The local manager objective is monitoring of the node's CPU utilization, saves the historical monitoring, and reports the global manager about the state of machine, then send migration requests. Although the scalability limitation may exist, the overall scalability of the system is significantly improved compared to existing completely centralized and manual solution for the project. This work focused to avoid the overload on physical machines in cloud computing at a suitable time and maintaining the required quality of service without a violation. For the purpose of knowing the scope of this research and its importance, we would start to explain the technique of cloud computing, and then define the main problem of the research, as well as the questions posed about the problem.

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Miniaturization Design of Two-Component Grouting Pump with Small Grouting Fluctuation and Automatic Cleaning Function

SUN Zhi-jia[1], GUO Ming-qi[2], GUO Jin-zhan[3]

[1] College of Mechano-Electronic, Lanzhou University of Technology, Lanzhou 730050, China;
[2] Harbin Institute of Technolgy, Weihai, 264209, China;
[3]Beite Mining Equipment Co. Ltd., Jiaozuo 45400, China.

Corresponding author is SUN Zhi-jia

Abstract
Under special conditions, such as mine, an urgent demand on two-component chemical grouting pump, including structural miniaturization, grouting stabilization, and pipeline automatic cleaning, has been raised by chemical grouting construction. For this purpose, system optimization design was made for mine two-component chemical grouting pump. Firstly, the linkage type of slave cylinders and structure of pump were optimized to reduce grouting fluctuation and structure size. Secondly, the pipeline system with full-automatic cleaning function was constructed according to the characteristics of modern chemical grouting process. Lastly, grouting test for and service performance evaluation on underground sealing of gas drainage borehole were carried out for prototype. Results show that, as compared with similar conventional grouting pump, prototype nearly doubles the stable grouting pressure, reduces weight more than 3/4, makes gas extraction concentration 30% higher than the latter and solves the blocked pipeline cleaning problem. It would have a certain significance to improve mine safety.
Key words: TWO-COMPONENT GROUTING PUMP DESIGN, GROUTING FLUCTUATION, PERIOD-COMPLEMENT LINKAGE OF FOUR CYLINDERS, MINIATURIZATION, AUTOMATIC CLEANING FUNCTION

1. Introduction

The grouting pump can inject grouting materials into the specified location; as the key equipment of chemical grouting, it plays an important role in mining industry, water conservancy & tunnel construction and other fields. The two-component grouting pump (also referred to as double fluid grouting pump) is a kind of slave-cylinders reciprocating plunger pump, which can simultaneously mix and inject two kinds of different materials according to proportion. For its broad applicability on modern chemical grouting materials and good reliability, it has been widely used in modern chemical grouting construction. However, the existing two-component grouting pump cannot well adapt to the change of the technological characteristics of modern chemical grouting [1, 2, 3], resulting in some defects, such as grouting fluctuation, bulky structure, especially the problem of pipeline blockage [4, 5]. Therefore, the aforesaid problems demand prompt solutions to improve the applicability of two-component grouting pump on mine modern chemical grouting technology and construction site and further enhance mine safety.

Up to now, some researchers have carried out related researches and development regarding the professional two-component chemical grouting pump, aiming to adapt to new changes and characteristics of modern chemical grouting [6, 7]. LIAO Xiang-hui et al. carried out analysis and test on the grouting fluctuation of two-component plunger chemical grouting pump and its causes, and put out a method to alleviate and improve grouting fluctuation [8]; WU San-you et al. designed the plunger-type continuous draining slave hydraulic cylinder, based on which QZB18 grouting pump with three slave cylinders synchronous movement was developed to stabilize grouting fluctuation to a certain extent [9]; HGB series grouting pump with multiple slave cylinders of independent movement, researched and developed by DONG Jian-jun et al., could independently control the draining movement of each slave hydraulic cylinder, theoretically meeting the proportioning requirement of any grouting material [10]; both the two-slave-cylinder linkage HFV grouting pump of Japan and two-slave-cylinder linkage 2ZBYSB grouting pump of China adopt the design of slave cylinder independent movement to improve the applicable scope on grouting materials.

