

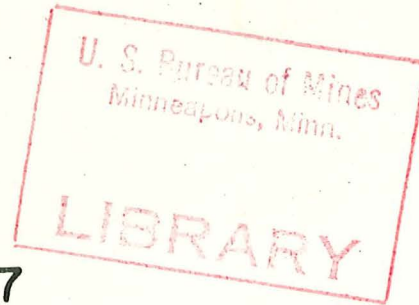
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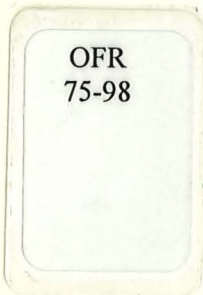


U S B M HO 122057

COAL MINE VACUUM SWEEPER

FINAL REPORT

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF MINES



USBM CONTRACT REPORT HO122057

ENVIROTECH



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DISCLAIMER NOTICE

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U. S. Government.

FOREWORD

This report was prepared by Eimco Mining Machinery, a division of Envirotech Corporation, Salt Lake City, Utah, under USBM Contract Number HO 122057. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of Pittsburgh Mining and Research Center with Mr. Ed Diver's acting as the Technical Project Officer. Mr. A. Young was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period April 21, 1972 to May 20, 1975.

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ABSTRACT

A mobile vacuum sweeper to remove loose coal and coal dust from underground coal mine workings was designed, built, tested, and evaluated.

The design was based on an extensive test program. Pick up and conveying rates vs. air volumes, velocities, and nozzle shapes were determined for coal rubble in a laboratory pneumatic handling system.

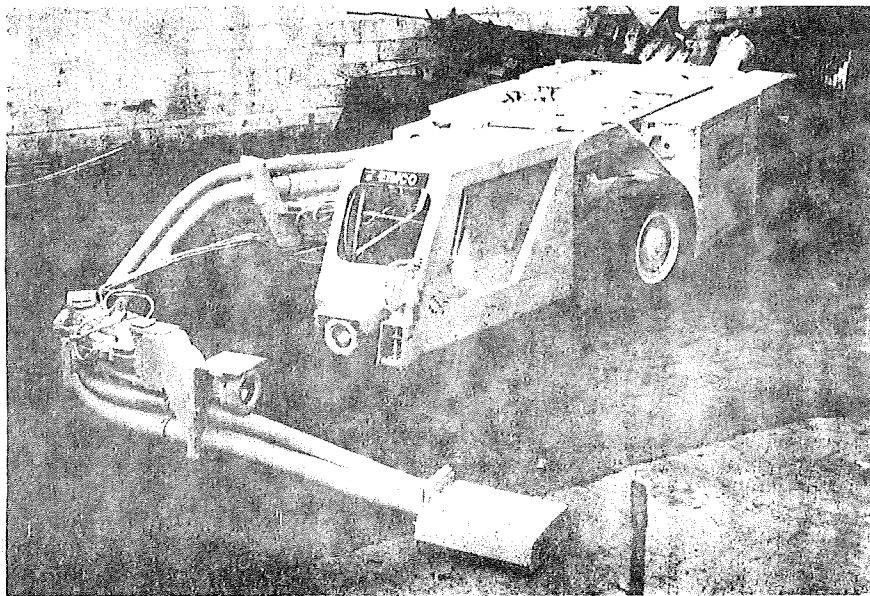
A gas/solids separation system was developed and tested in the laboratory capable of separating the solids loading from the vacuum system air stream to the very high degree required to preclude degradation of the ambient (mine) air.

Two designs were made, one for belt conveyor and one for general district cleanup.

The belt cleanup machine was chosen for test and demonstrated in an underground coal mine performing cleanup work in belt haulageways and on ribs.

SUMMARY

The study produced two concepts of an underground coal mine cleanup machine. One concept was for general cleanup, primarily in the active mining district. The other involves a machine especially designed for cleanup in belt haulageways. It was concluded that the later is more readily adaptable to prototyping and tests and application to current mining conditions. This machine was, therefore, chosen for demonstration and is shown in Figure 1.



COAL MINE VACUUM SWEEPER
FIGURE 1

The machine is capable of collecting coal mine rubble, storing it on board and discharging the collected material to a belt conveyor, shuttle car or similar transport device.

A great deal of emphasis went into devising and testing an efficient particulate collection system. The study produced a simple, compact collection system which emits air with a dust loading low enough to not adversely affect the mine air.

The prototype system design capacity of 100 lbs /min is insufficient for belt or general cleanup purposes. Cleaning of ribs can be achieved very effectively with the prototype machine and the prototype capacity is entirely sufficient for that purpose.

The prototype system had difficulties in handling coal rubble with very large quantities of rock dust. At a rockdust fraction of 90% in the rubble, the system nominal water rate of 2.3 gpm is insufficient to preclude sticking and caking of the rubble in the system interior.

Manual nozzle operation proved more effective in the mine tests than the machine operated nozzle. The prototype uses a 3" suction line for the 100 lbs /min solids flow. If the machine capacity is increased to 500 lbs /min , nozzle and suction line size increases to 6 inches and is likely to be too heavy for manual operation.

Battery power and operation is severely limiting the capacity and usefulness of a mobile vacuum cleaner system for underground coal mine application.

Diesel power applied to a coal mine vacuum sweeper is technically feasible and would vastly improve its capacity and general performance. If applied to the prototype, the available power more than doubles and handling capacity would increase five fold.

Diesel power has two advantages:

1. The energy storage of diesel fuel is many times that of the equivalent weight of and equivalent amount of energy stored in the electric storage battery. This concentration of stored energy allows an extension of the operating time and range by at least an order of magnitude; and,
2. The entire system is far more weight-effective. For instance, on the machine described in this report, a 35 HP diesel unit with radiator, water scrubber, water and fuel tankage would weigh about 3,000 lbs less than the two 120 volt batteries. The engine itself weighs little more than the 15 HP electric motor. This decrease in machine weight further extends the operating time and/or range of the machine, especially with regard to the power required for tramming.

A dry filter system used for the fine or secondary separation system would save substantial machine weight; operating range and unloading would be improved. A system was investigated which operates at a pressure differential of 2 to 4 inches H₂O, saving considerable power, uses self-cleaning, sequenced blow-down cycles, cartridge type elements, and promises to do a better job of cleaning the dust out of the air, especially the respirable dust. If safety considerations permit operating this system dry, the obvious advantages of eliminating the machine water tankage and the refilling trips would further decrease machine weight and improve productivity. Further, if the material in the hopper remains dry, it will be more easily handled and unloaded with a screw conveyor or other materials-handling system.

Mine layouts should be planned to accommodate machine cleaning. Belt conveyors should be offset from the center line of the entry and a travelway maintained along side of the conveyor for the vacuum sweeper. Also the conveyor should be suspended from the roof where possible to provide unencumbered clearance for manipulating the suction head under the conveyor.

The prototype coal mine vacuum sweeper should be equipped with diesel power, rebuilt and retested with those improvements incorporated which were indicated in the mine tests, including:

- improved boom and nozzle control
- improved operator seating
- improved noise control.

INTRODUCTION

Coal fines and coal rubble are generated in large amounts in underground coal mining operations.

If allowed to accumulate, the finer fractions of the loose coal constitute a hazard because:

- . They are a source of dust explosions and can support gas explosions.
- . They can cause spontaneous combustion.
- . If entrained in the mine air, they constitute a potential health hazard to the miner.
- . Accumulations of coal on transformer stations, mining machines, belt conveyors and other mining equipment increases the potential hazard associated with equipment fires.

These hazards can be virtually eliminated if, in accordance with mine regulations, most of the fines are removed shortly after deposition, and, if remaining rubble is diluted with rock dust.

However, keeping an underground coal mine free of excessive rubble is a requirement aggravated by a lack of effective cleanup tools and equipment. To a large extent, cleanup involves manual labor. For example, the only method available to clean under belt conveyors is manual shoveling. Yet, these often extend for miles in the mine and to maintain them in a safe, clean condition requires constant manual labor.

A method which has the potential of achieving thorough cleanup in underground mining is vacuum removal of the rubble. This method would involve a self-contained mobile machine with the ability to pick up, store, and discharge collected material to standard mine conveyances.

This program was undertaken to determine the feasibility of such a system applied to underground coal mining clean up operations.

CURRENT CLEANUP METHODS AND EQUIPMENT

To remove loose coal, the miner resorts to a number of methods all the way from the purely manual to mechanized ways. Equipment in use for cleanup varies. In some operations, the continuous miner is taken out of production for as much as two hours per shift for cleanup of shuttle car roadways. In other mines,

gathering arm loaders, front end loaders, and battery tractor scoops are used. All of the machines are useful only in gathering up piles of loose coal in the open roadways. None does a complete cleanup job.

Because the equipment works much like a manual shovel, it is not capable of removing any material lodging in pockets and crevices below the top surface. Fine coal is left on the floor in amounts, depending on the smoothness of the floor, as shown in Figure 2.

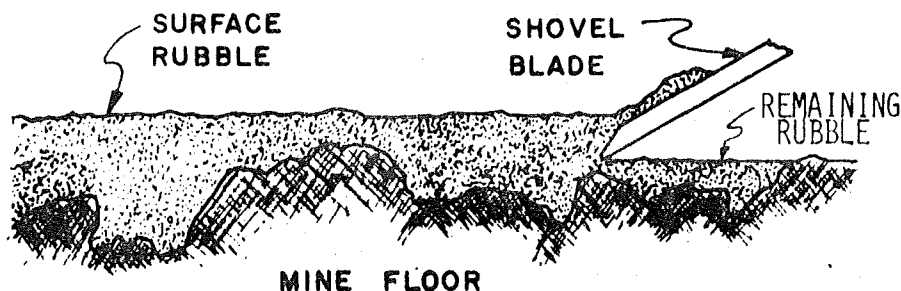


ILLUSTRATION OF SHOVEL LIMITATIONS
FIGURE 2

The remaining fines must be manually removed or maintained harmless by rock dusting or sprinkling.

FOREIGN DEVELOPMENTS

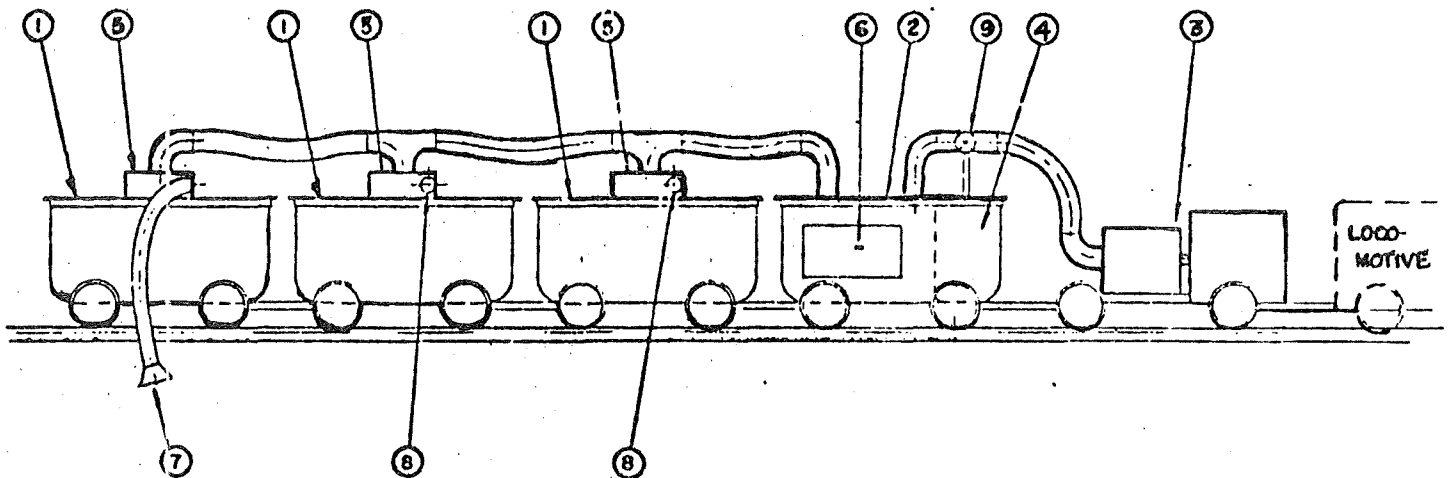
In England and Japan, efforts have been undertaken to develop mobile pneumatic vacuum cleaner systems for underground mine workings, including coal mines. These efforts have not resulted in any known workable products. In Germany, industrial-type vacuum cleaner systems have been in operation in underground mines. These are of low capacity with no application to American coal mining practices. Many industrial portable vacuum cleaners exist in the United States, but none is suitable for use in an underground coal mine.

British Development

In 1951, the National Coal Board in England started development of a coal mine vacuum sweeper.

The objective was a unit capable of removing float coal, rubble and dust from development and rail haulage entries.

Between 1962 and 1966 the machine shown in Figure 3 was tested and evaluated.



- (1) 8.5' long x 5' high x 3.5' wide, 40 cubic foot holding capacity rail car.
- (2) Filter car with 160 - 1½" x 16½" plastic filter elements.
- (3) Exhauster car, with 25 hp, permissible diesel, 8 stage 700 ACFM fan.
- (4) 50 gallon water tank.
- (5) Coarse separation cyclone on each collector/container car.
- (6) Clean out door to service filter elements.
- (7) & (8) Hose and quick disconnect. Hose nozzle with water connection to water supply.
- (9) Main air line shut off valve, interconnects with water and air supply.

BRITISH COAL MINE SWEEPER DEVELOPMENT

FIGURE 3

It had a number of operating problems and its development was ultimately dropped. The major difficulties were:

- . Clogging of the final porous elements used as the last particle separation device. The filters were changed to multiple cyclones but these clogged also.

- . The unloading method was manual, unwieldy and impractical.

In the process of this development work, it was decided to use water injection to avoid explosions within the system. From extensive tests, it was concluded that the entrainment of 20% water (by weight) into the coal fines picked up by the vacuum system provides safety from explosions.

The significance of this development lies in the fact that they:

- . Considered vacuum cleaning in underground coal mines a means for overcoming the dust accumulation problem there.
- . Established a credible, rigidly tested and proven means of rendering such a system safe from explosions.

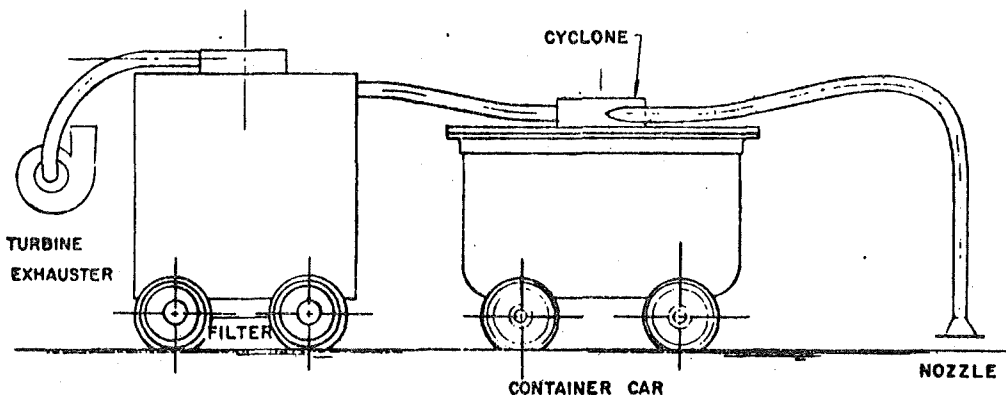
Furthermore, reference to their design points to some of the pitfalls in design which should be avoided, such as:

- . Storage and unloading of collected material, if not properly considered, can critically limit performance.
- . Filters used on heavy loadings of wet coal dust are apt to clog.
- . Dry cyclones cannot operate on wet fine coal.

German Development

The German mining industry has many years of experience with vacuum cleaning systems, stationary and portable. At least four manufacturers supply such equipment and the German mine authorities have approved its use.

