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**Geological and technological monitoring of reservoir engineering  
on the north part of Western Siberia**

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## REVIEW

Peculiarities of geology aspects of fields situated on the north part of Western Siberia, connected with large sizes of structures, variability of reservoir properties, active aquifer basin demand working out of non-conventional approaches to their field development, geological and field criteria coordination for providing the efficient use of earth depths, in other words a systems approach to study geological and technological problems.

Problem of deposit inundation in Cenomanian conditions has essential important meaning. On the one hand rate of drawdown of formation pressure is slowing due to advance of bottom water; on the other hand influence of advance of brine water is negatively affected on well efficiency.

Main tasks of rational development control of fields result from the analysis of outstanding geological and commercial characteristics and gas field conditions. These principal duties include the forecast of production data changes at the time, operations reassignment of gas extraction along the horizontal and through the section of reserves. They provide maximum gas recovery, establishment of optimal well operating practices, prevention of deposit inundation and rock breaking in near well bore.

Performance targets should be decided on the base of single geological-technological model, containing all elements of the system "deposit – well – gas collection systems – preparation - gas transport".

The main technology of field development monitoring is trade and geophysical methods of testing for wells and reservoirs. Assessment of gas and water volume break down on area and through the section of reserves, study of processes existent during the implementation of bottom and edge water in gas storage, analysis of dynamics of current gas saturation, definition of exploitation and monitoring wells integrity belong to current tasks.

Estimation of gas reserves should be pay special attention during operation. Authors created methodology and process flow schematic of reserves calculation with degree and quality evaluation of knowledge about deposit which uses in solving problem of choice the efficient variant.

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## Introduction

Cenomanian gas pools located in the north of West Siberia produce near 80 percent of natural gas extracted in Russian Federation. The immediate horizon of gas industry's development is also connected with the Cenomanian Aged reservoirs management, because of large amount of GIP (gas-in-place), high reservoir productivity and convenient reservoir characteristic of Cenomanian pools.

Geological aspects of Cenomanian pool concerned with large size of structure variety of reservoir properties and active extensional regime of the aquifer basin demand invention of non-conventional approaches to the field development and building-up interaction between field and geological data for sustainable mining, that means systems approach to the investigation and research of geotechnical issues [1].

Most part of Cenomanian pool belongs to reservoirs of massive or bedded-massive type. In these types fossil water underlie the whole gas-productive area. That's why central group well pattern is commonly used. The experience of usage of such well spacing has shown good results. But producing this type of in-field drilling it's impossible to involve whole area.

Nowadays it is of fundamental importance to solve the problem connected with the deposit inundation of the Cenomanian pools. On the one hand, increase of fossil water slows down the reservoir pressure decline (positive effect), but on the other hand it causes the reduction of well productivity. Premature flooding of producing wells usually occur in wells perforated in the bottom part of a column, what lead to reduction of strength properties and structural behavior and increase the danger of rock failure in the bottom-hole area.

Large size of structure is the reason for usage of phased commissioning in the area. Stage-by-stage approach influences the in-situ processes [2]. During phased commissioning different part of reservoir are being worked out unbalanced, that cause informational cross-flow of gas, formation pressure redistribution, building up the local pressure sink can take a long period. So it becomes difficult to control the in-situ processes, manage the field development and forecast the change of geotechnical parameters.

The signature feature of the gas Cenomanian pool is a large gas column, for example, at the Urengoy gas field gas column reaches the size of 260 m. To work out original gas in place proportionally through the section vertically differentiated system of drilling in, so perforation of section is made proportionally with the amount of gas, that lead to decrease of gas recovery in a low near-contact zone.

After analyzing of the geotechnical particularities of the gas field situated in the north of West Siberia we can emphasize main issues concerned to it successful management:

- monitoring of technical parameters,
- promotional recovery of gas, that provide maximum gas recovery;
- setting most effective operating practice
- prevention of deposit inundation and rock failure in the bottom-hole area.

The solution of these problems should base on the integrated model, that includes all elements of the system: "field-well-gas-collecting system-gas treatment – gas transfer"[3].

## 1. Trade and geophysical methods of investigation

The investigation of geology structure and reservoir properties with the help of logging cased wells begins simultaneously with the drilling and continues during the whole period of field development.

The main technology of the investigation of geology structure during the process of field development is field geophysical methods. They provide information according the estimate of in-situ expansion of gas and water and processes taking place during the input of bottom water and edgewater. Also these data can help to analyze the level of current gas saturation and determine integrity study of monitoring and producing well [4].

Unique Cenomanian Aged fields in the north of West Siberia are run at the active elastic water drive. The sign of elastic water drive usually appear after 3-4 year of placing on production . That's why it is necessary to provide a system check for the input of bottom hole water in the gas part of field.

