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The mechanical plugging technology research based on the leakage of hazardous pipeline

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ABSTRACT

Through the mode and state mathematical model of pipeline leak and dynamics model of hazardous pipeline are established by the leakage mechanism and form of hazardous pipeline, in the same time the computational fluid dynamics Simulation of fluid in pipeline and the flow and pressure states theoretical assess of leak location of pipeline are finished, we can obtain the relation between the leakage average total pressure and the change of hole size of leakage, and the situation of average pressure radical change of aperture leak, these put forward specific performance indicators to the design of the plugging device. Then a mechanical interior plugging based on pipeline leak of poison gas is designed, the research including the degree of difficulty of the operation of the apparatus, plugging pressure, response time, the performance of interior plugging gasbag etc, and the verification of plugging effect of interior plugging device are completed. Finally the nuclear framework of method library of hazardous emergency plugging is accomplished, this provide important technical support for safety of enterprise production and normal running of fluid delivery system

KEYWORDS

Leakage and plugging; Pipeline interior plugging; Method library of plugging; CFD; ANSYS.

INTRODUCTION

In the process of industrial production, pipeline and pressure-vessel usually storing Large amounts of toxic, hazardous, flammable and explosive hazardous chemicals are broken ordinarily by the aging of equipment and man-made destruction, this can lead to malfunction. So the hazardous leakage mechanism and technology of emergency plugging need urgent research, effective plugging equipment could be used to emergency processing to reduce or eliminate the significant harm caused by the accident, when hazardous leak[1-3].

The causes and influencing factors of the leakage of hazardous pipeline are analyzed to determine the principal leaking part and the mathematical model of leaking modes and states, and to establish the dynamics model of hazardous pipeline. Through the fluid and pressure state of leak location of pipeline are theoretically assessed by CFD dynamic simulation of fluid pipeline, the specific performance indicators of the design of plugging device are presented[4-6].

In this passage, a quick interior plugging device and plugging method that is used to solve the leakage of hazardous pipeline is presented. This is a new quick and effective plugging device that is produced to solve the problem that the low efficiency of plugging device is difficult to adapt to the complex operation mode and specific leak states. When hazardous pipeline breaks, cracks or holes leak, the method of interior plugging adding a new means for emergency processing of leakage of hazardous is the main plugging method. Secondly the experiment system used for plugging by device is researched, and experiment platform of composite plugging of straight nozzle and elbow holes leakage is developed. The experiment of interior plugging device and it's improved device is accomplished on experiment platform, and there are some useful experiment conclusions. The plugging performances of plugging device are verified by conducting finite element analysis for the plugging device and the coplanar contact problem of pipeline. Finally core architecture of emergency plugging method library of hazardous is proposed by inducing the multiple emergency plugging technologies of leakage of hazardous and the application of method library, this provides important basis for emergency processing of hazardous leakage[7].

THE LEAKAGE MECHANISM OF HAZARDOUS PIPELINE

The causes and influencing factors of hazardous pipeline leakage.

The causes of pipeline leakage

- Causes of design: congenital defects in the design can be created by having the problem of seal structure and sealing material of pipeline.
- Causes of machining: the influences are caused by machining accuracy, surface famishments and the technology of welding and expend tubes machining.
- Causes of installation: leakage is directly influenced by the installation of pipeline.
- Causes of the sealing material: sealing performance of sealing installation would be worse caused to improper selection of sealing material.
- Causes of pipeline corrosion created by medium: the metallic pipeline will leak caused to the corrosively of hazardous medium.
- Causes of harsh operation mode: the pressure and temperature of hazardous medium are harsh.
- Causes of large loss of medium leakage: the production of hazardous are generally continuous, when it leak, the minor consequence that product loss and the serious consequence that production stop are caused. Major accident will be caused by the leakage of combustible, explosive and toxic medium[5,8].

The main influencing factors of leakage rate of pipeline

The main factors of leakage rate of leakage surface are researched. The flow of fluid in the gap of the interface can be regarded as the flow that occur between the parallel plane, this can be knew from the hydrodynamics that the causes of the small gap and low speed can make flow be considered by laminar flow characteristics. The leakage rate can be calculated by formula (1).

$$Q = \frac{9.6\pi h^3 \cdot \Delta p}{13.9\eta \lg(r_2 / r_1)} \times 10^4 \quad \textbf{(1)}$$

Annotation: Q is the leakage rate of medium (cm^3/s), h is the size of gap (cm), $\triangle p$ is the pressure difference between inside an outside of the equipment (MPa), η is the viscosity of medium (Pa), r_1 is the flange ID (cm),r_2 is the flange OD (cm).

