DESIGN AND ANALYSIS OF OIL PRODUCTION AREA – A SIMULATION APPROACH

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ABSTRACT

Crude oil separation processes involve many high profile control systems and equipment that costing a vast amount of investment. Any mistake in the management will cause serious aftermath. The main focuses in this paper are the design of simulation modelling of an oil production area and is used as planning, controlling and decision making tool with associated factors such as crude oil input rate, capacity of separator, quality of crude oil and number of production lines. The experiments and results analysed prove that the simulation model is merely imitating the real system and few recommendations are concluded for the optimisation of productivity.

INTRODUCTION

Crude oil surface production operations are among the most dynamic chemical processes in the engineering field due to the complexity, high profile and high safety considerations. The whole refinery systems from crude oil to final consumable products are separated into several steps together with hundreds of complicated piping and control systems. The simulated processes in this paper include 2-phase and 3-phase separation to filter out the water and gas from crude oil. Due to the dynamical process behaviours and great competition in same industries, manufacturers always find it difficult to achieve high performance and thorough planning using traditional designs and analytical methods. The risk and cost are too great and too high for implementations which are not fully tested and analysed for its effectiveness. Mismatches and factors that come out unexpectedly are really worrying most of the operation planners as a result of failure to the systems and enormous losses both timely and financially.

The purpose of this paper is set to use simulation tools to help in design and analysis of oil production field. The model was initially designed and simulated to match the current real system, which was later used as a planning tool to help practitioner in decision making process. The behaviours of the separation systems are to be described; the processes and theories constructed and predictions made by analysing the results from the simulation. Factors affecting the separation outcomes could be added into the model for better integrity and more precise experimentations. The modelling and simulation enables engineers to visually observe every single step and effects caused by different factors introduced into the systems. Planners are able to evaluate physical layout, selection of facilities and equipments and operational procedure changes. Processes could be altered and tested repetitively at minimum cost and time without taking on the risk of failure.

The simulation model built is to be used in examining the effect of various parameters on the performance measurements for planning and control of production systems. Integrated user friendly interface are developed for variable set up enabling different experiments to be carried out easily.

LITERATURE REVIEW

While the level of oil reserved decreased over the world,

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higher optimisation in production systems and facilities are important to ensure the profitability. This paper focuses on the early stage of the separation process which included the vertical and horizontal separators. Air, water and oil were all separated from crude oil before being delivered for further stage of treatment.

There are various researches and works reported in the past to search for more effective optimisation approaches in oil production industries. Mathematical programming is one of the most widely implemented methods for modelling with the objective to maximise the profitability. Linear programming is a popular example in mathematical programming introduced for planning of maintenance shut-down and stock control. The theories of linear programming was developed further by Ballintijn (1993) and presented by Giliberti et. al (1995) for optimisation of the dynamic simulation at a giant oil field.

Shah (1996) used mathematical programming techniques for crude oil scheduling which is applicable to hybrid approach. Fichter (2000) showed that application of Genetic Algorithms in oil and gas portfolio optimisation was excellent at handling accurate and complex, non linear business model. Hansen (2001) discussed the distribution of the multi-phase fluid flow in a horizontal gravity separator. Computational Fluid Dynamics (CFD) could provide valuable insight, and the fluid flow behaviour in the liquid volume flow zone inside the separator was analysed and simulation was performed. Yu et. al. (2004) introduced an approach for solving the problem of bending optimisation based on history data and the effectiveness of proposed model were shown by using real data of oil field which, however, been criticised the design procedure of conventional oil-water separation was to be improved.

Rincon et. al. (2005) proposed a set of criteria for evaluating discrete-event simulation software capable of simulating continuous operations with a quality specifications model developed and demonstrated at a consultancy in Venezuelan oil industry.

Apart from the technologies, strategy was another important method of optimising the productivity of oil. Tavares et. al. (2006) assessed different strategies for the expansion of Brazil oil refinery segments, using criteria that range from energy security (reducing imports and vulnerability for key products) through to minimising the profitability of this sector (boosting the output of higher value oil products) and adding value to Brazil's oil production (reducing exports of heavy acid oil).

Although most of the previous research that have been carried out were mostly focussing on optimising the production using linear programming, statistical analysis, mathematical solutions and critical path analysis, simulation was one of the methods mostly chosen after statistical analysis as an operation research tool (The British Petroleum, 1977).

