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An Analysis and Control method on Preventing Gas Channeling in Cementing Operation

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Abstract: While waiting on cementing, the cement slurry weight loss can easily lead to early annular gas channeling and sustained casing pressure. Studying the weight loss process is an important means for reducing gas channeling risk. Due to complex physical and chemical changes during cement hydration process, conventional pressure reduction prediction models based on static gel strength theory produce distorted fits. Hence, a new dimensionless prediction model has been established through a large-scale physical experiment, and the effects of relevant parameters require further investigation. In this study parameters were investigated through sensitivity analysis with a styrene-acrylic latex cement slurry system as the study object. The results showed that a high temperature and a deep wellbore depth could cause the cement slurry to lose weight rapidly, whereas a high gas pressure and a high latex content could alleviate the weight loss trend. Weight loss rate was the most sensitive to changes in temperature, followed by wellbore depth and gas pressure. The latex content had a relatively insignificant effect but could be artificially adjusted. An anti-gas channeling method that primarily involves optimization of latex content and experimental evaluation of gas channeling was proposed. The results are reference significance to guiding anti-gas channeling cementing.

Keywords: Cementing, Hydrostatic Pressure Reduction, Prediction Model, Sensitivity Analysis, Anti-gas Channeling Method

1. Introduction

Accurately predicting changes in the hydrostatic fluid column pressure (P_c) of cement slurries and maintaining a well-bottom pressure balance are important means for preventing early annular gas channeling in high-pressure gas wells. While cementing a well and waiting for it to dry, the multiphase cement slurry medium gradually transforms from "particle aggregates" to "a skeleton-pore structure" [1-2] and becomes densified and coagulates, resulting in a significant decrease in the P_c of the cement slurry, thereby inducing gas invasion.

Limited by the complex physical and chemical hydration processes of cement slurries, static gel strength (SGS) is commonly used to approximately characterize the solidification state of cements [3-5]. Early experimental studies [6-7] found that gas invasion is prone to occur when SGS ranges from 48 to 240 kPa. Thus, based on the gelling suspension model, a series of cement slurry pressure reduction prediction and anti-gas channeling performance evaluation models have been established, including the fluid channeling potential factor method [8], the slurry response number method [9-10], a method that evaluates the chances of controlling gas migration [11], the coefficient of water loss during gelling (GELFL) [12] and a subsequent series of revised models [13-15]. However, extensive practices [16-19] have shown that as anti-gas channeling cement slurry systems become increasingly complex, it is difficult to use SGS to characterize changes in the P_c of cement slurries as a result of self-support, chemical expansion and contraction and a decrease in permeability. Consequently, conventional pressure reduction prediction models produce distorted fits [20]. Hence, there is an urgent need to formulate more accurate prediction methods to guide the design and implementation of anti-gas channeling well cementing.

In view of the aforementioned difficulties, through a large-scale physical experiment, a dimensionless pressure reduction prediction model [21] that comprehensively takes into consideration the special properties of cement slurries (key additive content) and formation (temperature T and gas reservoir pressure P_g) and wellbore (depth L and diameter d) conditions was established. The model fitting results were found to be in relatively good agreement with the measured experimental data (error: <15%). However, the patterns of effects of relevant model parameters on cement slurry weight loss require further investigation, and the model-based anti-gas channeling performance evaluation method needs to be further improved.

At present, various types of anti-gas channelling cement slurry systems have been formed [22-23], including thixotropic cement slurry, anti-cementing cement slurry, non-permeable cement slurry, etc., aiming to improve the compacting properties of cement slurry, slow down the volume shrinkage of cement slurry, and enhance the resistance of gas penetration and gas channelling. With the exploration and development of deeper oil and gas reservoir, the emulsion non-permeable slurry system has gradually become the mainstream of application [24-25], and the key anti-channelling additive is latex emulsion.

Hence, this study investigated the patterns of effects of various model parameters on the weight loss rate through a sensitivity analysis with an anti-gas channeling styrene-acrylic latex (SAL) cement slurry system as the study object and the rate R of decrease in hydrostatic fluid column pressure at various times as the primary objective function. Additionally, a gas channeling performance evaluation and prevention method based on the prediction model was also proposed. The results obtained from this study are of certain reference value to guiding anti-gas channeling well cementing.

