

Experimental Study on Leakage Pressure Drop of Simulated Airport Oil Supply Pipe Network

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Abstract: In order to simulate and study the change of pressure drop after the leakage of airport oil supply pipeline network, a set of simulation system of airport oil supply pipeline network leakage was built. The tightness of the system was tested based on the medium kerosene. The accuracy of the calculation model was verified quantitatively and qualitatively, and the leakage pressure drop calculation model under pressure and temperature was established. The results show that the tightness of the test system is good. Under the condition that the pressure remains unchanged, the leakage pressure difference decreases with the increase of temperature, which is consistent with the theory. The coefficient of determination of the data obtained from the test data and the calculation model can reach 0.9947, and the root mean square error can reach 0.0007075, with good accuracy.

Keywords: Airport pipe network, Leakage, Pressure drop.

1. Introduction

Due to the advantages of low cost, energy saving, high safety and stable supply, pipeline transportation is widely used in large and medium-sized airports at home and abroad. However, due to long-term operation corrosion and wear, equipment aging and natural disasters, leakage accidents of airport oil supply pipe network occur from time to time. On the one hand, the leakage of kerosene will cause the waste of resources, on the other hand, the leakage of kerosene in the open fire is prone to explosion accident, a serious threat to people's safety. Therefore, it is very important to study the pipe network to close the valve in time to avoid further damage when leakage occurs.

During the pipeline construction process, a cut-off valve is set to cut off leaks by identifying transmitted pressure drop signals. In view of the research on leakage pressure drop, Liao Yupeng et al. artificially studied the pressure drop rate of gas storage gas production trunk, established the pipeline leakage model by using simulation software, and obtained the influence of the volume, compression ratio, and the distance between the valve chamber and the compressor on the pressure drop and duration of the valve chamber under the condition of compressor pumping. Yang Yi et al. established a gas pipeline leakage simulation model through simulation software, and obtained the relationship between pressure drop and duration of cut-off valve in valve chamber downstream of leakage point. Huang Wen et al. studied the pressure drop characteristics of aviation kerosene in a U-tube under supercritical condition, and proposed a frictional drag

coefficient correlation formula modified by pressure and temperature, with a relative error of about 6.5%.

To sum up, leakage pressure drop is mainly concentrated in long-distance gas transmission pipeline research, and because of the complexity of field tests, simulation software is often used to simulate. In order to study the change of leakage pressure drop of airport oil supply pipe network, this paper built a set of simulation of leakage pressure drop of airport oil supply pipe network. Based on the reliability of data and the accuracy of calculation model, the change of leakage pressure drop under different temperature and pressure states was studied.

2. Test System

The structure of the experimental system is shown in Figure 1. The test liquid uses No.3 jet fuel. The whole experimental device is mainly composed of six parts: main pipeline module, pressurization module, temperature control module, leakage control and measurement module, data measurement and acquisition module, and data analysis and storage module. Test system of pressurized module and temperature control module is used to adjust and control the pressure and temperature of main line, when the pressure and temperature of test condition, adjust the leakage control and measurement module, real time measuring the actual leakage of kerosene in the subject line, data measurement and real-time acquisition module will kerosene in the subject line of pressure and temperature signal transmission to the data analysis and storage module, The theoretical leakage is obtained by calculation.

