For the underground haulage of mine cars in coal mines, mule power, the endless rope system and steam locomotives are being rapidly replaced by compressed air and electric locomotives. Experience has shown that when the grades do not exceed 5% for short distances and an average of 3% maximum against the loads, or for short distances 8% and an average of 5% maximum in favor of loads, locomotive haulage is the most economical form of haulage. When the grades do exceed the above figures, traction haulage is not as efficient as rope haulage.

Which of the two systems, compressed air or electricity, is to be chosen is the question for the engineer to decide. This question can only be satisfactorily answered after a careful [illegible] into the conditions of the mine at which it is proposed to establish the plant, the advantages and disadvantages of both systems, and the conditions necessary for the most economical use of each. No one system can be adopted generally on account of the variable conditions which each and every colliery presents.

Electricity as a motive power seems to be more in use at present than compressed air, at least in the bituminous mines, although improvements in the construction of air compressors and compressed air mine locomotives are bringing them more into use every day. The following data is taken from the Pennsylvania Mine Inspectors' Report for 1901 published in April 1902

Bituminous Regions	Air Locomotives	—	23
	Electric "	—	231
Anthracite Region	Air "	—	51
	Electric "	—	40

While this shows a considerably larger number of electric locomotives than air locomotives in this state, by comparing it with the statistics of 1900, we see that the increase in air locomotives over 1900 was 57½%, while the increase in electric locomotives was only 28% which tends to show that the air locomotive is coming to the front.

The three principal features to be considered in determining the best system of haulage adapted to existing conditions are:-

1st Its effect upon ventilation and safety [illegible] employed.

2nd Capacity, grade, distance and curvature of line.

3rd Cost of installation and operation.

In order to make a comparison in a specific case, the conditions existing in the Highland No. 5 Mine of Mess. G. B. Markle & Co., anthracite coal operators, were carefully gone over. At this mine they have a compressed air plant, which was installed March 1899, consisting of two Norwalk air compressors and five Porter pneumatic locomotives. A plan of the motor roads and pipe line is shown in attached blue-print. It will be seen from this plan that the work of the air motors consists of the bringing in of the loaded cars from the different points of the mine to the main turnout A at the bottom of the slope. However all the air motors do not make the complete trip into the foot of the slope, but they work in relays. The following is the schedule:—

Motor No. 5 runs from A to B and return, a distance of 1817 feet each way with an average grade of ½ %.

Motor No. 3 runs alternately from B to C, 1000 feet, average grade $2\frac{1}{10}$ %, and from B to D, 1547 feet, average grade ½ %.

Motor No. 2 runs from C to M, 1000 feet, average grade $4\frac{1}{6}$ %.

Motor No. 4 runs from D to E, 2200 feet, average grade ½ %.

Motor No. 1 runs in Tunnel D from E to F, 1800 ft, average grade ½ %.

All the grades are in favor of loads, except from M to N, where there is a heavy grade against the loads, but this part of the mine is about worked out and no coal has been taken out of this dip for nearly a year.

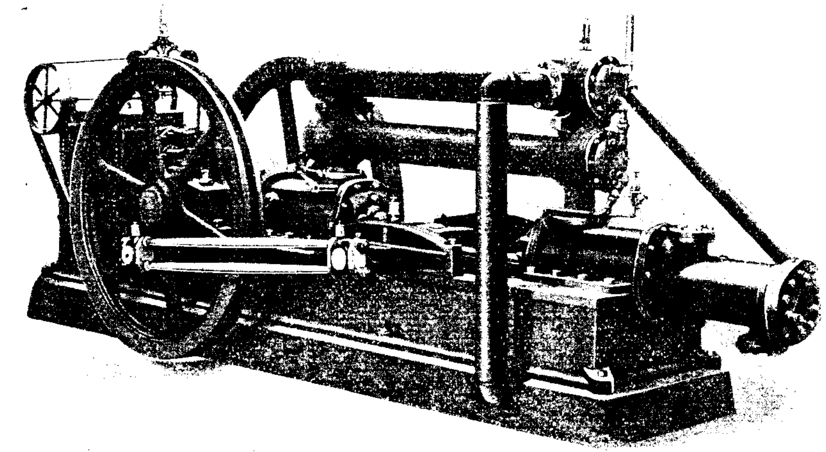
Motor No. 2 has taken 22 cars up the heaviest grade ($4\frac{1}{6}$ %) with 350 lbs drop in air pressure, starting

700 lbs., but the average trip is 14 cars.

