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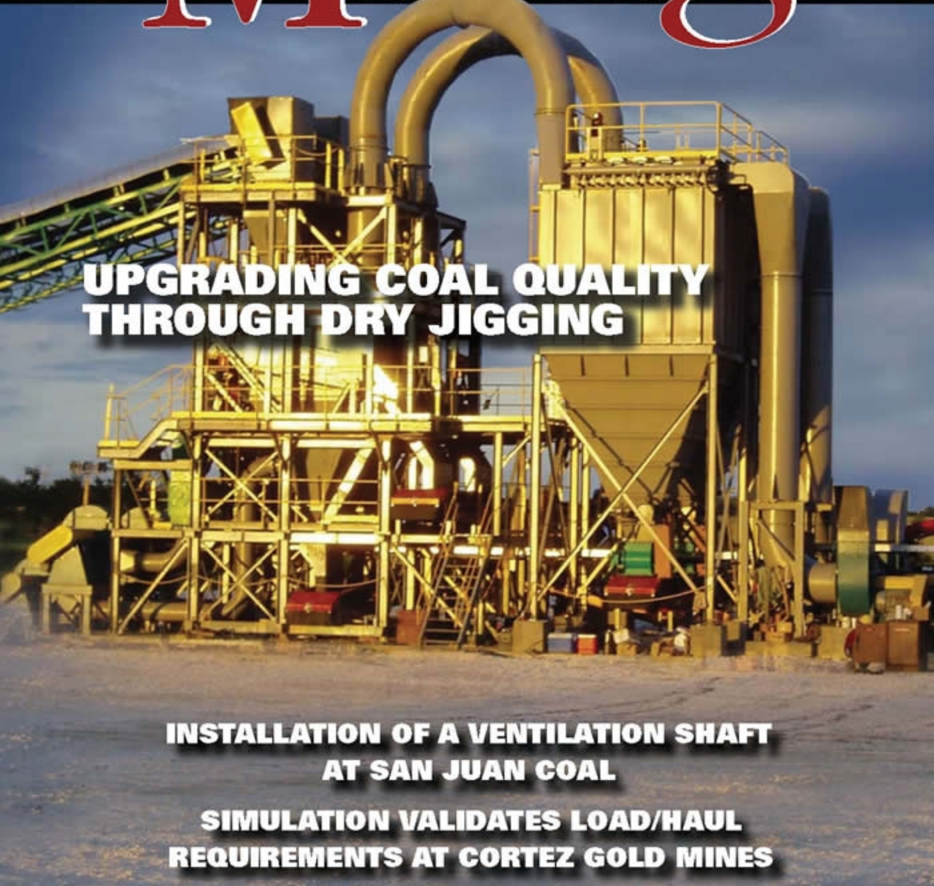

UPGRADING COAL QUALITY THROUGH DRY JIGGING

INSTALLATION OF A VENTILATION SHAFT AT SAN JUAN COAL

SIMULATION VALIDATES LOAD/HAUL REQUIREMENTS AT CORTEZ GOLD MINES

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Advances in dry jigging improves coal quality

Dry jigging of coal is environmentally friendly and uses less water. However, it is not right for every application.

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There are many advantages to upgrading coal with dry jigging technology. The most obvious is the lack of process water, which eliminates the need for fines dewatering and slurry confinement. Dry jigging eliminates the clean coal moisture penalty associated with wet processing. Particulate emissions are virtually nonexistent due to inclusions of fabric dust collectors on all modern dry jig plants. Because of the environmentally friendly nature of dry jig plants, installation permits are often measured in days, not months. There has also been a fundamental advance in dry jigging efficiency. All of these advantages have renewed the coal industry's interest in dry jigging. But air jigging is not right for every application. There are limitations due to particle size, particle shape, moisture and near gravity content.

This article explores the evolution of dry jigging. It reviews parameters important for determining the suitability of dry jigging. It also compares historical performance data as measured by imperfection, against results from modern dry jigging technology. The article also presents data from modern dry jig installations.

Advantages of dry processing

Whether coal is upgraded by wet or dry technology, the reduction in ash, sulfur, mercury and other mineral contaminants, while increasing the calorific value, benefit the cleanliness, efficiency and operating costs of coal users. This includes power plants, coke operations and sponge iron plants. Consuming high-ash and high-sulfur coal in the production of power contributes to pulverizer wear, boiler tube wear, slagging and fouling and loss of generation capacity. Poor quality coal produces unacceptable coke. At sponge iron plants, it decreases yield.