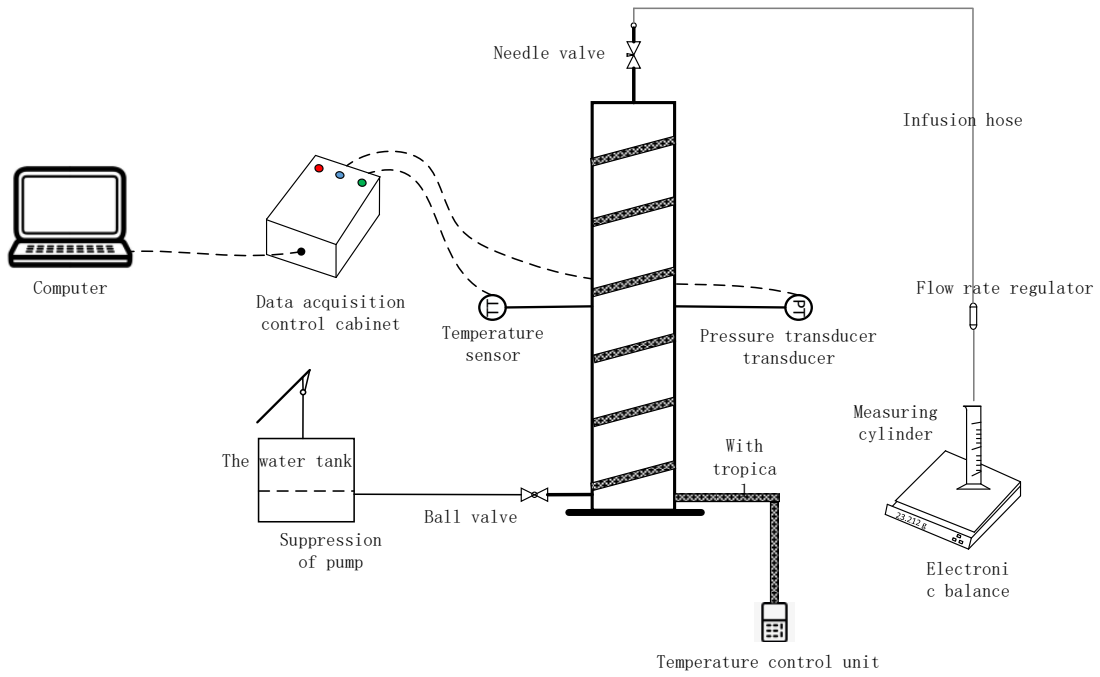


Figure 1. Process diagram of the test system

2.1. Main Pipe module

The main pipeline module is composed of stainless steel tank, ball valve and needle valve. The tank is composed of stainless steel with wall thickness of 3 mm, inner diameter of 213 mm and pipe length of 1.8 m. As a leakage detection unit, it simulates the airport oil supply pipeline. Ball valves (DN40 mm) and needle valves (DN15 mm) are connected to the tank to control the inflow and outflow of fluid.

2.2. Booster Module

The pressurization module is a high-pressure pressure pump device, which is connected with the ball valve at the bottom of the pipeline to pressurize the pipeline.

2.3. Temperature control module

The temperature control module adopts the automatic tracking belt with length of 10 m and power of 80 W/m, which is used to simulate the field temperature. The temperature range can be achieved from room temperature to 50°C.

2.4. Leakage control and measurement module

The leakage control and measurement module is composed of leakage hose, measuring cylinder and electronic balance, which is used to control and measure the leakage amount of real fluid. The leak hose includes an infusion hose and a flow rate regulator. The measuring range of the cylinder is 100 mL±1. The range of electronic balance (FA2204C) is 0-200 g, and the accuracy is 0.1 mg.

2.5. Data measurement and collection module

The data measurement and acquisition module is composed of pressure sensor, temperature sensor, data acquisition control cabinet and computer. The range of pressure sensor is 0-2 MPa, and the accuracy is 0.2. Temperature sensor in the range of 0-100 °C, the precision for grade A + (0.15 + 0.002 | t) °C. The data collection control cabinet encapsulates serial port I/O networking modules and power supplies.

2.6. Data Analysis and Storage Module

The data analysis and storage module is composed of OPCServer, PNS and MySQL database. OPCServer communicates with the data acquisition facility. PNS connects to OPCServer through OPC protocol and publishes data based on OPCServer for real-time analysis. At the same time, the analysis results are stored in the MySQL database.

3. Kerosene Leakage Rate Model

Based on the principle of mass conservation, when the tank is sealed, the total mass of the unit medium in the constant volume tank can be expressed as a function of temperature and pressure:

$$W = V\rho(P, T) \quad (1)$$

The total mass of the element medium is differentiated in time, and the change of the total mass of the element medium is:

$$\frac{dW}{dt} = \frac{d(V\rho)}{dt} = \frac{Vd\rho}{dt}$$

$$\delta W = V \int_0^\tau \frac{d\rho}{dt} dt = V(\rho_\tau - \rho_0) \quad (2)$$

$$\Delta W = V\rho(P_\tau, T_\tau) - V\rho(P_0, T_0)$$

Therefore, in the leakage process, the leakage rate of the unit medium in τ time can be expressed as follows.

