MINISSTRY OF EDUCATION AND TRAINING
UNIVERSITY OF MINING AND GEOLOGY
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RESEARCH ON SUITABLE WASTE ROCK HAULAGE TECHNOLOGY FOR DEEP OPEN PIT MINES IN VIETNAM

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SUMMARY OF DOCTORAL THESIS IN ENGINEERING

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The thesis is completed at the Department of Surface Mining, Faculty of Mining, Hanoi University of Mining and Geology

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INTRODUCTION

1. The necessity of the thesis

The haulage is one of the main technologies in production processing of open pit mining. The cost of haulage usually makes up from 50÷60% of the total production cost of a ton coal. There are a number of the advantages of haulage technology by using trucks. Firstly, the transport form with trucks is flexibility and suitability to the mountainous conditions and narrow area of the mining fields. Furthermore, this form of transport is suitable to the mines having the short working line and rapid development as well as the bedded deposit is complex. However, the cost of transport increases with the depth of exploitation. Currently, beside the form of transport with trucks, there are many haulage technologies in mining industry in the world such as the truck conveyor system, truck lift system and truck railway system. The applications of these forms of transport not only use the advantages, but also overcome the disadvantages of combined transport system. As a result, the cost of waste rock haulage decreases significantly.

One of the most features of Vietnam open pit mines is large depth and width. On the other hand, the application of the truck haulage technology will not beneficial because the mining intensity of these mines are large. Therefore, the research on the selection of the suitable haulage technology ensuring the required productivity as well as the minimal cost of transport for Vietnam open pit mines is an urgent problem. The content of the thesis have greatly contribution to the open pit mining industry in Vietnam.

2. The research aim of the thesis:

The research on the selection of the suitable transport technology for natural and technical condition of the deep open pit mines in Vietnam which ensures the required productivity, increase the effective exploitation as well as reduce environmental contamination.

3. Objects and the scope of research

- The object of the thesis is the waste rock haulage technology in open pit mines.
- The research scope of the thesis is to study the open pit coal mines in Vietnam which are deep exploiting.

4. Research contents

- The characteristics evaluation study and the ability to apply the waste rock transport technologies to the open pit coal mines in Vietnam.
- The research the optimization of the technical parameters for the waste haulage technologies in the deep open pit coal mines in Vietnam.
- The research on the selection of the suitable haulage technologies for the open pit coal mines in Vietnam.

5. Research method

- Using the legacy method;
- Using the analytics methods, modeling and artificial mind method;
- Using analysis, selection, comparison methods and expert experiences.

6. The scientific and practical significances

6.1. The scientific significance

The research results of the thesis will contribute to the supplement and the improvement in the theoretic of the open pit mining technology in generally and the suitable haulage technology for the deep open pit coal mines in Vietnam.

6.2. The practical significance

The research result of the thesis will be not only the investment orientation foundation for mining companies, but also play a crucial role on enhancing mining profit and protecting environment.

7. Arguments of thesis

7.1. The efficient exploitation of the deep open pit mines in Vietnam will be enhanced based on using the combined haulage technologies as well as optimizing the technical parameters of the transport equipments.

7.2. The energy consumption is objective criteria to assess the efficiency of the technological processes of open pit mining.

7.3. The using scope of haulage technologies of the deep open pit mines are based on estimating of the unit energy consumption and the transport costs in accordance with lifting height. As a result, the haulage technology for the deep open pit mines in Vietnam is suitable when the total cost of transport and the energy consumption are minimal.

8. The new points of the thesis

8.1. The thesis has proposed the classification method for the deep open pit mines basing on the mine geometrical dimension and the suitable haulage technologies.

8.2. The thesis has used the mathematical simulation to determine parameters and optimized norms of haulage cost. In addition, the thesis has built the relationship between the unit energy consumption and the haulage cost as well as the weight in accordance with load lifting height.

8.3. The thesis has established the using scope of haulage technologies based on comparing the unit energy consumption and the cost of transport in accordance with load lifting height.

8.4. The thesis has selected the most suitable waste rock haulage technologies for the deep open pit coal mines basing on the norm of the total haulage cost and the unit energy expenses in accordance with load lifting height as well as the volume of transport are minimal.

9. The structure of the thesis

Besides the introduction and conclusion part, the thesis content consists of 134 A4 typing pages and many tables as well as illustrations. In addition, the thesis is referred a lot of the reference materials in Vietnam as well as in the world. The structures of the thesis are arranged as follow:

Chapter 1- The overview of the research situation in the waste rock haulage technologies for the deep open pit coal mines in Viet Nam and in the world.

Chapter 2- The characteristic evaluation and the ability to apply the waste rock haulage technologies to the deep open pit coal mines in Vietnam.

Chapter 3- The research on the optimization for the technical parameters of the waste rock haulage technologies for the deep open pit coal mines in Vietnam.

Chapter 4- The research on the selection of the suitable waste rock haulage technologies for the deep open pit coal mines in Vietnam

10. Publication

According to the research of thesis, the researcher was published 17 science papers in the Journal of mining science and technology, the mining technology bulletin and the science conferences in Vietnam and in the world.

The basic contents of the thesis

CHAPTER 1- THE OVERVIEW OF THE CURRENT SITUATION AND THE RESEARCH WORKS ON THE WASTE ROCK HAULAGE TECHNOLOGIES FOR THE DEEP OPEN PIT COAL MINES IN VIET NAM AND IN THE WORLD

1.1. The overview of the technical situation of the waste rock haulage technologies in the open pit coal mines

1.1.1. The classification of the deep open pit coal mines in Vietnam.

The deep and wide open pit coal mines in Vietnam include: Deo Nai mine, Cao Son mine, Coc Sau mine and Khanh Hoa mine; the deep and narrow mine is Na Duong one.

1.1.2. The current situation of the waste rock haulage technologies in the open pit coal mines in Vietnam.

The deep open pit coal mines in Vietnam use the form of transport with trucks which have many kinds of the trucks including the payload from 58-96 tons. The cost of haulage, which increases in accordance with the depth of mine about 10% per year, is biggest

1.1.3. The technological situation of the waste rock haulage technologies in the deep open pit coal mines in the world

The deep open pit coal mines in the world typically use three technological schemes:

- Using the trucks transport the waste rock from working benches to the point of loading transfer of conveyor and then transporting by inclined conveyor to the dump area. .

- Using the trucks transport the waste rock to the point of loading transfer of the loading lift, and then the loading lift will hoist the truck with waste rock on the pit slope. Finally, the conveyor or railroad transports the waste rock to the dump area.

Using trucks transport in the mine site and combining with railroad in the pit slope.

1.2. The overview of the research works on the selection of the waste rock haulage technologies in Vietnam and in the world.

In fact, the waste rock haulage technology have been researched and applied widely in mining field since the 30s of the twenty century. There are a number of famous scientists in this field including N.V.Melnikov, V.V. Rzhevsky, V.L.Yakovlev, M.V.Vasilev, M.G.Novozhilov, M.G.Potapov and some others. These researches selected the suitable haulage technology based on the method of comparing the economic norms in accordance with the objective function:

- The cost of transport a ton ($1m^3$) of waste rock will minimal;
- The cost of excavating and dumping a ton ($1m^3$) of waste rock will minimal;
- The cost of the transfer of mining and transport a ton ($1m^3$) of waste rock will minimal.