From this, the size of gap, the pressure difference of inside and outside, and the viscosity of medium are influencing factors of the leakage surface in the static joint surface.

The specific influencing factors: the gap of joint surface, the viscosity of leakage medium, the pressure difference of the inside and outside of equipment, the temperature of external environment condition, the seal length of stuffing, the property of seal material, the eccentricity of hole axis, jerk factor etc.

The mathematical model of leakage of hazardous pipeline

The flow of gas along the pipeline can be divided into isothermal flow and adiabatic flow. Isothermal flow apply to the no adiabatic pipeline having constant temperature, and adiabatic flow apply to the adiabatic pipeline. The actual flow is somewhere in between. To adiabatic flow, with the flow of fluid, the flow velocity of fluid increases due to the declining pressure converted into kinetic energy[9]. The mathematical model about mass flow rate of gaseous leakage of hazardous pipeline is shown in formula (2).

$$G_m = \sqrt{\frac{2rM}{R_g(r-1)} \cdot \frac{T_2 - T_1}{(T_1/p_1)^2 - (T_2/p_2)^2}} \qquad \textbf{(2)}$$

Annotation: p_1 is the interior pressure of pipeline (Pa), p_2 is the environment pressure of leakage location (Pa), G_{m} is mass flow rate of unit area (kg/(m^2·s)), T_1 is the interior temperature of pipeline (K), T_2 is the temperature of leakage location (K).

The hydro dynamical model and CFD analytical method

Follow the law of conservation of mass, the basic control model of pipeline hydrodynamics is shown in the formula (3).

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \qquad \textbf{(3)}$$

Annotation: ρ is density (kg/m^3), t is time (s), u,v,w are three weights of velocity vector in rectangular axis (m/s).

Follow the law of conservation of mass, the momentum control model of three direction x,y,z can be Figured out,this is shown in formula (4).

$$\begin{cases} \dfrac{\partial(\rho u)}{\partial t} + div(\rho u \bar{u}) = -\dfrac{\partial p}{\partial x} + \dfrac{\partial \tau_{xy}}{\partial x} + \dfrac{\partial \tau_{yz}}{\partial y} + \dfrac{\partial \tau_{zx}}{\partial z} + F_x \\ \dfrac{\partial(\rho u)}{\partial t} + div(\rho v \bar{u}) = -\dfrac{\partial p}{\partial x} + \dfrac{\partial \tau_{xy}}{\partial x} + \dfrac{\partial \tau_{yz}}{\partial y} + \dfrac{\partial \tau_{zx}}{\partial z} + F_y \\ \dfrac{\partial(\rho u)}{\partial t} + div(\rho w \bar{u}) = -\dfrac{\partial p}{\partial x} + \dfrac{\partial \tau_{xy}}{\partial x} + \dfrac{\partial \tau_{yz}}{\partial y} + \dfrac{\partial \tau_{zx}}{\partial z} + F_z \end{cases} \qquad \textbf{(4)}$$

Annotation: τ_{xy},τ_{yz},τ_{zx} are the weights of viscous stress, effecting in the micro unit due to th*e* molecular viscous effect (MPa), F_x, F_y, F_z are physical power of the micro unit (N)(If weight only has gravity, and z-axis is vertically upward, F_x =0, F_y =0, F_z=0), p is the pressure of micro unit of fluid.

Follow the law of conservation of mass, energy control formula Figured out is shown in formula (5)[10-11].

$$\frac{\partial(\rho T)}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = \frac{\partial}{\partial x}\left(\frac{k}{c_p}\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{k}{c_p}\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{k}{c_p}\frac{\partial T}{\partial z}\right) + S_T \qquad \textbf{(5)}$$

Annotation: T is the temperature (℃), c_p is the specific heat capacity (J/kg·℃),S_T is the viscous dissipation (J/kg),k is the heat transfer coefficient of fluid[12].

The passage mainly analyses the circular leakage hole of horizontal crooked part of pipeline[13]. The solving steps of CFD shown in Figure 1. The analysis program of pipeline fluid is shown in Figure 2.