The equipment of the plant consists of compressor, storage tanks, pipe line, charging stations, and locomotives, which are generally termed air motors. In the above are omitted track system and cars. Generally these are already installed and operated by mule power.

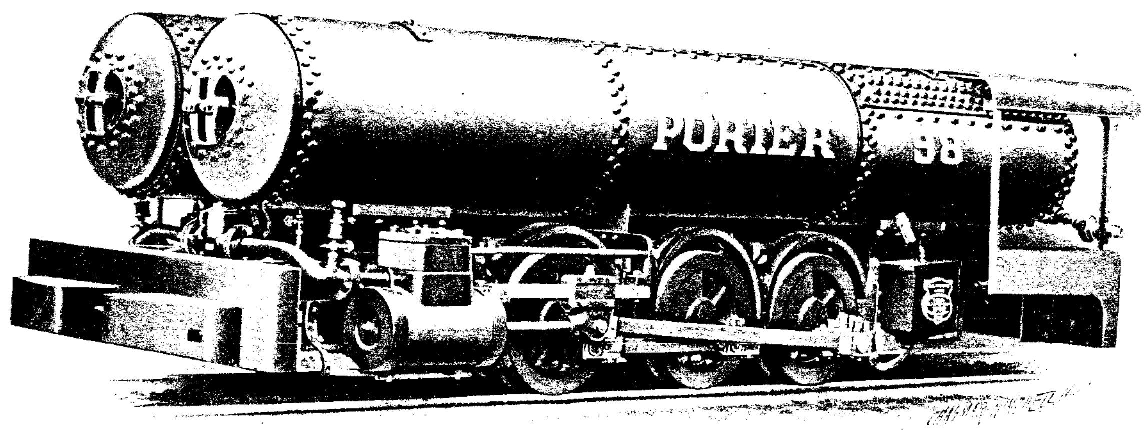
The compressor shown below is the one used. They are the three-stage, straight line, steam actuated Norwalk compressor, steam cylinder 28" x 30", taking the air at atmospheric pressure and compressing it to 900 lbs. in three stages with coolers between, and having a capacity of 1820 cu. ft. per minute. The steam end is fitted with adjustable steam expansion valves and speed governor. In operation the air is taken from some place cool and free from dust and is admitted to the large double-acting cylinder in the centre of machine. Here the

THREE-STAGE LOCOMOTIVE CHARGER.



compression is performed. The water jacket by which the cylinder is surrounded takes away a share of the heat of compression, after which the first inter-cooler extracts the remainder, bringing the air to the second cylinder at or near the temperature of the cooling water. The second cylinder is also water jacketed and performs another stage of compression. From this cylinder the air is led through the pipe shown in front of machine to the second inter-cooler, and thence into the third cylinder through inclined pipe at back. In this third cylinder [illegible] flexible metallic coupling that is absolutely tight. The coupling terminates with a brass nut which fits the check valve on the air tank of locomotive. The entire operation of charging consumes but 1 or 2 minutes.

Compressed Air Mine Locomotive, Two Tanks, Six Driving Wheels



The general appearance of the air locomotive is shown by cut. The construction is about the same as steam locomotives, so far as the machinery is concerned, or as we might say, the engines proper. In other words, all parts such as frames, valve motion, cylinders, rods, spring rigging, differ but slightly from the like parts of the steam locomotive. These parts, however, are of more liberal proportions than has been the practice in building steam locomotives of the same size, making a stronger and more durable machine. The principal difference consists in the substitution of air storage tanks in place of the steam boiler and accessories. Two tanks, 18 ft. long x 32" diameter are used. They are very heavy for carrying high pressures and are made of steel plates 7/8" thick. They carry a pressure of 700 lbs. per sq. in. and using plates having a tensile strength of 60,000 lbs. per sq. in., they have a factor of safety of 3½. This is ample margin, as the tanks are free from all strains of expansion and contraction to which a steam boiler is subjected. Each locomotive carries a check valve fitting charging station coupling; communication between the tanks is effected by means of a connecting pipe and the motor may thus be charged from either side. The air, before entering the [illegible] passes through an automatic stop and reducing valve into an auxiliary reservoir and then through a balanced throttle valve into the valve chests. A constant working pressure of 140 lbs. is thus maintained so long as the pressure in the main tanks equals or exceeds this amount. The auxiliary reservoir is a piece of wrought iron pipe 7" diameter by 12 ft. long and closed at the ends with cast steel heads. The distribution of air in the cylinders is controlled by a Stephenson link motion of the usual locomotive type and the air is used expansively.

