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Investigating the effects of rock porosity and permeability on the performance of nitrogen injection into a southern Iranian oil reservoirs through neural network

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Abstract. In this work, a comprehensive model for Nitrogen injection into an oil reservoir (southern Iranian oil fields) was developed and used to investigate the effects of rock porosity and permeability on the oil production rate and the reservoir pressure decline. The model was simulated and developed by using ECLIPSE300 software, which involved two scenarios as porosity change and permeability changes in the horizontal direction. We found that the maximum pressure loss occurs at a porosity value of 0.07, which later on, goes to pressure buildup due to reservoir saturation with the gas. Also we found that minimum pressure loss is encountered at porosity 0.46. Increases in both pressure and permeability in the horizontal direction result in corresponding increase in the production rate, and the pressure drop speeds up at the beginning of production as it increases. However, afterwards, this pressure drop results in an increase in pressure because of reservoir saturation. Besides, we determined the regression values, R, for the correlation between pressure and total production, as well as for the correlation between permeability and the total production, using neural network discipline.

1. Introduction

It is generally an accepted fact that at the present time, many of the major oilfields in Iran suffer from the incapable and undesirable conditions as they are in the second half of their life cycle process, and consequently, many of the oil reservoirs faced a shortage of gas injections for pressure maintenance. On the other hand, the need to continuously increase oil production requires high reservoir pressure which is to be maintained by gas or water injection. This discipline not only enhances the reservoir pressure to be adjusted at some needed levels, it also compromises the future production demands. Excluding gas injection as a consideration or any delay in implementing this unavoidable programme will lead to serious problems in meeting the future ever-increasing production rate needs. However, it is to be emphasized that only following-up gas injection at required volume may not lead to expected increase in recovery from the reservoirs. Thus, this implementation must be carried out in a more suitable period and situation; otherwise it could be unsuccessful to reach the desired results or demands [1-3].

In 2004, nitrogen injection into one of the gas caps of the southern Iranian fractured oil reservoir was simulated and it was claimed that matrix oil discharge by gas injection occurs effectively and rapidly when compared to the use of other miscible gases, which causes more oil contact that leads to an increase in sweeping efficiency [1]. In the present paper, we indicate that rock properties, specifically positive permeability change, gives high production rate by N2-injection into the selected oil reservoirs with the use of more accurate method of artificial neural network.

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1.1. *Nitrogen behavior*
As an injectant under identical conditions, the isothermal compressibility coefficient,-(ϑV/ϑP)T, for nitrogen is greater than that of other commonly employed or promising gases as injection materials. For this reason, the injected nitrogen will occupy large volume of the reservoir and, therefore, relatively less amounts of nitrogen will be required for a specified injection[4]. Besides, nitrogen is non-flammable and less soluble in water. N2 injection is a more suitable option for deep reservoirs containing light oil [5]. Those reservoirs containing oils lighter than 34˚ API are good options for miscible injection of this gas where the minimum miscible pressure is usually high. For example, this pressure for a sample of light oil from North Sea under miscible situation with nitrogen has been reported as 4730 psi [5].

2. Modelling and Simulation

2.1. *Reservoir characteristics*
The present model involves 9600(32*25*12) blocks [6]. The initial reservoir pressure and the base depth are 5000 psi and 7055 feet, respectively, at a reservoir temperature of 150˚ F. The oil-water contact (OWC) and gas-oil contact (GOC) are 7130 and 7000 ft, respectively. The reservoir under this study includes two producing wells and one injection well. Figure 1 shows the start of the gas injection and the beginning of production from the reservoir at a pressure and rate of 5000 psi and 12000 Mscf (Thousand Standard Cubic Feet), respectively.

