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Application of clustering analysis in oil wells corrosion and scaling management

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Abstract: This article demonstrates a method to make classification and dosing control for oil wells. To find the main factors that caused the corrosion and scaling in oil wells, water quality data of one oil production plant were made principal component analysis. Then the oil wells were divided into four types by using spss19.0 clustering analysis software according to the differences among main factors. Finally, wells dosing were applied in the field according to the classification. The effect is obvious, the corrosion inhibition rate can reach 70% above, and scale inhibition rate of calcium carbonate can reach 90% above. Costs savings of all the wells add up to 5390 thousands.

Introduction

Corrosion and scaling in oil wells is one of the key factors to cause oil wells exhaustive pumping that seriously affects the normal production of oilfield[1]. There are many complex fault blocks in Huabei oilfield, with the continuous production of oilfield, the available under-ground water suffers from a gradual build-up of salinity. The erosive ions such as Cl^-, HCO_3^-, Ca^{2+}, Mg^{2+}, et al in water have great effects on the corrosion and scaling in oil wells[2, 3]. At present, the common method is to determine the main factors affected corrosion and scaling in each well by means of analyzing the water quality of each single well, and then take separate dosing control. However, the main problem is that dosing control of each single well is so much workload that it's difficult to form scale classification management. In view of the fact that the corrosion and scaling in oil wells is the result of multiple factors, the previous single factor analysis could not reflect the overall situation. In order to improve the comprehensive management level of oil wells, it is necessary to form a regular method to guide on-site work.

Yongbin Xiang et al[4] classified the water quality data of Lasa city by using cluster analysis method combination with the main water quality survey data. Its credibility was extremely high, applied to environmental quality evaluation. Jingxin Su et al[5] used cluster analysis to classify the corrosion environment of base airport, obtained four kinds of corrosion environmental regions with similar effects on corrosion behavior of the aircraft. The research results had important value for selecting parameters of civil airport corrosion accelerated test. Gehong Wu et al[6] used cluster analysis to classify the reservoir physical property of Horqin oilfield, solved the reservoir classification problem, it had guiding significance for the next step development of classified reservoirs. Though cluster analysis has been applied in various fields of oilfield[7-11], but it had seldom application in oil wells management. This article demonstrates the novel approach of corrosion and scaling in Huabei Oilfield by using cluster analysis, and proposes dosing methods to solve the problems of oil wells corrosion and scaling in ten different fault blocks.

Clustering analysis methods

Different water quality data of an oil production plant were made clustering analysis by using spss19.0 software. The process of cluster analysis mainly contains (Fig.1) descriptive statistics analysis[12], data standardization, establishing approximate coefficient matrix, principal component analysis and cluster analysis.

