

Rational Application of Container Technology at Dumping

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Abstract – A new environmentally friendly container technology has been developed for lifting rock mass at quarry dumps using mobile complexes, which can reduce environmental pollution, improve mining regimes and reduce lifting costs. Container delivery of rock mass involves a single removal of the container and its lifting by lifting machines with a minimum tare coefficient. All equipment of the transfer point is placed on self-propelled carts, which allows for quick movement to a new location. The screen and jaw crusher, which are part of the equipment of the transfer unit, prepare the rock for loading into containers. Filled containers are transported to the unloading site using a conveyor belt and a lifting machine. The container's hydraulic system allows for automatic unloading of the rock mass. The simplicity of the design of the developed equipment allows it to be manufactured directly at the mining enterprise itself.

Keywords – Container; conveyor; dump truck; efficiency; gripper; lifting machine; productivity; reloading device.

1. INTRODUCTION

Environmental assessment of the negative impact of various types of factors on the environment is a constant subject of discussion among scientists [1]–[4] and is a complex and still unresolved problem.

An increase in the depth of the quarry is associated with an increase in the work of quarry transport in limited areas of sites, requiring a constant increase in the number of transport units, which increases the environmental load on the environment.

When developing an ore deposit by open-pit mining, it is necessary to remove a large amount of overburden, the volume of which is many times greater than the volume of ore mined. The rock mass extracted from the quarry is stored on external dumps, which occupy large areas and significantly worsen the ecology of the region.

The mining industry has entered a new stage of development and is capable of supplying the market not only with extracted minerals [5], but also with technogenic georesources formed during the extraction of minerals, which have a certain value [6]. The main areas of formation and use of georesources are:

- Targeted selective storage of overburden rocks in the form of man-made deposits for the purpose of their further development;

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- Targeted formation of quarry space and overburden rock dumps as independent objects for various purposes, including a recreation area, a construction site, a container for storing hazardous industrial waste [7].

At present, dumping technologies receive little attention and lag significantly behind quarry technologies in terms of productivity and cost [8]. Currently, several dumping technologies are known, depending on the means of transporting the rock mass and the physical and mechanical properties of the rocks.

The dumping of finely crushed rocks during their delivery to dumps by rail can be carried out by mouldboard ploughs. A mouldboard plough is a self-propelled or trailer car of a special design, equipped with ploughshares on one or both sides [9]. The technology of dump formation consists of moving the rock unloaded from dump trucks with the help of dump ploughshares towards the dump slope during its movement along rails. In this case, the dumping is carried out along the entire length of the dump dead end.

The placement of solid rocks in dumps during delivery by road transport is carried out by powerful bulldozers [10]. Dump trucks unload at some distance from the edge along the periphery of the dump. Bulldozers move it down the slope, leaving it at the edge of the protection embankment.

When developing deposits with durable rocks and transporting them by rail, a dump using mechanical excavators is used. The dumping technology consists of removing rock unloaded from dump cars and placing it in a dump by a single-bucket excavator. The excavator is located below the level of the railway tracks at the excavator unloading height. The rock is unloaded from the dump cars into a pit constructed by the excavator itself. After unloading the rock, the excavator places it first in the lower riser and then in the upper one [11].

For well-crushed rocks and when using conveyor transportation in the quarry, it is possible to organize the formation of a waste dump using transport waste dump bridges [12].

Bulldozer dumping is most widely used in quarries, when rock is delivered to the dump by dump trucks. The placement of strong rocks into dumps when delivered by road is carried out using powerful bulldozers. Dump trucks are unloaded at some distance from the edge along the periphery of the dump. Bulldozers move it down the slope, leaving a safety shaft on the edge [13]–[15].

In case of weak, unstable rocks, dump trucks are unloaded outside the possible collapse prism and the distance of rock movement by a bulldozer reaches 10–15 meters. Movement of dump trucks on freshly dumped waste is difficult, especially in spring and autumn. This significantly increases the load on the chassis of the vehicles, which is one of the main reasons for their emergency failure.

Dumping during road delivery of rock requires a significant length of the work front. This is due to the need to allocate zones for unloading dump trucks, zones for the work of bulldozers and zones for temporary settling of the dump slopes during the period of landslide processes in the freshly dumped massif [16]–[19].