RESEARCH METHODOLOGY

What are modelling and computer simulation? Modelling is a way to represent a group of objects ideas and behaviours of different systems and processes in the form of either physically or logically. Maki and Thompson (2006) differentiated the types of model into physical models, theoretical models, logical models, computational models, simulation models and mathematical models.

Mathematical models can be analysed through mathematics, theories, differential equations, partial-differentiation equations, diagrams and tables. It is also a set of process with approximation and assumptions attempts to match observation with logical or symbolic statements. Mathematical models are mostly simplified and idealised to identify the most important parts to be modelled especially in the prediction of the outcomes which is called 'real model'. Although it can provide the accuracy and precision of predictions, decisions and explanations, the model can be developed into more complex and difficult design when dealing with complicated systems.

A heuristic model can be used to seek immediate solutions in short time despite the feasibility or optimality. Nevertheless, there is a concern that it is likely to be erroneous and is unable to guarantee the accuracy to problems being solved.

Simulation modelling or computer simulation is chosen for this research work due to its powerful ability in dealing with either simple or complex systems which are more preferable. Computer simulation is a process of designing a digitalised model representing a real or a proposed system for the experimentation purpose and understanding of the system's actual behaviours with given factors and scenarios.

Simulation in the oil and gas industry allows managers and engineers obtaining a system wide view of the effect from local changes to the production area. Computer simulation is beneficial in cost saving, time saving, comparison of different scenarios especially in the impossibility of real system construction, wide areas of implementation, answering 'what-if' questions, the competencies and ease of use for supporting decision making. Other advantages are (i) advances in software technology where programming language improves the software power for rapid and valid decision making, (ii) provides training to operators without affecting the real operations, (iii) a better insight and understanding in visualisation of operations systems gained through animation in simulation model advancements.

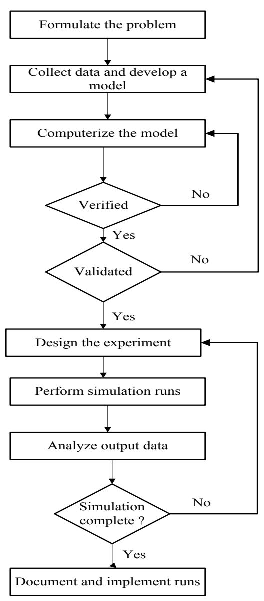

Figure 1: Framework in simulation study

Time and variability are the two most important aspects when designing a simulation model. Three main categories of simulation model classified by Kelton et. al (2007) are static versus dynamic, discrete versus continuous, and deterministic versus stochastic. This project has both discrete but mostly regarded to continuous systems. In continuous environment, the system could work around the clock without break except for maintenance. Examples of such system are the utilities companies, petrochemical factories, oil industries, etc. Figure 1 shows the framework of the general simulation process.

There are various simulation software tools in the market which are targeting at different industries. ARENA simulation tool from Rockwell Software was chosen as the simulation tool in this research project for advantages in higher performance, moderate modelling duration, developed skills in the software applications and ease of use of the software tool.

CRUDE OIL SEPARATION UNITS

A perfect model is preferable at all time by the modeller, nonetheless, this is not always possible due to the difficulties in obtaining full data required for real systems design.

A conceptual model is necessary to combining all the objectives of simulation, inputs variables, outputs performance and assumptions made to simplify the model. Figure 2 explains the process flow of the crude oil separation from early stage until the end of the process for delivery to the port. The amount of gas, water and oil from each stage to another differs according to the pressure of separators and contents of the hydrocarbon in crude oil delivered from wells.

Data collection and assumptions

The proposed model and the data collected are based on a real oil production area in one of the developing countries. Data collected were analysed and further assumptions and calculations were made in order to find out the rest of data required for modelling. Therefore, the more data gathered, the more accurate the simulation model could be designed.

