Simulation of salt production process

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Abstract. In this paper an approach to the use of simulation software iThink to simulate the salt production system has been proposed. The dynamic processes of the original system are substituted by processes simulated in the abstract model, but in compliance with the basic rules of the original system, which allows one to accelerate and reduce the cost of the research. As a result, a stable workable simulation model was obtained that can display the rate of the salt exhaustion and many other parameters which are important for business planning.

1. Introduction
The problem of the exhaustion of mineral resources has been one of the most important global environmental and economic problems of humanity. The problem progresses, which is not surprising, since the availability of natural resources is limited, whereas the demand for them is ever growing.

In this paper some amount of attention is paid to the salt mineral resource of Yar-Bishkadak deposit being the largest of salt deposits in the Southern Urals. Simulation will help to answer the question of how far people can suffice themselves with the salt reserves?

2. Simulation
Simulation is the process of creating and analyzing a digital prototype of a physical model to predict its performance in the real world. The model is created in the simulation software program iThink by “isee Systems” company. Visualization is provided by classic cognitive maps. Some similar methods were used in previous studies [1–6]. Classic cognitive maps represent a directed signed graph. Signed graph is a graph in which each edge has a positive or negative sign.

Figure 1 presents the basic flowchart of the model.
iThink provides access to the different layers of the model: “Interface”, “Model” and “Equation”. Each layer provides a different way of designing and presenting a model [7].

Figure 1 illustrates basic flowchart of the model in the “Interface” layer where three basic sub-models “Salt reserves”, “Wells” and “Productivity” interact through connectors, which show that the growing number of wells leads to lower salt reserves, and the growing salt reserves lead to the growing wells number and productivity, while the growing of productivity leads to a lower number of wells and salt reserves.

Figure 2 presents the detailed model of the salt reserves exhaustion in the “Model” layer, constructed in accordance with the three frames “Salt Reserves”, “Wells” and “Productivity” in figure 1.

![Diagram of the model](image)

**Figure 2.** The general view of the salt exhaustion model in the tab “Model”

To develop the model some available materials about the Yar-Bishkadak salt deposit were used. There were such input data as:

- salt reserves: 1 billion tons;
- the number of commissioned wells: 1 pcs;
- the average productivity of the well: 1 million tons per year;
- the planned annual percentage of commissioning: 25 %;
- the planned annual percentage of conservation: 5 %.

The table presenting all the data obtained is shown in figure 3. Let us take a look at what will happen to the system for example by the 24th year of functioning. Basic output parameters are as follows:

- remaining salt reserves: 729419609 tons;
- the number of operational wells: 7 pcs;
- the number of commissioned wells: 3 pcs;
- the number of conserved wells: 11 pcs;
• salt reserves exhaustion: 3246729 tons;
• well productivity: 279446 tons per year.

Figure 3. The table presenting all the data obtained

| Years | 22          | 23          | 24          |
|-------|-------------|-------------|-------------|
| Salt reserves remaining | 7421109740 | 7321566338 | 7291439588 |
| The number of operational wells | 30 | 10 | 7 |
| The number of commissioned wells | 10 | 6 | 3 |

Figure 4. The resulting graphs depicting the amount of salt (1), the total number of wells (2), the number of commissioned wells (3), the number of conserved wells (4)

The resulting graphs depicting the amount of salt (1), the total number of wells (2), the number of commissioned wells (3), the number of conserved wells (4) are shown in figure 4. Thus, figure 4 shows that over time, the growing number of operational wells and that of commissioning pace leads to significant depletion of salt reserves, but later the incrementally growing number of conserved wells leads to a lower number of both operational wells and commissioned wells down to zero values. The amount of salt reserves stops changing after approximately the 24th year which is quite expected in case of the wells out of operation.
3. Analysis of the model obtained

The stability of the simulation results means the degree of their non-sensitiveness to changes under simulation conditions [8]. The stability of simulation results is characterized by convergence of a simulation control parameter to a certain value with the change in some input parameters and the increasing of simulation time [9]. Sensitivity analysis helps to explore how sensitive are the simulation results to changes of the model parameters. So one could run sensitivity analysis while changing slightly any input parameter, and in case of convergence of an output parameter, it will be possible to state with confidence the stability of the simulation.

For example, after simulation model sensitivity analysis by changing the input parameter “Salt reserves” in the range from 1 to 5 billion tons with five numbers of runs (“# of Runs” in window “Sensitivity Specs”, figure 5) [10]. Drawing the graph of dependence of the number of operating wells on time for different values of the input parameter “Salt reserves”, one could easily notice convergence of parameter “Wells” as a zero value (figure 6). This is logical, because regardless of the initial salt reserves, this salt will eventually end up, and there will be no existing wells. The model works adequately; it can be considered stable.

It is also interesting to determine the beginning of the decline in salt production due to a significant exhaustion of these reserves and a reduction in the number of operational wells. This can be determined by the graph in figure 6. Curve (1) shows dependence of the number of operating wells on time, the input parameter “Salt reserves” being 1 billion tons, so that in this case one could notice a sharp decline of operational wells number starting with 21 years of their service; curve (2) – 2 billion tons of salt, decline 25 years on; curve (3) – 3 billion tons of salt, decline 27 years on; curve (4) – 4 billion tons of salt, decline 29 years on; curve (5) – 5 billion tons of salt, decline 30 years on.

![Figure 5. Window “Sensitivity Specs”](image-url)
Figure 6. The graph of dependence of the number of operating wells on time for different values of the input parameter “Salt reserves”

4. Conclusion

Mineral resources exhaustion depends on many factors: remaining reserves of minerals, production rates, production quota and many others that could seriously affect the enterprise activities. This is clearly seen in the simulation model of salt reserves exhaustion developed in iThink software using signed cognitive maps.

The result of simulation of the salt production system has been the resultant graphs and a table with statistical data, which show that a quarter of resources will be produced in almost 24 years, which is certainly absolutely essential. This is explained by the high production quota reflected in the input data. Nevertheless the developed model is fully operational, stable, and the use of more actual input data will increase simulation quality and precision.

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