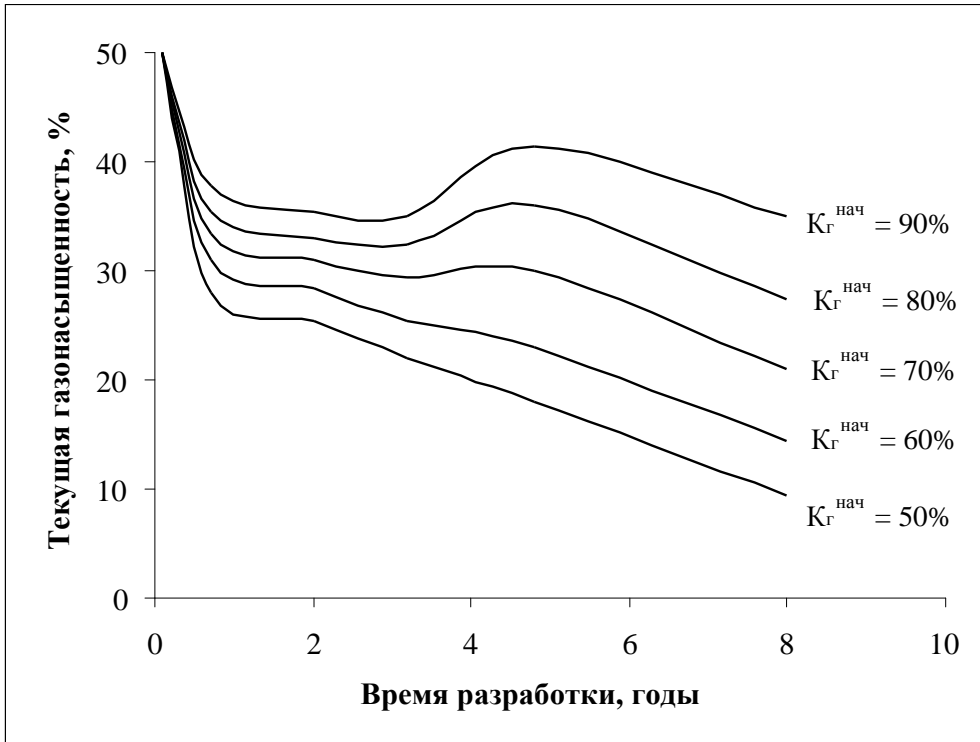
Geologic-geophysical control for flooding of wells allow to make decisions according the regulation of field development immediately and take measures directed to enhance gas recovery in a proper time [5].

As far as gas production is declining and flooding is increasing it is very important to estimate the amount of residual and final gas saturation in the water-flooded volume, the volume of occluded gas, constant monitoring of these data and its forecast. The reliability of these data influence on the faithfulness of the final gas recovery forecast and development parameters, especially during the final stage of development.

For the condition of Cenomanian pool a special new method has been developed by the authors. This method estimates the gas saturation factor subsequent to the results of electrical and radioactive logging. For the purpose of geological routine analysis of deposit inundation all the productive formation were divided in 3 groups depending on the initial reservoir properties: group IIIб –  $K_s > 75\%$  ( $K_s$  – gas saturation),  $K_p > 33\%$  ( $K_p$  – porosity); группа IIIа -  $75 \leq K_s < 56\%$ ,  $33\% \leq K_p < 28,5\%$  и группа I+II –  $K_s \leq 56\%$ ,  $K_p \leq 28,5\%$ .

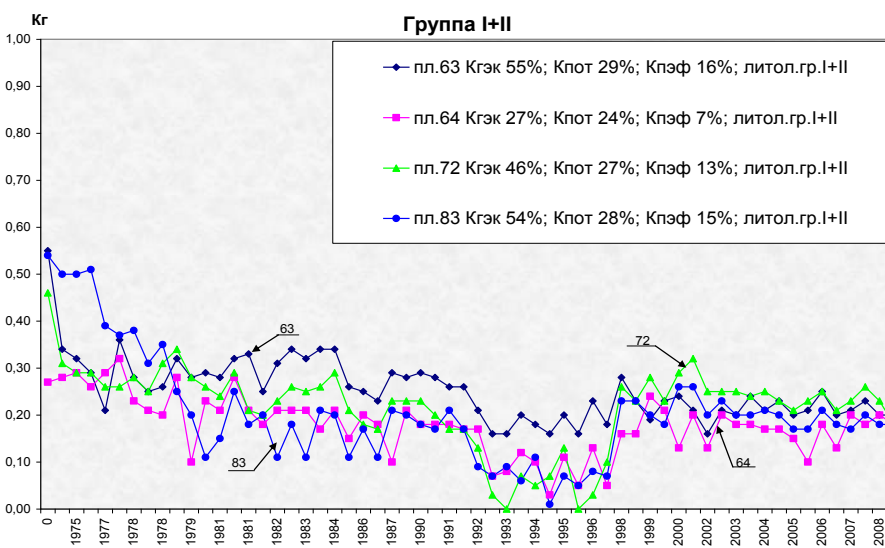
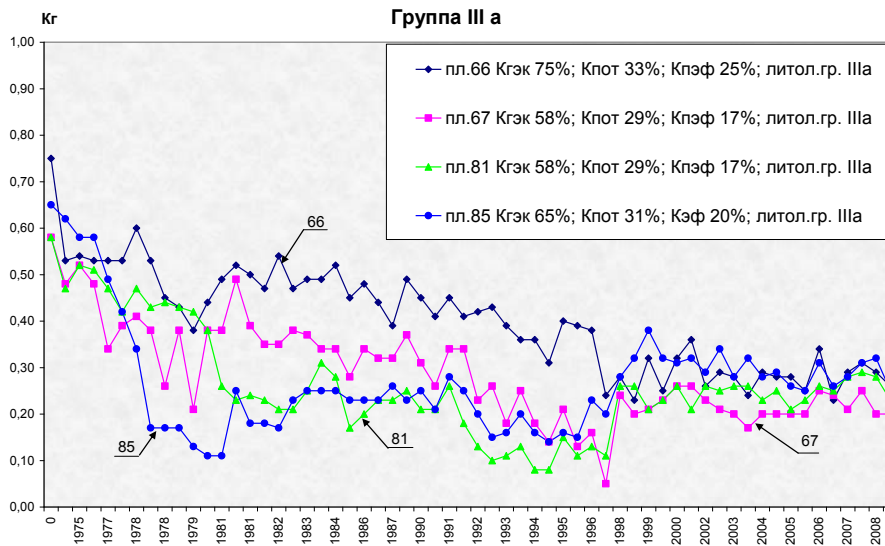
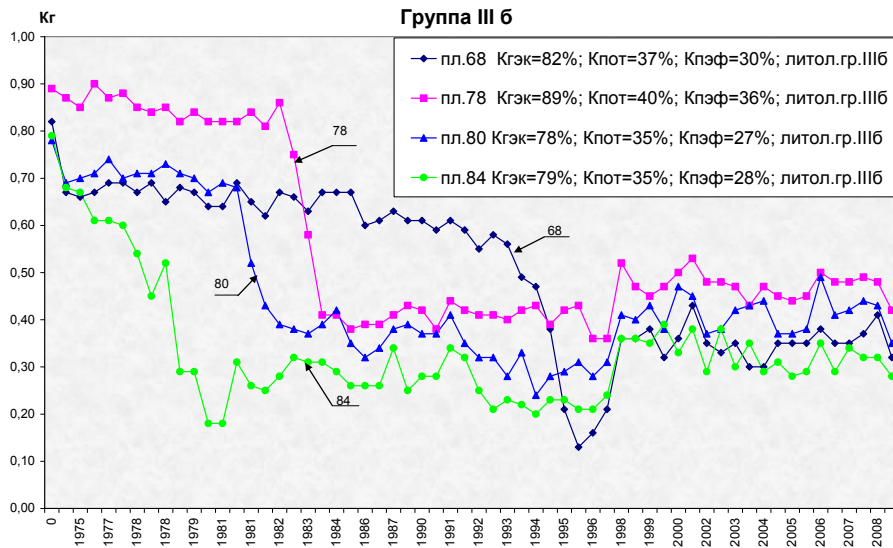
Conclusion about the flooding of Cenomanian formation is based on the declining of gas saturation till  $K_s^{HRK} \leq 40\%$ . Initially this limit was set according the theoretical experience, but lately it was proven in field. In 1986 during the experimental works on monitoring wells №66 and №68 of Medvezhie field in formation with the initial gas saturation ( $K_s^P=83-88\%$ ) which had been flooding according the data of the interpreting well logs perforation was carried out. During the testing fossil water and solute gas was found.

