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APPLICATION OF THE DIESEL ENGINE TO SMALL MINES

By

W. W. Staley

University of Idaho
Moscow, Idaho

Moscow, Idaho
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Dean A. W. Fahrenwald
Director, Idaho Bureau of Mines and Geology
Moscow, Idaho

Sir:

Material is submitted herewith for a pamphlet on the application of Diesel engines to small mines and concentrators. The object throughout the discussion has been to present the material in as non-technical a manner as possible. I fully realize the danger of attempting to condense a topic as technical and broad as this into comparatively few pages.

It should be emphatically stated that this paper is in no way a proposal advocating the Diesel engine as a competitor of established power companies. As a matter of fact, the Diesel manufacturer will readily concede the superiority of purchased power when careful calculations show that such conditions exist. The purpose here is to bring to the attention of the mine operator the reasonableness of cost, and the simplicity of operation of the small Diesel-type engine. The interior of Idaho is, to a great extent, inaccessible to purchased power. The cost of running in a power line, even under most favorable conditions, will probably exceed $1,000 per mile for poles, wire, labor, etc. On top of this, transformers have to be bought; bonds or guarantees posted agreeing to consume a minimum amount of power; and a contract made stipulating that operations will continue over a given period of years. The small operator can not meet these requirements.

The use of hydroelectric power is, in practically all cases, out of the question because of plant and transmission costs. Steam plants might be considered a competitor. However, the efficiency of these small plants is very low, and, unless cord wood is burned, the fuel cost will be much higher than for the Diesel. In addition, there are large standby losses.

This pamphlet is in no way a handbook or manual of Diesel engine operation or practice. A prospective purchaser should consult the manufacturer regarding his particular problem. Only in this way will maximum efficiency and freedom from trouble be attained.

Occasional statements in the text may appear vague or indefinite. In encountering such passages it should be remembered that the discussion is devoted to small semi- and full-Diesel engines. Also, because of limited space, much descriptive matter must necessarily be generalized.

I wish to thank the following for the help and information they have given me: Mr. C. A. Newton, Fairbanks, Morse and Company, Spokane, Washington; Fairbanks, Morse and Company, Seattle, Washington; Ingersoll-Rand Company, New York City; Chicago Pneumatic Tool Company, New York City; Hercules Motor Corporation, Canton, Ohio; Waukesha Motor Company, Waukesha, Wisconsin; Nordberg Manufacturing Company, Milwaukee, Wisconsin; Standard Oil Company of California, San Francisco; Texaco Company, New York City; Diesel Engine Manufacturers' Association, New York City. I am especially grateful to Mr. C. A. Newton for criticizing the manuscript.

Respectfully,

W. W. Staley
Mining Engineer, Idaho Bureau of
Mines and Geology

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W. W. Staley

INTRODUCTION

The first internal combustion engine was probably built by Huyghens in 1680. He used gunpowder as a source of power. In 1791, John Barber, an Englishman, designed an engine to operate on producer gas.

The first practical engine was built by Lenoir in 1860. The efficiency of these engines was extremely low (about 4 per cent), and their fuel comsumption very high.

Otto, in 1866 and 1878, and Beau de Rochas, in 1862, proposed cycles which bear their names. Otto's proposal did not prove satisfactory and the cycle which today bears his name should be known as the "Beau de Rochas cycle". 1/ The events occurring in the modern four-stroke cycle engine are identical with those outlined by Beau de Rochas. In 1921, more than 500,000 horsepower of the so-called Otto cycle engines were sold. 2/

From the time of Otto to 1897, when Dr. Rudolf Diesel, a German engineer, brought out the engine which bears his name, many suggestions were advanced and improvements made in fuel injection, compression cycle, heat control, etc. The first American Diesel was made in 1898. 3/

In 1932, there were about 4,500,000 horsepower of Diesel engines installed in the United States. 4/ This represented 38,453 engines. Of this 4,500,000 horsepower, almost 4,300,000 were still in actual use. Many of these engines had been in service for nearly 30 years, with only a nominal upkeep cost. This evidence should do much to allay the fears of those who feel that the Diesel engine is short-lived. The manufacturers make all parts, subjected to wear, readily accessible and replacable.

The industries in which Diesel engines are used may, according to Morrison 5/

1/ Morrison, L. H., Diesel Engines, p. 9, 1st Ed. (McGraw-Hill Book Co.)
2/ Idem
3/ Idem
4/ Morrison, L. H.: Diesel Power, p. 272, June, 1933.
5/ Idem

be classified as follows:

Applications	Per cent of total
General industry	21
Marine	20
Petroleum	11.3
Municipal light	10.2
Public utility	7.8
Contractors	5.1
Cotton gins	4.8
U. S. Navy	3.7
Mines and quarries	3.4
Railroads	2.4
Irrigation	2.4
Ice plants	2.2
Water works	2.2
Export	2.0
Government institutes	1.1
Buildings	0.4

By 1934 it was estimated that over 5,000,000 horsepower of oil engines would be installed. The field of use has increased rapidly. The reason for this rapid increase is probably due to two reasons: (1) their economy, and, (2) so far as the smaller (10-200 hp.) units are concerned, the fact that highly trained engineers are unnecessary for their operation. Common sense, adherence to the manufacturer's instructions, and a knowledge of the ordinary gasoline engine is sufficient training for the small plant operator. The idea has prevailed for years that the Diesel engine was something mysterious, a contrivance which would do the bidding of only a chosen few. This notion, fortunately, is rapidly being dispelled. To the mine operator, both large and small, the Diesel engine should prove a decided asset.

Of all the heat engines of present known application, the Diesel engine is by far the most efficient. That is, it converts more of its heat energy into useful work. Steam turbines of more than 100,000 horsepower do not have the thermal efficiency of a 10-horsepower Diesel engine. 1/ The following table gives a comparison of efficiencies of various heat engines: 2/

1/ Economy of Diesel Engine Power: Bull. No. 3010 Fairbanks-Morse Co.

2/ Abstracted from Wormser, F. E., The Diesel Engine in the Mining Field: Eng. & Min. Jour., July 25, 1925, p. 125.

Type of Prime Mover	Over-all thermal efficiency	Superiority of Diesel engine
Non-condensing steam engine (a)	6.30 - 9.1	5.6 - 3.6
Condensing steam engine using superheated steam	9.10 - 15.4	3.6 - 2.3
Locomobile engine with superheated steam and reheater, condensing	14.9 - 16.7	2.4 - 2.1
Steam turbine, superheated steam, 2000 to 10000 hp. (a)	16.2 - 18.1	2.2 - 1.95
Gas engine without producer	24.4 - 27.5	1.33 - 1.28
Suction gas engine (b)	18.1 - 22.7	1.95 - 1.55
Diesel engine (c)	32 - 35.3	-----------

(a) Includes boiler losses.
(b) Includes producer losses.
(c) Haas, Herbert, The Diesel Engine, Bull. 156, U. S. Bureau of Mines.

An important point in favor of the Diesel engine is the fact that the efficiency of engines of but a few horsepower is but very little less than that of the largest engines. This is far from being true in the case of steam plants.

The advantages of Diesel power are well summarized in the Fairbanks, Morse bulletin previously quoted. They are -

Low fuel cost
Maximum dependability
Long, useful life
Small operating force
Low maintenance cost
Delivers full power, instantly
No standby losses
Simplicity in design
Small floor space
Simplicity in operation
No service or demand charges
High efficiency in all sizes
Plant can be enlarged without sacrifice of original investment or over-all economy
Large water supply unnecessary
No chimney, smoke, or ashes
No coal or ash-handling apparatus

Of the above items, it might be well at this time to briefly discuss two of them. The advantages of the others are apparent.

Fuel cost. The fuel cost will depend primarily on three things: Cost delivered, heating value, and engine consumption per brake horsepower-hour (Bhp.-hr.). In most mining localities, especially those located distantly from oil-producing centers, fuel oil is relatively high. In Idaho it reaches a price in excess of 9 cents per gallon in one easily accessible locality. Under such conditions, coal, gasoline, or electrical energy will also generally be proportionately higher. The fuel oil costs will usually account for a little less than one-half the total operating cost.