The compared method of the economic norm depends on the market as well as the economic governance of the State, so this result will not reflect the substance of technology. Meanwhile, to lift one ton of waste rock to one height of meter height each the form of transport technology need to consume the amount of certain energy. The energy consumption is an objective criterion which will not depend on the operating policies of the State economy, inflation or market. Therefore, the choice of transport technology not only need to notice the economic criteria, but also should be combined with the criterion of energy consumption. Since then, the author focuses on solving the problem of the choice of the suitable waste rock haulage technology in accordance with the following conditions:

- The prerequisites: The scale of appropriate technology with the geometric characteristics, mining sequence, mining system and greatest productivity;
- The enough conditions: the transfer prices and the unit energy consumption cost of the selected haulage technology are minimal, and it has less impact to environment.

CHAPTER 2- THE CHARACTERISTIC EVALUATION AND THE ABILITY TO APPLY THE WASTE ROCK HAULAGE TECHNOLOGIES TO THE DEEP OPEN PIT COAL MINES IN VIETNAM

2.1. The feature of the deep open pit coal mines in Vietnam

Almost of the deep open pit coal mines in Vietnam often is the surface form. This form means that the amounts of overburdens concentrate on above and the coal lies in below. The volume of overburden and the length of mines are small in the upper and deep benches. The length of working bench and the biggest volume of overburden concentrate on the area of the main transport trench. The number of the working benches often is about 20-25 benches. The length of working line will reduce when to exploit deeper. In addition, the solidify of rock, the density of rock and the porosity of rock increase in accordance with the relationship of the first function. The mining intensity in each benches increase, so this leads to the development intensity of working line will also rise. Therefore, the length and the height of loading lift will increase as well.

2.2. To evaluate the factors having impacts on the waste rock haulage technology for the open pit mines in Vietnam

- The natural factors: influence on the technology forms, the unit energy consumption, the operating time, the cost of rock breakage.
- The technical factors include: the influence on the power of equipment, the cost price, the unit energy and the movement speed of the trucks.
- The organizational factors include: the productivities are created by the operating time of the equipments and the equipments capacity.

2.3. The research on the requirements for the haulage activities and estimates the using ability of the waste rock haulage technologies in the deep open pit coal mines in Vietnam

2.3.1. The requirements of the haulage activities:

The length of transport should be shortest, and the volume of transport is not limited by the height of the loading lift and pit slope angle. In addition, the consumption of the raw materials, energy and cost of the capital construction are minimal as well as to reduce the environmental pollution. These haulage activities should be less dependent on the climatic condition, and they are simple for operating, repairing and production safety.

2.3.2. The ability evaluation of using the haulage technology in the deep open pit coal mines in Vietnam

The haulage technology in the open pit mines divides three zones: the transport under the bottom pit, the transport lift to the pit slope and the transport outside of the surface pit limits.

In the deep open pit coal mines in Vietnam, the size of the under deep benches are restricted, and the groundwater increased. On the other hand, the mining technology in accordance with the season has applied, so the form of haulage with truck should be applied to the bottom benches. This is the most suitable technology.

The forms of haulage such as the truck system, truck - lift system and continuous system (conveyor) should be applied to the waste rock transport in the mines which have the large mining intensity and the requirement of reducing cost.

Furthermore, when the transport on the surface pit to the dump area in the mountain condition in which the mines interwoven should be used the discontinuous technology (trucks) or the continuous haulage technology (conveyor).

CHAPTER 3- THE RESEARCH ON THE OPTIMIZATION FOR THE TECHNICAL PARAMETERS OF THE WASTE ROCK HAULAGE TECHNOLOGY FOR THE DEEP OPEN PIT COAL MINES IN VIETNAM

3.1. Study on selecting the suitable size of waste rock particles to the deep open pit coal mines in Vietnam

The waste rock in the open pit coal mines in Vietnam needs to break by the drilling and blasting method with the diameters 250mm. The suitable size of waste rock should be decided based on the total cost of energy consumption of each technical process, such as blasting, excavating, and loading and dumping, are minimum. Depending on the kind of excavators, the suitable size of rock is defined by formulas as following:

+ When do not use the crusher machine:

- For the bucket excavator: $d_{tu} = 0,1561.\sqrt[3]{E} + 0,0011$, m (3.1)

- When using the backhoe hydraulic excavator:

$$d_{tu} = 0,2259.\ln(\sqrt[3]{E}) + 0,2501, \text{ m} \quad (3.2)$$

+ When using the crusher machine:

For the bucket excavator: $d_{tu} = 0,1229.\sqrt[3]{E} + 0,0358$, m (3.3)

- When using the backhoe hydraulic excavator:

$$d_{tu} = 0,1714.\ln(\sqrt[3]{E}) + 0,2356, \text{ m} \quad (3.4)$$

3.2. The research on the selection of the technical parameters for the transport form with single trucks.

3.2.1. The study on the selection of the optimal size of load of trucks in accordance with the bucket capacity.

With the mines is exploiting, the bucket capacity of excavators (E) depends on the length of working line, the optimal excavating block (L_b), the requirement of the volume of waste rock (V_d). The bucket capacity could be used within $E_{min} \div E_{max}$, and this value can be defined by the formula:

$$E_{\min} = \frac{V_d.t_{ck}}{7200.K_x.K_t.T.L_{tb}} \; ; \; E_{\max} = \frac{V_d.L_b.t_{ck}}{3600.K_x.K_t.T} \quad (3.5)$$

In which, L_b determined by the formula:

$$L_{bhl} = Q_x \sqrt{\frac{2.G_{cô}}{h.\left[2.Q_x.G_{cô} + V_ô.V_{tb}.T_{ca}.(C_x + C_b)\right]}} \quad (3.6)$$

In the case of the deep open pit coal mines in Vietnam, the high bench is h = 15÷22 m, and the bucket capacity of excavator is E = 8÷12m^3, so the optimal excavating block L_{bhl} = 170÷240m and the average value is 200m.

The assuming that the complex of excavator and truck operate with the closed cycle, so the complex of excavator and truck will be selected to base on the principle of objective function:

$$C_{kt} = C_{mx} + C_{ôtô} \rightarrow \min \quad (3.7)$$

$$C_{kt} = \frac{G_{cmx} + G_{cô}.N_c}{n_c.q.K_{tt}} + \frac{r(G_{ô}.N_c + G_{mx})}{Q_{ca}.T_n} \rightarrow \min \quad (3.8)$$

Showing that $G_ô$, $G_{cô}$ = f(q) and the relationship: $\frac{df(q)}{dq} = 0$ help to define the optimal size of load which suit E (E_{min} - E_{max})

$$q_{tu} = \sqrt{\frac{E.k_x.\gamma.T_n(\frac{120.L}{V_{tb}} + t_d)(1,363.T_n - 5,883.r)}{t_c.(0,092.T_n + 0,338.r)}} \quad (3.9)$$

The suitable complex of excavator and truck for the deep open pit coal mines in Vietnam is illustrated by the figure 3.1

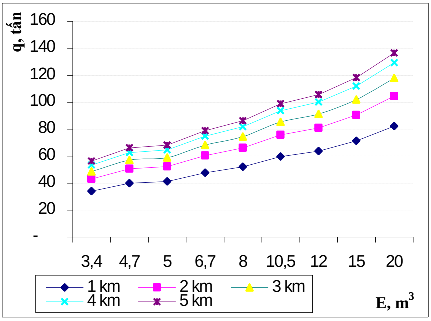

Fig 3.1: The relationship between the load size of truck in accordance with the bucket capacity and the length of transport.