2. Hydrostatic Pressure Reduction Prediction Model

2.1. Model Parameter Selection and Modeling Method

An anti-gas channeling latex cement slurry system is prepared with a class G oil well cement, an SAL (5.0–20.0%), a latex stabilizer (1.0–2.0%) and a dispersing agent (0.1–0.4%) at a water/cement ratio of 44.0%. The higher the SAL content C_{latex} is, the more easily a spatial network of impervious membranes can be formed, which will fill the gaps between cement particles and consequently lead to a higher anti-gas channeling performance of the cement slurry. Thus, C_{latex} is selected to characterize the special properties of cement slurries. Further, a dimensionless gas reservoir pressure P_d (bottom P_g/bottom water column pressure P_w) and a dimensionless temperature T_d (wellbore temperature T_w/initial cement slurry temperature T_c) are selected to characterize the formation conditions corresponding to the experiment; a dimensionless geometric parameter G_d (L/d) is used to characterize the simulated wellbore conditions corresponding to the experiment. Table 1 summarizes the values of the parameters. Then, an accurate cement slurry pressure conduction measuring system is used to measure cement slurry weight loss data in real time under various combinations of parameters.

Table 1. Dimensionless experimental parameters of the prediction model.

Dimensionless parameters	The range of values	Remarks
C_{latex}	0.0-0.2	C_{latex}=5%-20%
P_d	0-1.8	P_g=0-18 kPa, P_w=10kPa
T_w	1.5-3.5	T_c=30-70°C, T_c=20°C
G_d	17, 13, 9, 5	L=850, 650, 450, 250 mm, d=50mm

Based on the experimental data, an anti-gas channeling SAL cement slurry pressure reduction prediction model is gradually established. First, through screening, the logarithmic function $P_c=a-b\times\ln(t+c)$ is determined as the regression equation. Second, through unitary linear or nonlinear regression, the relationships between discrete univariate experimental parameters (cement slurry performance, formation and wellbore conditions, etc.) and the model parameters a, b and c, i.e., univariate parameter functions, are established. Subsequently, through multivariate linear regression, the relationships between the univariate parameter functions and the model parameters a, b and c, i.e., multivariate parameter functions, are established. Finally, a cement slurry pressure reduction prediction model that can take into consideration complex conditions is established. See elsewhere [21] for the modeling method and the accuracy validation of the model.

2.2. Model Calculation Equation

Based on the experimental parameters in Table 2, the ultimate expression of the anti-gas channeling SAL cement slurry pressure reduction prediction model can be calculated using the modeling method used in reference [21]:

$$P_c=a-b\times\ln(t+c) \tag{1}$$

Where, $a = -8.77C_{\text{latex}}-14.91P_d+52.35T_d+2.41G_d-81.18$;
$b = -1.75C_{\text{latex}} -1.72P_d+6.01T_d+0.22G_d-9.43$;
$c = 4447.82C_{\text{latex}}-158.01P_d+1166.28T_d-103.87G_d+171.69$.

2.3. Objective Function of the Model and Its Physical Meaning

The change in the P_c of the cement slurry with time is the objective function of the model. Based on the model, the cement slurry weight loss process under various conditions can be directly calculated. For example, by setting the time t to 0 s, the initial P_c of the cement slurry can be calculated.

$$P_c(0)=a-b\times\ln c \tag{2}$$

Further, by calculating the first derivative of the model $P_c=a-b\times\ln(t+c)$ with respect to t, the R of the cement slurry at various ts can be determined.

$$P_c^{'}(t)=\frac{-b}{t+c} \tag{3}$$

Studying the *R*s of cement slurries is of great importance to anti-gas channeling well cementing design. Extensive research [1, 16-19, 21] has demonstrated that cement slurry weight loss does not linearly increase with an increasing SGS. Thus, the *R*s of a cement slurry at various stages can be reduced by such measures as decreasing the expansion rate of the cement slurry, reducing water loss at high *T*s and improving the wellbore conditions, thereby ensuring that there will be ample time for the cement slurry to form a gelled network structure with sufficient strength. Under this condition, even if the ultimate P_c of the cement slurry is far lower than P_g, a sufficient gas channeling resistance will still be formed inside the cement slurry, thereby reducing the risk of early gas channeling.

