

**PETROLEUM DIESEL ENGINE  
SELECTION, RATINGS &  
CONFIGURATIONS**

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## Foreword

This section of the Application and Installation Guide generally describes Petroleum Diesel Engine Selection, Ratings and Configurations for Caterpillar® engines listed on the cover of this section. Additional engine systems, components and dynamics are addressed in other sections of this Application and Installation Guide.

Engine-specific information and data are available from a variety of sources. Refer to the Introduction section of this guide for additional references.

Systems and components described in this guide may not be available or applicable for every engine.

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# Petroleum Diesel Engine Selection, Ratings & Configurations

The various petroleum applications of Caterpillar engines require specific considerations for engine selection to ensure dependable performance and a long, trouble-free life. This guide may be used as a checklist of these specific considerations for engine selection. Referring to this guide during preliminary planning will reduce the possibility of after-installation changes.

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## Engine Configuration

### Load Analysis

A major concern in applying petroleum engines is proper application of engine horsepower to obtain desired performance, economic operation, and satisfactory engine life. Successful application of petroleum engines requires understanding of power requirements, how engines are rated, applicable emissions requirements, and knowledge of the proper selection and use of these ratings.

### Power Demand Based on Practical Experience

If the power demand of the proposed equipment is not already known, it must be analyzed. This process can be simplified if experience is available with similar equipment that is powered by an engine of known rating and fuel rate performance. This information shows whether the existing equipment is underpowered, correctly powered or overpowered. This assessment can serve as a starting point for the new installation; however, it is not a substitute for calculated horsepower demand.

### Calculated Horsepower Demand

Using basic engineering principles on work, energy and data on the type of task to be accomplished, it is possible to convert all functions of an application to torque demand and then to power demand. Calculation may be the only way available to estimate power requirements at the

start of a new machine design. Of course, this approach is accurate only if all factors are considered and assumptions are correct. For applications such as pumps or other continuous loads, where demand is known quite well, calculated values are quite accurate. In other applications, actual demand can differ significantly.

### Engine Measured Power Demand

Usually, the most practical way to assess power demand and engine capability is to make a selection based on calculation or comparison with an existing installation and test it. There is no substitute for a rigorous evaluation of an engine in service and operating equipment similar to the proposed application. This provides final proof of machine performance acceptability, or it will identify shortcomings in need of correction.

### Horsepower, Torque & Machine Productivity

Torque, speed and time are the components of horsepower. Understanding the relationship of these components allows them to be leveraged toward an advantage for a particular application.

Horsepower is the time rate of doing work; restated, horsepower is proportional to the product of torque and rpm. Some basic relationships are:

## English units

$$\text{bhp} = \frac{T \times \text{rpm}}{5252}$$

$$T = \frac{5252 \times \text{bhp}}{\text{rpm}}$$

$$1 \text{ hp} = \frac{33,000 \text{ ft-lb}}{\text{min}}$$

Where:

T = Torque, ft-lb

## Metric units

$$\text{bKw} = \frac{T \times \text{rpm}}{9537}$$

$$T = \frac{9537 \times \text{bKw}}{\text{rpm}}$$

$$1 \text{ hp} = \frac{33,000 \text{ ft-lb}}{\text{min}}$$

Where:

T = Torque, N•m

**Torque Rise Effect on Performance**

For equipment capable of lugging the engine (i.e., applying sufficient load to pull the engine speed down below rated speed at full throttle), it is important to consider two other characteristics of engine performance. These are torque rise and response to sudden load change.

Torque Rise % =

$$\frac{(\text{Peak Torque}) - (\text{Rated Torque})}{\text{Rated Torque}} \times 100$$

A torque curve is the graphical representation of torque versus speed.

Caterpillar diesel engines used in mechanical drives typically provide high torque rise to perform well in a wide variety of applications.