3.2.2. The research on the relationship between the width of truck and the volume of rock expanded the transport path

The tendency of increasing the load size of truck means the width of mined paths and the pit slope angle will be affected. When the pit slope angle changed, the volume of overburden will be defined by the formula:

$$V' = \frac{\Delta BH^2}{2i}, m^3 \quad (3.10)$$

In which: V'- the total volume of overburden have to be removed when opening the transport path, m^3; i - the inclination of path , %; H - the depth of mine, m.

The volume of overburden which needs to be removed when using the trucks for haulage in accordance with the depth of exploiting in the open pit coal mines in Vietnam is calculated and shown in figure 3.2.

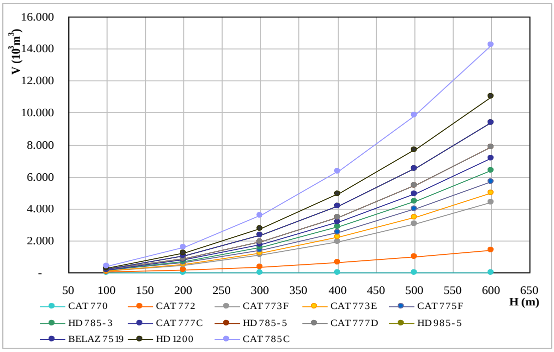

Fig. 3.2. The relationship between the volumes of overburden with each kind of trucks.

3.3. Study on the technical parameters of the conveyor haulage technology.

3.3.1. The width of conveyor:

The width of inclined conveyor is determined basing on the viewpoint of the waste rock will be sealed by conveyor, and it is defined by the formula:

$$B_b = 1,3\left(\sqrt{\frac{Q_{yc}}{C_1.v.\gamma}} + 0,1\right), \text{ m} \qquad (3.11)$$

In which: Q_{yc} - the required transport productivity ton/hour; C_1 - the coefficient related to the shape of conveyor; v - the speed of conveyor, meter/second; γ - the density of material on conveyor, ton/m^3; C_β - the calculate coefficient.

3.3.2. Calculating the transport speed of conveyor:

The moving speed of conveyor depends on the inclination and the distance between two rolls which are determined by table 3.1.

Table 3.1. The conveyor speed in accordance with the distance between two rolls and inclination

The inclination of conveyor β, degree	The conveyor speed value, m/s		
	X=0,76	X=0,91	X=1,06
18	3,46	3,79	4,09
30	3,30	3,61	3,90
35	3,21	3,51	3,79

3.3.3. The biggest size of material when transport by conveyor

Considering the material flow is moving on the conveyor which has a popular shape with three rolls in the figure 3.3. Basing on the geometry relationship, the biggest size of material on conveyor (d_{max}) is defined by the formula:

$$d_{\max} = \frac{l_b(1-\cos\theta) + 2.m_b.\left[\cos\beta_o - \cos(\theta+\beta_b)\right]}{2.\sin\theta} \quad (3.12)$$

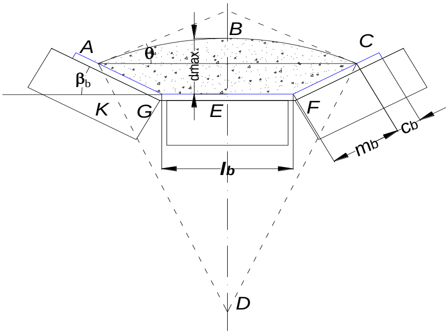

Fig.3.3: The diagram calculate the parameters of the conveyor with three rolls

With the parameter of conveyor: H = 100m, v= 3,15m/s the technical parameters of conveyor and loading lift illustrated by the table 3.2÷ 3.3.

Table 3.2: The conveyor with the inclination β=18^o; L=323,6m

Parameters	Unit	Value									
Q	t/h	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000	10.000
B_{tt}	m	0,64	0,89	1,07	1,23	1,37	1,49	1,61	1,72	1,82	1,91
B	m	0,8	1	1,2	1,4	1,4	1,6	1,8	1,8	2	2
N	kW	383	732	1084	1449	1790	2142	2494	2835	3204	3545
G	T	71	97	122	150	163	192	223	237	273	286

Table 3.3. The inclined conveyor has compression system with the inclination β=35^o, L=174,3 m

Parameters	Unit	Value									
Q	t/h	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000	10.000
B_{tt}	m	0,87	1,17	1,41	1,60	1,78	1,93	2,08	2,21	2,34	2,46
B	m	1	1,2	1,6	1,600	1,8	2	2,25	2,25	2,5	2,5
N_k	kW	278	522	796	1063	1320	1569	1817	2088	2361	2595
N_n	kW	107	216	318	397	495	617	725	800	882	993
G	T	95	129	201	219	257	317	362	379	423	440

3.4. Study on the selection of the technical parameters for the loading lift technology.

The hour productivity of lifting is defined by the formula:

$$A_t = \frac{k_d.V_d.\gamma}{N.n.t.\eta}\text{, ton/hour} \quad (3.13)$$

In which: k_d- non - harmonic factor, k_d = 1,2; V_d - the annual required volume of mine, m^3/year; γ - the density of waste rock, ton/m^3; N - the number of working days per year, day/year; n- the number of working ships per day; t - the working time of each ship, t = 8 hours; η - the time using coefficients of loading lift, η = 0,8.

- The average speed of the loading lift (basically) is determined by the formula:

$$V_{cd} = \frac{0,8\sqrt{H}}{1,2} \text{, m/second} \quad (3.14)$$

- The load size of lifting (selected) is determined by the formula:

$$Q_{tt} = \frac{A_g.T_{ck}}{3600} \text{, ton} \quad (3.15)$$

- The average speed (selected) of the lift is defined by the formula:

$$V_{tb} = \frac{2L_n}{T_{ck}} \text{, m/s} \quad (3.16)$$

- The maximum speed of lifting is determined by the formula:

$$V_{max} = (1 \div 1,5)V_{tb}\text{, m/s} \quad (3.17)$$

- The necessary capacity of the equipment:

$$N_{dc} = \frac{1,25.K.Q_{tt}.V_{max}.\sin\beta}{102.\eta_t} \text{, kW} \quad (3.18)$$

In which: β - the inclination of lifting, degree; V_{max} - the maximum speed of lifting, m/sec; η_t - transport efficiency ; K - the coefficient loading size coefficient of lifting.

