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Research Article

Risk Assessment of Steam-Injecting Pipe by the Grey Principle

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Abstract: Steam-injecting pipes of the heavy oil thermal recovery are always operating in high temperature and high pressure, corrosion, fatigue and creep are prevalent in the steam-injecting pipes which make the pipes be liable to fail. The paper considers the influences of the operator, the maintenance, the environment and the operation, and establishes the risk assessment system of the steam pipeline of the heavy oil thermal recovery by the Grey Principle.
Keywords: steam-injecting pipes, the Grey Principle, risk assessment, analytical hierarchy process

INTRODUCTION

In the heat injection system of the heavy oil thermal recovery, the steam pipeline transfers and distributes high temperature steam to each well. The steam pipeline on the ground is always operating at high temperature and pressure and the operating pressure changes frequently. There exists the potential hazard of the water hammer. The long service time which results in lowering the life expectancy and aging pipeline material makes the steam on the ground liable to fail. In addition, the operation and maintenance personnel are lack of risk awareness that make mistake, and it may lead to the pipeline accident. The way that the steam pipeline management handling the accident will affects the severity of the accident consequence. The influence of the factors above for the steam pipeline is uncertain. Therefore, the paper applies the gray theory [1] to establish the index system of the steam pipeline assessment and determines weights of the evaluation index by analytic hierarchy process in order to conduct risk assessment of the steam pipeline.

RISK ASSESSMENT BASED ON THE GREY THEORY

The Establishment of the Evaluation Index System and the Determination of the Index Weight

The steam pipeline on the ground, the operation and maintenance employees and the surrounding environment constitute as a organic whole. The pipeline accident must be the result of one or more factors. The steam pipeline is always operating at high temperature and high pressure, and the risk of the steam pipeline is mainly due to the unsafe condition of the tube, the pipe fittings and the pipe attachments. The steam of high temperature and high pressure in the pipeline liquefies as it is running at high speed, and it will apply huge impact to the elbows and other parts which may lead to wall rupture. One injection-production pipeline will shut down intermittently, and the water vapor ambient will condense on the surface of the pipeline when it is shutdown which will cause corrosion on the outer surface of the pipeline. The judgment that the operation and maintenance personnel make for the pipeline operation is in relationship to the operating level, the education level, the security awareness and the sense of responsibility which will have an important impact on the safe operation of the pipeline. The geological condition of the region where the steam pipeline is also has an impact on the safe operation, and earthquakes and landslides will severely damage the steam pipeline. The work is likely to cause surface damage or rupture unless the operating units communicate with the steam pipeline affiliation. The writer makes the research on the basis of the site. The writer considers the quality of the operator, the emergency treatment, the surrounding environment and the device and the operating parameters of the steam pipeline when constructing the risk assessment system [2] of the steam pipeline, as shown in Table 2.

Use the analytic hierarchy process to determine the index weights. At first, send the risk assessment system in tabular to the experts for quantitative assessment to establishment judgment matrix and the determine scale definition is the criterion of the numerical evaluation. Secondly, calculate the eigenvectors corresponding to maximum characteristic root and you can get the index weights required after normalizing. Finally, we should pass the consistency test, make sure the consistency, CR=CI/RI<0.1 by calculating the maximum Eigen value of the matrix, λ_{max} and the consistency index CI, and then the index weights meet the requirements.

Table-1: The determining scale

the determining scale	Provision
1	Index, a_i and index a_j are equally important
3	Index $a_i$is slightly more important than index a_j
5	Index $a_i$is obviously more important than index a_j
7	Index $a_i$is more important than index a_j
9	Index $a_i$is extremely more important than index a_j
2、4、6、8	Interposed between adjacent scales
reciprocal	The reciprocal represents that one index is not as important as another.

Table-2: Risk assessment system and the index weights

The index of the first level	weight	The index of the second level	weight
The quality of the operating staff U_1	0．263	Education u_{11}	0.200
		Safety awareness u_{12}	0.400
		Operational u_{13}	0.400
Accident treatment U_2	0．118	Pipeline emergency plan u_{21}	0.250
		Equipment of accident treatment u_{22}	0.375
		Rescue training of the accident u_{23}	0.375
Surrounding environment and work activities U_3	0．055	Climate u_{31}	0.333
		Geological disasters u_{32}	0.333
		Situation of crossing u_{33}	0.207
		Construction u_{34}	0.137
Pipeline index U_4	0．564	Pipeline vibration u_{41}	0.174
		Pipeline wall thinning u_{42}	0.174
		Operating temperature and pressure u_{43}	0.174
		Pipeline material aging u_{44}	0.065
		Water hammer damage u_{45}	0.174
		Insulation layer u_{46}	0.174
		Pipeline accessories u_{47}	0.065

