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THE MYSTERY AND UNCERTAINTY CLOUD DURING RESERVOIR SIMULATION IN THE PETROLEUM INDUSTRY

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ABSTRACT

The development of any petroleum field is a very complicated and risky project due to the involvement of different sources of mysteries and uncertainties on reservoir management. The understanding of mystery and uncertainty and the connection between these two form the core of a decision making process. During the appraisal and development phases of a reservoir, uncertainties related to geologic and fluid models play an important role. The mysteries related to the development of theories/laws are the key to reaching close to the real phenomena. This paper outlined the inherent mysteries of reservoir simulation and the involvement of uncertainty related to the reservoir engineering/management activities. This research identifies the main causes and sources of mysteries and uncertainties. As an example case, a comparative study of a newly developed model with existing model of risk analysis is shown in this study. The new model eliminates spurious assumptions in order to move in the direction of knowledge dimension. This will open a new dimension of research ideas in reservoir engineering and help develop a scheme for an in-depth analysis of the reservoir before taking any decision.

Keywords: porous media; reservoir characterization; representative elementary volume; input-output data.

1. INTRODUCTION

Uncertainty is a term used in a number of fields such as philosophy, statistics, economics, finance, insurance, psychology, engineering and science where the occurrence of event is so slight as to be difficult to detect or describe. It is an elusive term which is difficult to

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understand. The following is a general overview of uncertainty and then the uncertainty in engineering especially for reservoir management will be discussed briefly. According to Knight [1], the distinction between risk and uncertainty can be expressed as "Uncertainty must be taken in a sense radically distinct from the familiar notion of Risk, from which it has never been properly separated…. The essential fact is that 'risk' means in some cases a quantity susceptible of measurement, while at other times it is something distinctly not of this character; and there are far-reaching and crucial differences in the bearings of the phenomena depending on which of the two is really present and operating….. It will appear that a measurable uncertainty, or 'risk' proper as we shall use the term, is so far different from an immeasurable one that is not in effect an uncertainty at all". The term risk used in defining uncertainty can be expressed as an uncertainty based quantitative probability. Mathematically, it is expressed as

$$Risk = \ (probability\ that\ some\ event\ will\ occur) \times (consequences\ if\ it\ does\ not\ occur).$$

Uncertainty, on the other hand cannot be assigned by probability. Moreover, uncertainty cannot be reduced significantly by getting more information about the phenomena. The definitions and relationship between risk, probability and uncertainty are well explained by Knight [1]. Wilkinson [2] talked about certainty, risk, uncertainty, vagueness and chaos or total ambiguity. Islam [3] has given a detail idea about the chaos. Mathematicians handle uncertainty using probability theory, Dempster-Shafer theory, and fuzzy logic. Moreover, surprisal is a measure of uncertainty in information theory. These theories are available in any uncertainty and risk analysis book. The main focus of this study is to identify and analyze the uncertainty dealing with reservoir simulation and management.

The simulation of petroleum reservoirs is an essential practice in the development of more efficient techniques to increase hydrocarbon recovery and considered the main tool for modern reservoir management. Simulation is the ability of combining mathematics, physics, reservoir engineering, and computer programming to develop a tool for predicting hydrocarbon reservoir performance under different operating strategies. Presently, almost all phases of reservoir engineering problems are solved with a reservoir simulator. For optimal reservoir management, it is critical to determine the reserves, recovery factors and economic limits as quickly as possible. However, that is a difficult job due to the involvement of uncertainty and numerous unknowns (mysteries) related to reservoir information. Using reservoir simulation, engineers are able to forecast a range of production and depletion scenarios based on different variables. This greatly improves the decision-making up-front, before money is spent to drill new wells, establish infrastructure and surface facilities and above all damaging the reservoir and loosing great deal of production. Reservoir simulators allow engineers and geoscientists to build dynamic models that predict the movement of oil and gas flowing in reservoirs under in-situ conditions.

However, all beneficial aspects of a reservoir simulation are affected by the data that are fed into the simulators, input data, and also a correct recording of the performance of the simulated and real systems, output data. The system consists of reservoir, wells and other facilities. The reservoir simulator is normally constructed on very highly uncertain input data regarding the rock and fluid properties. The input data should be delineated based on the output information from the real and simulator systems during the production life of the reservoir. In reality, the mystery and uncertainty start when management initiates planning before knowing the complete information of the project. This is because complexity can arise from variation in formation and fluid properties with time and space that are directly related to data. However, the complexity of the reservoirs has always been handled with advanced technologies and advancement of research development.

In this paper, a general discussion including each steps of reservoir simulation, use of upscaling techniques, effects of representative elementary volume (REV), grid size, number of attributes, use of mathematical tool for computing and use of proxy models based on previous publications and results are gathered to have a clear idea about the relevant field of mystery and uncertainty.