The technical norms of lifting are illustrated in table 3.4 and 3.5

Table 3.4. The technical norms of haulage by hosting skip (β= 35^o, H = 200 m)

Number	Technical norms	Unit	Value				
1	Hour capacity	t/h	1.000	2.000	2.200	2.500	5.000
2	The length of lifting	m	348,7	348,7	348,7	348,7	348,7
3	The maximum speed	m/s	10,63	11,94	12,45	12,56	12,22
4	The weight of lifting	ton	29,25	55,25	81,25	107,9	120,25
5	The volume of waste rock	ton	45	86	125	166	185
6	The weight of 1 meter of cable	kg/m	20,2	41,7	57,1	81,6	81,6
7	The capacity of the equipment	kW	2.554	5.548	8.350	11.405	12.018

Table 3.5. The technical norms of transport by loading truck lift with the inclination 35°

Number	Technical norms	Unit	Value			
1	The capacity , Q_{hour}	ton/hour	1.000	2.000	2.200	2.500
2	The average lifting speed	m/sec	6,53	7,00	7,52	6,76
3	The maximum lifting speed	m/sec	8,16	8,75	9,40	8,45
4	The transport volume	ton	63	122	130	155
5	The transport volume of one time	ton	161,95	311,3	334,5	401,75
6	The weight of 1 meter of cable	kg/m	41,7	81,6	81,6	81,6
7	The capacity of equipment	kW	3.075	6.410	7.185	7.299

3.5. Study on the selection of the technical parameters for the combined haulage technology.

3.5.1. Study on the selection of the focused bench location in the group of benches.

In a group of benches, the transfer location from trucks to other forms of haulage could be installed at three different location (Fig 3.5): the first location can be installed at upper bench (the first position), the second can be installed at middle bench (second position), and finally position can be installed at under bench (third position). The bench has the transfer location called focused bench.

How to select the suitable focused bench location at the subgroup of benches, researcher would like to use the viewpoint: the total energy consumption of equipment on the subgroup bench is minimum.

$$\sum A = A_{ld} + A_{xd} + A_n \rightarrow \min \qquad (3.19)$$

It can be clearly seen that $\sum A =$ f(x) because of f(x) function is quadratic function, so the minimal point is at the bottom of parabola. Therefore, the focused bench location will be calculated by the formula (3.19).

As a result, when the number of benches in a subgroup bench is even number, the focused position will be installed at the bench x=0,5n+1. On the other hand

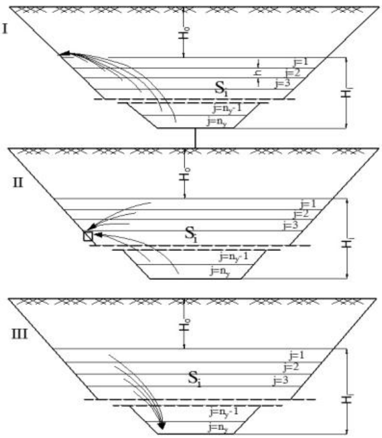

Fig. 3.5. The diagram distributes the focused bench in the subgroup bench.

when the number of benches is odd number, the focused position will be installed at the middle bench of the subgroup bench.

$$x = \frac{\frac{n.h}{i}(q.\omega + 2q_T.\omega) + 1000.q.h.g - \frac{(G_o + G)(\sin\beta + f.\cos\beta).h}{\eta.\sin\beta}}{2\frac{h}{i}\left[q.\omega + 2.q_T.\omega\right]} \qquad (3.19)$$

3.5.2. Study on the selection of the focused bench number in the working zone of the combined transport.

To select the focused bench number on the pit slope which has height bench H, researcher used objective function of the transport cost:

$$\Sigma G_m = G_{ô} + G_n \rightarrow \min \qquad (3.20)$$

Basing on the objective function build a mathematical modeling to define m optimal value of m when using (a) and do not using the crusher machine (b):

a) $m_{tu} = \sqrt{\frac{Q.H.(C_{ô} + \frac{G_{ô}}{Q_{ô}.T_{ô}})}{4000.i.\left[\frac{H.G_n}{2.T_b.\sin\beta} + \frac{G_d}{T_d}\right]}}$ b) $m_{tu} = \sqrt{\frac{Q.H.(C_{ô} + \frac{G_{ô}}{Q_{ô}.T_{ô}})}{4000.i.(\frac{H.G_n}{2.T_b.\sin\beta})}}$ (3.21)

CHAPTER 4 - THE RESEARCH ON THE SELECTION OF THE SUITABLE WASTE ROCK HAULAGE TECHNOLOGIES FOR THE DEEP OPEN PIT COAL MINES IN VIETNAM

4.1. Study on the haulage technology selection foundation for the deep open pit coal mines in Vietnam.

- Technical foundation includes the transport productivity and the technology norms.
- Economic foundations base on the total consumption energy and the cost of haulage which includes investment and operation cost.
- Social factors are labor productivity and environmental standards.

The objective function: The total consumption energy and the cost of transport are minimum cost.

4.2. Study on the technical norms of the form of transport with trucks for the deep open pit coal mines in Vietnam.

The complex of excavators and trucks is suitable when they could ensure the conditions as following:

+ Ensuring the required mine volume with the available technical conditions.
+ Ensuring the flow capacity of truck paths.
+ The consumption energy and the transfer price are minimum cost.

4.2.1. The consumption energy of the trucks transport

The kind of the trucks have the payload from 36-136 tons, and the required necessary energy raise one ton of weight by the lifting and loading height from 15m to 600m is calculated by the formula as following:

- On the uphill road: $A_{ld} = 25,041.q^{0,109}.H - 17,298.q^{-0,176}$, kJ/ton (4.1)
- On the downhill road: $A_{xd} = 17,145.q^{0,132}.H - 9,288.q^{-0,084}$, kJ/ton (4.2)
- On the level road: $A_b = 0,827.q^{0,19}.L - 3,571.q^{-0,1}$, kJ/ton (4.3)

4.2.2. Determining the haulage cost of single trucks.

The haulage cost of truck is defined by formula:

- On the uphill road:

$$C_{ôl}= 69,257.Q^{0,0181}.H+ 2915,314.Q^{0,0198}, \text{ VND/ton} \quad (4.4)$$

- On the downhill road:

$$C_{ôx}=17,255.Q^{0,0374}.H+2038,153.Q^{0,0027}, \text{ VND/ton} \quad (4.5)$$

- On the road:

$$C_{ôb}= 3695,411.Q^{0,026}.L+ 3259,3.Q^{-0,0029}, \text{ VND/ton} \quad (4.6)$$

4.3. Study on the technical norms of the conveyor haulage technology for the deep coal mines in Vietnam

- The capacity among the links of trucks, receiver bunker, and the haulage transport has been shown as follows:

$$Q_ô \le Q_{bk} \le Q_{bt} \le Q_{th} \quad (4.7)$$

- The waste rock haulage volume of the biggest equipment complex:

$$Q_ô, Q_{bk}, Q_{bt}, Q_{th} \rightarrow \max \quad (4.8)$$

In which: $Q_ô$, Q_{bk}, Q_{bt}, Q_{th} – is respectively the hour productivity of the equipment complex including trucks, excavators, the transfer point and the conveyor on pit slope.

