Chapter-1

INTRODUCTION

The chapter introduces Dehydration and Desalting Process employed at oilfield. It also explains the motivation and research objectives.

1.1 Dehydration and Desalting Process (DDP)

Petroleum wells, at oilfield, generally give a mixture of gas, oil, water and various contaminants, which must be separated and processed [18]. Production facilities are installed to collect and separate the well-fluid into oil, gas and water phases, and process them into some marketable products or dispose them in an environmentally acceptable manner [7].

Producing crude oil of desired specification is complicated by water produced with the oil. The complication lies in the fact that water can be present in oil as free water as well as emulsion, and contains salts and various contaminants. Free water is referred as to water that will settle out fairly rapidly [27], whereas, emulsions are formed when two immiscible fluids are dispersed in each other in such a way that they will not separate by gravity alone [16]. Emulsions are difficult to treat and cause a number of problems [32]. Removal of water and salts is important in view of several reasons such as:

i. Crude purchasers specify maximum permissible limits on the amount of water and salts present in the crude [32].
ii. Water lowers the API gravity and reduces the market value of the oil.
iii. Water would occupy and cause wastage of capacities of equipment / pipeline / tanker, and thereby bigger capacities (of vessel / tank, pump, pipeline or tanker) to handle a fixed quantity of crude oil would be necessary.
iv. Water increases the overall viscosity of the oil it accompanies, causing lots of flow and separation related difficulties [32].

v. Salts / contaminants present in water corrode equipment / piping at production facilities, pipeline / transportation, tankages [32].

vi. Water in crude oil makes the pipeline and the refining processes costly and even may cause oil refining process unstable [32]. Salts, such as sodium, magnesium, and calcium chlorides, in crude oil may corrode the downstream equipment, obstruct the pipes and make the catalysts poison [55].

Separating water out of produced oil is performed by various schemes with various degrees of success [48] depending upon the nature of emulsion that water forms with the oil phase. Since the early days in the history of crude oil production at large scale, various techniques were tried to remove water from oil-water emulsion. Electrical coalescence and chemical dosing in addition to heating and gravity settling are the underlying techniques being widely employed in the oilfield for a long time.

A large scale oil production facility includes Dehydration and Desalting Plant (DDP), which primarily deals with removal of water present as emulsion and accompanied salt. As understood at oilfield, 'dehydration' refers to removing water droplets i.e. BS&W (Basic Sediment and Water) from oil and 'desalting' refers to reducing the salt content of a crude oil by diluting the entrained / emulsified water and then dehydrating [32].

A typical oil production process-train at a large scale oilfield facility, consisting of DDP, is depicted in Appendix-A1. The process shown at DDP, primarily involves chemical dosing (addition of demulsifiers), preheating and heating, mixing, dilution (effluent water recycling / fresh water addition), electrical coalescing and gravity settling. The core idea behind applying all the techniques is to treat the emulsion to finally facilitate the gravitational separation governed by Stoke's law. Applying each technique involves a set of process equipment and practices whose effectiveness may depends on many factors. It may be recalled that water-oil emulsion is of various types and occurs frequently, during oilfield handling, and has complex

physico-chemical and engineering aspects and thereby involves multitudes of issues. It has been studied by many researchers belonging to various basic sciences as well as applied sciences / engineering disciplines.

To summarize, DDP is crucial in achieving desired specifications of crude oil, has significance to environment as well as performance and integrity of downstream system. Overall requirements of a DDP are to reduce BS&W and salt content to desired specifications (typically, less than 0.1% and 10 ptb, respectively). DDP involves emulsion treating and dilution, and depends upon many factors like settling time, chemical (demulsifier) dosing, heating, adding fresh water, mixing (of emulsion, chemical, fresh water), electrical voltage application, pH. In this thesis, some of these have been considered.