Dry beneficiation of coal offers a number of advantages. Governments all over the world are continuing to place more stringent limits on the release of pollutants from coal cleaning plants. Air jigging has an inherent advantage since it uses no process water. Also, modern air jig plants are supplied with fabric dust collectors that eliminate dust as a pollutant. Therefore, one of the principal advantages of the modern air jig plant is environmental friendliness.

Dry cleaning does not introduce a moisture penalty to the clean coal product. This advantage is particularly important if the amount of improvement needed is minimal. The processing cost for upgrading coal with dry technology is often low and further enhanced by the elimination of

Air jigging uses no process water, which helps reduce the amount of pollutants that are released from coal cleaning plants.

water treatment and fines dewatering and disposal. And there are many locations where water is scarce or expensive. Dry processing for these applications is sometimes the only option, short of abandoning the reserve.

Many surface coal mines lose 10 percent or more of their reserves due to mining methods that discard top and bottom cleanings and ribs. Air jigs can be used to recover a significant portion of this lost coal. Not only will this “opportunity” coal provide a new revenue stream, it will also reduce the amount of waste that must be handled; and extends the mine’s reserve life.

Most of the advantages mentioned are inherent with all dry processing technologies. Yet, for many decades, little coal was improved with dry methods. The reason was the poor separating efficiency of dry processing and a properly earned negative reputation. The renewed interest in dry cleaning in general, and air jigging in particular, is primarily due to improvements in performance. By optimizing the stratification of feed particles and introducing an automatic refuse removal control system, mine operators are able to use a dry processing system with a quantum improvement in separating efficiency. Their coal can be upgraded, dry, without a severe penalty in yield.

Evolution of dry jigs

Dry beneficiation is a natural outgrowth of mining. It is easy to imagine the first miners selecting high quality ore from a pile of broken particles at the face. Most people in the coal industry have seen old pictures of men and boys hand-picking rock from a slow moving conveyor. According to the fourth edition of *Coal Preparation*, the first commercial pneumatic machine for concentrating coal was introduced in 1916. By 1938, air separators accounted for 16 percent of the clean coal produced in the United States.

Historically, the coal industry preferred air jigs to other dry separating devices. This is where the development of Allmineral’s air jig (Allair Jig) began. Because there had been no advances in air jig technology for more than 50 years, it was not difficult to identify areas of improvement.

By applying already developed and proven wet jigging technology with the design of a modern air jig, the Allair Jig began to take form. From simple concepts, such as ensuring the feed is homogeneous and evenly distributed, to more complicated concepts like structuring the jigging stroke, each component of the Allair Jig was optimized and Allmineral revolutionized dry jigging technology.

Excluding crushing and screening, coal was first upgraded by handpicking. Many mines employed slow moving picking conveyor. This was where workers stood on either side of the belt and lifted or pushed waste material into bins. During the 1920s, pneumatic cleaning was introduced to the United States’ coal industry. Hand picking operations declined and eventually disappeared. Pneumatic cleaning of coal encompasses a number of processes and devices. But soon two basic concepts dominated, air tables and air jigs.

Table designs were based on stratifying feed material with a constant upstream of air followed by separation of coal from rock at different places around the table. Since tables’ principal stratifying mechanism involved differential falling velocity between coal and higher specific gravity minerals, the particle size range of the feed was critical. The closer the feed’s particle size distribution, the more efficient the tables became. Preparing a closely sized feed is not always easy, especially if moisture values are high or changing.

Improvements in the performance of dry processing, including the introduction of automatic refuse and removal control systems, has sparked a renewed interest in air jigging.

The amount of refuse in the feed was also important. It should not exceed the table’s transport capacity. High-density reject material usually required transportation to a discharge point by traveling along grooves or being pushed from ridge to ridge by an oscillation movement. If the amount of refuse in the feed exceeded capacity, rock reported to clean coal. Since it is necessary for the coal and refuse to find their way to different discharge points, the flow of material on a table must be countercurrent and the bed depth must be thin.

