Technology and performance analysis of preventing surface subsidence by sealing and backfilling the goaf with Urban waste

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Abstract

In order to solve the current two major environmental problems of urban waste pollution and surface subsidence above the coal mine goaf, the technology of sealing and backfilling the goaf with urban waste is proposed. This technology takes "waste disposal" and "goaf backfilling" as the design theme, and uses waste screening, processing, transportation, and backfilling as the design links. Aiming at the processing of loose waste, the waste drying and briquetting integrated machine is designed, which comprehensively utilizes the methods of waste physical disposal and heat disposal to dehydrate and press the waste into a block with a particle size of 150mm, and finally pass the six-sided winding package. The entire processing technology ensures the strength of the waste materials and no filtrate. For the processing of solid aggregate waste, it is crushed into recycled concrete raw materials for goaf backfilling. Aiming at the goaf backfilling, the goaf backfilling coal mining method is designed, the backfilling hydraulic support is modified, and the backfilling mechanism is added to realize the integration of “mining-backfilling” in the working face. The backfilling technology embodies the key issues of the sealing of the backfilling space and the strength of the backfilling body with third times of sealing strengthening. Using urban waste as the backfilling materials for the goal area, the waste pollution and the surface subsidence are turned into “two benefits”, and the construction of waste-free cities and green mines is promoted.

1. Introduction

China is a big coal mining country. After large-scale underground coal mining, if the traditional caving management roof continues to be adopted, it will inevitably lead to large-scale surface subsidence and large-scale landslides and other geological disasters, which greatly affects the integrity of the ecological environment of the entire region (Xu et al. 2020; Tan et al. 2020; Yang et al. 2021). According to statistics, there are 4716 geological disasters caused by mining in nationwide, including 1,887 goafs subsidence, accounting for 40.01% of the total mine geological disasters. The underground mining subsidence areas are mainly concentrated in Shanxi, accounting for 58.08% of the nationwide underground mining subsidence area. Secondly, Chongqing, Hebei, Shaanxi and Anhui are also more distributed, and the underground mining subsidence areas in the four provinces account for 21.27% of the nationwide.

Urban waste is a mixture of wastes generated in people's daily life and production. The disposal of waste is directly related to the image of the city, the quality of life of residents, the rational use of resources, and the sustainable development of social economy. According to the 2020 Environmental Annual Report issued by the Ministry of Ecology and Environment, 196 large and medium-sized cities produced 1.38 billion tons of general industrial solid waste and 23.562 million tons of domestic waste. In densely populated large cities, a large amount of urban waste accumulates in the suburbs because it is not treated in time, polluting the environment and occupying a large amount of land. Waste siege has become the heart disease of many cities, and waste pollution has become an urgent problem (Lorena et al. 2021; Sharma et al. 2021; Cheng et al. 2021).

Faced with the current two major environmental problems of "surface subsidence in mining areas" and "urban waste disposal", they have increasingly become huge obstacles hindering social and economic progress and the sustainable development of resources and environment (Muhagir et al. 2021; Mohamed et al. 2021; Emily et al. 2020; Swiedler et al. 2019). In view of the above two major environmental problems, some scholars have proposed a comprehensive environmental management method for backfilling the goaf with solid waste, and analyzed the feasibility of the implementation of the method (Gaziev et al. 2004). There are only a few proposals on this point of view. According to the current research status of urban waste disposal and goaf backfilling, the research focus is put forward: the key technology of urban waste compression and solidification performance, the backfilling process design of using urban waste to backfill the goaf, backfilling equipment research and development, etc (Liu et al. 2010). But so far there have been no substantive results. Many scholars have done a lot of research on the above two major environmental issues. In terms of coal mine goaf management and surface subsidence prevention and control, the solid backfilling technology of goaf is commonly used. In this research, backfilling materials are the focus of the research, such as the use of phosphogypsum, fly ash, and coal gangue to backfill the goaf. On the one hand, it solves the pollution of the environment by the accumulation of solid wastes such as coal gangue and fly ash, and on the other hand, the backfilling mining has achieved the goal of building a green mine (Rong et al. 2020; Wang et al. 2020). For the goaf backfilling, system design is indispensable. For the management of the goaf, the method of backfilling and grouting, the partial filling method of the large inclination goaf, etc. are designed, and reasonable coal pillars are reserved to ensure safe mining (Liu et al. 2015; Wang et al. 2020). However, the research on the backfilling law of the goaf shows that no matter which backfilling material or backfilling process is used, it is difficult to achieve the ideal filling effect (Guo et al. 2012). In the disposal of urban waste, incineration (Natsuko et al. 2021), composting (Laville et al. 2014) and landfilling (Janas et al. 2018) are commonly used. On the basis of waste disposal technology, some scholars combine various disposal methods to reuse waste. For example, waste incineration ash can be used as raw materials for concrete and cement (Alderete et al. 2021; Chen et al. 2021). Recycling of resources such as biogas and other resources by means of landfill (Ogata et al. 2016). In view of the above three commonly used waste disposal methods, there are different environmental problems, and the secondary pollution to the environment is immeasurable.