1.2 Motivation for the Research

Context:

Though from process system point of view, conventional crude oil processing, as employed by E&P (exploration and production) companies, might appear somewhat mature; nevertheless, deteriorating reservoir conditions, global competitiveness, and industry's ever increasing interest for HSE, integrity, and enterprise risk management impose some of the driving forces for further improvements. Environmental regulations, the need of CAPEX and OPEX reduction, production fluid of poorer quality, more stringent product specifications and the requirement of more flexible designs have been listed as few of the most important factors which boosted technological evolution of the oil and gas surface facilities [33].

Accordingly, as can be seen from the literature survey, many studies have been done and are under progress in a quest to improve the core items pertaining to DDP (e.g. to improve the equipment based on the principle of electrical coalescence, or to incorporate improvements based on other principles like separation by ultrasonic waves, centrifugal forces, etc.). Many

studies are of basic or pilot kind of research and some other have led to improvements added in the products (like improved model of electrostatic desalter or improved demulsifying chemicals) available in the market; though the industry has not adopted any major process change in the equipment except procuring improved model with apparently similar process.

However, irrespective of any improvements in the new products, most of the process engineers employed at oilfield to provide technical support for the existing facilities have to use chemical / process system engineering skills to perform some kind of optimization exercise for deciding optimum operating conditions during day-to-day operations in order to reduce CAPEX / OPEX needs, fulfilling HSE requirements and meeting product quality specifications. Evidently, some model-based decision support tools would be useful for process engineers in conducting their duty aptly. Various kinds of Decision Support Systems (DSS) are already seen emerging, in general, in the industry. A DSS is an information system that support businesses and organizations in the decision making [53].

Emerging modelling trend at oilfield:

In view of increasing need of optimization, supported by the advancement in the field of automation and information technology, now-a-days, oil industry is taking interest in the concept of intelligent / smart oilfield. A Decision Support System (DSS) is a pre-requisite for an intelligent oilfield [53]. Therefore, various kind of model-based decision support tools are being developed by the software developers.

Accordingly, Integrated Asset Optimization Modelling and Real-Time Optimization are the emerging buzzword in the industry. Such model incorporates various components of surface facilities but focus on mass balance of the oil, water and gas phases and not on the emulsion-aspect.

Need of process model for DDP:

Out of various surface operations at oilfield for crude oil production, DDP represents a crucial step. However, performance of DDP depends upon combination of operating parameters in a complex manner because of complexity associated with the behavior of emulsion. More often 'experiments' can't be conducted on real plants to perform any optimization exercise for deciding optimum operating conditions during day-to-day operations.

A process model to predict DDP performance for a given set of operating conditions would be useful to simulate various operating scenarios in order to support decision making for betterment. Thus, some optimization exercise may be conducted through such process model, which in turn could result into many benefits, which will include saving of fresh water which is scarce in desert. Further it will lead to saving in pumping energy and chemical consumption.

Gaps in modelling of DDP:

<u>No direct provision in state-of the art Process Simulation Package (like Hysys):</u>

Developers of state-of-the art Process Simulation Packages (e.g. Aspen Hysys) have incorporated several types of process equipment (including those employed at oilfield process-facility) but not the 'DDP'.

<u>Previous modeling attempts: limitations and opportunities</u>

For the sake of brevity, previous modelling attempts are presented in three categories:

1. Models having 'white elements' predominantly: As can be seen from the literature survey compiled in this thesis, several of the previously developed models, having predominantly 'white elements', possibly because of involved complexity, mainly focus on 'narrow' aspects of the idealized portion of the entire process. Thereby, such models incorporate parameters, whose presence is not interesting from production operations

point of view. Further, it lacks broad correlation between several bulk process parameters, altogether, that are of interest for a plant operator. Such models may provide great information for developing a new product / enhancing a product design; but may not be practically able to serve the afore-mentioned need of a process engineer at oilfield.