Of machines reviewed, the most successful is that manufactured by BVC Staubsauger. It simply consists of an axial turbine exhauster, a filter unit, and a cyclone mounted in the cover of a small mine car as can be seen in Figure 4.

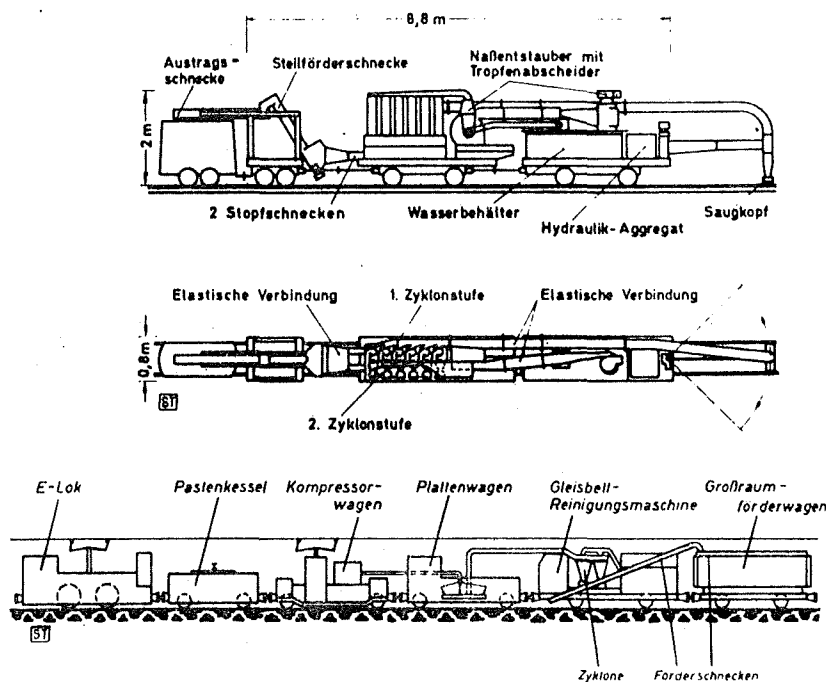


GERMAN VACUUM SWEEPER USED FOR COAL MINES

FIGURE 4

All German commercial systems reviewed are dry. Considering their small size, limited capacity, crude particulate collection system and lack of tramping power, they are of no significance as models other than to indicate a need and one solution possibly more practical to German mining conditions than for American coal mines.

In strong contrast to the commercial units available in Germany, there are systems in that country developed or in development during recent years on funding by the Silikose Forschung Institute der Bergban-Berufsgenossenschaft and other organizations which, as shown in Figure 5 are large, complex engineered systems.



SILIKOSE FORSCHUNG INSTITUTE MINE OR TUNNEL VACUUM CLEANER

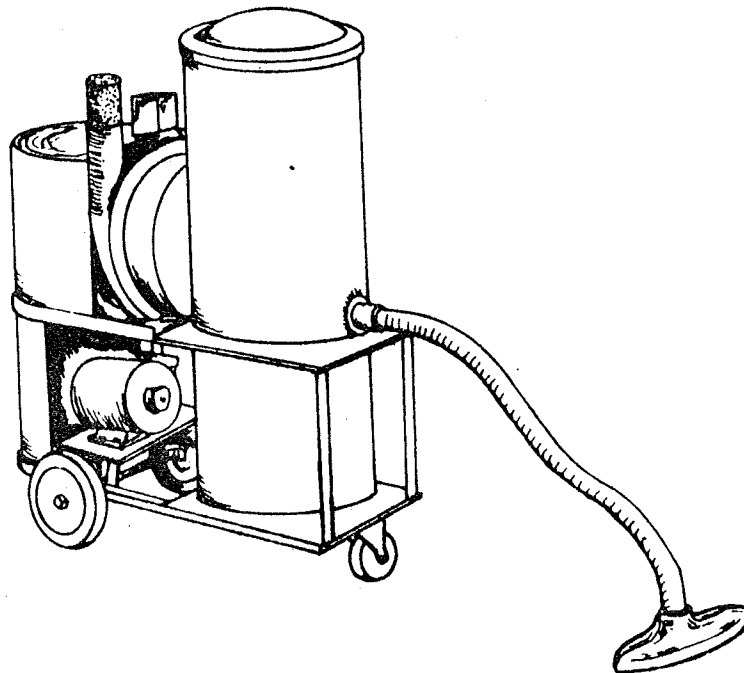
FIGURE 5

They involve a greater degree of sophistication in particle collection than the smaller, simpler commercial systems. They are, however, exceedingly large and heavy. Their design appears to be modelled from stationary plant installations, i.e., they are stationary dust collection systems on wheels. It is difficult to see how they could be economically justified in a mining operation.

Domestic Industrial Vacuum Cleaners

The American industrial scene abounds in a variety of mobile, trammable vacuum cleaners used to clean plants, streets, etc. None is developed to fit an underground environment, either from a dimensional or safety point of view. Their dust collection systems are dry, consist of gravitational settling chambers, cyclones and filters, and are unsuited to the efficient collection of fine coal. The unloading systems utilized by these machines are dumping-type systems and do not possess the elevating, transferring features required by an underground coal mine vacuum sweeper.

One device, however, was recently put in operation in a Pennsylvania Coke plant to remove accumulated coal dust. The device is the Invincible Vacuum Corporation Model 700 in MESA 2-G construction. The device is shown in Figure 7.



INVINCIBLE VACUUM CORPORATION VACUUM CLEANER
MODEL 700

FIGURE 7

TECHNICAL DISCUSSION

INTRODUCTION

The development of a mechanized vacuum-type system for removal of coal mine rubble and dust requires the collection and evaluation of certain data taken from typical operating mines, such as the amounts and characteristics of the material to be handled; consideration of mine conditions, prevailing mine regulations, the development of concepts of the total system and subsystems; and finally, a synthesis of the data obtained from these preceding steps into a complete machine design.

BACKGROUND

How Rubble is Formed

Coal rubble is formed in the mine primarily in three ways:

- . From spillage in the course of mining and transporting the coal.
- . From sloughage of roof and rib coal.
- . From the settling out of float coal, generated in the mining process, on all surfaces of the mine.

The most demanding cleanup chores result from:

- . Continuous spillage and dribble along belt conveyors.
- . Spillage along shuttle car roadways and around the shuttle car discharge station.

Examples of Difficult Cleanup Situations

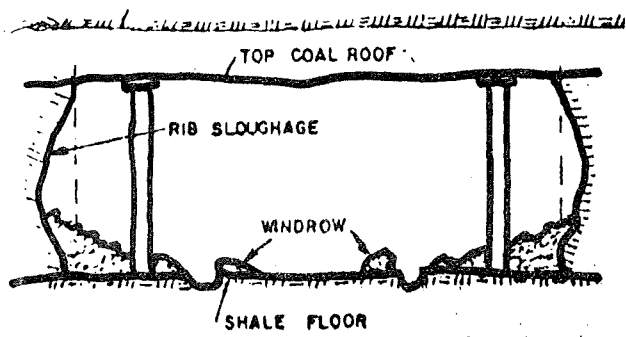
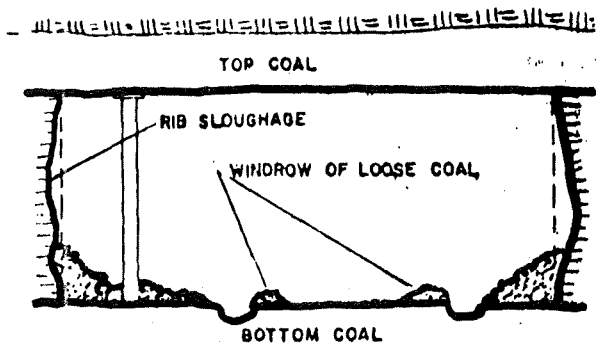


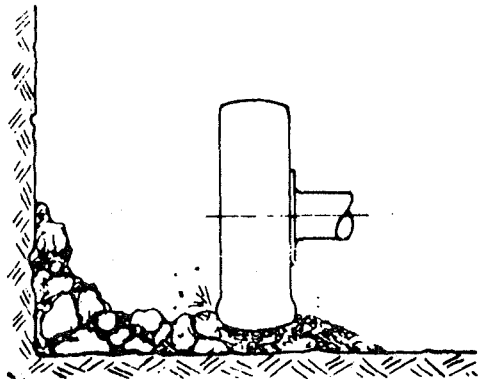
FIGURE 8a

Space between timbers and ribs inaccessible to cleanup by conventional machines. Loose coal along ribs and in places which cannot be reached by the machine such as behind timbers, etc., must be shoveled by hand as part of the removal job.



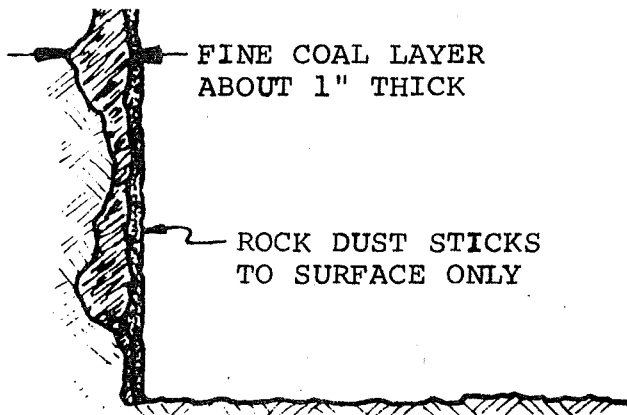
Bottom coal continuously ground to rubble by shuttle car traffic.

FIGURE 8b



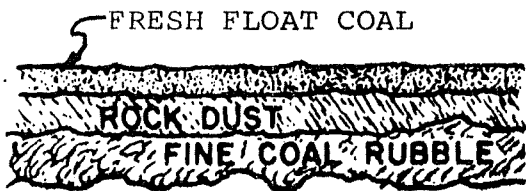
Severe sloughage and crushing of sloughed material by equipment traffic.

FIGURE 8c



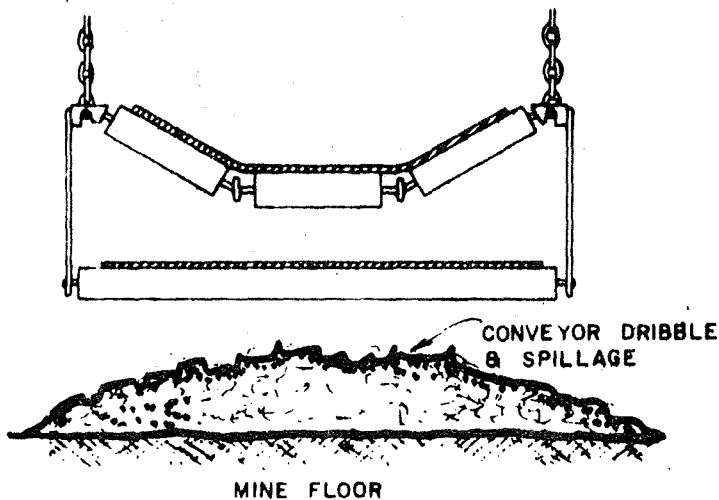
Moist coal dust produced by continuous miners sometimes adheres to rib in thick layers at face area. Rock dust cannot be applied in layers thick enough to meet inerting requirements.

FIGURE 8d



Float dust settling on rock dusted surfaces requiring frequent rockdusting. A practical removal method does not exist.

FIGURE 8e



Belt Conveyor Entries

Conveyor continuously spills fine coal from bottom of return belt. An occasional lump may fall from the carrying side of the belt. Pile up may rub against return belt and idlers. Frictional heat can result in fire.

FIGURE 8f

Estimated Rubble Quantities

Six mines were visited to determine amounts of rubble produced in the mining and materials handling process. While conditions vary from mine to mine, the following averages were considered for machine design purposes:

Belt Conveyors

The dribble from belt conveyors was estimated at up to one cubic foot per 100 feet of conveyor in an 8 hour period.

Face Area

An average of 5% of the mined coal turns to rubble in the mining process. At a production rate of 500 tons per shift, 5% amounts to 25 tons per shift.

Particle Size and Distribution

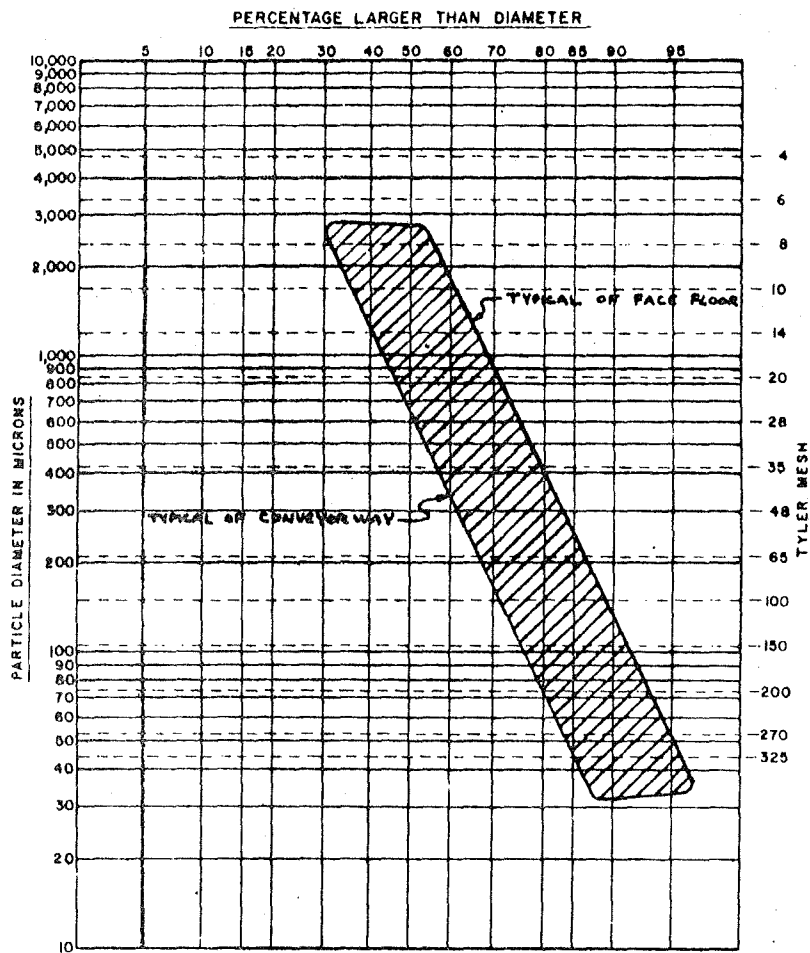
Data obtained from the Bureau of Mines, Report No. RI 7446, was combined with data given in the Garret Research Corporation Report No. GR&D 70-105 (U.S.B.M. PB 739). This combined data gives a representation of the particle size distribution in the underground coal mine rubble and is shown in Figure 9.

<u>Sieve Size</u>	<u>Microns</u>	<u>% through</u>
1 1/2 inch		91.7
1 inch		84.2
1/2 inch		65.8
3/16 inch		37.5
1/8 inch		30.4
20 mesh		15.2
28 mesh		12.2
35 mesh	500	9.7
48 mesh	300	7.6
65 mesh	230	6.1
100 mesh	150	4.8
150 mesh	100	4.0
200 mesh	74	2.4
325 mesh	44	1.2
	20	.8
	10	.44
	5	.22
	3	.093
	2	.040
	1	.009
	.5	.002

COAL RUBBLE PARTICLE SIZE DISTRIBUTION
BASIS: BUREAU OF MINES RI7446 - GARRET REPORT GR&D 70-105

FIGURE 9

Samples taken from three eastern and three western underground coal mines were analyzed for particle size and distribution. This data is shown in Figure 10. The combined data was used to formulate coal material for use in testing of the collection and separation system developed.



RUBBLE PARTICLE SIZE & DISTRIBUTION DETERMINED FROM MINE RUBBLE SAMPLES

FIGURE 10

CAPACITY REQUIREMENTS FROM BACKGROUND DATA

From the observations made in the mines visited, the following pickup and handling rates were chosen for prototype design:

- . For belt haulage cleanup, 100 lbs /min.
- . For general cleanup, 200 lbs /min.