Air jig operation is also based on stratification of the feed before separation, but there are fundamental differences. The air jig used pulsed air and co-current flow of refuse and coal. This concept stratified the feed by several different mechanisms. Differential falling velocity plays a role. But air jigs also used hindered settling and consolidated trickling of particles. The practical benefit of air jigging was the ability to efficiently process wider particle size distributions. It was not unusual for air jigs to process feeds with a particle size range of 10 to 1. The air jig's deeper bed had the additional benefit of allowing very high-density, fine particles, such as pyrite, to trickle through the bed.

Separation of rock from coal was crude with the early air jigs. Typically, an operator was required to watch the jigged bed and manually adjust the discharge. Alternately, a discharge gate was set to a fixed position and a fixed volume of sink product was removed. Of all the technologies and machines available for dry cleaning coal, the marketplace favored the air jig because of its high unit capacity, ability to accept a large range in feed size and superior performance.

Knowing the history of air jigging as well as modern jigging technologies, Allmineral began to develop the Allair Jig. It was apparent that this new jig must be competitive within the market and the most efficient air jig to date. The design began by looking at the Alljig, Allmineral's wet jig and air processes of the past. The prime goals were automatic refuse removal, low costs, low manpower and modular construction.

A star gate was integrated into the Allair Jig design to meter homogeneous feed evenly across the entire width of the jigging bed. A constant velocity fan (working air) was used to loosen the bed of material. Transport in the jig was enhanced with external vibrators. A pulse air fan was added to optimize stratification by offering independent control of stroke frequency, amplitude and acceleration. The last major improvement was a fully automatic bed level controller with analog measurement of the interface between coal and reject.

The Allair Jig is a deep-bed separator that exploits the advantages of hindered settling and consolidation trickling. Feed is introduced to the deck of the jig from a surge hopper using a variable speed star gate. This permits the controlled, full-width distribution of feed across the bed. Each revolution of the star gate delivers a controlled volume of feed and the engineered design of the discharge throat eliminates material bridging.

Air is provided to the jig in two forms — a continuous flow and a superimposed pulsated airflow that provides the impetus for stratification and consolidation trickling. This system is analogous to the operation of a wet jig. The hutch structure uniformly distributes air to all areas of the jigged bed, reducing turbulence and dead spots. A pulsed air stroke is superimposed on a constant stream of rising air currents. This allows the Allair Jig to independently control stroke amplitude, frequency and acceleration. Thus, stratification of the feed material is enhanced. The perforated deck and hutch design work together to provide an even distribution of air across the deck, independent of the coal burden on the deck.

Lower forces are developed in an air jig than in a wet jig due to the density of air being much less than water. These lower forces make traditional measurement of the reject coal interface impossible. The solution was an automatic bed level control system using nuclear density instrumentation. The information from the nuclear instrument is conditioned and fed forward to activate a refuse discharge star gate. For the first time, an air jig was able to remove refuse in proportion to the amount coming in with the feed. Additionally, the design of the Allair Jig discharge, a single discharge mechanism, maintains a reserve layer over the discharge gate of high-density material. This system keeps the low-density particles a fixed distance from the screen bed, minimizing misplace-

Table 1

Modern air jig performance vs. 1979 U.S. Department of Energy (DOE) air jig data.

Test Reference	B-2	A	C
Feed Size	2 in. x 0	0.75 in. x 0	+0.75 in. x 0
Performance data size	2 in x 0.25 in.	0.75 in. x 0.25 in.	2in. x 8#
Feed Ash	16.80%	52.00%	16.04%
Clean coal ash	11.30%	34.81%	7.15%
Refuse ash	18.50%	71.95%	29.77%
Specific gravity of separation	2.20	2.10	1.50
Probable error	0.40	0.55	0.21
Imperfection	0.33	0.50	0.42

Table 2

Modern air jig data from 2005 (DOE).

Test Reference	Bituminous	Bituminous	Lignite Plant 1
Feed Size	2 in. x 0.5 in.	0.75 in. x 0	1.25 in. x 14#
Performance data size	2 in. x 0.5 in.	0.75 in. x 20#	1.75 in. x 14#
Feed Ash	14.81%	21.29%	N/A
Clean coal ash	6.69%	13.06%	N/A
Refuse ash	51.03%	60.40%	N/A
Specific gravity of separation	2.00	2.20	1.95
Probable error	0.16	0.21	0.27
Imperfection	0.16	0.18	0.28

Table 3

Coal quality percentage improvement ranges — North Dakota lignite testing.