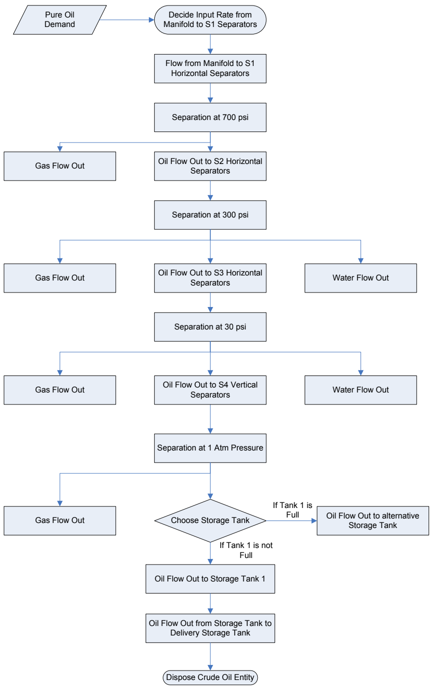

Figure 2: Process Flow Chart of Crude Oil Separation

Model constructions

Due to the complexity and great size of the model, few selected parts of the model are explained and discussed. Four different entities were created at time zero and were used to trigger the crude oil separation process in Arena software. Each of these entities was assigned with their own attributes for the computer to understand their characteristics and identity. The 'seize' module seized the manifold output regulators and the input regulators which is particularly available for the assigned entities.

The flow rate of the transfer between manifold and Stage 1 separator was adjusted by the 'regulate' module. Different pre-recorded values of input flow rate were available for users to choose and these would lead to different utilisation of the separator as well. The model would automatically show the latest utilisation of separator according to the number of crude oil production line activated. By referring to Figure (3-a and 3-b), the entity will go through a series of process to check if the level of separators was in the allowed limit. A sensor was used to represent the level valve in real system to detect the level of crude oil in the manifold.

The entity was entered into the line for lowering the regulator rates, or vice versa, otherwise it was disposed for not meeting the requirements of design. The entity that met the requirements would then circulate in the loop until the end of the process.

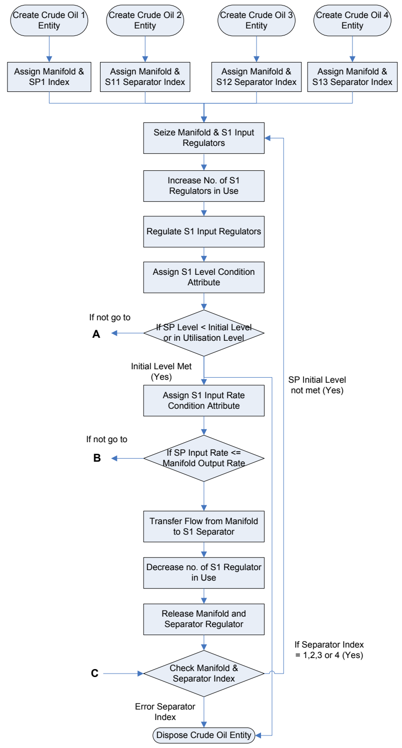

Figure 3-a: Crude Oil Separation at Stage 1

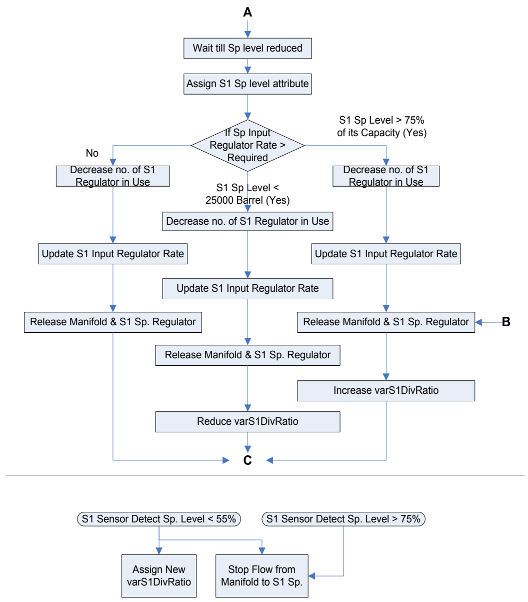

Figure 3-b: Crude Oil Separation at Stage 1

Another entity was created in next stage to activate the flow from stage 1 to stage 2 separators. Same procedure was applied to the process from stage 2 to stage 3, stage 3 to stage 4 and stage 4 to stage 5 until the end of the production line by creating different entities. Extra entities were duplicated to activate the flow of gas and water at same stage of process when the entities entered the systems. At the end of the production line, the entities were able to choose the storage tank for storage depending on the availability of space.