As found in the actual grouting construction, although the existing two-component grouting pump of slave-cylinders linkage stabilized the grouting fluctuation and improved the quality of the chemical grouting to a certain extent, the bulky structure and lack of automatic cleaning significantly affected the grouting quality and efficiency in some special grouting conditions, such as mine. In view of this, taking miniaturized mine two-component chemical grouting pump as research object, this paper concludes the pump structure design method of two-component chemical grouting pump with stability and miniaturization and the construction method of pipeline system with automatic cleaning function; further, this paper evaluates the comprehensive performance of the prototype through mine grouting test.

2. Design and analysis of conventional two-component chemical grouting pump

Modern chemical grouting usually needs to mix material A and B into the grouting fluid; at the technological forefront, the professional chemical grouting pump introduces slave-cylinders linkage to complete the extracting and mixing of two kinds of materials. As shown in Figure 1, slave-cylinders linkage coordinates with other parts or systems of the chemical grouting pump, such as the pipeline system, control system, pump power supply and mixing & grouting part, to complete the extracting, mixing and grouting of two-component materials.

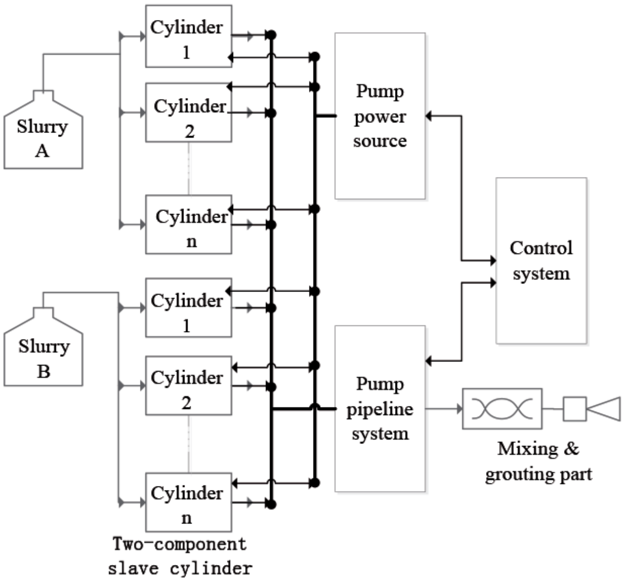


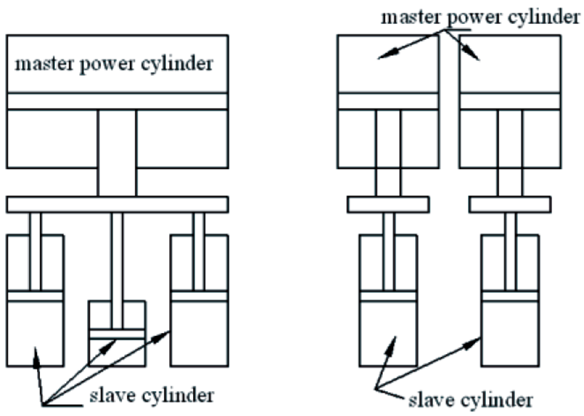
Figure 1. Diagram of working principle of chemical grouting pump with slave-cylinders-linkage

In consideration of mine construction environment and safety, pneumatic feature, miniaturization and lightweight are the development trends of mine construction equipment, especially the mine chemical grouting equipment. Therefore, this paper chooses pneumatic master cylinder as the power supply of the pump.

For the research and development of mine two-component chemical grouting pump, the design of slave-cylinders linkage and the construction of the pipeline system are its two main contents; the former needs to solve the problem of grouting fluctuation and miniaturization of the pump, while the latter needs to solve the cleaning after the pipeline blockage.

2.1. Slave hydraulic cylinder linkage and its analysis

Two sets of slave hydraulic cylinders of the two-component chemical grouting pump are respectively corresponding to slurry material A and B. Two cylinders extract the slurry materials under the action of power piston of the master cylinder, and inject them into the mixing part of the grouting pump through the pipeline system to produce the pre-grouting fluid. The linkage types of two groups of slave hydraulic cylinders include multi-cylinder synchronous movement and multi-cylinder separate movement. Multi-cylinder synchronous movement refers to that a master power cylinder drives all slave hydraulic cylinders to extract and drain the slurries synchronously. As shown in Figure 2a, three-cylinder linkage grouting pump adopts a master power cylinder to synchronously drive three slave hydraulic cylinders with different volumes, to realize the mixture ratio of 1:1 or 1:4 of two kinds of grouting materials. This linkage type and structure has the advantages of simple control, compact structure and accurate mixture ratio, but multi-cylinder synchronous movement intensifies the grouting pressure fluctuation and easily causes the damage of construction part and decline in the grouting quality.