	Falkirk Mine				Freedom Mine	
	Typical Coal		Opportunity Coal		Typical Coal	
	Low	High	Low	High	Low	High
Btu	1	6	19	25	1	2
Ash	-5	-23	-38	-52	-4	-13
Sodium	-2	2	-7	27	1	4
So_2/ MMBtu	-8	-31	-30	-67	-10	-31
#Hg/ TBtu	-13	-32	-42	-70	-20	-31
Energy recovery	94	99	72	73	96	99

ment. The layer of high-density particles also enhances the hindered settling and consolidated trickling aspects of the jigging stroke. The Allair Jig's automatic bed level control system minimizes the misplacement of coal and improves stratification.

From concept to pilot to prototype to production, each Allair Jig component was academically studied and field-tested before being offered commercially. Dry cleaning coal is often the lowest cost technology for operating, maintaining and capital costs. The result is a pneumatic cleaning device that is friendly to the environment, safe and easy to operate, rugged, inexpensive to operate, inexpensive to maintain and efficient.

Application criteria

Equipment venders do not want to install their equipment in the wrong application. With the idea in mind that all air jigs will be placed in the proper applications the following criteria is suggested:

- An air jig should usually be used in relatively low, near-gravity applications. Normally, this means high specific-gravity separations.
- If water is available, make calculations to determine what difference in yield can be expected with different circuits.
- Identify surface moisture. Modern air jig plants can typically process any feeds that will not plug existing material handling systems. Regardless, the coal and reject particles must be discreet. Agglomerates will report to either discharge (clean coal or reject) in gravity separation equipment, such as air jigs.
- Identify the support circuits required. The performance of most dry, processing equipment declines above 50 mm (2 in.) and below 0.5 µm (28 mesh). Modern air jigs are no exception. Crushing and screening equipment are often needed at air jig plants. The feed should be relatively homogeneous and constant. Some type of surge storage with a feeder usually meets this need.

Positive criteria for an air jig application include:

- Water is expensive or not available.
- The separation is high gravity and "black and white."
- Coal will be discarded in the mine due to excessive dilution rock.
- Recovery of coal from waste.
- Deshaling of sized, run-of-mine (ROM) coal prior to long hauls.
- Clean coal ash requirements less than 5 percent lower than feed ash.
- Pyrite removal is the principal objective.
- Coal that breaks down upon exposure to water.

Performance: past and present

There are many reasons to prefer dry processing for upgrading coal. Of course, the advantages must be measured against the limitations. Until recently, the principal disadvantage was poor separating efficiency. Between 1960 and 2000, there was essentially no improvement in any dry processing technology. Not surprisingly, the amount of coal cleaned with dry processing equipment declined to nearly zero.

During the last 10 years, several new dry processing machines have been introduced to the coal market. One of them, the Allair Jig, has been used to upgrade metallurgical coal, steam coal and lignite. It has cleaned high ash and low ash feeds. From these many installations, as well as hundreds of pilot plant tests, it was possible to construct dozens of imperfection curves. Tables 1 and 2 illustrate how the Allair Jig offers a quantum improvement in efficiency.

In addition to the performance information in Tables 1 and 2, there was a project undertaken to identify the benefits of improving the qual-

Feed is introduced to the deck of the jig from a surge hopper using a variable speed star gate, which permits even distribution across the bed.

ity of lignite for the production of electricity. This project was sponsored by Falkirk Mining, Great River Energy, Coteau Properties, Basin Electric, North American Coal, the University of Kentucky, Electric Power Research Institute (EPRI), Energy and Environment Research Center (EERC), Barr Engineering and Allmineral As part of the scope, hundreds of air jig separation tests were conducted on dozens of different lignite seams.

The typical coals are those currently being delivered for power production. The opportunity coals are those being discarded during the mining process due to low Btu as the result of contamination or high sulfur content. The opportunity coal presents the potential to recover more of the in place resource.