The heating value of the fuel oil depends on its grade and purity. Engines are usually rated on an oil containing at least 19,000 Btu. per pound. Diesel fuel oil supplied by reputable oil companies is seldom less than this. A low Btu. value will usually mean a higher fuel consumption. This may not in itself amount to much. However, the transportation charges will be the same for low grade oils as high grade oils, and this is important for isolated districts. It behooves the purchaser to get the standard grade of oil.

The fuel consumption on most modern engines of low horsepower is in the neighborhood of 0.40-0.50 pounds per brake horsepower-hour. At full load, this is usually attainable and guaranteed by many manufacturers. The consumption increases slightly at less than full load.

Maintenance cost. One of the points of controversy for years between the manufacturers of other prime movers and Diesel engine manufacturers has been maintenance cost. A survey by manufacturers of a large number of engines which have operated over a period of years indicates that a yearly maintenance charge of 2 per cent of the factory cost of the machinery, without regard to the annual output, is more than ample to cover repairs and upkeep.

It is interesting to note that the greater number of engines sold (1920-1932) ranged from 20 to 200 horsepower.

FUTURE OF DIESEL ENGINES

There are three things that might be considered as making an investment in Diesel power risky.

1. Obsolescence
2. Engine wearing out
3. Exhaustion of oil supply

Obsolescence. For our purpose, obsolescence may be taken as meaning such a rapid change in design, construction, and efficiency of the engine that the investment in a few years would be worthless. To refute such a statement regarding the Diesel engine, the argument is advanced that since its development, over 35 years ago, the efficiency has been increased but very little. As a matter of fact, it is claimed that there is very little room left for increasing the present thermal efficiency beyond 35 per cent. From a structural and operating standpoint, there has been a great advancement. However, the fuel consumption of a great many of the old engines is but a few tenths of a pound more than the modern engine. In most cases, the older engine can be adapted with later improvements in combustion and fuel injection, etc., with but a small outlay. When it is all summed up, there is little to fear from obsolescence.

Engine wearing out. Diesel engine manufacturers have compiled statistics to show that with ordinary care and attention there should be no trouble from worn parts for at least 10 years. The parts receiving the greatest abuse, with consequent wear, are the valves, pistons, and cylinder liners. Even though wear on these parts, in exceptional cases, becomes excessive, there is no great expense incurred in rectifying the trouble. The cost of completely overhauling an engine, i.e., reboring cylinders and fitting new pistons; rebabbiting crank-pin bearings; replacing piston-pin bearings, and main bearings; replacing all wearing parts in fuel and control systems; etc., (in other words, completely rebuilding the engine) is but a very modest part of the original cost. This cost amounts to (including cost of parts, labor, and freight) about 20 per cent for large engines (800 to 1000 hp.) to 40 per cent for small engines (25 to 200 hp.). A yearly sinking fund (on the basis of 10 years) of 1.6 to 2.9 per cent of the original cost with accessories will provide for complete rebuilding.

Exhaustion of oil supplies. So far as mining men are concerned, it would seem superfluous to offer a defense against Diesel fuel supplies becoming depleted in the near future. Even when pumped oil is exhausted, that remaining (about 70 per cent) can be extracted by mining methods. The oil shale reserves apparently approach the reserves of petroleum in size. In the last analysis, coal can be converted into a usable Diesel fuel. Aside from the United States, other countries in the Western Hemisphere contain tremendous oil reserves. So far as the next few centuries are concerned, the possible lack of fuel for Diesel engines has caused far more apprehension than it deserves. Of the three items discussed, the lack of a fuel is the least to be feared. As a matter of fact, none of the three is of great importance.

The only real competition that the Diesel engine has to fear is the production of cheap hydroelectric power. From the present outlook, it will be some years before outlying mining properties can expect to buy electric power at a reasonable cost. Investigations at the present time indicate that transmission and distribution costs are responsible for the major portion of the cost. The capital investment in hydroelectric plants is also very great.

TYPES AND SIZES OF DIESEL ENGINES

There are three types of Diesel engines (so far as we are concerned).

1. Stationary
2. Marine
3. Automotive

Of these we are primarily interested in the stationary engine. The application of the marine engine in the stationary field is very doubtful. If done at all, it should only be after very careful consideration and analysis of the proposed loading by an experienced Diesel consultant.

The automotive Diesels of the Waukesha and Hercules types (both of these companies also make small stationary engines), while primarily for truck and bus uses, may be mounted on a base and adapted to stationary work. They are relatively light in weight, and should prove advantageous for prospecting or development work. (Direct drive to compressors, generators, etc., of small capacity; or chain, gear, or direct drive to diamond drills). Because of their light weight, they would cause a minimum of transportation trouble in mountainous regions.

Stationary Engines

It is with the small to moderately sized stationary engine that we are mainly interested. In a great many mining regions there is an almost total lack of year-round passable roads. The topography is rough and mountainous which increases transportation costs enormously. Because of these features, a light weight engine is very desirable. In many cases, it may be necessary to dismantle the engine. This requires simplicity in design and as few heavy parts as possible. These requirements are substantially met by the present day engine ranging up to 180-200 horsepower. As will be shown later, it will seldom be necessary to require an engine of greater than 200 horsepower. The load-cycle of a mine and mill is usually such that two or more engines of small rating will prove more economical than one large engine. This subject will be more fully discussed under the heading of Selection of Equipment.

Before continuing further with the discussion, it is desirable that the two methods of rating heat engines be explained. An engine may be rated on its indicated horsepower (Ihp.) or on its brake horsepower (Bhp.). The indicated horsepower is the power produced in the cylinder of the engine. It depends on the mean-effective-pressure, length of stroke, area of piston, and revolutions per minute. It may be calculated from specifications or it may be determined by means of an indicator diagram. The Ihp. gives the power up to the piston. It does not consider the power lost in overcoming friction in the piston-pin bearings, main bearings, piston rings, or cylinder walls, etc. The Bhp. is the power actually delivered at the fly-wheel. It takes into consideration all losses up to the fly-wheel. In other words, it is the net power the engine is capable of delivering. The Bhp. is about 80 per cent of the Ihp., although it actually depends on the size and design of the engine.

Brake horsepower-hour is the product of the brake horsepower delivered times the hours that such delivery is made. It is commonly expressed as Bhp.-hr.

The range in size of engines (this does not mean total power) for small mines and mills, and for prospecting and development work, may be confined between 10 and 200 horsepower. Where only the mine is being operated, one engine connected to a compressor or to a compressor and small generator may be sufficient. Or one engine may operate both a hoist and compressor. Or they may have separate engines. The rating of such engines will, of course, depend on the number of drills operated, the tonnage of material hoisted, accessory equipment in the shops and the altitude of the engine. Ordinarily, 10 to 100 horsepower would be sufficient.

Where both the mine and mill are operating, the horsepower required will depend on the tonnage of ore and waste hoisted, the tonnage and method of treatment by the mill, and the altitude of the engine. The brake horsepower required for both mine and mill may be roughly estimated at 4-6 Bhp. per ton milled.

Accessory Equipment

The nature of the accessory equipment required for the range of units under consideration will depend on the method of starting the engine and whether the operating equipment is driven by electric motors or directly by the Diesel engine.

The small to moderately sized units (up to 200 hp.) may be started by either a storage battery and electric motor or by compressed air. Practically all of the recent models are electrically started. The principle is the same as for the ordinary automobile engine. A charging generator and motor are mounted on the Diesel engine and a storage battery used to supply power. When compressed air is used as a starting medium, a small gasoline engine-driven compressor with a storage tank is used. Other accessory equipment, among other items, will consist of the following:

1. Fuel oil storage tank.
2. Filter or some form of purifier or cleaner for lubricating oil.
3. Cooling water thermometer.
4. Pump to circulate cooling water.
5. Pump to handle fuel oil.
6. Switch-board if electrical energy is generated.
7. Muffler for exhaust.
8. In cold climates some arrangement of utilizing waste exhaust-heat to warm building.

One of the accessories requiring special mention is the cooling system. No definite data can be given here concerning the proper cooling water temperature as it depends on the size and design of the engine. The manufacturer's recommendations must be followed. The most satisfactory method is by means of a constant pressure pump, as compared to a valve operated from a water main or standpipe. Many of the small to moderately sized engines are now built with a radiator and fan similar to the ordinary automobile engine. This insures a good temperature control, especially where only intermittent attention is given to the engine.