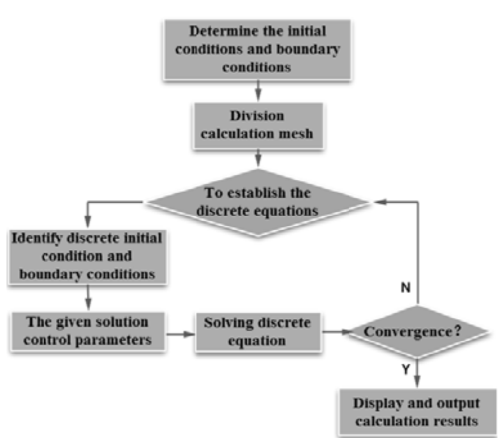

Figure 1 : CFD solving process diagram

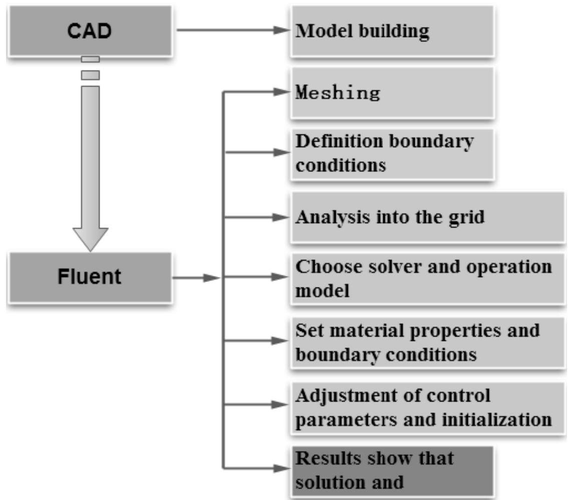

Figure 2 : Pipeline fluid simulation procedure block diagram

SIMULATION ANALYSIS OF LEAKAGE STATE OF HAZARDOUS PIPELINE.

The simulation model of leakage state

Simplified model of straight elbow leak[7,14-16], it is shown in Figure 3, the analysis model of FLUENT fluid is shown in Figure 4.

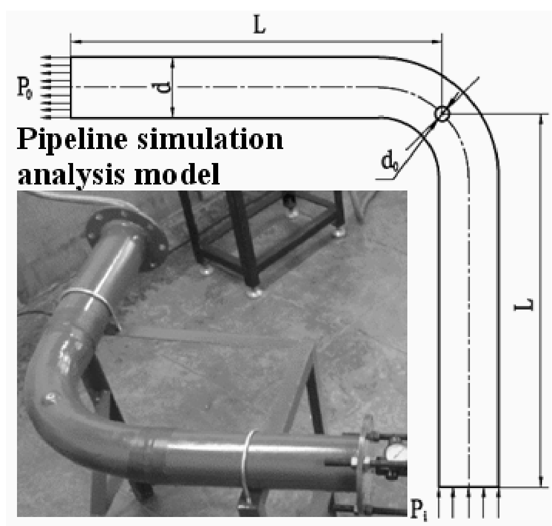

Figure 3 : Simulation analysis model

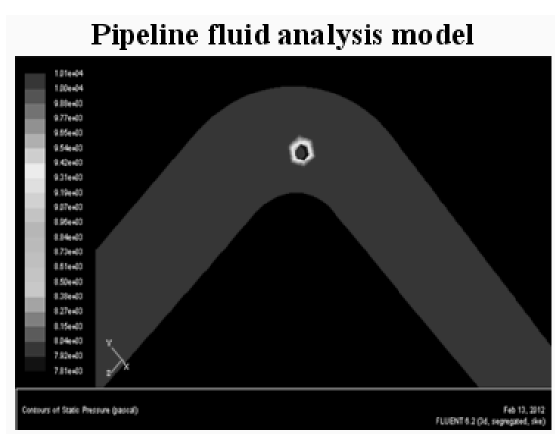

Figure 4 : The fluid analysis model

The analysis of simulation results

Initial conditions: d=120mm, L_0=1600mm,L=800mm. The simulation only for leakage to load effect limited situation, in particular pipe connection condition, to determine the inlet pressure values: p_i=[0.1,0.2,0.3,0.4,0.5,0.6]MPa. The simulation parameters set up in the Fluent are shown as follows: Material: Gas;Model-solver: unsteady; Operating conditions: 100000; Solver: segregated; Formulation: implicit; Space: 3D; Time: steady; Velocity Formulation: Absolute[11,17-18].