4.3.1. The energy consumption of the inclined conveyor

The unit energy of the inclined conveyor (the inclination $\beta = 18^o$), which has technical parameters: Q = 1.000÷10.000 ton/hour; the speed of conveyor 3,15m/s, H = 30÷600 m, is calculated by formula:

$$A_{bt} = 15,92.Q^{-0.027}.H+76,793.Q^{-0,1}, \text{ kJ/ton} \quad (4.9)$$

When $\beta = 0^o$: $A_b = 2,503.Q^{-0,186}.L+60,274.Q^{-0,098}$, kJ/ton (4.10)

4.3.2. The energy consumption of the hight angle conveyor

The unit energy consumption is calculated by the formula as following:

$A_{bd} = 23,497.Q^{-0,064}.H - 138251,63.Q^{-0,98}$, kJ/ton (when $\beta = 30^o$) (4.11)

$A_{bd} = 22,851.Q^{-0,0617}.H - 177833,6.Q^{-1,023}$, kJ/ton (when $\beta = 35^o$) (4.12)

$A_{bd} = 22,463.Q^{-0,06}.H - 236503,6.Q^{-1,063}$, kJ/ton (when $\beta = 40^o$) (4.13)

4.3.3. Determining the cost of conveyor transport

The cost of conveyor transport in accordance to the lifting height (when the lifting inclination of conveyor $\beta=18^o$, inclined conveyor $\beta=30 \div 40^o$), the haulage transport and the hour productivity is calculated by the formula:

When $\beta = 18^o$: $C_{bt} = 490,16.Q^{-0,37}.H+1549944,48.Q^{-0,61}$, VND/ton (4.14)

When $\beta = 30^o$: $C_{bd} = 856,657.Q^{-0,415}.H+345953,8.Q^{-0,481}$, VND/ton (4.15)
When $\beta = 35^o$: $C_{bd} = 691,721.Q^{-0,401}.H+345815,9.Q^{-0,481}$, VND/ton (4.16)
When $\beta = 40^o$: $C_{bd} = 577,945.Q^{-0,387}.H+345688,8.Q^{-0,481}$, VND/ton (4.17)
When $\beta = 0^o$: $C_{nm}=501,218.Q^{-0,556}.L+2342091.Q^{-0,66}$, VND/ton (4.18)

4.4. Study on the technical norms of the truck - hoist combined haulage technology for the deep open pit coal mines in Vietnam.

4.4.1. The energy consumption of hoisting

4.4.1.1. The energy consumption of hoisting skip

When $\beta = 30^o$: $A_{sk} = 71,64.Q^{-0,028}.H + 18,693.Q^{0,403}$, kJ/ton (4.19)
When $\beta = 35^o$: $A_{sk} = 123,466.Q^{-0,099}.H + 0,314.Q^{0,982}$, kJ/ton (4.20)
When $\beta = 40^o$: $A_{sk} = 94,548.Q^{-0,062}.H + 93505,9.Q^{-0,587}$, kJ/ton (4.21)

4.4.1.2. The energy consumption of the truck uplift in pit system

When $\beta = 30^o$: $A_{tn} = 85,886.Q^{-0,013}. H+19,657.Q^{0,363}$ kJ/ton (4.22)
When $\beta = 35^o$: $A_{tn} = 102,156.Q^{-0,037}. H+0,682.Q^{0,932}$, kJ/ton (4.23)
When $\beta = 40^o$: $A_{tn} = 105,742.Q^{-0,043}. H+34,526.Q^{0,469}$, kJ/ton (4.24)

4.4.2. Determining the haulage cost of hoisting transport technology:

- The price of unit transfer of the hoisting skip transport technology when Q = 1000÷6.000 ton/hour; H ≤ 400 with the inclination angle of the hoisting line $\beta=30^o$, 35^o, 40^o is calculated by the formulas:

When $\beta = 30^o$: $C_{sk} = 80,936.Q^{-0,027}.H + 1078807,956.Q^{-0,796}$, VND/ton (4.25)
When $\beta = 35^o$: $C_{sk} = 107,686.Q^{-0,065}.H + 563232,885.Q^{-0,69}$, VND/ton (4.26)
When $\beta = 40^o$: $C_{sk} = 84,367.Q^{-0,0278}.H + 693001,5.Q^{-0,723}$, VND/ton (4.27)

- The price of unit transfer of the truck uplift in pit system haulage technology when Q = 1.000÷3.200 ton/hour; H ≤ 350 is calculated by the formula:

When $\beta = 30^o$: $C_{tn} = 64,599.Q^{0,118}.H + 714404,093.Q^{-0,737}$, VND/ton (4.28)
When $\beta = 35^o$: $C_{tn} = 126,399.Q^{0,027}.H + 211469,547.Q^{-0,527}$, VND/ton (4.29)
When $\beta = 40^o$: $C_{tn} = 229,907.Q^{-0,053}.H + 181242,608.Q^{-0,483}$, VND/ton (4.30)

4.5. Selection the suitable haulage technology for the deep open pit coal mines in Vietnam:

The using scope of the haulage technologies is evaluated through the norm of the unit energy consumption and the transfer price of the haulage technologies in accordance to the loading lifting height A=f(Q,H); C=f(Q,H). To select the optimal transport solution use the method of selection the technologies, which has the total transport and the energy consumption, is minimum cost.

4.5.1. The using scope of the haulage technology in accordance to the energy consumption:

The result comparing A = f(H) of the haulage technologies are shown in Figure 4.1.

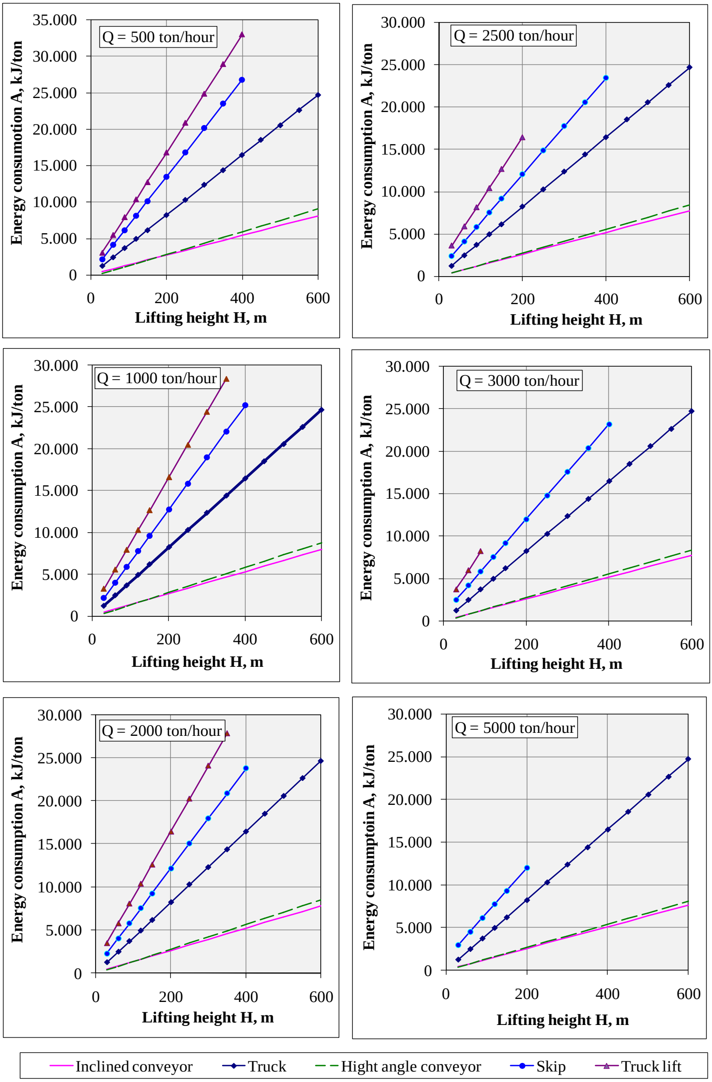

Fig.4.1. the energy cost of the haulage technologies in accordance to the depth of mine.