$$Q_i = \frac{\delta W}{W} = \frac{V \int_0^\tau \frac{d\rho}{dt} dt}{V\rho_0} = 3.6 \times 10^6 \frac{\rho(P_\tau, T_\tau) - \rho(P_0, T_0)}{\rho(P_0, T_0)\tau}, \quad L/(h\gamma m^3) \quad (3)$$

Where, W is the total mass of unit medium, kg; V is unit

volume, m³; ρ is the average density of unit medium, kg/m³; P is the average pressure of unit medium, MPa; T is the average temperature of unit medium, °C; τ is the detection time, s.

4. Kerosene Closed Experiment

4.1. Measurement of kerosene density

Petroleum densitometer and constant temperature water bath device were used to measure the standard density of kerosene. The experimental steps were as follows:

(1) Start the constant temperature water bath device and adjust its temperature to 20°C;

(2) Put kerosene into the measuring cylinder, gently put it into the constant temperature water bath box, and stand for 5 minutes to make it reach thermal balance with the temperature of the water tank;

(3) Put the glass petroleum densitometer gently into the measuring cylinder and read after it is stable.

The multiple measurement data are shown in Table 1, and the average value of all the data is 776.9 kg/m³.

Table 1. Standard density measurement data

The number of	First time	Second time	Third time	Fourth time	Fifth time
Density / kg/m ³	776.2	775.0	777.5	778.3	777.4

Based on the standard density of kerosene ρ_{20} , based on the calculation method of No. 3 aviation kerosene volume temperature correction coefficient C_{tl}, dynamic measurement of petroleum and liquid petroleum products, and oil volume pressure correction coefficient C_{pl}, the density calculation model of kerosene can be obtained, and the model can be used to calculate the kerosene density at other temperatures and pressures. Corroborate the reliability of the test data.

4.2. Kerosene tightness test

In order to prevent leakage in the simulation system, the

density calculation model mentioned above was used in the test to study the pressure changes with the detection time in four different temperature ranges: 14.6-16.6 °C, 16.7-18.5 °C, 18.5-20.1 °C and 20.0-21.9 °C.

5. Kerosene Leakage Test

In order to analyze the reliability and rationality of the experimental data, the law analysis is carried out according to the theoretical model.

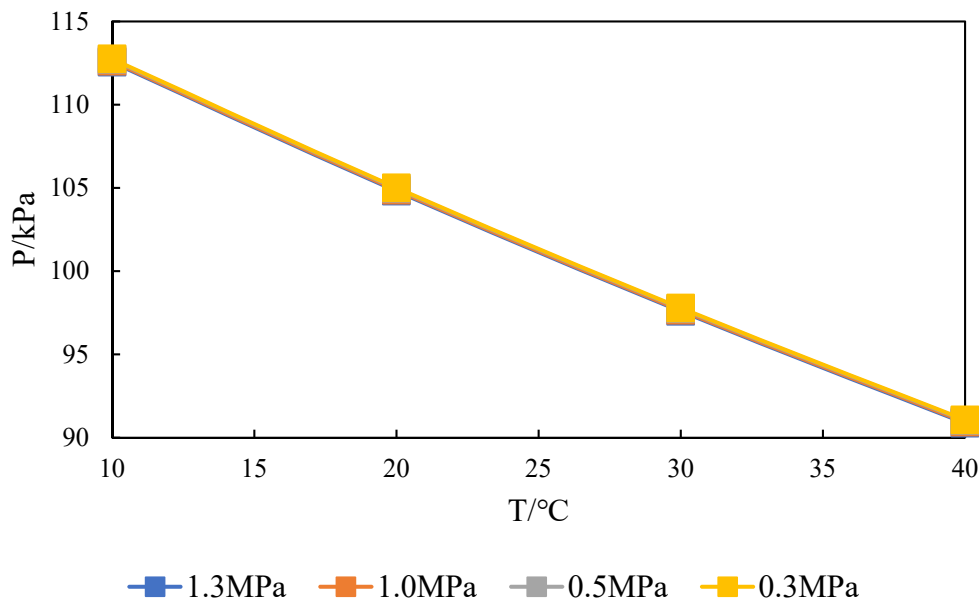


Figure 2. Theoretical values of 1-hour leakage pressure difference with temperature at 0.1 L/h/m³ leakage rate under different initial pressures