The five locomotives are all of the same size and design. The cylinders are 9½" x 14", 6 driving wheels 26" diameter. Rigid wheel base 5'6", gauge of track 4'8½" length over bumpers 15' 11½". Capacity of main storage tanks 178 cu. ft. Wt. of locomotives 32600 lbs. Maximum storage pressure in tank 800 lbs. per sq. in. Pressure in auxiliary reservoir 140 lb. per sq. in. [illegible] the compression is completed, and the air discharged at the connection shown at the bottom.

Storage tanks are not used at this plant as the pipe line is sufficiently large to act as a reservoir. 4800 feet of special 6" pipe for a working pressure of 900 lbs. per sq. in. is used. They are tested to a pressure of 1800 lbs. The pipe is lap welded wrought iron pipe and joints are made by heavy threaded sleeves which have an annular caulking groove at each end, into which a strip of soft metal can be driven and stop leaking should any occur. At intervals of 300 or 400 feet a bolted flange joint is placed for convenience in making extensions.

The location of the charging stations is shown in diagram. They consist essentially of cast tee with flange outlet, a 1½" gate valve and three 1½" metallic ball joints. The latter are connected to gate valve by short lengths of extra strong wrought iron pipe. [illegible] valve is used between the main storage tanks and the auxiliary.

This plant was installed for a maximum capacity of 900 mine cars per day of 10 hours. The highest output reached was 700 cars, with four of the six motors in service, the greatest length of haul being 4500 ft. at that time. This output was not due to any shortage of motive power, but to the fact that only 700 cars could be handled on the surface. These cars weigh 12000 lbs. loaded and 4750 lbs. empty, giving 3262 net tons which could readily have been handled by the locomotives.

The capacity of the two compressors was originally somewhat in excess of the locomotive requirements, as a No. 12 Cameron Pump also received its power from the same source.

The track is standard gauge (56½") [illegible] with 60 lb. rails. The cars are hauled in trips of from 10 to 18 each, so ~~that~~ taking into consideration the large cars the trains are very heavy for mine practice, utilizing the full power of the locomotives. This feature, combined with intelligent supervision, has resulted in extremely low operating expenses. But ~~four~~ of the locomotives were used for day work, and the fifth for night work; it being the policy of the company to make each its locomotive runner responsible for the condition of his machine. This could not be done if the night man took one of the day machines for his work.

At present the greatest length of haul is 9364 feet, and the average output 500 cars per day of 9 hours. This increased length of haul has necessitated the use of the five locomotives for day work, the addition of 2400 feet of [illegible] in line and two more charging stations.

The purchasers had in view absolute reliability and ultimate economy rather than extremely low first cost, and their liberal and conservative policy has been fully justified by the subsequent economical and continuous operation.

The size of a compressed air locomotive is generally determined by the rate of consumption of compressed air, which depends upon the load, length of haul, the topography of the track, and the important item, the clearances for the motor, as for instance, the height and width of mine entry. To avoid frequent charging however, it was necessary to elect a locomotive with large storage capacity, weighing about 16 tons. The speed is from 6 to 10 miles per hour.

Taking the case where 22 empty cars are taken up a maximum grade of [illegible]% [illegible]

The maximum tractive force as follows:–

22 empty cars @ 4750 lbs. = 104500 lbs = 52.25 tons

Tractive effort due to grade = $.04\frac{1}{6} \times 2000 = 83$ lbs.

Assuming 25 lbs. per ton as the coefficient of rolling friction, we find the total tractive effort to be:–

$83 + 25 = 108$ lbs. per ton

or $108 \times 52.25 = 5630$ lbs.