Falkirk Mining, EERC, Black and Vetch and Great River Energy evaluated power plant performance improvement efficiency and cost improvements for baseline coal and air jig cleaned coal. The results of these evaluations determined the benefit for cleaning typical mine shipments as well as for the improved coal recovery of opportunity coal from coal ribs and coal cleanings.

During the past 10 years, several new dry processing machines have been introduced to the market.

Additional tests were conducted on nearly 10 different seams and combinations of lignite seams from mines operated by North American Coal and subsidiary companies in Mississippi, Louisiana and Texas. Positive results were seen for the opportunity coal. And the typical coal improvement has indicated that a good percentage of current deliveries would be substantially improved.

The Mississippi mines had more near-gravity material and the performance there fell below the performance seen at the other locations.

Overall, the testing showed that the modern air jig can substantially reduce the ash content of the coal, resulting in increased heating value. Further, a significant reduction in sulfur and mercury can be realized while achieving high energy recovery. The refuse generated by the process is a stable, dry material that can be returned to the mine for placement in a non-oxidizing environment and covered by subsequent open cast mining operations.

Case histories

There are modern air jigs in operation around the world. The reasons and justifications for their installation are as varied as the cultures where they reside.

The first commercial sized, modern air jig was tested at a coal operation in Colorado. During its initial shakedown, several mechanical problems were identified. These included plugging of the feed chute, weakness in the jigging bed subframe and transport capacity of the refuse chute. Nevertheless, it was clear that coal could be efficiently cleaned.

The production air jig was tested at a coal mine in Ohio. During the test period, mechanically weak areas were identified and corrected

After six months of testing, a larger duel air jig plant was purchased.

The test period proved there would only be a small difference in overall yield between a wet plant and an air jig plant. But there was never any doubt that a wet plant would provide higher recoveries. The decision to purchase an air jig plant was not obvious. Like most decisions, many factors contributed to the justification. First, mine production was only 200 kt/a (220,000 stpy). The cost and time to permit a wet plant, and the bonding requirements for a wet plant were substantial. But the most important was that there was a never-ending liability associated with the wet plant slurry ponds.

The production air jig plant received crushed and sized raw coal from Ohio seams Number 5 and Number 6. Operating protocol called for coarse coal 50 x 13 mm (2 x 0.5 in.) to be processed in the morning and -13 mm (-0.5 in.) in the afternoon and evening. The coarse feed rate normally varied between 100 and 120 t/h (110 and 132 stph). The fine feed rate varied between 50 and 80 t/h (55 and 88 stph). The reason for varying the feed rate was usually determined by the plant operator, based on the amount of misplaced coal observed in the reject.

As with all gravity-based separating equipment, the modern air jig is more efficient with coarser particles. Because both seams were continuously mined and comingled, the feed and product ashes would constantly vary. Typically, feed coal would be delivered to the air jig in the range of 15 to 25 percent ash and a coarse, clean coal product of 10 to 14 percent would be produced, depending upon the blend. The fine feed would be delivered at similar raw ash levels, but the fine clean coal would only be cleaned to an ash content of 13 to 18 percent. Reject ash ranged between 50 and 60 percent. When viewing the reject, it was always dramatic to see the "gold nuggets" of pyrite. It was not uncommon for the sulfur content of the reject to be in double digits.

From a steam coal in Ohio to a metallurgical coal in Colombia, the modern air jig was quickly gaining diversity. Colcarbon, one of the largest coking coal producers in Colombia, operates several coke oven plants in the north central region of the country. Nearly half of the feed coal comes from captive mines and the other half is purchased on the open market from local mines. The quality of the purchased coal varies widely. To meet world coking coal standards, it was clear some form of coal preparation would be needed.

Colcarbon's president, Camillo Montana, came to the United States to observe two modern air jig installations. One of the plants, the prototype commercial air jig plant, initially tested in Colorado and later at Holmes, was sitting idle at a coal mine in West Virginia. Shortly after the visit, this plant was on its way to Colombia. Since this first purchase, five additional machines have been ordered. Two machines are in operation at each of three coke plant locations. These machines upgrade two distinct sizes of coal at each location. A coarse feed of 50 x 10 mm (2 x 0.37 in.) reports to one air jig, while a finer feed of -10 mm (-0.37 in.) reports to the second one.