If torque rise capability is higher than necessary, the machine driveline may be subjected to torque levels which may shorten the life of gearing and bearings. For this reason, it is sometimes desirable to let the machine operator shift to a lower gear to increase engine speed instead of always lugging the engine without a gear change. So, the decision to use an extra high torque rise engine must also consider driveline capability. By contrast, an engine with insufficient torque rise will seem weak and may even stop running before the operator has time to make a gear change. This is not acceptable either. The best compromise is to use enough torque rise to satisfy machine performance requirements, but not so much that driveline life becomes unacceptable.

Devices such as blowers and centrifugal pumps cannot lug an engine because power demand drops off faster than engine capability as speed is reduced. The amount of torque rise available in these applications is generally meaningless because torque rise is not required, except as it may contribute to the ability to accelerate the load.

Generator sets are constant speed applications and the engines do not need torque rise capability.

### **Transient Response Performance**

The load response characteristics of the engine need to meet the load demands of the driven equipment. This is not only true for steady state loads but also for transient load changes. For applications where the load changes rapidly, proper engine selection is important to ensure the engine's ability to pick up the load while maintaining the desired speed.

An important factor in transient response is the engine air intake system. Naturally aspirated engines use air at atmospheric pressure; the air is not pressurized or forced into the combustion cylinder. The intake air on turbocharged engines is pressurized before entering the combustion cylinder.

A naturally aspirated engine has the fastest response to sudden load increase because the required combustion air is readily available. There is no additional process of compressing the air prior to delivery. However, naturally aspirated engines may not meet the applicable emissions requirements and have lower power density (power to weight ratio) than a turbocharged

There is a momentary lag in the response of a turbocharged or turbocharged and aftercooled engine because it takes a moment for the turbo to accelerate upon load increase.

Progress in turbocharger development has produced smaller, faster responding turbochargers and, therefore, turbocharged engines which respond quickly to sudden load increase. With steady load and

speed, turbocharger response is of no consequence. Air/fuel ratio controllers, also called smoke limiters, momentarily limit fuel delivery until sufficient air is available for combustion. They respond to inlet manifold boost pressure. The proper air/fuel ratio setting provides optimum machine responsiveness and acceptable level of transient smoke for a particular application.

For applications with widely varying cyclic loads (e.g. petroleum jack pumps or sucker rod pumps), care must be taken to match the engine's capability with the load demand. On some applications, the lag due to the turbocharger may not allow the engine to keep pace with the load changes.

### **Adequate Machine Performance**

Manufacturers and customers develop their own ideas of what constitutes adequate machine performance. Insufficient power causes low productivity and user dissatisfaction. Excessive power costs more to purchase, requires heavier drive system components, and may reduce equipment life if the operator is careless. The ideal machine is responsive, productive, and durable, satisfying the owner's need for performance and overall value.

### **Tolerances**

Actual engine power output may vary by up to  $\pm 3\%$  from nameplate value on a new engine. Similarly, where load demand of some work-producing device is published, the manufacturer's tolerance should be

added to the demand power, if power needs are to be met in all cases.

**Auxiliary Loads**

In addition to the engine's main load, allowance must be made for engine-driven auxiliary loads. Extra loads imposed by a cooling fan, alternator, steering pump, air compressor and hydraulic pump may represent a significant proportion of total engine power available.

After establishing main load power demand and adding all auxiliary power demands, some additional power should be allowed for peak loads (such as grades and rough terrain) and reserve for acceleration, where applicable.

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## Engine Ratings

Published engine ratings are representative statements expressing engine power and speed capability under specific loading conditions. It is important to understand the ratings and the methods in which they are determined. Proper use of the ratings will assist in the selection of an engine that meets desired performance, economic operation, and satisfactory engine life.

There are several ratings for each configuration of petroleum engine model.

### Engine Capability Determines Ratings

Horsepower rating capability is determined by engine design. Combined capability and durability of all engine components determine how much horsepower can be produced successfully in a particular application.