Thus, it is necessary to use the anti-channeling cement slurry pressure reduction prediction model to analyze the sensitivity to various parameters and the pattern of decrease in the pressure of the cement slurry with the *R* of the cement slurry as the objective function.

3. Sensitivity Analysis of the Model Parameters

In this experiment, because a retarder was not added in the cement slurry formula, the thickening time was short, and the P_c of the cement slurry decreased to P_w, generally within 2-3 h. Therefore, t=0 s was selected as the time node of the initial stage of the decrease in pressure; t=3,600 s (1 h) was selected as the time node of the middle stage of the decrease in pressure; and t=7,200 s (2 h) was selected as the time of the late stage of the decrease in pressure. Various experimental parameters were thus calculated using Equations (2) and (3). Tables 2–5 summarize the extents of change in the initial P_c of the cement slurry and its *R*s at various times corresponding to changes in C_{latex}, P_d, T_d and G_d.

Table 2. *Effects of the change in C_{latex} on the initial P_c and R.*

Values of the reference parameters			Latex content and its extent of change (%)		Extents of change in the initial P_c and *R* (%)			
P_d	T_d	G_d	P_d	T_d	ΔPc(0)	ΔPc'(0)	ΔPc'(3600)	ΔPc'(7200)
1.0	2.5	11.0	0.000	-100	7.01	28.46	11.35	7.95
1.0	2.5	11.0	0.025	-75	4.97	20.10	8.34	5.89
1.0	2.5	11.0	0.050	-50	3.14	12.66	5.45	3.88
1.0	2.5	11.0	0.075	-25	1.49	6.00	2.67	1.92
1.0	2.5	11.0	0.100	0	0.00	0.00	0.00	0.00
1.0	2.5	11.0	0.125	25	-1.34	-5.43	-2.57	-1.87
1.0	2.5	11.0	0.150	50	-2.55	-10.36	-5.05	-3.70
1.0	2.5	11.0	0.175	75	-3.63	-14.87	-7.44	-5.49
1.0	2.5	11.0	0.200	100	-4.60	-19.00	-9.74	-7.23

Table 3. *Effects of the change in P_d on the initial P_c and R.*

Values of the reference parameters			Gas reservoir pressure and its extent of change (%)		Extents of change in the initial P_c and *R* (%)			
C_{latex}	T_d	G_d	P_d	ΔP_d	ΔPc(0)	ΔPc'(0)	ΔPc'(3600)	ΔPc'(7200)
0.1	2.5	11.0	0.00	-100	8.40	19.63	24.73	25.99
0.1	2.5	11.0	0.20	-80	6.84	15.92	19.88	20.86
0.1	2.5	11.0	0.40	-60	5.22	12.10	14.99	15.70
0.1	2.5	11.0	0.60	-40	3.55	8.18	10.05	10.50
0.1	2.5	11.0	0.80	-20	1.80	4.15	5.05	5.27
0.1	2.5	11.0	1.00	0	0.00	0.00	0.00	0.00
0.1	2.5	11.0	1.20	20	-1.87	-4.27	-5.11	-5.30
0.1	2.5	11.0	1.40	40	-3.80	-8.65	-10.27	-10.64
0.1	2.5	11.0	1.60	60	-5.80	-13.17	-15.49	-16.02
0.1	2.5	11.0	1.80	80	-7.87	-17.83	-20.77	-21.43
0.1	2.5	11.0	2.00	100	-10.01	-22.63	-26.10	-26.88

Table 4. *Effects of the change in T_d on the initial P_c and R.*

Values of the reference parameters			Temperature and its extent of change (%)		Extents of change in the initial P_c and *R* (%)			
C_{latex}	P_d	G_d	T_d	ΔT_d	$\Delta P_c(0)$	$\Delta P_c'(0)$	$\Delta P_c'(3600)$	$\Delta P_c'(7200)$
0.1	1.0	11.0	1.0	-60	-101.67	-318.93	-167.58	-158.08
0.1	1.0	11.0	1.3	-48	-62.66	-147.86	-123.48	-120.95
0.1	1.0	11.0	1.6	-36	-37.47	-78.07	-85.83	-86.93
0.1	1.0	11.0	1.9	-24	-20.11	-40.16	-53.32	-55.63
0.1	1.0	11.0	2.2	-12	-8.06	-16.34	-24.96	-26.74
0.1	1.0	11.0	2.5	0	0.00	0.00	0.00	0.00
0.1	1.0	11.0	2.8	12	4.91	11.91	22.13	24.83
0.1	1.0	11.0	3.1	24	7.21	20.98	41.89	47.94
0.1	1.0	11.0	3.4	36	7.29	28.12	59.65	69.52
0.1	1.0	11.0	3.7	48	5.46	33.88	75.68	89.69
0.1	1.0	11.0	4.0	60	1.92	38.63	90.24	108.61