Based on the above research status, in the face of these two major environmental problems, although many results have been achieved in the study of coal mine backfilling mining and waste disposal, there are many economic and environmental problems in the actual application. Therefore, this technology proposes to combine urban waste disposal and mine goaf management, that is, to use urban waste as a backfilling material to close the coal mine goaf to form a systematic project. It not only solves the problem of difficult disposal of urban waste to a certain extent, but also provides materials for the roof of coal mining backfilling management, and controls the surface subsidence of the mining area, which can turn the "two harms" into "two benefits". Finally, on the basis of effective control of surface subsidence, the pollution-free disposal of urban waste is of great significance to promoting the sustainable development of the urban economic environment and the construction of green mines in my country.

2. System Technology For Sealed Backfilling Of Coal Mine Goaf With Urban Waste

When urban waste is used as a backfilling material to backfill the goaf, the strength, tightness, and backfilling equipment of the material must be considered, and none of them are indispensable. This technology mainly includes two parts: waste processing and goaf backfilling.

2.1 Waste disposal and processing technology

2.1.1 Waste performance screening

Urban waste includes domestic waste, construction industry waste, and medical waste, etc. Non-recyclable waste is screened. According to its strength, structure, composition and other characteristics, it is divided into solid aggregate waste such as coal gangue, concrete, slag, etc. and other low-strength loose waste such as waste plastics and electronic waste, etc. On this basis, the solid aggregate is screened with a powerful vibrating screen to ensure that the aggregate particle size is less than 40 mm.

2.1.2 Waste processing technology

The screened waste is processed and packaged into blocks to meet the requirements of backfilling materials. First, the solid aggregates with a particle size larger than 40mm are sent to the jaw crusher to ensure that the particle size is smaller than 40mm; Secondly, considering the leachate problem of waste as a backfilling material, the strength of loose waste, and avoiding secondary pollution in the mine during transportation, the design of a waste drying and briquetting integrated machine (see Figure 1), after the equipment is processed, the loose waste is compressed into a block with a particle size of 150mm, followed by a six-sided sealed winding packaging.

In Figure 1: 1- Pressure mechanism, 2- Heating forming partition, 3- The seepage frame, 4- Leachate hole, 5- Unload the bottom plate, 6-Bottom handle, 7- Load-bearing pier, 8-Upper beam, 9-Pillar, 10- The base.

After the crushing of solid aggregate waste and the compression and packaging of loose waste, two types of backfilling materials are finally formed, namely solid aggregate backfilling materials and block backfilling materials.

2.2 Goaf backfilling

In coal mining, the goaf is backfilled with processed solid aggregate backfilling materials and block backfilling materials, and the waste-backfilling mining method in the goaf is designed here, as shown in Figure 2.

In Figure 2: 1-Belt conveyor, 2- Transportation roadway, 3- Bridge conveyor, 4- Scraper conveyor, 5- Shearer, 6- Backfilling the hydraulic support, 7- Backfilling scraper conveyor, 8- Unwinding baffle, 9- Rhombic retractable blocking net, 10- Advance support, 11- Bridge conveyor for transporting materials, 12- Concrete

mixer, 13- Roadway of the return wind, 14- Sewage pump, 15- Belt conveyor for transporting materials, 16- Block backfilling body, 17- Solid aggregate backfilling body, 18- Tamping machine, 19- Tamper the baffle, 20- Compact jack, 21- Storage chamber, L- Backfilling length of goaf, h- Mining height, a, b, c- are the heights of the top, middle, and bottom of the goaf backfilling, respectively.

2.2.1 Sealed backfilling

Considering that the backfilling material is urban waste, if water inrush occurs in the goaf area, a large amount of underground waste leachate may be brought in, resulting in mine pollution. Disposal of waste, but pollutants must not be passed on to the mine, so the entire goaf must be sealed for disposal.

(1) First of all, in the initial stage of the mining roadway excavation, the side of the coal pillar of the roadway of the return wind, the open cut and the transportation roadway are sprayed with concrete

(2) Secondly, during the backfilling process, each backfilling cycle includes bottom backfilling, middle backfilling and top backfilling of the goaf. The top and bottom parts of the backfilling body are backfilled with recycled concrete formed by "solid aggregate + cement". The estimated backfilling thickness is c=100 mm at the bottom and a=200 mm at the top.