It can be clearly seen from Fig 4.1 that:

- When the required volume of mine is less than 2000 ton/hour, and the lifting ability of the truck uplift in pit system can be used to lift to the height H = 370÷400 m. On the other hand, when the required volume of mine is Q

= 2.500 ton/hour, the lifting ability of the truck uplift in pit system can be used to lift to the height H = 200 m; similarly, when Q = 3000 ton/hour the height of truck uplift in pit system H = 80m. In the case of using the hosting skip when Q is less than 3.000 ton/hour, the height of lifting is H = 400m. Similarly, when Q is 6000 ton/hour, as a result the height of lifting is H = 120m.

- The truck and conveyor could be used when the height of lifting reaches to H = 600m.

4.5.2. Evaluating the using scope of haulage technologies based on the price transfer criteria in accordance with the depth of mine:

The results comparing C=f(Q,H). It can be seen that the inclination of normal conveyor β = 18^{o} and the hight angle conveyor, the inclination of hosting β = 35^{o}. The price of transport in accordance with the height of lifting of these technologies including truck, conveyor, truck uplift in pit system, hosting skip are shown in the Fig 4.2.

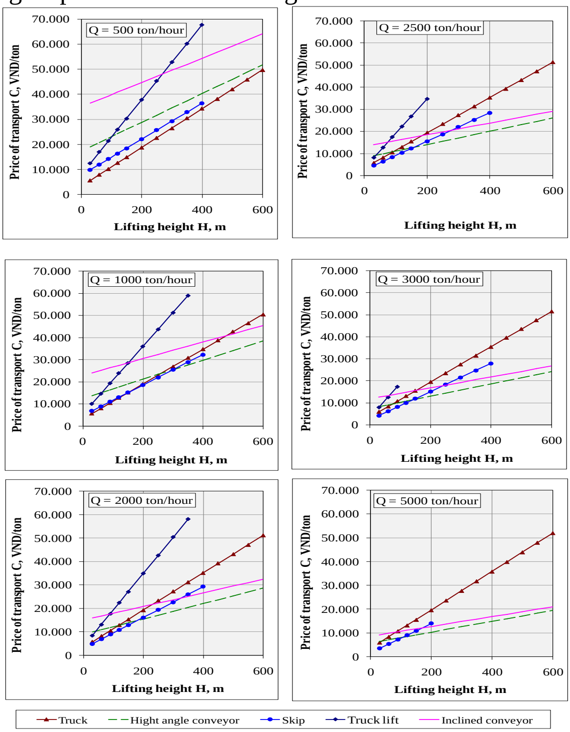

Fig 4.2. The price of haulage technologies in accordance with the productivity and the depth of mine.

It can be clearly seen from Fig 4.2 that:

- The single truck technology is the most effective when the mine volume (Q) is less than 500 ton/hour. In addition, when the mine volume (Q) is 1000 ton/hour, this technology work effectively with the height of lifting reaching to H = 200m.

- The hosting skip work effectively when the mine volume (Q) is 1.000 ton/hour with the height of lifting H = 200÷300 m. Furthermore, when the mine volume (Q) is 2.000÷5000 ton/hour, the hosting skip technology works effectively with the height of lifting H < 200÷100 m.

- The hight angle conveyor has compressed conveyor system, which works effectively when the height of lifting H > 300 m and Q = 1000 ton/hour. Other cases, when Q = 2.000÷5.000 ton/hour, the inclined conveyor works effectively with the depth of mine H > 200÷ 100m.

Currently, the height of lifting and the total volume of required transport in the deep open pit coal mines in Vietnam are extremely big (H >120m, Q>5000 ton/hour).When evaluating based on the criteria of the unit energy consumption cost and the price of transport in accordance with the depth of mine showed that using the hight angle conveyor which has compressed conveyor system is the most effective.

4.5.3. Selection the suitable waste rock haulage technology for the deep open pit coal mines in Vietnam.

The haulage technology selected basing on the comparing of the total transport cost of the single truck technology and the combined haulage technology which are shown in relationship:

$(C_{ô} - C_{LHi}) > 0$

$C_{tu} = \min(C_{ô}; C_{LHi})$ (4.31)

The selection diagram shows in Figure 4.3. The calculated result is shown in Figure 4.4.