Diesel engines are equipped with replaceable liners for the cylinders. When the output of the engine is seriously reduced, because of cylinder wear, the liner is quickly and easily replaced. All moving parts are as readily accessible. This ability to replace worn parts, and all machines having moving parts (the Diesel included) eventually loosen up to the point where their economy is affected, contributes to a relatively high resale value. The replacement of cylinder liners, valves, piston rings (in extreme cases, pistons), bearings, etc., can be done at a comparatively small outlay considering the first cost of the machine (20 to 40 per cent of original cost with accessories on large to small engines respectively). After such replacements are made, the efficienty and output of the Diesel engine are slightly, if any, less than when new.

Diesel engines are made in either two-stroke or four-stroke cycle.

In the two-stroke cycle, the piston makes two movements, one in both directions to complete the cycle. This type of engine usually has no valves, and therefore none of the cam shafts, lifters, gearing, etc., that usually accompany tappet valves. Naturally, this is a very important feature from the standpoint of maintenance. However, for high speed engines (above 300-400 rpm.) the combusted gases are not satisfactorily removed. The reason for this is as follows: Instead of valves the two-cycle engine has exhaust ports in the cylinders which are uncovered by the piston shortly before it reaches the end of the exhaust stroke. As soon as the ports are uncovered, air at a pressure slightly greater than atmosphere is blown into the cylinders. This air is supposed to sweep out the burned gases. In engines having a speed greater than about 400 rpm., the removal of burned gases is not complete because the piston starts its return stroke before the gases are ejected. The two-cycle engine requires either crank-case compression or a separate compressor to furnish the scavenging air. For the small installations we are considering, the four-stroke cycle for high speed engines is preferable to the two-stroke cycle.

Briefly, the operation of the two-cycle engine is as follows: The two strokes are (1) the admission and compression stroke, and (2) the power and exhaust stroke. When the exhaust ports are closed on the return stroke of the piston the air remaining in the cylinder is compressed. Near the end of the return stroke the fuel oil is injected into the cylinder. Combustion and expansion then take place. The piston is forced downward. When the exhaust ports are uncovered, the cleaning air is blown through the cylinder. The compression stroke then begins. From this we see that admission and compression is done in one stroke, and expansion and exhaustion in one stroke. Hence, the name, two-stroke cycle. The outstanding advantage is the lack of valve trouble and maintenance. One complete revolution of the crank shaft is made during the cycle. In some makes of engines, valves are used to admit scavenging air.

In the four-stroke cycle engine, four strokes or two complete revolutions of the crank-shaft are necessary to complete the cycle. Intake and exhaust valves are necessary. They are located in the engine head. Scavenging air is not used, except in special cases where the sea level rating of the engine is desired at high altitudes (over 2000-3000 ft.). The four-strokes of the cycle are as follows: (1) Admission stroke; air at atmospheric pressure is drawn into the cylinder; (2) the compression stroke in which the admitted air is compressed, thus furnishing heat for the later ignition of the oil; (3) power stroke, the piston being repelled back from the compression stroke; and (4) the exhaust stroke, in which the piston returns from the power stroke, expelling the spent gases. Strokes one and two are accomplished in one revolution of the crank-shaft, and strokes three and four by one revolution of the crank-shaft. Thus, we have two complete revolutions of the crank-shaft to give the four-stroke cycle.

The development in recent years seems to be toward the two-stroke cycle (two cycle), airless (solid), injection engine. A better structural balance in the engine parts is claimed and fewer parts that cause trouble through wear and adjustment (valves, gears, etc.) are found in the two-cycle engine. Crank-case compression of air for scavenging has apparently been developed to practically a trouble-free point. As before mentioned, the two-cycle engine does not satisfactorily remove burned gases at speeds higher than 400 rpm.

From the standpoint of compression pressure, Diesels may be considered as full Diesels or simply Diesels; and as semi-Diesels. The full Diesel compresses the air to a pressure of 450-600 pounds per square inch with a temperature of 900-1400 degrees Fahrenheit. The exhaust temperature, after passing the exhaust valve, is 400 to 750 degrees Fahrenheit. Either air injection or solid (also known as airless and mechanical) injection is used. In the air injection type, the fuel oil is forced into the cylinder by means of air compressed to a pressure of about 1000 pounds per square inch. In the solid injection engine, the oil is forced into the cylinder through an atomizer by means of a fuel pump exerting a pressure of over 4000 pounds per square inch. The solid injection method appears to be rapidly superseding the other. About 6 to 8 per cent of the engine's rating is required to operate the 3-stage air compressor needed in the air injection engine.

The semi-Diesel operates at a considerably lower pressure (in the neighborhood of 300 lb. per sq. in.) than the full Diesel. These engines are sometimes erroneously known as solid injection engines. (Solid injection is not an exclusive feature of the semi-Diesel).

From the economy standpoint, the semi-Diesel consumes more fuel oil per Bhp.-hr. (at least 0.22 lb.) than the Diesel. 1/ The lubricating oil consumption is much higher 2/ (about 600 Bhp.-hr. per gallon as against about 3000 for the Diesel).

Morrison 3/ states that the semi-Diesel is more economical in 100 horsepower sizes or less when the capacity-use factor is less than 70 per cent. That is, the engine should operate 70 per cent of the time fully loaded or 70 per cent loaded 100 per cent of the time based on a 10-hour day. Above 100 horsepower, the capacity-use factor should be 50 per cent. The first cost of the semi-Diesel is considerably less than the Diesel. Because of its lower compression pressure, it need not be built nearly as strong and massive. From a transportation standpoint, this is of importance because it means a reduction in weight.

The following table 4/ gives some idea of the comparative use of the semi-Diesel, the Diesel, and the gasoline engine, for mining purposes:

Horsepower class	Diesel, per cent	Semi-Diesel, per cent	Total Diesel and semi-Diesel, per cent	Gasoline, per cent
1 - 25	2.38	11.90	5.48	32.50
25 - 50	3.34	17.80	8.05	48.75
50 - 100	12.86	26.75	17.35	6.25
100 - 200	21.40	25.72	22.80	11.75
200 - 300	21.40	9.90	17.68	0.25
300 - 400	9.05	7.93	8.69	-----
400 - 500	5.26	----	3.54	0.50
500 - 600	2.86	----	1.93	-----
600 - 1000	6.20	----	4.18	-----
1000 - and up (a)	15.25	----	10.30	-----

(a) Includes Phelps Dodge Corp., and Commerce Mining & Royalty Co. among others.

1/ Morrison, L. H., Diesel Engine, 1st Ed., p. 63, McGraw-Hill Book Co.

2/ Idem

3/ Idem

4/ Hubbell, A. H., Internal-Combustion Engines in the Mining Industry: Eng. & Min. Jour., p. 266, March 23, 1931. Expressed in percentage of total number of units (engines) in each classification.

As has been stated, the use of the solid injection engine is rapidly replacing the air injection. From the standpoint of fuel consumption, there is very little, if any, difference between it and the air injection (if anything, it is superior to air injection). For the size of engine we are considering, the solid injection engine is undoubtedly better suited. It is much lighter (air compressor for charging air is not necessary), has fewer moving parts to keep in order, and the first cost is less. In over-all efficiency, the air injection engine is less than the solid injection.

Fuel Oil

For satisfactory operation, a good grade of fuel oil should be used. The engine manufacturer's rating is usually based on a fuel oil having a heat value of 19,000 Btu. per pound.

The following table gives a typical analysis of the Standard Oil Company of California, Standard Diesel Oil 27 plus. It is well within the limits recommended by the American Society for Testing Materials in their publication "Diesel-Fuel-Oil Classification" (1934).

Gravity, A.P.I.	27 plus
Specific gravity at 60°F.	0.8927 (Minimum)
Pounds per gallon	7.434 (Minimum)
Flash point (Pensky Martens)	150-200°F.
Fiscosity at 100°F. (Saybolt-Universal)	40-45 seconds
Power point	0°F. (Maximum)
Water and sediment	0.10% (Maximum)
Conradson carbon residue	0.15% (Maximum)
Distillation temperature	
10% point	475°F. (Maximum)
90% point	685°F. (Maximum)
Btu. per pound	19,000 plus

The marketing guarantee on this oil is that its A.P.I. gravity at 60°F will never be lower than 27°.