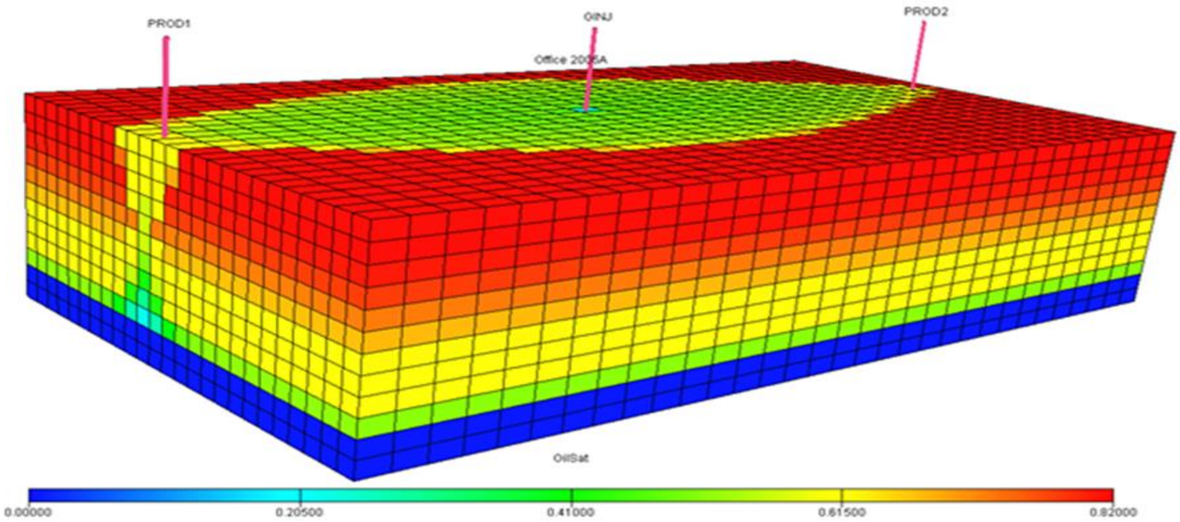

Figure 1. Reservoir Model

2.2. *Reservoir fluid properties and modeling*
The fluid undertaken in the present investigation is a 14-component hydrocarbon and non-hydrocarbon mixture as presented in the table 1. The Peng-Robinson equation of state (PR-EOS) with commonly used mixing rules have been used to evaluate the properties of the reservoir fluid [7]. The values of relative permeability and capillary pressure are given in table 2.

Table 1. Reservoir fluid composition

Components	**N_2**	**H_2S**	**CO_2**	**C 1**	**C_2**	**C_3**	**I-C_4**	**N-C_4**	**I-C_5**	**N-C_5**	**C_6**
ZI(percent)	0	0	0.24801	26.264	6.7921	5.9321	0.957	3.061	1.291	1.469	2.913

Table 2. Relative permeability and capillary pressure

S_w	K_{rw}	K_{row}	P_{cow}	S_{gas}	K_{rg}	K_{rog}	P_{cog}
0.18	0	0.9	50	0	0	0.9	0
0.2	0	0.808	43	0.05	0	0.555	0
0.32	0.001	0.412	22	0.1	0	0.371	0
0.42	0.082	0.26	11	0.12	0	0.212	0
0.5	0.165	0.068	508	0.18	0.002	0.104	0
0.59	0.249	0.015	2.36	0.25	0.005	0.04	0
0.68	0.38	0.002	1.412	0.3	0.013	0.011	0
0.73	0.482	0	1.09	0.33	0.036	0.001	0
0.82	0.82	0	0.8	0.36	0.06	0	0
1	1	0	0	0.8	0.9	0	0

3. Results

3.1. *Scenarios for reservoir simulation and results*

The scenarios undertaken in this study involve porosity change and permeability change in the X-direction as they are given in Tables 3 and 4, respectively. The variation of pressure (FPR) as well as total production rate with porosity and similarly with permeability at X-direction were determined. Figure 2 indicates the results obtained.

Table 3. Porosity Change

POROS1	0.07	**POROS21**	0.27
POROS2	0.08	**POROS22**	0.28
POROS3	0.09	**POROS23**	0.29
POROS4	0.1	**POROS24**	0.3
POROS5	0.11	**POROS25**	0.31
POROS6	0.12	**POROS26**	0.32
POROS7	0.13	**POROS27**	0.33
POROS8	0.14	**POROS28**	0.34
POROS9	0.15	**POROS29**	0.35
POROS10	0.16	**POROS30**	0.36
POROS11	0.17	**POROS31**	0.37
POROS12	0.18	**POROS32**	0.38
POROS13	0.19	**POROS33**	0.39
POROS14	0.2	**POROS34**	0.4
POROS15	0.21	**POROS35**	0.41
POROS16	0.22	**POROS36**	0.42
POROS17	0.23	**POROS37**	0.43
POROS18	0.24	**POROS38**	0.44
POROS19	0.25	**POROS39**	0.45
POROS20	0.26	**POROS40**	0.46