The main reason Colcarbon chose dry cleaning was a lack of water at the sites. A second reason was the low reduction in ash sought. Typically, the difference between feed ash and product ash would be less than 5 percent. With wet beneficiation, an undesirable increase in product moisture would occur. The reason a modern air jig was selected rather than some other dry process was due to its efficiency. Without a modern air jig, Colcarbon would find it difficult, if not impossible, to make an economic coke product.

In another example, 12 modern air jigs were retrofitted into an existing 600 t/h (660 stph) lignite cleaning plant in Europe. The original plant contained 36 air tables for cleaning the plus 6 mm (0.25 in.) and 48 wet shaking tables, along with a thickener, slimes pond and other equipment associated with fines dewatering. The feed was limited to a top size of 30 mm (1.25 in.). A clean product with 3,500 kcal/kg (6,356 Btu/lb), and minimum 5.5 percent sulfur was prepared from feeds with 3,400 kcal/kg (6,174.4 Btu/lb) and 5.8 percent sulfur at a recovery of 91 to 92 percent.

Performance of the renovated plant, with modern air jigs, is identical with the old one, except for costs. The new plant uses 50 percent fewer people and maintenance costs are lower. The circuit is simplified as well.

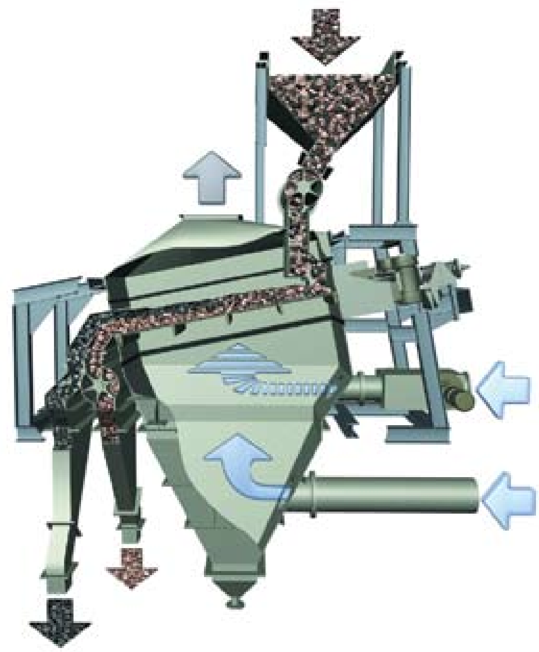
With the new plant, raw feed is classified at 30 mm (1.25 in.). Everything -30 mm (-1.25 in.) is fed to the air jigs. For this mine, performance was critical. But, once performance was confirmed, cost made the decision easy.

Indian coals are well known for being highly intergrown with mineral matter (ash). It is not unusual for raw coal to have ash contents in excess of 40 percent. Due to regulations and other reasons, such as the condition of India's transportation system, coal consumers have little control about the source and consistency of the coal they receive.

OCL is a major Indian conglomerate. It was interested in improving the quality and consistency of the coal the company used in its direct iron reduction plant. Often, the most efficient wet process is the only option for upgrading Indian coal.

At OCL, there was a unique opportunity to use the modern air jig. By air jigging 50 x 4 mm (2 x 0.15 in.) feed coal with an ash content of 40 to 45 percent, a clean coal product of 34 to 37 percent can be produced. This quality of clean coal significantly improves the operation and economics of OCL's sponge iron plant. At the same time, a reject product with an ash under 50 percent can be made (with blended fines from the dust collector) that is acceptable to burn in the steam plant. By using all of the products (clean coal, reject and dust) minimizing operating costs and streamlining the permitting process the purchase of an air jig plant was justified.

Air is provided to the jig in a continuous flow and a superimposed pulsated airflow.



Summary

There are many advantages to dry processing coal. Costs are reduced that are associated with process water, environmental fees and maintenance when coal is upgraded without added moisture. While there are many operators that want to use the modern air jig, there are limitations. Careful analysis of the most economic system should be conducted.

The performance efficiency of the modern air jig offers a quantum improvement compared with air jigs tested in the 20th century. This fundamental advance in efficiency offered by the modern air jig extends the boundaries for dry processing of coal. It is now possible to upgrade coal into a salable product that was previously discarded. This not only improves the bottom line, it also extends the life of our resources. ■

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