Lubricating Oil

The use of a high grade lubricating oil cannot be too highly emphasized. Maintenance and trouble-free operation depends to a very large extent on successful lubrication. The lubrication of the Diesel presents no more difficulty than other types of prime movers.

It is beyond the scope of this pamphlet to undertake a discussion of Diesel lubrication. It is sufficient to stress the point that the best grade of oil recommended by the established oil companies be used. The use of an oil filter or purifier will do much towards lowering lubricating oil costs.

Capacity Factor

Ordinarily, an engine should be so selected that it will operate at slightly below the manufacturer's continuous full load rating. This permits momentary overloads without undue injury to, or stalling of, the engine. In the selection of an engine for mining purposes, it is probably better to base the selection on approximately its three-quarter load rating (75-80 per cent).

The reason for this is the difficulty in choosing exactly the right size of mining and concentrating equipment to handle a given tonnage. The nature of underground conditions and ore and waste (hard, soft, wet, sticky, fine, coarse, etc.) contribute to this uncertainty. Some parts of the equipment selected may prove capable of operating at well over their rating. Other parts, because of the physical condition of the material treated, may fall below their rating. An excess of available power would thus permit a better operating adjustment. Also, the starting of hoists and ball mills usually take about 100 per cent overload of their normal running requirements. Some of this may be taken up in the clutch, but the engine must be capable of supplying a large part of the overload.

The fuel oil consumption per Bhp.-hr. of the Diesel is but slightly greater at a three-quarter load than at full load. It is apparent that the excess stand-by power more than compensates for the slight increase in fuel costs.

APPLICATION TO MINING AND CONCENTRATING EQUIPMENT

Diesel engine power can be applied to drive any type of equipment where steam, water, or electrical power may be used. During recent years it has been adapted to power shovels, drag-lines, excavators, dredges, trains, ships, etc., where formerly steam or electricity were used exclusively. The development of suitable clutches, chain, gear-drives, and Texrope drives, have furthered the applications. Belt-drive and direct connection to the crank-shaft are very common and much used. The development of relatively high speed engines (formerly the speed was in the neighborhood of 80-400 rpm.; engines may now be had with a speed in excess of 2000 rpm., and for units of 200hp. or less, 1200 rpm. is not unusual) has probably contributed to their application to both direct and indirect drives.

Practically any sort of machine usually found applicable to the mineral industry, with the exception of underground equipment (such as pumps and fans), may be driven by Diesel engines without the medium of a generator.

The connection to the engine may be direct (clutch or coupling to crank-shaft) or indirect (belt and pulley, gears, chain and sprocket, Texrope, with or without clutch). Equipment such as hoists and ball mills, because of their overload requirement, should be connected through a clutch. Crushers, because of their liability to plugging up (large pieces of ore or waste, hammer heads, picks, drill steel, etc.) should be belt or Texrope connected. Slippage of the belt will prevent damage to crusher or engine. This also would apply to rolls. Line shafting for operating machine shop, drill sharpening equipment, or the odds and ends of small apparatus around the mine or mill may be easily rigged up.

Figure 1 gives sketches of the possible application of the Diesel engine to mining and crushing machinery. They are as follows:

a. Diesel engine
b. Flywheel
c. Friction clutch
d. Exciter for generator
1. Chain drive for ball mill
2. Belt drive for reciprocating pump (the inclusion of a clutch is recommended)

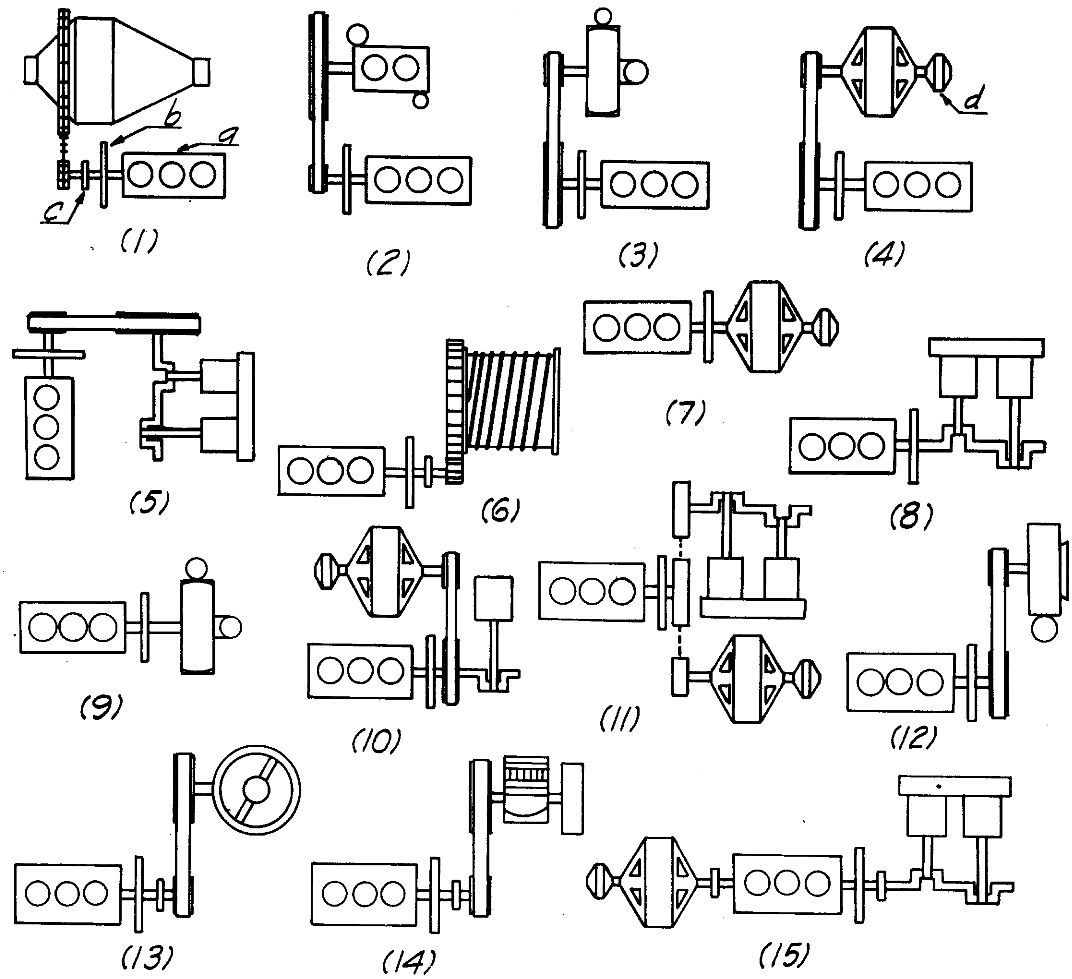

Figure 1

3. Belt drive for centrifugal pump (the inclusion of a clutch is recommended)
4. Belt drive for generator
5. Belt drive for 2-stage compressor (or single-stage compressor) (the inclusion of a clutch is recommended)
6. Gear drive for hoist drum
7. Direct connection to generator (exciter sometimes belt connection)
8. Direct connection to compressor (the inclusion of a clutch is recommended)
9. Direct connection to centrifugal pump (the inclusion of a clutch is recommended)
10. Direct connection to compressor and belted to generator
11. Dual operations, either generator or compressor by simply changing belt
12. Belt connection to ventilating fan.
13. Belt connection to gyratory crusher.
14. Belt connection to jaw crusher
15. Direct connection to generator and compressor
16. Belt connection to ball mill (not especially recommended) (not shown)
17. Direct connection to hoist, through clutch (not shown)
18. Belted to line shafting (not shown)
19. Texrope drive to any of above (not shown)

It should be mentioned that direct connection to the crank-shaft of the engine can be made only when the driven machine operates at the same revolutions per minute as the engine. Most mining and concentrating equipment operates at relatively slow speeds. In the case of electric generators, the higher their speed the lower their cost. Centrifugal pumps, depending on their size and capacity operate at high speeds (1000-2000 rpm.) and will usually, therefore, have to be indirectly connected.

In selecting the type of drive, the loss in efficiency between the Diesel crank-shaft and the shaft of the driven equipment must not be overlooked. For estimating purposes, the following figures are within safe limits:

Belt connected. It is customary to assume a loss of about 10 per cent between the engine and the driven pulley when belting is used. The speed, load, length of belt, and use of belt tighteners must, of course, be considered. The figure given is probably the maximum.