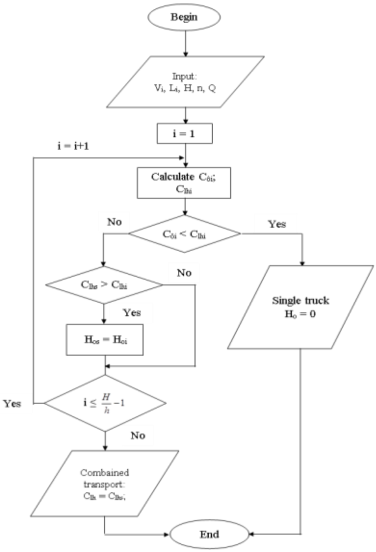

Fig. 4.3. The diagram selected the waste rock haulage technology in the mines

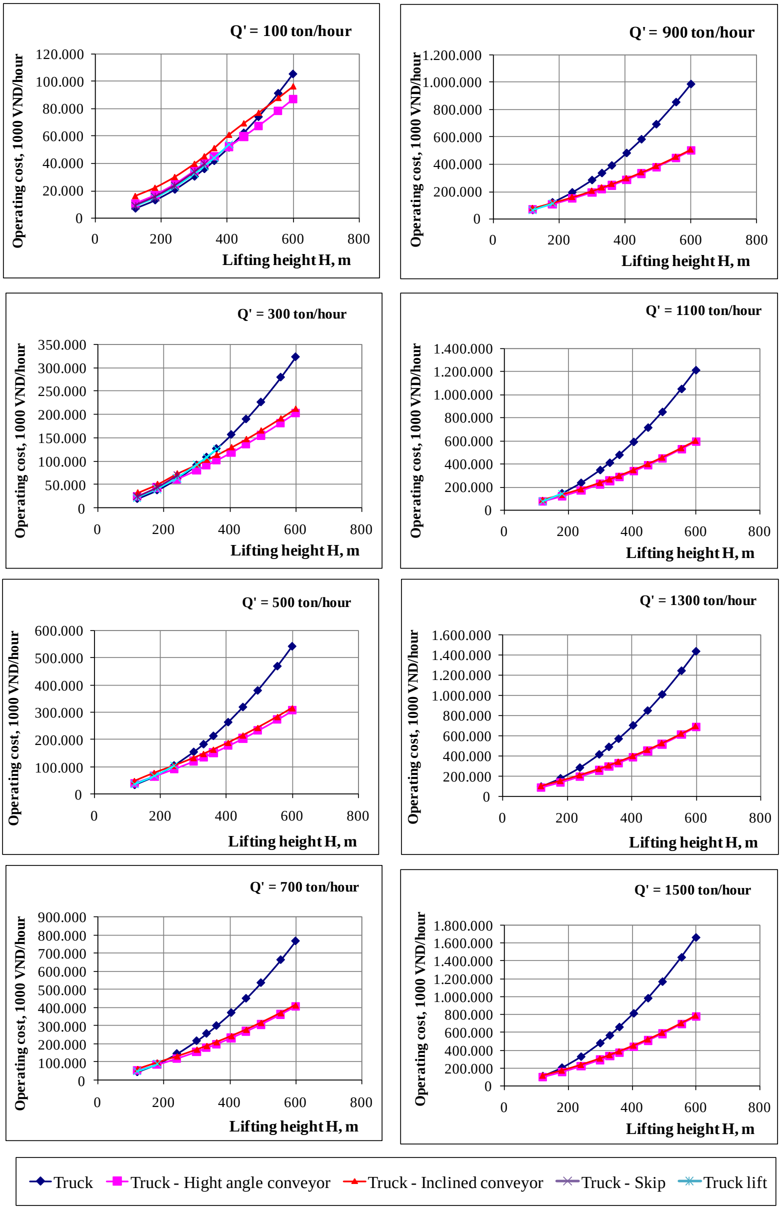

Fig 4.4. The relationship between the total cost of the haulage technologies in accordance with the volume mine and the height of lifting.

It can be clearly seen that:

The total transport cost of haulage technologies depends on the depth of mines in accordance with the relationship of quadratic function. When the required mine volume at the each benches are 100 ton/hour, the total cost of transport technology with single truck is the most effective.

Other cases, when the required mine volume at the each benches Q' = 300 ÷500 ton/hour, the total cost of transport technology with single truck works effectively with the height of lifting about H= 180÷240 m. On the other hand, when the height of lifting is more than H > 240m, the total cost of the combined haulage technology between truck and hight angle conveyor, which has the compressed conveyor system**,** is minimum transport cost.

When the volume of mine is Q' = 700÷1.100 ton/hour, the total transport cost of single truck technology is minimum cost with the height of lifting H < 120 m. However, when the height of lifting is H> 120 m, as a result the total transport cost of the combined haulage technology of truck and hight angle conveyor is minimum cost.

When the volume of mine is Q'> 1.100 ton/hour, the total transport cost of the combined haulage technology of truck and hight angle conveyor, which has compress system, is minimum cost.

With each different mining depth and depending on the volume of overburden of each bench, the transition depth of haulage form will be different. As a result, the transition depth of haulage form will increase when the required productivity of haulage operating is small. Similarly, this transition depth will reduce when the required capacity of transport is big.

When concerning the environmental impact of haulage technologies showed that the consumption process of fuel is one of the causes to emit gasses to environment. According to the providing document of WHO, the amount of emission gasses when using one tone of oil of the internal combustion engines create the amount of gasses q_i as following: SO_2: 2,8 kg; NO_2: 12,3 kg; HC: 0,24 kg; Dust: 0,94 kg. The volume of waste is calculated by formula:

$$Q_{ti} = Q_{nl} \times q_i \quad (4.32)$$

In which: Q_{ti}- the component waste volume; Q_{nl}- the amount of consumption oil of haulage technology, ton; q_i – the amount of emission gasses.

When the depth of mine is 120m and Q'= 500÷700 ton/hour, the largest amount of NO_2 emission gas when operating is 36.65 – 95.29 tons. When the depth of the mine is 600m, the amount of NO_2 emission gas increases to 695.72 – 1808.86 tons. Due to the conveyor transportation technology with using electrical energy, the level of the impacts to the environment is much less than the truck transportation technology. The proper overburden transportation technology at Vietnam deep open pit coal mines has been shown in the table 4.1.

Table 4.1. The suitable haulage technology for the deep open pit coal mine in Vietnam

<table>
<tr><th rowspan="3">The height of lifting H, m</th><th colspan="16">The value in accordance with norms</th></tr>
<tr><th>H_o, m</th><th>Haulage techn-ology</th><th>H_o, m</th><th>Haul-age techn ology</th><th>H_o, m</th><th>Haula-ge technol ogy</th><th>H_o, m</th><th>Haul-age techn-olog-y</th><th>H_o, m</th><th>Haul-age tech-nology</th><th>H_o, m</th><th>Haula ge techn-ology</th><th>H_o, m</th><th>Haul-age techn-ology</th><th>H_o, m</th><th>Haul-age techn-ology</th></tr>
<tr><th colspan="2">Q'=100 Ton/hour</th><th colspan="2">Q'=300 Ton/hour</th><th colspan="2">Q'=500 Ton/hour</th><th colspan="2">Q'=700 Ton/hour</th><th colspan="2">Q'=900 Ton/hour</th><th colspan="2">Q'=1100 Ton/hour</th><th colspan="2">Q'=1300 Ton/hour</th><th colspan="2">Q'=1500 Ton/hour</th></tr>
<tr><td>120</td><td colspan="2" rowspan="7">Single truck</td><td colspan="2" rowspan="3">Single truck</td><td colspan="2" rowspan="2">Single truck</td><td colspan="2">Single truck</td><td colspan="2">Single truck</td><td colspan="2">Single truck</td><td>45</td><td rowspan="11">truck +hight angle conv-eyor</td><td>45</td><td rowspan="11">truck +hight angle conv-eyor</td></tr>
<tr><td>180</td><td>75</td><td rowspan="10">truck + hight angle conv-eyor</td><td>45</td><td rowspan="10">truck + hight angl-e conv-eyor</td><td>45</td><td rowspan="10">truck + hight angle conv-eyor</td><td>45</td><td>45</td></tr>
<tr><td>240</td><td>75</td><td rowspan="9">truck + hight angle conv-eyor</td><td>75</td><td>75</td><td>75</td><td>75</td><td>75</td></tr>
<tr><td>300</td><td>105</td><td rowspan="8">truck + hight angle conv-eyor</td><td>75</td><td>75</td><td>75</td><td>75</td><td>75</td><td>75</td></tr>
<tr><td>330</td><td>105</td><td>105</td><td>75</td><td>75</td><td>75</td><td>75</td><td>75</td></tr>
<tr><td>360</td><td>105</td><td>105</td><td>105</td><td>105</td><td>105</td><td>75</td><td>75</td></tr>
<tr><td>405</td><td>120</td><td>120</td><td>120</td><td>90</td><td>90</td><td>90</td><td>90</td></tr>
<tr><td>450</td><td>150</td><td rowspan="4">truck + hight angle conve-yor</td><td>135</td><td>105</td><td>105</td><td>105</td><td>105</td><td>105</td><td>105</td></tr>
<tr><td>495</td><td>165</td><td>150</td><td>120</td><td>120</td><td>120</td><td>120</td><td>120</td><td>120</td></tr>
<tr><td>555</td><td>135</td><td>150</td><td>150</td><td>150</td><td>150</td><td>150</td><td>120</td><td>120</td></tr>
<tr><td>600</td><td>195</td><td>165</td><td>165</td><td>135</td><td>135</td><td>135</td><td>135</td><td>135</td></tr>
</table>