(3) Finally, when the mining at this working face is completed, the concrete shotcrete treatment is also carried out at the coal pillar of the stop line to form a six-sided enclosed backfilling space.

(4) In order to ensure the strength of the backfilling body and the sealing of the backfilling gap, after the backfilling is completed, the backfilling body is grouted and cemented.

2.2.2 Backfilling facilities

(1) Considering the strength of the backfilling body in the goaf and the top backfilling problem, a tamping machine and a tamper the baffle are designed in the backfilling part.

(2) Considering that the backfilling material can accurately backfill the goaf and without material exposure under the support, a side-discharge backfilling scraper conveyor is designed (see Figure 3). Set a discharge port for every other support, that is, each discharge port is responsible for the backfilling space within the width of the two supports, and the tamper baffle is seamlessly overlapped with the backfilling scraper conveyor when unloading.

(3) Fully considering that each backfilling cycle can be completed independently and effectively, to ensure that the backfilling materials in the previous cycle will not leak and slip to the backfilling space of the next cycle. Rhombic retractable blocking net (see Figure 4) is set between the tamper baffle of every two supports.

In Figure 4: 1- The tamper baffle of the adjacent support, 2- The tamper baffle of the support of this cycle operation, 3- Retractable net.

(4) Taking into account the solidification of the "solid aggregate + cement" recycled concrete material, firstly, cement with a long setting time should be selected. And secondly, the mixing point of the recycled concrete should be close to the goaf area, so a concrete mixer should be installed in the roadway of the return wind.

(5) Finally, considering that each backfilling cycle is completed by alternate backfilling of solid aggregates and block wastes, materials transportation is complicated, so the storage chamber is designed next to the concrete mixer to store solid aggregates and cement to ensure that the backfilling work takes over in an orderly manner.

2.2.3 Calculation of theoretical backfilling volume

Under the premise of ensuring the backfilling efficiency and the roof will not collapse and sink, the amount of backfilling material required for the goaf backfilling theoretically is the amount of coal mined. According to the advancement of the working face, the required backfilling amount for each cycle is calculated. The amount of backfilling materials required to design the bottom, middle and top backfilling are V_1, V_2 and V_3 respectively:

$$V_1 = 2 \times B \times c \times D \times R_1$$

$$V_2 = 2 \times B \times a \times D \times R_1$$

$$V_3 = 2 \times B \times (h - a - c) \times D \times R_2$$

Where: 2- The length of each filling cycle is the width of the two supports; B- Backfilling the width of the hydraulic support; D- Cycle progress of the shearer; R_1, R_2- Compression ratio of block backfilling materials and solid aggregate backfilling materials, generally 3~5, and $R_1 > R_2$.

3. The Technical Principle And Process Flow Of Waste Sealed Backfilling Goaf

3.1 Waste processing technology

In order to ensure that the waste is used as the backfilling material of the coal mine goaf, the solid aggregate waste is crushed to make it the raw material of recycled concrete. For the processing of loose other waste materials, the waste drying and briquetting integrated machine is designed to reduce the waste filtrate and ensure the strength of the backfilling material. The design comprehensively adopts the methods of physical waste disposal and heat disposal, and utilizes the thermal deformability of most wastes, high temperature destroys or changes the composition and structure of loose waste, and then undergoes physical compaction to achieve volume reduction. In addition, most of the plastic waste has a certain degree of cementation after heat disposal, so that it can be compacted to enhance its strength as

a backfilling material. In the whole process, after heat disposal and compaction, the effect of dewatering the waste block is also achieved.

The specific process flow is:

(1) As shown in Figure 1, the pressure mechanism is raised, and the remaining low-strength loose waste materials from the screening are put into the seepage frame, in order to cause thermal deformation of the waste. Adjust the initial temperature of the thermoformed partition according to the main type of waste, and generally keep the initial temperature at the highest temperature of waste thermal deformation (temperature range 50℃~300℃).

(2) The pressure mechanism drops lightly, and when the volume is compressed, continue to throw in the waste, and repeat the operation until the required compressed volume is reached.

(3) The pressure mechanism maintains pressure, and the temperature gradient of the heating partition is reduced for 20 to 30 minutes to ensure that the waste is dried without filtrate.

(4) After the waste is pressed and dried, the unload bottom plate is opened to discharge the shaped blocks and transport them to the packaging workshop.

(5) Six-sided sealed winding packaging for block waste materials.

3.2 "Mining-backfilling" integration

Under the condition that the shearer can cut the coal normally, the scraper conveyor and the belt conveyor can transport the coal, and the hydraulic support can move normally, the hydraulic support backfilling mechanism and the compaction mechanism are added. When the shearer completes a cycle schedule, it is necessary to ensure that the backfilling completes all cycle schedules for the entire length of the working face. The working of each backfilling cycle is:

(1) Overlap the tamping baffles of the two supports in the operation range of this cycle with the backfilling scraper conveyor, and at the same time push the tamping baffles of the adjacent supports (supports for the next cycle) to the goaf. Open the rhombic retractable blocking net (see Figure 4).