The result of the need for a large front of waste dump operations is the impossibility of carrying out the mining and technical stage of reclamation of the external waste dump before the completion of its backfilling. The period of alienation of land areas for the placement of waste dumps is maximum – it is equal to or exceeds the period of formation of the waste dump. During the entire period of waste dump backfilling, the area of dust blowing is also maximum – one of the main factors of pollution of the surrounding lands.

Environmental problems associated with the use of quarry vehicles have several directions [20]:

- pollution of the quarry atmosphere from exhaust gases emitted by diesel engines;

- dust emission when blowing off the surface of the rock mass in the body and from the interaction of car wheels with the road surface;
- dust emission from the surface of external waste rock dumps;
- increased land areas for the placement of external dumps and withdrawal of these areas from agricultural circulation for long periods.

For all known technologies of waste dumping [21]–[23] it is necessary to organize the movement of vehicles on the dump surface, therefore, to create good roads. Since the deposited rock has low stability, it is necessary to carry out constant monitoring of roads and railways. The scheduled railway track on the dump is shown in Figure 1, according to which it is clear about the possible consequences of laying the track on low-bearing rocks.



Fig. 1. Railroad track on a waste heap. 1 – buckle of rail track; 2 – subsidence of ballast layer; 3 – wagon.

The operation of mining equipment on dumps with existing technologies causes a number of problems, the main of which is the movement of equipment near the prism of a possible rock collapse. It is necessary to develop special measures to help prevent rock collapse [24].

The purpose of this work is to establish the possibility of increasing the efficiency of quarry waste dumping technologies by substantiating the conditions and parameters for the application of container waste dumping technology in quarries and open pits, taking into account the provision of a standard level of industrial and environmental safety.

To achieve the stated goal, the task of substantiating the conditions and parameters for the application of container waste dumping technology in quarries and open pits is being solved, which will reduce environmental pollution, improve mineral extraction modes and reduce the costs of lifting rock mass.

2. METHODS AND METHODOLOGY

An analysis of the current state of quarry waste disposal technologies at dumping has made it possible to establish their most important indicators, the value of which can be used to judge the degree of perfection of these systems and identify possible directions for their further development, taking into account the reduction of the negative impact of mining equipment on the environment.

An increase in the depth of quarries and an increase in the volume of mineral extraction influence the formation of quarry dumping technologies [13], [17]. The main disadvantages of modern quarry waste dumping technologies are the pollution of the atmosphere by exhaust gases and dust during high traffic intensity in the limited dimensions of the quarry, as well as the relatively high operating costs for the movement of rock mass. The current practice of developing waste dumping technologies generally does not take into account the level of their negative impact on the environment, pollution of the atmosphere with dust as a result of it being blown off the surface of the transported material, which leads to unfavourable working conditions for personnel and to a deterioration in the technical and economic performance of enterprises.

To solve all these issues, it is proposed to use container technology for transporting backfill rocks in the dump. The main element of the technology is a mobile lifting machine, and there is no need to build roads or railways on board and on the surface of the dump [25].

The proposed technology of container delivery of rock mass carries out lifting of the container with rock by lifting machines with a minimum tare coefficient. The screen and jaw crusher, which are part of the equipment of the handling plant, prepare the rock for loading into containers. Filled containers are transported to the place of lifting and unloading using special container trucks and a lifting machine. The hydraulic system of the container allows for automatic unloading of the rock mass. The simplicity of the design of the developed equipment allows for its manufacture directly at the mining enterprise itself.

In the process of open-pit mining, using the proposed technology, the rock mass can be delivered to the dump site using two schemes: using the first scheme, the rock mass in the faces is loaded into containers and delivered directly to the site of lifting and dumping by special container trucks; according to the second, the rock mass from the faces is delivered by dump trucks to the hoppers of crushing plants, equipped with plate or belt feeders, with the help of which containers are loaded for further lifting and laying the rock in the dump.

The containers are equipped with self-unloading capability, as a result of which the rock mass is poured directly to the dump site. Containers with rock are installed in front of the dump front, and the lifting machine is placed on special pre-dump platforms.

When using container technology, transportation costs are reduced by reducing the time it takes to unload vehicles, and therefore, the productivity of the entire complex of equipment for lifting rock mass is increased [26]. The technological scheme for lifting containers on dumps has sufficient reliability and flexibility. This allows for a gradual increase in lifting height, distribution of lifting equipment across the entire dump, and distribution of rock into different types, which will allow it to be used in the future.