FIG. 2 shows the theoretical value of 1-hour leakage pressure difference with temperature for 0.1 L/h/m³ leakage rate under different initial pressures. As can be seen from the figure, under the condition that the pressure remains unchanged, the leakage pressure difference gradually decreases as the temperature increases. Under the condition that the temperature remains unchanged, the leakage pressure difference has a small change with the increase of pressure. This law is mainly caused by low compressibility and high thermal expansion of kerosene and other liquid fuels.

Then, the leakage pressure difference under different leakage duration at 0.1 L/h/m³ leakage rate was tested, and

the relationship between the theoretical leakage pressure difference and the experimental leakage pressure difference was compared.

5.1. Kerosene sealing test results and analysis

Under four different conditions, the pressure changes of each 1 °C change in temperature are 0.581 MPa/°C, 0.562 MPa/°C, 0.552 MPa/°C and 0.531 MPa/°C, respectively. As can be seen from the figure: with the increase of the detection time, the temperature and pressure will show the same growth trend; As the temperature range increases, the pressure variation will gradually decrease.

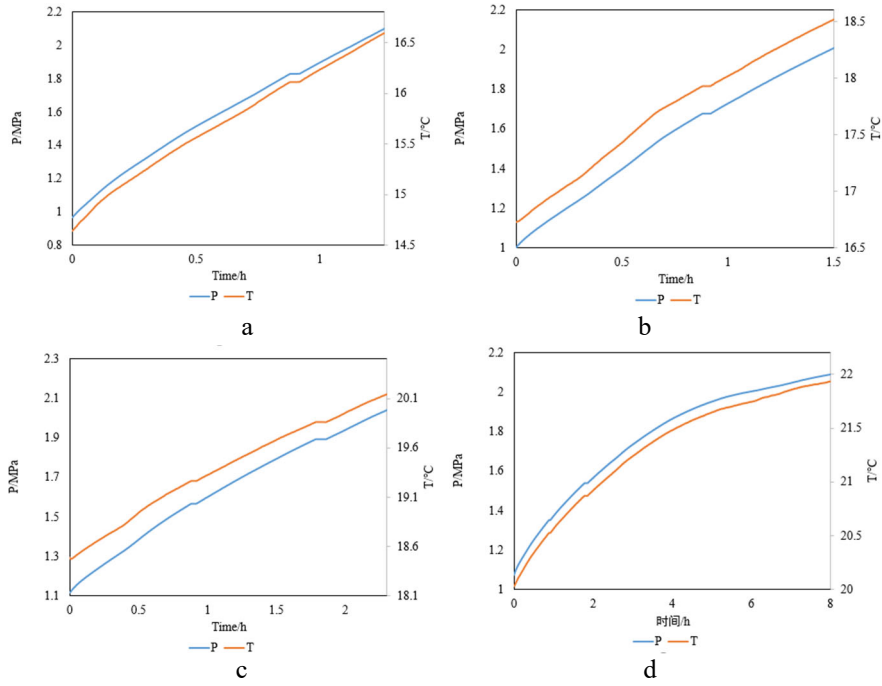


Figure 3. The relationship between temperature and pressure in different temperature ranges

Will be four different temperature range of kerosene density changes in the data statistics as shown in the table 2, it can be seen from the table that the temperature range, the greater the kerosene calculation error, the greater the density

model, when the temperature constant, the density model to calculate minimum error, also illustrates the system tightness is good, in the case of temperature changes smaller, kerosene density model accuracy of calculation is reliable.

Table 2. Calculation results of closed experimental data of kerosene density model

Range of temperature variation /°C	The initial density	The end of the density	Density difference	Leak rate
14.6	16.6	781.8266	781.2606	0.566
16.7	18.5	780.2289	779.5984	0.631
18.5	20.1	778.9228	778.1833	0.739
20.0	21.9	777.6955	776.8442	0.851

5.2. Kerosene leakage test results and analysis

It can be seen from Table 3 and Figure 4 below that the

leakage pressure difference is basically in direct proportion to the leakage duration when the pressure and temperature remain unchanged within the range of one hour.