The tractive force for the locomotive is calculated from its dimensions as follows:–

$$\pi D T = \pi d^2 \times .85p \times l$$

$$\text{or } T = \frac{d^2 \times .85p \times l}{D}$$

where T = tractive force of locomotive

d = diameter of cylinder in inches

l = length " stroke of cylinder in inches

.85p = 85% of the boiler pressure in lbs. per sq. in., this being found by practical test to be the effective pressure in the cylinders.

d = diameter of driving wheel in inches.

The locomotive in question with $9\frac{1}{2}" \times 14"$ cylinders, 26" drivers and using the air at 140 lbs. give the following tractive force:–

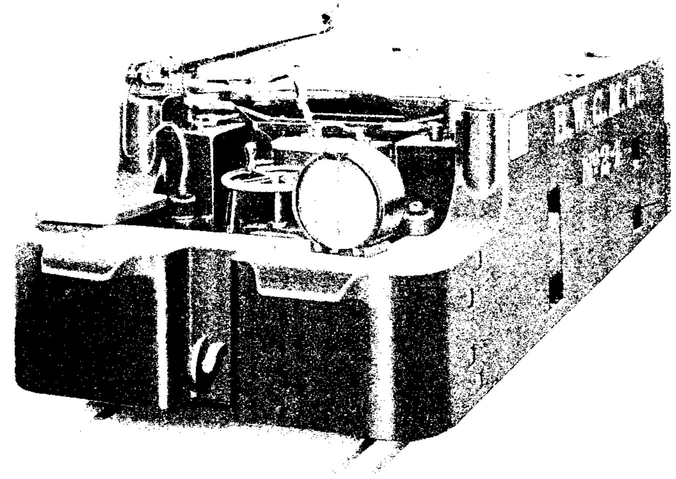
$$T = \frac{(9.5)^2 \times .85 \times 140 \times 14}{26} = 5780 \text{ lbs}$$

This shows that the motor is working almost at its limit when pulling 22 cars up the grade of 4½%. Let us take the average trip of 14 cars. Here the total weight of train is $\frac{14 \times 4750}{2000} = 33.25$ tons and the tractive force required is $108 \times 33.25 = 3557$ lbs, so that the motor has a good margin when working under ordinary conditions. As the other motors work on lesser grades and their trips average about the same number of cars, it is seen that the capacity of the motor is ample. However it was considered advisable to get all five motors of exactly the same size and dimensions on account of the fact that in this case they can be interchanged in case of breakdown; also it would be cheaper in case of repairs as duplicate parts can be kept on hand to be applied immediately in case of breakdown.

Let us see what size of electric locomotive would be required to do this work. From the catalogue of the Westinghouse Electric & Manufacturing Co., we find that their largest size locomotive is 26000 lbs., for which size at a speed of from 6 to 10 miles an hour a draw bar pull of 3260 lbs. is developed on a 4% grade. While this locomotive might be able to keep up the average number of cars per day, still it has hardly a large enough draw bar pull. The General Electric Co. make a locomotive of 26000 lbs weight which for a speed of 8 miles an hour has a drawbar pull 4500 lbs. on the level, which would be about 3600 lbs. on a 4% grade. The approximate kilowatt input at the rated drawbar pull and speed is 95 kilowatts from their catalogue.

The Jeffrey Manufacturing Co. make a locomotive of 24000 lbs weight which they rate at 4500 lbs normal draw bar pull or 3000 lbs. on a 4% grade. They say in their letter that the kilowatt input is about 105.

The locomotives made by the different firms are nearly alike in construction. They are driven by two motors separately spring supported, one geared to each axle by single reduction gearing running in oil in tight, dust proof cases. These motors are designed especially for mine service and are of the four pole, steel clad railroad railway type, and the armature is iron clad. The motors are arranged central, that is, turned toward each other between the axles. A trolley pole has been especially designed for this service, which may be reversed and placed upon a switch



GENERAL ELECTRIC COMPANY'S STANDARD 13 TON MINE LOCOMOTIVE.

on either [illegible] side of the frame and thoroughly insulated.
The trolley wire is generally located 6" to 15" out [illegible] of the rail and is thus out of the way [illegible] [illegible] rules.