Table 4. Permeability Change in X-direction

K1	1	**K21**	360
K2	5	**K22**	380
K3	10	**K23**	400
K4	20	**K24**	420
K5	40	**K25**	440
K6	60	**K26**	460
K7	80	**K27**	480
K8	100	**K28**	500
K9	120	**K29**	520
K10	140	**K30**	540
K11	160	**K31**	560
K12	180	**K32**	580
K13	200	**K33**	600
K14	220	**K34**	650
K15	240	**K35**	700
K16	260	**K36**	750
K17	280	**K37**	800
K18	300	**K38**	850
K19	320	**K39**	900
K20	340	**K40**	950

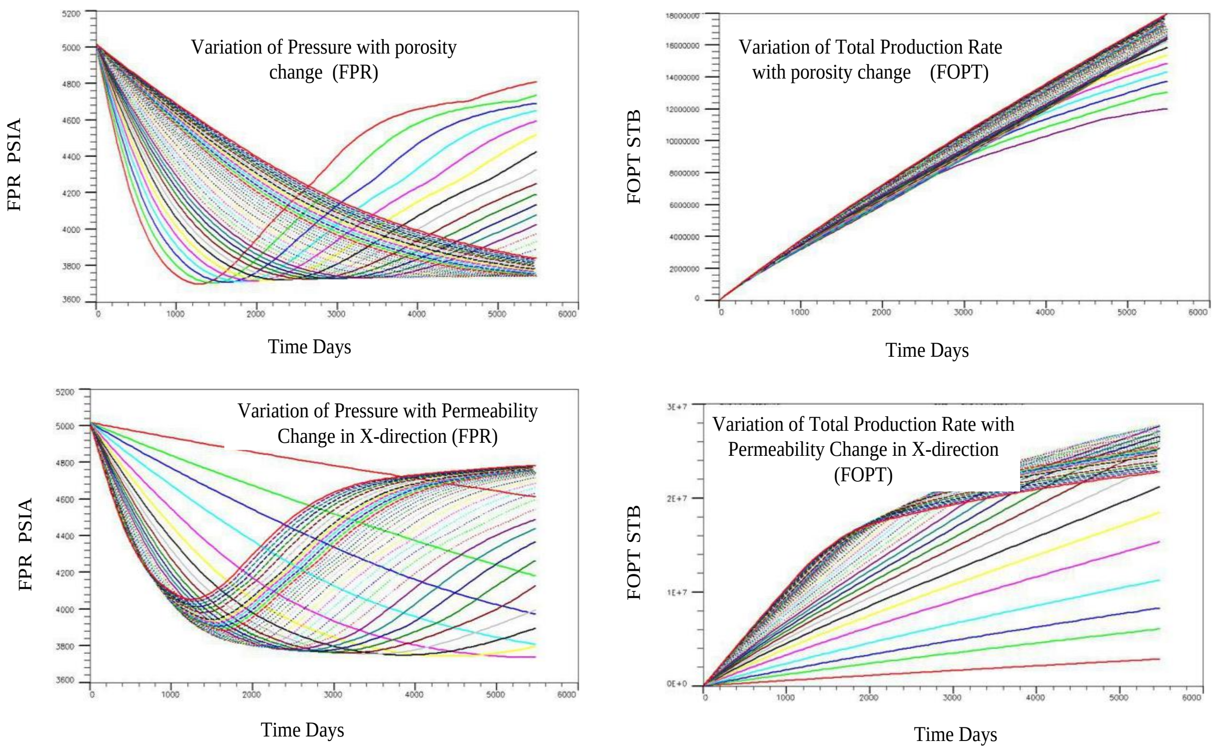

Figure 2. *Results of scenarios*

3.2. *Prediction through neural network*

Regression values, indicated by R2, for the above mentioned scenarios were also determined. These results are graphically presented in figures 3 to 6.