2. Mystery and Uncertainty in Reservoir Simulation

Decisions to invest financial capitals in exploration for oil/gas have always involved significant risk and uncertainty. The management decision of an oil field project depends on the feedback information from the lower level to upper level. If the information is not correct or misleading, the decision outcome will bring a financial loss of the project. Therefore, the feedback information should be more realistic and free from errors and uncertainty. There should not be any mystery behind the development of the simulator. It is very difficult to assure the management that the data/information gathered is correct. It is due to the inherent mysteries, uncertainties and risk in every step of the project development. If the key features of the reservoir are at least close to the reality, it is not far away to get the true picture of the project which may help save millions of dollars. From the practical stand-point, it is very important to have an in-depth understanding before developing any simulator. Once an in-house simulator is built or a commercial simulator is set to be used, many associated concerns emerge. The key features of these concerns in reservoir simulation are outlined in this paper.

2.1. Mystery during the Development of Theory

The mystery begins in any branch of knowledge when it is discovered that established laws and theories are based on some inherent assumptions behind it. These assumptions are impossible to verify. The petroleum industry is a branch of study, for which the core of reservoir management is the prediction of information about the reservoir through a simulator. Most commonly used simulator is numerical. The simulator is based on numerous theories and laws available in the literature, with many assumptions underlying the formulation. Figure 1 describes the major steps involved in the development of a reservoir simulator [4].

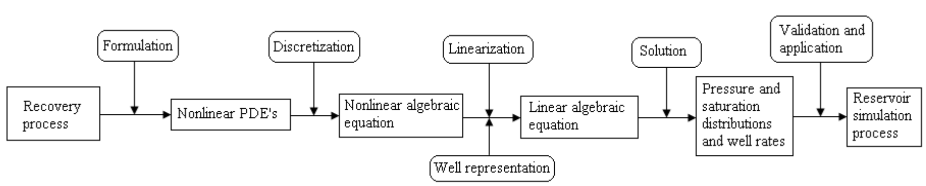


Figure 1. Major steps used to develop reservoir simulators, present source: [4].

In this figure, the inherent assumptions and limitations are identified from the "formulation" to "validation and application" steps. Mustafiz and Islam [4] outlined in detail the huge mysteries and of using the available theories and laws to develop reservoir simulator. Moreover, Zatzman and Islam [5] pointed out the most interesting issue, the absence of time-space correlation (pathway rather than end result), which may be explained as anything can be correlated with anything, making the whole process of scientific investigation spurious. They make their point by showing the correlation between global warming (increase) with a decrease in the number of pirates. This extreme example, while worked backward, makes it clear that the assumptions of the numerical techniques are equally aphenomenal.

2.2. Uncertainty in Reservoir Management

The development and management of a petroleum field is strongly related to risk due to several uncertainties. The geological model, economic conditions and technological developments are the most important areas of uncertainties. However, the problems in understanding and the sources of uncertainties are widespread from an attempt of a field discovery to the end point use of petroleum products. The conventional practice to quantify the impact of these uncertainties in petroleum engineering is expressed in terms of hydrocarbon volumes in place, recovery factor and economic indicators [6]. Uncertainty on the economic conditions is always present in the petroleum industry. The impact of uncertainty becomes dominant during the exploration phase when hydrocarbon volume in place is calculated. Moreover, when appraisal and development phases go on, more information is obtained. As a result, the importance of the uncertainty on recovery factor becomes significant.

To develop the geological model or any other reservoir simulator, input data in modeling or simulation is the key to getting a reasonable representation. The reservoir input data that are used in simulation, are the measured data from only a small fraction of the total reservoir volume. This is an uncertainty because the measured data may not be representative for the whole reservoir due to its heterogeneity in every point of the formation zone. Therefore, the starting point of uncertainty in reservoir management is the input data gathering that are obtained from different seismic data, log, core and well-test data from exploration and appraisal wells, and geological knowledge of the region or from analogue reservoirs. For any reservoir future prediction (e.g. to forecast oil and gas production profiles under selected development scenarios), reservoir simulation is used. The use of these uncertain data in reservoir simulation itself falls short in accuracy and makes wider range of uncertainty. This uncertainty may be quite large, as is usually the case for the distribution of rock properties away from the wells. Consequently, the production profile associated with any development scheme cannot be predicted exactly; the best that can be done is to calculate a range of possible profiles.

Production forecasts for petroleum reservoirs are essentially uncertain due to the lack of data. First, direct measurements of rock and fluid properties are available at only a small number of sparse well locations. Secondly, oil production and pressure data reflect roughly integrated responses over a limited number of time intervals. As a result, a reservoir engineer needs to calibrate the unknown petrophysical parameters based on insufficient observations which cannot constrain the subsurface properties all over a field. Reservoir simulation is routinely employed in the prediction of reservoir performance under different depletion and operating scenarios. This practical use of reservoir simulation requires two steps: one is history-matching, and the other is quantification of uncertainty in forecasting. In the traditional approach, a single history-matched model, conditioned to production data, is obtained, and is used to forecast future production profile. The history-matching is non-unique and the forecast production profiles are uncertain. Recently, a new methodology for uncertainty quantification has been introduced to the petroleum industry [7,8]. This method adopts the Markov Chain Monte Carlo method along with the Neighbourhood approximation [9, 10]. A detail analysis is on uncertainty is outlined by Islam et al. [11]. Here a summary of uncertainty in reservoir simulation is presented.