When L=800mm, hole diameters d_0=20mm,d_0=16mm,the leakage pressure change along pipeline and the pressure change along holes are simulation analyzed in the case of inlet pressure p_i=0.4MPa, and residual error picture is drawn by some iterative computations. The results of simulation analysis are shown in Figure 5. and Figure 6. The other pictures of simulation are omitted.

The highest and lowest pressure can be summarized by analysis picture, the highest and lowest pressure of leakage hole, the average total pressure of leakage hole is pa. when inlet pressure p_i is 0.4MPa, the relationship between average total pressure of leakage hole and size of leakage hole is shown in TABLE 1. Obviously when the sizes of hole are different, the change of average pressure of hole leakage is less than 0.93%,but the change between highest pressure and lowest pressure is obvious in the hole. When the pressures of main pipeline are different, the change of average pressure of hole leakage is obvious, change will increases with the inlet pressure increases. The accuracy of model is high due to the changes of various stages of residual error picture are well-distributed.

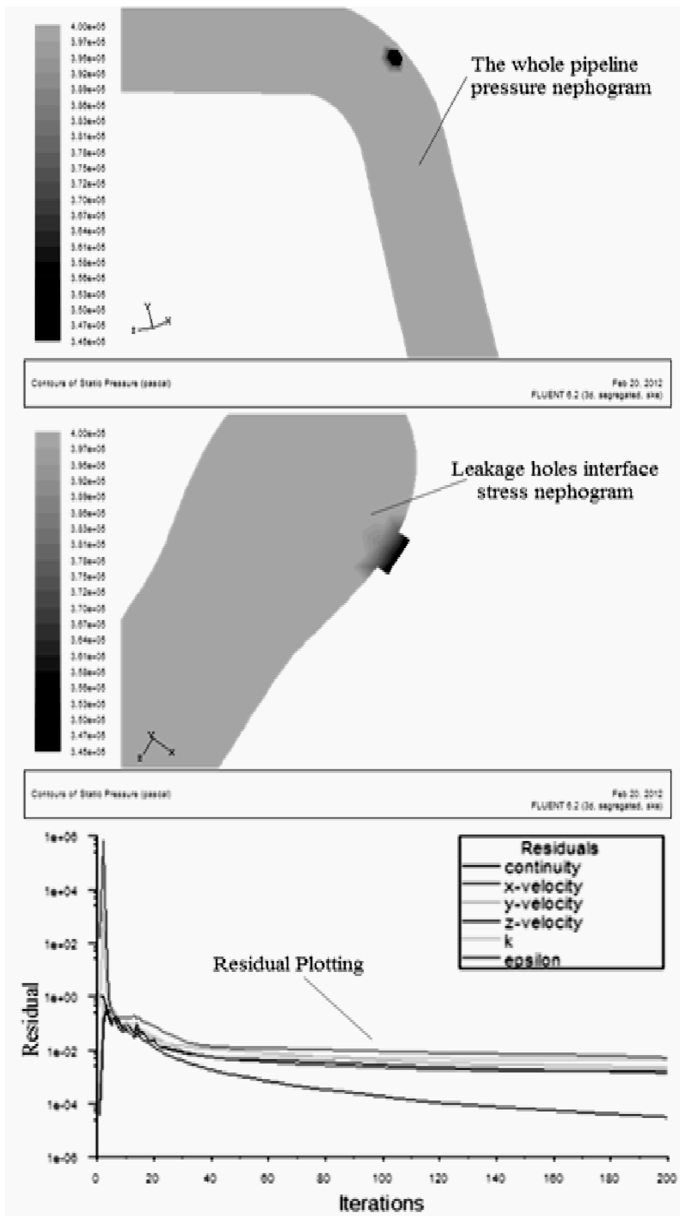

Figure 5 : d_0=20mm, p_i=0.4MPa,Leakage hole simulation analysis

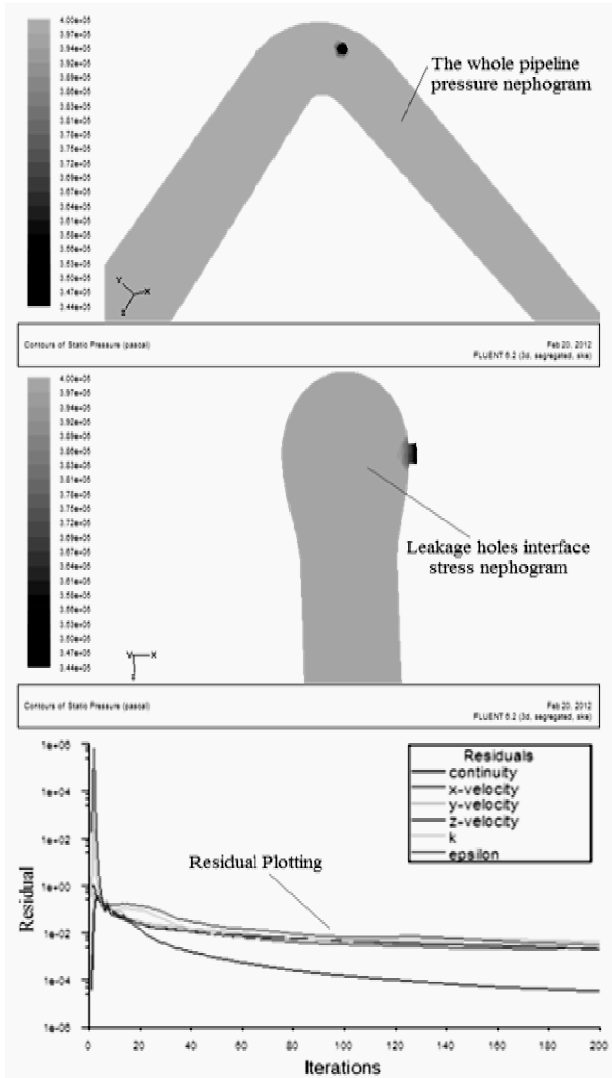

Figure 6 : d_0=16mm, p_i=0.4MPa,Leakage hole simulation analysis

TABLE 1 : The relationship between the average total pressure of leakage hole and the size of hole (p_i=0.4MPa)

Pressure(Pa) Leakage aperture (mm)	The iteration number(n)	The highest pressure of hole (Pa)	The lowest pressure of hole (Pa)	The average pressure of hole (Pa)
20	200	4.00e+05	3.45e+05	3.725e+05
16	200	4.00e+05	3.41e+05	3.705e+05

THE PIPELINE INTERIOR PLUGGING MECHANISM OF HAZARDOUS LEAKAGE