Table 5. *Effects of the change in G_d on the initial P_c and R.*

Values of the reference parameters			Geometric parameter and its extent of change (%)		Extents of change in the initial P_c and R (%)			
C_{latex}	P_d	T_d	G_d	ΔG_d	$\Delta P_c(0)$	$\Delta P_c'(0)$	$\Delta P_c'(3600)$	$\Delta P_c'(7200)$
0.1	1.0	2.5	2.0	-82	-59.50	-52.32	-41.70	-38.45
0.1	1.0	2.5	3.8	-65	-48.75	-44.49	-34.31	-31.33
0.1	1.0	2.5	5.6	-49	-37.49	-35.60	-26.48	-23.94
0.1	1.0	2.5	7.4	-33	-25.66	-25.44	-18.19	-16.26
0.1	1.0	2.5	9.2	-16	-13.19	-13.70	-9.38	-8.29
0.1	1.0	2.5	11.0	0	0.00	0.00	0.00	0.00
0.1	1.0	2.5	13.0	18	15.63	18.19	11.15	9.60
0.1	1.0	2.5	14.6	33	29.00	35.68	20.68	17.60
0.1	1.0	2.5	16.4	49	45.12	59.50	32.12	26.96
0.1	1.0	2.5	18.2	65	62.61	89.33	44.40	36.72
0.1	1.0	2.5	20.0	82	81.79	127.77	57.62	46.91

Based on Tables 2–5, sensitivity analysis curves of the initial P_c and Rs at various times were produced, as shown in Figures 1-4.

3.1. Sensitivity Analysis of the Initial P_c

As demonstrated in Figure 1, T_d and G_d were significantly positively correlated with the initial P_c, whereas C_{latex} and P_d had a relatively insignificant effect on and were weakly negatively correlated with the initial P_c.

As T_d increased from -60% to 60%, the initial P_c increased by 103%. The same extent of change in G_d led to an approximately 70% increase in the initial P_c, while the same extent of change in P_d resulted in an approximately 13% decrease in the initial P_c. The same extent of change in C_{latex} led to the smallest change (an approximately 6% decrease) in the initial P_c.

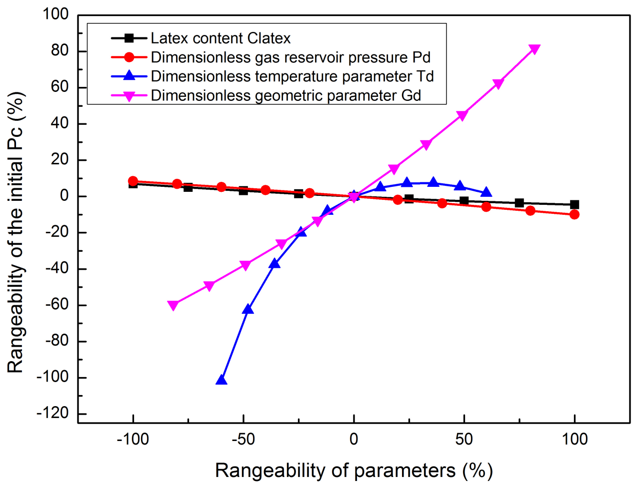

Figure 1. *Sensitivity curves of the initial P_c.*

Thus, the initial P_c was the most sensitive to the change in G_d, followed by T_d, but was weakly correlated with P_d and C_{latex}.

The above analysis is basically in agreement with the actual working condition. The greater L is, the liquid column height h of the cement slurry is, and the higher the initial P_c at the corresponding location is. The higher the environmental T is, the more easily the cement slurry can undergo thermal expansion after its displacement reaches a satisfactory level, which will result in the generation of a certain additional thermal stress, which in turn will increase the bottom P_c of the cement slurry. With the absence of gas channels, P_g and C_{latex} are unable to significantly affect $P_c(0)$.