2.2.1. Input and Output Data

Figure 2 depicts as a schematic diagrams to illustrate the input and output data at different level of reservoir modeling [11]. The first sets of data are generated through the geological and geophysical studies. The geological and geophysical model based on the core analysis and well logging with application of seismic survey model is a preliminary identification of a hydrocarbon reservoir. The fluid flow model can be used to test physical model against production performance of the reservoir. The initial geological data are usually obtained by the seismic surveys, well logging, core sampling. These data are explained with the information obtain during the oil and gas production through the history matching process. The effectiveness of the procedure depends on the duration of updating input data and the history matching process. So, there is an inherent uncertainty level in using input-output data.

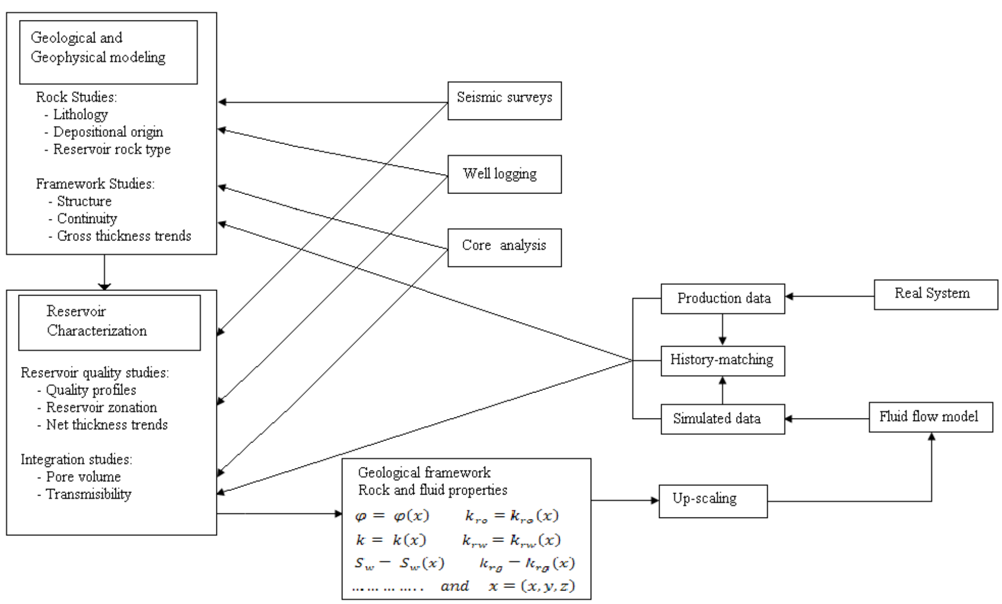


Figure 2. A schematic descriptions of history matching and geological activities regarding to a reservoir, present source: [11].

2.2.2. Effects of REV on Fluid Flow Model

The definition of REV itself is a mystery and uncertain presentation of a reservoir. The REV is an important parameter, on which the fluid flow models are based. The mathematical modeling is transferred into a numerical formulation to find quantitative description for the fluid flow [11]. The problem with REV and its mystery are well explained by Islam et.al. [11]. The scale length and its orders of magnitude issues are the paramount in REV which create a data gap. This data gap constitutes the weakest link between geophysical information and reservoir engineering [12]. This leads to the problem of up- and down-scaling that become either skewed or totally irrelevant.

2.2.3. Fluid and Rock Properties

The fluid is considered to be a continuum media and the rock properties are averaged on a REV. However, the existence of the REV is tenuous, because it is never been identified in real media. As a very rough number, the typical REV size is somewhere around 100-1000 grain diameters. It should be emphasized that despite of all ambiguities, the notion of REV is essential to allow one to use continuous mathematics. The main focus is to incorporate all properties in the flow computations. These properties formed a central part of the inputs to a numerical simulator. As a result, there is a huge uncertainty involved in defining fluid and rock properties within the REV.

2.2.4. Geological and Geophysical Modeling

The first sets data are generated through the geological and geophysical studies. The reservoirs are normally thousands of feet under the ground level, the size, the shape and the constituent of that reservoir are uncertain. Finding an oil-bearing rock and providing data on the quality and quantity of the rock and fluid are the duty of geologists and geophysicists. Geologists and geophysicists provide information about the reservoir and its contents which leads to an uncertain situation for reservoir information and management. The major tools and techniques of formation evaluation (mud logging, wireline logging, etc) should be viewed only as a means to construct a reliable model of the reservoir rock in the subsurface. The geological modeling represents all major geological features (faults, flow barriers, compartments, pinch outs, etc) that are likely to affect the connectivity of the reservoir. These features contain built-in uncertainty. Moreover, the underground petroleum trap structure is totally dependent on the sedimentation procedure, age of the rock, type of rock, and the geographical location of the reservoir. The use of modern technology can give a general idea of the structure. However, uncertainty remains as to the geometrical structure of the reservoir. Reservoir physical dimension is also an uncertain issue because of the uncertainty behind the prediction of gross geometrical structure. The physical dimensions of a reservoir mean length, width, height or radius and depth of the reservoir. For any reservoir engineer/geologist, the initial task is to calculate the area or volume of the reservoir.