The pipeline interior plugging device can quickly seal when hazardous pipeline breaks, cracks and holes leak. It's structure is made up by sealing organization, diversion organization, holding organization and fixing organization. Sealing organization consists of plugging airbag. Diversion organization consists of diversion pipeline nozzle, diversion ball valve and gasket, and diversion pipeline nozzle can connect diversion pipeline. Holding organization consists of hollow axle sleeve with gas-charging connection on its left surface. Fixing organization consists of the airbag clamping sleeve and conical flange cover. In the part of material selection, the material of plugging airbag is acrylonitrile-butadiene rubber also called Butadiene-acrylonitrile rubber which has the excellent characteristics of oil resistance, wear resistance, heat resistance, strong adhesive force, high elasticity, strong seismic performance and good sealing effect. Other structures of plugging device are made by high-strength duralumin (LY12) which is a aluminum alloy having strength of super-strength steel. The structure and physical picture of interior plugging device are shown in Figure 7.

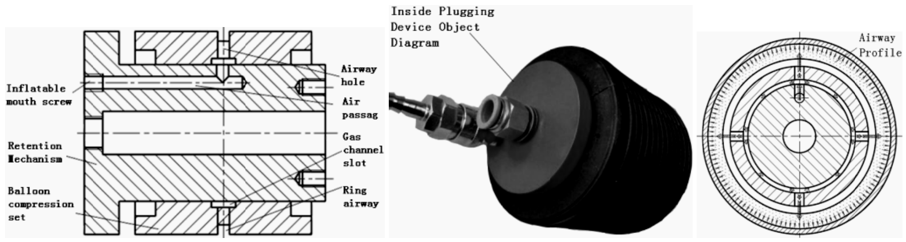

Figure 7 : The structure and physical picture of interior plugging device

When we use interior leakage plugging diversion airbag of hazardous pipeline to plugging, first, the sealing organization, the diversion organization, the holding organization and the fixing organization fixed together, secondary, the diversion pipeline nozzle connect the diversion pipeline, and gas-charging nozzle connect the gas-charging pipeline, then, the interior plugging airbag is put into hazardous pipeline, once again, gas-charging pipeline inflates plugging airbag by opening the diversion ball valve, at last, hazardous pipeline is quickly plugged by closing the diversion ball valve. The diversion ball valve will be opened when diversion is necessary. Plugging airbag having strong adaptability can adapt to the pipeline of a certain even more larger diameter, because it like rubber tire.