Container lifting allows solving some problems of rock dumping:

firstly, the rock mass is lifted using lifting machines, which reduces energy costs compared to transportation by road;

secondly, unlike rail transport, when placing rock in a dump, the process of transferring rock mass from the quarry is not carried out;

thirdly, the long boom of the lifting machine allows significantly increasing the height of the dump tier and the width of the approach [27].

The new equipment set allows the height of the dump to be increased, which will reduce its area. This will provide significant environmental and economic benefits.

Container technology will change the way work is done, while at the same time reducing the height of the rock mass due to its layer-by-layer horizontal laying. The large dimensions of the boom of the lifting machine will increase the volume of rock mass stacked within the dump area.

The safety of mining operations will be achieved by the absence of transport communications on the surface of the dump. A mobile transfer point will be created on the surface of the earth next to the dump, where containers will be intercepted. The rock will be automatically unloaded at the required point on the surface of the dump, after which the empty container will be delivered back to the loading area by a lifting machine [28].

Filling of the containers with rock mass on quarry dumps will be carried out through an intermediate bin with a plate or belt feeder. The dump formation scheme is shown in Fig. 2.

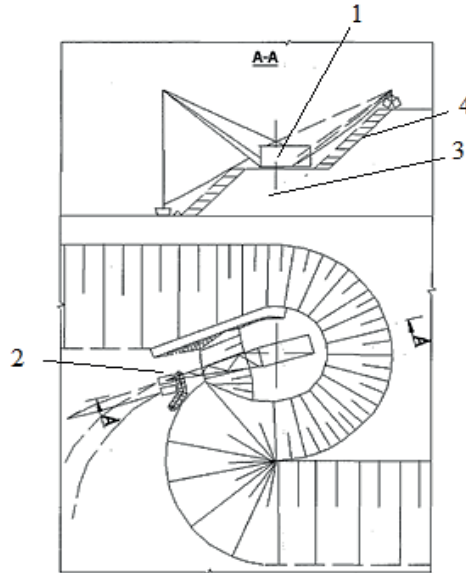


Fig. 2. Dumping scheme for container technology with layer-by-layer rock stacking. 1 – lifting machine; 2 – container loading area; 3 – dump tier; 4 – layer-by-layer rock stacking platform.

According to this scheme, the rock mass is delivered from the faces by dump trucks of any lifting capacity and unloaded into the hopper of the plate feeder, which fills the containers as they are fed by the quarry lifting machine.

The crane based on the *Liebherr* HS-8300 rope excavator, shown in Fig. 3, is proposed to be used as a lifting machine. The HS-8300 excavator is designed for heavy-duty mining conditions and is distinguished by its high productivity. The accumulator provides the ability to recuperate energy during operation, simultaneously reducing fuel consumption and wear of the free unloading winch.

To determine the height of the dump tier, we use the diagram shown in Fig. 4.

The unloading radius of the lifting machine R_p , m, is determined by the formula [29]:

$$R_p = L_c \cos(\gamma) + d, \quad (1)$$

where

L_c is the boom length, m;

γ is the boom angle, deg.;

d is the distance from the axis of rotation of the lifting machine to the heel of its boom, m.

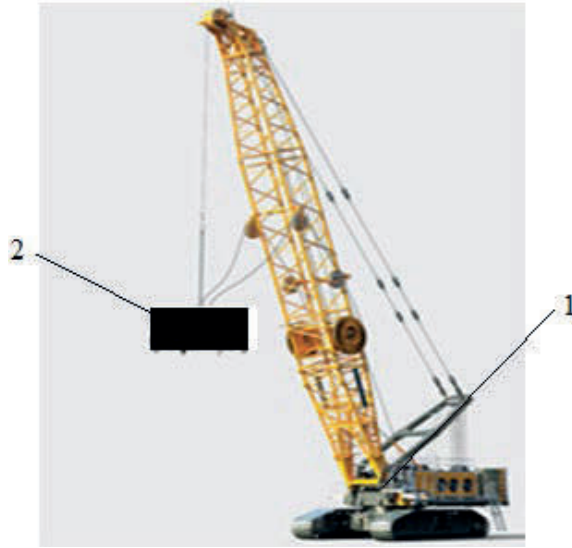


Fig. 3. HS-8300 rope excavator with grab; 1 – HS-8300 excavator; 2 – container.

