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Assessing the Impact of Uncertainty Parameters on Forcasting Production Parameters

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Оценка влияния параметров неопределенности на прогнозирование показателей разработки

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uncertainty parameters, multivariant simulation, stochastic analysis, model adaptation, forecast of production process parameters, adjustment of oil production levels, sensitivity analysis, incremental oil production, equilibrium adaptation options, sector model, probabilistic risks assessment, percentile, mathematical expectation, factor analysis.

At the stage of developing a geological and hydrodynamic reservoir model, uncertainties in input data may lead to errors in simulation results and subsequent inaccurate economic evaluations of oil or gas field potentials.

In order to improve predictive reliability, a study was completed to assess how input data of a hydrodynamic model influence forecasts of main parameters of a production using the example of the Tournaisian site of the Soldatovskoye field.

The study presents an approximate algorithm reducing uncertainties and improving the forecast reliability of the production parameters obtained using a geological and hydrodynamic reservoir model. The algorithm includes a substantiated selection of the initial sensitivity parameters, an evaluation of the impact of the initial parameters on the hydrodynamic reservoir model using the sensitivity analysis, as well as a selection of an optimal range of variations of the uncertainty parameters as a result of the multivariant hydrodynamic simulation adaptation, calculation and analysis of the multivariant hydrodynamic reservoir model forecast.

The study aims to clarify the design process parameters of the development, assess the risks of non-confirmation of the hydrodynamic simulation forecasting, and make recommendations and proposals to study those uncertainty parameters, which influence most on certain predicted production parameters of an asset. As a result, a block diagram of the approach is presented in order to generalize and replicate it on potential and important oil and gas fields.

The described approach of the model adaptation and calculations of the predicted options in conditions of uncertainty of the initial model parameters make it possible to obtain a more accurate and less arbitrary hydrodynamic reservoir model, which reduces probability of an incorrect evaluation of potentials of a *young* field or a field at an early production stage.

Ключевые слова:
гидродинамическое моделирование, параметры неопределенности, многовариантное моделирование, стохастический анализ, адаптация модели, прогноз технологических параметров разработки, уточнение уровней добычи нефти, анализ чувствительности, прирост добычи нефти, равновесные варианты адаптации, секторная модель, вероятностная оценка рисков, перцентиль, математическое ожидание, факторный анализ.

Неопределенности исходных данных при создании геолого-гидродинамической модели пласта могут привести к погрешности результатов моделирования и, следовательно, к неверной экономической оценке и перспективе нефтяного или газового месторождения.

С целью повышения прогнозной надежности осуществлена оценка влияния исходных параметров гидродинамической модели на прогноз основных технологических показателей разработки на примере турнейского объекта Солдатовского месторождения.

В исследовании представлен ориентировочный алгоритм, позволяющий снизить неопределенности и повысить надежность прогноза технологических показателей разработки, полученного с помощью геолого-гидродинамической модели пласта. Алгоритм включает в себя обоснованный выбор исходных параметров неопределенности, оценку степени влияния исходных параметров на гидродинамическую модель пласта с помощью анализа чувствительности, выбор оптимального диапазона изменения параметров неопределенности в результате многовариантной адаптации гидродинамической модели, расчет и анализ многовариантного прогноза гидродинамической модели пласта.

Итогом работы является уточнение проектных технологических показателей разработки, оценка рисков неподтверждения прогноза гидродинамической модели, а также рекомендации и предложения по исследованию тех параметров неопределенности, которые оказали наибольшее влияние на расчетные технологические показатели разработки объекта. Как итог представлена блок-схема применяемого подхода с целью обобщения и тиражирования на перспективных и значимых месторождениях нефти и газа.

Описываемый подход адаптации модели и расчета прогнозных вариантов в условиях неопределенности исходных параметров модели позволит получить более достоверную и менее субъективную гидродинамическую модель пласта, что, в свою очередь, снизит вероятность неверной оценки перспективы «молодого» месторождения или месторождения, разрабатываемого на ранней стадии.

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Introduction

To increase efficiency of oil field productions, it is required to build geological and hydrodynamic models (GHM) for production sites. A dydrodynamic model is intended to provide the most precise description of permeability parameters, as well as physical and chemical processes characteristic of an actual reservoir [1–7].

In Perm Krai, small-scale oil fields are in priority. Due to small volumes and mobility of geological reserves, input data errors may lead to incorrect evaluations of a field's potential. Thus, a review of initial data uncertainties is required to obtain reliable forecasts during the design process, and at the stage of building hydrodynamic models of fields at early production stages.

