International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 12 (2015) pp. 31691-31705

http://www.ripublication.com

A Study on Application and Comparison of Warehousing Systems in Coal Storage and Transportation

Wang Yao[1,2] and Meng Wen-jun[1,2]

1. School of Mechanical Engineering,
Taiyuan University of Science & Technology, Taiyuan, Shanxi, 030024, China;
2. The Key Lab of Intelligent
Warehousing and Logistics Equipment of Shanxi Province,
Taiyuan, Shanxi, 030024, China

Abstract

A new enclosed rectangular flat bottom silo was proposed based on the requirements of energy conservation and environmental protection. Its storage capacity can reach 270,000 m^3. And its capacity of automatic discharging or feeding system can reach 1400t/h for bulk solids including higher moisture content or difficult flowing materials. The conical bottom silo and the flat bottom silo were separately applied in an engineering study of warehousing systems of coal. Taking the development on enclosed warehousing system of coal in the new coal chemical recycling economy project of a company as an example, the comparative analysis was carried out for different warehousing systems. It was concluded that the circular bottom silo had little loss of storage capacity and higher space utilization than the conical bottom silo. But both of them had the potential risk of agglomeration and obstruction. Although it had a little disadvantage in land occupation, the enclosed rectangular flat bottom silo could solve the problems of agglomeration and obstruction compared with the former two. In the conditions of equal spatial dimensions, the enclosed rectangular flat bottom silo had almost same space utilization with the domed silo, but was the lowest cost. Meanwhile, some

advantages were obtained as below. It is easy to implement the classification of storage for multi-coal and store or reclaim four kinds of coal at the same time. It reduced the moisture of coal feeding into gasifier and energy consumption during coal carbonization, because the drier materials of the surface layer could be got when reclaiming. The precipitated water in the end of silo could be discharged by trench located in the bottom. And it could be directly as the clean waste water to be reused for the production and so on.

Key words: warehousing systems; enclosed rectangular flat bottom silo; conical bottom silo; flat bottom silo; domed silo; coal storage and transportation

0 Forward

Along with the sustainable development of energy market, increasingly diversified needs of coal customers as well as higher and higher environmental requirements of the bulk material storage, enclosed coal storage system has the attention of society for its prominent advantages such as cleanliness, environmental protection, saving space and safety [1~2]. Compared with open-air coal storage, enclosed storage can save the area of about 40%, and the material does not pollute the environment, also will not be polluted by the external environment. Besides, the production will not be affected by the climate. As since reform and opening up, the extensive growth mode of domestic economy has lasted a long time, weak awareness of environmental protection and resource conservation, and some technical monopoly in abroad [3~4], enclosed coal storage system in our country in the field of coal, electricity, coking and application is still in the stage of development.With few experience in designing and management, there are many practical engineering problems remain to be solved.

The documents and reports of coal storage system at home and abroad are mainly involves silo model [5], among which the cone bottom warehouse and warehouse are more widely applied. Since the 1980s, the coal storage and transportation in developed countries and areas has entered the era of fully enclosed storage and transportation, and single storage has tended to be large-scale step by step. For example, Dutch company Eurosilo designed the storage capacity of 100,000 m^3 of closed large coal storage system, which can stored almost all materials, including liquid or frictionless [6]. At the same time it has carried out researches to closed silo system [7] of hard flow medium material, which is on a world leading level. Germany's E.ON is building two closed circular storage bunker, each store coal storage capacity of 220,000 t [8]. Siemens power production system finished the construction of the two coal storage silo [9], whose storage capacity is 100,000 m^3, etc. In the research and application on warehousing system in our country, compared

with abroad, the structure design, security technology, environmental protection energy conservation science and technology content is low. In recent years, with industry-university-institute cooperation and continuously review all kinds of storage system design and engineering problems found during the construction, making the warehousing system research and development rapidly developing in our country, such as, the Qingda new energy technology co., Ltd. The designed capacity of 100,000 t single storehouse coal fully enclosed circular flat-bottomed silo [10], and Jiangsu port of the power plant of 30,000 t closed cone bottom coal storage silo, etc. In addition, there are reports of hemispherical dome storehouse [11], such as, Asia's largest hemispherical enclosed storage bunker , diameter of 120 m, 33.5 m high, the reserves of 200,000 t. These storage systems are not meaningful flat silo structure, or the appearance looking like a ‘flat’, while the actual discharge way is with conical funnel, or other forms, etc., but the development of the enclosed storage concept has made great progress.