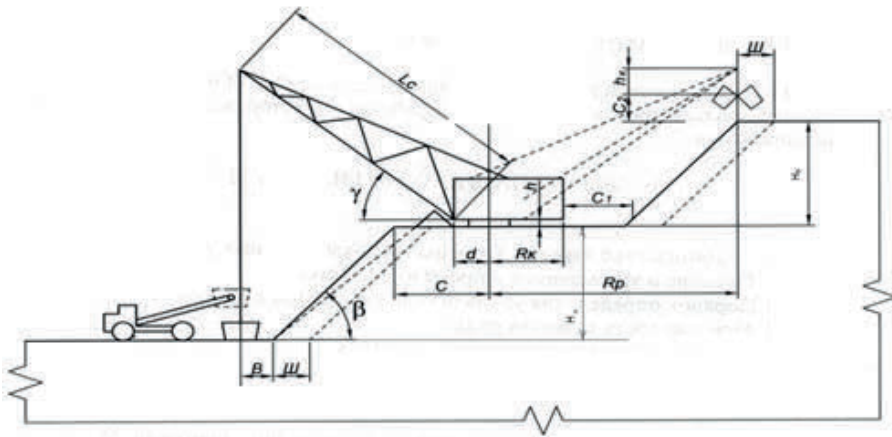


Fig. 4. Scheme for determining the lifting height.

The height of the lower ledge H_{hy} , m, is determined by the formula [30]:

$$H_{HY} = (R_p - B - C) \operatorname{tg}(\beta), \quad (2)$$

where

- B is the distance from the container axis to the lower edge of the lower bench, m;
- C is the safe distance from the dragline rotation axis to the upper edge of the lower bench, m;
- β is the bench batter angle, deg.

The height of the upper bench H_{VU1} , m, according to the safety condition of rotation of the lifting machine is determined by the formula:

$$H_{BY1} = (R_p - C_1 - R_k) \text{tg}(\beta), \tag{3}$$

where

C_1 is the safe distance between the body of the lifting machine and the slope of the upper ledge, m;

R_k is the radius of rotation of the body of the lifting machine, m.

The height of the upper ledge H_{BY2} , m, according to the condition of lifting the container is determined by the formula:

$$H_{BY2} = L_c \sin(\beta) + h - h_k, \tag{4}$$

where

h the height of the boom heel axis above ground level, m;

h_k height of re-lifting of the container when installed on the upper ledge, m.

The height of the upper ledge (according to the minimum condition) is determined by comparing H_{vu1} with H_{vu2} .

The smaller value is taken as the value of the ledge. The lifting height is determined by the formula (5):

$$H_{II} = H_{HY} + H_{BY}, \tag{5}$$

Calculations were carried out for the boom length of the lifting machine equal to 50 meters. Based on the calculations performed, a graph of the dependence of the lifting height on the boom angle of the lifting machine was constructed (in accordance with Fig. 5).

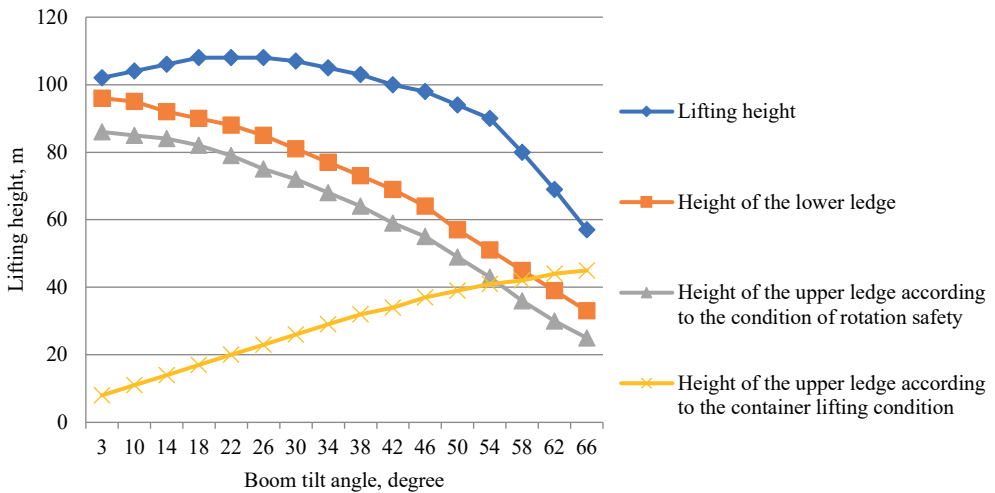


Fig. 5. Dependence of the lifting height on the angle of inclination of the lifting machine boom.