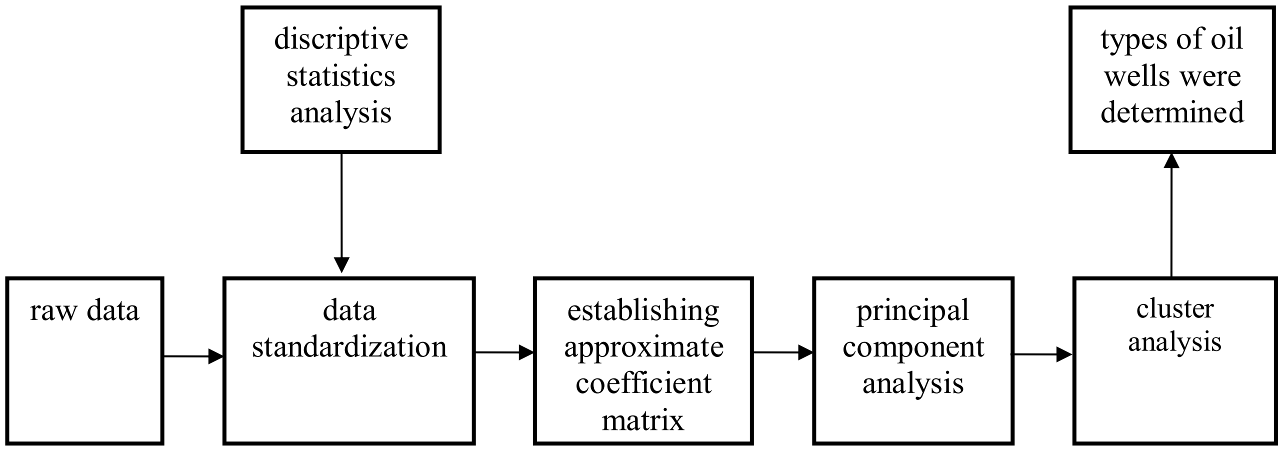

Fig.1 Flow chart of cluster analysis

Principal component analysis and cluster analysis were the key parts of the whole process[13]. First, by linear combination, the original multiple indicatiors had become a few independent indicators that fully reflected the overall information, so as to make further analysis[14]. Second, the main factors that caused oil wells corrosion and scaling were determined by removing the dependent variable. Third, cluster analysis was used again to classify oil wells according to the differences among main factors[15]. Finally, oil wells with the same main factors would be included in a same category.

Principal component analysis of water quality data

Water quality data of oil wells were made principal component analysis by using spss19.0 software to find the main factors that caused corrosion and scaling in oil wells. Principal components were selected according to the order of contribution rate of different components, then the selected principal components were as weights for linear weighting[14]. They were sorted according to the score value[16]. Finally, the main influence factors of corrosion and scaling in oil wells were determined through quantifying and objectively weighting various factors, and eliminating the interrelated influence of each factor. Table 1 illustrates the variance contribution rate of eleven components. Cumulative variance contribution rate of the first four principal components reaches more than 70%, and the initial eigenvalue are all greater than 1, so the data of the first four principal components can represent most of the original data. The variance contribution of the first four principal components F1, F2, F3, and F4 are 35.240%, 14.196%, 11.631%, and 9.617%, respectively.

Table 2 is the initial factor load matrix obtained from the principal component analysis. It shows that salinity, Cl^-, Ca^{2+}, Na^+, HCO_3^- have the highest loads on the first principal component F1, the load of them corresponds to 0.983, 0.979, 0.470, 0.779 respectively. SO_4^{2-} and Mg^{2+} have the highest loads on the second principal component F2, the load of them corresponds to 0.827 and 0.704 respectively. SRB and pH have the highest loads on the third principal component F3, the load of them corresponds to 0.589 and 0.565 respectively. CO_3^{2-} and free CO_2 have the highest loads on the fourth principal component F4, the load of them corresponds to 0.694 and 0.604 respectively.

Tab.1 Variance contribution rate

Components	Initial eigenvalue			Extraction square and loading		
	Total	Variance contribution [%]	Cumulative variance contribution rate [%]	Total	Variance contribution [%]	Cumulative variance contribution rate [%]
1	3.876	35.240	35.240	3.876	35.240	35.240
2	1.562	14.196	49.436	1.562	14.196	49.436
3	1.279	11.631	61.067	1.279	11.631	61.067
4	1.058	9.617	70.684	1.058	9.617	70.684
5	.921	8.374	79.057			
6	.812	7.382	86.440			
7	.692	6.293	92.733			
8	.464	4.219	96.952			
9	.335	3.045	99.997			
10	.000	.003	100.000			
11	5.948E-8	5.407E-7	100.000			

Tab.2 Initial factor load matrix

	Components			
	1	2	3	4
Salinity	.983	-.013	.098	-.023
Cl^-	.979	-.033	.092	-.030
HCO_3^-	.470	-.123	.394	.232
CO_3^{2-}	-.052	-.100	.291	-.694
SO_4^{2-}	.144	.827	-.199	-.014
Ca^{2+}	.779	-.059	-.208	-.143
Mg^{2+}	.245	.704	-.388	-.166
Na^+	.975	-.043	.120	-.014
SRB	-.006	.429	.589	.061
Free CO_2	.229	-.122	-.328	.604
pH	-.195	.389	.565	.323