2. 'Semi-empirical' based on statistical methods: Some of the reported models, built through semi-empirical approach using statistical tools, though involve some bulk operating conditions of interest for process engineers at oilfield, but are prone to be applicable only for the case it was developed for, because the constants of the model were attained for a particular geometry / make of the equipment subjected to a specific experimental set-up.
3. Models developed through 'black-box' approach using emerging technique from the realm of Artificial Intelligence (AI): Some of the reported models, built using Artificial Neural Network, do have somewhat inherent flexibility because of the used techniques, in order to be implemented for different DDPs at different locations without depending on specific physical / geometrical aspect of any unit, and do correlate bulk process parameters of operational interest, but used software like MATLAB which obviously inhibits its usage by operating personnel at oilfield.

Emerging trend in Process Modelling for Plant Operation:

Application of MS Excel for enabling model-based decision support:

In industry, it is observed that versatility of easily available Excel is being recognized also at the time when lots of sophisticated tools are being developed. As mentioned above, various drivers in Oil & Gas industry require certain level of optimization; and to overcome such challenges model-based decision support tools are emerging. Some of such tools developers prefer to provide user interface through MS Excel for carrying out some calculations in comfortable manner by the users.

Even developers of rigorous process modelling software (like Aspen Hysys) recognize the importance of MS Excel software for enabling model-based decision support for plant personnel. MS Excel offers versatility and enables use of models by wider users. Accordingly, Aspen has incorporated Excel add-in for Hysys to allow the end users like process plant personnel to derive benefit from the process model built by simulation experts, through Excel interface, without simulation expertise [46]. Such provision include 2-way interaction, i.e. feeding input from Excel worksheet into the model in Hysys environment as well as deriving output from Hysys model into Excel worksheet.

Therefore, performing the subject modelling, simulation and optimization of DDP using MS Excel should not only offer the benefits to cultivate which the developer of reputed software like Hysys utilized the versatility of MS Excel as explained previously, but also it will enable coupling of thus developed model of DDP in MS Excel with Hysys (which has not got any direct provision of modelling performance of DDP) and any other decision support tools which allow some kind of data export/import to/from Excel spreadsheets.

Application of Artificial Neural Network (ANN) for Process Modelling:

In the era when computing capabilities are increasing, wherein ever-enhancing sophisticated tools like CFD (computational fluid dynamics) based on fundamentals of mass, energy and momentum balances are developed, re-emergence of black-box approach for modelling is also noted. From literature survey, it is found that ANN, is considered a 'promising' tool, and has also been attractive to researchers for process modelling.

Particularly, in view of the complexity involved, any white-box model for dehydration and desalting process is likely to be very complicated, if developed, and might not be of much interest for users at the oilfield facilities. It is already recognized that in a realistic process modeling activity there is almost always a need for empirical model building [14]. In fact, along with black-box principle, some first principle aspects are also incorporated. However,

adding basic physical laws, in terms of mathematical equation, is likely to add complications. Fortunately, concept of artificial intelligence has emerged in black-box modeling. Many complex engineering problems are being solved using the concept of ANN. To quote from a traditional text book on process plant simulation, "Neural networks have been used as an alternative to the traditional mathematical models to simulate complex patterns. The simplicity of their implementation makes them appropriate for modeling various complicated processes" [8]. To quote further, "In recent times, Artificial Neural Networks (ANNs), which also come under the category of models using black box principles in general and the grey box principle in particular, emerged victorious with a wide range of applications in all fields of research (be it engineering, science, arts or commerce)" [8].

In short, ANN has potential:

i. To handle complexity which is practically difficult and uninteresting to be expressed through explicit equations
ii. To be used for process plant where large actual data are present (plant historian)

Therefore, ANN process model is likely to be of more use for the above described purpose. Also, in view of its inherent versatility, an appropriately developed model through ANN can be populated, trained, and continually updated for facilities located at different locations with different specifications for individual piece of equipment.