(2) Open the unwinding baffle at the discharge port of this cycle operation, and close the other discharge ports (see Figure 3).

(3) The backfilling scraper conveyor transports the backfilling material, and the backfilling materials are unloaded by its own weight at the discharge port.

(4) In the process of discharging and backfilling, the tamping machine can adjust the angle arbitrarily within the backfilling height, and tamping slightly, so that the backfilling rate of the backfilling area reaches about 60%.

(5) When the backfilling reaches the final height, close the discharge port and stop the material transportation.

(6) Push the tamping baffle toward the backfilling body, and cooperate with the tamping machine to ram the top of the backfilling body (see Figure 2, B-B profile) to complete this cycle.

In the entire length of the goaf area, the cycle operation is continuously completed to realize the backfilling of the goaf area. During the backfilling process, the tamping baffle and the backfilling scraper conveyor are seamlessly overlapped, and the rhombic retractable blocking net is opened. The purpose is to ensure that each backfilling cycle forms an independent small area, and there is no phenomenon of insufficient backfilling height caused by the side falling of the materials. The main function of the tamping baffle is to push the backfilling body into compaction after stopping the discharging in the final backfilling stage, and at the same time cooperate with the compaction machine to ensure that the backfilling body can be connected to the top and achieve the purpose of compaction, so that the backfilling rate of the backfilling body reaches about 90%.

In terms of time, the backfilling process of the entire goaf lags behind coal mining at the working face and is completed after the hydraulic support is moved. In terms of space, the shearer cuts the coal and the belt conveyor transports the coal. The whole process is completed in the coal mining working face and the transportation roadway; Transportation of backfilling materials and goaf backfilling are completed in the roadway of the return wind and goaf respectively. Realize the parallel operation of "mining" and "backfilling".

3.3 The system of waste sealed backfilling goaf

When the waste is screened and processed, it forms a backfilling materials to backfill the goaf of the coal mine. The system is shown in Figure 5:

The most critical link in this system is "waste processing" and "goaf backfilling". First of all, as the backfilling material of the goaf, the urban waste must ensure the sealing of the backfilling; Secondly, for the goaf, the strength of the backfilling body must be ensured.

The sealing performance of the backfilling is ensured in the system, and it has been sealed for three times

(1) In the process of "waste processing", the block waste is sealed on six sides.

(2) In the process of "goaf backfilling", the bottom and top of the backfilling body are backfilled with solid aggregate (recycled concrete), combined with the concrete shotcrete at both sides of the roadway, the open cut, and the stop line, a six-sided sealed backfilling space is formed.

(3) After the backfilling is completed, the backfilling body is grouted and cemented, and its function is to close the gap in the backfilling body to ensure that it is completely sealed.

The strength of the backfilling body is ensured in the system and undergoes three strengthening disposal:

(1) In the process of "waste processing", the loose waste is compressed into blocks and then wind on six sides. Starting from the backfilling materials, the strength of the backfilling body is ensured.

(2) In the process of "backfilling", the backfilling body is compacted by the tamping mechanism, and the top is pushed forward, which is the secondary strengthening of the backfilling body.

(3) After the backfilling is completed, grouting and cementation can also improve the strength of the backfilling body.

4. Prospects Of Technology Application

According to statistics, 30 provinces in China all have mine waste solid land occupation, of which 22 provinces have more or less goaf surface subsidence, especially Shanxi, Hunan, Henan, Hebei, Xinjiang and other provinces have large surface subsidence. In addition, the output of urban waste has increased significantly year by year, and the provinces with annual solid waste production exceeding 50 million tons include Inner Mongolia, Liaoning, Shandong, Jiangsu, Shaanxi and other provinces; The provinces with annual domestic waste production exceeding 10 million tons include Guangdong, Jiangsu, Zhejiang, Shandong, Sichuan and other provinces. Faced with the two major environmental problems of goaf subsidence and waste disposal, the severity of these two major environmental problems is different due to the different conditions in each province.

The sealed-backfilling goaf system technology of urban waste fully considers and analyzes the current focal issues of urban waste disposal and environmental destruction of surface subsidence in mining areas, and combines waste disposal and goaf backfilling. The application of this technology has higher requirements for the selection of mines. First of all, there must be no aquifer around the goaf and no hidden danger of groundwater; Secondly, for close-distance coal seams, the surrounding rock fractures caused by repeated mining are relatively developed, so this type of goaf is not suitable for applying this technology; In addition, the backfilling technology of the system can be directly applied to the goaf of gently inclined coal seams. For steeply inclined coal seams, the length of the goaf backfilling length L needs to be designed, and the key technology of the system is also applicable.