The frames of these [illegible] are of cast iron, heavy in structure and designed [illegible] to protect the mechanism. [illegible] frame consists of two heavy side castings [illegible] [illegible] and [illegible] [illegible] [illegible] [illegible] to run as close [illegible] [illegible] [illegible] is consistent [illegible] the proper clearance, thus preventing [illegible] obstruction [illegible] the track from getting under [illegible] [illegible]. This feature is also of advantage in [illegible] the locomotive is derailed, for as soon as the wheels leave the track the frame slides on the rails and brings the machine to a stop. The working parts are made as light as is consistent with strength and the extra weight required for traction is put in the frame which is supported on springs.

For the locomotive of the General Electric [illegible]

Drawbar pull in Lbs.	Weight of Standard Rail per Yd. in Lbs.
700	10
1200	11
2500	16

kilowatt input of the five locomotives at their full rated loads would be 475 kilowatts. Using a potential of 500 volts and allowing 70% load factor, a higher figure than is used in ordinary practice, a generator of 332.5 kilowatts would be required or about 420 H.P. Upon stating the conditions to Mr. Culbertson of the General Electric Co, at Scranton, we advised the use of two-200 H.P. generators at 525 R.P.M. so that possibly 70% load factor is too high. Mr. Clarke of the same company in an article on electric locomotives, said that 60% was a much higher figure than is used in ordinary practice. So it is likely that 400 H.P. or 310 Kw. of generators would be sufficient. The prevailing pressures are 250 and 500 volts. The disadvantages of 500 volts is that it is enough to kill a man or mule while 250 is not, but with 500 volts nearly 75% of copper is saved, and 500 volts is generally used.

The generators would be 500 volt, direct current, compound wound, multipolar and belt driven.

For each of these generators a high speed engine of about 225 H.P. would be required. Taking the steam pressure at the engine at 75 lbs. and speed of engine at 200 R.P.M., this would give an engine with about 16" diameter cylinder and 18" stroke.

The distance of the power house from the top of the slope is about 200 feet, the slope is 500 feet deep, and the total length of haul inside is 9364 ft. This is a total length of wire of 10064 feet.

The rails will serve as return by means of bond wires. The wires are hung along the sides or tops of the gangways, tunnels and headings. Feeders will not be used as the distance is not too great.

To determine the size of wire required we proceed as follows

The length of wire required to carry the full current would be to B on map or a length of 1817 + 700 = 2517 ft. The current in this wire would be $\frac{310 \times 1000}{500} = 620$ amperes. Allowing a drop of 20% in potential in order to reduce the cost of copper in the circuit, would give a loss of 100 volts.

We then have $20\% E = R I$

and $R = 10.6 \frac{l}{d^2}$ (Prof. Franklin)

where E = electromotive force in volts

R = resistance of conductor in ohms

l = length of conductor in feet

I = current in amperes

d = diameter conductor in mils.

Combining these two equations, we have:–

$$d = \sqrt{\frac{10.6\, l I}{.20 E}}$$

$$= \sqrt{\frac{10.6 \times 2517 \times 620}{.20 \times 500}} = .404 \text{ mil.}$$

This diameter is #000 copper wire. The weight of 1000 feet is 507.01 lbs. This makes a total weight of 2.517 × 507.01 = 1276.14 lbs.

In a similar way the wire from B to C is found to be #0 or a weight of 319.04 lbs.; from B to D #00 is required or 1.547 × 402.09 = 629.29 lbs; from C to M, #1, weight 252.88 lbs. From D to E, #0 wire, or 2.2 × 319.04 = 723.88 lbs; from E to F, #1 wire or 252.88 × 1.8 = 455.08 lbs. This gives a total weight of copper of 3656 lbs. and at 15 cents per pound gives $548.40. To this is to be added the bond wire for the rails which will bring the total up to about $700.00

For the power house a generator panel would be required, also two endless belts.

The power house used at present for the compressors is an addition built to an engine house for the slope hoisting engines and this same engine house could be used for an electric plant.

Also the steam connections for the compressor would be the same for the two generator engines, and need not be considered in a comparison of the first costs of the plants.