Taking into account the need for a 40 m lift on the lower and upper tiers of the dump, the installation angle of the lifting machine boom was adopted at 56 degrees. At the same time, the total lifting height reaches 80 m per lift.

The advantage of container technology on the dump is the possibility of reducing the average height of rock lifting. To do this, the rock is laid in horizontal layers within the step of the lifting machine. As the rock is dumped between the movements of the lifting machine, the height of the rock lifting gradually increases to a maximum equal to the height of the dump tier. Thus, the weighted average height of rock lifting is equal to half the height of the dump tier. After filling part of the entrance to the dump from one point of installation of the lifting machine, it is moved along the ramp, and filling the entrance to the dump is repeated within the step of movement by horizontal layers from bottom to top.

3. RESULTS

Let us determine the impact on the ecology of the area of the transition to a new waste disposal technology. With the old technology, 8 dump trucks were used to lay the rock, and the rock delivered to the dump was pushed by 1 bulldozer. Thanks to the new technology, one lifting machine will perform the same amount of work. Let us determine the intensity of dust emission from each internal source operating on the dump.

TABLE 1. DUSTING WHILE WORKING WITH A BULLDOZER

	Initial data	Designation	Units	Quantity
1	Capacity of the transfer unit or amount of processed material	G	t/h	145.76
2	Bulldozer operating time	t	h/year	7360
3	Weight fraction of dust fraction in the material	K ₁	–	0.05
4	Proportion of dust turning into aerosol	K ₂	–	0.02
5	Coefficient taking into account meteorological conditions	K ₃	–	1.2
6	Coefficient taking into account local conditions	K ₄	–	1
7	Coefficient taking into account material moisture	K ₅	–	0.01
8	Coefficient taking into account the size of the material	K ₇	–	0.6
9	Coefficient taking into account the height of pouring	B	–	0.4

Dust emission volume of one bulldozer:

$$Q = \frac{K_1 \cdot K_2 \cdot K_3 \cdot K_4 \cdot K_5 \cdot K_7 \cdot B \cdot G_{hour} \cdot 10^6}{3600}, \tag{6}$$

$$Q = \frac{0.05 \cdot 0.02 \cdot 1.20 \cdot 1.00 \cdot 0.01 \cdot 0.60 \cdot 0.40 \cdot 1920 \cdot 10^6}{3600} = 1.54 \text{ g/s}. \tag{7}$$

Total dust emission of one bulldozer during the year:

$$M = K_1 \cdot K_2 \cdot K_3 \cdot K_4 \cdot K_5 \cdot K_7 \cdot K_8 \cdot B \cdot G_{\text{year}}, \quad (8)$$

where G_{year} is the total amount of material processed during the year, t/year;

$$M = 0.05 \cdot 0.02 \cdot 1.20 \cdot 1.00 \cdot 0.01 \cdot 0.60 \cdot 0.40 \cdot 14131200 = 40.7 \text{ tons/year.} \quad (9)$$

Dust formation during the movement of dump trucks on the surface of the dump occurs as a result of dust being blown off the surface of the transported material and during movement when the vehicle wheels interact with the road surface [31]. Factors influencing intense dust formation include: speed of movement, carrying capacity of vehicles aggregates, road condition, type of top covering material, etc. [31]. The area where the loading point is located is characterized by a frequently recurring wind speed of 4.0 m/s.