2.2.5. Reservoir Characterization

The reservoir characterization is a branch of science in petroleum engineering. Reservoir characterization involves detailed description of the reservoir. It includes reservoir architecture, heterogeneity, and performance. Reservoir characterization concept is used in modeling of reservoir. Models based on this concept are used to simulate the behavior of the fluids within the reservoir under different sets of circumstances. Finally the ultimate goal is to find the optimal production techniques that will maximize the production level during the production life time of a reservoir. The geological, geophysical, petrophysical and other data from outcrop and subsurface studies are combined to describe and characterize the reservoir. It models architecture, facies, rock fabric, and heterogeneity of reservoirs. The steps of reservoir characterization methodology include determining reservoir architecture, establishing fluid-flow trends, constructing reservoir model, and identifying reserve growth potential. Based on reservoir type, it is also a concern of integrating petrophysical, seismic, and geologic attributes; 3-D geocellular model building; delineating flow units and fluid flow compartments, and documenting reserve growth concepts under varying reservoir conditions.

2.2.5.1. Reservoir Architecture

Reservoir architecture includes the gross geometrical structure of the reservoir and its physical dimensions. The architecture also belongs to the characteristics of contiguous water-bearing reservoir and the uniformity or variability of the producing section within the reservoir. The application of 3D seismic interpretation play greater role in the development of early stage and to find out the architecture of the reservoir where limited data are available.

2.2.5.1.1. Gross Geometrical Structure of the Reservoir

Gross geometrical structure of the reservoir represents the shape of the reservoir whether it is in a regular (rectangular, circular, cylindrical etc.) or any irregular shape. The underground petroleum trap structure is totally dependent on the sedimentation procedure, age of the rock, type of rock, and the geographical location of the reservoir.

2.2.5.1.2. Reservoir Physical Dimensions

Reservoir physical dimension is also an uncertain issue because of the uncertainty behind the prediction of gross geometrical structure. The physical dimensions of a reservoir mean length, width, height or radius and depth of the reservoir. For any reservoir engineer/geologist, the initial task is to calculate the area or volume of the reservoir.

2.2.5.2. Reservoir Heterogeneity

Reservoir heterogeneity is the most complex and unpredictable feature in reservoir characterization. It includes mainly the formation properties such as porosity, permeability, wettability, formation factor, tortuosity, surface tension, saturation, and rock compressibility. The heterogeneity also deals with rock–fluid interaction. The geostatistical methodology and well logging are used to capture the complexity of the reservoir. However, the different methodologies used in identifying the heterogeneity themselves have limitations. As an example, seismic data are accurate for horizontal continuity, but lacks critical vertical information. Under these conditions, geostatistical methods can be used to integrate data whose volume support are inherently different, and predict vertical detail throughout the reservoir. Both cases represent different levels of uncertainty that may be measured using stochastic principles and allow for more accurate development strategies.

2.2.6. Upscaling

Up-scaling is an averaging process from one scale to a larger scale [11]. The upscaling in reservoir simulation refers to scale up from a geological cell grid to a simulation grid, the second level of upscaling. It is one of the most challenging problems in modeling of a petroleum reservoir. It is also challenging problem in the description of a heterogeneous medium. A medium property is observed at one scale on a particular support (volume) of measurement, but the value of that property is needed on a different volume size at a different location. Another upscaling problem refers to scaling up the geological fine grid to the simulation grid. Geostatistical methods are capable of providing many more values than can be easily accommodated in reservoir fluid flow simulators; hence the geo-statistically derived values are often up-scaled [13]. The main problem in upscaling is related to the non-additive properties like the effective permeability. These properties are not intrinsic characters of the heterogeneous medium. They depend on the boundary condition and the distribution of the heterogeneities which depend on the volume being considered [11].

2.2.7. Reservoir Simulator Output

Reservoir simulators, either the in-house built or the commercially used ones agree on at least two issues. The first is that a numerical solution approach (finite differences or finite elements in most cases) has to be employed to produce a solution for the model, and second, the output is nothing but a huge data in a digital form - in many cases hundreds of pages. It is impossible to grasp a meaning of the output without a graphical representation of these data. That is why the output of modern simulators always displays in plotting or graphical, very often in 3-D representation. Usually, the simulator includes a code written specifically to convert input and output data from simulator raw data to graphical mode. The inclusion of data for each grid block describes each geologic property (rock properties, etc.), fluid properties and a dynamic parameter (commonly called transmissibility). This process is done at an arbitrary initial time (may be one minute, one hour or one day, etc.). This is to be updated for each grid block in the previous time-step for the second time segment with the same description. The interaction of flow parameters of the grid blocks is also included by imposing suitable boundary conditions at the interface between any adjacent blocks. With this much detail it is difficult to form an image of the reservoir without 3-D plots. However, all the features are very much dependent on the description of natural phenomena and real data input.

The degree of changes in seismic response to production within the reservoir is highly dependant on the physical properties of the reservoir rocks. Accurate modeling of these properties from existing data will allow consideration of their effect on the 4-dimensional response. Modeled acoustic/elastic properties include pore volume (V_p), Solid volume (V_s), bulk density, bulk Poisson's ratio, and reflectivity, both at normal incidence and non-vertical incidence. The rock physics model will allow variation in fluid saturation, fluid properties, and reservoir pressure, allowing fluid substitution modeling to represent realistic reservoir changes. The use of dynamic reservoir simulators helps in generating different production scenarios, quantifies oil/gas reserves in the reservoir and predicts future oil, gas and water productions. These important simulation outputs are very crucial in determining production strategies and implementations of improved recovery techniques.