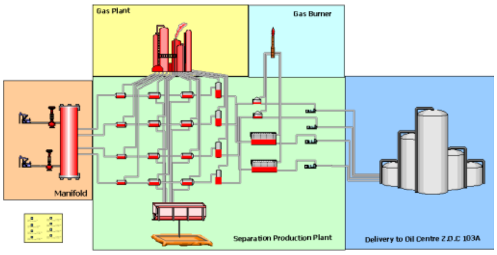

Figure 4: Overall modelling view of the simulated environment

Verification and validation

This crude oil separation model was verified by checking on the model codes, visually checking and inspecting of output reports. Any changes made were all recorded and could be referred back by the modellers and users. Visually checking method was carried out of ensuring the event and entity occurred and moved at the right sequence. A step forward button was used in checking the event happened at every step. The speed could be reduced to allow more time for entity movement observation. Animation was useful in the visual checks apart from stepping through the logic modules. Both visual checking by analysing the animation as shown in Figure 4 and tracing of the entity over time were applied together for the best model verification results.

A simpler version of the model was built with the whole process and results were compared to real systems for validation process. The simple model was then expanded to more complicated design and continuously tested, verified and validated to avoid any mistiness searching for errors when the model grew more complex.

EXPERIMENTATIONS, RESULTS ANALYSIS AND DISCUSSIONS

Factorial designs are the common experimental design that most people used such as 2^k or 3^k. However, the experiments carried out in this simulation model contain more than three levels. Mixed factorial designs are more appropriate. Two types of experiments are carried out. First experiment is based on the interaction of crude oil arrival input rates, number of production lines and quality of crude oil. Second type of experiment is based on interaction of crude oil arrival rates, number of production lines and capacity of separator. Both experiments are based on 2^4 x 7 which is 112 runs and 2^4 x 3 with 48 runs. An extra experiments are carried out that examine the relationship between crude oil input rates and separator capacity.

Total of 177 runs were completed and results were displayed in figure 5, 6, 7 and 8. Four different crude oil input regulator rates were used in this model and were increased from 5433.62bbl/min to 21734.47bbl/min throughout the four sets of experiments. From the results in figure 5, the oil output rate was decreased linearly with lower quality oil even when the number of activated lines was increased. It is obvious that the more production lines activated, the more oil output produced at the end of production. However, the declines are caused by the increment of the water in the crude oil.

Figure 6 displays the relationship between the input and output rates, as expected the output rate increases as the input rate increases, however, we could not experiment with higher input rate more than +125% as the utilisation was found to be almost 100%.

Figure 7 compares the effect of different crude oil input rates on the utilisation of the separators. The input rates were reduced or increased from their original figures gradually in the range of -75% to +75% to optimise the separation process and avoid any over flow in the system. As can be seen in figure 7, the utilisation was increased gradually at the same time when the input rates were increased. The minimum utilisation was found at 50% while the maximum was almost 99%.