In this paper, based on the requirement of energy conservation and environmental protection, we put forward a new enclosed rectangular flat bottom silo, with material storage capacity of 270,000 m^3, which can be achieved for different coals classified storage, on-demand picking, and for difficult repose of the material flow at the same time, automatic discharging or feeding system capacity of 1400 t/h, filled the domestic large coal storage system of the same size flat blank (China).

1 Project Summary

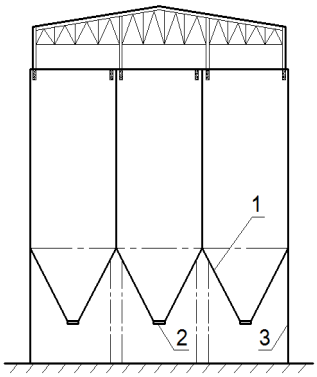
To promote the coking upgrade, and further consolidate the circular economy foundation, a circular economy pilot enterprises based on the integration of acquisition capacity, with the construction of 5 million tons/year chamber height of 6.25 m type tamping coking, adopts the dry coke quenching process, 4×18 MW waste heat power generation device, form a complete set of 2×300,000 tons 100,000 tons of methanol, ammonia and 200,000 tons of tar deep processing and 5 million tons of railway private sidings logistics cycle series project, namely ‘the 5 million tons per year of new coal chemical industry circulation economy project’. The project is an important part of the new ten-million-ton coal chemical industry base of a city economic development zone. The coking processing capacity is 5 million tons per year. Suppose plant material is according to the three major categories, which are, coking coal, gas coal, fat coal, and distribution ratio of clean coal is according to 1.35 [12], which is the need to plant the amount of 6.75 million tons/year, combined with

the energy conservation and environmental protection requirements, this article selects enclosed storage system to study.

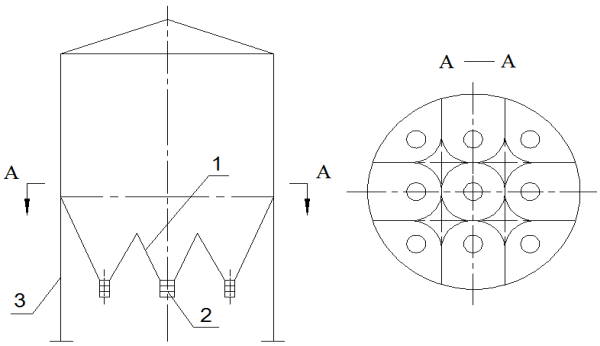
2 Solutions to Discuss

2.1 Conical bottom silo

Among the existing material storage structures, the cone bottom storehouse widely used in all kinds of raw materials and finished product storage or in transit, as shown in Fig. 1.



(a) Small diameter conical bottom silo



(b) Large diameter conical bottom silo

1. Conical funnel 2. Discharge outlet 3. Supporting steel column

Fig.1 Structure diagram of conical bottom silo

Cone bottom silo has the following features:

1) To facilitate smooth material unloading, positions on the conical bottom discharging funnel wall angle in general in more than 60°, some even up to 75°.
2) For loose liquid materials, it can automatically discharge cone bottom silo, generally without forming arch.
3) For poor liquidity, there is a requirement for water material, easy to form the bottom of the cone silo arch caused by unloading of congestion, and it need to be equipped with human or broken arch, power facilities to ensure material discharged from the warehouse smoothly.
4) Short-term storage mainly use small shallow silo diameter, and large diameter deep warehouse is mainly used for medium and long-term storage of materials.
5) Storage structure is generally designed for the tower structure, height for at least twice of the diameter.

According to structure characteristics in the cone bottom silo, conclusion as follows,

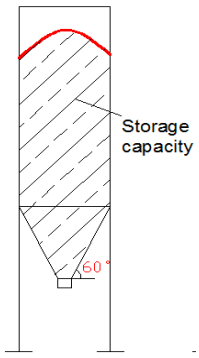
1) If the structure is high, the cost will be higher.
2) For materials of poor liquidity, tapered structure is easy to cause the material adhesion and arch, despite the design of large diameter conical bottom storehouse, adopting multipoint discharge, and discharge position also careful registration, but the problem still exists arch material.
3) Funnel part storage's capacity is small, causing the loss of storage, and material storage volume is also small.