The result of interpreting well logs that characterize the trend of gas saturation in the water-flooded formation is shown at the pic. 1,2 and table 1. The data show that after 4-6 years after flooding current gas saturation is increasing, notice, that the more the inial gas saturation the better it is shown.



Текущая газонасыщенность – Current gas saturation  
 Время разработки, годы – The development period, years

Picture 1-The dynamics of changing of gas saturation water flooded rock of different petrophysical composition



Группа - Group  
 Picture 2- Medvezhie field. Well №60. The dynamics of changing of gas saturation water flooded rock.

Table 1 – Average factors of current gas saturation of water-flooded formation

№№GAS TREATMENT PLANT/ UNIT	The group of reservoir-formation		
	III <sub>б</sub>	III <sub>а</sub>	I+II
1	38,96	27,88	17,5
2	-	-	-
3	36,41	28,36	16,61
4	38,09	24,25	22,46
5	38,70	21,82	12,07
6	37,25	20,43	13,40
7	35,05	33,84	24,24
8	29,74	22,86	12,45
9	38,39	29,22	18,36
South arch (Gas treatment plant -1, 2, 3, 4)	37,92	25,98	19,84
Central part (Gas treatment plant -5, 6, 7, 8)	36,34	22,39	16,98
Nadyn arch (Gas treatment plant -9)	39,12	29,65	18,97
Recovery zone	38,00	26,16	17,42
Periphery	37,99	24,80	22,27
Whole field	38,00	25,87	18,15
Average gas saturation factor 27,16%			

Probably, it is connected with in-situ conditions that are created after certain pressure decrease. In such condition expansion of residual gas takes place. We can suggest that in certain circumstances in water flood ledges energy of residual gas is sufficient to edging of water from effective pores. After that gas can move up in the ledge and in 7-8 years current gas saturation temporary declines.

This phenomena can be seen in gas pools with  $K_{\bar{A}} > 60\%$ , whilst in the formation with  $K_{\bar{A}} < 60\%$  the changes of level of gas saturation can be hardly seen. Such phenomena can be explained by small volume of gas-flow within the accuracy of observation. Such ledges are characterised by steady decline of gas saturation during the whole period.

According to the result of the survey such conclusions can be made:  
relative current gas saturation in water-flooding zone decline during the field development. The real value of current gas saturation is essentially lower than the critical one.

The amount of current gas saturation strongly depends on initial reservoir properties.

Average gas saturation factor is 27%, particularly in the group of reservoir-formation: III<sub>б</sub> – 38 %, III<sub>а</sub> – 25 %, I+II – 18 %.

The rate of decline of the current gas saturation for various groups of reservoir formation is different. This factor is higher in ledges with high reservoir properties.

## 2. Specification of raw hydrocarbon deposits

During the gas production in water-flooded formation gas saturation increases, it is connected with the gas expansion in pores, what is caused by the decrease of pressure in the water-flooded reservoir.

Probabilistic approach to the estimation of crude oil, natural gas and gas condensate can hardly be found in the most part of native books. Only one version is usually presented at the expertise, in other words only one working hypothesis without the analysis of alternative hypothesis. Though it was proved long time ago, that the estimate of crude raw materials can't be limited by the



circuit according to the formula of volumetric method of reserves estimation. It must provide the system of action aimed at the studying of objective laws of geological aspects of field, structure of reserves, reveal of interactions between geological bodies with different quantity and quality of resources.

The first task to be solved during the estimation of resources is to create a technology of gathering information about the initial reservoir properties and issues of justification of volumetric parameters.

Another important task is to analyze and choose the mathematical model as a way of reserve calculation by the volumetric method. It was proven practically that usage of different formulas can show different results.

The solutions of these two problems leads to the task of setting and estimate parameter of optimal and effective exploration of the field.