Gear drive. A loss of 5 per cent for each reduction or increase is safe for gearing. Thus, if two changes in speed (necessitates three gears) were desired, a loss of 10 per cent would be assumed.

Chain drive. Same figure as for gear drives is used.

Texrope drive. Somewhat less than for gears.

Direct connection. The consideration of loss of power when the engine is directly connected is necessary only in the case of a generator. The loss here is not entirely a mechanical one, but is mostly a generator (electrical) loss. For most generators (with the exception of very small ones) an efficiency of 90 per cent is a safe figure. (This is slightly excessive, but is on the safe side). For other directly connected equipment (fans, pumps, compressors, crushers, etc.,), the manufacturer's efficiency for the machine must be used. It is difficult to generalize on these figures because they vary with the size and capacity. With the exception of pumps and fans, a loss of 15 per cent will usually be sufficient for estimating purposes. Centrifugal pumps range from about 60 per cent to over 90 per cent in efficiency, depending on their size. The larger the pump, the higher its efficiency.

The use of efficiencies will be illustrated later.

SELECTION OF EQUIPMENT

Effect of Altitude

The manufacturer's rating (in brake horsepower) is given for sea level conditions. Because, with increasing altitudes above sea level, the density (weight per cu. ft.) of air decreases, the oxygen available for combustion decreases. This means that less oil is burned and consequently there is a loss in power. This decrease in the sea level rating is about 3 per cent for each 1000 feet above sea level. A similar loss occurs for compressor ratings and steam plants. In addition to the effect on combustion, heat radiation (cooling of engine) is lowered, so that the regulation of cooling water and possible overheating of the engine must be closely watched. Figure 2 shows a curve giving the loss in power with an increase in altitude.1/

A loss of power because of altitude may be overcome by providing a scavenging pump which compresses air to slightly above sea level pressure (14.7 lbs. per sq. in.) for the two-cycle engines. For the four-cycle type a compressor furnishes air for the air intake valve. In the past, a number of engines have been equipped to supply compressed air to the cylinders. It is generally thought now that the better way is to increase the engine size rather than equip the plant with auxiliary compressors, etc.

SELECTION OF POWER PLANT FOR A SMALL MINE AND MILL

To illustrate the selection of Diesel power for small scale mining, the following example will be investigated:

KNOWN REQUIREMENTS

1. Elevation of mine above sea level . . . . 4000 ft.
2. Ore to be hoisted per day . . . . 50 tons.
3. Waste to be hoisted per day . . . . 25 tons.

1/ Morrison, L. H., Ibid, p. 537.

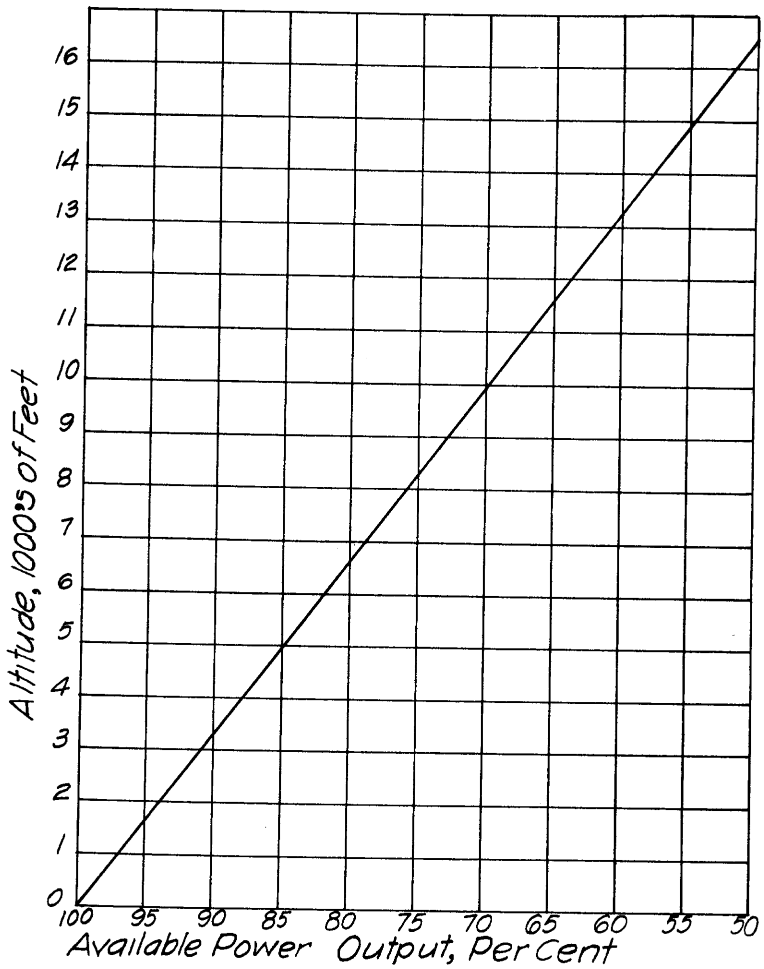

Figure 2

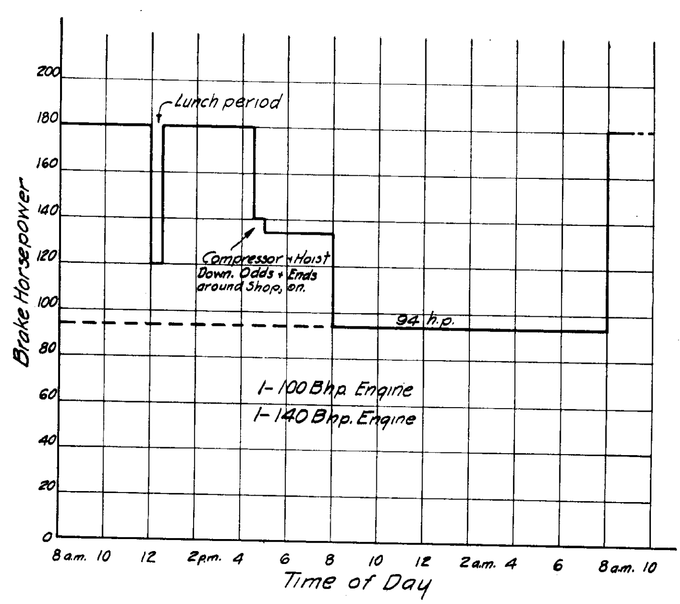

Figure 3

4. Shifts that mine operates per day . . . . 1 shift of 8 hr.
5. Shifts mill operates per day. 3
6. Days worked per year 300
7. Tonnage treated by mill per 24 hours 50
8. Life of mine (for purpose of redeeming power plant investment) . . . . 10 years
9. Type of driving power for equipment . . . . . Electric motors
10. Rated (motor) horsepower of equipment
    A. Mine
        a) Hoist . . . . 15 hp.
        b) Compressor - two-stage . . . . 50 hp.
        c) Lights, machine shop, etc. . . . . . . 20 hp.
    B. Mill
        a) Crusher . . . . 15 hp.
        b) Rolls . . . . 25 hp.
        c) Ball mill . . . . 50 hp.
        d) Flotation . . . . 12 hp.
        e) Classifier . . . . 2 hp.
        f) Filter . . . . 5 hp.
        g) Lights, etc., ... 25 hp.

DESIRED

1. Horsepower of Diesel engine or engines
2. Probable cost
    a) Per brake horsepower-hour
    b) Per kilowatt-hour.

To arrive at the plant-horsepower required, the known data is listed in the following table. This shows at just what time of day it is desirable for each piece of equipment to be operated.