Resolutions:

In view of the above mentioned observations in the previous paragraphs, this work was intended to contribute towards handling the above mentioned challenges and opportunities observed by process engineers serving at the oilfield for oil production taking care of reduction in CAPEX, OPEX, attainment of desired quality, prioritizing HSE, and integrity issues, through embracing the application of broad-base emerging tools into the chemical engineering discipline domain.

Accordingly, to enable a model-based decision support for operational optimization, focus was made onto the modelling, simulation and optimization of DDP, which is crucial not only to achieve desired oil specifications, but also has somehow significance to HSE and integrity. DDP actually involves handling and treatment of emulsion, which is a complex phenomenon and involves multitude of issues, but emerging Integrated Asset Models appear to ignore such aspect. Also, the fact that there is no provision of direct modeling in Hysys (or any other reputed process simulation software available) for evaluating the performance of DDP, need of building a process model for DDP was always felt. The idea was to build a model from overall system perspective involving major operating parameters which are found to affect the system at operational level. Also, the idea was to develop a model which remains applicable for various existing plants (each having pieces of equipment of different size, make, etc. than the others) in a convenient manner.

Thus, this work was aimed to enhance the applicability of previous such work done for modelling DDP using ANN presented in [42], by combining versatility of ANN and MS Excel. Particularly, because of such novelty, the work will be not limited to solving a specific modelling problem but should result into a versatile process model that can be utilized as a tool or modelling framework for decision support for handling variety of issues including optimizing plant's operation. Such model should also be used for increasing awareness of ANN as a handy tool and for creating knowledge from available data, which are abundant at operating plant. To explain, further, such ANN process model in Excel:

- will provide an opportunity to capture implicit relationship between input and output in a manner that can be accessed and applied by users freely, instead of depending on a software to run, every time. Also, it can serve as a fundamental framework for further process studies and development even beyond the realm of dehydration and desalting process, in view of versatility of ANN.

- can be easily adapted for variety of applications: for industrial or academic needs.
- can be customized for different applications by end users without having any specialized computer program coding skills or advanced mathematical skills.
- may not require expensive software licenses other than what is generally available in any computer in industries and academic / research institutions.
- can be coupled with widely used proprietary process simulation software like Aspen Hysys.
- can supplement use of advanced proprietary tools by saving expensive computational time and shedding the inhibitions in using sophisticated tools requiring expertise and efforts.

An overview of the above discussions is presented pictorially in the figure below:

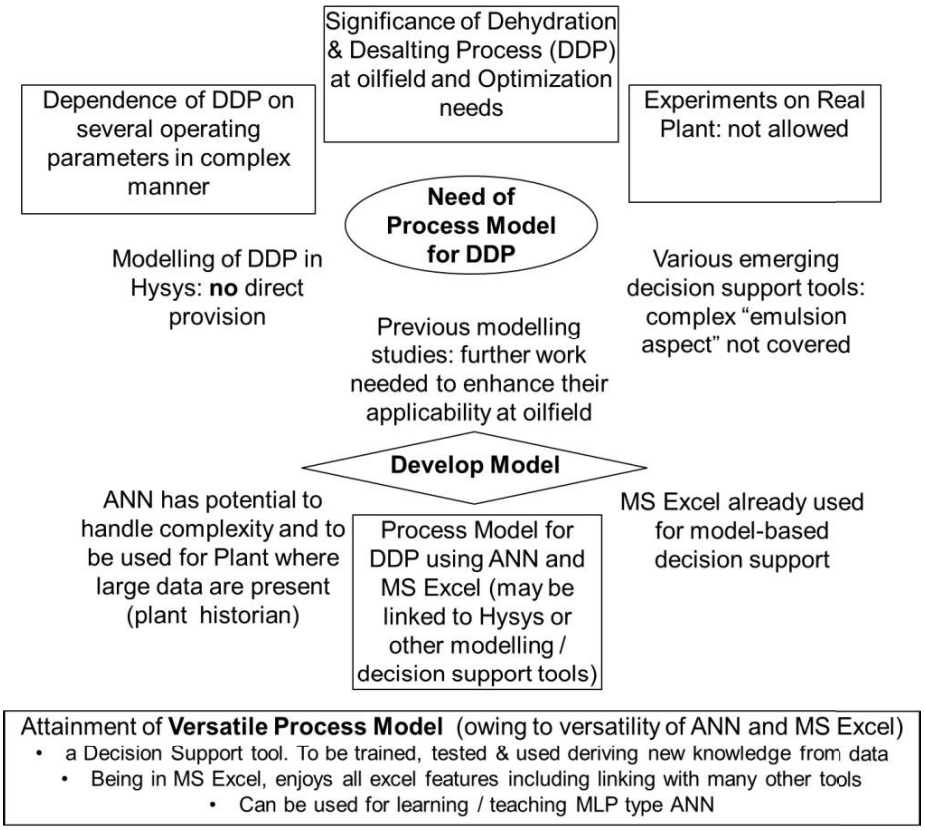

Fig. 1.1: Research Motivations – Overview

1.3 Research Objectives

As can be seen from the previous section, the trigger for this research is to develop process model for DDP that may be used at oilfield plant to simulate various operating scenarios in order to support decisions for optimizing plant's operations at different locations.

It is aimed to utilize the advanced simulation power of Artificial Neural Network (ANN) from the realm of ever growing Artificial Intelligence (AI) for building such model. This technique will allow to correlate performance of a process with various process parameters of interest, in a generalized manner, through black-box modelling, which otherwise could be complex and specific to a particular equipment design if first-principles model is built.

Further, to reap the benefit of ANN model's generalization capability, to extend its application beyond modelling DDP, to maximize its versatility and outreach, it is aimed to develop ANN model in MS Excel. As development of ANN, itself, does not involve embedding any phenomenological information, and because even blank cells in MS Excel can be correlated to each other through powerful mathematical formula, the work is aimed to attain a versatile process model, that is, a modelling tool / framework which may serve as a building block for many other emerging model-based decision support systems. It is expected to be very useful, because MS Excel provides easy access and further use of the implicit relationship between input and output of the ANN model. In short, such modelling tool once developed could be trained, tested and used in deriving knowledge from data, which is particularly available in large amount at process plant.

Summarizing the above, the aim of the research is to:

> "Carry out development of a versatile process model (named VP Model) by combining the versatility of ANN and MS Excel, in reference to Dehydration and Desalting Process, but which may be adapted for model-based decision support for variety of applications".

To emphasise, the overall perspective is to attempt modelling, utilising emerging techniques, not limited to solving a specific case of modelling, simulation and optimization, but to attain a framework for wider applications and outreach.

1.4 Content of this thesis

The content of the thesis is structured in the following manner to achieve stated objectives of the research.

Chapter-1 introduces dehydration and desalting process (DDP) employed at oilfield. It also explains the motivation and research objectives.

Chapter-2 presents the literature review needed to propose and complete the research work.

Chapter-3 presents the specification of hardware and software used to complete the work. Also, it describes development of the versatile process model (VP Model) utilizing the concept of ANN using MS Excel.

Chapter-4 provides an overview of VP Model attained through the work described in the previous chapter, and presents two modelling problems pertaining to DDP solved through the developed VP Model. It also illustrates, use of VP Model for simulation and optimization and linking of VP Model with a reputed software, through examples pertaining to DDP.

Chapter-5 presents results achieved through the completed research work. Output of the process models that were developed (as explained in the previous chapters) for two different modelling problems pertaining to DDP: (i) one problem involved calculating SRE and WRE, and (ii) another problem involved calculating wash water flowrate, are presented. Also important conclusions derived from such observations and significance of the completed work are highlighted.

Chapter-6 provides brief conclusion regarding the completion of the current research work. Core feature of the completed work is reiterated. Recommendations regarding future work are also outlined.