From a perspective of scientific methodology, the system approach, the process of field exploration includes different variants of gas gathering, gas treatment, gas storage and analysis of mixed lithological, stratigraphic, inorganic-geochemical, field geological, geophysical and other kind of information, which helps to build up, create a model and make forecast decisions from the stage of reserve calculation till the process of analysis, control and management of field development.

Most part of Cenomanian pool belongs to reservoirs of bedded-massive type. It is considered that field is consolidated during the different phases of development, it means that rock beds and soil units represent complete unit. But the results of field geophysical exploration and current stage of development demonstrate complex geology of Cenomanian aged formations, defined by unstable areal thickness and reservoir properties, considerable variability of lithological composition of reservoirs, breaks and stratified heterogeneity.

Density of producing and exploration wells in Cenomanian pools is irregular. Because of wells situation in roof reservoir area and updip 2 it is difficult to evaluate the reserves, the inaccuracy during development drilling is 7-12%. At the periphery the rate of inaccuracy achieves 20-30%. This phenomena happens because of huge (37-80 km<sup>2</sup>) area of deposit which fall ob one well, whilst at the zone of development drilling – 6-11 km<sup>2</sup>.

That's why it is ineffectively to use only one model, because of high rate of inaccuracy. Difficulty of making decisions using various methods of estimation of gas reserves is shown at the picture 3.

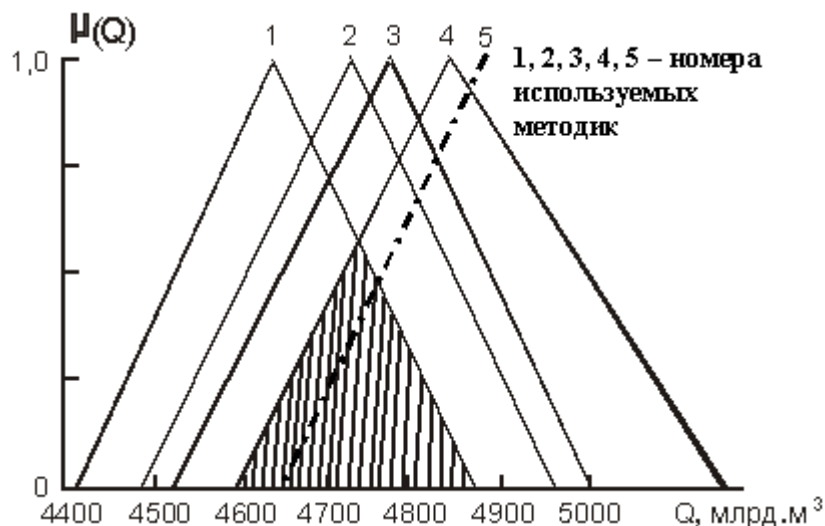
The analysis of theoretical and practical of modeling of gas and gas condensate fields of West Siberian aspects shows that chose of conceptual model of reservoir geology as a base for building up for field geologic and full field model depends on the accumulation type. Actually on the one hand a model as a static system should rely on a real object, on the other as a dynamic system it should reflect all the in-situ processes during whole period of development (such processes as pressure distribution, flow of fossil water etc).

The last but not least task is to choose and evaluate the mathematic model for estimation of gas reserves.

Unique characteristics of estimation of gas reserves of Cenomanian pools are given below:

Information field geologic model for all methods should be fix as of the date of estimation of reservoir properties, number of wells, amount of sublayers in the well and location of the well.

The sum of the reserves in formation members can't be more than the reserves of the whole field.



Номера используемых методик - the numbers of methods  
 Млрд. М3 – billion cubic meters

Picture 3 – The chose of an effective formula volumetric method of reserves estimation (figures stand for the number of methods, shaded area is a dwelling time)

Between  $K_n$  and  $K_g$  there is a positive dependence, it is the reflection conditions of sedimentation and rock development together with the peculiarity of estimation method according well logging.

Most part of producing and monitoring wells were drilled at the updip area. At the periphery there is widely spaced drilling grid. That's why the inaccuracy of C1-category reserves estimation is higher than B-category reserves estimation. So it is important to estimate reserves stage by stage and as the accuracy of exploration maturity is increasing replace them in the higher category.

The task of field geologic technology depends on the development target's characteristics; location, field, accumulation type, geological structure, gas resources, technological and economic criterion. To concretize stages and possible variant of development the authors have developed the classification of natural gas reserves based on the fields' energy stage. Gas reserves can be initially low pressure or became it at the certain stage of development.

Profitability of reserve recovery is evaluated after exploration and appraisal at the stage of gas resources estimation. Profitability of field exploitation is evaluated at the stage of whole field development and formation member separately.

Cases of development of unprofitable fields are very common for natural gas and gas condensate fields. Usually it happens if:

- a productive formation is deep-sunk with shallow thickness and small amount of gas resources;
- a reservoir with bottom water-drive.

Different methods of estimation gas recourses show different results. For example, the difference between results of revised estimation of Vyngapurovskoe Field carried out by reserves estimation volumetric method and material balance method in 1987 was 25-30%, initial data were different at 100%. The presence of accidental mistakes and consistent error explain the differernce between results.