Time at which equipment is running

Period

Equipment	8 A.M.	9	10	11	12	1 P.M.	2	3	4	5	6	7	8	9	10	11	12	1 A.M.	2	3	4	5	6	7
	Horsepower required																							
Hoist	15	15	15	15	15	15	15	15	15															
Compressor	50	50	50	50	50	50	50	50	50															
Lights, etc.	20	20	20	20	20	20	20	20	20															
Total mine	85	85	85	85	85	85	85	85	85															
Crushers										15	15	15												
Rolls										25	25	25												
Ball Mill	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Flotation	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Classifier	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Filter	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Lights, etc.	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Total mill	94	94	94	94	94	94	94	94	94	134	134	134	94	94	94	94	94	94	94	94	94	94	94	94
Grand total	179	179	179	179	179	179	179	179	179	134	134	134	94	94	94	94	94	94	94	94	94	94	94	94

It will be seen from the above table that, if the coarse crushing is done after the mine shuts down (after 4 p.m.), the maximum power required will not exceed about 180 hp. If, for any reason, it is necessary that the mine work two shifts, the crushing can be done after 1 A.M. so the same power balance can be maintained. From this tabulation it is indicated that two engines would be desirable, one supplying about 85 motor-horsepower, the other about 100 motor-horsepower (the 85 hp. engine will operate when crushing is being done, thus supplying the 134 motor-horsepower requirement). The total required is 179 motor-horsepower.

This may be split between two engines of 80 horsepower and 100 horsepower. The question may be raised that the 80 horsepower engine would not handle the mine load alone if the larger engine were not running (in other words, if the mill were shut down). In answer to such a question, it may be said that if the mill were down, it would be very unlikely that the compressor would maintain full load rating as constantly, because less drilling would be done; also, a hoist does not draw continuously its full rating. Other mine equipment would operate at correspondingly reduced capacity. However, in case the mine did operate at maximum output, the larger engine could be run instead of the smaller one. It would operate at about three-quarters load. Its efficiency and oil consumption would differ but slightly from the smaller engine.

The horsepower of the engines selected is the motor-horsepower. That is, it is the manufacturer's rating on the name plates. This rating must be converted to brake horsepower. As the generated power is to be electrical energy, the generators will be directly connected to the engine's crank-shafts. The efficiency is 90 per cent.

Bhp. = 80 ÷ 90 per cent = 90 hp.
= 100 ÷ 90 per cent = 111 hp.

From Figure 2 the altitude equivalent of the sea level rating is 87 per cent. The brake horsepower must be increased as follows:

90 ÷ 87 per cent = 103 hp.
111 ÷ 87 per cent = 127 hp.

Choosing the nearest engine rating (engine to be based on continuous rating, not normal rating; if manufacturer's rating is for maximum output, select engines on the basis of 50 per cent of engine (maximum) rating), we find that a 100 horsepower engine and a 140 horsepower engine will supply the requirement. This is the full load rating with a maximum overload factor of safety of 25 per cent. This provides for a short period of time (0.5 to 1 hr.),

100 x 125 per cent + 140 x 125 per cent = 300 hp. maximum output.

This will take care of such a contingency as starting the ball mill if crusher and rolls are running when the mine is also operating. Or the 140 horsepower engine will handle the starting of the ball mill if the concentrating equipment is on.

On the basis of the above engines, the probable cost of generating power will now be determined. Figure 3 shows the duty cycle of the proposed plant.

It will be noted that two shifts could be worked by the mine without increasing the power plant capacity. No allowance is made in the calculation of costs for mine operations being reduced during the lunch hour. This is, to some extent, offset by the fact that the hoist and compressor are held available one-half hour after the shift has ended for blowing out headings, etc. The mill would not shut down during the lunch hour. The rated capacity of the jaw crusher and rolls selected should readily provide for reducing 50 tons in 3 hours. If they do not, no overloading will occur by keeping them on longer. However, storage bins must be provided of such capacity that it will never be necessary to crush when the mine is operating, if the rest of the mill is running.

Probable Operating Cost of Engine Selected

In making the following estimation, two items entering into the cost can not be determined with any degree of accuracy. They are the transportation costs of the fuel oil and equipment from the railhead to the mine, and the cost of constructing the power house if a separate building is provided for the engines. With the engine-horsepower selected, a separate power house would not be absolutely necessary. Extra space in the mill building could be provided. A building of the size required would probably cost in the neighborhood of $1000 to $2000. Its cost will be ignored. Because even a rough estimation of the cost of transporting the oil can not be made, the delivery price at the railhead will be used. The installed cost of the engine and accessories will be taken at $100 per brake horsepower. The actual factory price of the engines will probably not exceed $65 per Bhp. with accessories. The extra $35.00 should take care of transportation, installation, generating, equipment, etc.

Probable Operating Cost

Total horsepower installed = 100 + 140 = 240
Operating time = 300 days per year

Fuel oil at 8¢ per gallon - - - - - - - - - - - -	$7216.00
Lubricating oil at 50¢ per gallon - - - - - - - -	225.00
Labor -	4500.00
Maintenance - 2% at 65% of installed cost - - -	312.00
Fixed charges 16.95% - - - - - - - - - - - - - - -	4068.00
Total operating cost - - - -	$16321.00

Bhp.-hr. output at 64.7% annual capacity - - - -	1,353,000
Kwh. output at 64.7% annual capacity- - - - - - -	1,009,338
Total cost per Bhp.-hr. - - - - - - - - - - - - - -	$0.01206
Total cost per Kwh. - - - - - - - - - - - - - - - -	0.01617
Cost without fixed charges per Bhp.-hr. - - - - - -	0.00906
Cost without fixed charges per Kwh. - - - - - - - -	0.01213
Fuel and lubricating oil charges per Bhp.-hr. - -	0.0055
Fuel and lubricating oil charges per Kwh. - - - -	0.0073
Bhp.-hr. per gallon of fuel oil - - - - - - - - - -	15.0
Kwh. per gallon of fuel oil - - - - - - - - - - - -	11.2

The various items in the above table were arrived at in the following manner:

Fuel oil. The total brake horsepower-hours generated is found as follows:

Bhp.-hr. = 100 hp. x 11.5 hr. x 300 days + 140 hp. x 24 hr. x 300 days
= 345,000 + 1,008,000 = 1,353,000 Bhp.-hr.

This is arrived at on the basis of the 100 hp. engine running 11.5 hours per day, and the 140 hp. engine running 24 hours per day, both 300 days per year.

The fuel oil consumption, using a standard Diesel 27 plus fuel, is taken at 0.50 lb. per Bhp.-hr. Actually it will probably be slightly less than this. The weight of one gallon of fuel oil is taken at 7.5 lbs.

Total gallons consumed per year = 1,353,000 Bhp.-hr. x 0.5 x $\frac{1}{7.5}$
= 90,200 gals.
Cost = 8 cents x 90,200 = $7,216.00.

Lubrication. With a good grade of lubricating oil and an oil filter or purifier, 3000 Bhp.-hr. per gallon is a safe assumption. (Even though one-half this figure were used, the cost per Bhp.-hr. would be but very little greater.)

1,353,000 ÷ 3000 = 451 gal.
451 x 50 cents = $225.50

Labor. Up to 700 hp. one man per shift can easily operate a Diesel plant. No chief engineer (as an extra man) is required for the 240 hp. plant under consideration. One man per shift is more than ample. If the power plant were located close to or in the mill building, it would probably be possible to do without an attendant on the midnight shift and let the mill operator supervise the power plant operations. One man for each shift is assumed in the present example.

Labor cost = 3 shifts at $5.00 x 300 days = $4,500.00.

Maintenance. As stated previously, companies supplying power other than Diesel do not agree with Diesel manufacturers on the use of the yearly 2 per cent maintenance figure. An investigation of some hundreds of operating plants has shown that 2 per cent of the factory cost is ample. 1/ If this were increased to twice or even three times this amount, the total operating cost per brake horsepower-hour would be but slightly increased. Competitive salesmen contend that the maintenance should be based on the plant production (in our case, 1,353,000 Bhp.-hr. per year). Experience has shown that the 2 per cent figure based on factory cost of equipment is sufficient.

1/ Adkins and Bacon: Applications, Economies, and Operation of Modern Diesel Engines; National Engineer, May and June, 1926.

The installed cost of the two engines was assumed at $100 per Bhp. It was also stated that $35.00 of this was allowed to cover cost of accessories other than those included with the engines, transportation, and installation. The factory price is then $65.00 per Bhp.

Total cost of engines with oil tank, switch-board, generator, lubricating oil filter, batteries, etc., installed,

$$= 240 \text{ hp.} \times \$100 = \$24{,}000.$$

Only 65 per cent of this is the factory price.

Maintenance cost = 24,000 x 65% x 2% = $312.00

Fixed charges. The fixed charges will consist of interest on the power plant investment, insurance, taxes, and redemption of the plant investment.