Therefore, through integrating of Table 1 and Table 2, it can be concluded that F1 mainly reflects that corrosion and scaling in the first type wells were mainly caused by more salinity, Cl^-, Ca^{2+}, Na^+ and HCO_3^- than other wells[17]. So, F1 could be used as salinity, Cl^-, Ca^{2+}, Na^+ and HCO_3^- corrosion and scaling identification factor. F2 mainly reflects that the corrosion and scaling in the second type wells were mainly caused by more Mg^{2+} and SO_4^{2-} than other wells[18]. So, it could be used as Mg^{2+} and SO_4^{2-} corrosion and scaling identification factor. F3 mainly reflects that the corrosion and scaling in the third type wells were mainly caused by more SRB and pH than other wells[19, 20]. So, F3 could be used as SRB and pH corrosion and scaling identification factor. F4 mainly reflects that the corrosion and scaling in the fourth type wells were mainly caused by more CO_3^{2-} and free CO_2 than other wells[21]. So, it could be used as CO_3^{2-} and free CO_2 corrosion and scaling identification factor.

Data of the principal component score coefficient matrix (Table 3) and standardized data (Z value) were used to calculate the factor score of F1, F2, F3, F4 and F. The score of comprehensive principal component F could be concluded according to the four factor scores. The calculation steps are shown in formula (1), (2), (3), (4) and (5).

the factor score of $F1=0.254\times Z(Salinity)+0.253\times Z(Cl^-)+\ldots\ldots-0.050\times Z(pH)$. (1)

the factor score of $F2=-0.008\times Z(Salinity)-0.021\times Z(Cl^-)+\ldots\ldots+0.249\times Z(pH)$. (2)

the factor score of $F3=0.077\times Z(Salinity)+0.072\times Z(Cl^-)+\ldots\ldots+0.442\times Z(pH)$. (3)

the factor score of $F4=-0.022\times Z(S)-0.028\times Z(Cl^-)+\ldots\ldots+0.305\times Z(pH)$. (4)

the comprehensive factor score of $F=0.35240\times F1+0.14196\times F2+0.11631\times F3+0.09617\times F4$. (5)

Tab.3 Component score coefficient matrix

	Components			
	1	2	3	4
Salinity	.254	-.008	.077	-.022
Cl^-	.253	-.021	.072	-.028
HCO_3^-	.121	-.079	.308	.219
CO_3^{2-}	-.013	-.064	.228	-.656
SO_4^{2-}	.037	.530	-.156	-.014
Ca^{2+}	.201	-.038	-.162	-.135
Mg^{2+}	.063	.451	-.303	-.157
Na^+	.251	-.028	.094	-.013
SRB	-.002	.275	.460	.057
Free CO_2	.059	-.078	-.256	.571
pH	-.050	.249	.442	.305

Clustering analysis of oil wells

Taking the four principal components (F1, F2, F3, F4) which influenced the corrosion and scaling in oil wells as independent variables, different wells as the dependent variable, the level of corrosion and scaling was clustered by spss19.0 statistical software. The distance between regions was calculated by Euclidean distance ward method. Then, the two wells with minimal distance (maximum similarity) were merged into one type by Q clustering[22]. The samples were weighted average, formed a new sample combination. The approximate coefficient matrix was calculated using the newly formed samples data. In this way, repeat the prior steps, until all the wells belong to one type[23].

According to the variance analysis method in the software to verify the final classification is shown in Table 4. It can be known that when the oil wells are divided into four types, the similarity among types based on F1, F2, F3, and F4 is almost zero respectively, which suggests the clustering effect is the best. Thus, it is right that the oil wells are divided into four types according to the differences among F1, F2, F3 and F4.

Tab.4 Variance analysis

	Two types	Three types	Four types
Similarity among types based on F1	0.000	0.000	0.000
Similarity among types based on F2	0.812	0.368	0.000
Similarity among types based on F3	0.006	0.000	0.000
Similarity among types based on F4	0.025	0.009	0.004

Results and discussion

Integrating the results of principal component analysis and clustering analysis, the corrosion and scaling in oil wells of the oil production plant can be divided into four types. Table 5 shows classification of corrosion and scaling in different oil wells. The following section made further detailed analysis of corrosion and scaling reasons according to the water quality data and the scale analysis data of oil wells. Water analysis data of four types of wells are shown in Table 6. Scale morphology of typical oil wells is shown in Figure 2. Scale analysis data are shown in Table 7.