An uncertainty is a state of a full or partial absence of information about a site to be modeled, which is required to understand a certain event, its consequences and their probability [8–12].

The purpose of the study is to improve certainty of forecasting main process parameters of fields at early production stages.

Current Status of the Tournaisian Site Development in the Soldatovskoye Field

The Tournaisian site in the Soldatovskoye field havs been developed since 2012. The asset contains several uplifts, including the Kukleyanovskoye uplift. The latter is of interest as it holds 47 % of geological oil reserves of the Tournaisian site.

In 2017, the asset reached an early development stage with the current production well stock of eight horizontal wells. Current oil rates vary from 1.3 to 27.9 t/day. The watering rate of the producing wells is from 4.8 to 93.0 % (Fig. 1).

The production diagram analysis reveals that the weighted average reservoir pressure within the site is preserved at the level of 17 MPa. However, in the area of producing wells 404 and 403 at the Kukleyanovskoye uplift, the reservoir pressure is decreased by 41–54 %, compared to the initial pressure (from 17.5 to 8 MPa), when the saturation pressure is 10.2 MPa.

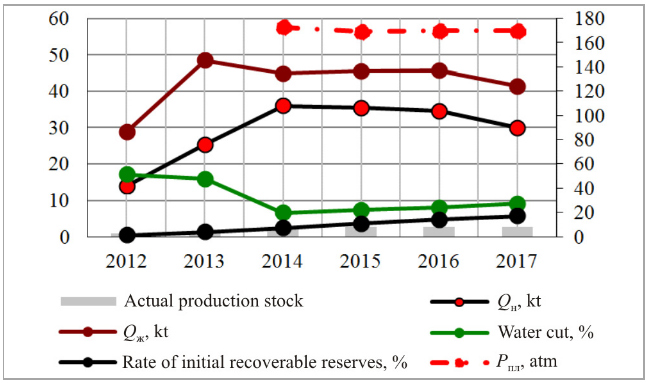

Fig. 1. Production diagram, the Soldatovskoye field, the Tournaisian site

Table 1

Geological and physical characteristics of the Tournaisian site in the Soldatovskoye field

Parameter	Kukleyanovskoye uplift
Average roof depth, m	1,803.5
Reservoir type	Carb.
Average effective oil-filled thickness, m	8.9
Porosity factor, decimal fraction	0.12
Permeability, um^2	0.0145
Sand factor, decimal fraction	0.443
Partitioning, decimal fraction	10.4
Initial reservoir pressure, MPa	17.5
Oil viscosity at reservoir conditions, mPa·sec	13.7
Oil density at surface conditions, g/cm^3	0.912
Saturation pressure, MPa	10.2
Gas factor, m^3/t	38.8
Displacement ratio, decimal fraction	0.56
Productivity factor, m^3/day·MPa	3.4

Table 1 gives a brief overview of geological and physical characteristics of the Tournaisian site.

In order to optimize time consumed for GHM calculations, a separate sector model was built for the Kukleyanovskoye uplift with a geological model (GM) level of detail. The number of active cells reduced seven times, while the calculation time was 15 times quicker. For initialization, an aquifer was created at the sector model borders using the Carter-Tracy aquifer flow model.

Justification of Selecting the Uncertainty Parameters

At the adaptation stage of per-well actual rates, an adequate creation of the hydrodynamic model was complicated due to low absolute permeability values. Based on geophysical well logging (GWL) results, the average absolute permeability value for the uplift under study was adopted as 14.5 mD. As a result, it was decided to consider hydrodynamic researches (HR), which established that the farfield reservoir (FR) permeability at one of producing wells was 787 mD in 2012 and 23 mD in 2014. Taking into account the difference in permeability values obtained with the HR and GWL studies, and also variations in permeability values obtained with HR during the reservoir pressure reduction, we may assume that there was a fracture system [13–19].

The rock permeability containing a fracture system is known to depend on the reservoir pressure to a much greater extent vs. permeability of a porous medium. Supposedly, the reduction in the reservoir pressure in 2014 increased the external load on the rock skeleton, which resulted in a smaller openness of fractures. This decreased permeability from 787 to 23 mD after performing HR in 2014 within the producing well area.

Presumably, values of the reservoir properties were incorrectly determined due to an incomplete GWL in the wells with a nominally horizontal borehole section, as they have a small diameter.