3.2.1. *Linear Regression for figure 2*

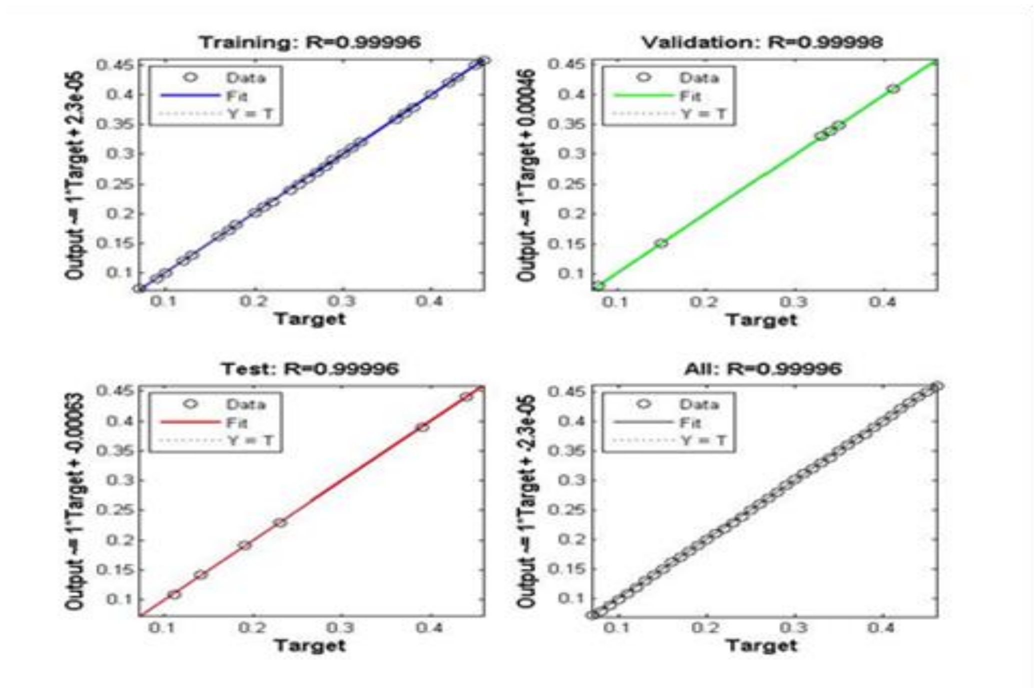

Figure 3. Linear Regression for Variation of Pressure with Porosity Change

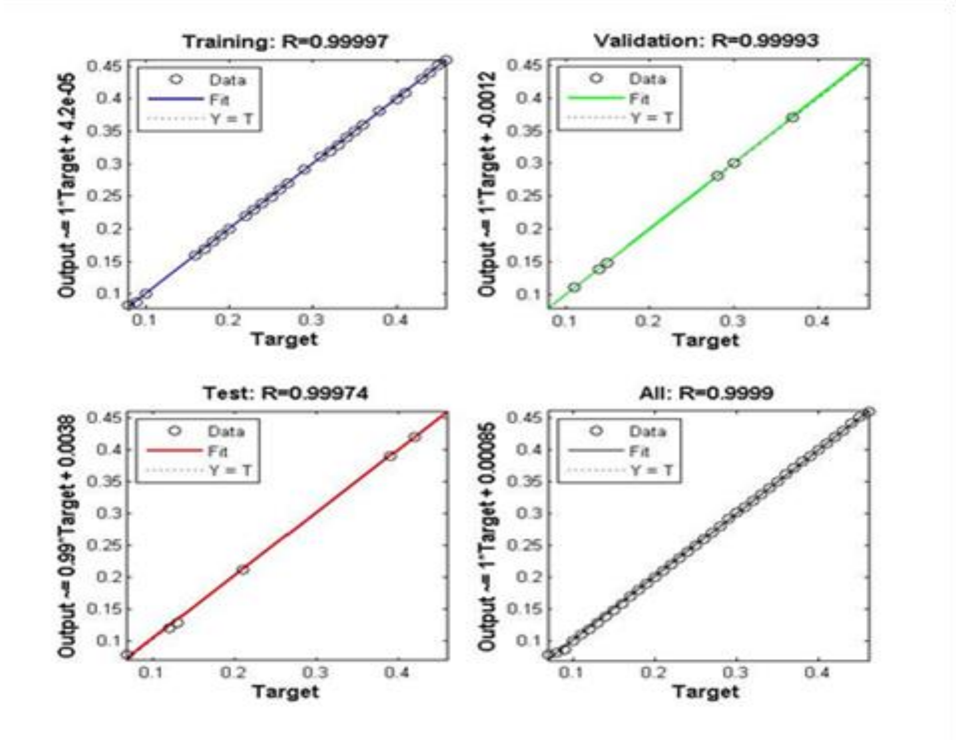