2.2.8. History Matching

A schematic layout of history match of the real and simulated data is depicted in Figure 2. The initial (static) geological modeling and reservoir characterization carry a large degree of uncertainty. The field information is usually sparse and noisy. Some parts of data are obtained from cores of a few centimeters in length and diameter. This is about 10^{-17} –

10^{-16} of a normal reservoir volume. The uncertainty may be quite large for the rock properties in inter-wells. Consequently, the production profile associated with the development schemes cannot be predicted exactly. The standard procedure is transferring the static model into a dynamic model by constraining the model to data representative of the chosen recovery scheme in the form of oil, water and gas production rates and pressure. In contrast to the static data (e.g., geometry and geology) obtained prior to the inception of production, the dynamic data are a direct measure of the reservoir response to the recovery process in application. History matching incorporates dynamic data in the generation of reservoir models and leads to quantification of errors and uncertainty analysis in forecasting. A detail analysis is outlined by Islam et al. [11] to improve the quality of match.

2.3. Risk Analysis in Petroleum Industry

It is already mentioned that the field development and its management always have risks due to several uncertainties pertaining to large investments. The decision making tools and methodologies for measuring the impact of uncertainties are not well defined in the literature. Most analyses do not consider important intangibles, such as long-term impacts on the environment and the ecosystem. This problem is not unique to the petroleum industry, as the inclusion of only the science of tangibles is an inherent problem with the new science of the post-renaissance era [14]. The correct form of risk assessment should include uncertainties and risks as a continuous function of time, in which imbedded are information on individual field, the socio-economic dynamics, and the geographical location of the field of application. Previously, limited approach has been proposed only in the context of environmental justice [15-19]. As some advocacy groups have argued, “On a global scale, climate change is likely to be the biggest environmental justice issue ever [16]. However, the approach that takes in account of all known dimensions is new and has been proposed only recently in the context of humanizing the environment [5, 20]. The uncertainty begins during appraisal and development phases where the improvements of accuracy in the prediction of reservoir performance are important. The computational accuracy, improvement on hardware, software and geological modeling are increasing day by day. However, this accuracy does not guarantee the existence of correct solutions, unless intangibles are included in the computer program, which is not the case most of the time [11].

According to Ligero et al. [6] and Demirnen [21], there are three types of development risks, such as, opportunity loss, uncommercial development and suboptimal development. The production strategy model and the management decision process also affect the quantification of risk [6]. During the assessment of risk of any event, time dimension is the most important parameter because all the influential factors related to risk vary over time. Therefore, time dimension should be considered during the risk analysis.

Recently, Hossain et al. [22] developed a model to assess the individual risk due to flammability in natural gas pipeline where time dimension is introduced. In this study, natural gas pipeline is considered as an example case in order to have a clear idea about the impact of time dimension during the assessment of risk. In the case of risk assessment in natural gas pipelines, Fabbrocino et al. [23] reported that the assessment must be as conservative as possible. They also added that whatever the final assessment, the “worst case” scenario should always be considered. When uncertainties are faced, the deterministic assessment even in the framework of probabilistic safety assessment should be taken into account. This approach is particularly effective, when late or early ignition assumption is considered in risk assessment [23]. However, human health risk assessments determine how threatening a pipeline accident will be to human health for the long run. The main objective of human health risk assessment is to determine a safe level of contaminants or releases of toxic compounds, such as oil and natural gas from a pipeline. In the case of individual humans, there is a standard at which ill health effects are unlikely. It also estimates current and possible future risks. So, all these aspects are related to time factor. The currently used models assume that the safety factor is the most important consideration. However, that assumption implies that the impact decreases with time. This makes the risk analysis inherently focused on short-term. Hossain et al. [24] examined the individual risk of natural gas flammability on human health and identified how to manage risks to acceptable levels. They also recommended a method for risk managers to incorporate risk assessment information for the planning and development of pipeline networks. Finally, it is realistic and very important to analyze the impact of time dimension in risk analysis. A comparative analysis is outlined here as an example case.

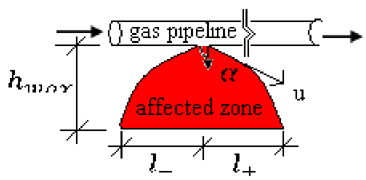
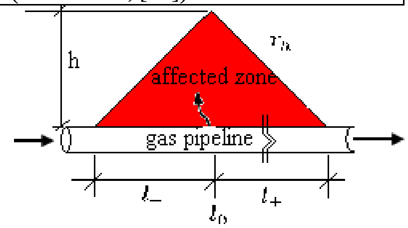
Table 1 shows a comparison between conventional and a newly developed risk analysis model. Conventional risk analysis techniques focus on short-term impacts. The fundamental differences between two models are also outlined in the table.