(a) multi-cylinder synchronous movement (b) multi-cylinder separate movement

Figure 2. Schematic diagram of cooperation mode of slave cylinders of two-component chemical grouting pump

Multi-cylinder separate movement refers to that two or more master power cylinders respectively drive their own slave hydraulic cylinders to independently extract and drain the grouting slurries. As shown in Figure 2b, one master cylinder piston drives slave cylinder of fluid A and another master cylinder piston drives slave cylinder of fluid B; by the asynchronous collaboration of two master cylinders, it realizes the mixing proportion of two kinds of grouting materials. To some extent, this linkage type and structure meet the requirements of more chemical grouting materials and proportioning of grouting process, but the structure of pump with multiple master cylinders increases the overall size of the equipment and causes some difficulties to the construction of the control system, as well as the existence of the grouting pressure fluctuation.

Based on the above analysis, it can be concluded that in order to miniaturize the two-component chemical grouting pump with stable grouting, the number of master power cylinders should be reduced and the pump structure should be compacted; meanwhile, the asynchronous movement of slave hydraulic cylinder is needed to decrease the grouting fluctuation.

2.2. Analysis of the requirements for construction of pipeline system

Pipeline system of two-component chemical grouting pump is the connection part between the pump and the mixing & grouting part.

Under the command of the control system, the pipeline system will inject the materials from the pump to the mixing & grouting part of the grouting pump. Pipeline blockage is a problem urgently to be solved for the chemical grouting pump. The blocked pipeline system and pump will not only lead to the drop of the grouting pressure and flow and slurry proportioning imbalance to further affect the grouting quality, but also lead to the damage of grouting pump, grouting construction period delay, waste of grouting materials and other problems.

Currently, the pipeline blockage problem is solved only by manual dismantling & cleaning and chemical cleaning, which not only has the disadvantages of long construction period, high labor costs and environmental pollution, but also does not work under some special conditions, such as mine grouting; all of the aforesaid problems have seriously affected the construction quality and efficiency of chemical grouting.

Based on the above analysis, the construction of the pipeline system should not only satisfy the basic requirements of two-component grouting pump on slurry mixing and grouting; more importantly, it should be suitable for the process characteristics of chemical grouting under the working conditions of mine, so as to realize full-automatic & timely cleaning of the grouting pump.

3. The optimization of pump and pipeline system design

3.1. The optimization of new pump design and its influences on the grouting fluctuation

According to the measured data and simulation results of the hydraulic system, the fluctuation curve of grouting flow of single cylinder of the reciprocating plunger pump under the stable working condition can be regarded as a positive half sine wave with a cycle of motion [11]:

$$Q = 0.5FS\eta_v \left|\sin(\frac{\pi}{60}nT)\right| \quad (1)$$

Where Q is instantaneous flow of single-acting plunger pump, m^3/s, F is cross sectional area of pump cylinder, m^2, S is piston stroke, m, η_v is volume fraction, n is piston stroke speed, r/min, and T is time, s.

Generally, flow or pressure differential coefficient can be used to measure the fluctuation of grouting pump

$$\delta Q = \frac{Q_{max} - Q_{min}}{Q_m} \quad (2)$$

$$\delta P = 4\delta Q \quad (3)$$

Where δQ indicates flow fluctuation and δP indicates pressure fluctuation.

The fluctuation curve of grouting flow of single cylinder is shown in Figure. 3; $T_1 - T_2$ is corresponding to the slurry extracting cycle, in which the grouting flow becomes smaller gradually; $T_2 - T_3$ is corresponding to the slurry draining cycle, in which the grouting flow increases gradually, and the fluctuation range is $|Q_{max} - Q_{min}|$. The grouting flow and pressure fluctuation can easily cause the decline in quality of the grouting fluid, below-standard of the grouting pressure, damage of the rock mass and other problems [12].