Table 3. Leakage pressure difference data under different leakage duration at 0.1 L/h/m³ leakage rate

The temperature /°C	Pressure /MPa	Leakage pressure difference at different times /MPa			
		10 min	20 min	30 min	60 min
10	1.3	0.0187	0.0374	0.0562	0.11256
	1	0.0187	0.0374	0.0562	0.11261
	0.5	0.0187	0.0375	0.0563	0.11271
	0.3	0.0187	0.0375	0.0563	0.11275
20	1.3	0.0174	0.0348	0.0523	0.104806
	1	0.0174	0.0349	0.0523	0.104866
	0.5	0.0174	0.0349	0.0524	0.104966
	0.3	0.0174	0.0349	0.0524	0.105006
30	1.3	0.0162	0.0325	0.0487	0.097589
	1	0.0162	0.0325	0.0487	0.097649
	0.5	0.0162	0.0325	0.0488	0.097749
	0.3	0.0162	0.0325	0.0488	0.097789
40	1.3	0.0151	0.0303	0.0454	0.090868
	1	0.0151	0.0303	0.0454	0.090928
	0.5	0.0151	0.0303	0.0454	0.091028
	0.3	0.0151	0.0303	0.0455	0.091068

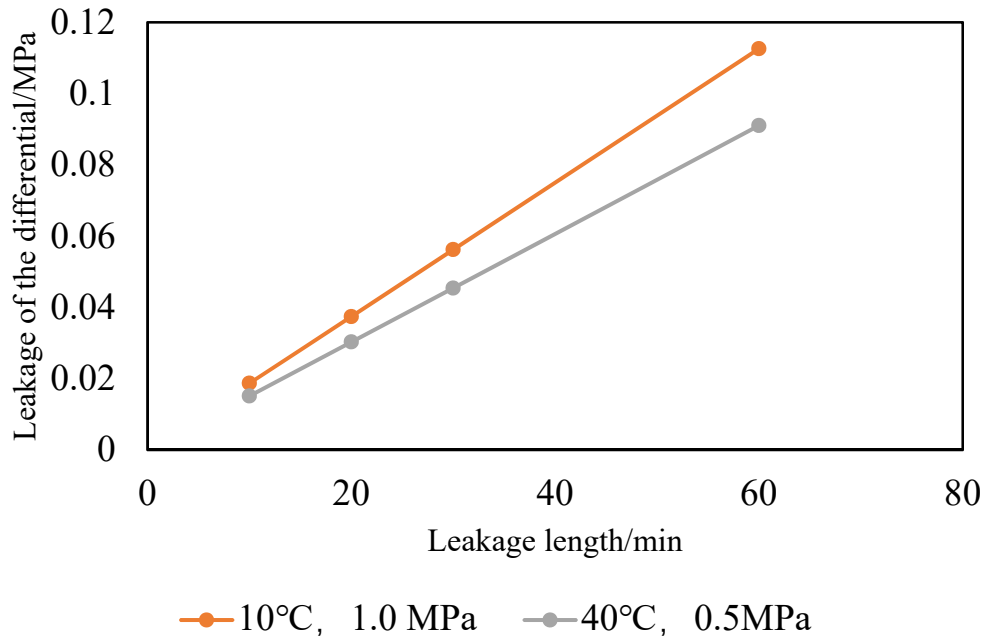


Figure 4. Positive ratio between leakage pressure difference and leakage duration (taking 10°C,1.0 MPa, 40°C,0.5 MPa as an example)

For the leakage process of airport pipe network, the 1-hour leakage of 1 m³ volume of oil is 0.1L, and the leakage under the experimental system is only 6.42ml, and its value decreases with the shortening of the leakage time, so it is difficult to measure or the measurement error is greater. Therefore, the leakage test data were analyzed by the 1-hour leakage duration, and the leakage pressure difference under

other leakage durations was obtained by proportional conversion. In order to reduce errors, the data of the three groups of repeated leakage experiments were sorted out, and the mean value was taken as the final experimental data (see Table 4), which was compared and analyzed with the theoretical data.