The specific application of the backfilling technology can be completed independently on the one hand, that is the waste processing of the province and city and then backfilling; On the other hand, it can be completed across provinces and regions according to the conditions of each province. For example, the large amount of waste generated in Guangdong, Zhejiang and other provinces and cities can complete the waste processing on the spot to form the finished waste backfilling material, and then adopt the principle of proximity transportation to other provinces to backfill the goaf. It can be widely used in various provinces and coordinate with each other to achieve a win-win situation in environmental governance.

The application of this technology, on the one hand, can provide new disposal methods and ideas for the problem of urban garbage, on the other hand, it can demonstrate new technologies and directions for coal mine backfilling and mining.

5. Conclusions

(1) The technology of sealed-backfilling of coal mine goafs with urban waste uses waste screening, processing, transportation, and backfilling as the design links. The most critical links are "waste processing" and "goaf backfilling". First of all, as the backfilling materials of the goaf, the urban waste must ensure the sealing of the backfilling; Secondly, for the goaf, the strength of the backfilling body must be ensured.

(2) In order to ensure that urban waste can effectively backfill the goaf of coal mines, independently designed a waste drying and briquetting integrated machine to realize the preliminary waste processing. On the one hand, it can reduce the landfill leachate, and on the other hand, it can achieve solidification disposal of waste. Finally, the six-sided winding package of the waste is used as the backfilling material of the goaf to prevent the secondary pollution of the mine caused by the waste backfilling.

(3) Design the coal mining technology for backfilling the goaf with urban waste, and realize the integration of "coal mining" and "waste backfilling". In the entire process of waste processing and backfilling, in order to ensure the sealing of the backfilling and the strength of the backfilling body, the sealing problem of the backfilling body and the backfilling space is solved from the three links of six-sided sealed winding packaging, concrete shotcrete, and grouting cementation; The strength problem of the backfilling body is solved in three links: compaction of loose waste into blocks, tamping machine, and grouting cementation.

Declarations

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References

Alderete NM, Joseph AM, Van den Heede P et al (2021) Effective and sustainable use of municipal solid waste incineration bottom ash in concrete regarding strength and durability. Resour Conserv Recy 167:105356. https://doi.org/10.1016/J.RESCONREC.2020.105356

Cheng H, Li YM, Hu YS et al (2021) Bioenergy recovery from methanogenic co-digestion of food waste and sewage sludge by a high-solid anaerobic membrane bioreactor (AnMBR): mass balance and energy potential. Bioresource Technol 326. https://doi.org/10.1016/J.BIORTECH.2021.124754

Chen L, Wang YS, Wang L et al (2021) Stabilisation/solidification of municipal solid waste incineration fly ash by phosphate-enhanced calcium aluminate cement. J Hazard Mater 408. https://doi.org/10.1016/J.JHAZMAT.2020.124404

Emily A, Anthony I, Robert W (2020) Investigations on longwall mining subsidence impacts on Pennsylvania highway alignments. Int J Min Sci Techno 30(1): 85-92. https://doi.org/10.1016/J.IJMST.2019.12.012

Gaziev YA, Rizaev KA (2004) Goaf filling with industrial wastes. J Min Sci 40(5):528-530. https://doi.org/10.1007/s10913-005-0039-7

Guo L, Xie B (2012) Study on the Stochastic Law of Gob Stowing Effect. Appl Mech Mater 1800:502-505. https://doi.org/10.4028/www.scientific.net/AMM.170-173.502

Janas M, Zawadzka A (2018) Assessment of the Monitoring of an Industrial Waste Landfill. Ecol Chem Eng S 25(4):659-669. https://doi.org/10.1515/eces-2018-0044

Lorena EP, Kurt ZR, Teresa EPA et al (2021) Closing the gap in the municipal solid waste management between metropolitan and regional cities from developing countries: A life cycle assessment approach. Waste Manage 124:314-324. https://doi.org/10.1016/J.WASMAN.2021.02.020

Liu Y, Guo XX (2010) Research on Control Techniques of Surface Subsidence by Stowing Municipal Solid Wastes in Coalmine Gobs. Journal of Shandong University of Science and Technology(Natural Science) 29(04):30-34. https://doi.org/10.16452/j.cnki.sdkjzk.2010.04.017

Liu CY, Yang JX, Wu FF (2015) A Proposed Method of Coal Pillar Design, Goaf Filling, and Grouting of Steeply Inclined Coal Seams Under Water-Filled Strata. Mine Water Environ 34(1):87-94. https://doi.org/10.1007/s10230-014-0314-4