3.2. Sensitivity Analysis of the R at the Initial Stage

As demonstrated in Figure 2, T_d and G_d were significantly positively correlated with the R at the initial stage, whereas C_{latex} and P_d were relatively weakly negatively correlated with the R at the initial stage.

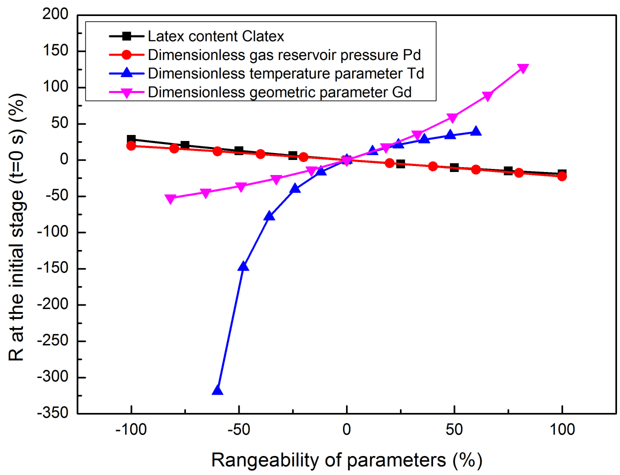

Figure 2. *Sensitivity curves of the R at the initial stage (t=0 s).*

As T_d increased from -60% to 60%, the R at the initial stage increased by 358%. The same extent of change in G_d led to an approximately 132% increase in the R at the initial stage, while the same extent of change in C_{latex} resulted in an approximately 30% decrease in the R at the initial stage. The same extent of change in P_d led to the smallest change (an approximately 25% decrease) in the R at the initial stage.

Thus, the R at the initial stage was the most sensitive to an extent of change in T_d, followed by G_d, but was relatively weakly correlated with C_{latex} and P_d.

In fact, the R at the initial stage is closely related to the cement hydration rate, which is primarily affected by T. The higher T is, the higher the cement hydration rate is, and the faster weight loss is. On the other hand, the cement hydration rate is also affected by low pressure (<20 MPa). The higher the pressure is, the higher the cement hydration rate is. Under the conditions of this experiment, limited by the scale of the equipment, the pressure varied within 1 kPa. Additionally, the pressure at each corresponding measuring point was mainly controlled by G_d (the height of the measuring point). Therefore, the *R* at the initial stage was positively correlated with G_d. The higher G_d was, the faster the cement slurry lost weight. Compared to the aforementioned two parameters, the latex and P_g affected the rate at which the cement slurry lost weight by a mechanism different. The latex and P_g prevented weight loss primarily by preventing the cement slurry from contracting and, to a certain extent, supporting the gelled structure already existing inside the cement slurry. Thus, with the absence of air channeling, the higher C_{latex} and P_d were, the lower the weight loss rate was. However, the effects of C_{latex} and P_d were not as significant as those of T_d and G_d.

3.3. Sensitivity Analysis of the R at the Middle Stage

As demonstrated in Figure 3, as T_d increased from -60% to 60%, the *R* at the middle stage increased by 257%. The same extent of change in G_d resulted in an approximately 70% increase in the *R* at the middle stage, whereas the same extent of change in P_d led to an approximately 29% decrease in the *R* at the middle stage. The same extent of change in C_{latex} led to a relatively small change (an approximately 13% decrease) in the *R* at the middle stage. Thus, the *R* at the middle stage was the most sensitive to a changing extent of change in T_d, followed by G_d, but was relatively weakly correlated with P_d and C_{latex}.