The Jo and Ahn model [25], as presented in the table, has no room to consider time dimension during risk analysis. On the other hand, the Hossain et al. model [22] has a time dimension which is an important parameter in assessing individual risk due to flammability. From the practical stand point, all researchers agree that pipeline explosion and fire hazards have the risk of instantaneous loss of life, economy and environment. However, no model considered what would be the next or future effects on human, animals, plants, insects and global warming in the long run.

The consideration of intangibles (i.e., continuous time) reverses the current trend of risk management, which is focused on the short-term (i.e., $\Delta t \rightarrow 0$), for which safety is the biggest concern. The geometry of the affected surface area of the conventional model implies that the concentration has diminishing impact as the value goes down. This principle applies to safety considerations, for which explosion hazards are the biggest concern. In the Hossain et al. model [22], the opposite principle is applied. It is well known in other disciplines (e.g., long-term health research, homeopathy, etc.) that as the concentration go down; the vulnerability of environment goes up because smaller cells are preferentially more accessible. Recently, Miralai [26] and Miralai et al. [27] have used this principle to launch a series of sustainable products.

This principle justifies the choice made in the Hossain et al. model. The Hossain et al. model [22] shows that as the gas release rate increases, the impact increases significantly, creating environmental damage, economic losses and injury to the population over time. On the other hand, the conventional model does not have any indication of time effects. While Hossain et al.'s approach provides one with a tool to calculate safety impacts from short-term to long-term; the conventional approach has the severe shortcoming of focusing on long-term impacts. The conventional models can be considered as the perception-based ($\Delta t \rightarrow 0$) models [28]. Hossain et al. [22] outlined some of the shortcomings of conventional approach. In contrast, the Hossain et al. model can be considered as the knowledge-based model ($\Delta t \rightarrow \infty$).

Table 1. Conventional risk analysis techniques focus on short-term impacts

Sl. No.	Description	Long-term ($\Delta t \rightarrow \infty$) model Knowledge-based model (Hossain et al., [22])	Short-term ($\Delta t \rightarrow 0$) model Perception-based model (Jo and Ahn, [25])
1	Nature of the area covered		
2	Physical basis	Projectile concept	Reverse triangular concept
3	Mathematical basis	$$IR_f = \sum_i \frac{\varphi_i}{100} \int_{l_-}^{l_+} \int_0^{h_{max}} (UFL_i - LFL_i)\, dh\, dl$$ $$u = 1.273 \frac{q_{min}}{d_{hole}^2}$$ $$h_{max} = \frac{1}{2} u\, t\, \cos\alpha$$ $$l_\pm = \frac{1}{2} u\, t\, \sin\alpha$$ $$\alpha = \tan^{-1}\left(\frac{l}{h_{max}}\right)$$ Where, IR_f = individual risk due to flammability limit UFL_i, LFL_i = upper and lower flammability limit due to accidental scenario i q_{min} = minimum gas flow rate evolved through the hole that causes an explosion , m^3/s d_{hole} = diameter of the hole through which gas passes, m h_{max} = hazard distance, m u = velocity of gas,m/s t = travel time to reach the hazard distance, *sec* α = angle between velocity of gas and hazard distance, *degree*	$$IR = \sum_i \varphi_i \int_{l_-}^{l_+} p_i\, dl$$ $$r_h = 10.285\sqrt{Q_{eff}}$$ $$l_\pm = \sqrt{106 Q_{eff} - h^2}$$ Where, IR = individual risk φ_i = failure rate per unit length of the pipeline associated with the accident scenario i due to soil condition, coating, design and age, *1/year km* l = pipeline length, *m* p_i = lethality associated with the accident scenario i Q_{eff} = effective release rate from a hole on a pipeline carrying natural gas, *kg/sec* r_h = hazard distance, *m* $l_\pm$ = ends of the interacting section of the pipeline in which an accident poses hazard to the specified location, *m*
4	Locality effects	Wider range of area towards locality	Narrower range of area towards locality
5	Time effect	Long term effects on human, plants, animals and insects ($\Delta t \rightarrow \infty$). Environment and the global security is the concern.	Short term effects on plants, animals and insects ($\Delta t \rightarrow 0$). Safety of humans is the concern.
6	Effects of concentration (gas-air mixture)	As concentration goes down, the impact increases within the locality or the environment	As concentration goes down, the impact decreases within the locality or the environment
7	Gas release rate	Initial impact is less than long-term impact.	Initial impact is the most prominent, with decreasing impact with time.

3. Analysis and Sources of Uncertainty

The main task of a reservoir simulator is to give an estimate on the hydrocarbon-in-place. The physical quantity of hydrocarbon-in-place is a fixed quantity. Therefore, it is question how accurately this hydrocarbon-in-place is quantifying because there is an involvement of uncertainty, mystery and risk. If the sources of uncertainty are identified, it is easy to understand and handle the problem which may reduce the uncertainty level and improve the accuracy of the result. The sources of uncertainty can be categorized by breaking down into its basic component. The followings are the basic categories of uncertainty [11, 29].