Tab.5 Classification of corrosion and scaling in different oil wells

Category (the order of scores)	The first type (F1>F>F2>F3>F4)	The second type (F2>F3>F>F1>F4)	The third type (F3>F2>F>F4>F1)	The fourth type (F4>F2>F3>F1>F)
wells	C31-58, C12-208, C33-28, C12-97 et al	C12-291, C19-3, C74-201, C80-19 et al	C19-5, C19-213, C30-60, C48-130 et al	C31-136, C31-65, C79-18, C19-100 et al

Tab.6 Water analysis data of four types of wells

	wells	Salinity [mg/L]	Cl^- [mg/L]	HCO_3^- [mg/L]	CO_3^{2-} [mg/L]	SO_4^{2-} [mg/L]	Ca^{2+} [mg/L]	Mg^{2+} [mg/L]	Na^+ [mg/L]	SRB [Cells /mL]	Free CO_2 [mg/L]	pH
The first type	C12-208	33820	19880	776	0	28	360	61	12715	0	52	6
	C31-58	33129	19405	842	0	27	340	61	12455	0	47	6
	C12-97	31983	18636	1061	0	9	453	0	11825	0	52	6
	C33-28	51148	29910	1455	0	0	1027	12	18744	0	33	6
The second type	C74-201	18838	10236	826	0	624	511	150	6490	5	58	6
	C12-291	24938	13878	638	0	841	343	88	9149	0	15	7
	C19-3	20518	11244	539	0	700	399	363	7272	9	15	6
	C80-19	25853	14141	622	0	1233	356	586	8915	0	10	6
The third type	C19-5	26153	11506	832	0	124	60	53	13579	25	20	8
	C19-213	20205	11858	465	0	47	178	58	7600	25	32	6
	C30-60	21074	12090	730	0	15	98	22	8110	25	0	7
	C48-130	21020	11936	942	0	18	170	49	7890	25	0	7
The fourth type	C31-136	24928	12084	747	0	98	306	82	11612	0	160	6
	C31-65	19270	10945	839	0	72	170	65	7179	0	107	6
	C79-18	12067	6647	542	8	288	246	30	4314	0	61	6
	C19-100	18161	10256	603	15	320	162	27	6794	0	53	6

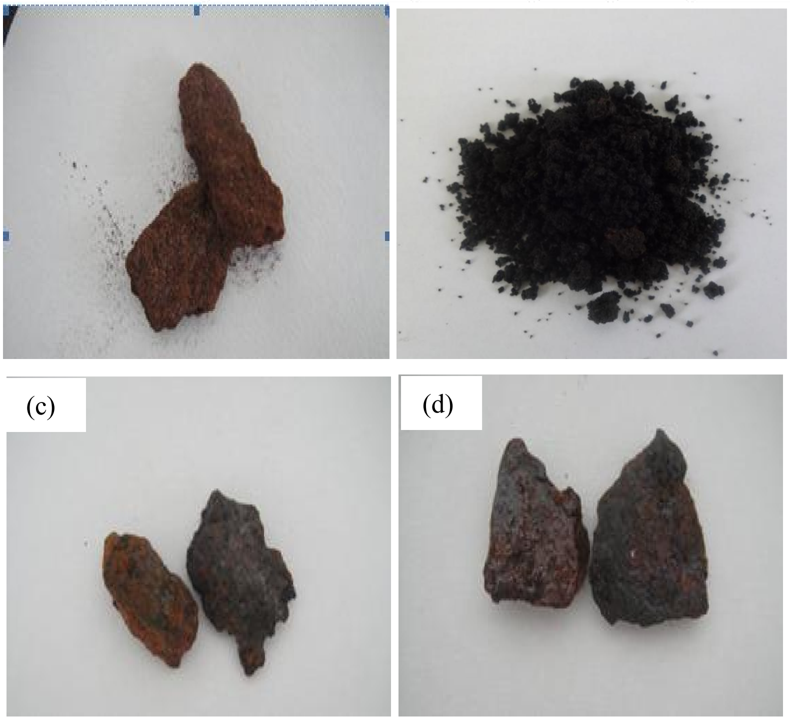

Fig.2 Scale morphology of typical oil wells
(a) C33-28 well (b) C80-19 well (c) C19-213well (d) C31-136 well