The analysis of the Kukleyanovskoye uplift resulted in the following parameters selected as uncertainty:

1. The absolute permeability parameter of an aquifer and oil-saturated reservoir parts to indirectly account for the Tournaisian reservoir fracturing.

2. The influence of the aquifer. It was modeled using the Carter-Tracy aquifer flow model, taking into account replacement zones. The Carter-Tracy aquifer maximally accounts for the aquifer property due to such parameters as average reservoir permeability, average reservoir porosity, a sum of the rock and water compressibility, an internal aquifer radius, an average effective thickness, an initial reservoir pressure, reservoir water viscosity. Given the underexplored level of the site, parameters of the average permeability, porosity, reservoir thickness and internal aquifer radius are taken as uncertainty.

3. Uncertainty of the rock phase permeabilities. Permeability values of the experimental phase exist only for two values of the absolute permeability at the Soldatovskoye field. Phase permeability curves were used for simulation, modified subject to the residual water saturation.

4. Uncertainty of the *reservoir-to-well connectivity* and skin factor. The connectivity and skin factor are selected as a parameter of uncertainty, as within time, the well has its hydrodynamic imperfection changed according to its penetration nature [20].

Table 2 presents boundary values of uncertainty parameters.

Multivariant Simulation

The next stage of the study implies performing a multivariant simulation with regard to the selected range of uncertain parameters using Enable software by Roxar [20–27]. In total 110 calculations were performed. Fig. 2 shows a diagram of the cumulative oil production for all options of the hydrodynamic model adaptation.

On basis of the obtained options of the model adaptation, their quality was evaluated, during which calculations complying with temporary rules of quality evaluations and acceptance of three-dimensional digital geologo-hydrodynamic models were selected. That is, a deviation of the calculated cumulative fluid and oil production will not exceed 5 %, while the deviation of the calculated annual fluid and oil production will not exceed 10 %. Table 3 shows adaptations results of boundary calculations, complying with the regulation. Calculations shown in Fig. 6 and distributed either above or below the boundaries, fall beyod the regulation range.

Table 2

Boundary values of uncertainty parameters

Uncertainty parameter	Value		
	minimal	average	maximal
Aquifer permeability parameter, Md	14.5	25	207
Aquifer porosity parameter, %	0.08	0.12	0.17
Parameter of average effective aquifer thickness, m	70	75	100
Internal radius of aquifer, m	2,000	2,500	3,000
Reservoir to well connectivity, decimal fraction	1	5	10
Skin factor	–10	0	10
Single phase flow multiplier, decimal fraction	0.75	1	1.25
Permeability multiplier (presence of fraction networks), decimal fraction	1	1.5	2

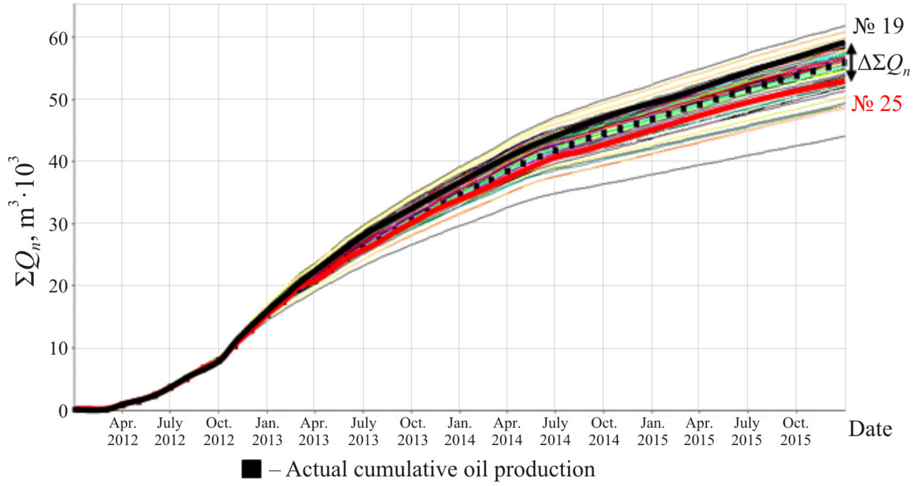

Fig. 2. Diagram of calculated cumulative oil production of all model adaptation options