Following is given a comparison of the first costs of the two different systems. The cost of the compressed air plant is the actual cost of the plant in question, while the cost of the electric plant is to a certain extent estimated, although the costs of the motors and generators are as quoted by Jeffrey Mfg. Co. The figures are as close as can be arrived at and they have been compared to actual costs of installation as given in several articles and seem to be about right. It is possible that the total cost for the electric plant is a little higher than would actually be the case, as the contract would be taken for the whole plant by one firm and they might give better estimates than we have given.

Compressed Air Plant

5 - 4½" x 14", six drive pneumatic motors, @ #3640 f.o.b.	#18200.00
2 - 28" x 30" 3 stage Compressors, complete with gages, safety valves, regulators, &c	7500.00
4800 feet of special 6" pipe, complete with couplings	2700.00
5 Metallic Charging Stations complete	350.00
6" pipe flanges, tees, &c	192.00
Total	# 30942.00

Electric Plant

2 - 225 H.P. horizontal non-condensing high speed engine, cylinders 16" x 18"	2500.00
2 - 200 H.P. compounded generators, 500 volts, 525 R.P.M., capable of carrying 30% overload for at least 30 minutes	4000.[illegible]

5- Electric locomotives, 26 000 lbs. weight each, 4 drivers, 2 motors arranged central ——	10,000.00
2 Endless belts	150.00
Trolley and bond wire	700.00
Insulation and labor of wiring	800.00
1 generator panel with rheostat and instruments —	250.00
Total	$18,400.00

This shows quite a decided advantage in first cost in favor of electric haulage and this seems to be admitted by the compressed air people.

In regard to operating expenses of the two systems, it is hard to decide which is the greater. After a very careful and exhaustive examination into operating expenses, Mr. J. H. Bowden, M.E., of the Susquehanna Coal Co., at Wilkes-Barre, found that the average operating expenses, including

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In a report on the electric plant at the Eureka mines of the Berwind-White Co., they gave as the cost of operation about one cent per ton mile. The Norton Coal Co. of Virginia has also an electric plant which they claim costs about one cent per ton mile. The above two places however did not add in interest and depreciation which would bring their figures up considerably.

At the Green Ridge Colliery, Scranton, they calculated a cost of 2.76 cents per ton mile, including interest and depreciation.

The cost of electric haulage of the Hillside C. & I. Co. is given at 1.42 cents per ton, but this cannot be taken for comparison as the distance hauled is not given.

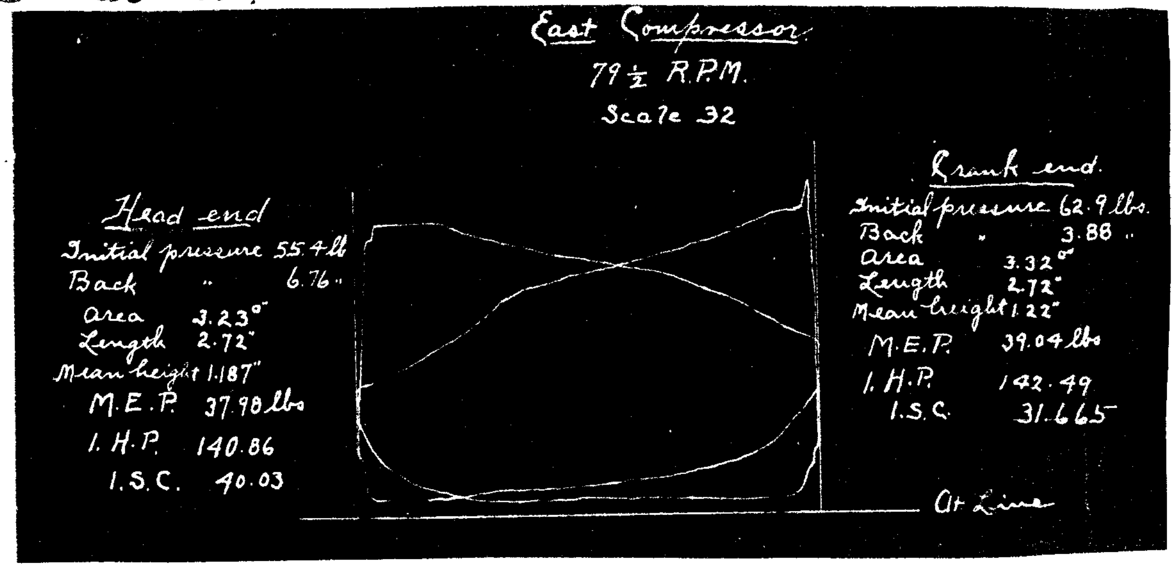
Another instance of compressed air haulage is at the Buck Mountain Colliery the cost per ton mined was 1.06 cents.

