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Simulation Study on Characteristics of Gas Combustion and Explosion in Pipeline

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***Abstract*—In view of the flame retardant of gas flame in pipelines, the important topic of coal mine safety field, this paper firstly collected the state parameters of the gas flame through field test, and then used the Fluent software to simulate the state of the gas combustion explosion. By comparing the simulation results with the field test results, the error was within a reasonable range. In this way, we obtain the convincing data of characteristics of gas combustion and explosion, and find a simulation model that can replace the field test. All of these can provide more reference for research in the field of coal mine safety.**

Keyword—pipeline; fluent; parameter determination; computer simulation experiment

I. INTRODUCTION

In the process of coal mining, a large amount of gas is generated in the underground coal seam, and the gas is usually pumped and transported by pipes to obtain better economic benefits. However, in the process of gas transportation, if there are unexpected factors such as open flames or lightning strikes, the gas may be ignited or even explode, which may affect the entire pipeline system, causing huge economic losses and a large number of casualties. Therefore, the flame retardant of gas flame has become an important research topic in the safety of coal mines today[1,2,3].

The premise of effectively preventing the gas flame is to understand the characteristics of gas combustion and explosion in the pipeline. In recent years, there have been some reports on this aspect of research, but most of the existing research is carried out through field tests[4]. However, field tests are often costly, and data from field tests are less convincing because of error factors[5].

In view of the above factors, this paper first conducts field tests on the combustion and explosion of methane in the pipeline, and then simulates it with Fluent software. Through the comparison between the field test results and the simulation results, the accuracy of the selected turbulence model and combustion model in the simulation is determined, and the simulation results are used to verify the field test results.

II. FIELD TEST SYSTEM AND SIMULATION MODELING

A. *Data Acquisition System for Field Test of Methane Combustion*

The field test system in the study includes: pipeline system, gas distribution system, information acquisition system, and ignition system. Figure 1 is a schematic diagram of the piping system.

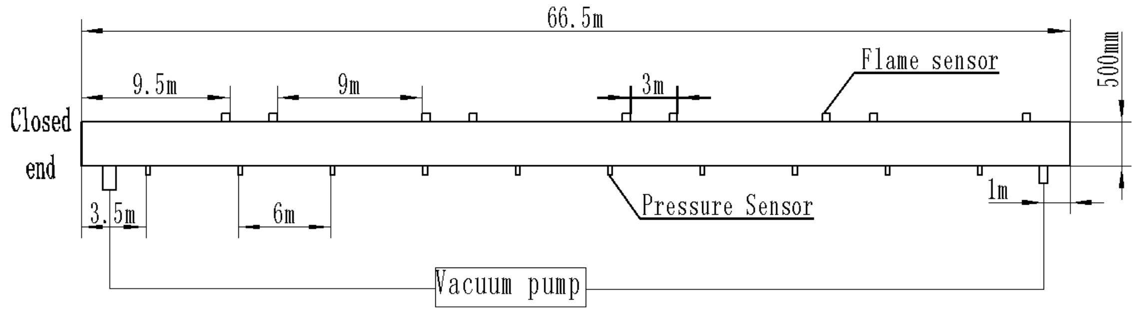

FIGURE I. SCHEMATIC DIAGRAM OF THE PIPING SYSTEM

Select a circular stainless steel pipe with a diameter of 500 mm, the pipe length is 66.5 m, and the pipe wall thickness is 20 mm. The left end of the pipeline is closed, and the right end outlet of the pipeline is closed by two layers of PVC plastic film with a thickness of 0.12 mm. Five sets of flame sensors are installed in the pipeline, each consisting of two, with a distribution distance of 3m. The first set of flame sensors are laid at 9.5 m and 12.5 m from the left end of the pipe, and then each group is separated by 9 m in sequence, and the signal change at the arrangement point is detected by the sensor to obtain the time when the flame reaches the arrangement point.