Table 3

Adaptation results of boundary calculations

Year	Fluid production, thou. m^3		Δ, %	Oil production, thou. m^3		Δ, %	Water saturation, %		Δ, %
	actual	calculated		actual	calculated		actual	calculated	
Calculation # 19									
2012	28.1	27.1	3.6	15.4	16.2	–4.9	45.1	40.3	10.7
2013	38.2	38.0	0.4	19.3	20.6	–6.5	49.3	45.9	7.1
2014	15.9	15.8	0.8	12.2	12.5	–2.4	23.6	21.1	10.4
2015	12.6	12.5	0.5	9.0	9.3	–3.2	28.7	26.1	9.3
Total period	94.8	93.4	1.4	55.9	58.5	–4.6			
Calculation # 25									
2012	28.1	28.1	0.0	15.4	15.2	1.7	45.1	46.1	–2.0
2013	38.2	38.0	0.5	19.3	19.2	0.8	49.3	49.5	–0.3
2014	15.9	15.6	2.3	12.2	11.6	4.5	23.6	25.3	–7.4
2015	12.6	12.6	0.0	9.0	8.2	8.5	28.7	34.8	–21.2
Total period	94.8	94.2	0.6	55.9	54.2	3.1			

Table 4

Corrected boundary values of uncertainty parameters

Uncertainty parameter	Value		
	minimal	average	maximal
Parameter of aquifer permeability, mD	50	55	65
Parameter of aquifer porosity, %	0.12	0.13	0.14
Parameter of average effective aquifer thickness, m	85	90	95
Internal radius of aquifer, m	2,289	2,392	2,544
Reservoir to well connectivity, decimal fraction	1	5	10
Skin factor	–10	0	10
Rock wettability (single phase flow multiplier), decimal fraction	1	1.25	1.25
Permeability multiplier (presence of fracture networks), decimal fraction	1.45	1.5	1.55

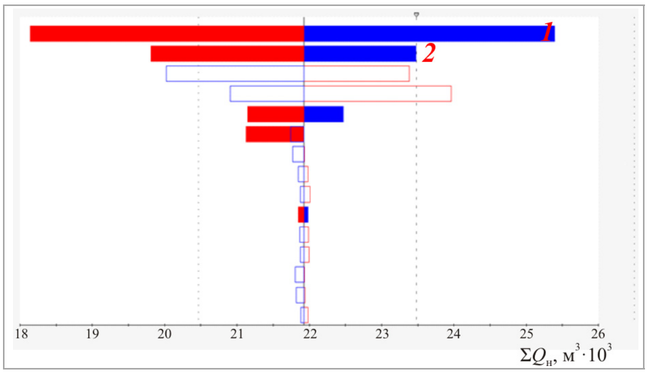

Fig. 3. Tornado diagram: *1)* absolute permeability multiplier; *2)* multiplier (single phase flow)

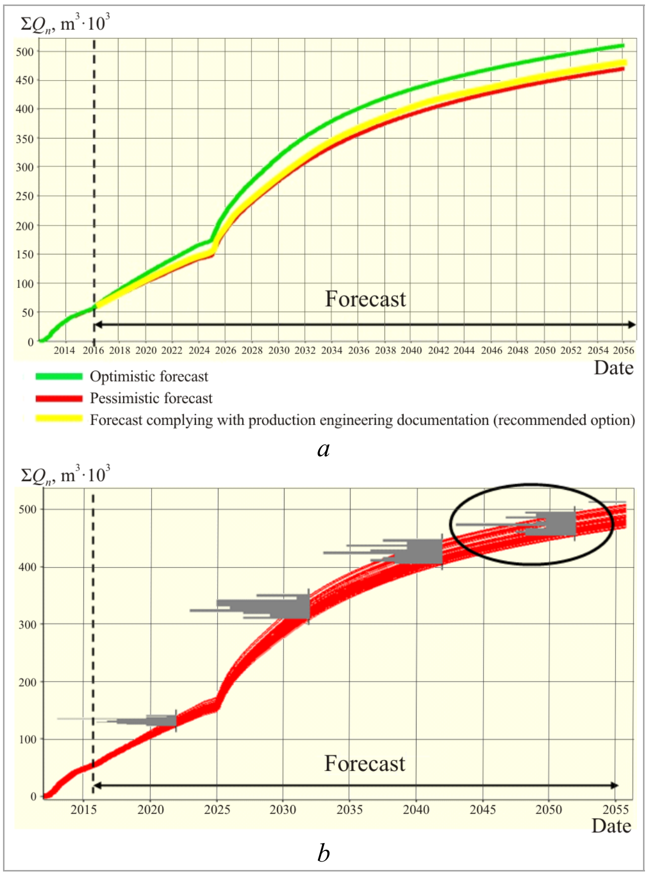

Fig. 4. Diagram of forecasted values: *a)* cumulative oil production; *b)* cumulative oil production with plotted histograms of calculations density distribution

It is found that 77 calculations out of 110 fall within the regulation range, which is 70 % of the total amount.