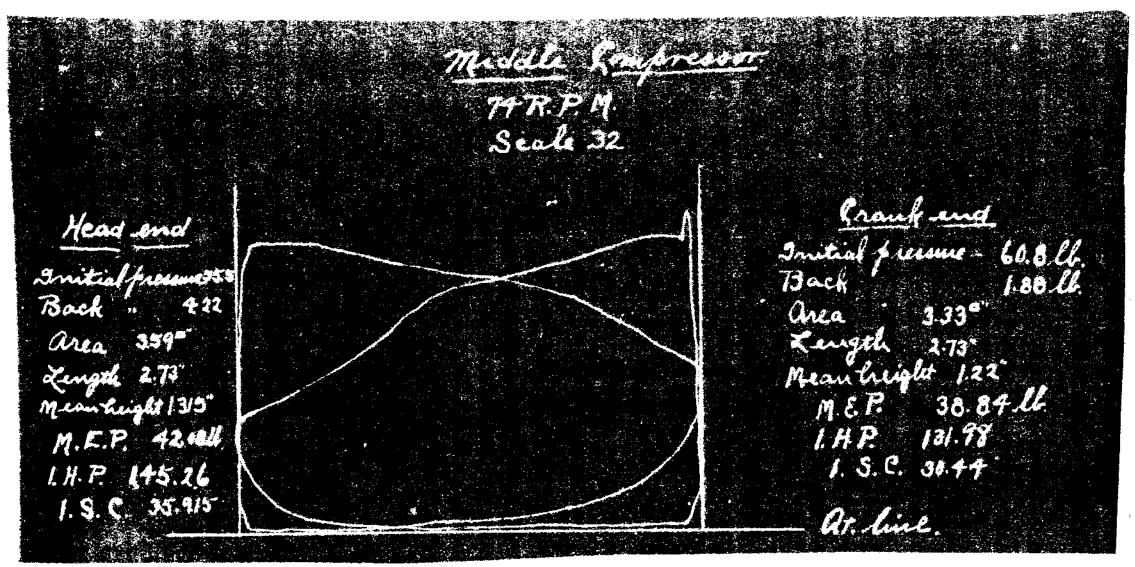
All of the above figures are taken from various articles and reports by the coal companies' engineers and so are pretty reliable.

While a good comparison cannot be made from the above figures, still it is seen that compressed air haulage had the better of the cost of operation. This seems to be due principally to the increased cost of repairs of the electric plant over the compressed air plant. The wages of the motorman and helper or "patcher" as he is called, would be about the same, as it is very probable the same man would be the motorman in the case of installation of either electric or compressed air. The cost of oil &c would also be about the same.

An attempt was made to calculate the cost of operating ~~expense~~ per ton mile for the compressed air plant but no record had been kept of repairs, although they were very light, and the amount of coal hauled and distance hauled could only be estimated, so it was very difficult to get even an approximate figure and the attempt was given up. In this case it would not be necessary to pay an electrician for the electric plant as the regular electrician of the light plant could look after the repairs of the generators and motors, so perhaps not very much would be gained in cost of operation by compressed air after all.

As to the relative steam consumption of the two plants, there seems to be very little difference. Below will be found indicator cards taken from the East and middle compressors. The West compressor was installed last month and is an exact duplicate of the other two.





However as this new compressor is not necessary for the haulage system as described above, but was put in on account of some expected extension of the haulage road and the use of a drainage pump using air, only the two original compressors need be taken into account in our estimate. From the cards it is seen that horse power of the east compressor is 283.35 and of the middle compressor 277.24 or a total of 560.59 H.P. The mean indicated steam consumption for the east compressor is 35.84 lbs. and for the middle compressor it is 33.17 lbs. Upon inquiry of the Norwalk Iron Works Co. as to the probable indicated steam consumption of their 28" x 30" single cylinder compressor at about two thirds cut-off, which is the average cut-off from cards, they stated that it would probably be in the neighborhood of 28 lbs. per horse power [illegible]

The generator engines would probably consume about 28 lbs steam per horse power per hour and as the compressor develops 560 H.P while the engines would only develop 450 H.P there would be quite a saving in steam if the compressors were run all day at the rate the cars run. But they are not run continuously, perhaps 8 hours a day, and the generator engines must run continuously so it seems as if there is very little difference in the total steam consumption per day. Besides in either case a new boiler would have to be installed and as the fuel (fine buckwheat) is very cheap at the mines, there would be very little difference in actual cost.