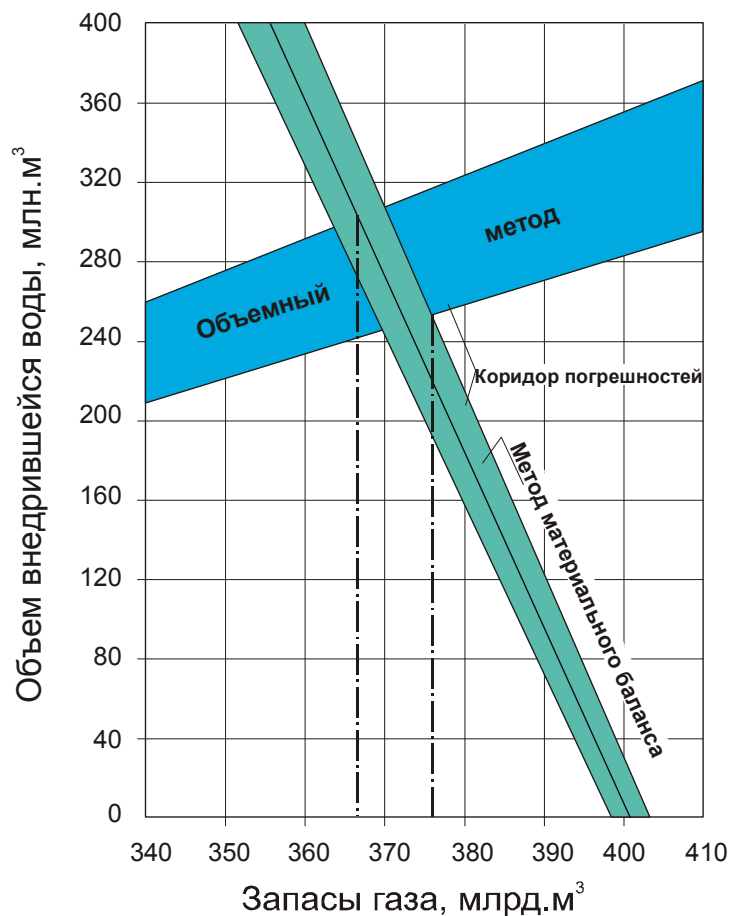
In the reserves estimation volumetric method large amount of gas resources means (all other things being equal) the bigger volume of intruded water in formation. If the material balance method is used there is inverse relation. In other words, increase of gas resources in the volumetric method

leads to increase of the volume of water in formation, and hence it declines estimated amount of gas resources counted with the usage of material balance method. So the task of estimation of initial gas resources is solved like an optimization problem. The authors have proven that initial gas reserves in case of simultaneously fulfilling the conditions of volumetric and material balance methods can be determined by the formula:

$$Q_3 = \frac{\bar{P}_H Q(t)}{\bar{P}(t) \frac{h_{ГВК}}{h_{об}} (1 - \frac{K_{ГО}}{K_{ГН}}) + \bar{P}_H - \bar{P}(t)}, \quad (1)$$

где  $\bar{P}_H = P_H / Z_H$ ;  $\bar{P}(t) = P(t) / Z_t$ ;  $Q_3$  - gas reserves,  $P_H$  - original reservoir pressure;  $P(t)$  - current reservoir pressure (at  $t$ );  $Z_H, Z_t$  - initial and current supercompressibility factor;  $Q(t)$  - cumulative gas production by the time  $t$ ;  $h_{ГВК}$  - lifting height of gas-water contact;  $h_{об}$  - whole formation thickness;  $K_{ГН}$  - initial gas saturation factor;  $K_{ГО}$  - residual gas saturation factor.

Graphical determination of this formula for Vyngapurovskoe Field is shown at the picture 4.



Объем внедрившейся воды, млн м3 – Volume of intruded water, mln cubic meters  
 Объемный метод-Volumetric method  
 Коридор погрешностей – The sector of inaccuracy  
 Метод материального баланса – Material balance method  
 Запасы газа, млрд. м3 –Gas reserves, billion cubic meters

Picture 4 – Comparison of estimation of gas reserves using volumetric and material balance method/

So material balance method is less sensitive to the inundation of deposit and flooding of formation. So, if all other things being equal, the change of estimation of flooding volume at 5% leads

to changes of reserves at 0,25% using the material balance method and at 1% using the volumetric method.

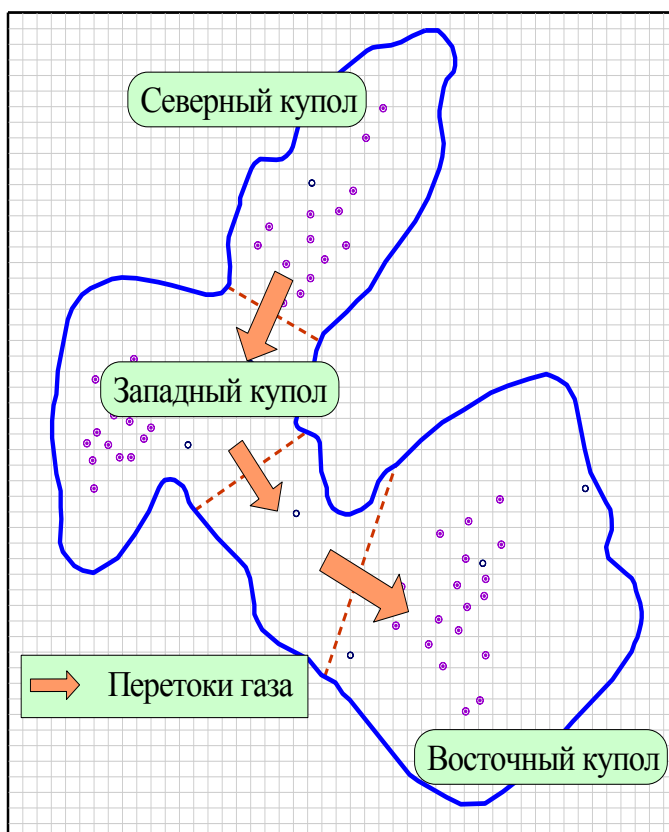
Practically it is difficult to estimate the volume of intruded in formation volume because of fair exploration of aquifer basin's parameters.