THE FINITE ELEMENT ANALYSIS OF SURFACE CONTRACT

The pipeline leakage experimental system

The experimental schematic diagram of dangerous source of pipeline leak shown in Figure 8.Leakage medium can be a gas or a liquid, the main leakage form is pipeline leakage. We use the self-developed blocking air bag device. In the experimental process mainly records the experimental data after plug the pipeline gas leakage, then analysis and handle the collected experimental data. Finally verify sealing performance of the plugging device. The controlling flow chart of the pipeline leak experiment system shown in Figure 9.

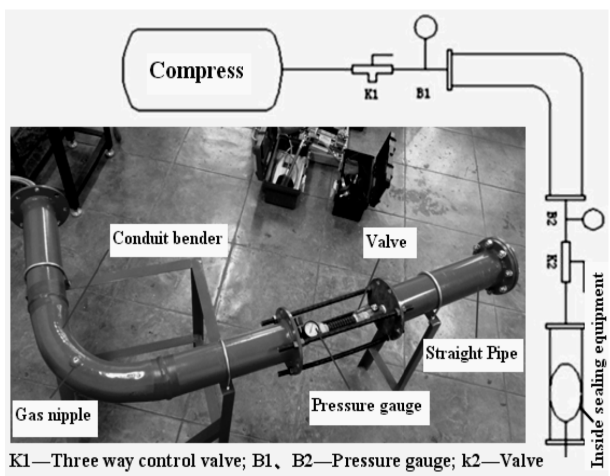

Figure 8 : Schematic of the experimental system

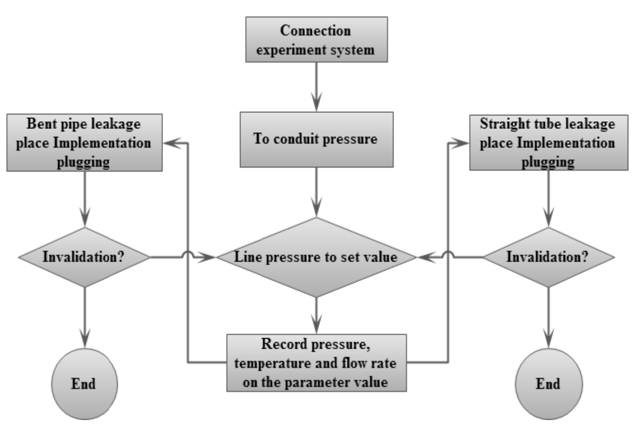

Figure 9 : The structure and physical picture of interior plugging device

Pipeline plugging experiment

Before improving experimental conclusion

Determine the suction temperature is 9.4 ℃. The part date of inside plugging experimental determination shown in TABLE 2.

TABLE 2 : Sealed plugging test data sheet

Name / Serial number	The main pipeline pressure(MPa) (Artificial regulation)	Internal straight pipe pressure(MPa)	Sampling time(s)
1	0.014	0	30
2	0.024	0.050	30
18	0.435	0.425	180
26	0.625	0.619	250
30	0.725	0.714	300
31	0.750	Failure	23

Through the experimental data in TABLE 2,pressure extreme value of the inner plugging device which can plug pipe is 0.75 MPa, actual plugging pressure is 0.70 MPa. When the straight pipe pressure value is maximize 0.75 MPa, plugging will failure.

Improved measures

The sealing rubber balloon sleeve of internal plugging device has been improved, which makes its original size increase the length of 20 mm, makes the total length of gland cover by the original 90 mm increase to 110 mm; external round ring of airbag increases to 18 ring (the original one be 13 ring); the diameter of hollow shaft end cover has increased from 76 mm to 100 mm. According to the above experimental steps to make the further experiment, measurement data sheet was shown as in TABLE 3.

TABLE 3 : The experimental data table of improvement in plugging

Name / Serial number	Main pipeline pressure(MPa) (Artificial regulation)	Internal straight pipe pressure(MPa)	Sampling time(s)
1	0.014	0.000	30
2	0.024	0.050	30
10	0.425	0.425	30
20	0.675	0.672	250
31	0.975	0.975	300
35	1.175	1.126	400
36	1.180	Failure	33

The improved experiment conclusion

Plugging effect is quite obvious, the biggest plugging pressure almost increased by 45%, 1.175 MPa. Plugging device has no damage after fail. If air gasbag internal pressure rise to 0.5 MPa (it is under 0.35 MPa now), plugging pressure extreme value is likely to limit inflation pressure value of compressor. Improvement effect is obvious.

