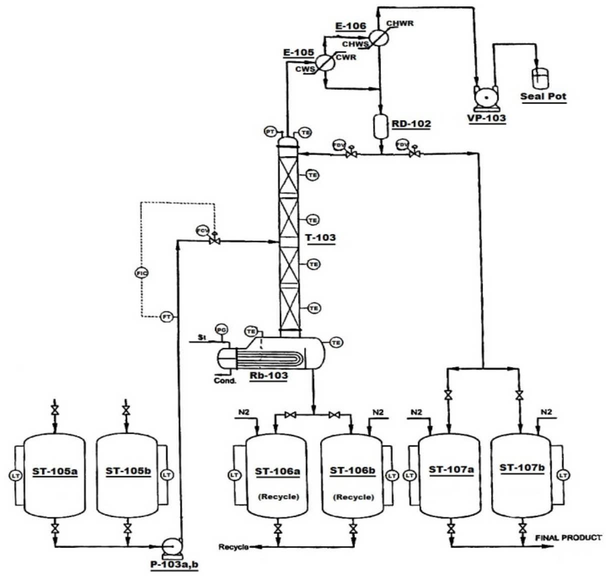

Fig. 2 Process Flow Diagram of vacuum distillation process

C. Piping And Instrumentation Diagram (P&ID)

P&ID shows all piping which includes the physical sequence of branches, reducers, valves, equipment, instrumentation and control interlocks. The P&ID are used to operate the process system. A P&ID should not include equipment rating or capacity, instrument root valves, control relays, manual switches and indicating lights, primary instrument tubing and valves, pressure temperature and flow data, extensive explanatory notes [4].
Fig. 3 shows the piping and instrumentation diagram for the vacuum distillation process described in the Fig. 2. It contains the complete instrumentation and controls for all the process lines as well as the utility lines. The same naming convention described in the PFD is followed in PID as well [5]. All the instruments are named in a particular order. First the process line instruments are named in a serial order followed by the instruments used in the utility lines. The PFD and the PID drawings described in this paper are part of a large diagram and hence the naming is abrupt. H or L written above and below any indicator denotes that they are the alarms. (H stands for High alarm and L stands for Low alarm). If HH or LL is written above or below the indicator symbol, it means alarm High High or alarm Low Low respectively i.e., it is connected to an interlock to take an automatic action when extreme conditions occur. We can observe the LL alarms for the level indicators of the storage tanks that are connected to the metering pumps as an immediate action has to be taken to shut off the motor of the pump if the storage tanks are empty or has very low level in order to avoid dry running of the pump and damage of the pump.

1) Utilities: Utilities are the service lines used for heating or cooling the equipment in the process for the reactions to take place. While designing a process separate piping and instrumentation diagrams are drawn for utilities along with the main process diagram and the instrumentation and controls are tabulated separately in data sheets for the utility lines. The common utilities used in any process are described below:
For heating purpose:
Steam (up to 120^{o}C to 130^{o}C)
Hot Oil (up to 230^{o}C to 240^{o}C)
Hot Air (up to 400^{o}C)
For cooling purpose:
Cooling Water (room temperature)
Chilled Water (4^{o}C to 8^{o}C)
Brine (-20^{o}C to -30^{o}C)