Table 4. Experimental data of aviation kerosene leakage (orthogonal table of pressure and temperature)

	0.1 L/h/m ³ 1 h Leakage of pressure drop	Absolute pressure /MPa			
		0.445	0.7	1	1.3
Temperature /°C	10	0.072725	0.072696	0.081500	0.091814
	14	0.065892	0.065133	0.072812	0.078351
	17	0.063321	0.062626	0.069082	0.073016
	18	0.062732	0.062152	0.067773	0.071849
	21	0.061222	0.061569	0.067117	0.070051
	23	0.059894	0.061091	0.065185	0.067534
	28	0.059494	0.060063	0.064290	0.067227
	30	0.054480	0.057279	0.062575	0.066203
	32	0.053910	0.057045	0.061802	0.064287
	34	0.052180	0.055520	0.060410	0.062136
	36	0.050825	0.054849	0.058960	0.060752
	38	0.047930	0.054140	0.056765	0.057684
	40	0.047763	0.051849	0.053728	0.057439

Qualitative analysis: As can be seen from FIG. 5, when the pressure remains unchanged, the leakage pressure difference decreases with the increase of temperature, and its regularity is consistent with the theory. Under the condition that the

temperature remains unchanged, the leakage pressure difference increases with the increase of pressure, and the variation range is larger than the theoretical value.

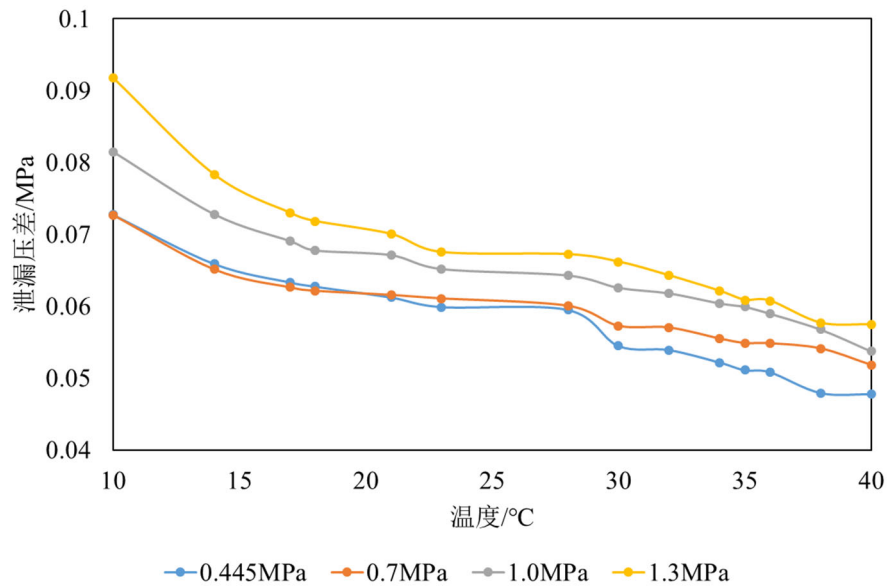


Figure 5. Variation of leakage pressure difference with temperature under different pressures

Quantitative analysis: the theoretical value corresponding to Table 4 was calculated by using the model (see Table 5), and the deviation was obtained by comparing with the experimental data. Its average absolute deviation is 0.0378

MPa, the maximum deviation is 0.044474 MPa (temperature 17°C, pressure 0.7MPa), the minimum deviation is 0.020686 MPa (temperature 10°C, pressure 1.3 MPa)

Table 5. Calculation data of aviation kerosene leakage model (orthogonal table of pressure and temperature)

	0.1 L/h/m ³ 1 h Leakage of pressure drop	Absolute pressure /MPa			
		0.445	0.7	1	1.3
Temperature /°C	10	0.112600	0.112600	0.112500	0.112500
	14	0.109500	0.109400	0.109400	0.109300
	17	0.107200	0.107100	0.107000	0.107000
	18	0.106400	0.106300	0.106300	0.106200
	21	0.104100	0.104100	0.104000	0.104000
	23	0.102700	0.102600	0.102600	0.102500
	28	0.099100	0.099000	0.099000	0.098900
	30	0.097700	0.097600	0.097600	0.097500
	32	0.096300	0.096300	0.096200	0.096100
	34	0.094900	0.094900	0.094800	0.094800
	36	0.093600	0.093500	0.093500	0.093400
	38	0.092300	0.092200	0.092200	0.092100
	40	0.091000	0.090900	0.090900	0.090800