The plugging performance index of Pipeline plugging device

Improvement, Curve comparison about in plugging pressure as showing in Figure 10.

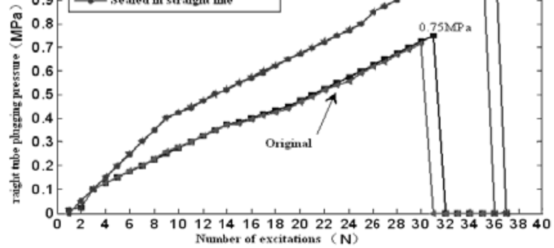

Figure 10 : Curve comparison about improvement in plugging pressure

Obviously showing, Failure case be clear at a glance, the advantage of sealing pressure is also very obvious. Before improving device, the main pipe pressure and plugging straight pipe pressure shows saline change, appearing plugging was unstable phenomenon from 0.4 MPa after that, but the failure process is stable; after improving, before the main pipe pressure reach 1.0 MPa, two curve almost completely coincide, describing that on the pressure range block off quite close and stability. Of course the improved than before improvement in extreme pressure in branch explain plugging pressure is higher, the safety factor that need to be installed should be the greater.

THE FINITE ELEMENT ANALYSIS OF THE PLUGGING DEVICE CONTACT PROBLEM.

Contact problem involved in two boundary surface is between rigid and soft body, which can set a boundary for the target surface (rigid surface), another boundary for interface (flexible surface). The contact between target surface and interface is aspects to contact.

Choosing the face of the applied load and apply pressure load, pick up value 0.2 MPa, 0.35 MPa and 0.45 MPa respectively and proceed with finite element analysis. Set the load of the limited time is 250. As 0.2 Mpa pressure load for example, after the solving arithmetic, get analysis pattern of inflatable rubber sleeve shown in Figure 11, as shown in the diagram has marked the graphic definition and characteristics.

According to Figure 11, on condition that to load 0.2 MPa, we can get maximal stress value is 1.65 MPa, and which is located in the middle of the rubber lining; the maximal displacement value is 30.901 mm. The experiment of 0.35 Mpa and 0.45 Mpa concluded pneumatic rubber sleeve have been able to meet tight sealed pipeline characteristic in the inflation pressure is less than 0.35 Mpa, completely plug pipe inner for 108 mm to 140 mm pipeline. So make sure the plugging inflation pressure of air sealing rubber sleeve is only average 0.35 MPa.

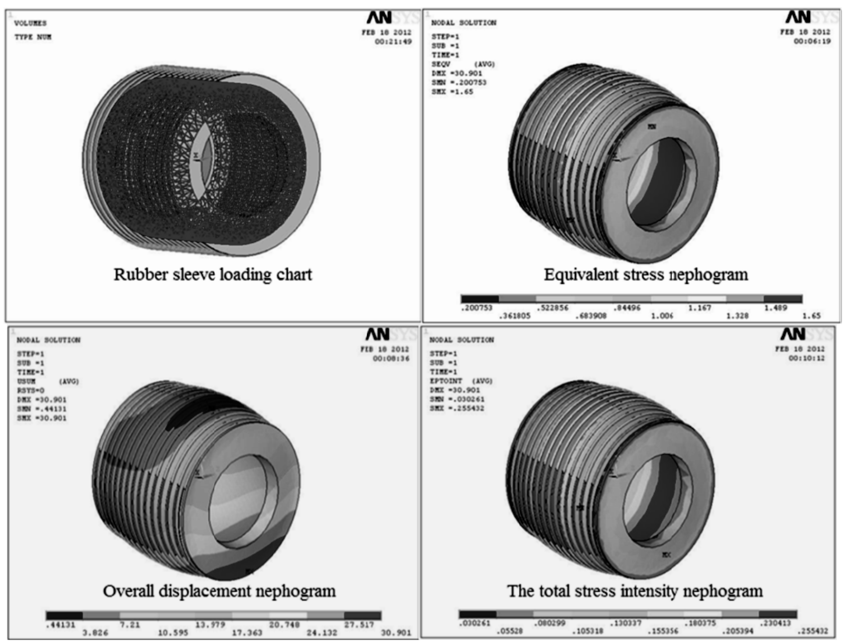

Figure 11 : Rubber sleeve ANSYS graphic analysis

THE GENERAL FRAMEWORK OF HAZARD LEAK EMERGENCY PLUGGING METHOD

Studying and establishing industrial major hazard leak emergency plugging method library can provide enterprises with disposal process data of urgent need hazards leak emergency, and has the vital significance to design emergency disposal database. Using client or Server structure (SQL Server software platform) sets up database system of hazard leakage emergency process disposal measure. The design frame diagram of emergency plugging method library shows in Figure 12.