Starting from the left end of the pipeline at a distance of 3.5m, 10 pressure sensors are installed in the pipeline. The sensors are separated by 6m, and the pressure change over time can be detected at each arrangement point. In the test, the spark was ignited at a distance of 3.5 m from the left end of the pipe, and the ignition energy was 375 mJ. The pipeline is filled with the methane-air mixture gas with a concentration of 10%, and a vacuum pump circulation system is used as a stirring device to uniformly mix the mixed gas in the pipe. We use electronic ignition to ignite the mixed gas in the pipeline and record individual sensor data.

B. Simulation Model of Methane Detonation in Empty Pipeline

Due to the large diameter and length of the pipeline in the study, and also considering the premise factors such as simulation accuracy, calculation amount and application, the paper uses the RNG k-e turbulence model and the general finite-rate combustion model in Fluent 15.0 software to simulate the detonation of the combustible gas in the coal pipeline.

A 3D pipeline simulation model is established based on the pipeline system of the field test, as shown in Figure 2.2. In the model, the ignition area is marked 3.5m from the left end of the pipeline, and the right end of the model is open. According to the position of the flame sensor and the pressure sensor in the field test, the corresponding flame detection points and pressure detection points are respectively marked in the model, as shown in Figure 2 and Figure 3, in order to detect the flame parameters at these points during the simulation.

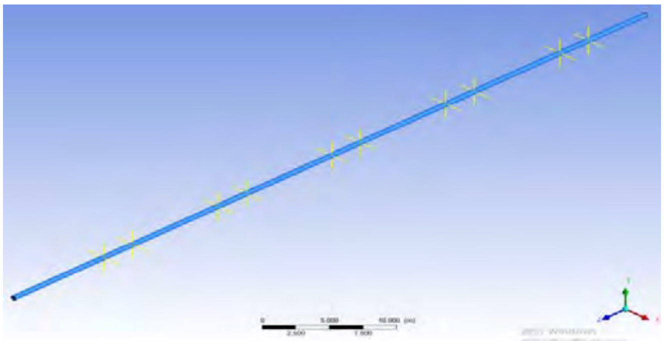

FIGURE II. DISTRIBUTION OF FLAME DETECTING POINTS

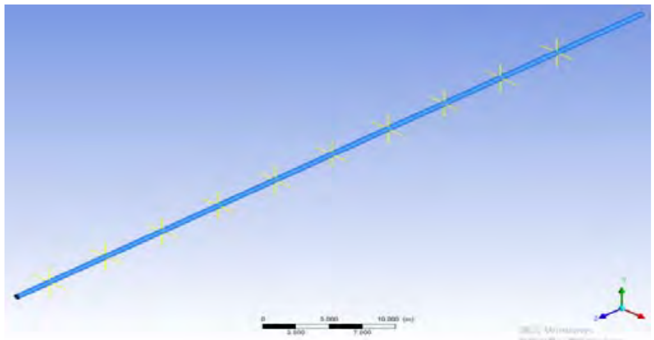

FIGURE III. DISTRIBUTION OF PRESSURE DETECTING POINTS

III. COMPARATIVE ANALYSIS OF SIMULATION RESULTS AND FIELD TEST RESULTS

A. Field Test Results

Due to the instability of the explosion and the limitations of the test conditions, the test results inevitably have errors. Therefore, we have done a total of five sets of field tests of combustion and explosion to ensure the accuracy of the data. The average value of the test results in the five groups is shown in the Table 1 and Table 2.

In the simulation, the flame sensor records the arrival time of the flame at each detecting point, as shown in Table 2. Then we can calculate the average velocity of flame propagation between adjacent sensors, that is, the propagation velocity of the flame in each interval section of the pipeline, as shown in Table 3.