2.2 Flat Bottom Silo

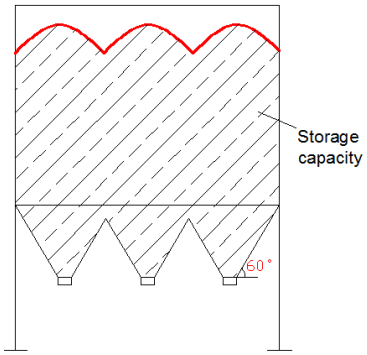
Flat bottom silo for loose and viscous material storage and transportation, energy, chemical industry and agriculture has a wide range of applications [13]. At present, the development and application of the product basic is in a state of foreign monopoly.

2.2.1 Circular flat bottom silo

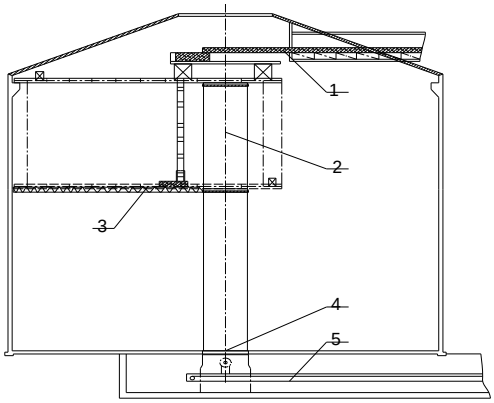
Compared with the cone bottom silo, circular flat bottom silo has no losses, greatly improving the storage capacity, as shown in Fig. 2.



(a) Small diameter conical bottom silo



(b) Large diameter conical bottom silo



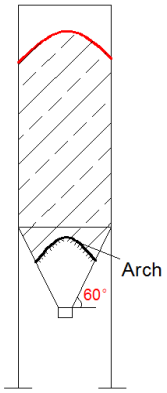
1. Feeding system 2. Column 3. Screw conveyor 4. Discharge outlet 5. Discharging system (c) Circular flat bottom silo

Fig.2 Schematic diagram of storage volume

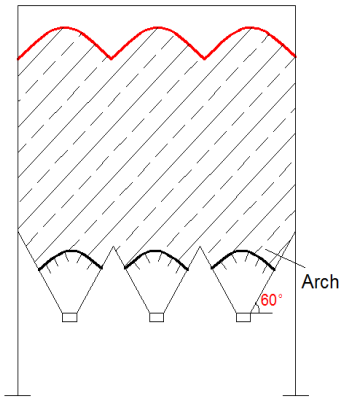
Analysis on Fig. 2 shows:

1) The small diameter conical bottom silo generally uses one feeding point; the top is a hillock shape. Large diameter conical bottom silo uses more than one feeding point, the top shape is more hillock. But circular flat bottom silo adopts screw conveyor to realize feeding. The same height can be filled the 'hill' vacant place, high space utilization.
2) Conical funnel discharge at the bottom of the conical bottom silo, so real storage materials of the space is lesser. Besides, the circular flat bottom soil opens multiple discharge outlet at the bottom, without taking up the material storage space. Bottom-up can uniform feed materials, mass bulk storage.
3) At the bottom of the conical bottom silo is supported by many pillar of steel. The circular flat bottom silo is directly on the ground, which demands less for geological conditions.

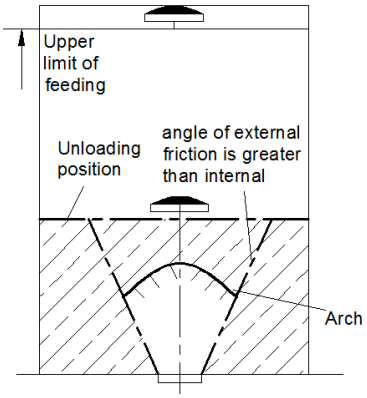
Obviously, compared to the conical bottom silo, circular flat bottom silo exist above three advantages, breakthrough the limitation of the size. But, perhaps more than 70% of the material is easy to tide, easy solidified, agglomerate, so that their liquidity is not ideal. There were at the time of discharge material of arch and jamming problems, as shown in Fig. 3.