TABLE 2. CALCULATION OF DUST FORMATION DURING OPERATION OF DUMP TRUCKS SERVICING A QUARRY

	Initial data	Designation	Unit	Quantity
1	Coefficient taking into account the humidity of the material	K_0	–	1.2
2	Coefficient taking into account the wind speed	K_1	–	1.2
3	Specific gravity of solid particles blown off from 1 m ² of rock surface transported over a distance of 1 km	q_{m}	g/m ²	3
4	Surface area of transported material in the body of a dump truck	S_A	m ²	14
5	Number of working dump trucks	N_{AP}	unit	8
6	Number of dump truck trips per year	n_{pa}	unit	14200
7	Crushing factor of rock mass	γ_{H}	–	0.1
8	Coefficient taking into account the average speed of movement of dump trucks in a quarry	K'_0	km/h	2.0
9	Coefficient taking into account the condition of roads	K'_1	–	1.0
10	Specific dust emissions when one dump truck passes 1 km of temporary (stationary) road	$q_{\text{sp}}(q_{\text{ps}})$	kg/km	1.01
11	Length of temporary (stationary) roads	$L_p (L_s)$	km	1.1 (2.4)

The mass of dust blown off the surface of material transported by dump trucks:

$$m_{\text{ATM}} = K_0 \cdot K_1 \cdot q_{\text{m}} \cdot S_A \cdot N_{\text{AP}} \cdot n_{\text{pa}} \cdot \gamma_{\text{H}} \cdot 10^{-6}, \quad (10)$$

$$m_{\text{ATM}} = 1.2 \cdot 1.2 \cdot 3 \cdot 14 \cdot 8 \cdot 14200 \cdot 0.1 \cdot 10^{-6} = 0.146 \text{ tons/year.} \quad (11)$$

Mass of annual dust formation during the movement of dump trucks:

$$m_{\text{АП}} = K'_0 \cdot K'_1 \cdot (q_{\text{cp.p}} \cdot 2 \cdot L_p + q_{\text{cp.s}} \cdot 2 \cdot L_s) \cdot n_{\text{pa}} \cdot N_{\text{AP}} \cdot 10^{-3}, \quad (12)$$

$$m_{\text{All}} = 2.0 \cdot 1.0 \cdot (1.01 \cdot 2 \cdot 1.1 + 1.01 \cdot 2 \cdot 2.4) \cdot 14200 \cdot 8 \cdot 10^{-3} = 1606.3 \text{ tons/year.}$$

The total amount of dust generated by the old technology is 1647.15 tons per year.

According to the new technology, transportation and placement of rock into a dump is carried out by one reloading machine (excavator).

The intensity of dust emission by the excavator is greatly influenced by the volume of rock being unloaded at the same time, the unloading height, and the angle of rotation of the machine [30].

The maximum amount of rock loaded per hour is 1920 tons. For a reloading machine, the method for calculating dust generation is similar to [31].

Volume of dust emission by an excavator:

$$Q = \frac{0.05 \cdot 0.02 \cdot 1.20 \cdot 1.00 \cdot 0.01 \cdot 0.60 \cdot 0.70 \cdot 1920 \cdot 10^6}{3600} = 2.69 \text{ grams/sec.} \quad (13)$$

Total dust emission of an excavator during the year:

$$M = 0.05 \cdot 0.02 \cdot 1.20 \cdot 1.00 \cdot 0.01 \cdot 0.60 \cdot 0.70 \cdot 14131200 = 71.22 \text{ tons/year.} \quad (14)$$

The mass of dust blown from a freshly dumped dump per year is:

$$m_{\text{AO}} = 86.4 \cdot 1.2 \cdot 1.0 \cdot (365 - 120) \cdot 0.1 \cdot 175000 \cdot 0.17 \cdot 10^{-6} = 75.57 \text{ tons/year.} \quad (15)$$

Thus, the total damage to the environment during the operation of bulldozer and vehicles on the site using the old technology is 1647.15 tons/year.

4. CONCLUSION

The use of container technology in the formation of the dump shows that when unloading rock from containers into the dump, energy consumption during the formation of the dump is reduced, while the economically advantageous height of the dump increases. This reduces the area occupied by the dumps and reduces the harmful impact of mining operations on the environment.

The article discusses the technology of backfilling when forming dumps using bulldozers in the conditions of Northern Kazakhstan. Traditional technology involves the involvement of a complex of equipment consisting of 8 dump trucks and 1 bulldozer. According to the new technology, the same amount of work can be performed using 1 lifting machine.

Based on the calculations, it was found that the intensity of dust emissions from internal sources is reduced by 1576 tons per year. A reduction in dust emissions is also observed with an increase in the height of the dump due to a decrease in area, with the difference being 75.57 tons per year. The overall reduction from container technology is 1651.57 tons per year.

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