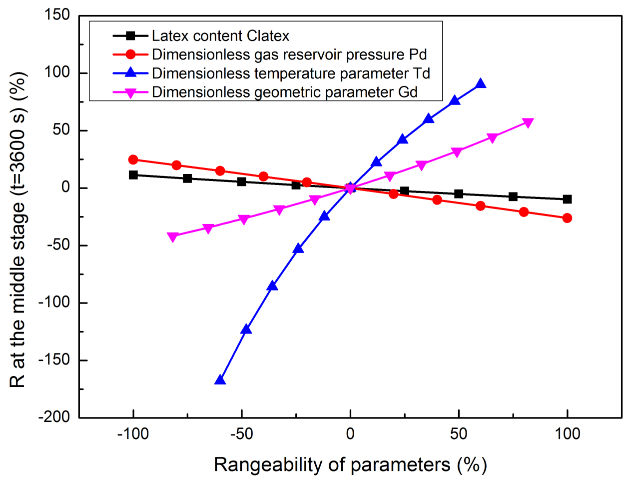

Figure 3. *Sensitivity curves of the R at the middle stage (t=3,600 s).*

The pattern of change in the sensitivity of the *R* at the middle stage was similar to that of the *R* at the initial stage. The *R* at the middle stage was mainly affected by the cement hydration rate. Thus, the effect of *T* was the most pronounced. On the other hand, the change in P_c caused by G_d decreased from 137% to 70%, suggesting that the effect of the environmental pressure on the *R* at the middle stage weakened over time. Compared to T_d and G_d, the effects of C_{latex} and P_d still remained at a relatively low level, but they could still, to a certain extent, alleviate the fast weight loss of the cement slurry.

3.4. Sensitivity Analysis of the R at the Late Stage

As demonstrated in Figure 4, as T_d increased from -60% to 60%, the *R* at the late stage increased by 266%. The same extent of change in G_d resulted in an approximately 61% increase in the *R* at the late stage, whereas the same extent of change in P_d led to an approximately 31% decrease in the *R* at the late stage. The same extent of change in C_{latex} led to the smallest change (an approximately 9% decrease) in the *R* at the late stage.

Thus, the pattern of change in the sensitivity of the *R* at the late stage was similar to those of the *R*s at the initial and middle stages. The *R* at the late stage was also affected by the cement hydration rate. Thus, *T* had the most pronounced effect on the *R* at the late stage and caused it to change by approximately 260%, which was basically the same extent as that to which it changed the *R* at the middle stage. On the other hand, the change in P_c caused by G_d further decreased from 70% at the middle stage to 761%, suggesting that the effect of the environmental pressure on the *R* at the middle stage further weakened over time. Compared to T_d and G_d, the effects of C_{latex} and P_d still remained at a relatively low level.

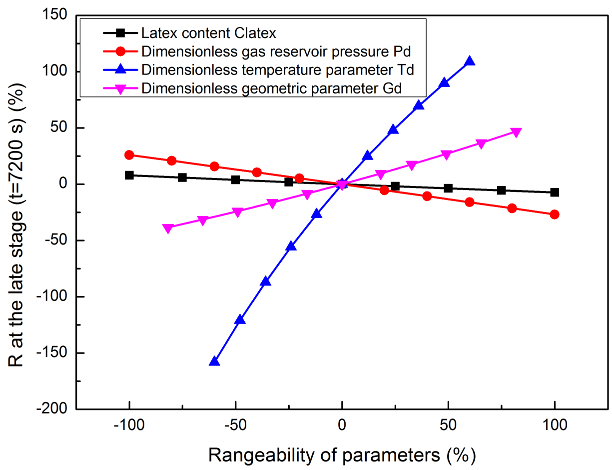

Figure 4. *Sensitivity curves of the R at the late stage (t=7,200 s).*

3.5. Comprehensive Analysis of the Effects of the Model Parameters

The above analysis of sensitivity to the parameters shows that the weight loss condition of a cement slurry is closely related to the hydration process. Thus, the weight loss curve is affected primarily by the experimental *T* and pressure and relatively weakly by P_g and C_{latex}.

The higher *T* and initial P_c are, the higher the weight loss rate under pressure is. The higher *T* is, the easier it is for the cement slurry to undergo thermal expansion after becoming still, which will generate a certain additional thermal stress, which in turn will increase the bottom P_c. Additionally, the cement hydration rate gradually increases with an increasing *T*, resulting in a fast weight loss. Thus, considering the significant effect of *T* on model calculation results, when fitting the P_c of a cement slurry in a long, sealed section, it is necessary to first divide the section into multiple subsections based on the geothermal gradient and fit each subsection individually and then superpose the P_cs of the subsections in order to ensure calculation accuracy.

The greater G_d (L) is, the higher the initial P_c of the cement slurry is and the faster the cement slurry loses weight under pressure. However, the change caused by G_d is not as significant as that caused by T. The greater L is and the greater the h of the cement slurry is, the higher the initial P_c of the cement slurry at the corresponding location is. Additionally, the greater L is and the higher the environmental pressure is, the easier the hydration of the cement slurry can be accelerated. However, the sensitivity analysis shows that G_d mainly had a relatively significant effect on the weight loss rate at the initial stage but a relatively weak effect on the weight loss rates at the middle and late stages when compared to T.