In the leakage accident, first judge the type of leakage accident quickly and accurately and formulate corresponding rescue plan. With the progress of science and technology, the complication of plugging technology and the diversification of sealing equipment, the existing rescue training is difficult to train the related person systematically. But computer training have a lot of advantages in this respect which can use computer technology to create a vast hazard information base and plugging tool base, cartoon reflect key action of plugging process, which can reduce the amount of funds that used to buy a wide variety of plugging equipment for special rescue teams. Therefore, establishing the emergency plugging method library has very important practical significance.

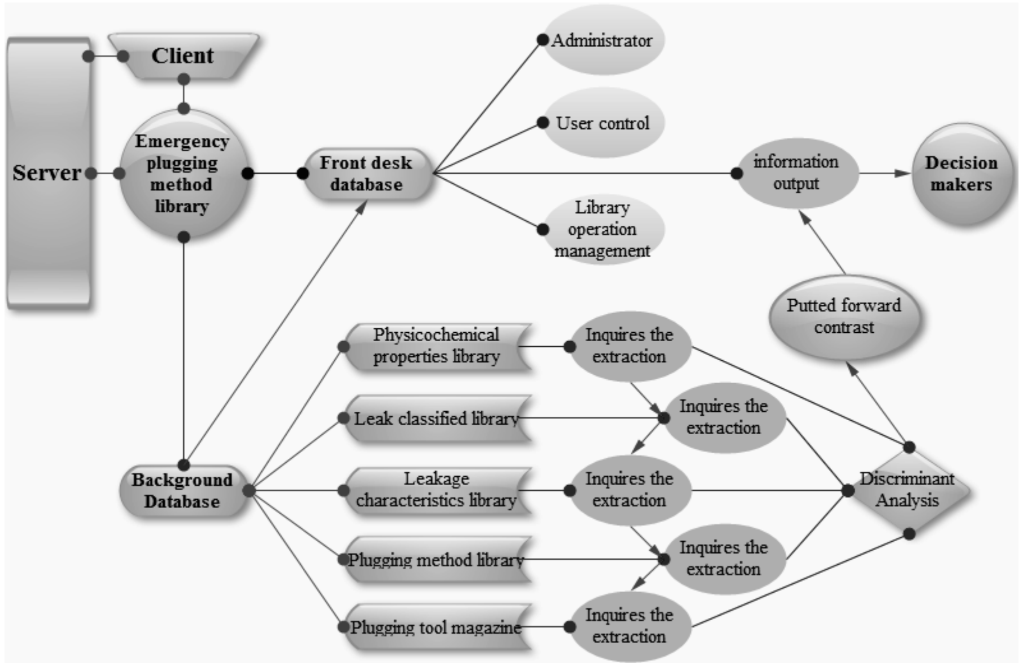

Figure 12 : The design frame diagram of emergency plugging method library

CONCLUSIONS

The breakthrough and innovation of this article embody the following aspects mainly:

Through CFD dynamics simulation of the pipeline fluid, putting forward the theoretical assessment of leakage flow and of leakage pressure state pipeline and storage tank in the hazard leakage process and getting the jump condition of leakage holes average pressure.

Based on the theory of rigid-soft body contact problem, put forward the sealed method of the hazard pipeline leakage which implement rapid plugging and invent "Risk source within the pipeline leak air sealing and its rapid plugging method", and get China's national invention patent (Authorized number: 201010562453.5).

We study plugging experiment system of hazard straight-bending nozzle leakage and test straight tube leakage plugging device and improving the sealing device that has been designed through the result of experiment. We get the finite element analysis conclusion of useful face-face contact problem.

It puts forward the architecture design thought of the emergency plugging method library when hazard leakage occurred and provides leaking accident emergency disposal with an important theoretical basis.

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