Literature [8] research and experimental results show that addition of asynchronous slave hydraulic cylinder can stabilize the grouting fluctuation. But the

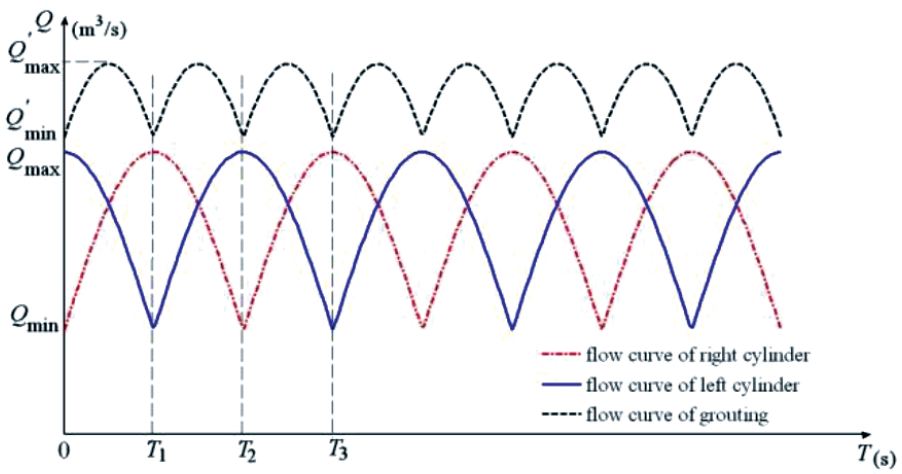


Figure 3. Influence of period-complement linkage of four-slave- cylinders pump design on grouting flow fluctuant curve

increase in the numbers of slave hydraulic cylinders is bound to lead to the bulky pump structure and the difficulty for construction of the pipeline system and control system, which will reduce the reliability of the equipment.

Based on the analysis of the above, this paper provides the optimization of the slave cylinders linkage. About the pump structure optimization, period-complement linkage of four hydraulic cylinders is applied to stabilize the grouting fluctuation, which is to say, two slave cylinders are added to supplement the extracting and draining of the primary slave cylinders. As shown in Figure 3, set the $T_1 - T_2$ to be draining period of the cylinder added, $T_2 - T_3$ to be the slurry extracting period, then the fluctuation curve of grouting flow forms complementation on the fluctuation cycle, which will make the fluctuation range of the grouting pressure reduce to $|Q'_{max}\text{-}Q'_{min}|$. It not only reduces grouting differential coefficient, δQ and δP, but also improves the average grouting flow and pressure of the grouting pump.

In order to improve the applicability of chemical grouting pump under the special working conditions and realize the miniaturization of chemical grouting pump, this paper elaborates the optimized design of pump structure based on the period-complement linkage of multiple cylinders. As shown in Figure 4, two sets of slave hydraulic cylinders at both left and right are equipped with cylinder A and B; the piston rods of four cylinders are firmly connected to the piston rod of the master power cylinder located in the center; the power piston reciprocatingly drives two sets of slave hydraulic cylinders at both left and right to complete the slurry extracting and draining.

3.2. The construction method of the pipeline system with automatic cleaning

From the analysis of mine chemical grouting process, compared with the pump and the pipeline system, the grouting solidification blockage are more likely to occur in the mixing & grouting part; in order to speed up the construction progress, a part with the wok completed needs to be cleaned timely; and in order to maintain the equipment, the pump and pipeline system needs to be thoroughly cleaned after a set of construction is completed,; that is to say, the mine grouting pump should be equipped with a pipeline system with automatic cleaning function.

In view of the above problems, the pipeline system as shown in Figure 5 is constructed; the use of transformation between liquid pipeline and gas pipeline can realize the full-automatic cleaning of subsystem of the grouting pump.

As shown in Figure 5, a dotted line is the gas pipeline and a solid line is liquid pipeline of the grouting station. Under the control of the changeover valve 3, the grouting pump realizes the movements of three stations: o is the standby station; 1 is the grouting station; 2 is the cleaning station.

When the changeover valve 3 is at 1, two sets of cylinders at both left and right completes the slurry extracting and draining movement under the control of Stroke switch 6.