There is one economy peculiar to electric locomotives, and that is the lighter rails that can be used. It is claimed by many that it is necessary to put down just as heavy a rail for an electric locomotive as for a steam or compressed air locomotive. This does not seem to be the case. A 13 ton electric locomotive will run on a 40 lb. rail according to the catalogue of the General Electric Co., Westinghouse and Jeffrey, with a minimum of repairs, whereas a compressed air locomotive of the same capacity requires at least a 50 lb. rail. At the Highland No. 5 Colliery the Mine Foreman said that they had originally a 40 lb. rail; this was too light and was pounded to pieces. They changed this to 50 lb. rails in part of the track and finally decided to change the whole track to 60 lb. rails, which was then done. The difference between the two locomotives seems to be that the [illegible] rotary motion and that if designed and built properly, the entire weight except wheels and axles rests on good spiral springs, so doing away with the hammering of the track.

The compressed air locomotive necessarily has connecting rods and counter weights and a rigid wheel base. The action of the connecting rods and counter weights is to hammer the track at every joint. The action of the steam cylinders with cranks set at 90° also tend to vibrate the locomotive sidewise and so spread the rails. The difference in cost of the road beds would be a large item in a long haul.

Summing up the advantages and disadvantages of the two systems of haulage, we see that the compressed air system has a larger ...

cost and also that its efficiency is less than the electric system. This latter however is not very important due to the low cost of fuel at the mines.

The efficiency of the air system can be quite materially increased by heating the air before it enters the cylinders of the motor, and when so used, the efficiency of the two systems is not very different. However it does not seem as if it was quite practical to do this yet in the mine locomotives, although re-heating has been done in experiments with compressed air for traction purposes in Washington and New York.

On the other hand in the matter of operating expenses, the [illegible] is a little the cheaper, [illegible] to be [illegible] renewals. While the cost per ton mile is only given for air for two collieries, still the officials of the Markle Company also say that their cost of repairs since installation have been very low indeed.

Deterioration is even of less moment in the air system, as a large part of the plant suffers no wear or deterioration whatever, and requires no repairs or attention. The writer has ridden on a locomotive which had been under water in a flooded mine for over a week and the machine was none the worse for its submersion.

One advantage of the air motor which has not yet been mentioned is that the air motor will run where there is tracks and there is no additional cost of laying pipe. [illegible] latitude. For instance should it be necessary to extend the line several hundred feet or to lay new sidings, with electric motors this requires the addition of wire, while the air line remains the same.

It can also be said that a temporary stoppage of the air compressor does not tie up the system.

The element of danger, when considering both electricity and compressed air as motive powers, is a very important factor in deciding upon either system. The high voltage and low hung trolley wire causes danger of shock to men and mules. While accidents due to coming in contact with the line wire are not as frequent as would be supposed, still the Mine Inspectors' Report contain a number of such accidents.

Also the danger of ignition of explosive gases by means of sparks from the electric connections, must receive consideration. If there is explosive gas even in small quantities, to be found in the pockets of the roof or crevices, it would not be safe to install electric haulage, as a single explosion may cost more than the whole installation, and the chance of such explosions where electricity is used is by no means uncertain, a fact which can also be substantiated by reference to the Report of the Mine Inspectors.

It is claimed that the air exhausted by the motors help ventilation. In speaking to the Mine Foreman at the Highland colliery he that while it brought in fresh air, still this advantage was offset by the fact that [illegible] motors running contrary to the direction of the air currents in the tunnels and gangways tend to destroy the velocity of the current.

It would therefore seem that the electric system has the advantage in first cost and efficiency, but that the compressed air system costs less to operate, is safer, more reliable and more durable. It remains for the engineer in charge to decide which of these considerations is the most important.