A customary figure for interest on the plant investment is 6 per cent per annum.

Insurance and taxes, for want of a more exact figure, are taken at 1.5 per cent each.

The redemption or amortization of the capital invested in the power plant depends on the life assigned to the equipment. In our case, it depends on the life of the mine. It has been very definitely shown that Diesel engines are good for at least 30 years as there are engines in service that have operated over that period, and are still operating. Their life is undoubtedly much longer. In the case of a mining property. the machinery investment should be written off during the life of the property, if the mine has a shorter life than the equipment. Some allowance probably should be made for the resale value of the Diesels. However, as this value is impossible to determine, it is left out of the calculations. An idea may be had of their resale value when we consider that engines used in the Texas oil fields have been resold in the northwest at about 40 per cent of their original value, and this after they had been in use upwards of 5 years.

In amortizing capital, various interest rates may be obtained. Tables may be had giving such charges over a long period of years at rates as high as 8 per cent compound interest. The following table gives a few such values for interest rates ordinarily obtained, and the life in years commonly assigned to mineral properties.

Very few mines can show at the start of operation an assured life of more than 2 to 5 years. A great many properties start operation with no more than 1 to 2 years of ore blocked out. (Many even less than this.)

Redemption Table

Amount to be set aside each year for redemption of capital outlay, Per cent

Year	Interest Rate			
	3%	4%	5%	6%
1	100.00	100.00	100.00	100.00
2	49.26	49.02	48.78	48.54
3	32.35	32.04	31.72	31.41
4	23.90	23.55	23.20	22.86
5	18.84	18.46	18.10	17.74
10	8.72	8.33	7.95	7.59
15	5.38	4.99	4.63	4.30
20	3.72	3.36	3.02	2.72

It will be seen from the above table that the longer the life of the mine or equipment the less becomes the annual redemption charges and thus the fixed charges. If a definite and assured resale value can be assigned to the equipment, this amount can be deducted from the total costs. The annual fixed charges will in consequence be reduced because the capital investment is less. The per cent to set aside will not be changed.

In the problem under consideration the redemption must take place in 10 years as that is the life of the mine. The interest return on investing the yearly sum set aside is taken at 5 per cent compounded annually. Entering the table at 10 years and 5% interest, we find that the amount to be set aside and invested at 5 per cent is 7.95 per cent of the total power plant investment.

The total interest for the fixed charges is -

7.95 per cent for redemption of capital
6.00 per cent for capital invested
1.50 per cent for taxes
1.50 per cent for insurance
16.95 per cent for fixed charges

If an amount is set aside each year, but not invested, the total interest would be

10.0% + 6.0% + 1.5% + 1.5% = 19 per cent

(A redemption in 10 years means 1/10 of 100 per cent each year. If invested at 5 per cent, the 10 per cent, because of interest earned, is reduced to 7.95 per cent.)

The cost of the power plant = 240 x $100.00 = $24,000.

Fixed charges = $24,000 x 16.95% = $4068.00 yearly

Annual plant output. The annual plant capacity is the per cent of actual operating time compared to maximum possible output.

In one year there are 24 hours x 365 days = 8760 hours.

If a power plant of 240 horsepower operated continuously for one year, there would be produced: 240 hp. x 8760 hrs. = 2,102,400 Bhp.-hr.

The plant actually operates -

100 hp. x 11.5 hr. x 300 days + 140 hp. x 24 hr. x 300 days = 1,353,000 Bhp.-hr.

The annual plant capacity is therefore -

$$\frac{(100 \times 11.5 \times 300 + 140 \times 24 \times 300) \times 100}{(100 + 140) \times 8760} = 64.7 \text{ per cent}$$

The annual output in brake horsepower-hours is -

(100 x 11.5 x 300) + (140 x 24 x 300) = 1,353,000 Bhp.-hr.

Expressed in kilowatt-hours, this becomes -

1,353,000 Bhp.-hr. x 0.746 Kwh. per hp. = 1,009,338 Kwh.

From the cost table, it is found that power may be generated at a probable cost of 1.21 cents per brake horsepower-hour. As stated previously, this does not include fuel oil transportation charges from the railhead to the mine, nor the cost of constructing the building. If we assume the cost of the oil delivered to the mine to be 12 cents per gallon and the cost of constructing the building $1,500.00, the cost per brake horsepower-hour becomes 1.49 cents.

Selection of Diesel Engines to Operate a Ball Mill

Four methods of driving a ball mill are possible:

1. Through a generator and motor.
2. Gear drive.
3. Belt or Tex-rope drive.
4. Chain drive.

The ball mill considered is a 6 ft. x 22 in. mill, grinding about 70 tons per 24 hours, 3/4 in. to 80 mesh. The electric motor recommended is 50 horsepower and the power to run, 45 horsepower. The electrical equipment must be capable of withstanding a 100 per cent momentary overload. This means that for starting, a 50 horsepower motor capable of supplying 100 horsepower for a short period is necessary, with a generator having a minimum rating of 100 horsepower to supply the energy. The motor would be connected to the ball mill through gears. One reduction is necessary if a motor speed of about 300 revolutions per minute is used. No allowance for the motor efficiency is made because it is assumed that the mill manufacturer took this into consideration when he recommended a 50 horsepower motor. The generator would be directly connected to the Diesel engine. Its efficiency is 90 per cent.

If the recommended motor rating is expressed in kilowatts, we have -

$$50 \times 0.746 = 47.3 \text{ kw.}$$

The generator rating will be -

$$47.3 \div 90\% = 54 \text{ kw.}$$

The generator must be capable of supplying a 100 per cent overload. The minimum generator rating is

$$2 \times 54 = 108 \text{ kw.}$$

This converted to horsepower becomes -

$$108 \div 0.746 = 145 \text{ Bhp.}$$

This can represent the maximum horsepower obtainable from the engines. Its rated continuous horsepower will be about 25 per cent lower.

Bhp. of engine necessary = 145 x 75 per cent = 109 or 110 hp.

The nearest commercial size to this is apt to be 100 or 120 hp. The exciter for the generator will require about 6 - 7 horsepower. This makes the total 110 + 7 = 117 hp. The 120 horsepower engine would be needed. It will require a 110 kilowatt generator. The power required to run the ball mill is 45 horsepower, or 45 x 0.746 = 34 kilowatt. The engine will operate at $\frac{34 \times 100}{(120-7) \text{ hp.} \times 0.746} = 40.3\%$ of rated full load value. The other 59.7 per cent would be available for other equipment.

Gear drive. To run the mill, after starting, 45 horsepower are necessary. The efficiency of single reduction gearing is 95%. There would be required at the pinion gear, 45 ÷ 95% = 47.4 horsepower.

Considering this as the three-fourths load rating of the required engine, a 4/3 x 47.4 = 63 horsepower, or 60 horsepower engine is necessary. For momentary overload, the 60 horsepower Diesel will supply 72 horsepower for its maximum rating. (This applies only to those engines where the engine is given a rated horsepower and not the maximum horsepower). The power to start the mill is about 2 x 47 = 94 horsepower. That available from the Diesel is 72 horsepower. This leaves 94 - 72 = 22 horsepower to be obtained elsewhere. A friction clutch will handle the load.

Belt drive. The same procedure for the gear drive is followed, with the exception that the belt efficiency will be about 90 per cent instead of the 95 per cent for the gear.

$$45 \div 90 = 50 \text{ hp.}$$
$$4/3 \times 50 = 67 \text{ hp.}$$

The nearest rating would probably be 80 horsepower. With a 25 per cent overload capacity, it would be suitable.

Chain drive. The calculations for chain drive are identical with the gear drive. Its only advantage is less noise.

From the above calculations, we see that where only one machine is to be operated, gear or chain, or even belt drive so far as first cost goes, is much cheaper than the motor-generator-Diesel method.

COSTS

We are interested in the cost of a Diesel installation from two viewpoints: (1) Cost of engines and accessories; (2) operating costs.

Engines. The following tables give data on various sizes and makes of engines. The cost is f.o.b. the factory and includes accessories sufficient for their operation unless otherwise stated.

FAIRBANKS, MORSE AND CO.