1. measurement inaccuracy (i.e., random measurement, systematic (bias) uncertainty);
2. upscaling process;
3. model uncertainty or computational approximation (i.e. model error);
4. incomplete data (i.e., lack of representativeness or incomplete data);
5. Stochastic Systems;

3.1. Measurement Uncertainty

Almost all oilfield measurements have some degree of errors or inaccuracy. Such errors may be the result of a fundamental level of imprecision of the instruments making the measurement, or may be due to poor calibration, or even human error in performing the measurement [29]. These differences are normally called random errors. There are a number of basic statistical concepts and terms that are central for estimating the uncertainty attributed to random measurement. The process of estimating uncertainties is based on certain characteristics of the variable of interest (input quantity) as estimated from its corresponding data set. The detail information can be found in existing literature [11].

3.2. Upscaling Uncertainty

The main issue in upscaling is related to the upscaling of non-additive properties such as permeability and relative permeability. There are different methods for upscaling of the rock and fluid flow properties. Some of them are mentioned in section 2.2.6. The upscaling method may be classified as single-phase and multi-phase upscaling. In the single-phase upscaling, the absolute permeability is only up-scaled from a geo-cellular grid to the simulation grid. The relative permeability is considered identical for both scales. The relative permeability and capillary pressure are also up-scaled along with the absolute permeability from a fine grid into a coarser grid. In many cases, the coarse block properties are obtained by considering only the fine grid scale region corresponding to the target coarse block. It is called as the local upscaling. The global upscaling is referred to the case where the entire fine scale model is solved. Hence the solution is applied to obtain the coarse scale behavior. However, there are other categories as extended local upscaling; a border region around the coarse grid is also taken into account, and quasi-global upscaling in which an approximate solution of entire flow region is adopted to derive the coarse blocks behavior. The local upscaling methods do not consider the permeability connectivity.

The most important detrimental effects of the upscaling are: homogenization of the medium; and coarsening of the computational grid [11]. The permeability field is made smoother due to the homogenization and the truncation error is increased by using larger computational girds. Error introduced due to the homogenization may be referred as the "loss of heterogeneity error" and due to the coarsening of the computational grid may be referred as the "discretization error" [30]. The combination of this two gives the total error due to the upscaling process. The total error may be small due to the opposing effect of these two type of errors contributed to the total upscaling error. As mentioned in REV that the representative volume should be as large as the dimension of the field, in the low level upscaling the discretization error may be dominated while the loss of heterogeneity error may dominate for high level upscaling.

3.3. Model Error

The model error includes the approximation in mathematical representation. The computation during the reserve estimation depends upon formulae or correlations that have been developed (many several decades ago) from empirical data. Such mathematical model or correlations do not work with time because the degree of scatter in the original data and also the range of the original data; the correlations extrapolating beyond the range of the data points. The ignorance and insufficient or leggings of information create simplified models that do not truly represent the more scattered nature of the data or formulation of the model.

The solution method is mostly numeric and also the model of error estimation. The mathematical formulations in most of the available simulators are based on the material balance equation and Darcy's law. These two fundamental equations do not mimic the reality of the flow inside the porous rock. The assumptions behind them are expressed by Mustafiz and Islam [4]. However, the final solution is nonlinear that is complicated to solve analytically and the solution of it should be obtained with numerical methods. There are some analytical solutions for a few special problems in reservoir engineering such as Buckley-Leveret flow that suffer a quite large number of assumptions and do not show the real situation in the fluid flow inside the reservoir rock. The most applied methods are the finite difference and finite element methods. The finite difference method is based on the Taylor series expansion. The nonlinear parts of the Taylor series expansion are normally neglected to approximate the derivation. If we consider that the normal size of a grid block is in order of 10 m, the neglecting of the nonlinear part of the Taylor series expansion produce a substantial uncertainty. Therefore, if it is assumed that reservoir model, the geological and characterization model are exactly correct in every detail, one can not get exact prediction of the reservoir performance due to the fact that reservoir fluid flow model does not mimic reality.

This may have fixed certain aspects of reservoir model (for example, the reservoir geometry) and only attempted to predict uncertainty with regard to other parameters such as porosity and permeability. Even if those parameters are exactly correct, it may not be possible to get an exact prediction because of errors in the fixed aspects of the model. This second source of model error could in principle be removed by including all possible parameters in the uncertainty analysis but this is never feasible in practice. The true model error is virtually impossible to quantify, so in practice it has to be neglected. The size of the model error depends strongly on the parameterization of the model, and one may hope that if this is well chosen, the model error will be small [31].

3.4. The Prediction Uncertainty

The information gap or the missing of information is a common mystery or uncertainty in almost every evaluation. In such situation, personal judgment is applied and some assumptions are made to fill the gaps. This is the area where bias effects the evaluation or prediction. This biasness ultimately reveals the personal competence and experience, preferences and motivations of the evaluator(s). Since the choice, thought, understanding capability etc. differ from person to person, the assumptions will vary which makes the decision to achieve the goals variable. Therefore, it is very important to fix the parameters first and then should go for the next step to remediate the uncertainty. When the parameters are set according to the production data, the next step is obtaining the uncertainty envelope and the confidence region. This is important in forecasting the reservoir behavior and decision making process. Islam et al. [11] developed the models how to quantify the uncertainty envelop.

3.5. Stochastic Systems

There are some inherent mystery in engineers and geoscientists. They use the known information from the technical level to estimate and calculate what they do not know which might have some other non-technical events. It is well established that “factors outside the realm of an engineering estimate” continually play a role and do affect final answers, sometimes significantly. As an example, one might gives the reference of oil and gas prices. The change of prices and costs will affect the economic limit which is directly related to oil recovery. So, here the management decision on EOR is totally dependent on economic condition.