PNEUMATIC SYSTEM SIZING

INTRODUCTION

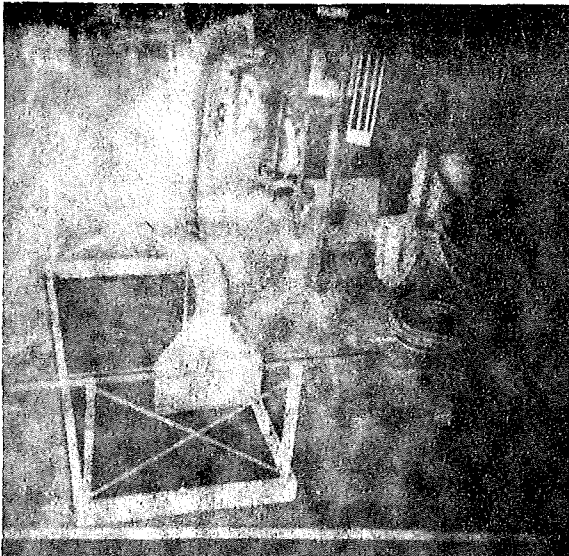
Air volume and velocity are the parameters which exercise the greatest influence on the size of an underground coal mine vacuum sweeper system. Therefore, it is necessary to determine the minimum air flow and velocity required to pick up and move the coal rubble at the minimum rate required.

A 200 lbs /min rate was selected for testing purposes as the program initially focused on a machine for general cleanup. Since final development was for a belt haulage cleanup machine, the ultimate design was directed to a rate of 100 lbs /min.

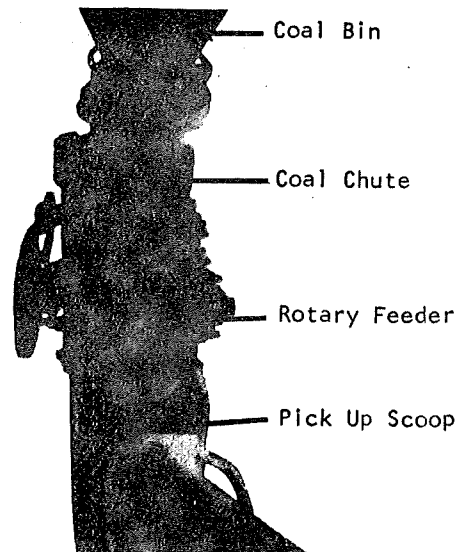
TEST SET-UPS

Two types of tests were run. To determine pickup parameters, hand-held nozzles were manually operated over a coal rubble bed. To determine conveying parameters, coal was fed to the nozzle at a constant rate.

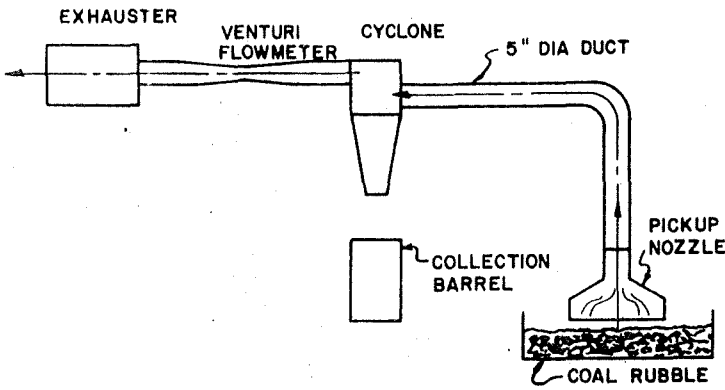
The two arrangements are illustrated in Figures 11, 12, 13, and 14.



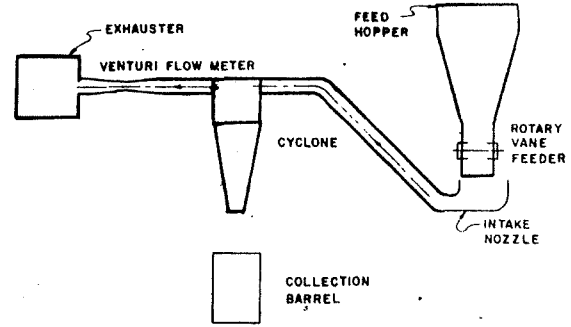
PICKUP RATE TEST SET-UP
FIGURE 11



CONVEYING RATE TEST SET-UP
FIGURE 12



SCHEMATIC OF TEST APPARATUS FOR DETERMINATION OF PICKUP & CONVEYING RATES USING HANDHELD NOZZLE
 FIGURE 13



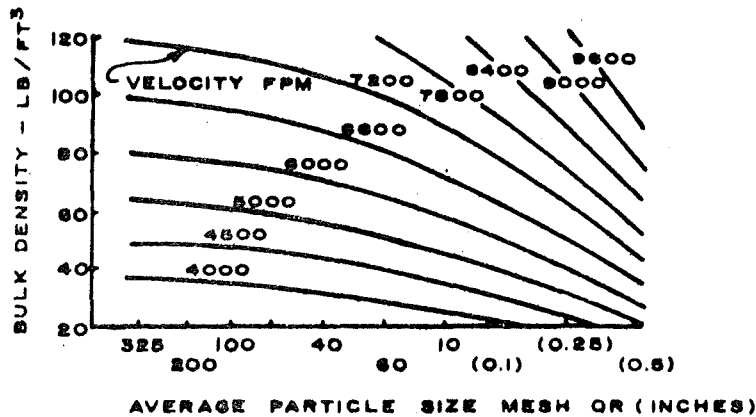
SCHEMATIC SHOWING TEST APPARATUS TO DETERMINE CONVEYING RATES USING CONTROLLED FEED
 FIGURE 14

RESULTS

From the tests, using both a hand manipulated nozzle and a controlled feed rate, it was determined that a handling rate of 200 lbs /min is possible using 600 SCFM at a duct velocity of 4400 FPM.

Tests were also performed at 375 CFM at a duct velocity of 4590 FPM and a pickup rate of 100 lbs /min was established. On that basis, 375 CFM, and a velocity of 5500 FPM were established as a design criteria for the belt haulageway cleanup machine.

This compares favorably with industrial guidelines for pneumatic handling systems conveying velocities as shown in Figure 15.

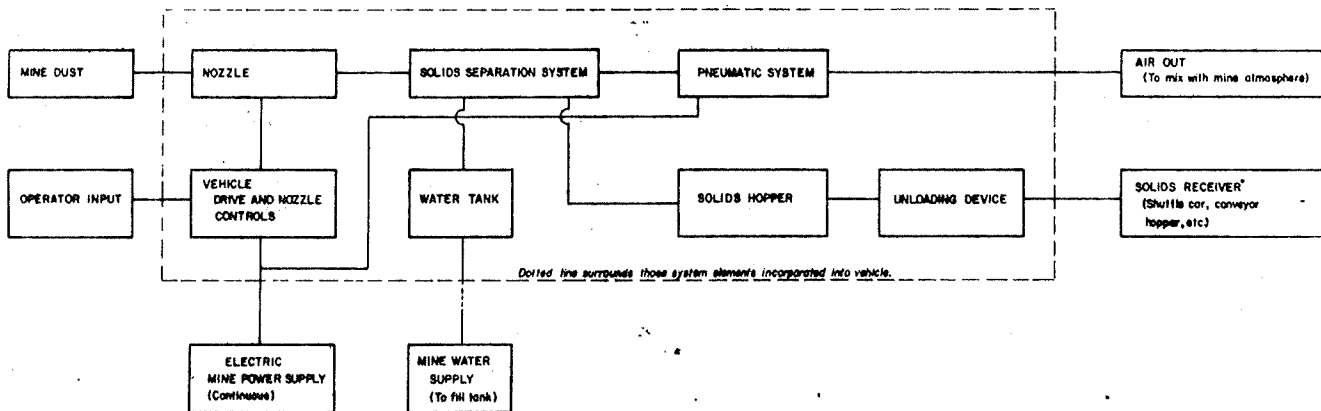


RECOMMENDED PNEUMATIC HANDLING CONVEYING VELOCITIES

FIGURE 15

IDENTIFICATION OF BUILDING BLOCKS FOR A VACUUM SYSTEM

A generalized system of a coal mine vacuum sweeper is shown in Figure 16.



GENERALIZED COAL MINE VACUUM SWEEPER SYSTEM
FIGURE 16

From this generalized system, the major sub-systems of a coal rubble vacuum cleaning machine can be identified as follows:

Pneumatic System

- Vacuum nozzle
- Exhauster
- Noise Suppression
- Exhaust Diffusion

Separation System

- Coarse Separation
- Fine Separation
- Liquid Handling System

Vehicle System

- Drive
- Nozzle Controls
- Solids Storage Hopper
- Unloading Device

Of the above systems, the Solids Separation System development involved extensive model testing and will be discussed first. All other systems are discussed under "Design".

Separation System

Requirements

The separation system must be packaged into a mobile, compact machine system and must, therefore, be small and compact.

With a solids thruput of 100-200 lbs/min and a maximum outlet loading of about 8 mg/m³, collection efficiency must be very high.

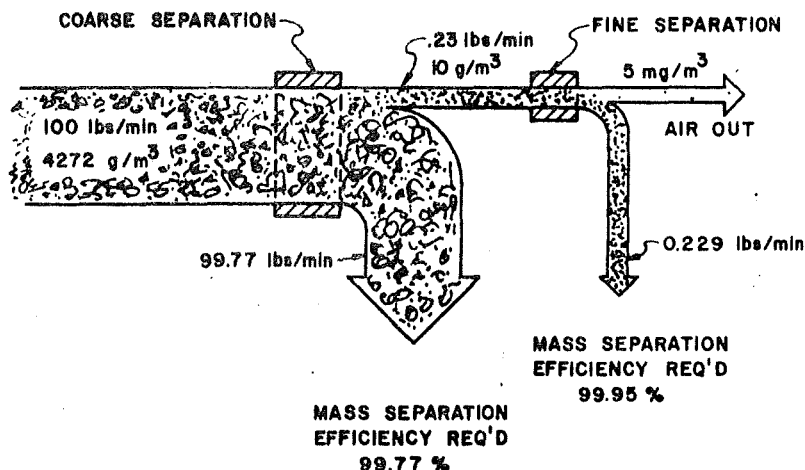
Typically, gas/solids separation and collection efficiencies improve with increased system pressure drop, but a vacuum machine is limited in size and power. Therefore, system pressure loss must not be excessive.

If water is used for gas cleaning, it must be carried on board the machine. But storage space is limited, so water consumption must be low.

Review of available Processes

A review of the basic processes available for gas/solids separation quickly establishes that no single process can alone collect the broad spectrum of particulates in coal rubble to the degree required for a coal mine vacuum sweeper. The problems of separating 1/2" coal particles from a moving air stream is quite different from that of separating and collecting micron-sized particles. Therefore, it becomes necessary to divide the total spectrum of particulates in coal rubble into a coarse and a fine fraction, and to treat these separately to attain the desired removal efficiency.

The efficiency requirements for the two separation stages are graphically depicted in Figure 17.



SEPARATION SYSTEM EFFICIENCY REQUIREMENTS

FIGURE 17

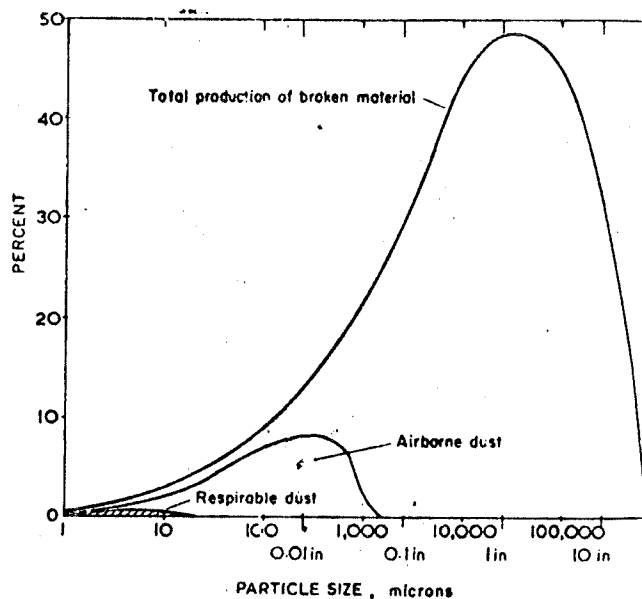
Among devices which qualify for bulk disengagement in a first stage, or a coarse separation process, the following were selected for investigation:

Cyclones
Gravitational Settlers
Submerged Bath Scrubbers

Of these, the first two utilize a gravitational field to disengage the particulate matter. The third device is based on gravity separation together with capture by impingement of the particulates passing through a water bath.

The purpose of the Fine Separation System is to remove the material below 25 microns from the system air.

The amount of material in this fine fraction (by weight) is not high it will rarely exceed two percent of the total weight of material picked up and may, in most cases, represent less than one percent of the total material by weight. Figure 18 from U. S. Bureau of Mines IC8458, graphically illustrates the point, although it refers to breakage product.



TYPICAL SIZE DISTRIBUTION OF
BREAKAGE PRODUCT FROM MINING

FIGURE 18

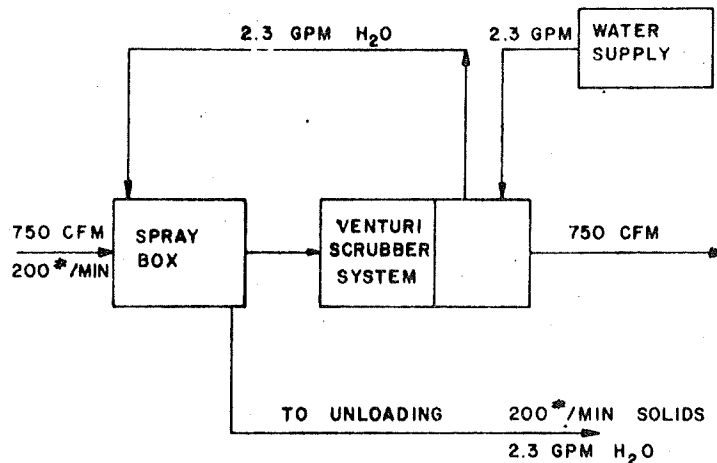
For this secondary separation stage, a survey of known processes reveals a great many variants based on the attachment of dust particles to water droplets and their later separation by gravitational or impingement means. In the present state of the art, however, the Venturi scrubber stands out as the most successful high-efficiency fine particle separator. The type system selected for the separation of this material from the air flow is, therefore, a Venturi Scrubber followed by a de-mister.

De-mister devices are of two general types--impingement and centrifugal. The centrifugal works on the cyclone principle, utilizing centrifugal forces to speed the settling rate of the water-coated particle. Since the separation of the water-coated particles actually occurs in the de-mister device, different configurations of de-misters were tested in an effort to reach the targeted concentration of fines of less than 10 mg/m³.

Total Separation System Selected

System Description

Satisfactory performance was obtained with a spray box as a coarse material separator followed by an open throat Venturi with a cyclonic mist eliminator. The total system flow sheet is shown in Figure 19.



TOTAL SEPARATION SYSTEM FLOWSHEET

FIGURE 19

Note: Airflow and solids handling rate was selected as 750 CFM and 200 lbs /min for test purposes but the Prototype Design was based on 375 CFM and 100 lbs /min.