Figure 4. Linear Regression for Variation of Total Production Rate with Porosity Change

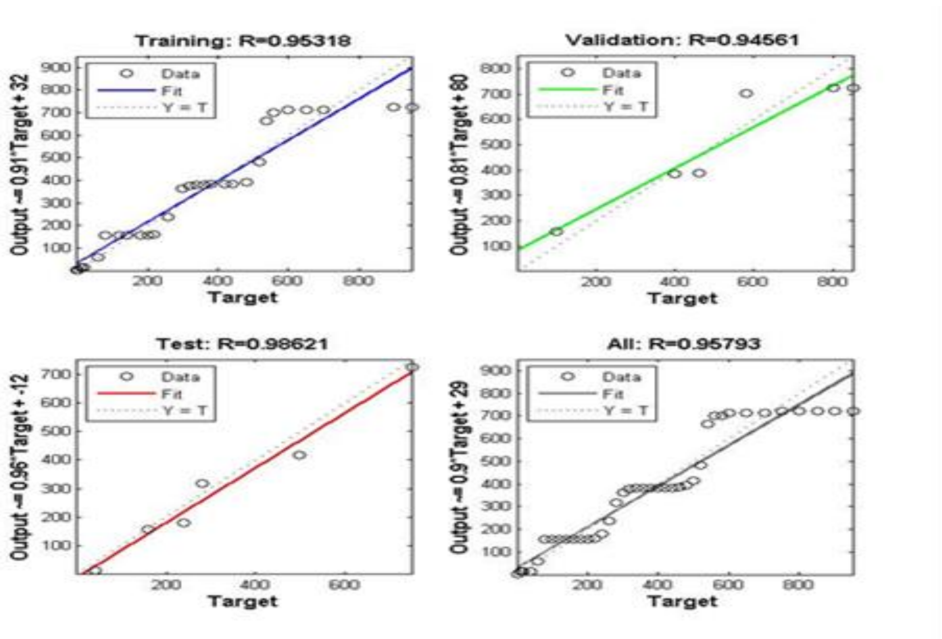

Figure 5. Linear Regression for Variation of Pressure with Permeability Change in X-direction