P_g has a weak effect on the initial P_c of the cement slurry. However, a relatively high P_g can reduce R. Analysis shows that with the absence of air channels, a relatively high P_g can alleviate the downward movement trend of a cement slurry caused by volume contraction during the hydration process and reduce the hanging force exerted by the wellbore wall on the gelled structure, thereby reducing the weight loss rate of the cement slurry. The sensitivity analysis shows that P_g affected the weight loss rates at the initial, middle and late stages.

Similarly, C_{latex} has a relatively insignificant effect on the initial P_c of the cement slurry. However, a relatively high C_{latex} can, to some extent, reduce the weight loss rate of the cement slurry. In the experiment, as C_{latex} increased from -60% to 60%, the Rs at the initial, middle and late stages decreased by approximately 25%, 13% and 9%, respectively. The sensitivity analysis shows that C_{latex} mainly affected the weight loss rate at the initial stage. At this stage, small (0.05–0.5 μm) inertial latex particles effectively filled the gaps between cement particles (20–50 μm) and thus prevented the overall downward movement of the cement slurry structure caused by its volume contraction, thereby, to some extent, alleviating the weight loss trend. At the late stage of the weight loss process of the cement slurry, latex particles prevented air channeling in the cement slurry primarily by shrinking air channels. In practical well cementing, when formation and wellbore conditions are difficult to improve, optimizing C_{latex} is a technical measure for effectively reducing the weight loss rate of the cement slurry and improving the resistance of the cement slurry matrix to gas invasion.

Hence, a gas channeling performance evaluation and prevention method, with the R of the cement slurry as the main objective function and optimization of C_{latex} as the main technical measure, can be preliminary formulated.

4. Model-based Gas Channeling Performance Evaluation and Prevention Method

Based on the prediction model, it is possible to increase C_{latex} to decrease the R of the cement slurry and improve its rheological properties. This measure, together with an anti-gas channeling evaluation experiment and an annular pressure application process, can improve the anti-gas channeling performance of the cement slurry while waiting on cementing. The evaluation method is described in detail as follows (see Figure 5 for the flowchart).