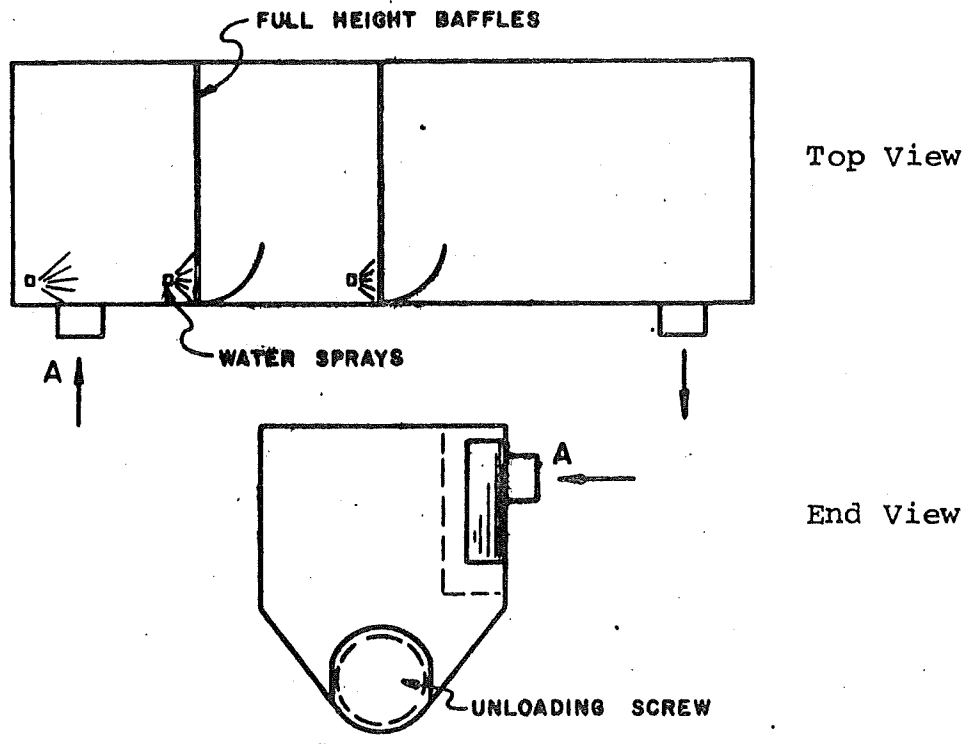
This system utilizes 2.3 gpm of clean water, stored in a tank on the coal mine vacuum cleaner, and introduced to the Venturi throat through a common hollow cone spray nozzle. The dirty water collected by the mist eliminator is used, without cleaning or treatment, as coarse separation spray water and is completely absorbed by the coarse coal removed by this device.

Coarse Separation System

A simple gravitational sprayed air settler was devised for testing purposes as shown in Figure 20.

Two basic processes combine to promote separation in this device. The primary process is gravitational. In addition, the wetted surfaces of the box act as impingement collectors for the finer fraction of the coarse solids.

The solids laden air stream enters at Point A. A water spray wets the incoming coal and most solids drop out in the first of three baffled compartments. The air stream passes through a small opening in the first baffle, striking a curved baffle on the downstream side of the opening. This baffle is completely irrigated by means of a water spray. The captured bulk is removed by an unloading screw in the bottom of the collector.

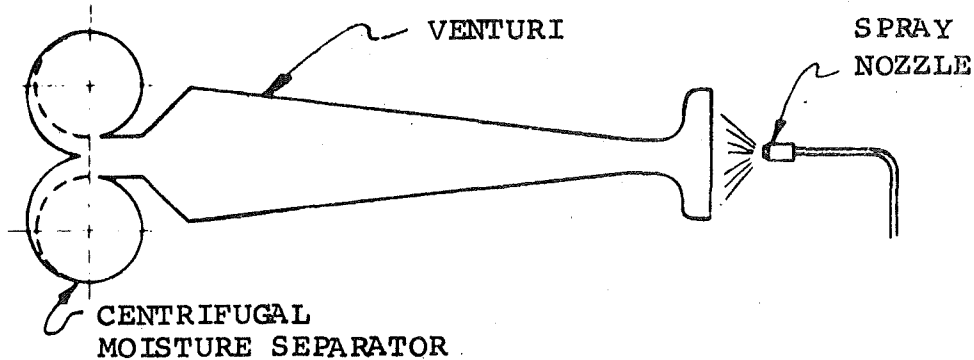


SPRAY BOX TEST
CONFIGURATION USED

FIGURE 20

Fine Separation System

This device consists of a commercial open-throat Venturi of circular cross section followed by a centrifugal cyclone type mist eliminator or de-mister.



FINE SEPARATION SYSTEM

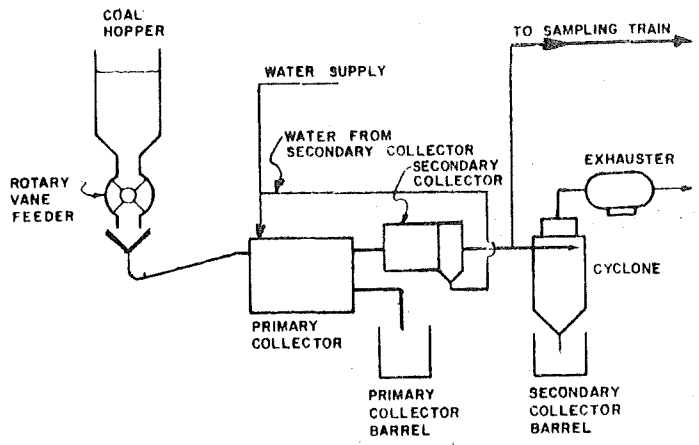
FIGURE 21

Tests and Test Results

Using a feed material similar to typical coal mine rubble, several series of tests were run, first on the individual primary and secondary separation stages and finally on the combined total system.

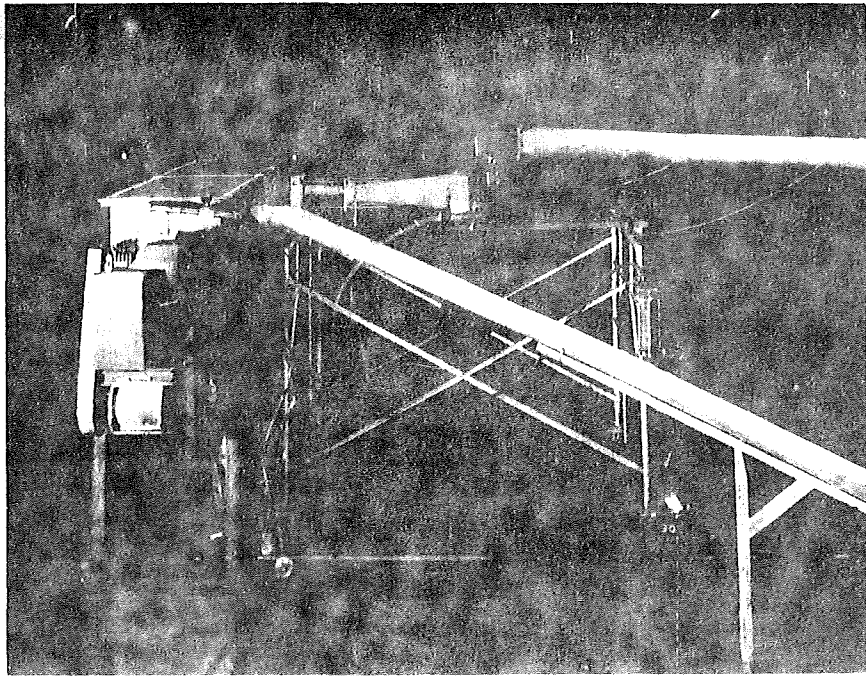
Detailed data on these tests are given in an earlier, separate Phase I report (listed in the Bibliography).

The total system test set up is shown as a schematic in Figure 22 and as hardware in Figure 23.



GENERALIZED TEST SETUP
COARSE SEPARATION AND TOTAL SYSTEM

FIGURE 22



TOTAL SEPARATION SYSTEM TEST SET-UP
FIGURE 23

In repeated tests, using 200 lbs/min of feed material, the system produced an outlet particulate loading of less than 10 mg/m³ at an average water input rate of 2.3 gpm with a system pressure drop of 50" water column and a Venturi throat velocity of 25000 fpm.

At 100 lbs/min thruput, outlet loadings were predominantly under 4 mg/m³ in the laboratory tests. Equally low outlet loadings were measured with the actual machine in tests along a beltway in an underground coal mine.

MINE TESTS

The Coal Mine Vacuum Sweeper prototype was tested in the Gordon Creek Mine of the Swisher Coal Company at Price, Utah.

Test I

Cleaned under belt conveyor--using boom controls, see figure 24.
Depth of conveyor spillage--4-6 inches.
Material approximately 85% rock dust.
Loading time--8½ minutes.
Total load--494 pounds.
Advance rate approximately 75 ft /min.

Discharged material ranged from very wet and sloppy to almost dry.

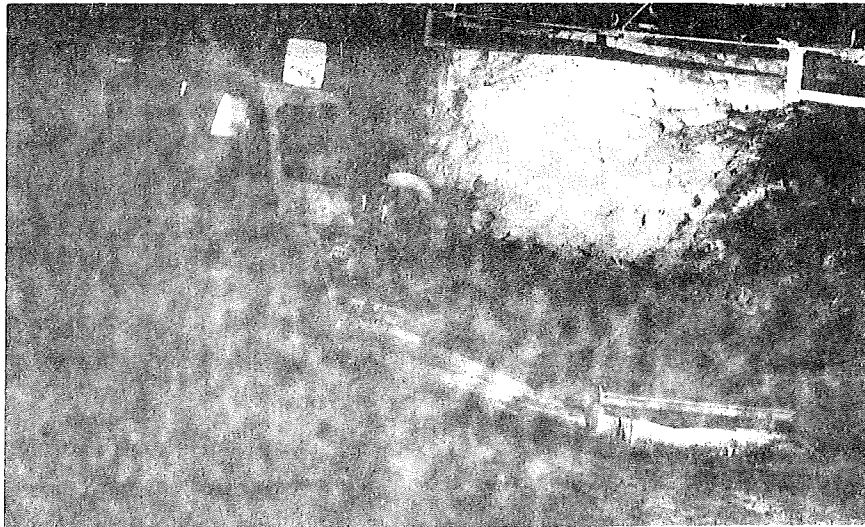


PHOTO OF BELT CONVEYOR CLEANUP USING BOOM CONTROLS
FIGURE 24

Test II

Cleaned under 42" belt conveyor using hand-held nozzle on flex hose, see figure 25.
Depth of conveyor spillage--4-6 inches.
Material approximately 85% rock dust.
Loading time--5½ minutes
Total load--411 pounds
Advance rate approximately 1 ft /min.

Material dry--difficult to discharge.



PHOTO OF BELT CONVEYOR CLEANUP USING HAND-HELD NOZZLE

FIGURE 25

Test III

Cleaned rib using hand-held nozzle on flex hose, see figure 26.

Material approximately 65% rock dust.

Loading time--10 minutes

Total load--190 pounds

Material wet and soggy, easily discharged.
Cleaned very effectively.



PHOTO OF RIBCLEANSING USING HAND-HELD NOZZLE

FIGURE 26

Operational Problems Encountered

Loading the machine rapidly gives a material that is dry and difficult to unload with screw conveyors. (No water to lubricate material.) Loading the machine over an extended period of time allows for excessive water to accumulate in the tank leading to a very wet and sloppy discharge. Both situations require different unloading procedures.

Difficult to keep nozzle at proper elevation to pick up material in the most effective way.

Machine does not climb grades greater than 10 degrees.

Machine occasionally digs nose into ground when moving over rough mine floor.

On loose muddy and uneven ground wheel spin and loss of traction was sometimes encountered.

Conclusions from Mine Tests

The machine performs essentially as designed. However, the design capacity of 100 lbs/min was not achieved primarily because of difficulty in maintaining the nozzle at the optimum distance from the surface to be cleaned. A capacity of 60 lbs/min was the maximum achieved.

Considering the advance rate in belt conveyor cleanup, the mine tests made it clear that even a rate of 100 lbs/min is insufficient under the prevailing mine convention of frequent rock dusting over fresh conveyor spillage. On the other hand, the machine, at its present capacity, easily can remove all normal conveyor spillage if operated along the conveyor at frequent intervals and with rock dusting taking place after, rather than before, cleanup.

In its present form, using screw conveyors, the machine discharge system is not suitable to handling large amounts of rock dust at the separation system water rate used.

TANK EXPLOSIONS

Before the mine tests, the machine was tested at a local coal yard, vacuuming in near 100% coal dust and rubble. Four incidents occurred which were interpreted as explosions within the tank of the Coal Vac. These explosions were of a magnitude to be both felt and heard by the operator. With the high noise level and vibrations in the cab, it would take a significant explosion in the tank for the operator to be aware of it. The first two explosions occurred the same day, about 15 minutes apart. The last two occurred another day and were about 10 seconds apart. The explosions all occurred when the nozzle was very close to the ground, producing a higher than normal system pressure drop and vacuum level.

No damage was noted, and no further explosions were encountered during testing or at the mine.

DESIGN

INTRODUCTION

This program has accomplished the following steps:

1. Background data for a coal mine vacuum sweeper design was gathered and design criteria were established.
2. Separation system concepts were tested and reviewed and a final separation system design was selected, built and tested.
3. A battery-operated belt haulageway cleanup machine was selected for design; machine parameters were set on the basis of the job to be done and the total energy available for the machine operation.
4. The machine was designed, built and tested.
5. Test results and operating experience were obtained and suggested solutions to the problems encountered are set forth in this report.

MACHINE DESIGN

General

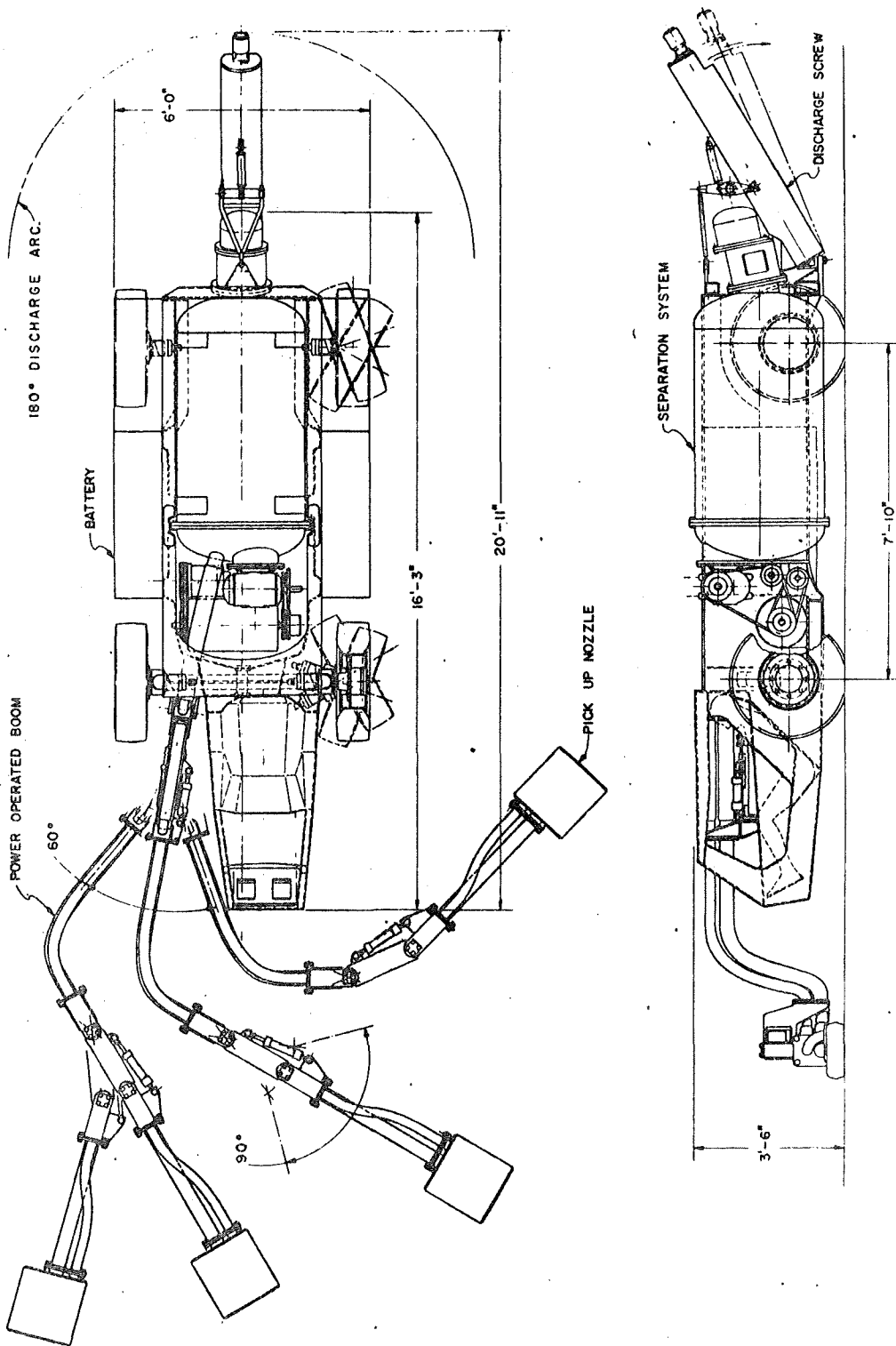
The machine was designed as a coal mine belt haulageway cleanup device, to the following general specifications:

Width	6' maximum
Height	To operate in a 4' entry
Length	Not specified
Power	Battery-operated (MESA permissible throughout)
Pickup Capacity	100 lbs/min
Dust Separation	Wet system

The overall design is illustrated in Figure 27.