When the changeover valve 3 is at connection location of 2, the grouting pump opens the automatic cleaning function of subsystem and the liquid pipeline is converted to the gas pipeline, by which the compressed air is used to realize rapid cleaning of mixer 12 and the grouting head 13, as shown in

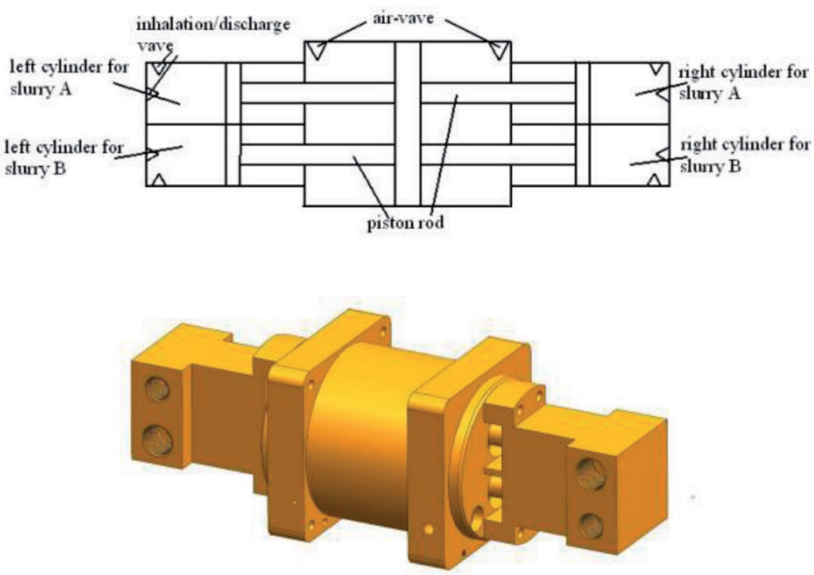
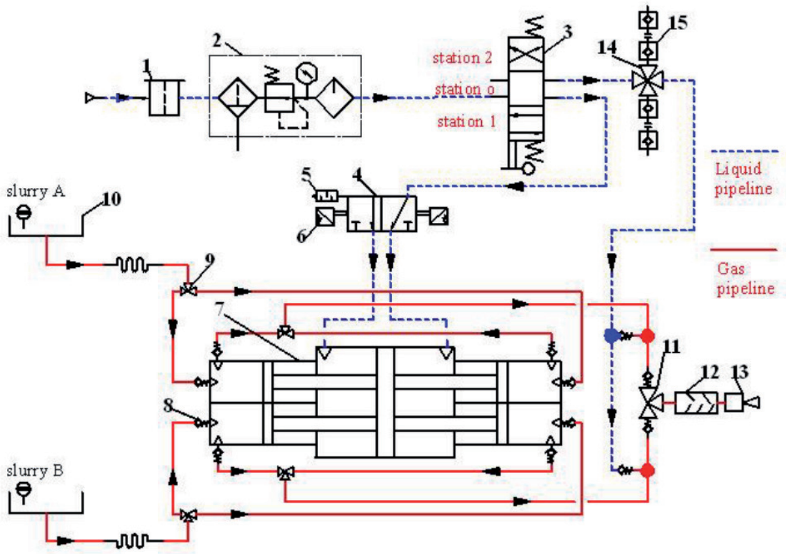


Figure 4. Diagram of pump structure of period-complement linkage of four-slave-cylinders



*Notes: 1 Tank purifier 2 Air triplets 3 Changeover valve a 4 Changeover valve b 5 Silencer 6 Stroke switch 7 Cylinder 8 One-way valve 9 Tee 10 Slurry cylinder 11 One-way tee 12 Static mixer 13 Grouting head 14 Cross joint 15 One-way with joint

Figure 5. Schematic diagram of pipeline system with auto-cleaning function

Figure. 6a, and also the cleaning of the pump and pipeline system, as shown in Figure. 6b.

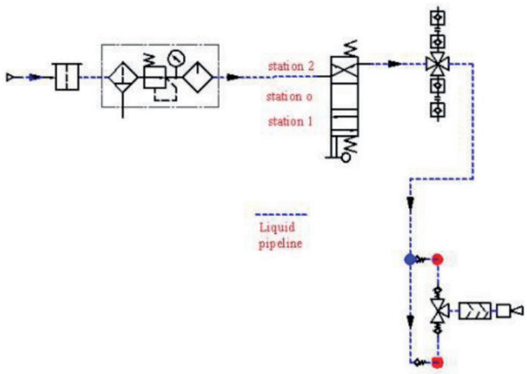
4. Test of overall performance evaluation of the prototype