(a) Small diameter conical bottom silo



(b) Large diameter conical bottom silo



(c) Circular flat bottom silo

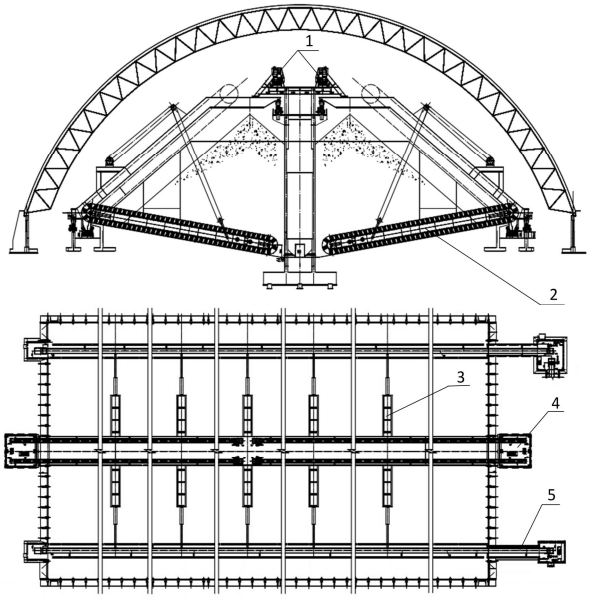
Fig.3 arch sketch

The Fig. 3 shows:

1) Whether the small diameter or large diameter conical bottom silo adopt conical funnel discharge, it is easy to cause the material forming arch (or agglomeration), as well as the unloading jams (or obstruction). Material handling capacity is limited.
2) For drying liquid material, the circular flat bottom soil can effectively improve the situation. However, when the angle external friction is greater than the angle of internal friction, it is still likely to cause agglomeration and obstruction.

2.2.2 Rectangular flat warehouse

Combined with engineering project for coal storage system in loading and unloading process, energy conservation, environmental protection, amount of clean coal requirements, we put forward a new type of rectangular enclosed flat bottom silo, operating with a reversible belt conveyor, belt feeder, automatic discharging or feeding system, flat bottom silo, automatic material level detection and control system, etc. Aimed at the difference of various kinds of coal, the design of storage and transportation system is divided into 12 areas, which can meet the 4 kinds of materials at the same time for transportation and storage. Its total width is of 90 m, total length of 327 m, storage capacity of 270,000 m^3. Changes of parameters in temperature, moisture, and the concentration within warehouse can be real-timely detected, and discharging or feeding function is put 1400 t/h, as shown in Fig. 4.



1. Feeding machine 2. Scraper conveyor 3. Warehouse wall 4. Incoming material conveyor belt 5. Taking material conveyor belt

Fig.4 Rectangular enclosed flat bottom silo

Compared with the circular flat bottom silo, it has the following advantages:

1) The accumulation of material in rectangular flat bottom silo can keep the material's nature, while in circular flat bottom soil material compaction can be caused because of screw conveyor fabric.

2) The rectangular flat bottom silo is changeable in dimension, more flexible and adapts to any construction site.
3) The rectangular flat bottom silo is easy to realize the coal block storage, while circular flat bottom silo should be built as group silos.
4) The rectangular flat bottom silo section, 2 section can share a partition, save material and covering, cost savings, while the circular flat bottom silo could not use the warehouse wall.
5) The rectangular flat flat bottom silo has simple structure, less equipment, small investment. Using 1 belt conveyor in rectangular flat flat bottom silo can realize multi-point 12 types of clot, and 2 portable scraper conveyor feeding. While circular flat bottom silo need 12 sets of screw conveyor fabric, 12 belt conveyor feeding.
6) The rectangular flat bottom silo construction period is short, simple infrastructure.
7) The rectangular flat bottom silo always can take when you pick up the material to the surface is relatively dry material, reduce the boiling coal moisture, and reduce the energy consumption in the process of coal carbonization.
8) The rectangular flat bottom precipitation in trench at the bottom of the discharge water will pass, as clean wasted water reuse for the production directly. As shown in Fig. 5 for rectangular flat bottom silo local real figure.