The design discussion will be divided into the discussions of the following general systems and subsystems:

1. The vacuum pickup and separation system
 - a. Nozzle and Boom
 - b. Separation System (Primary and Secondary)
 - c. Unloading System
 - d. Water System
 - e. Air System (Exhauster, Muffler)



BELT HAULAGEWAY CLEANUP MACHINE

MACHINE DIMENSIONS

FIGURE 27

2. Chassis (vehicle)

- a. Trimming system (gear reductions, motors, brakes, hydrostatic drive system)
- b. Steering and suspension
- c. Operator compartment - canopy module

3. Controls

- a. Electrical controls, switchgear, safety stop devices.
- b. Hydraulic nozzle, steering, unloading and other operational controls.
- c. Trimming controls.

4. Power system

- a. Motor and battery arrangements.
- b. Battery charger.

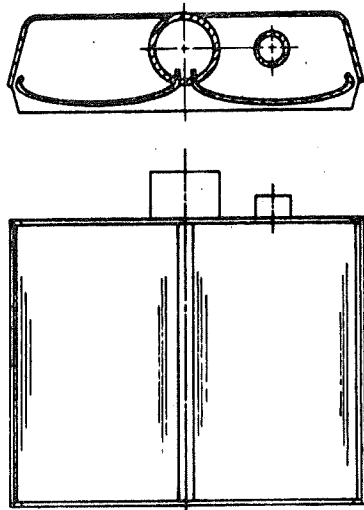
A general discussion of the complete machine will follow as a summation of the design and field experience.

Vacuum Pickup and Separation System

a. Nozzles

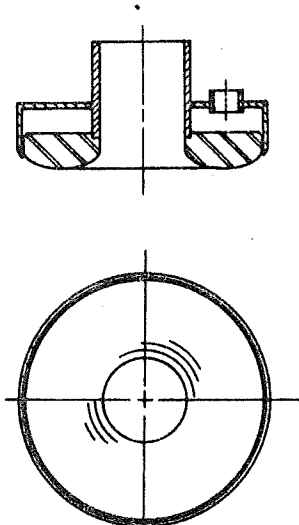
Three nozzles were built and tested on the machine boom; a fourth nozzle was built and tested as a manually-operated unit on the end of a flexible suction hose. This fourth unit was used for rib-cleaning tests only.

The first nozzle is shown in Figure 28. This rectangular unit was designed in an attempt to increase the area swept by the air stream and to operate when traversed across the mine floor at right angles to its axis. The airflow available and the nozzle geometry selected created an entry in the form of a slot along the length of the nozzle, communicating with the inlet pipe in the boom. Pressure assist air was admitted to the nozzle from a plenum or chamber which communicated with the pressure pipe on the boom; the use of this pressurized air was intended to improve the mechanical "sweeping" efficiency of the dust removal process and to improve the separation efficiency of the unit (since not all of the exhaust air is dumped into the mine environment, the overall or total amount of dust rejection to the mine air is theoretically decreased).



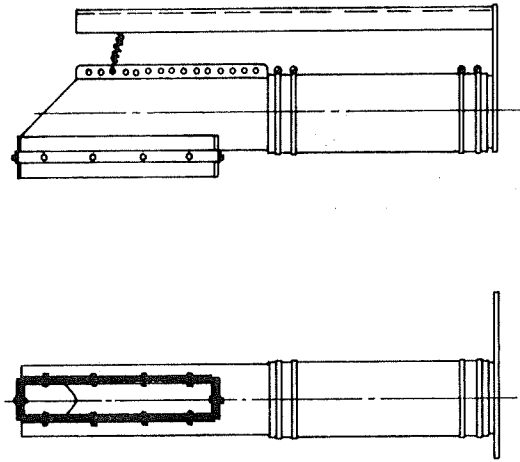
RECTANGULAR NOZZLE WITH PRESSURE ASSIST
 FIGURE 28

The second nozzle (Figure 29) is a circular analog of the first nozzle; this unit has symmetry which allows it to be traversed in any direction over the floor. The center of this nozzle was originally equipped with a pin intended to prevent or postpone plugging and to aid in the positioning of the nozzle above the mine floor.



CIRCULAR NOZZLE WITH PRESSURE ASSIST
 FIGURE 29

The third nozzle (Figure 30) is in the form of a tube with a rectangular slot in the bottom surface; this slot was surrounded with flexible "lips" which extend from the inlet slot to the floor. The entire nozzle was suspended flexibly from the boom structure; this allowed it to follow the contour of the floor with less operator attention and to deflect horizontally and/or vertically when an obstacle was encountered. These three nozzles can also be seen in Figure 31.



"FLEXIBLE" NOZZLE
FIGURE 30

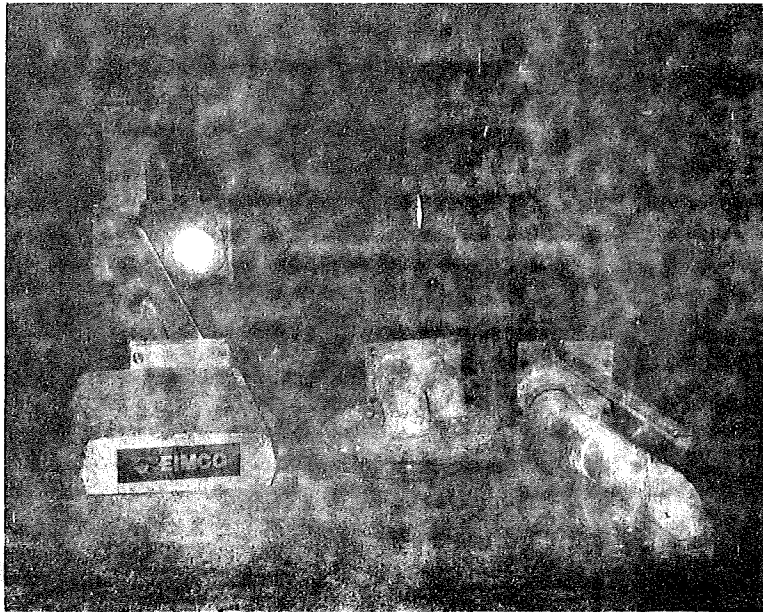
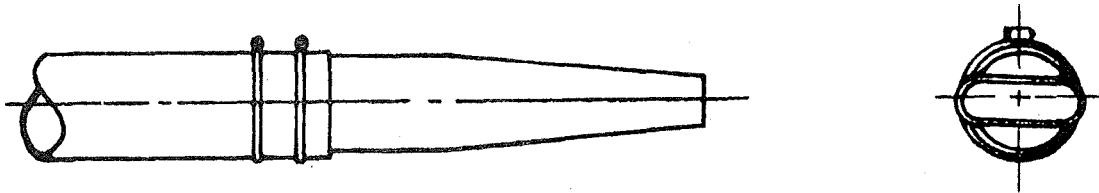


PHOTO OF NOZZLES TESTED IN MINE
FIGURE 31

The fourth nozzle was tested for cleaning the mine rib (Figure 32). This unit is similar in appearance and function to those supplied with household vacuum cleaners for the cleaning of narrow slots or confined areas.

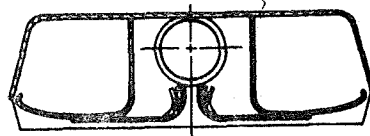


NOZZLE FOR RIB CLEANING
FIGURE 32

Operation

The first nozzle (Figure 28) encountered severe plugging problems. The entry slot was so narrow that most mine dust contained particles large enough to lodge in the slot and plug the nozzle in seconds.

A possible remedy for this problem is shown in Figure 33. This design preserves the airflow geometry (which does seem to work) and attempts to take care of the clogging problem by utilizing flexible elastomeric lips. The airflow holds the lips in the proper position during operation; particles large enough to clog the slot will create pressure differentials across the flexible lips which will act to increase the size of the slot. This proposed solution has not been built or tested.



NOZZLE WITH PROPOSED ANTIPLUG PROVISION
FIGURE 33

The second nozzle (Figure 29) encountered severe plugging when it was equipped with the center pin. Removal of this center pin improved the performance of this unit, but did not completely prevent plugging.

The use of the pressurized air "blow" or "assist" in the first and second nozzle designs caused puffing of dust at the nozzle when the underside of the nozzle encountered the floor; maintaining a proper distance between nozzle and terrain is critical to the proper function of nozzles of this type, and tends to be one of the main problems of the machine.

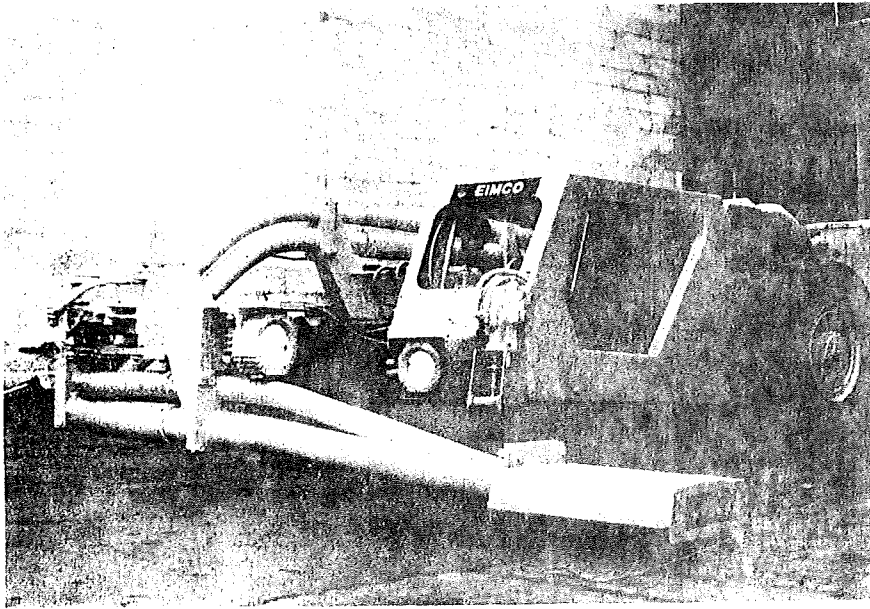
The third nozzle was the most practical of the three (Figure 30). The elastic suspension of this unit allowed it to follow the contour of the floor; this significantly increased its pickup rate. One disadvantage encountered in the use of this unit was that it extended the reach or boom length; this was advantageous during the cleaning cycle, but made the maneuvering of the machine more difficult in some (tramming) circumstances.

The fourth (manual) nozzle (Figure 32) functioned successfully. The amount of rib area covered was of necessity limited to that which could be traversed by hand (the nozzle was manually held) and the total material pickup was low as compared to those nozzles used in the floor cleaning situation. It was found during the field tests that mine conditions were different from those for which the first two nozzles were designed. These nozzles were constructed to "sweep" small quantities of dust off a solid surface; every effort was made to get the maximum possible horizontal air velocity to blow the dust loose from the mine floor.

In the actual mine situation, an average depth of about four inches of rock dust was encountered; little nozzle sophistication was required to attain the required pickup rate and the limited load capacity of the machine was more of a factor in extending cleaning time than was nozzle performance.

a. Boom

The articulated boom is shown in Figures 34 and 35. This boom consists of two pipes, a larger pipe for the suction of nozzle to separation system, and a smaller pipe which ducts pressurized "assist" or blowing air to the nozzles (for use with nozzles 1 and 2).



ARTICULATED BOOM
FIGURE 35

Special double-joints are used as hinges for both articulating points of the boom; these joints allow the flexible suction hose to bend without "humping" during the operation of the boom. Increased flow efficiency and reduced abrasion on the suction hose sections was expected and apparently realized by the use of this system.

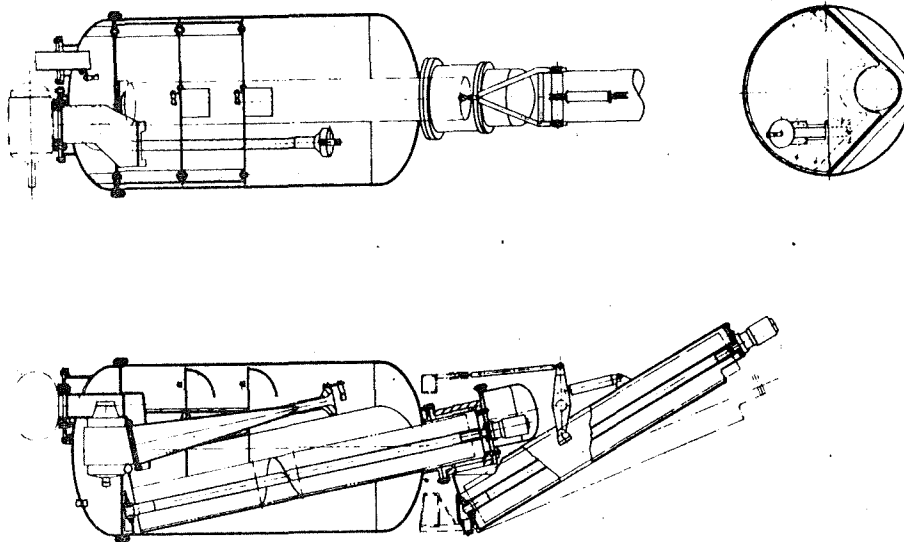
The outer joint of the boom has a total articulation of 90° ; the inner or machine-end joint has an articulation of about 55° . The entire boom is hinged at the point of attachment to the machine to allow the nozzle to be lifted or lowered by a hydraulic cylinder. Nozzle controls are covered in the "controls" section of the design discussion.

Operation

No mechanical or structural problems were encountered with the boom during the operation of the machine. One design problem was noted; the center of the vertical hinge (which allows the nozzle to be lifted or lowered) was too close to the mine floor. This caused the nozzle to rise from the floor when it was moved away from the machine and to approach the mine floor when it was moved toward the machine. These variations in nozzle height multiplied the amount of operator attention which had to be given to the nozzle-to-floor positioning. Together with the critical nozzle-to-surface distance requirements of the first two nozzles, this boom fault became one of the major operational problems of the machine.

b. Separation System (Primary and Secondary)

The integrated primary and secondary separation system is shown in Figure 36 together with its associated unloading system.



SEPARATION AND UNLOADING SYSTEM
FIGURE 36

The primary system was finalized by Phase I tests; this system is essentially an enclosed box having two spaced baffles at right angles to the air flow. Each of these baffles is equipped with an orifice followed by a deflector; the orifice is sprayed with a hollow-cone nozzle. The inlet pipe (from the boom and nozzle) projects into the first baffled chamber; the incoming dust-laden air is sprayed with water at this entry point.