4.1. General parameter comparison between the prototype and conventional grouting pump

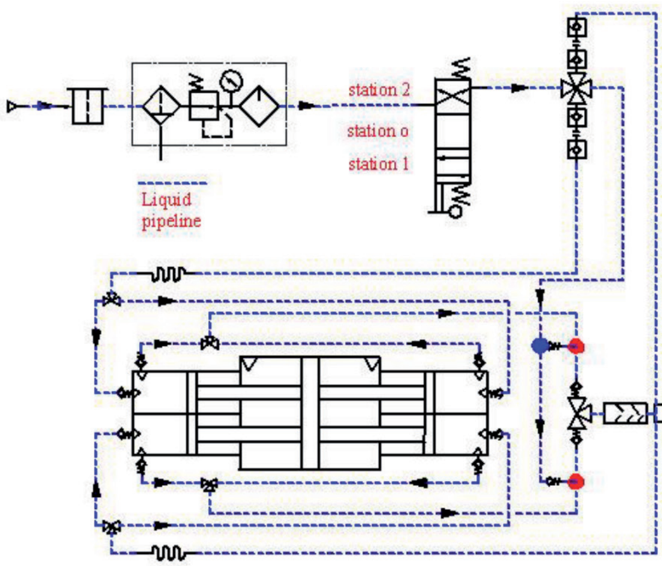
The prototype structure is shown in Figure 7; the pump structure and cleaning pipeline system of the prototype has obtained multiple *national invention patents of Chin*a [13].

The investigation and evaluation of the service conditions of the prototype under a variety of construction environments such as coal mine were made, and its parameters have been compared with that of the similar chemical grouting pump, as listed in Table 1.

Table 1 shows that the prototype realizes the miniaturization of chemical grouting pump; compared with the similar common chemical grouting pump, the gross weight of the prototype is reduced by more than 3/4, and the average grouting pressure is nearly doubled; and also the accurate proportioning of two groups of chemical materials and full-automatic pneumatic cleaning of pipeline system are realized,



(a) Cleaning of the mixer and the grouting head



(b) Cleaning of the pump and pipeline system

Figure 6. Diagram of pipeline system on station 2

Figure: 1 Station control switch 2 Air triplets 3 Gas pipeline 4 Air purifier 5 One-way valve 6 Slurry cylinder 7 Stroke switch 8 Pneumatic master cylinder 9 Slurry draining pipeline 10 Slurry extracting pipeline

Figure 7. Photo of prototype

thus greatly improving the grouting quality and the scope of application.

4.2. Mine grouting test of the prototype and relevant analysis

Sealing gas drainage borehole is common mine chemical grouting construction. The higher the sealing quality of the grouting pump is, the better the air tightness of drainage hole will be; the higher the volume percentage of the gas drainage is, the greater the concentration of the gas drainage will be. In a mine of China Henan Coking Coal Group, the grouting sealing comparison test between the prototype and conventional chemical grouting pump was carried out.

Test location: Bottom drainage roadway 1602 and Air return roadway 16021; grouting process: both-ends self-plugging pouch sealing process; grouting material: two-component polyurethane chemical materials; volume proportioning of grouting materials: 1:1.

Construction conditions show that, compared with the conventional two-component chemical grouting pump, the prototype has small volume and light weight, more suitable for the narrow construction environment in the mine; and the stable grouting and accurate proportioning of grouting materials effectively solved the problem of grouting nozzle blockage caused by residual slurry solidification.

In order to compare the grouting quality of them, the gas drainage concentration test was carried out in multiple gas drainage boreholes in some consecutive days, with the testing data listed in Table 2 and 3.

All gas drainage boreholes of Bottom drainage roadway 1602 reach the coal bed after penetrating the rock layer, which brings good gas drainage effect and

Table 1. Parameter comparison between prototype and similar type grouting pump

Parameter	Volume fraction [%]	Grouting pressure [MPa]	Master cylinder bore [mm]	Hydraulic cylinder bore [mm]	Master cylinder stroke [mm]	Weight [Kg]	Proportioning of materials	Cleaning means	Pressure fluctuation
Common grouting pump	< 80% (not adjustable)	6	250	75	130	>100	Inaccurate	Manual dismantling for cleaning	Moderate
The prototype	> 95% (adjustable)	11-12	125	20	43	<25	Accurate	Full-automatic cleaning	Tiny

*Note: Some parameters in the Table, such as proportioning of materials and pressure fluctuation, may change with the air supply pressure, grouting material and working condition, so only probability description from the large sample statistics is given.