4. Real-Time Monitoring

The history-matching process can be considered as a closed-loop process. The production data from the real system are adopted to modify the reservoir and model parameters and to use for future prediction. The history matching process is usually carried out after period of years. The traditional history-matching involve manual adjustment of model parameters and is usually ad hoc. According to Brouwer et al. [32], the drawbacks of a traditional history-matching are:

1. It is usually only performed on a campaign basis, typically after periods of years.
2. The matching techniques are usually ad-hoc and involve manual adjustment of model parameters, instead of systematic parameter updating.
3. Uncertainties in the state variables, model parameters and measured data are usually not explicitly taken into account.
4. The resulting history-matched models often violate essential geological constraints.

5. The updated model may reproduce the production data perfectly, but have no predictive capacity, because it has been over-fitted by adjusting a large number of unknown parameters using a too small number of measurements.

To adopt an optimum production strategy and to produce oil and gas in challenging physical environments such as deepwater reservoirs and oil-bearing formation in the Arctic, it is required to update the model more frequently and systematically. If the model is also smart, it will produce real-time data. Smart field technologies are currently generating significant interest in the petroleum industry, primarily because it is estimated that their implementation could increase oil and gas reserves by 10-15% [33]. This help to optimize the reservoir performance under geological uncertainty and also incorporate dynamic information in real-time and reduce uncertainty. Islam et al. [11] describes the smart reservoir modeling system which is depicted in Figure 3. It is a real-time closed-loop to control the reservoir behavior and to attain an optimum production. This figure illustrate a true closed-loop optimal control approach that shifts from a campaign-based ad-hoc history matching to a more frequent systematic updating of system models, based on data from different sources, while honoring geological constraints and the various sources of uncertainty. Detail optimization process and simulation models are available in literature [11].

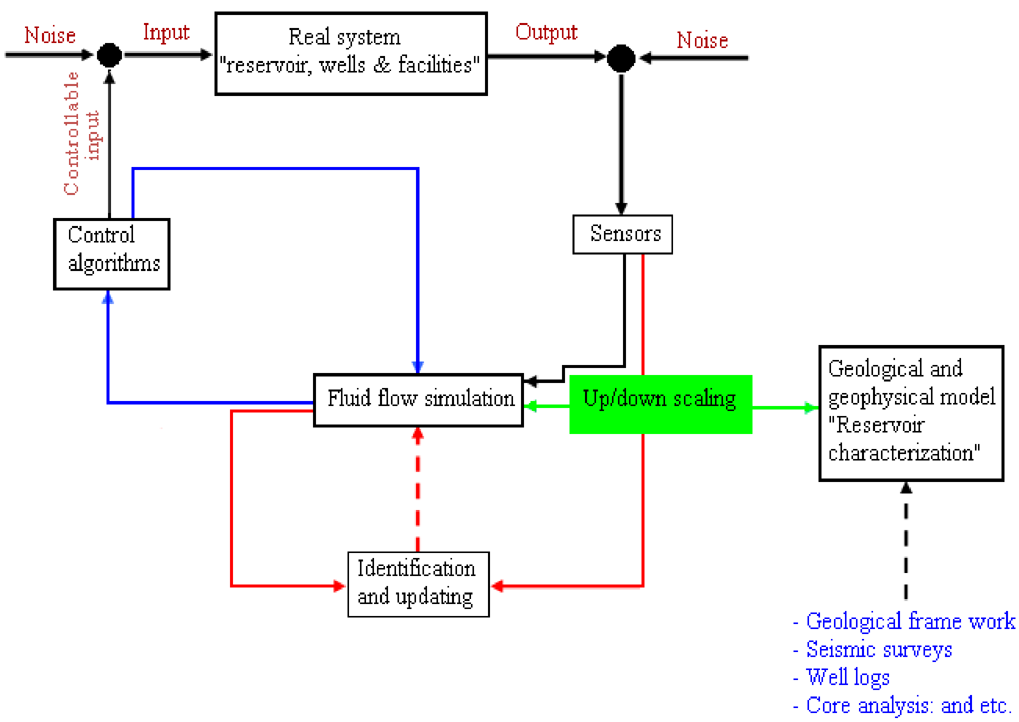


Figure 3. Schematic layout of a comprehensive smart reservoir modeling, present source: [11].

CONCLUSIONS

The lacking of information, the linearization (by making assumptions) of the model, inaccuracy of the tool and human error are the major sources of mystery and uncertainty. The identification and breaking down into components of the uncertainty associated with oil/gas evaluations facilitate an understanding of the relative impact of each component. The realm of mystery and uncertainty is identified and this paper looks at the sources of uncertainty in an oil/gas evaluation. The attempts to characterize the sources of these mysteries and uncertainties are outlined by their definition and interrelationships in order to better understanding of how to handle them. In characterizing uncertainty, the inclusion of measurement inaccuracy, computational approximation, the effect of incomplete or missing data give an insight understanding of the cloud during the reservoir simulation in petroleum engineering.

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