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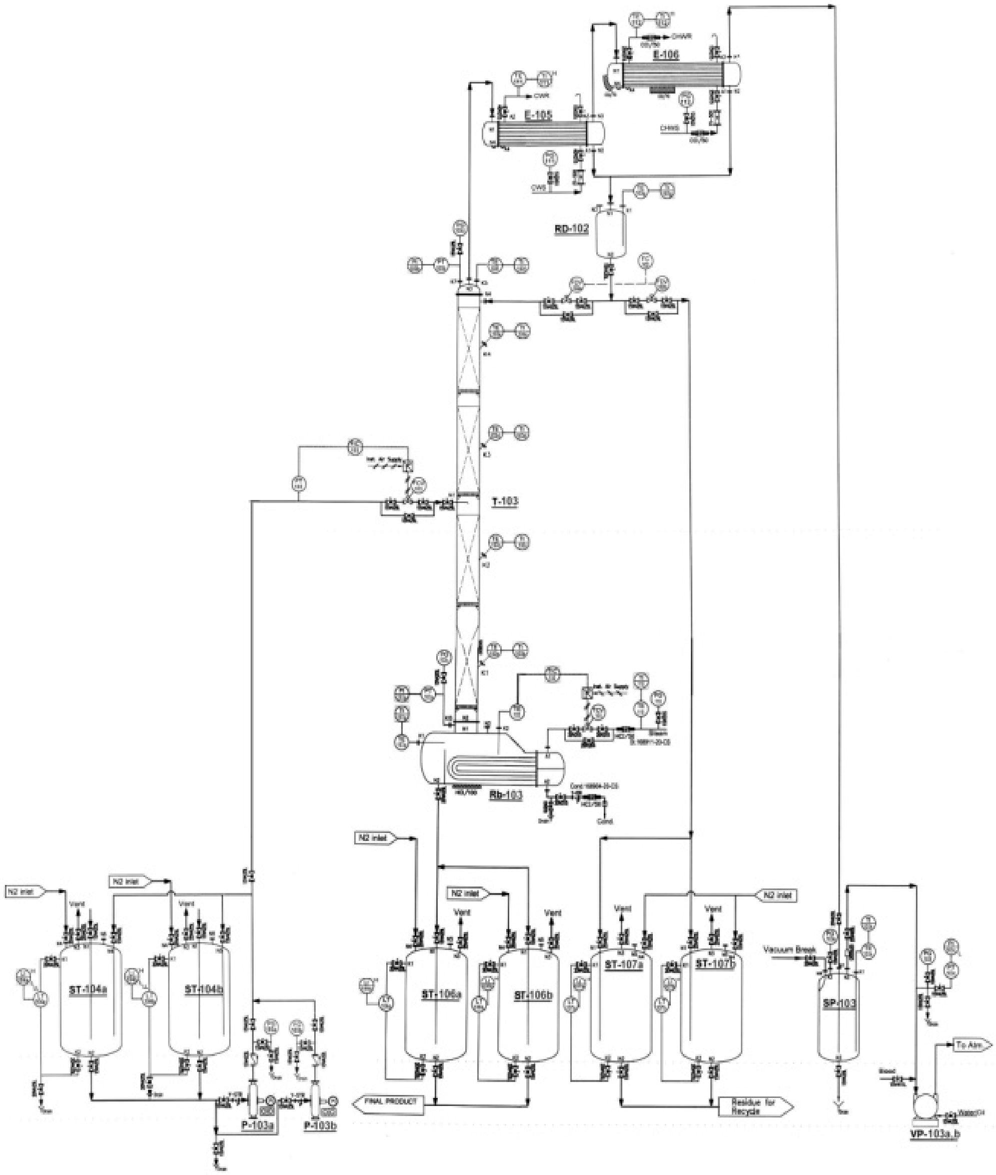

Fig. 3 Piping and Instrumentation Diagram of vacuum distillation process

D. Instrumentation Documentation

In any new process, instrumentation documentation is equally important as designing a process. These documents give detailed view of the number of instruments used in the process, type and range of the instruments, instruments that are connected to the Programmable Logic Controller (PLC), interlocks used in the process, etc. For large processes these data sheets are made separately for the process instrumentation and the instrumentation of the utilities respectively. The main data sheets included in the instrumentation documentation are:

1) *Instrument Index:* It gives the list of all the instruments used in the process, location of the instrument, range and type of the instrument and the units of measuring parameter.
2) *Alarms And Interlocks Summary Sheet:* This document includes the list of all the alarms used in the process, location of the alarm, range of the indicator for which alarm is specified, units of the measured value, action to be performed for that particular alarm, interlocks used in the process and the action performed on reaching the critical conditions, etc.
3) *PLC I/Os Summary Sheet:* This document will list the total number of analog inputs (AI), analog outputs (AO), digital inputs

(DI) and digital outputs (DO) that are present in this process and the total number of open loops and closed loops present in the process. Looking at this document it is very easy to define tags for connecting the process to the PLC for automation.

4) *Specification Sheets:* Specification sheets will give detail information of every instrument like the range of the instrument, quantity required, type of the instrument, tag number and location of the instrument, accuracy, material of construction (MOC) of the instrument, size of the instrument, working temperatures, mounting type, precision, maximum and minimum acceptable ranges of the flow, temperature and pressure, etc.