Table 2. Comparison of gas drainage concentration data in bottom drainage roadway 1602

Drainage hole number	First ten-day period (%)	Second ten-day period (%)	Third ten-day period (%)	Drainage hole number (Conventional grouting pump sealing)	First ten-day period (%)	Second ten-day period (%)	Third ten-day period (%)
409	51	45	64	B1286	31	25	20
80	64	51	44	B1294	35	31	26
96	60	57	52	B1289	34	28	26
88	51	49	36	B1288	38	25	20
95	34	30	37	B1273	25	19	22
82	79	76	37	B1277	34	26	22
97	51	49	44	B1281	17	9	13

Table 3. Comparison of gas drainage concentration data in air return roadway 16021

Date of data collection	Extraction area number	Negative pressure (KPa)	Gas drainage concentration (%)	Drainage area number (Conventional grouting pump sealing)	Negative pressure (KPa)	Gas drainage concentration (%)
Aug 31st	28	48	30	31	48	23
Sep 7th	28	55	21	31	55	17
Sep 9th	28	47	25	31	47	19
Sep 14th	28	44	28	31	44	18
Sep 21st	28	47	26	31	44	16

high concentration. Table 1 lists the gas concentration data collected every 10 days of two groups of adjacent holes at Bottom drainage roadway 1602; the former is sealed by the prototype and the latter is sealed by the conventional chemical grouting pump.

It can be seen from Table 1 that, in first 10 days, the average concentration of the former is 45.2%, higher than that of the latter; in second 10 days, the average concentration of the former decreased by 9.23%, while the latter by 23.7%; in the last 10 days, the average concentration of the former decreased by 19.49% compared with initial average concentration, while the latter by 30.25%, and at this point, the former is 52.5% higher than the latter. Analysis shows that the prototype has better grouting quality in bottom drainage roadway; compared with conventional grouting pump, the average gas drainage concentration can increase by more than 30%, and air tightness of the sealing hole drops a little with time.

Table 2 shows the data of gas drainage concentration at two gas drainage areas of Air return roadway 16021 in some consecutive days; the gas hole directly reaches the coal bed, so gas drainage concentration is generally lower than the value in Table 1. Area No. 28 is sealed by the prototype, while Area No. 31 is sealed by the conventional chemical grouting pump. Compared with the data in Table 1, initial gas drainage concentration of Area No. 28 is 30% higher than that of Area No. 31; after 21 days, the concentration of the former decreased by 13%, while the latter by 30%, which proves that the prototype also well adapted to the working condition of Air return roadway; compared with the conventional pump, the gas drainage concentration was raised by 30% or more.

The above construction situation and data analysis show that, compared with the conventional chemical grouting pump, the prototype not only has a higher chemical grouting quality to effectively improve the sealing quality of mine gas drainage boreholes, but also solves the problem of grouting head blockage to greatly improve the efficiency of mine chemical grouting and well adapt to the process characteristics of modern mine grouting construction.

5. Conclusions

(1) Mine two-component pneumatic chemical grouting pump with automatic cleaning function designed in the paper, realized the aim of miniaturization, lightweight and automatic cleaning of pipeline, improving the quality and efficiency of mine chemical grouting.

(2) The “period-complement linkage” of four cylinders can optimize the pump structure and stability of grouting fluctuation and realize the miniaturization of two-component chemical grouting pump. Compared with the same type of conventional chemical grouting pump, the gross weight of prototype decreased by 3/4, and the average grouting pressure was nearly doubled.

(3) The pipeline system with full-automatic cleaning function of grouting blockage was constructed to solve the problem of difficult cleaning for chemical grouting pump blockage.

(4) The grouting test for and service performance evaluation on underground sealing of gas drainage borehole toward prototype show that the prototype can improve mine gas drainage concentration by more than 30%, and the good performance makes it more suitable for narrow construction environment in mine, improving the construction quality and efficiency of mine grouting. The prototype is also applicable to the chemical grouting construction of the tunnel, water conservancy and subway.

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