Investigations were made during Phase I of continuous-unloading systems equipped with vane-feeder mechanisms to isolate the internal atmosphere of the enclosed box from the mine atmosphere, and to preserve the vacuum required for the system to operate. The decision to make the machine battery-powered made it necessary to convert to the concept of a "batch" machine which is operated until loaded, and is then dumped. The vacuum-tight integrity of a batch-type unit is easier to maintain than is that of a continuous-unloading unit and that power required to operate the unloading mechanism is not required when the exhaustor and water system is in operation.

The secondary separation system consists of a Venturi scrubber (having a throat velocity of about 24,000 fpm) and its associated cyclonic water separator. The outlet from this water separator communicates directly with the inlet of the exhauster; it is manifolded to and supported by the exhauster support plate.

The entire dust separation system was designed as a module or self-contained unit. This allowed the performance testing and optimization of the complete unit before assembly into the vehicle; some economies of space were obtained by integrating all of these separation components into the pre-assembled unit. In addition, it was felt that the explosion-proof integrity of the entire system would be much easier to achieve and maintain if all of the working parts were contained in that pressure vessel which serves as a dust container and system enclosure.

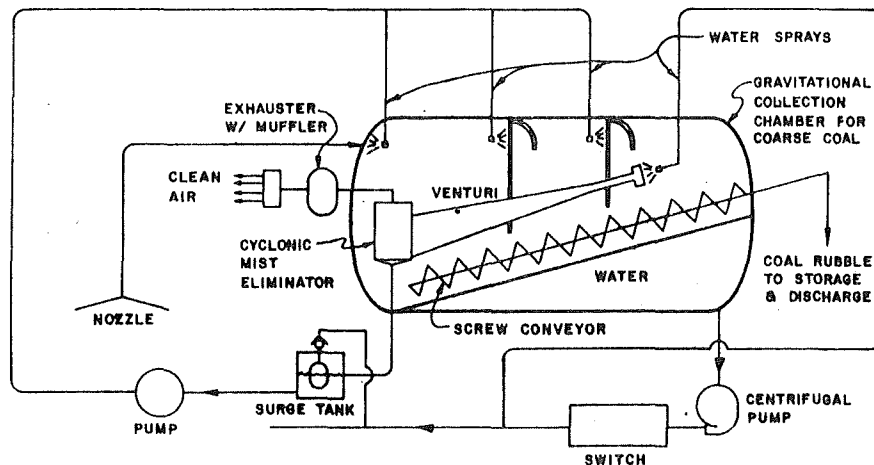
This vessel was designed as an ASME pressure vessel capable of a working pressure of 150 psi. All joints and details of the vessel are designed to ASME code; in addition, the provisions of Schedule 2G with regard to flange width (flame path) are complied with. Access ports on top of the unit allow servicing of the sprays and internal plumbing. Sealing clearances and flame paths on the rotatable external sleeve valve through which material is unloaded also conform to the flamepath requirements of Schedule 2-G.

A screw conveyor is installed in this pressure vessel, operating against the sloping bottom of the system chamber. This screw conveyor moves material to the exit port which is covered and sealed by a rotating external valve sleeve during the operation of the vacuum system. During the unloading cycle, material from the exit port is dropped into the hopper of a second screw conveyor, transported the length of this conveyor tube and deposited onto the conveyor belt under which the machine is cleaning. Both screws are operated by slow-speed hydraulic motors; the hydraulic pressure which operates these motors also operates hydraulic cylinders which open the rotating external valve sleeve and swing the secondary conveyor to a position over the conveyor belt.

Water flows required for the proper operation of the primary and secondary separation systems were derived from experimental work done during Phase I of this project. Fresh water from machine tankage (80 gallons) is directed to the Venturi scrubber whenever the machine is in the vacuum cleaning mode. Pressure is supplied by a belt-driven centrifugal pump; water is pumped through a permissible flow-sensing switch which causes the exhauster to stop if no water flows in this circuit. This safeguard assures that both the exhauster and the mine environment will be protected from the high dust concentrations which would prevail if the Venturi scrubber were operated without water.

Water directed through the Venturi scrubber is captured in the cyclone moisture separator. It must be pumped out of this unit against that head produced by the exhauster (in the case of this machine, a minimum of 75" H₂O). A rubber paddle pump is used for this service. The recovered water is directed to the two sprays on the baffle orifices and the spray unit on the entry pipe.

The three sprays inside the separation system chamber require somewhat more water than is obtained from the cyclone separation unit; this is made up by drawing fresh water from the output of the centrifugal pump feeding the Venturi. The complete water circuit is shown in Figure 37. Hollow-cone spray nozzles were used in all locations; the performance of the total system was satisfactory with regard to dust control.



WATER SPRAY SYSTEM

FIGURE 37

Explosion Hazards

The following discussion of the explosion hazard existing in the pneumatic conveying system handling coal dust is based on judgment.

It was established in previous work by the British Coal Board that the operation of water sprays, together with

automatic shutdown devices to insure their continuous operation, will prevent explosions in the separation unit. During the pre-mine testing with coal fines, on the Coal Mine Vacuum Sweeper, occasional reports were heard inside the machine which might be interpreted as explosions. There was no apparent damage to the separation system pressure vessel or to any of the internal components as a result of these explosions, and there was no apparent visible external flame or inlet air flow reversal. No damage to the exhauster, or its associated drive, occurred.

Determining the effect of an ignition at various points in the system and with various fuel (methane and coal dust) mixtures is almost impossible to calculate and would more readily be done by testing. However, it can be described qualitatively as follows:

If the inlet or nozzle duct velocity is maintained at a level greater than the limiting flame front velocity of the combustible material, then the inlet opening is effectively flame proofed. Since the limiting flame front velocity for methane mixtures is about 2 ft /sec , there is little problem in confining a methane explosion to the separation system (if it is in operation). The limiting flame front velocity for coal dusts is in the 30 ft /sec range for stoichiometric mixtures (with 30% volatile material, 30% ash) and about twice as high (60 ft /sec) for coal containing 30% volatiles and 5% ash. Figures are from Perry's Chemical Engineers' Handbook, 4th edition.

Since the inlet duct velocity is in excess of 80 ft /sec , these considerations indicate that as long as the ignition occurred in the intake pipe, the vacuum cleaner would be safe (this assumes that no methane is in the machine reservoir). If the reservoir were full of a stoichiometric mixture of methane and air, and ignition occurred in the reservoir, then the resultant expansion of the mixture would reverse the nozzle flow completely, in the case of an empty tank, for as much as 40 seconds. This, of course, would blow the flame out of the inlet pipe.

This suggests that, with regard to methane, one method of keeping the machine explosion proof would be to have a continuous ignition device just inside the nozzle inlet in the tank, to prevent methane from building up inside the reservoir.

Another possible answer to this situation is the application of a pressure check valve to the inlet pipe inside the reservoir or holding tank. This would prevent the flow from reversing if an explosion occurred inside the reservoir, forcing the combustion gases out through the Venturi and the blower.

The geometry of the constant displacement exhauster is such that an airseal is always maintained across the tips of the rotors; this blower is also protected from explosion pressures by the Venturi. Sonic flow would be reached in the Venturi throat, limiting flow to the exhauster, under conditions which would produce only mild pressure increases in the primary separation chamber itself. At most, the exhauster would be forced to "motor" or increase in speed temporarily.

It is possible, in case of an explosion in the reservoir, and for appropriate combustion rates, that the flame would travel through the exhauster following the path of normal gas flow. To cover this eventuality, a flame arrester would have to be fitted to the blower exhaust pipe.

In any event, safety from explosions is provided by insuring continuous wetting of the dust in the reservoir. If the loud percussions heard during the initial testing of the machine were, in fact, explosions, it is most probable that these occurred at times of interrupted water flow to the sprays, an event, which, in later test work, was observed to occur. The machine is designed to shut down in such event, but the circuit which provides this feature was not operative during the time of initial testing.

Operation

Phase I tests, concerned with the development of the primary and secondary dust control system, used coal fines and coal fines mixed with small amounts of rock dust for the test material. In actual operation, differences in material being handled caused problems with the separation system.

Preliminary (pre-mine) testing of the machine was done in a local coal yard. The material handled here was coal fines and small lumps of coal. In this situation, water flow to the sprays deposited more water in the system than the material could absorb. Because of the nature of the material being handled and the conditions under which this was accomplished, the total amount of solids per operating cycle was small. The dust collection system became filled with a slurry too thin to handle with the screw conveyor system. The screw conveyors tended to operate as liquid-solids separation systems--the solids were ejected from the outlets while the liquid component tended to remain in the hopper.

The coal mine tests gave a different set of problems. The material being handled was at least 90% rock dust. This material tends to agglomerate when sprayed with water. The

collected material in the dust separation system would bridge over the conveyor screw and remain in this position during the entire unloading cycle. It became necessary to remove the top access covers and poke the material down into the unloading screw to clean the system between runs.

The secondary screw did not work well with the rock dust which tended to stick to the screw. Insufficient horsepower was available from the hydraulic service system to allow experimentation with higher conveyor screw speeds.

The internal baffling of the separation system was installed at right angles to the inlet airflow. This caused the incoming particulate matter to impinge on the first baffle at high velocities. This resulted, when handling coal during the pre-mine testing in Salt Lake City, in at least four internal explosions. No damage to the machine or to the separation module occurred. It must be assumed that at least some of these explosions occurred with spray water being injected into the separation system atmosphere. No explosions occurred during the mine tests.

The right-angle or cross-baffling is bad from another standpoint; rock dust first fills completely the primary compartment, then fills completely the second compartment, etc. Had the baffles been longitudinal, more of the separation system capacity could have been utilized for this dry material while providing sufficient space for the second and third compartments to collect small amounts of the finer particulate material. Other structural and mechanical advantages would have accrued to this design; some weight and system complexity would have been eliminated.

The cross-baffling design came directly from the Phase I test chamber; baffling for the final design was maintained in this configuration. It was felt that changing such a major feature of the settling chamber might compromise the good separation characteristics obtained with the Phase I baffling.

Water is supplied to the Venturi scrubber and thence to the other sprays from machine tankage; approximately 80 gallons of water is carried on the unit. This is sufficient for about three loads of dust; then the tanks must be refilled. In the coal mine tests, this required tramping down a considerable distance of drift to the water supply location.

Fill time depends on the amount of flow available from the mine water system. This requirement for refilling the water tank periodically is a capacity limitation imposed on the machine by the decision to go to a wet dust control system.

A dry filter system would eliminate the requirement for water tanks and the associated filling and travel time required. Dry dust might also unload easier. However, if the dry dust is to be unloaded inside the mine, mine atmosphere dust requirements may make water sprays necessary to make this unloading operation relatively dust free.

c. Air System (Exhauster-Muffler)

The coal mine vacuum sweeper is equipped with a Schwitzer positive-displacement gear-type air pump, used as an exhauster. This unit is belt-driven (through an oil-operated clutch) directly from the vacuum sweeper 15 HP motor. The exhauster is mounted on a manifold plate which, in turn, bolts to the front of the separation system pressure vessel; this manifold plate also supports the moisture separator and the Venturi scrubber inside the separation system and makes all air connections with these components.

The exhauster pumps air from the separation system into a muffler which is mounted across the machine frame ahead of the exhauster. This muffler unit, which offers about 30 dbA of noise reduction, exhausts into a tee. One branch of this tee supplied air at low pressure and volume to the "assist" air conduit of the boom; the other branch of the tee allows the air to escape to the rear of the machine, away from the operator.

Operation

No problems were encountered with the exhauster, muffler or exhauster drive systems during the test series. It was necessary to drill holes in the muffler to allow water to escape during a period of the machine development--it was later discovered that a fault in the pump which scavenged water out of the moisture separator was allowing water to accumulate in this device, to be pumped out through the exhauster.

Chassis (vehicle)

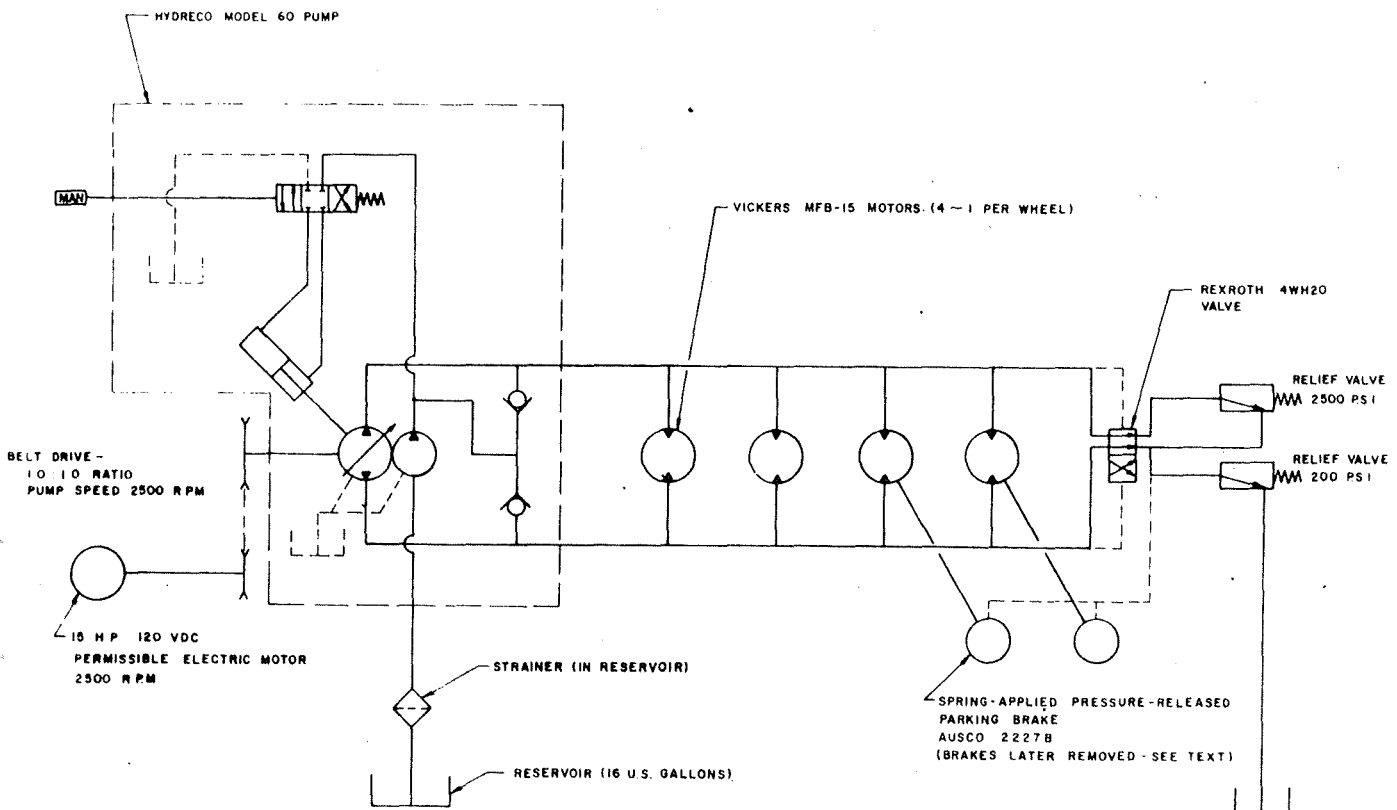
a. Tramming System (Hydrostatic Drive)

The coal mine vacuum sweeper is powered with a 15 horsepower 120 volt direct current compound wound permissible electric motor. Motor control is by a permissible starter, remotely controlled from the operator's compartment. Speed control devices are not used on this electric motor; the system depends on the inherent stability of the compound wound motor for speed control.

This single power source operates the hydrostatic drive system, the service system (which operates all of the machine control functions including brakes and steering), the exhauster and the associated water (spray) pumps for the dust separation system. Exhauster and water pumps operate only when the operator engages a clutch.

The terrain of coal mine floors and conveyerways makes four-wheel drive and four-wheel steering necessary for most vehicles. In this vehicle, the separation system module sits horizontally between the rear wheels, making the use of an axle impossible. Individual wheel drive units were used; major savings in machine space results from this approach.