### 3. Development simulation

Geological model is a foundation for simulation of development processes. The papers of Russian sciences S.N. Zakirov, A.I. Grizenko, Yu.N. Vasilieva, E.M. Nanievskogo, S.V. Kolbikova, O.M. Ermilova are devoted to the issue of control automation of field development. At the beginning of XX century numerous complexes of bidimensional network simulation (pic.5) were widely spread. Network models almost for all developed Cenomanian pools in the north of West Siberia were built by V.P. Gorochov and A.S. Gatsolaev. The authors used some elements of systematic approach to the simulation problems.

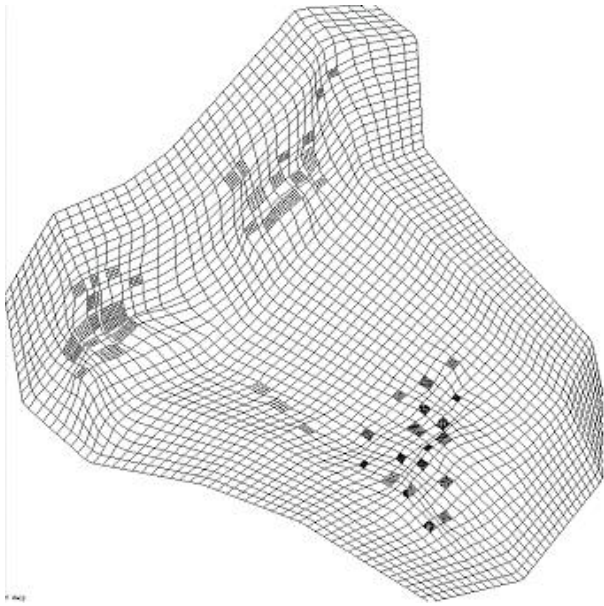
Nowadays methods of 3D geological simulation and hydrodynamic simulation are widely spread.

The example of 3D simulation is represented at the picture 6. Modern simulating software system allow to study the oil and gas development process as a whole system "formation – wells - service equipment – consumer". This system also responds to parameters changing, even if they are fair. Geological simulation is very important for making decision according field development.



Северный купол – North arch  
Западный купол – Western arch  
Восточный купол – Eastern arch  
Перетоки газа – Gas-flow

Picture 5 –Bidimensional network model of Komsomolskoye gas field



Picture 6 –Flow pattern of Komsomolskoye gas field

In practical task of complicated field systematic approach is realized as a system analysis. System analysis is a group of methods and means, which are intended to solving applied problems.



Системный анализ – System analysis

Геология - Geology

Петрофизика - Petrophysics (rock physics)

Картирование - Lateral exploration, plotting

Разработка - Development

Гидродинамика – Flow mechanics

Загрузка данных и управление БД - Data upload and data base management

Утилиты и связи с другими пакетами – Utility software and connections with data package

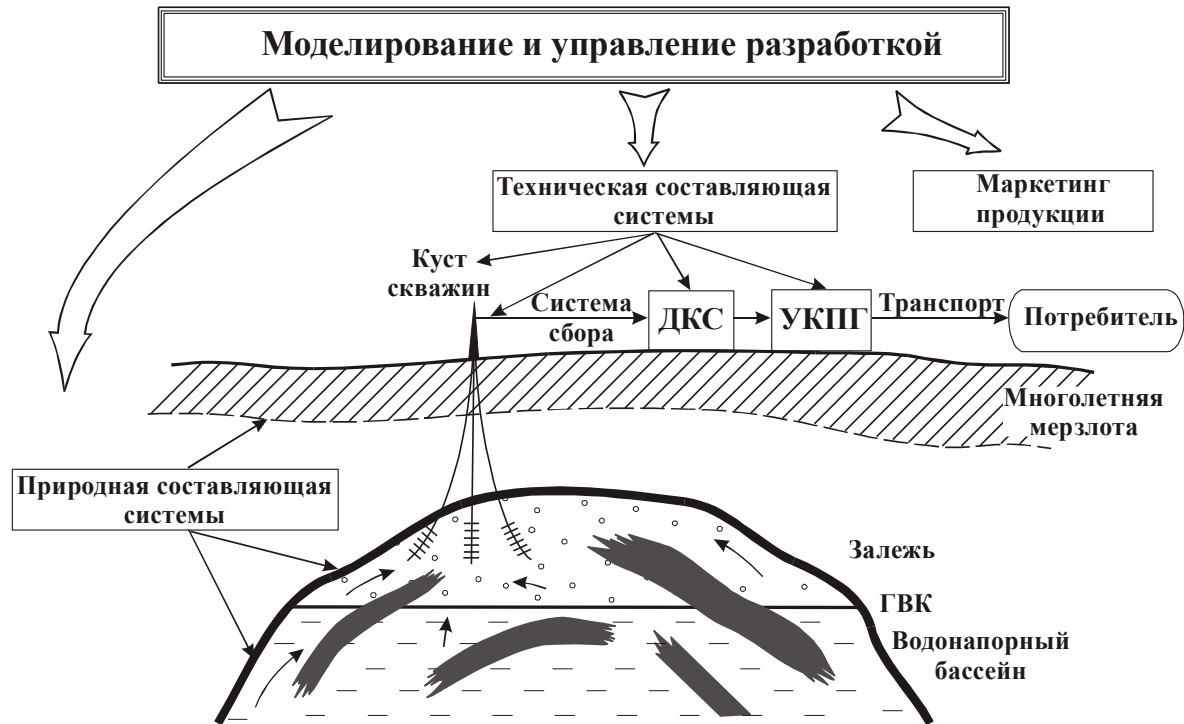
Сейсморазведка - Seismic survey/ exploration seismology

Picture 7 - Oil and gas field system analysis based on 3D software system

Based just on these principals of system approach the stage field development idea is realized. Papers written by A.P. Krylov, S.N. Zakirov and others Russian scientists have proved the practicability in using stages during pilot work.