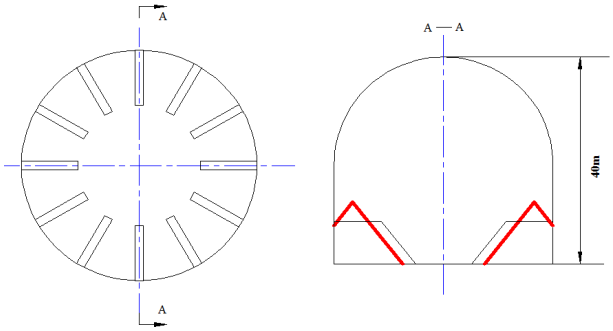
Fig.5 Rectangular flat bottom silo local real figure

2.3 ***Domed silo***

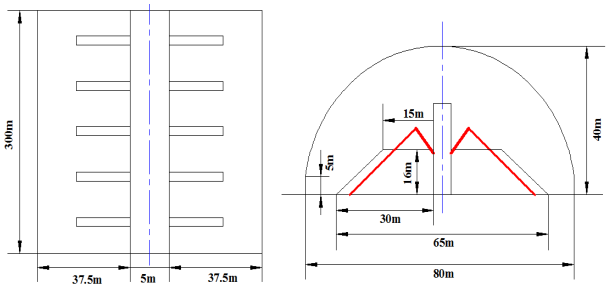
Domed silo, because of its' center funnel for direct feeding, can effectively adjust the loading capacity. Stacking work does not need mobile devices. Space utilization is higher, and pollution is less. Therefore, in electric power, building materials, chemical industry, mine, dock, coal, etc, it is widely applied [14~15].

Because domed silo can keep the material nature, store more fragmentation of coal, save material and covering, such aspects as with this article puts forward a new type of rectangular enclosed flat bottom silo has the advantages of the same, so it is necessary to carry out the deeper comparative analysis.

Under the condition of the same height and area (or equal space dimension), according to the design requirements of 12 areas, the structure diagram as shown in Fig. 6, compared with the results as shown in table 1.



(a) Hemispherical dome



(b) Rectangular closed flat warehouse

Note: the red line in figure for material accumulation outline.

Fig.6 Structure diagram of domed silo and rectangular flat bottom silo

Table 1 Space utilization comparative analysis

	Area /m^3	Capability /m^3	size			Warehousing space utilization
			length	width	height	
Rectangular flat bottom silo	750,000	270,000	300m	80m	40m	36%
Domed silo	250,000	90,000	diameter (in theory87．4m) Calculated at 90 m		40m	36%

As can be seen from table 1, under the condition of equal space dimension, rectangular enclosed flat bottom silo with dome silo space utilization is roughly equal.

3 The Results Analysis

The combined engineering project storage system is mainly used for the storage and transportation of coal. Due to different types of coal, the greater the moisture content, the greater the cohesiveness, and the more hard to flow. For the flame retardant and isolation, and deposited in the open air for a long time to avoid the coal metamorphism, considering the material properties, comparing the warehousing system development plan. It can be concluded that:

1) The circular flat bottom silo compared with conical bottom silo, there is no storage loss ,high space utilization, which greatly improve the storage capacity of bulk material. Moreover, less requirements of the geological condition are asked for.But these 2 kinds of structures are not be able to avoid the material problem, arch cannot effectively avoid the potential risk.
2) Compared with the circular flat bottom silo, although rectangular enclosed flat bottom silo covers larger area, but compared with the outdoor storage, the advantages of saving space has still been obvious. And it can keep the material properties. In addition to these, it has more advantages, like simple structure, less equipment, less investment, energy conservation, and environmental protection, etc. At the same time, it can be effectively avoided the problem of material on agglomeration and obstruction.
3) Under the condition of equal space dimension, the rectangular enclosed flat bottom silo with domed silo space utilization is roughly equal. Combined with

the project requirement for plant material used for coal blending, the rectangular closed flat warehouse can realize 4 kinds of clean coal transport and storage at the same time. The domed silo, to achieve this requirement, need to increase the equipment composition, and higher construction cost. Domed silo for circular structure, at the same time, because the dome is not easy to achieve under-bin precipitation water reuse and so on. Compared with the rectangular enclosed flat bottom silo, there is still a gap in terms of energy conservation and environmental protection.