By the multivariant adaptation of GHM and further selection of calculations complying with the regulation, the variation range of the uncertainty parameters was narrowed, which resulted in corrected boundaries of the uncertainty parameters (Table 4) [28–31].

At the given values of the uncertainty parameters, all the calculations obtained by using GHM comply with the regulation. However, during calculations of the long-term forecast parameters, a significant deviation will be observed.

Analysis of Influence of the Uncertainty Parameters on the Calculated Production Parameters

During the study, sensitivity calculations were performed, which showed that parameters with the greatest impact on the model adaptation are the absolute permeability multiplier, which indirectly accounts for the reservoir fracturing, and relative phase permeabilities multiplier.

Tornado diagram in Fig. 3 shows an extent of variations in the cumulative oil production depending on values of the uncertainty parameters.

Multivariant Forecasts using the Recommended Development System

We performed the forecast calculations for the recommended option of adaptations complying with the regulations at the next stage related to evaluations of quality and determinations of parameters, which have the greatest influence on the model adaptation [32, 33].

As a result, optimistic (510 thou. m^3) and pessimistic (469 thou. m^3) options of the cumulative oil production forecast were obtained. The difference between them is 41 thou. m^3 (Fig. 4).

By analyzing Fig. 4, *a*, one can see that the recommended forecast option is included into the highlighted area and is distributed closer to the pessimistic option. Further on, a probabilistic forecast assessment was performed using histograms characterizing a density of the distribution of calculations, according to values of the cumulative oil production (Fig. 4, *b*) [34].

Fig. 5 shows an enlarged histogram characterizing the density of the distribution of the cumulative oil production in 2056 with percentile marked up.

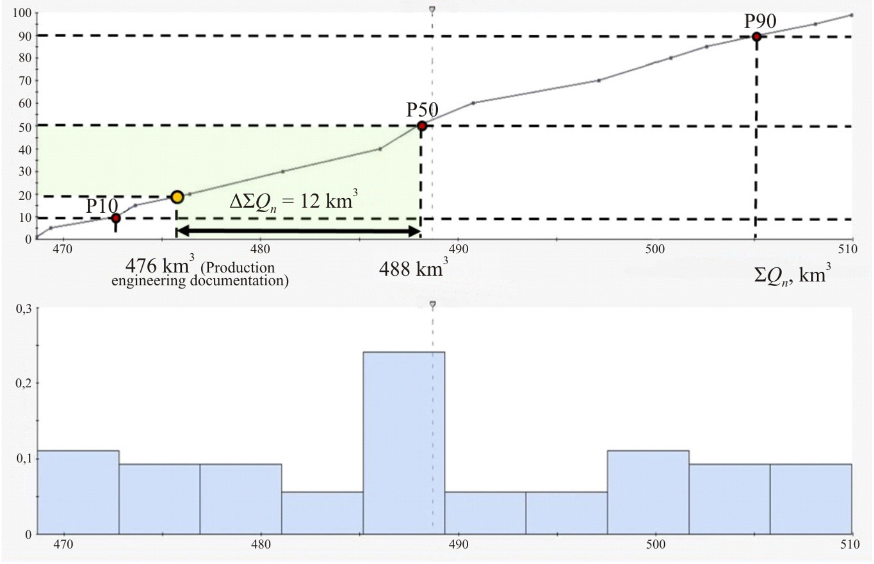

Fig. 5. Diagram of GHM calculations of density distribution with the plotted percentile

The percentile shows that it is possible to separate the most probable or pessimistic level of the cumulative oil production (P10), the optimal level (P50) is almost always close to the mathematical expectation, which is the level most frequently forecasted by GHM, and the most optimistic oil production level (P90). Also, the percentile marks the oil production level approved by the present design document on the Soldatovskoye oil field development within the Tournaisian reservoir of the Kukleyanovskoye uplift. As the oil production level approved by the production engineering documentation is lower than P50 by 12 thou. m^3, then it is possible to state a moderate potential for the site under development.

In addition, the percentile analysis makes it possible to conclude that the cumulative oil production level, approved in the current field development design documentation, will be confirmed with the probability of 81 %, according to the calculations based on the geological and hydrodynamic reservoir model.

As the Kukleyanovskoye uplift is taken as a separate site, it reached an early development stage and has a small amount of geological and mobile oil reserves, the increase of 12 thou. m^3 will be sufficient to strengthen the commercial effectiveness of the investment project.