The hydrostatic drive system circuit, Figure 38, consists of a variable volume piston pump (its output controlled by the operator), a shuttle valve arrangement which applies the pressurized oil from the pump output to the proper motor ports (responsive to the operator-controlled output of the piston pump) and four independent hydraulic wheel drives.



HYDROSTATIC DRIVE SYSTEM CIRCUIT
FIGURE 38

b. Tramming System (Brakes)

The coal mine vacuum sweeper is equipped with 4-wheel disc brakes with two modes of control. The brakes may be applied by means of a foot pedal or they may be locked "on" by means of a small two-position hand valve which routes oil directly to the brakes from the accumulator-equipped central hydraulic service system. This valve is not intended to transform the service brake system into a parking brake system, but only to secure the machine against moving when it is running, or for a short period after motor shutdown.

The machine was to be equipped with oil-released spring-actuated parking brakes; these units were purchased and installed, but trouble was encountered in making them function properly. There was much difficulty in getting the brakes to release; every start (tramming) of the machine was sudden; sometimes the machine would not move. These brakes were designed to be released by the hydrostatic transmission charge pressure; the shuttle valve with which this system is equipped apparently did not always sense the hydrostatic pump flow direction until some considerable pressure had built up.

These parking brakes were removed and have not been re-installed. It is possible that if they were actuated in a different manner, more reliable and/or satisfactory operation could be obtained. The limited (250 psi maximum) brake release pressure prevents utilizing the service system pressure to affect the brake release; an intermediate pressure reducing device would have to be interposed between the service system and the brake release cylinders to accommodate the difference between operating and allowable pressures.

Operation

The drive system functioned satisfactorily in the mine except that it did not provide output torque to the wheels adequate to negotiate all of the slopes in the test mine. The machine is limited to slopes of 10% or less; this hill-climbing ability is further deteriorated when the machine is operating in the vacuum-cleaning mode. The machine has a good speed range, a good response to operator control and ran without any problems.

One operational problem is that no "no-spin" provision is made in this drive system--if one drive wheel becomes unloaded, the entire output of the hydraulic system will go to this wheel and the machine will stall. In effect, this situation combined with the long overhang of the operator's cockpit, gives a machine which will become stuck if both front wheels encounter a depression in the floor sufficient to "ground" the front end of the operator's cockpit.

c. Operator Compartment and Comfort

The operator cockpit or station was designed for a 50th percentile individual; it is small for many operators. Entry and machine operation with a mine-dressed operator can be difficult. The machine headroom requirement made necessary a large seat tilt angle; this tilt angle is beyond that which allows good forward vision without strain. Ample width was provided for the operator, although it proved impossible to mount the traditional steering wheel in a position which would allow operator access and visibility. Steering is controlled by means of a direct acting four-way hydraulic control valve which supplies oil to the steering cylinders.

The coal mine vacuum sweeper is equipped with a positive displacement gear-type air pump, used as an exhaustor. Units of this type are inherently noisy. This unit is mounted directly behind the operator's compartment.

The operator's station or cockpit was welded solid to the machine frame; this allowed transmission of all machine-generated noise to the flat plates forming the top, back wall and bottom of the operator station. These plates resonate or vibrate to the extent that it has not been possible to reduce the cab noise to less than 88 dbA (with the exhaustor de-clutched and the service pump idling). When the service pump operates, cab noise reaches 103 dbA; with the service pump and exhaustor operating, levels of 105-106 dbA were measured at the operator's ear.

The hydrostatic drive pump is mounted solid on the machine frame; this unit is quiet enough that no isolators are required. The electric motor required no isolators, nor did the Schwitzer blower itself, or any components of the dust separation system.

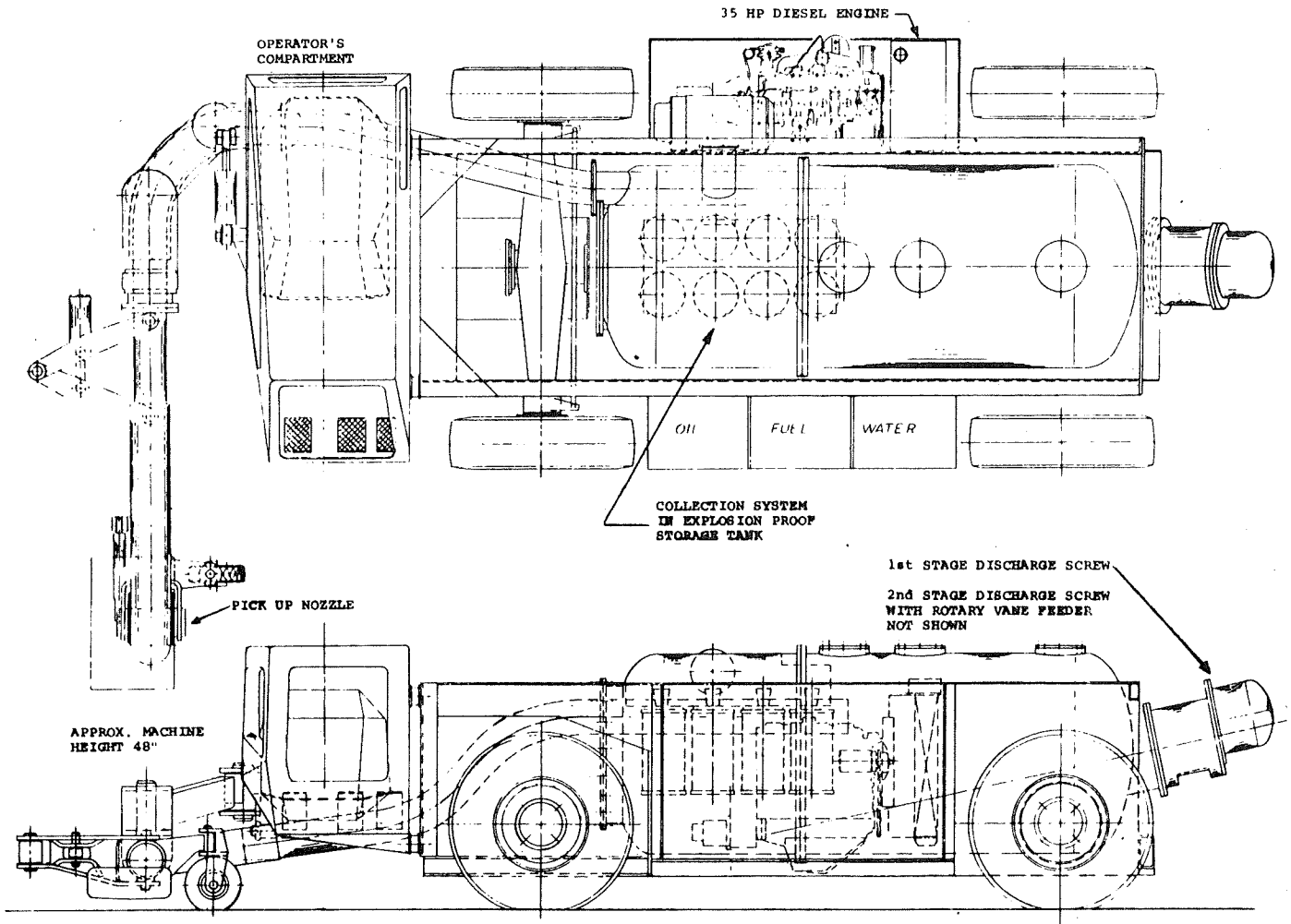
Operation

The operator's cockpit should be suspended on vibration isolators to prevent the transmission of mechanical noises into this area. A larger machine or a different machine configuration might offer more room for the exhaustor muffler; muffling effectiveness (transmission loss) is roughly proportional to muffler volume.

The extreme forward projection of the operator's compartment coupled with the machine's limited ground clearance and short wheelbase makes the unit sensitive to uneven terrain. If the front wheels of the machine encounter a depression in the mine floor, the front of the operator's station will ground against the mine floor, leaving the front wheels of the machine unloaded. This will cause one or more of the unloaded wheels to spin freely, and the machine will not move.

Visibility to the rear is non-existent. To overcome this, the operator's compartment could be turned crosswise in front of the machine (over the wheels) to allow backing. See Figure 39. This change would also substantially shorten the machine, making it less susceptible to contact with an uneven mine floor.

The operator compartment (in this orientation) could be longer and higher to allow the accommodation of a larger individual. Visibility to the front would be improved, and the operating visibility (boom) would be as good or better than it is with the present arrangement.

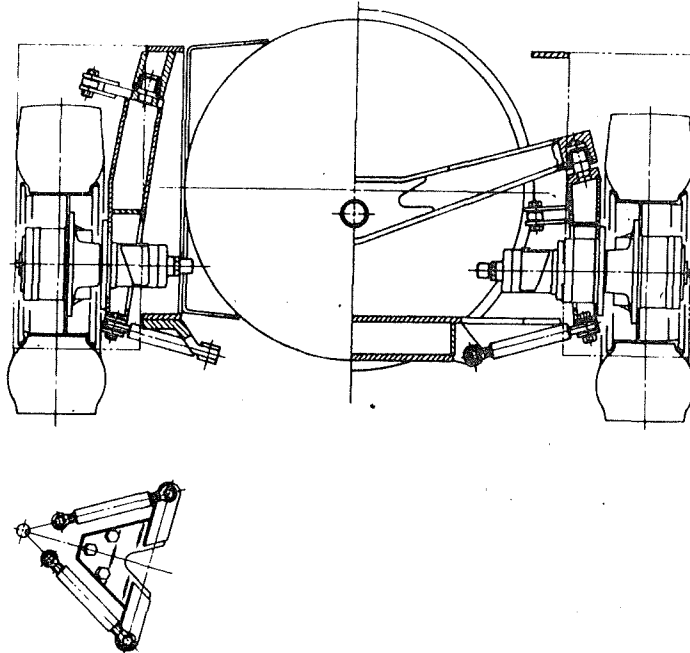


COAL MINE VACUUM SWEEPER REVISED FOR DIESEL OPERATION

FIGURE 39

d. Steering and Suspension

The separate wheel-motor drive units are mounted on the machine frame with a linkage arrangement which allows the wheels to be steered while minimizing the steering effort and obstacle reaction forces by causing the axis of steering rotation to pass through the center of the tire footprint (Figure 40). This linkage also provides room (because of its open "space-frame" design) for the hydraulic motor-wheel drive components.



STEERING AND SUSPENSION SYSTEM
FIGURE 40

The same construction is used for the front and rear suspensions except that the front suspension system was also equipped with a bolster or equalizer to allow the wheels to follow the contour of the roadway.

The machine is equipped with four-wheel hydraulically-operated steering; front wheels are equipped with a tie rod system which coordinates the motion of the right and left wheels; the rear wheels are steered through a drag link from the front wheels. Two hydraulic cylinders power the steering; hydraulic power is obtained from the service hydraulic system on the machine.

Operation

No problems were encountered with this unit except that the oscillation of the bolster or equalizer beam in the front axle unit had to be restricted in the "up" direction on the right-hand side of the machine to allow for clearance around the inlet pipe of the separation system. This limited oscillation tended to bottom at times, but no damage to the performance or structure of the machine resulted.

Controls

a. Switchgear, Safety Stop Devices

The use of a hydrostatic drive system removes electrical controls from the vehicle except for the permissible switchgear required to start the 15 HP 120V DC main motor and the switches required to operate the lights. The motor start-stop functions and the light switches are controlled from a remote box in the operator's station.

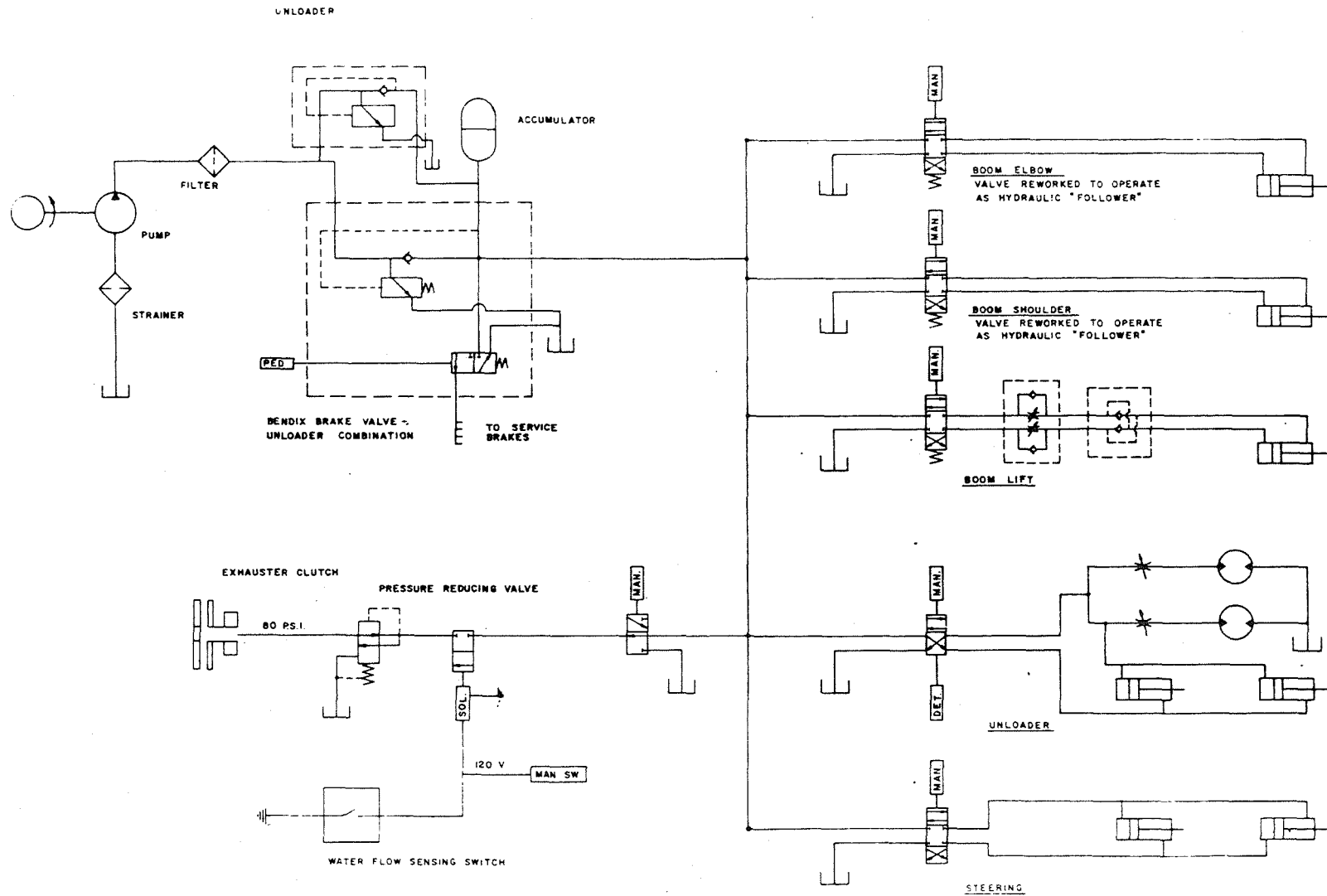
In addition to the above controls, a permissible flow-sensing switch monitors water flow to the Venturi scrubber; if the flow ceases, the switch closes and actuates a permissible solenoid valve (hydraulic) which causes the blower drive clutch to disengage. Reengagement is impossible without filling the system with water or otherwise restoring water flow. This is shown in Figure 41.

A circuit drawing for the hydraulic service system controls is shown in Figure 41. A closed center constant pressure hydraulic system is used, which supplies oil at 1450 to 1600 psi (the opening and closing pressures of the unloader valve) on demand at all times when the machine is operating. The system accumulator will maintain this pressure to the service system (including brakes and steering, for some time after the main electric motor is shut off.

b. Hydraulic Nozzle and Machine Controls

Hydraulic valves for the control of the boom positioning functions are located on the boom (except for the valve which controls the height of the nozzle above the floor) and are arranged so that they cause the action of the boom to mimic or follow the actions of the control handle in the operator's compartment. This gives a natural type of control--moving the handle in the direction in which you wish the boom to move results in the desired boom motion.