4.6. The calculated result for Cao Son coal mine

4.6.1. General overview on the Cao Son coal mine.

From 01/01/2015, the total volume mine of Cao Son coal mine includes 981.800×10^3 m^3 of overburden and 105.720×10^3 tons of rough coal in which the average stripping ratio k_{tb} = 9,29 m^3/ton. The required volume of transport is 40.000.000 m^3 per year or 14.767 ton/hour. The volume of overburden on a bench changes in range 56÷911 ton/hour and the average volume of overburden on a bench is 642 ton/hour. The average distance of transport is 7 km.

The haulage technologies can be used:

+ The single truck haulage technology: In the bench locations are near the surface mine, the suitable haulage technology is use the equipment complex with excavator and truck in which the bucket capacity is E=10,5 m^3 and the load size of truck is q=96 tons. In case, the bench position located at the deep benches, it is better when using the equipment with the bucket capacity of excavator is E = 6,7 m^3 combining with the load size of truck is q=58 tons;

+ Truck - conveyor haulage system: The parameters of hight angle conveyor which has the compress system is that: the width of conveyor B is 2 m, the speed of conveyor is 3,15 m/s and the inclination of conveyor is β=35°. The load size of truck is 96 tons, and the average distance of transport from working face to the focused bench location is 1,5 km;

+ Truck - hosting skip haulage technology: The selected truck load is 96 tons, the skip load is 100 tons, the axial line angle is equal of the pit slope angle which is β=35°.

The technical norms of the waste rock haulage technology solution for Cao Son coal mine is shown in table 4.2.

Table 4.2. The technical and economical norms of the waste rock haulage technology solution.

Factors	Height of lifting m	The transition depth of haulage form in accordance with the haulage solution, m			The operating cost in accordance with the haulage solution 10^3 đ			
		Truck - hight angle conveyor	Truck - inclined conveyor	Truck - hoisting skip	Truck - hight angle conveyor	Truck - inclined conveyor	Truck - hoisting skip	Single truck
Energy consumption, kJ	60	15	15		2.376	2.477	5.426	4.302
	105	45	45		6.981	6.984	13.929	12.069
	150	60	60		13.734	13.603	26.324	23.729
	195	75	75		22.718	22.436	42.611	39.279
	255	105	105		38.328	37.815	70.381	66.068
	300	120	120		52.420	51.747	95.749	90.700
	345	135	135		68.700	67.875	125.008	119.223
Cost, đ	60				24.345	33.630	19.129	17.480
	105			45	45.171	54.231	40.596	39.188
	150			60	69.506	81.859	68.054	68.264
	195	60	60	75	93.122	106.178	101.595	104.709
	255	90	90	75	128.235	140.930	156.264	164.765
	300	75	75	120	156.556	169.133	214.214	218.403
	345	90	90	135	187.229	199.369	270.536	279.411

It can be seen from table 4.2:

- The total energy consumption of the truck - conveyor combined haulage solution is minimum. Beside that the total energy consumption of the truck – hight angle conveyor and truck – inclined conveyor system is approximately equal.

- The total transport cost of single truck is minimal haulage cost when the height of lifting reaching to 150 m. In case, the height of lifting is more than 150m, the technology solution by using the truck – hight angle conveyor system has minimal transports cost. The total cost of truck – hight angle conveyor system makes up 89 percent comparing with the single truck using solution.

Concerning the environmental factors: The amount of emission gasses from the diesel engines of trucks is extremely large. It is about a range 12,18 ÷ 142,13 tons per year in which the NO_2 component will change in accordance with the depth of mine from 20,09 ÷35,89 tons per year.

Basing on the analyzed above, the most suitable haulage solution for Cao Son coal mine:

- Form the depth of mine is -100 to +50, this means that the height of loading lifting is 150 m. The most suitable haulage form is single truck in which the load size of truck is q= 96 tons combining with the bucket capacity of excavator is E = 10,5 m^3;

- When the height of loading lifting is more than 150m. The most suitable haulage technology is the combined haulage system with truck and hight angle conveyor. The technical parameter of this system includes the width of conveyor is 2m, the speed of conveyor is v = 3,15m and the inclination of conveyor $\beta = 35^o$. At that the transition depth of haulage form from single truck form to the combined haulage system of truck and conveyor is 60 meter.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS:

The thesis is a scientific study which researches on selecting the suitable waste rock haulage technology for the deep open pit coal mines in Vietnam. The results of this thesis ensure the mining productivity, increasing the economical effectiveness as well as reducing environmental pollution. The content of the thesis is a matter of great urgency which will have greatly contribution to the open pit mining industry in Vietnam. This is several results of thesis as following:

1. The thesis has proposed the classification method for the deep open pit mines basing on the mine geometrical dimension and the suitable

haulage technologies.

2. By using the mathematical model, the optimal parameters and norms for the transportation technology can be determined, the relationship among the energy consumption, transportation cost of the transportation technology with the traffic volume and haulage height can be established. The definition method ensures the reliability and provides conditions for selecting the transportation solutions, applying to the actual production and increasing the mining efficiency at Vietnam deep open pit coal mines.

3. The thesis has established the using scope of the haulage technologies basing on the comparing of unit energy consumption and the transport cost in accordance with the height of loading lifting. The thesis has selected the most suitable waste rock haulage technology for the deep open pit coal mines in Vietnam basing on the principle of the total transport cost and the energy consumption in accordance with the height loading lifting as well as the volume of transport are minimal cost.

4. In the deep open pit coal mines in Vietnam, depending on the height of loading lifting and the volume of waste rock at each bench, the suitable haulage technology should be selected as following: the single truck haulage technology operates effectively when the height of loading lifting reaching to 180 meters. On the other hand, when the height of loading lifting is more than 180 meters, using the truck – hight angle conveyor combined haulage technology in which the inclination of conveyor and the pit slope are equal, the focused bench located in the middle of group benches, and the transition depth from the single truck form to the combined form with truck and hight angle conveyor is là 60÷75 m.

5. The results of thesis is applied to calculate for the waste rock haulage operation of Cao Son Coal Mine. In fact, this results is not only suitable to real conditions of production , but also it demonstrates the validity of the proposed method which can be applied to the other deep open pit mines having similar conditions.

RECOMMENDATION

The research results of thesis can be applied to the waste rock haulage technology design for the deep open pit coal mines. In addition, in the coming time the demand of research on improvement of the hight angle conveyor arragerment diagram is neccessary because the moving shift of the focused bench is suitable deepening operation and mining sequence of the deep open pit coal mines.

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