Model 36 (a)

Data	Number of cylinders				
	1	2	3	4	6
Bhp. (normal) (b)	10	20	30	40	60
Bhp. (continuous)	20 per cent less than normal rating				
Rpm.	1200	1200	1200	1200	1200
Weight (approx.) lbs.	1000	1600	1900	2300	3000
Cycles	4	4	4	4	4
Injection	Solid	Solid	Solid	Solid	Solid
Starting	handcrank	handcrank or battery	battery	battery	battery
Fuel consumption	0.48	0.48	0.48	0.48	0.48
Cost (c)	$600.00	$800.00	$1000.00	$1500.00	$2000.00

(a) Obtainable also in 20 hp. per cylinder units, 4, 6, and 8 cylinders.
(b) Maximum Bhp. better than 25 per cent greater than rating shown.
(c) Approximate.

Model 32-E (12" x 15" engine)

Bhp. (continuous)	55	110	165
Rpm.	360	360	360
Weight, lb.	12,600	18,200	22,300
Cycles	2	2	2
Injection	solid	solid	solid
Starting	compressed air	compressed air	compressed air
Fuel consumption	0.40	0.40	0.40
Cost	$65.00 per hp.	$65.00 per hp.	$65.00 per hp.

Model 32-E (14" x 17" engine)

Data	Number of cylinders		
	1	2	3
Rhp. (continuous)	70	140	210
Rpm.	300	300	300
Weight, lb.	16,700	25,400	35,200
Cycles	2	2	2
Injection	solid	solid	solid
Starting	compressed air	compressed air	compressed air
Fuel consumption	0.38	0.38	0.38
Cost	$65 per hp.	$65 per hp.	$65 per hp.

INGERSOLL-RAND CO.

Data	Number of cylinders
	3
Bhp.	175
Rpm.	360
Weight, total, lb.	24,500
Heaviest piece	6,200
Cycles	4
Injection	solid
Starting	compressed air
Fuel consumption	0.425 to 0.46
Cost (a)	$71.00 per hp.
Generator size, 0.8 p.f.	100 kw.

(a) Includes everything except driven equipment

NORDBERG MFG. CO.

Data	Number of cylinders	
	3	4
Bhp.	150	200
Rpm.	400	400
Weight (shipping) lb.	20,000	24,000
Cycles	4	4
Injection	solid	solid
Starting	compressed air	compressed air
Fuel consumption	0.40 - 0.44	
Cost (engine) (a)	$65.00 per hp.	$65.00 per hp.
Cost (generator & exciter, (AC)	$2500.00	$2800.00

(a) Includes starting compressor in addition to other necessary auxiliaries.

CHICAGO PNEUMATIC TOOL CO.

Data		
Bhp.	150	200
Rpm.	---	---
Weight, total, lb.	17,000	20,000
Heaviest piece	4,000	4,000
Cycles	4	4
Injection	solid	solid
Starting	compressed air	compressed air
Fuel consumption	0.39 - 0.43	
Cost [a]	$100 per hp.	$100 per hp.
Generator capacity:		
Direct connected	103 kw.	137.5 kw.
Belt connected	101 kw.	135 kw.

(a) Complete cost of power plant, engines, etc.

WAUKESHA MOTOR CO. [a]

Data	Model					
	XBKHU	VBKH	HAHU	HLHU	WFHU	6ELHU
Net hp.	46	69	50	73	95	160
Rpm. at net hp.	2400	2000	1250	1250	1050	1200
Hp. continuous duty	38	55	38	55	75	130
Speed continuous duty	1400	1200	1050	1050	950	1000
Wt. with power take off	715	915	3000	3025	4870	7120
Ignition [b]	Magneto	Magneto	Magneto	Magneto	Magneto	Magneto
Starting [c]	---	---	---	---	---	---
Cost	$884	$1313.50	$1795	$2035	$3132	$4657

(a) These engines are moderately high compression. Require electrical ignition (spark plugs) for igniting fuel. Any standard distilled fuel oil, suitable for solid injection Diesel engines is satisfactory. The fuel limit on the Centene scale is 75 to 0.

(b) Fuel consumption between 0.50 and 0.58 lb. per Bhp.-hr., depending on loading.

(c) Handcranking, battery, or small gasoline engine.

HERCULES MOTORS CORP.[a]

Data	Model	
	DRXB	DHXB
Peak load hp.	104	160
Speed, peak load	1600	1600
Continuous hp.	80	120
Speed continuous hp.	1200	1200
Cycles	4	4
Injection	solid	solid
Starting	battery	battery
Weight (about)	1430	2300
Fuel consumption	0.40 - 0.48	0.38 - 0.44
Cost	----	----

(a) These are automotive engines. They may be mounted on bases for stationary work.

Operating costs. The preliminary Report on Oil-Engine Power Cost for 1933 1/ contains information on 156 oil-engine generating plants, containing 398 engines, totaling 216,010.5 rated Bhp. The data included in the report covers lubricating oil economy, fuel economy, itemized costs and total costs, and comparative costs for 1929, 1930, 1931, 1932, 1933. The total installed Bhp. of the plants investigated varies from 100 Bhp. to 15,640 Bhp. The fuel oil cost per gallon varies from a little less than 2 cents to slightly over 6 cents. Lubricating oil varies over a wide range.

The following table reproduces, in part, data from the above report. Only plant sizes approaching those discussed in this pamphlet are given. Attention is called to the fact that with the exception of three plants the engine repair cost is almost negligible compared to the total cost. Also the attendance cost in most cases is considerably more than would be expected for small scale mining installations.

1/ Submitted by the Subcommittee on Oil-Engine Power Cost, Oil and Gas Power Division, A.S.M.E.

Power Plant Costs

Plant No.	Bhp.	Capacity factor %	Cost of fuel oil ¢ per gal	Cost of lub. oil ¢ per gal	Cost per net. kwh.-mills						
					Fuel oil	Lub. oil	Attendance	Water supply	Engine Repairs	Plant repairs	Total
382-I	300	27.2	3.64	37.5	3.63	0.50	3.73	0.19	0.02	0	8.07
858-U	270	26.7	3.12	46.4	7.17	3.13	16.40	3.81	6.85	1.00	38.36
169-I	240	28.8	4.50	50.8	6.34	1.13	4.52	0.98	8.74		21.71
677-I	240	74.1	4.61	41.7	3.95	1.19	1.43	0.36	0.95	0	7.88
591-U	225	66.8	3.43	50.1	3.99	0.93	3.60	0.16	0.23	0.21	9.12
984-U	225	48.5	4.29	45.7	5.07	0.60	5.59	0.75	0.82	0.19	13.02
318-M	$212\frac{1}{2}$	----	3.69	53.2	6.81	2.37	13.43	2.00	0.34	1.20	26.15
1193-MW	200	64.0	5.00	42.9	6.24	0.64	2.74	----	0.26	----	10.59
733-U	175	53.2	6.03	50.0	16.00	3.17	38.34	20.20	0	37.2	114.91
646-M	120	11.1	5.39	55.5	14.62	4.34	21.92	12.87	9.91	8.55	72.71
1201-M	100	----	6.36	65.4	15.52	6.22	39.85	3.60	0.18	0	65.37

I = Industrial power plant

U = Private power company

M = Municipal power plant

W = Municipal pumping plant

Cost of Fuel and Lubricating Oil in Idaho

Costs delivered to a few localities in Idaho and Washington are given in the following tables. They are quoted for December 28, 1934, and are subject to change without notice. These products are produced by Standard Oil Company of California.

Cost of Standard Diesel Oil - 27 plus

Into buyer's tank trucks at Standard Oil Company plants:

Walla Walla, Washington	$0.065 per gal.
Spokane, Washington	0.07 per gal.
Craigmont, Idaho	0.08 per gal.
Boise, Idaho	0.0925 per gal.

Into tank cars at Standard Oil Company plants:

Point Wells (Richmond Beach, Washington)	0.04 per gal.
Willbridge (Portland, Oregon)	0.04 per gal.

Cost of Lubricating Oils

Price per gallon in returnable steel barrels

	Spokane	Walla Walla	Craigmont	Boise
Calol Diesel engine oil	$ 0.44½	$ 0.45	$ 0.50	$0.47
Calol Diesel engine oil (heavy)	0.44½	0.45	0.50	0.47
Calol compressor oil	0.48½	0.49	0.54	0.51

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