4 Conclusion

1) Take a company of new coal chemical industry circulation economy in the project of coal storage system development, for example, the conical bottom silo and flat bottom silo are applied to coal storage system engineering research, and comparative analysis of different storage system has carried on the concrete.
2) In this paper, a new type of rectangular enclosed flat bottom silo, compared with the conical bottom silo and the circular flat bottom silo, solves the problem of the material of agglomeration and obstruction. Under the condition of equal space dimension, domed silo has equal space utilization, but lower cost, is easy to realize the classification of coal storage, and apply 4 kinds of incoming material storage and transportation at the same time, etc.
3) The rectangular enclosed flat bottom silo, with the storage capacity of 270,000 m^3 , has automatic discharging or feeding capacity of 1400 t/h, without material of agglomeration and obstruction problems, including difficult flowing material of the higher moisture content. It covers less area, needs small investment cost as well as energy conservation, environmental protection, and radiation effect. In conclusion, the application prospect in the coal industry chain will be larger and larger.

Acknowledgments

The project is supported by The key scientific research project of coal base in Shanxi Province (MJ2014-09, MJ2014-02), Graduate student education innovation project in Shanxi Province(2015BY49), The research of the graduate reform education in Shanxi(20142059), Jincheng science and technology plan projects(201501004-14), The science and technology research foundation project for School youth (20133001).

References

[1] The National Natural Science Foundation of Engineering and Materials Science (China). Mechanical engineering disciplines development strategy report (2011~2020) [M]. Beijing: Science Press, 2010

[2] Sun J P, Jiang J. Laser triangulation measurement of the level in a coal silo [J]. Mining Science and Technology (China), 2011, 21(6): 881-884

[3] Perge C, Aguirre M A, Gago P A, et al. Evolution of pressure profiles during the discharge of a silo [J]. Physical Review E, 2012, 85(2): 021303

[4] Liu S D, Zhou Z Y, Zou R P, et al. Flow characteristics and discharge rate of ellipsoidal particles in a flat bottom hopper [J]. Powder Technology, 2014, 253: 70-79

[5] Wang X W, Yang Z J, Shu X F, et al. The static contact statuses between granular materials and flat-bottomed steel silos[J]. Powder Technology, 2013, 235: 1053-1059

[6] Huitema L P. Advantages of the Eurosilo (R) concept as a large-scale storage method for coal [J]. Bulk Solids Handling, 1998, 18(2): 205-210

[7] Fischer U, Scholz C. Fire protection in closed coal storage yard [J]. VGB PowerTech, 2009, 14(12): 83-87

[8] Boumans G. Grain handling and storage [M]. Elsevier, 2012

[9] Qingda New Energy Technology Co., Ltd. QD bulk coal storage integration solutions profile [EB/OL]. (2013-11-14) [2015-06-02]. http:// www. docin.com/p-725823781.html

[10] Shen W. An energy conservation and environmental protection storage bunker built in our country which is largest in Asia [J]. Coal Science & Technology Magazine (China), 2009 (3): 43-43

[11] Yu Z D, Zheng W H. Modern coking production technology manual [M]. Beijing: Metallurgical Industry Press, 2010

[12] Ruijgrok J P J. Silo technology-large scale fuel storage silos [J]. Bulk Solids Handling, 2012, 32(5): 22-27

[13] Brown R L, Richards J C. Principles of powder mechanics: essays on the packing and flow of powders and bulk solids [M]. Elsevier, 2013

[14] Hood K, Nilsson B, Bennett S. Air cushion conveyor stacker reclaimer device and method thereof: U.S. Patent 8,177,053 [P]. 2012-5-15

Biographical notes

Wang Yao, born in 1988, is a PhD candidate at *Key Lab of Intelligent Warehousing and Logistics Equipment of Shanxi Province*, *Taiyuan University of Science and Technology*, *China*. His research interests include tribology, interfacial binding strength and logistics equipment & technology.
Tel: +8613485311641; E-mail: 710603645@qq.com

Meng Wenjun, born in 1963, is currently a professor and a PhD candidate supervisor at *Key Lab of Intelligent Warehousing and Logistics Equipment of Shanxi Province*, *Taiyuan University of Science and Technology*, *China*. His main research interests include key technologies of special high-performance transport machinery and hoisting machinery.