Otherwise, if the GHM calculations produce a value of oil production level of percentile P50, which is less than in the approved development project, one risks a project profitability decline. Therefore, it is necessary to consider uncertainties that may impact a project profitability in cases of either promising and important fields being developed at an early stage, or fields with a small volume of geological and mobile oil reserves [35–37].

All the data are further acummulated in a generalized algorithm to analyze the impact of uncertainties and assess risks for the technological and commercial effectiveness of an investment project, which, in fact, can be applied to assets being developed at an early stage (Fig. 6) [38–45].

This algorithm may be modified and addded depending on the level of studies, development stage, economical and political factors.

Conclusions

The completed study has resulted in selecting uncertainty parameters and their range of variations. Also, we have performed the multivariant adaptation, which allows specifying the range of variations of earlier selected uncertainty parameters.

The sensitivity analysis, or the factor analysis, made it possible to conclude that the absolute permeability multiplier within the area of the producing wells (indirectly accounting for an influence of fractures on the fluid filtration in the reservoir) and functions of the relative phase

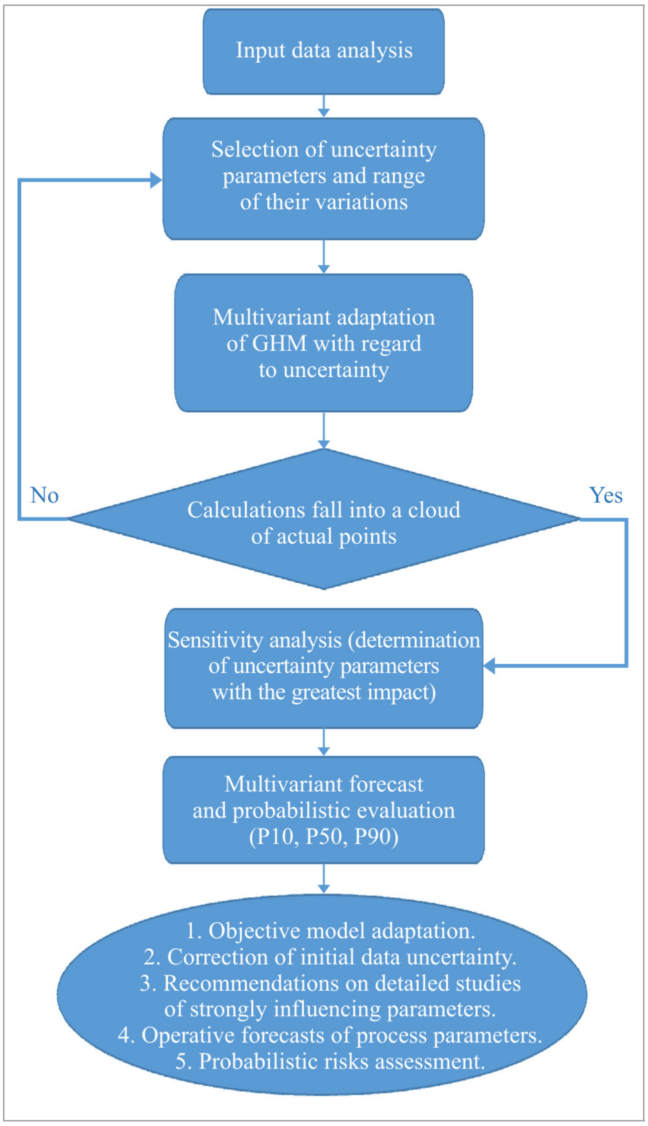

Fig. 6. Algorithm of impacts of uncertainties and risk assessment analysis

permeability have a great impact on the cumulative oil production. A more detailed study of these parameters is recommended.

Based on the obtained data, the multivariant forecast allowed completing a probabilistic evaluation and identifying pessimistic (P10), optimal (P50) and optimistic (P90) oil production levels in 2056. It is determined that the optimal (P50) level of the cumulative oil production is 12 thou. m^3 higher than the level approved by the present production engineering documentation. Thus, we can conclude that it offers a slight potential.

The completed study offers the algorithm showing the impacts of uncertainties and risk assessment analysis. The latter allows optimizing the approach of the hydrodynamic model adaptation, making the adaptation process more objective and reliable, reducing uncertainty of input data, developing recommendations on further studies of assets, forecasting, evaluating the main production engineering parameters and performing the probabilistic risk assessment.

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