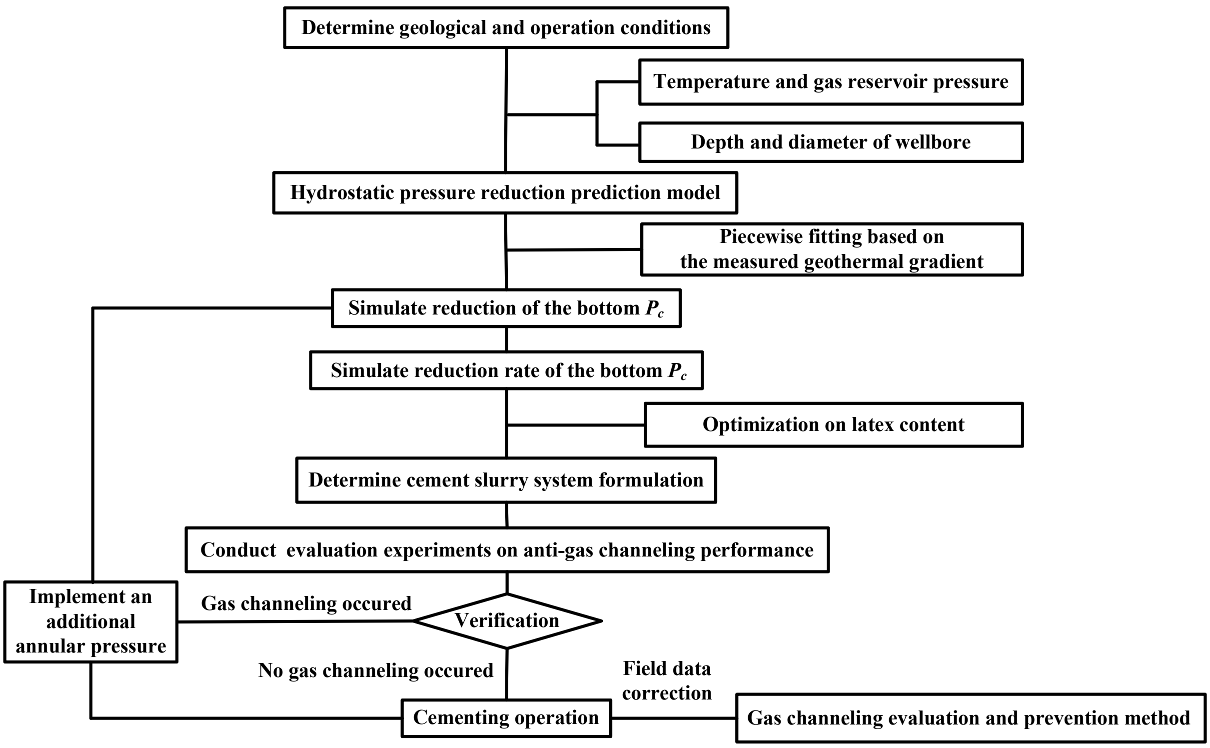

Figure 5. *Flowchart of the gas channeling performance evaluation and prevention method.*

(1) Determine the value ranges of C_{latex}, P_g, the wellbore condition and the formation T and establish an SAL cement slurry pressure reduction prediction model that conforms to the actual geological and operation conditions;
(2) Based on the prediction model and the measured geothermal gradient, perform a piecewise fitting to the pressure during cement slurry weight loss and calculate the reduction of the bottom P_c of the cement slurry and the Rs at various stages under various C_{latex} conditions;
(3) Optimize C_{latex} based on the calculation results obtained in Step (2) to improve the rheological properties of the cement slurry and reduce the Rs at the initial and middle stages (a C_{latex} of 10–15% is recommended for the conditions of the experiment conducted in this study);
(4) Determine the ratios of the admixture and additive in the cement slurry system based on the C_{latex} determined in Step (3) and conduct an experiment to evaluate the anti-gas channeling performance of the cement slurry system using the pressure conduction measuring system [21];
(5) During waiting on cementing, implement an additional annular pressure to make up the hydrostatic pressure reduction. This measure is for high-pressure gas reservoirs whose pressure cannot be effectively stabilized based on the experimental results obtained in Step (4) as well as the loss of the P_c of the cement slurry calculated in Step (3);
(6) Modify the gas channeling performance evaluation and prevention method by validation with the after-effects and correction with the field data.

5. Conclusions and Suggestions

In this study, based on an anti-gas channeling SAL cement slurry pressure reduction prediction model, a sensitivity analysis pertaining to formation T, P_g, the geometric parameter of the wellbore and C_{latex} was conducted, and the pattern of weight loss of a cement slurry system was examined. The conclusions derived from this study are summarized as follows:

(1) R is an important parameter characterizing the hydrostatic pressure reduction of cement slurry. Reducing the R of cement slurry at each stage can ensure that the cement slurry has ample time to form a gelled network structure with sufficient strength. Under this condition, even if the ultimate P_c of the cement slurry is far lower than P_g, a sufficient gas channeling resistance will still be formed inside the cement slurry, thereby reducing the risk of early gas channeling.
(2) T and L were found to be significantly positively correlated with the R of the cement slurry, and T was the main factor affecting the R of the cement slurry. Thus, when fitting the liquid column pressure of a cement slurry in a long, sealed section, it is necessary to first divide the section into multiple subsections based on the geothermal gradient, fit each subsection individually and then superpose the liquid column pressures of the subsections to ensure calculation accuracy.
(3) P_g and C_{latex} were found to be negatively correlated with the R of the cement slurry. A relatively high P_g and C_{latex} can, to a certain extent, alleviate the downward movement trend of the cement slurry caused by volume contraction during the hydration process. At the late stage of the weight loss process of the cement slurry, the latex can improve the anti-gas channeling performance of the cement slurry by further shrinking gas channels.
(4) When wellbore and formation conditions are impossible to improve, it is possible to optimize C_{latex} to reduce the R of the cement slurry. This measure, together with an anti-gas channeling performance evaluation experiment and an annular pressure application process, can further improve the anti-gas channeling performance of the cement slurry.
(5) It is necessary to further modify and improve the anti-gas channeling performance evaluation method based on field data.

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