Through the fitting of table data and comparative analysis, the final fitting result is shown in Equation (4), and the fitting index calculated is: R²=0.9947, RMSE=0.0007075.

$$f(x, y) = 0.1799 - 0.2458x - 9.656 \times 10^{-3}y + 0.329x^2 + 4.337 \times 10^{-3}xy + 4.526 \times 10^{-4}y^2 - 0.1072x^3 - 0.01017x^2y + 1.819 \times 10^{-4}xy^2 - 1.263 \times 10^{-5}y^3 + 2.923 \times 10^{-3}x^3y + 2.705 \times 10^{-5}x^2y^2 - 2.686 \times 10^{-6}xy^3 + 1.263 \times 10^{-7}y^4 \quad (4)$$

6. Summary

In this paper, the relationship between density change and leakage pressure difference of No.3 jet kerosene in the simulation system and leakage time is studied through experiments, and the influence law of temperature and pressure on leakage pressure drop is obtained.

(1) The larger the range of temperature variation, the larger the error of kerosene density model calculation. When the temperature remains constant, the smaller the error of density model calculation.

(2) Within 1 hour, under the condition that the pressure and

temperature remain unchanged, the leakage pressure difference of the system is basically in positive proportion to the leakage time.

(3) Under the condition that the pressure remains unchanged, the leakage pressure difference decreases with the increase of temperature, which is consistent with the theory; Under the condition that the temperature remains unchanged, the leakage pressure difference increases with the increase of pressure, and the variation range is larger than the theoretical value. When the temperature is in the range of 10-40 °C and the pressure is in the range of 0.445-1.3 MPa, the average error between the calculated value of the model and the experimental data is 0.0378 MPa, the maximum deviation is 0.044474 MPa, and the minimum deviation is 0.020686 MPa.

(4) Comparing the data obtained from the leakage pressure drop calculation model established according to pressure and temperature with the test data, the coefficient of determination can reach 0.9947, and the root mean square error can reach 0.0007075.

References

- [1] Huang Tengfei, Chen Qiuling. Micro-leakage detection system of apron pipe network based on simulation technology [J]. Oil & Gas Storage and Transportation, 2013, 32(09): 982-985.
- [2] WANG Jia. Research on Leakage Detection System of Airport Oil Supply Pipe Network [D]. Xi'an Shiyu University, 2014.
- [3] Liu Hongfei, Song Shiguo, Wang Xuefeng, Su Huai, Leng Xue, Yu Weichao, Liu Mengya. Aviation oil pollution problems in storage and transportation system and the measures to prevent and control [J]. Journal of modern chemical industry, ploydy of 2022 (7) : 1647-1650. The DOI: 10.13840 / j.carol carroll nki cn21-1457 / tq. 2022.07.038.
- [4] QIN Yifeng. Discussion on Electrostatic Hazards and Protection of Jet Fuel [J]. China Petroleum & Chemical Standards & Quality, 2011, 31(12): 264.
- [5] Liao Yupeng, Jia Wenlong, Zhao Wenjia, Wen Chuanxian. Research on Pressure drop Rate of gas storage injection and Production Line under pumping condition of Reciprocating Compressor [J]. Pipeline Technology and Equipment, 2021 (04): 1-5.
- [6] Liao Yupeng, Jia Wenlong, Zhao Wenjia, Wen Chuanxian. Research on Pressure drop Rate of gas storage injection and Production Line under pumping condition of Reciprocating Compressor [J]. Pipeline Technology and Equipment, 2021(04): 1-5.
- [7] Huang Wen, Deng Hongwu, Xu Guoqiang, Zhu Kun. Supercritical pressure aviation kerosene u-shaped tube pressure drop characteristics [J]. Journal of air power, 2011, 26 (3) : 582-587. The DOI: 10.13224 / j.carol carroll nki jasp. 2011.03.037.
- [8] GB/T 9109.5-2017, Dynamic Measurement of petroleum and liquid petroleum products Part 5: Oil quantity calculation [S].