This principle was fully realized at Medvezhevskoe field. In the first design project (published in 1971) drilling of 280 wells was planned, but nowadays there are twice more wells.

Modern software system allow to study the oil and gas fields development process as a integrated system including formation, wells, service equipment This system also responds to parameters changing, even if they are fair (see pic.8).



- Моделирование и управление разработкой – Development simulation and management
- Техническая составляющая системы Technical system element
- Маркетинг продукции – Production marketing
- Куст скважин – well cluster (group of wells)
- Система сбора - field gathering system
- ДКС - BCS - booster compressor station
- УКПГ - Gas treatment plant
- Транспорт - Transportation
- Потребитель – Consumer
- Многолетняя мерзлота - ever frost
- Природная составляющая системы – Natural system element
- Залежь - field
- ГВК – GWC –gas –water contact
- Водонапорный бассейн - aquifer basin

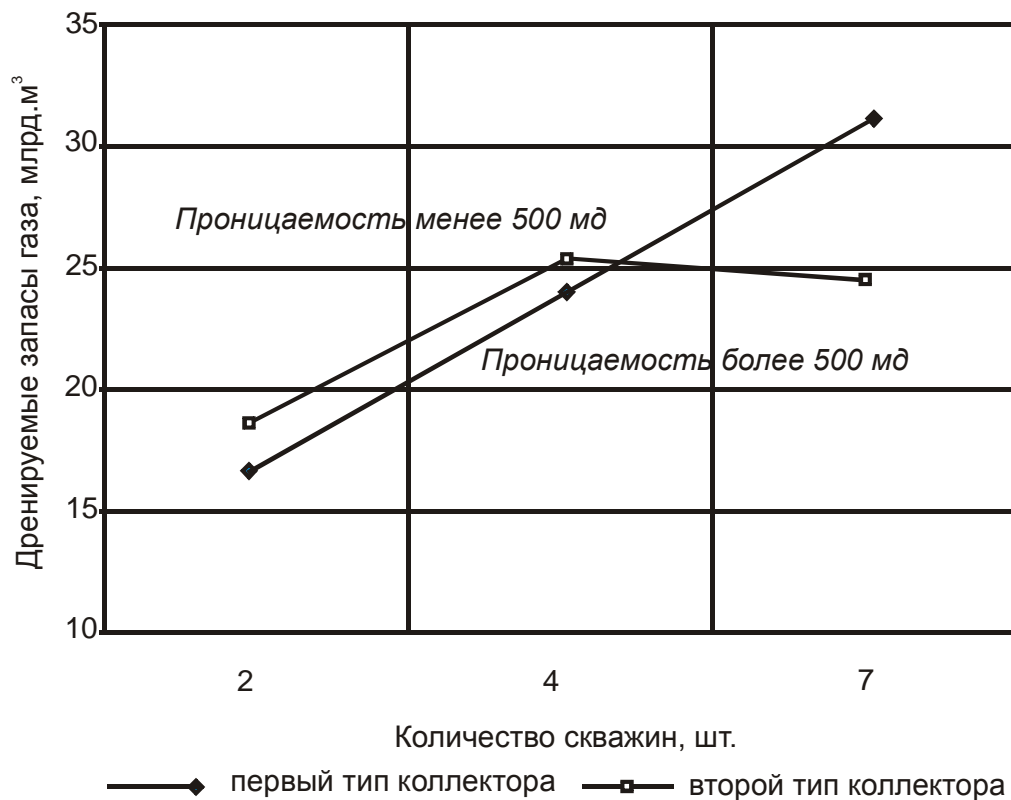
Picture 8 – The system strategy of field development management

In practical task of complicated field systematic approach is realized as a system analysis. System analysis is a group of methods and means, which are intended to solving applied problems.

## 4. Designing of development

At early stages of development work the amount of producing wells in the cluster was determined by net reservoir thickness. At all fields with thickness of arch zone is below 100 meters and more there are 5-7 wells in a cluster, maximum amount of wells is in the Yamburgskoe Arctic Gas Condensate Field (9 wells).[6] As the most part of gas is concentrated in the arch zones, it is right. But because of the difference in geologic structure and the way of permeability distribution there is some difference in the amount of drained reserves.

Results represented in the pic. 9 show that using of differentiating system of perforation with the same working reservoir thickness (about 20-25 m), the amount of wells in the cluster if the permeability 500 mD should be 3-5, if the permeability 500 mD – 7 and more.



Дренируемые запасы газа - drained reserves

Проницаемость – permeability

Количество скважин – amount of wells

Первый тип коллектора - First type of collector

Второй тип коллектора - Second type of collector

Picture 9 – Pestsovoe field. The correlation between drained reserves and amount of wells and types of collector

The main criteria is the increasing amount of drained reserves. This law is always used during development work at 3D models.

Primary engineering of field is characterized by the lack of information about geological and technical parameters.

That's why initial design project should contain common decisions which can be easily improved without significant capital expenditure as far as more geological and technical information will be available.

Developed methods can be divided in two main groups:

1. Improving of conditions infiltration of producing horizon.
2. Optimisation working of system "formation-well- gas treatment plant.

The first group includes extension drilling of producing wells, gas extraction redistribution temporally in production zone proportionally with drained reserves (table 2).

Table 2 - Medvezhie field. Additional gas recovery after extension drilling

Номер УКПГ	Годы	Количество скважин, шт	Дополнительная добыча газа, млрд.м <sup>3</sup>
1	1982-1998	25	63,1
2	1990-1998	6	4,1
4	1982-1998	34	67,1
5	1990-1998	7	8,3
8	1987-1998	32	66,1
9	1982-1998	34	89,6
Всего	1982-1998	138	298,4

Номер УКПГ – the gas treatment plant number

Годы - term

Количество скважин, шт – amount of wells

Дополнительная добыча, млрд м<sup>3</sup> – additional gas recovery, billion cubic meters.