Laville P, Michelin J, Houot S et al (2014) Soil N_2O Emissions from Recovered Organic Waste Application in Versailles Plain (France): A Laboratory Approach. Waste Biomass Valor 5(3):515-527. https://doi.org/10.1007/s12649-013-9249-4

Muhagir EK, Ioannis P, Constantinos L et al (2021) Omari Khalid, Kontoes Charalampos. Monitoring of land surface subsidence using persistent scatterer interferometry techniques and ground truth data in

arid and semi-arid regions, the case of Remah, UAE. Sci Total Environ 776. https://doi.org/10.1016/J.SCITOTENV.2021.145946

Mohamed A, Sadeque H, Ahmad S (2021) A multi-objective optimization model for strategic waste management master plans. J Clean Prod 284. https://doi.org/10.1016/J.JCLEPRO.2020.124714

Natsuko K, Yukio N, Mayumi T et al (2021) Destruction of decabromodiphenyl ether during incineration of plastic television housing waste at commercial-scale industrial waste incineration plants. J Environ Chem Eng 9(2). https://doi.org/10.1016/J.JECE.2021.105172

Ogata Y, Ishigaki T, Nakagawa M (2016) Effect of increasing salinity on biogas production in waste landfills with leachate recirculation: A lab-scale model study. Biotechnology Reports 10:111-116. https://doi.org/10.1016/j.btre.2016.04.004

Rong K, Lan WT, Li HY (2020) Industrial Experiment of Goaf Filling Using the Filling Materials Based on Hemihydrate Phosphogypsum. Minerals 10(4). https://doi.org/10.3390/min10040324

Sharma BK, Chandel MK (2021) Life cycle cost analysis of municipal solid waste management scenarios for Mumbai, India. Waste Manage 124:293-302. https://doi.org/10.1016/J.WASMAN.2021.02.002

Swiedler EW, Muehlenbachs LA, Chu ZY et al (2019) Should solid waste from shale gas development be regulated as hazardous waste?. Energ Policy 129:1020-1033. https://doi.org/10.1016/j.enpol.2019.02.016

Tan M, Wang K, Xu Z et al (2020) Study on Heavy Metal Contamination in High Water Table Coal Mining Subsidence Ponds That Use Different Resource Reutilization Methods. Water 12(12):3348. https://doi.org/10.3390/W12123348

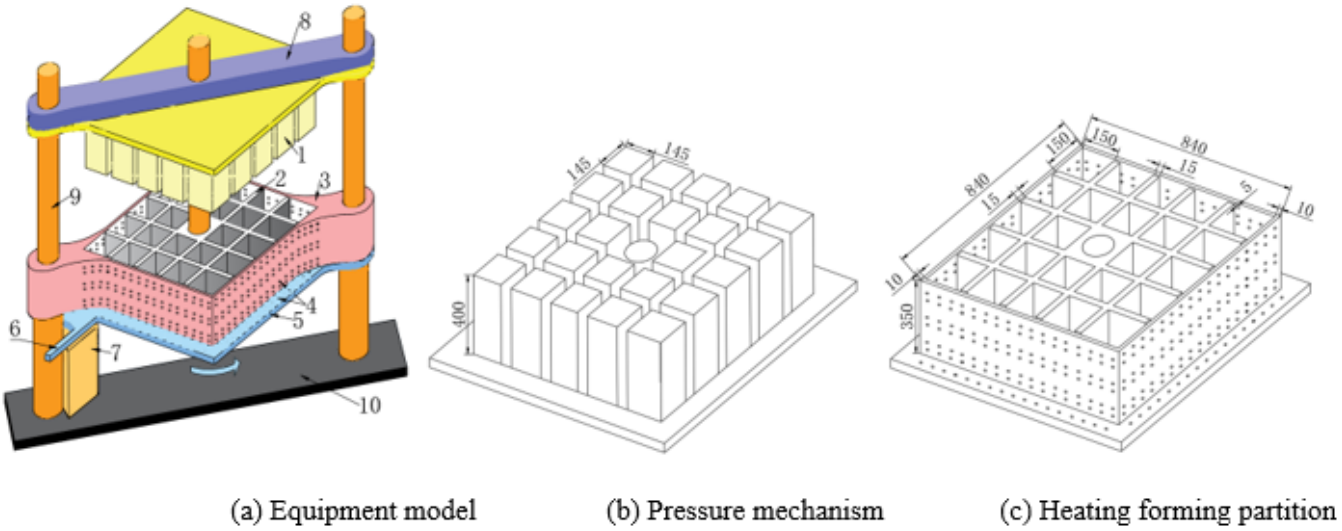
Wang Y, Wu L, Cheng Y et al (2021) Comparison of Two Expanding Excavation Schemes Based on Settlement Control with Field Monitoring Analysis. Geotech Geol Eng. https://doi.org/10.1007/s10706-021-01708-z