Nozzle height is controlled by a foot pedal in the operator's compartment.



HYDRAULIC SERVICE SYSTEM CIRCUIT WITH WATER FLOW SENSING SWITCH
 FIGURE 41

Unloading functions, partially described in the separation system discussion, are controlled by a lever in the operator's compartment.

Hydraulic system fluid is a fire-resistant water-in-oil emulsion system (PYROGUARD D). This system fluid serves both hydraulic and hydrostatic systems. The hydraulic system service pump pumps oil continuously through a 5-micron filter cartridge contained in a pressure housing. This pressure filter approach was resorted to in order to prevent particulate matter from reaching any of the valves or other operating parts of the system. The reservoir is equipped with a suction strainer which protects the pump intakes against harmful objects or particles. This suction strainer is accessible for service through a cover plate on the side of the hydraulic tank--the flat shape of the hydraulic reservoir made a special reservoir design necessary to accommodate the strainer and maintain good intake conditions for the hydraulic pumps.

c. Tramming Controls

Tramming is accomplished by changing the output flow and direction of flow of the hydrostatic drive. A pedal in the operator's compartment controls the hydrostatic drive pump to select the travel direction and tramming speed.

Operation

It was difficult to make the nozzle follow the contour of the mine floor. This was because:

- . Awkward position and action of the foot (raise and lower) nozzle control made precise control difficult.
- . An error in boom geometry resulted in the nozzle rising off the floor when the boom was extended (relative to the machine) and descending when it was moved rearward. This made frequent nozzle height adjustments necessary.
- . More frequent small scale variations in ground or floor contour occurred than were expected.
- . Extreme nozzle versus machine wheelbase overhang; any pitching movement of the vehicle itself was exaggerated at the nozzle location by this effect.
- . Low horsepower (and the resulting low airflows) made precise level control, i.e., control of the distance between nozzle and surface, critical to the performance of the nozzle.
- . A surface-following nozzle and some reworking of the geometry of the boom arrangement plus a more sophisticated manual or pedal control to govern nozzle height would eliminate most of the above problems.

Power Systems

a. Motor and Battery Arrangement

Battery power was specified for this machine. A lead-acid battery was selected because of low cost, ready availability and acceptance in the coal mining community. The platform of the machine required that the battery be divided into two modules, to be carried on the right and left sides of the machine. This arrangement gives good battery access; removal of either of the modules can be accomplished when access is required to those machine components covered by the batteries.

Battery charging is accomplished through a single connector arrangement; the total battery voltage is 120 volts; the two battery modules are connected in series to obtain this voltage.

A 15 horsepower electric motor was selected for the main machine drive; the power level of this motor was determined to be that minimum which would allow the simultaneous operation of the exhauster and its associated water pumps, intermittent operation of the service hydraulic system, and slow tramming of the machine up a grade. A larger motor would have depleted the battery charge very quickly.

The motor-battery selection was made on the basis of a two-hour vacuuming time per charge; this operating time included travel to the work point and travel to water stations for refilling the machine tankage. The two hours was to have been operating time; in practice, this period would occupy more than two hours when the travel time and emptying time was added to the operating time.

Additional battery weight would not have greatly extended the operating time; much more weight would have required a larger motor to move the machine. The short discharge times expected with the current draw required by the 15 horsepower motor reduced the usable battery energy per charge cycle: further reduction of the usable battery energy is dictated by that (good) operating practice of using only about 70% of the available full charge energy in order to attain acceptable total battery life (number of charge-discharge cycles).

In addition to the main machine motor, 120 volt permissible lights were mounted on the machine and operated directly from the main battery; two lights were directed to the rear of the machine, one directed to the front and one mounted on the boom, directed at and moving with the pickup nozzle.

Operation

No operational problems were encountered with the electrical components, battery, motor or lights in the field. The machine was equipped with a permissible battery charge indicator device (which was supposed to indicate to the operator when the battery approached that 70% discharge point) which operated erratically; this had no overall effect on the reliability of the machine.

As will be mentioned in the general summary regarding the operation of the vacuum sweeper, the lack of power is the main shortcoming of the unit.

In a battery-operated machine, power consumption vs. operating time is the principal design parameter which, in the end, governs the design and selection of almost all of the machine components. Any selection which can be made suffers from those compromises which must be made between battery weight, operating time, and performance. This machine would have been quite different had the use of a diesel engine been possible.

b. Battery Charger

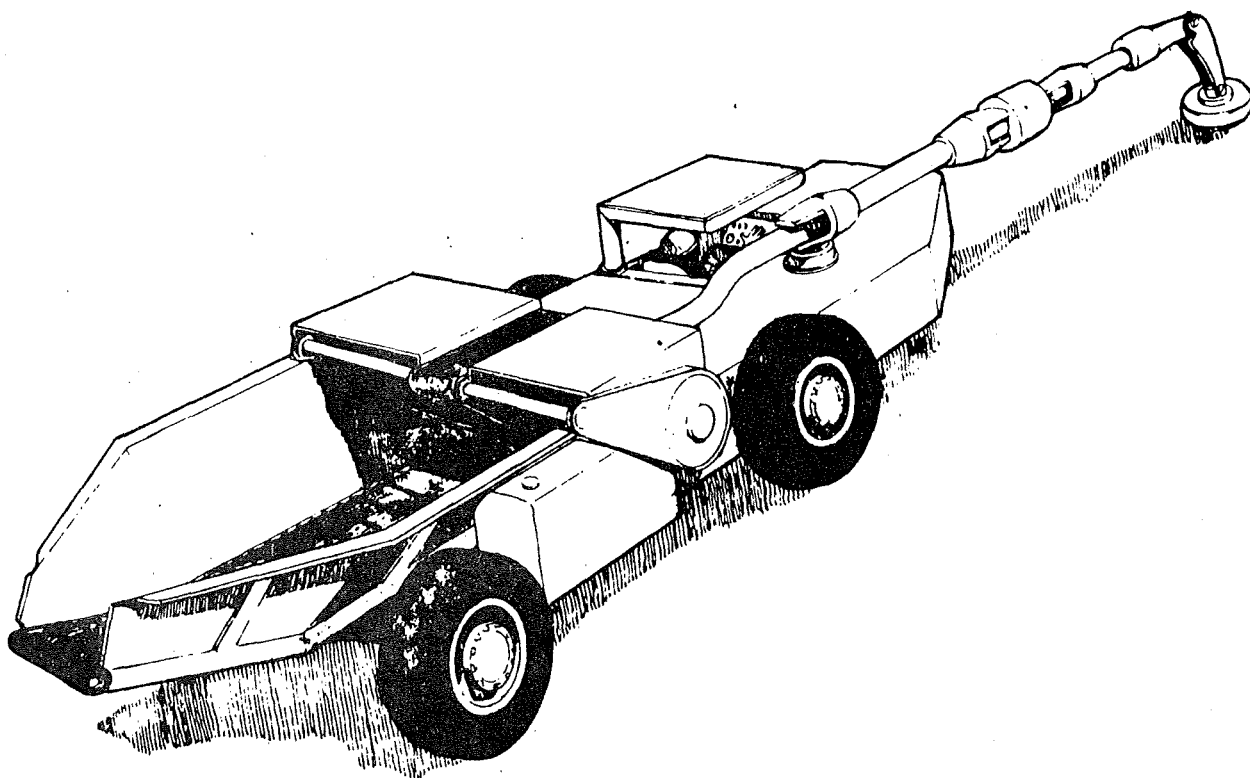
A commercial battery charger was purchased for use with the coal mine vacuum sweeper. This is a 120 volt DC unit; both batteries are charged simultaneously (in series) without removal from the machine. The charger is equipped with an automatic charge cycle controller--it begins a timed charge cycle when the charge lead is plugged into the vacuum sweeper junction box. Power supply to the charger is 400-460 V, 3 PH, AC current.

Operation

No field problems were encountered with this charger unit.

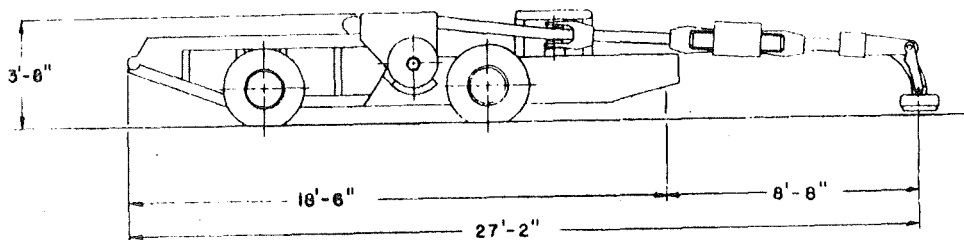
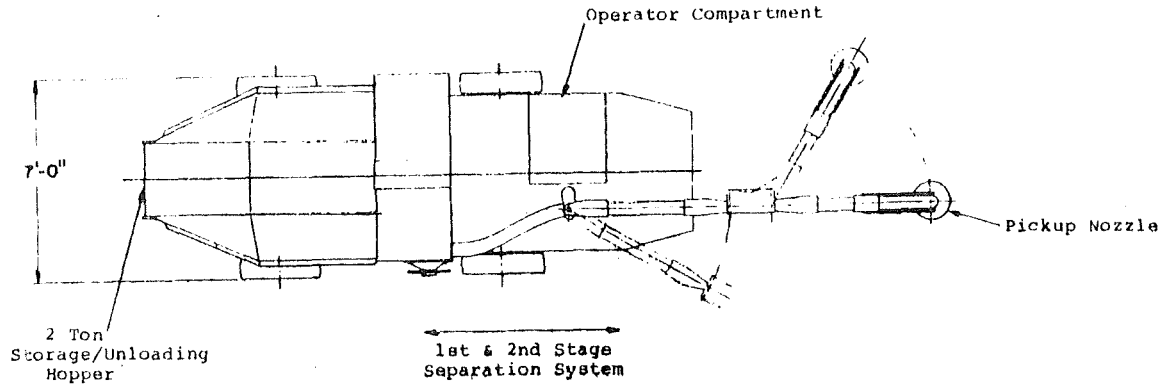
OTHER MACHINE CONCEPTS

A machine was designed to function as a cleanup machine, in the active mining district. It is depicted in Figure 42 and its dimensions given in Figure 43.



CABLE REEL POWERED MACHINE FOR GENERAL CLEANUP WORK

FIGURE 42



DIMENSIONS OF MACHINE FOR GENERAL CLEANUP WORK

FIGURE 43

This machine is designed for cleanup in the conventional or continuous mining cycle. The maximum lump size it can handle is limited by its duct size which is five (5) inches. For this reason, it must either limit itself to such cleanup chores as cleaning of ribs, cleanup after moving feeder breaker or can be operated in conjunction with a small bucket loader which will take care of the large lumps.

This application would be more practical if the machine were diesel driven because of an inherently greater excursion capability.

This machine could also be redesigned to include a small bucket or dozer blade, with some penalty to its performance as a vacuum cleaner.

The important machine parameters for this machine are shown on the following page.

Power	AC Cable Reel
Range	500 Ft. Cable
Vacuum	60: H ₂ O
System CFM	750 CFM
Cleanup Rate	200 Lbs /Minute
Maximum Lump Size	4 Inches

This machine has a greater capacity to store collected material than the belt haulageway cleanup machine. (4000 Lbs versus 500 Lbs). At 200 lbs /min capacity, it has a continuous operating time of 20 minutes between unloadings. At a water usage of 2.3 gpm, it requires a water storage capacity of approximately 50 gallons to complete one cleanup-dumping cycle. It was designed with a water storage of 100 gallons and is capable of operating for nearly one hour before water resupply.

This machine, although feasible as a concept, was discarded for complete design and demonstration because complete cleanup in the active mining district would require a companion machine to handle the larger lumps always present in the face area.

If either the belt conveyor cleanup machine or the unit described above were equipped with a permissible diesel engine package, the Coal Mine Vacuum Sweeper concept would immediately become brighter for two reasons:

- . The increase in available power would increase the machine handling capacity to at least 500 lbs /min.
- . The excursion range of the unit would be unlimited.

A redesign of the belt conveyor cleanup machine is shown in Figure 38. A number of improvements incorporated into this design based on the experiences gained in testing the prototype coal mine vacuum sweeper.

Power

Diesel is proposed as a practical power source for a coal mine vacuum sweeper, using a Perkins engine package having a 35 HP rating in Schedule 31 version with scrubber. This engine/scrubber package has Schedule 31 approval as used with the EIMCO 911 Load Haul Dump.

Separation System

Figure 38 shows a dry filter system contained by an explosion proof surge tank. The system incorporates automatic timed blow-back, providing continuous operation without filter clogging.

This system operates at a pressure differential of only 2 to 4 inches H₂O compared to the 70 inches demanded by the current wet Venture type system. However, engine power is sufficient to drive either a wet or a dry separation system.

If a wet system is employed, a water recycling system with cyclones must be used to render the machine practical.

Pickup Nozzle

A nozzle, flexibly mounted in the vertical, with some form of ground support means is suggested to achieve good conformance with the ground.

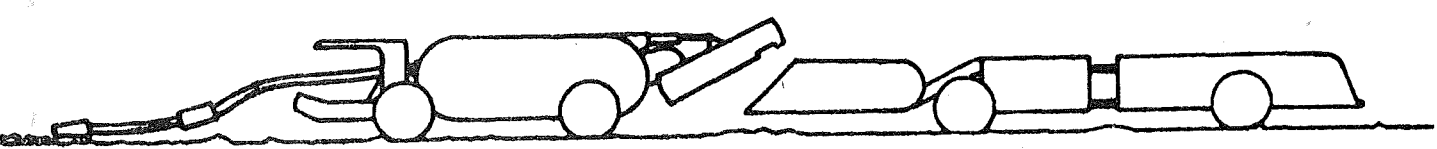
Operator Compartment

The operator's compartment is turned crosswise to provide visibility in any direction and increased in size for increased comfort.

Unloading System

Conventional screws would be used in case of a dry system. For a wet system, the spray water flow could be increased to produce a non-sticking slurry which could be "pumped" out by close-fitting higher rpm screws or other type of pump. An airlock would be added to provide continuous, rather than batch type, operation. A rotary vane feeder, hydraulically powered could simply be added at the final screw discharge.

With the addition of an airlock at the discharge point, continuous discharge can be accomplished. It is visualized that discharge be to the carrying side of a belt conveyor in case of belt cleanup and to a companion machine such as a scoop in other applications as shown in Figure 44.



COAL VAC OPERATING WITH TYPICAL SCOOP

FIGURE 44

COSTS OF CLEANUP WORK

A cost comparison between conventional and vacuum cleaning methods was made in 1973 based on an expected progress rate of cleaning under a belt at 30 feet per minute or two hours to clean 3500 feet with the vacuum. Expected progress rate of vacuum machine cleaning the entry floor was 15 feet per minute or 4 hours to clean 3500 feet of entry floor. These figures were based on reasonably frequent cleanup, maintaining accumulations to about one inch thickness. Included in these cost comparisons were labor and supervision, cost of machinery (amortization, maintenance, etc.) and rock dusting. These costs, of course, would have to be escalated to reflect current prices. The ratio or percentage of savings, however, would be similar. It is believed the rates of cleaning assumed in the estimate are attainable and a machine having the above capability can be built, especially if diesel power is used.

A summary of the 1973 estimated Cost Comparison of Vacuum Cleaning vs. Conventional Cleaning is shown in the following table. For further details, refer to the Phase I report referred to in the bibliography.

ESTIMATED COST COMPARISON 1973

**VACUUM CLEANING VS CONVENTIONAL CLEANING
(Rock Dusting Included)**

ITEM	CONVENTIONAL CLEANUP COST PER TON	WITH VACUUM COST PER TON	DIFFERENCE PER TON
Mine Belt Conveyor Sys- tem Cleanup, Rock Dusting Included	0.22	0.06	0.16
District Clean- up, Rock Dust- ing Included	0.54	0.46	0.08
TOTAL	0.76	0.52	0.24

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