The second group includes linkage potential productivity in productive zones with technical machine capacity of equipment for gas treatment and compression and modernization of booster compressor station.

These methods help to achieve current gas recovery at the level of 82%. Expecting gas recovery is more than 90%.

Also extension drilling led to the enhanced gas recovery at Yubileinoe and Yamsoveyskoye field by 25-30%.

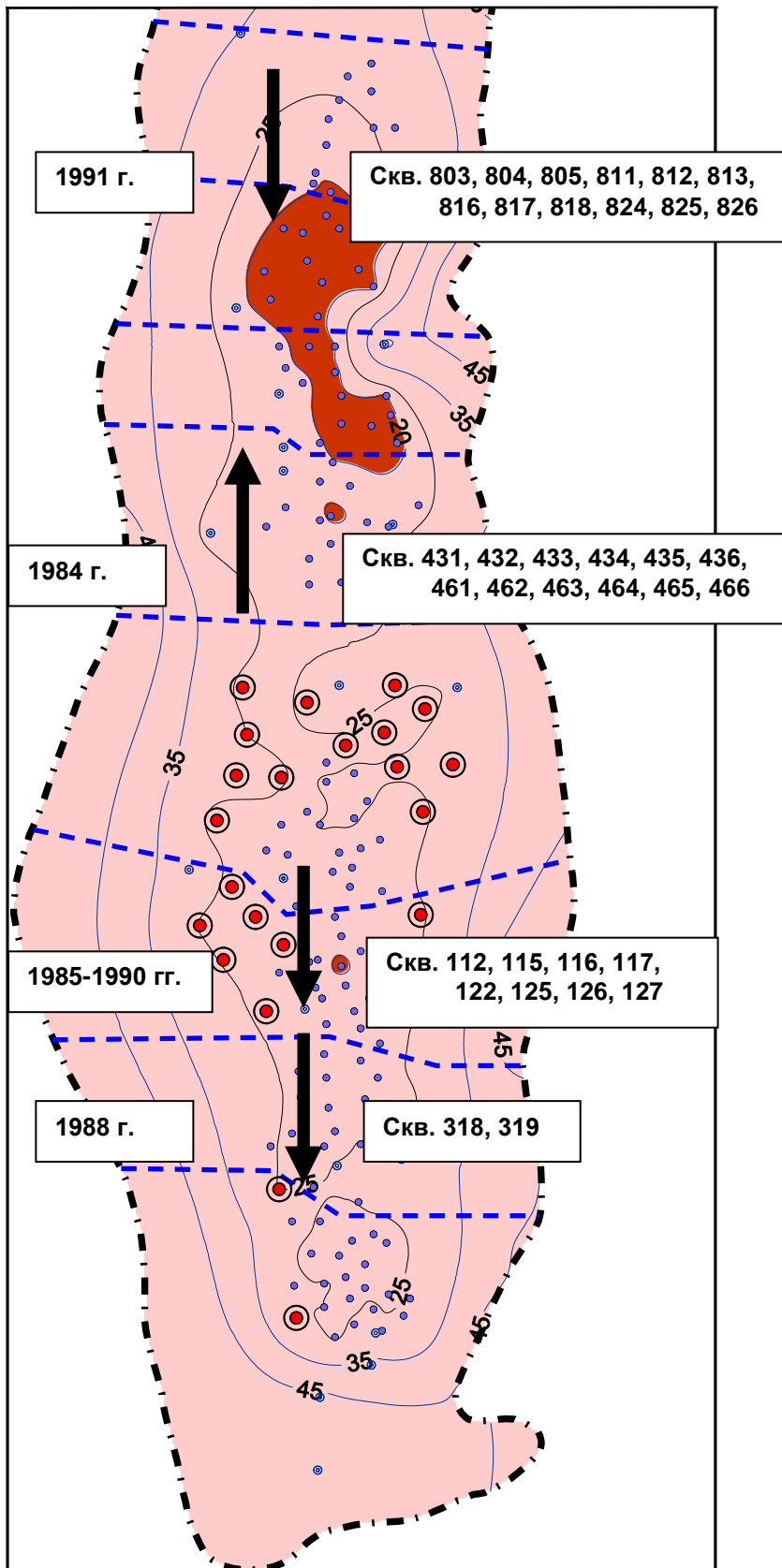
## 5. Key finding and proposals

1. West Siberian oil – and-gas- province will remain one of the most important source of hydrocarbon raw materials for Russian Federation and others countries.

2. Particular emphasis should be put on the development of remaining gas reserves in the West Siberia, because the amount of remaining gas reserves in the West Siberia is equal to the gas-in-place in some oil – and-gas- province of Russia.

3. The necessity of resources differentiation is closely connected with the problem of development optimization. The authors took part in the development of method and concept scheme of the estimation of gas resources.





Picture 9- Medvezhie field. Shifting of wells dynamics

4. Cenomanian Aged reservoirs are developed with active immigration fossil water in formation. That's why it is important to use effective geologic-geophysical methods.

5. Field geological control under gas field development involve various tasks. The main part play geophysical methods.

6. As the recovery is falling and the water flooding is decreasing it is very important to reevaluate current gas saturation and forecast the rate of its changing.

7 The main principals of rational mining according to the study of papers written by native and foreign scientists are:

- optimization of well spacing,
- paying attention on the geological features during the development management,
- effective construction of producing wells.

8. Effective development management includes:

- improving of conditions infiltration of producing horizon;
- optimization working of system "formation-well- gas treatment plant.

Following these principals has proved its efficiency after 30 years of fields development and achieve high levels of current gas recovery.

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