It can be known that the salinity of the first type wells are up to 51148mg/L higher than other types, Cl^- content is 18636-29910mg/L, Ca^{2+} content is 340-1027mg/L, HCO_3^- content is 776-1455mg/L. From Fig.2(a), it can be seen that the scale color is reddish brown, texture is hard. And a large number of bubbles appeared in acid dissolution, the dissolution was yellow green with no smell of rotten eggs. Then according to the scale analysis data of C33-28 well (Tab.7), it can be known that Ca^{2+} and Mg^{2+} content are higher than other wells, and Fe^{3+}, Fe^{2+} content are relatively low. Thus, it can be concluded that the first type wells were mainly with calcium carbonate scaling, meanwhile existed Cl^- electrochemical corrosion[17]. The salinity of the second type wells are relatively low, SO_4^{2-} and Mg^{2+} content are higher than other types, SO_4^{2-} content is 624-1233mg/L, Mg^{2+} content is 53-586mg/L. From Fig.2(b), it can be seen that the scale color is black, texture is soft. And a few bubbles appeared in acid dissolution, the dissolution was yellow green with no smell of rotten eggs. Then according to the scale analysis data of C80-19 well (Tab.7), it can be known that the content of corrosion products

Fe^{3+} , Fe^{2+} and Ca^{2+}, Mg^{2+} content are relatively high. So, the second type wells were mainly with SO_4^{2-} electrochemical corrosion[18], meanwhile existed a small amount of calcium carbonate and magnesium carbonate scaling. SRB and pH content of the third type wells are higher than other types, SRB content is 25mg/L, and pH is 6-8. From Fig.2(c), it can be seen that the scale color is black with red, texture of most of the sample is soft. When the sample was placed in acid solution, a few bubbles appeared, and the solution became yellow green with no smell of rotten eggs. Then according to the scale analysis data of C19-213 well (Tab.7), it can be known that Fe^{3+} and Fe^{2+} content are relatively high, and Ca^{2+} content is a little. Thus, it can be concluded that corrosion and scaling in the third type wells were mainly caused by SRB and pH corrosion[19, 20] and a little calcium carbonate scaling. The salinity of the fourth type wells are the lowest, but CO_3^{2-} and free CO_2 content are higher than other types, CO_3^{2-} content is 0-15mg/L, free CO_2 content is 53-160mg/L. From Fig.2(d), it can be seen that the scale color is black with red, texture of most of the sample is soft. And a few bubbles appeared in acid dissolution, the dissolution was yellow green with no smell of rotten eggs. Then according to the scale analysis data of C31-136 well (Tab.7), it can be known that the content of corrosion products Fe^{3+}, Fe^{2+} are relatively high, and Ca^{2+} content is a little. So, it can be concluded that corrosion and scaling in the fourth type wells were mainly caused by free CO_2 electrochemical corrosion[21] and a little calcium carbonate scaling.

Tab.7 Scale analysis data of typical oil wells

	Typical wells	Water, volatile and organics [%]	Inorganic [%]	Acid insoluble substance [%]	Ca^{2+} [%]	Mg^{2+} [%]	Fe^{3+} [%]	Fe^{2+} [%]
The first type well	C33-28	4.3	48.2	3.0	20.86	2.7	12.0	5.9
The Second type well	C80-19	4.8	20.7	7.3	9.86	5.18	20.3	28.5
The third type well	C19-213	21.6	7.1	4.4	4.2	0.6	5.3	52.5
The fourth type well	C31-136	20.2	13.6	0	6.0	2.5	8.4	42.4

Application in the field

Finally, oil wells dosing were applied in the field according to the classification. The dosing effect is obvious. The corrosion inhibition rate is 70% above, scaling inhibition rate for calcium carbonate scale is 90% above. Average pump period extends from 181 days to 873 days. According to the production of oil wells, it can be known that pumping caused by corrosion and scaling in most of oil wells seldom occur after dosing. The amount of pump reduction adds up to 395 wells. Costs savings of all the wells add up to 5390 thousands.

Conclusions

The corrosion and scaling in oil wells were divided into four classifications by using principal component analysis and cluster analysis. And dosing effects in the field is obvious according to the classification. It can save a lot of management costs, and realize the large-scale management of oil wells.

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