TABLE I. PRESSURE PEAK AND ITS PRESENTATION TIME

Location of detecting points[m]	3.5	9.5	15.5	21.5	27.5	33.5	39.5	45.5	51.5	57.5
Pressure[MPa]	1.27	1.32	1.28	1.26	1.22	1.19	1.18	1.16	1.20	1.29
Time[ms]	166	147	152	166	188	195	195	193	210	202

TABLE II. ARRIVAL TIME OF FLAME AT EACH DETECTING POINT

Location of detecting points[m]	9.5	12.5	21.5	24.5	33.5	36.5	45.5	48.5	57.5	60.5
Time[ms]	147	150	156	160	180	188	192	195	202	204

TABLE III. FLAME SPEED IN EACH INTERVAL SECTION OF PIPELINE

Interval[m]	9.5-12.5	12.5-21.5	21.5-24.5	24.5-33.5	33.5-36.5	36.5-45.5	45.5-48.5	48.5-57.5	57.5-60.5
Velocity of flame[m/s]	373	400	395	390	382	385	377	388	613

B. Simulation Results

According to the mark of the detection point in Figure 2, the variation trend of temperature over time at ten detecting points is shown in Figure 4. Thus, the arrival time of flame at each detecting point can be obtained, which is shown in Table 4. From the data in the table, the average velocity of flame propagation between the two neighboring detecting points can be calculated, as shown in Table 5.

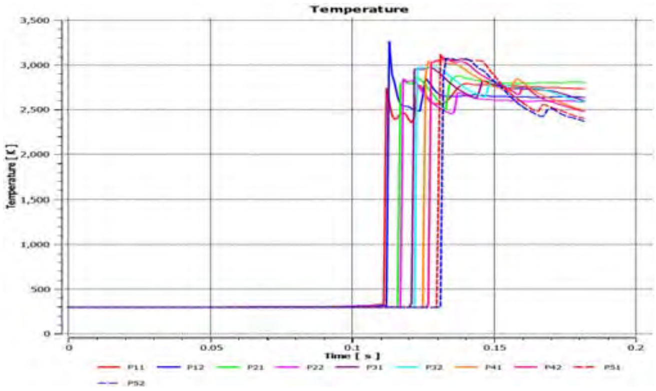

FIGURE IV. VARIATION TREND OF TEMPERATURE OVER TIME AT TEN DETECTING POINTS

According to the location of the detection point marked in Figure 3, ten detecting points are defined from left to right as P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, and the variation trend of pressure over time at ten detecting points is shown in Figure 5. The pressure peaks at each detecting point are read from the Figure 5 and shown in Table 6.

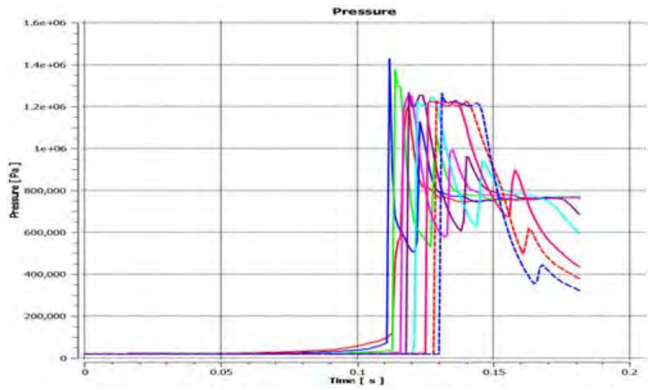

FIGURE V. VARIATION TREND OF PRESSURE OVER TIME AT DETECTING POINTS

TABLE IV. ARRIVAL TIME OF THE FLAME AT EACH DETECTING POINT

Location of detecting points[m]	9.5	12.5	21.5	24.5	33.5	36.5	45.5	48.5	57.5	60.5
Time[ms]	111	112	115	116	121	122	124	126	130	131

TABLE V. FLAME SPEED IN EACH INTERVAL SECTION OF PIPELINE

Interval[m]	9.5-12.5	12.5-21.5	21.5-24.5	24.5-33.5	33.5-36.5	36.5-45.5	45.5-48.5	48.5-57.5	57.5-60.5
Velocity of flame[m/s]	397	430	395	390	375	374	365	368	580