Wang XD (2020) Experimental study on the performance of goaf filling materials with high content of fly ash. IOP Conf Ser: Earth Environ Sci 569(1):012014. https://doi.org/10.1088/1755-1315/569/1/012014

Wang HW, Wu YP, Liu MF et al (2020) Roof-breaking mechanism and stress-evolution characteristics in partial backfill mining of steeply inclined seams. Geomat Nat Haz Risk, 11(1):2006-2035. https://doi.org/10.1080/19475705.2020.1823491

Xu JX, Yin PC, Hu WM et al (2020) Assessing the ecological regime and spatial spillover effects of a reclaimed mining subsided lake: A case study of the Pan'an Lake wetland in Xuzhou. PloS one 15(8). https://doi.org/10.1371/journal.pone.0238243

Figures



(a) Equipment model (b) Pressure mechanism (c) Heating forming partition

Figure 1

Waste drying and briquetting integrated machine

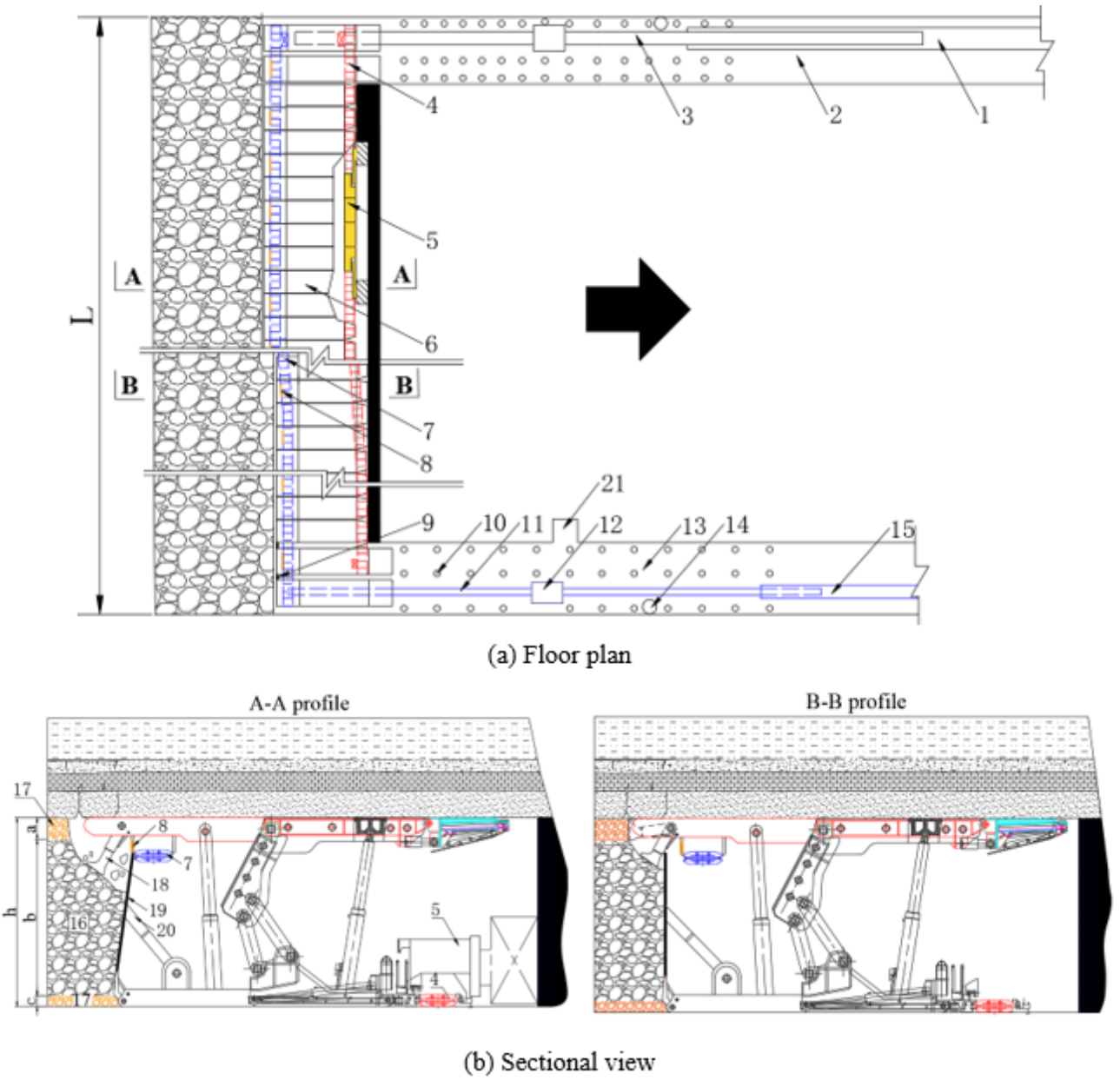


Figure 2

Working face "mining-backfilling" method diagram

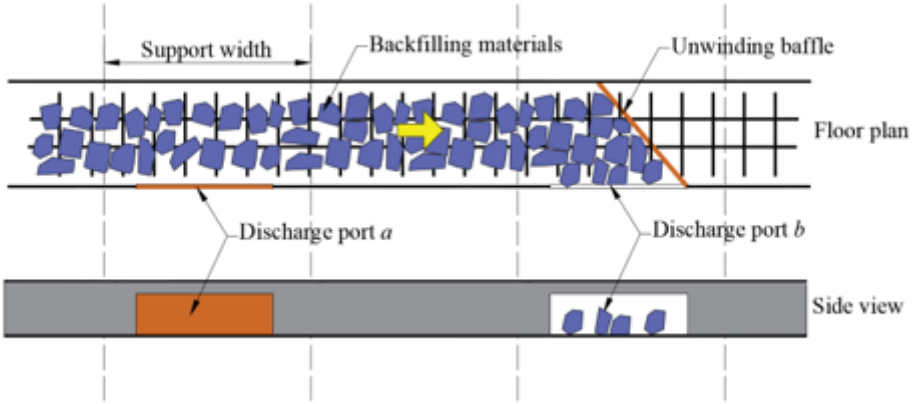


Figure 3

Schematic diagram of a side-discharge backfilling scraper conveyor

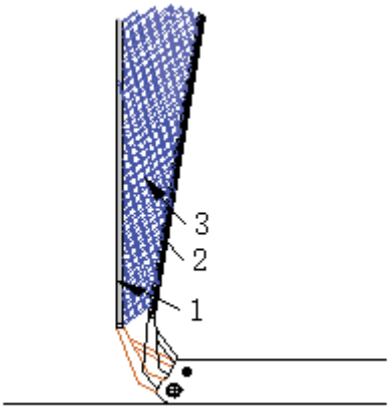


Figure 4

Rhombic retractable blocking net

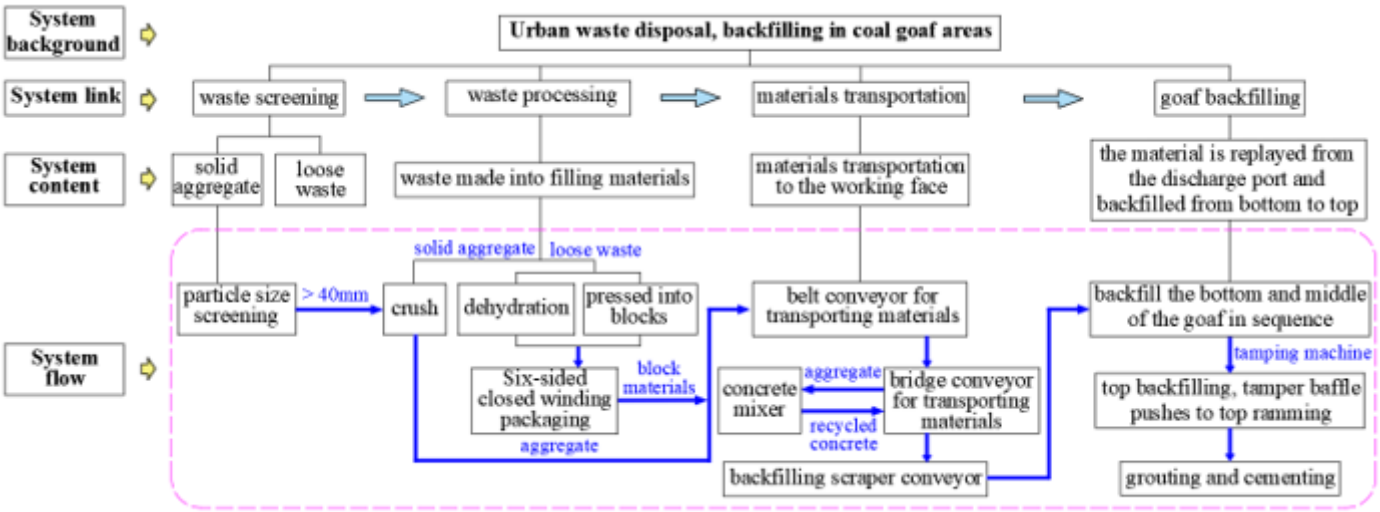


Figure 5

System diagram of sealed waste backfilling goaf