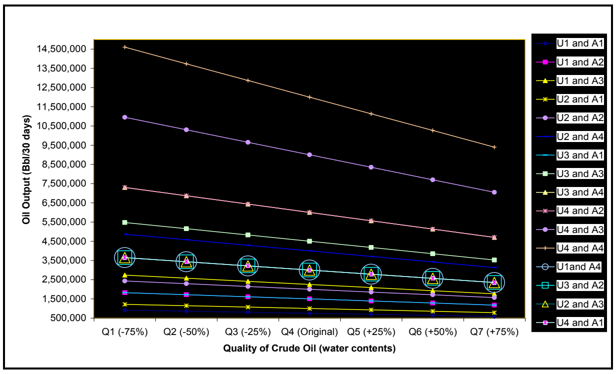

Figure 5: Oil output versus quality of crude oil

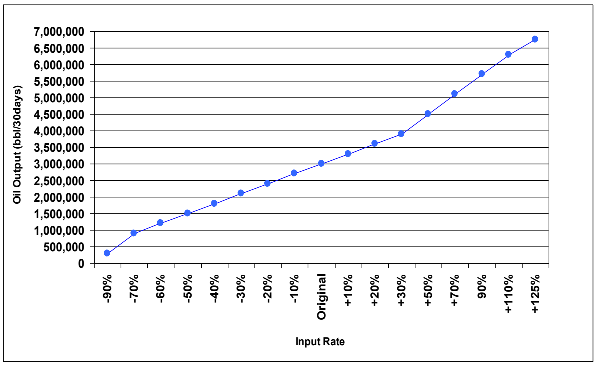

Figure 6: Oil output versus input rate

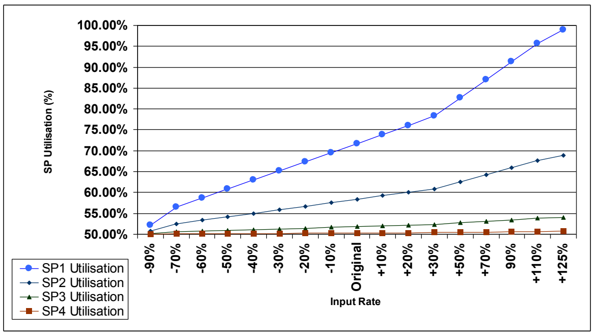

Figure 7: Separator utilisation versus input rate

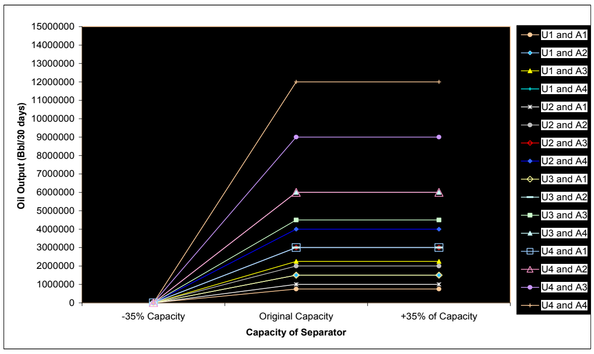

Figure 8: Oil output versus separator's capacity

In figure 8, the crude oil input rates are kept at original value. This is to compare and to show the importance of balance between input rate and capacity of separator. Any separator sized less than original capacity would not be able to cope with the original input rate of 21734.47 barrel/min, which means the separator is over utilised. In fact, any separator sized bigger than original capacity will have no effect on the amount of oil output which means it is under utilised. At points -35 percents or less, there were zero oil output. This happened since the model was designed to dispose the entity created in simulation if there is an enormous amount of crude oil input entered the system which might cause dangerous situation.

Through the analysis of the results and graphs, it is obviously notified that the crude oil input rate is the main criteria to decide the amount of oil output. However, co-factors which affect the output are the quality of crude oil, capacity of separator and number of production lines. This model shows that it is able to simulate the system, process and give a reliable outcome based on the criteria set. Some user interface dialogue boxes are designed to enable users to modify the value of the factors.

CONCLUSIONS, RECOMMENDATIONS AND FURTHER WORKS

Cost reduction is a major benefit for using simulation in spite of having real implementation for testing out the plans or design in the crude oil separation system without building up or taking out any facilities. The animation designed based on the modelled system provides the users with a clear overview on what is happening throughout the process for better understanding and confident in planning and decision making without taking risk of unworkable solutions.

Although this proposed simulation model has its beauties and advantages, the accuracies are all depend on the skills of the modeller, time period and detailed data provided/collected and power of the software tool to handle such design. Due to lack of complete data, this model was slightly simplified and assumptions were made to meet the reliability as representation of the real system. Validation of the model was hindered due to lack of data and unavailability of similar models in the literature using simulation tool. Overall, the testing results and experiments were very closely equal to actual results and this model could imitate the real production system only based on the four factors.

All the four factors taken into account of the design are all inter-related to each other. Crude oil input rate is considered as the main factor to decide the amount of oil output. The utilisation of the separators indicated the importance of balance between crude oil input rate and the load the separator could take. Over utilisation would cause failure to the whole system while under-utilisation meant the lower profitability.

Recommendations

The production planning is important for understanding what is the average production needed over years and if the supply of crude oil is enough for the demands. It is recommended that crude oil quality should be pre-investigated to ensure lower water content. Capacity of separator should be finely justified with its utilisation with commonly at 60 percents to allow the reduction and increase of productivity when necessary. Make to order is more likely to be cost-effective way to minimise extra production and storage cost. However, minimum stock should be kept for emergency like strike or problems in production system. Productivity can be increased by increasing the crude oil input rate and more production lines created only with good counterpoise between cost and profit.

Further work

This model can be designed with some differentiation equations for better estimation of the output within a range of input rates instead of specific values set in advance. More advanced VBA code can help to enhance the flexibility of the system in handling the changing of the input rates with coordination with the differentiation equations. Framework and model integration with other application software like Microsoft Excel and Access could be explored more in order to provide more function and ease of use to the user through programming. More factors affecting the crude oil separation could be included for handling various complicated scenarios.

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