Sample Matrix of Risk Assessment

Organize the experts to assess the index of the assessment and score. The score reflects the judgment of the evaluators for the steam pipeline. The score value ranges from 1 to 10. Increasing the number of the evaluators can reduce the judgment error for the situation of the pipeline. But there needn't too many evaluators which will increase the cost of the risk assessment and cause sample overlap. The appropriate number is 10 to 15. We should consider the practical experience and research when selecting the evaluators and evaluators should contain the university teachers and the oil field experts. Then we can get the assess sample matrix of the grey theory.

$$E = \begin{bmatrix} e_{111} & e_{112} & \cdots & e_{11n} \\ e_{121} & e_{122} & \cdots & e_{12n} \\ \vdots & \vdots & \ddots & \vdots \\ e_{mn1} & e_{mn2} & \cdots & e_{mnk} \end{bmatrix}$$

In which, e_{mnk} is the assessment score responding to the index u_{mn}, k is the number of the evaluators.

Determine the Grey Class of the Risk Assessment

The sample matrix reflects the work experience and understanding of the evaluators, and we should determine the grey class [3-4] of assessment in order to classify the risk level of the pipeline. To determine the grey class is to determine the level of the grey class, the grey number and the whiter function. The paper use five grey assessment categories to assess the seam pipeline, such as safe, relatively safe, moderate, relatively serious and serious, and the corresponding value intervals are 9~10、7~9、5~7、3~5 and 1~3. The corresponding whiten function is described as the follow.

The first grey class is "safe", h=1, grey number $\otimes_1 \in [10, \infty]$, the whiten function is:

$$f_1(e_{mnk}) = \begin{cases} e_{mnk}/10 & e_{mnk} \in [0,10] \\ 1 & e_{mnk} \in [10,\infty) \\ 0 & e_{mnk} \notin [0,\infty) \end{cases} \quad \text{-------(1)}$$

The second grey class is “relatively safe”, h=2, grey number $\otimes_2 \in [0,8,16]$, the whiten function is:

$$f_2(e_{mnk}) = \begin{cases} e_{mnk}/8 & e_{mnk} \in [0,8] \\ 2 - e_{mnk}/8 & e_{mnk} \in [8,16] \\ 0 & e_{mnk} \notin [0,16] \end{cases} \quad \text{----(2)}$$

The third grey class is “moderate”, h=3, grey number $\otimes_3 \in [0,6,12]$, the whiten function is:

$$f_3(e_{mnk}) = \begin{cases} e_{mnk}/6 & e_{mnk} \in [0,6] \\ 2 - e_{mnk}/6 & e_{mnk} \in [6,12] \\ 0 & e_{mnk} \notin [0,12] \end{cases} \quad \text{--(3)}$$

The fourth grey class is “relatively serious”, h=4, grey number $\otimes_4 \in [0,4,8]$, the whiten function is:

$$f_4(e_{mnk}) = \begin{cases} e_{mnk}/4 & e_{mnk} \in [0,4] \\ 2 - e_{mnk}/4 & e_{mnk} \in [4,8] \\ 0 & e_{mnk} \notin [0,8] \end{cases} \quad \text{------(4)}$$

The fifth grey class is “serious”, h=5, grey number $\otimes_5 \in [0,2,4]$, the whiten function is:

$$f_5(e_{mnk}) = \begin{cases} 1 & e_{mnk} \in [0,2] \\ 2 - e_{mnk}/2 & e_{mnk} \in [2,4] \\ 0 & e_{mnk} \notin [0,4] \end{cases} \quad \text{--------(5)}$$

Assessment of Grey Theory

We can get the weight matrix by calculating the assessment coefficient of grey theory and the weight vector of grey theory. We can get comprehensive evaluation vector of grey theory by calculating the index weights from AHP and the matrix of grey theory, and then calculate the assessment value of grey theory. We evaluate the steam pipeline on the ground of Liao He Oilfield with grey theory. We invite 12 evaluators to score and get the sample matrix as the follow:

$$E = \begin{bmatrix} 7 & 8 & 7 & 6 & 5 & 5 & 7 & 7 & 8 & 7 & 4 & 7 \\ 8 & 8 & 5 & 7 & 7 & 6 & 7 & 6 & 8 & 5 & 6 & 7 \\ 8 & 5 & 7 & 7 & 9 & 8 & 7 & 8 & 8 & 7 & 8 & 8 \\ 6 & 5 & 5 & 7 & 7 & 6 & 7 & 7 & 4 & 5 & 5 & 7 \\ 8 & 8 & 9 & 9 & 10 & 8 & 8 & 6 & 7 & 6 & 6 & 7 \\ 6 & 7 & 5 & 6 & 6 & 6 & 7 & 8 & 9 & 7 & 8 & 5 \\ 7 & 8 & 6 & 6 & 8 & 6 & 7 & 7 & 6 & 6 & 6 & 8 \\ 8 & 8 & 6 & 7 & 5 & 6 & 6 & 5 & 7 & 7 & 7 & 8 \\ 6 & 7 & 7 & 6 & 5 & 5 & 8 & 8 & 6 & 7 & 8 & 7 \\ 6 & 7 & 7 & 8 & 6 & 6 & 5 & 7 & 8 & 8 & 6 & 7 \\ 8 & 7 & 7 & 6 & 7 & 8 & 8 & 6 & 8 & 8 & 7 & 8 \\ 6 & 6 & 5 & 5 & 4 & 4 & 7 & 5 & 6 & 6 & 7 & 6 \\ 7 & 8 & 7 & 8 & 8 & 6 & 6 & 5 & 5 & 6 & 7 & 7 \\ 7 & 8 & 8 & 6 & 5 & 6 & 7 & 7 & 8 & 6 & 7 & 8 \\ 6 & 5 & 4 & 4 & 2 & 5 & 5 & 3 & 6 & 5 & 6 & 7 \\ 7 & 6 & 6 & 5 & 6 & 7 & 8 & 8 & 8 & 5 & 7 & 8 \\ 7 & 8 & 8 & 7 & 6 & 6 & 5 & 7 & 7 & 8 & 6 & 7 \end{bmatrix}$$

We can get grey weights of the assessment index by calculating the assessment coefficient of grey class. The grey weight matrix of the operators’ quality is:

$$G_1 = \begin{bmatrix} 0.214 & 0.268 & 0.394 & 0.124 & 0 \\ 0.249 & 0.313 & 0.313 & 0.125 & 0 \\ 0.203 & 0.247 & 0.099 & 0.451 & 0 \end{bmatrix}$$

The grey weight matrix of the pipeline accident treatment is:

$$G_2 = \begin{bmatrix} 0.298 & 0.372 & 0.575 & 0.425 & 0 \\ 0.304 & 0.344 & 0.281 & .0661 & 0 \\ 0.250 & 0.304 & 0.313 & 0.133 & 0 \end{bmatrix}$$

The grey weight of the surrounding environment and construction work is:

$$G_3 = \begin{bmatrix} 0.249 & 0.314 & 0.322 & 0.115 & 0 \\ 0.250 & 0.313 & 0.313 & 0.124 & 0 \\ 0.250 & 0.313 & 0.313 & 0.124 & 0 \\ 0.252 & 0.315 & 0.316 & 0.117 & 0 \end{bmatrix}$$

The grey weight of the steam pipeline is:

$$G_4 = \begin{bmatrix} 0.282 & 0.342 & 0.301 & 0.065 & 0 \\ 0.296 & 0.370 & 0.125 & 0.209 & 0 \\ 0.279 & 0.349 & 0.232 & 0.140 & 0 \\ 0.276 & 0.345 & 0.272 & 0.108 & 0 \\ 0.220 & 0.274 & 0.241 & 0.208 & 0.057 \\ 0.286 & 0.357 & 0.229 & 0.132 & 0 \\ 0.270 & 0.338 & 0.276 & 0.116 & 0 \end{bmatrix}$$

We can get comprehensive assessment vector by calculating the index weights from AHP and the weight matrix of grey theory.

$$P = (0.260, 0.321, 0.256, 0.214, 0.006)$$

The comprehensive assessment value of grey theory:

$$Q = [0.260 \quad 0.321 \quad 0.256 \quad 0.214 \quad 0.006][10 \quad 8 \quad 6 \quad 4 \quad 2]^T = 7.572$$

We can know from the comprehensive assessment value that the steam pipeline on the ground in this block is relatively safe. The steam pipeline is relatively safely in general and there is no need to conduct a comprehensive renovation and maintenance. We can conduct a partial renovation and maintenance according to the value of the sample matrix, such as the potential of water hammer which we need to take action.

CONCLUSIONS

We combine the AHP and the grey theory to establish the risk assessment of the steam pipeline. The index weights determined by AHP can combine the actual situation of the heavy oil field and the theoretical which overcomes the defect that the weights by objective weighting method and actual result don't meet. The risk assessment based on the grey theory considers the operation of the steam pipeline, management, maintenance and the environment, and can quantify the impact to determine the risk level when we are in the absence of basic data. The method has reference value to heavy oil field.

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