IV. CONCLUSION

In this paper the authors' has generalized the various intricacies faced by the instrumentation designer involved in the instrumentation development process. The work can be further expanded to detailed engineering aspects also. Further considerations can also be extended to maintainability and operational aspects.

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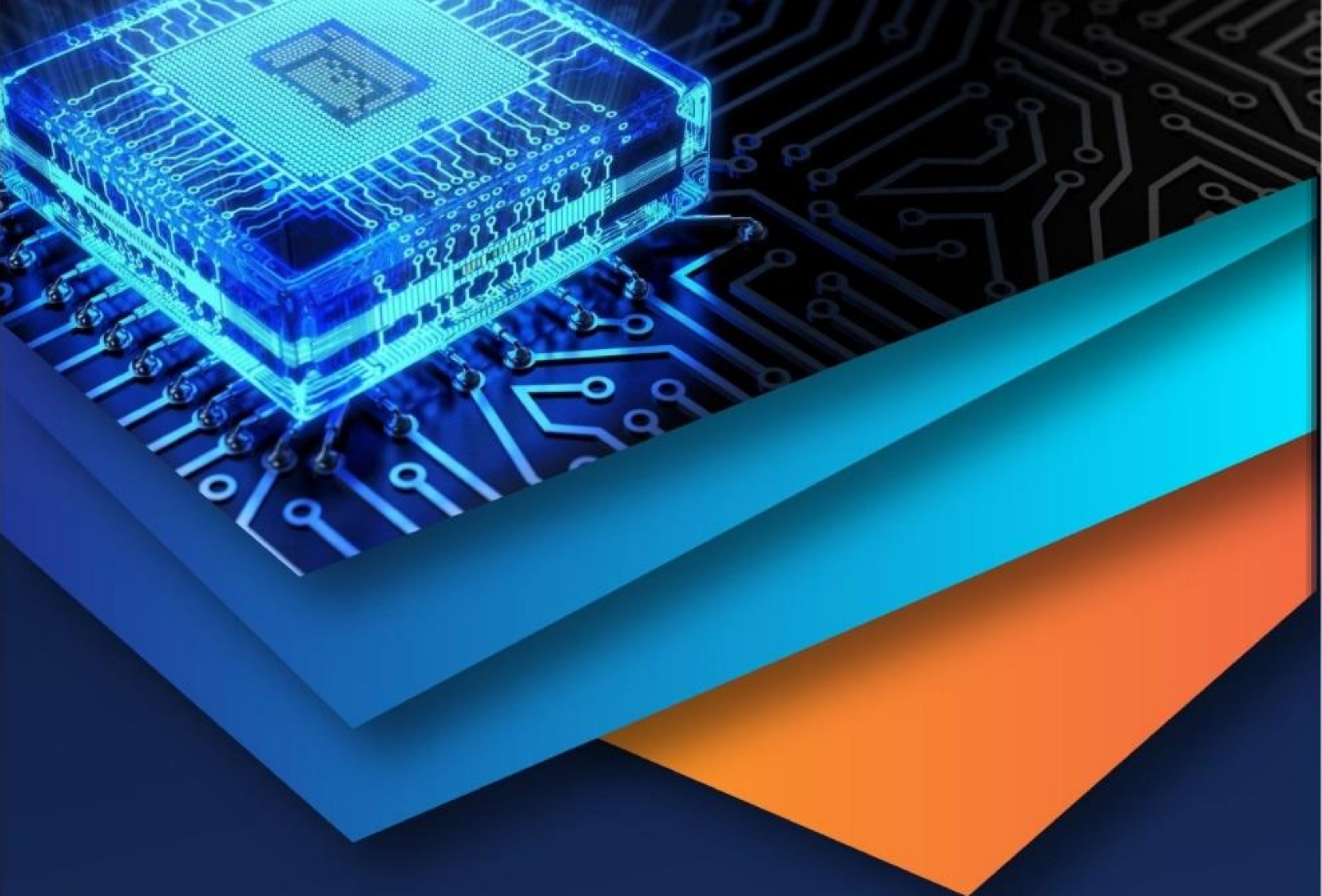

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