TABLE VI. CHECKPOINT PRESSURE PEAK AND ITS PRESENTATION TIME

Location of detecting points[m]	3.5	9.5	15.5	21.5	27.5	33.5	39.5	45.5	51.5	57.5
Pressure[MPa]	1.2	1.42	1.38	1.25	1.26	1.24	1.24	1.23	1.23	1.25
Time[ms]	118	111	113	118	122	126	126	125	135	130

C. Comparative Analysis of Results

Comparing the field test results with the simulation results, the comparison results are shown in Figure 6 and Figure 7.

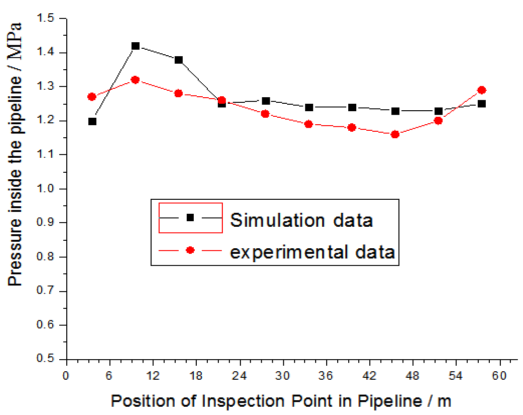

FIGURE VI. COMPARISON OF FIELD TEST PRESSURE AND SIMULATED PRESSURE

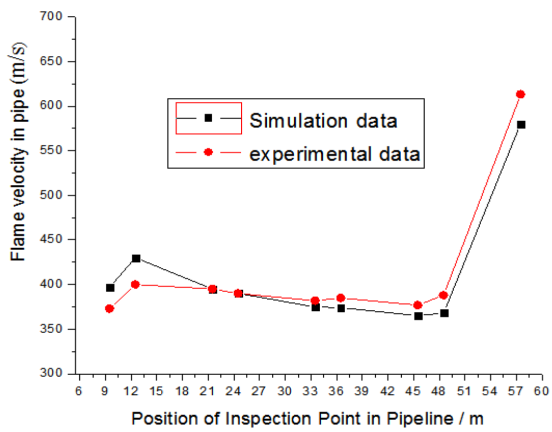

FIGURE VII. COMPARISON OF FIELD TEST VELOCITY AND SIMULATED VELOCITY

It can be seen from Figure 6 that starting from the inlet end of the pipeline at a distance of 9.5m, the pressure of the flame in the pipeline slowly decreases with the increase of the length of the pipeline, and gradually becomes smoother. However, at the outlet end of the pipeline, the flame pressure increases due to the sealing of the plastic film. Comparing the simulation data with the field test results, the average error of the ten groups of data was 4.23%, of which the error at 9.5m was the largest, 7.57%; the simulation data and the field test results showed the same trend.

It can be seen from Figure 7 that in the initial stage of flame propagation, the flame velocity in the pipeline fluctuates greatly. After 21.5m, the velocity inside the pipeline tends to be stable, basically stable at about 380m/s. At the outlet end of the pipeline, the flame propagation speed rises rapidly; Simulation data and field test results, the average error of the nine groups of data is 4.09%, the maximum error exists at 12.5m, which is 7.14%; the trend of simulation data is basically the same as the field test. In summary, through the comparative analysis of simulation data and field test results, the detonation combustion simulation model selected in this paper is feasible.

IV. Conclusion

The field test of methane detonation was carried out in empty pipeline, and the parameters of the selected RNG k-e turbulence model and the general finite-rate combustion model in the Fluent 15.0 software were determined according to the field test data, and the error is controlled within the allowable range to make the selected model reasonable. Therefore, the subsequent research and design can be performed by a computer simulation instead of a methane detonation field test.

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