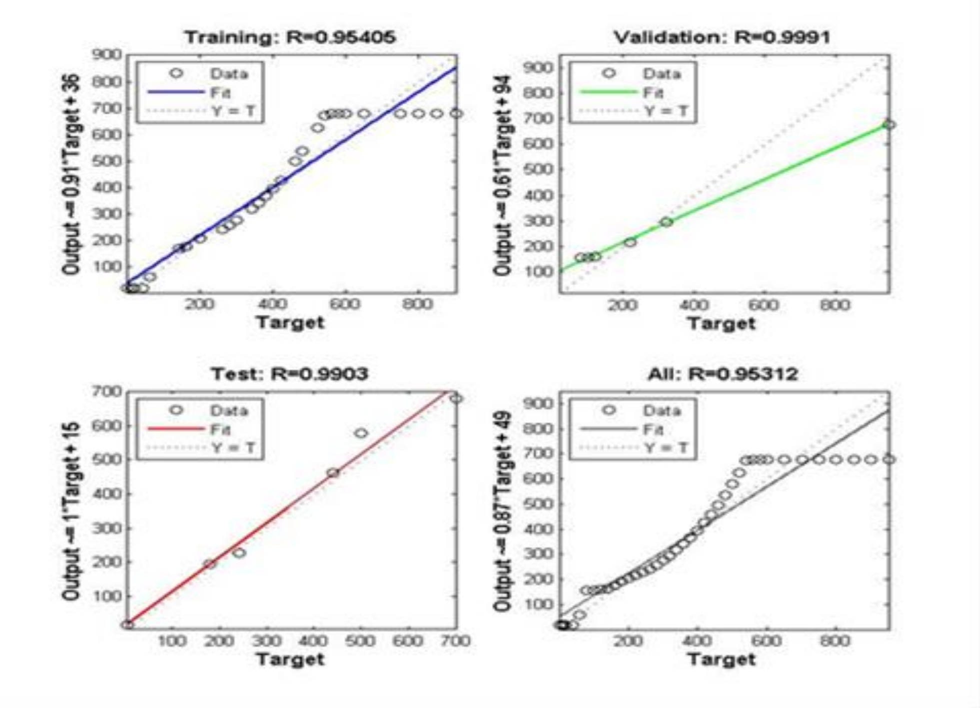

Figure 6. Linear Regression for Variation of Total Production Rate with Permeability Change in X-direction

4. Discussion

As it seems from the above figures indicating the pressure rate (FPR), most pressure loss occured at porosity 0.07. The pressure continued to fall for 1200 days, and when this period came to the end, there was no increase in pressure in the reservoir, because of occupation of pore spaces by fluids. Minimum pressure loss happened at a porosity of 0.46 which is considerably high. Also from the Figure (2) indicating the total oil production (FOPT), it is clearly observed that the most production and the least production are met at porosities 0.46 and 0.07, respectively. This obviously reflects the significant effect of high porosity on the increase in the total production rate. Certainly, at the lower porosity, the capillary pressure went up and the injected gas movement within the system was restricted. The most pressure loss situation is being indicated by the curves obtained at the permeability of 950 md (millidarcy), which continued for 1200 days. This is because of the reservoir containment by the gaseous Nitrogen. After this period, as the curve in the Figure (2) indicates, the pressure in the reservoir increased. This is because of the reservoir saturation by Nitrogen and its expansively. The least pressure loss is signified by the curve provided with a very low permeability of 1 md. In a similar manner, as it is seen from the curve presenting (FOPT), the highest production rate is met at a permeability of 950 md. So a high increase in production, from the beginning up to 2500 days, is reached continuously, and afterwards the pressure went up slowly. The least production becomes available at the permeability of 1 md. Through the predictions by neural networks for porosity changes, two profiles indicating changes in pressure rate (FPR) and total oil production (FOPT) have been produced. As it is observed from Figure 6, for changes in pressure rate within 20 hidden layers, R2 = 0.9999 is obtained. From Figure (4), for total oil production within 10 hidden layers, the value for R2 is 0.9995. Through additional predictions made by using neural networks, we produced another two profiles indicating changes in permeability in the X-direction and changes in pressure rate. These are presented in Figures 8 and 9. For the changes in pressure rate within 20 hidden layers and for total oil production within 12 hidden layers, the values of R2 were obtained as 0.9726 and 0.9807, respectively. These reliable data signify the accuracy of the results obtained which reflect, in turn, the extent and importance of parameters involved and the strong scenarios and method employed.

5. Conclusions

This investigation provides some guidelines as well as relevant limitations for oil production from an Iranian oil reservoir by N2 injection through variations occuring in rock properties. These are as follows:

(1) Increase in porosity results in pressure loss reduction and an increase in total production rate.

(2) The pressure loss raises up as the permeability in the X-direction increases. As the effect of injecting gas comes to action and reservoir get saturated by the gas, an increase in pressure as well as an increase in total production rate will be observed.

(3) For each couple of profiles for changes in pressure and total production which have been produced by neural network method, four values of regression R2 are over 0.9. This represents a good correlation between inputs and outputs and obviously indicates, in turn, the significant effects of variations in porosity and permeability on the pressure and total production.

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Nomenclature

ANN	: Artificial neural network
API	: American petroleum institute
FOPT	: Field oil production total
FPR	: Field pressure rate
N_2	: Nitrogen
T	: Temperature
ϑV	: Volume differential
ϑP	: Pressure differential

6. References

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