### Power Setting Determines Maximum Fuel Rate

Horsepower output of a basic engine model can be varied within its design range by changing the engine fuel setting or speed setting. Both settings affect the engine's maximum fuel rate and, therefore, the horsepower output capability. Thermal and mechanical design limits will not be exceeded if an appropriate engine and rating is selected.

## Caterpillar Petroleum Engine Rating Classifications

Caterpillar ratings are offered in a five tier format:

### Industrial A — Continuous Ratings

- For heavy duty service when engine is operated at rated load and speed up to 100% of the time without interruption or load cycling.
- Time at full load up to 100% of the duty cycle.
- Typical examples are: pipeline pumping, well service mixing units.

### Industrial B — Ratings (Mud Pump Service)

- For service where power and/or speed are cyclic.
- Time at full load not to exceed 80% of the duty cycle.
- Typical examples are: oil field mechanical pumping/drilling, independent rotary drive, well service blenders, cementers.

### Industrial C — Intermittent Ratings (Hoisting Service)

- For service where power and/or speed are cyclic. The horsepower and speed capability of the engine which can be utilized for one uninterrupted hour followed by one hour of operation at or below the Industrial A — Continuous power.
- Time at full load not to exceed 50% of the duty cycle.

- Typical examples are: off-highway truck, fire pump application power, blast hole drills, oil field hoisting, nitrogen pumping, well service kill pumps, cementers, electric drill rig power (also called Prime power).

#### **Industrial D — Ratings**

- For service where rated power is required for periodic overloads. The maximum horsepower and speed capability of the engine can be utilized for a maximum of 30 uninterrupted minutes followed by one hour at Industrial C — Intermittent power.
- Time at full load not to exceed 10% of the duty cycle.
- Typical examples are: offshore cranes, fire pump certification power, coil tubing units, offshore cementer.

#### **Industrial E — Ratings**

- For service where rated power is required for a short time for initial starting or sudden overload. For emergency service where standard power is unavailable. The maximum horsepower and speed capability of the engine can be utilized for a maximum of 15 uninterrupted minutes followed by one hour at "IND C" — Intermittent power or duration of emergency.
- Time at full load not to exceed 5% of the duty cycle.

- Typical examples are: oil field well servicing frac/acid pumping.

**Note:** Applications examples are for reference only. For exact determination or rating tier, refer to the specific application information and guidelines in TMI.

#### **Establishing a Rating**

Some of the application conditions considered by a manufacturer in determining a rating for an application include the following.

- Load Factor
- Duty Cycle
- Annual Operating Hours
- Historical Experience at a Particular Rating Level
- Expected Engine Life to Overhaul.

#### **Rating Validity**

A properly maintained engine in actual use will determine whether a particular rating level is appropriate. Ratings which are validated by acceptable field experience are retained. Continuing engine development results in ongoing engine improvement and some increase in ratings may result from this process.

#### **Engine Design**

Engines are designed and developed to produce specific power levels for particular applications. Subsequent lab and field experience confirms the rating validity. Increasing engine horsepower beyond approved levels to compensate for excessive load is not

acceptable; excessive engine wear or damage can result.

### **Rating Curves**

Consult Technical Marketing Information (TMI) for available ratings at various speeds for each model and configuration. Specification sheets also provide some of this information for preliminary sizing purposes.

### **Special Ratings**

Most engine applications are well understood and utilize one of the above existing published ratings which have been confirmed by thousands of hours of successful experience. However, occasionally, a unique application merits special rating consideration because of unusually low load factor or unusually short life requirements. In this case, consult your engine supplier. Factory application engineers will require that a special rating request data sheet be submitted for review before a special rating can be considered for approval. Emissions certification regulations reduce the feasibility of some special rating requests.

### **Actual Power Output Derives from Load Demand**

Regardless of engine rating (power and speed setting), the actual power developed by an engine is determined by the load imposed by driven equipment. For example, an engine set to produce 500 hp (373 kW) will actually produce only 40 hp (30 kW) if the driven load demands only 40 hp (30 kW). For this reason, average fuel consumption indicates

average load demand. Average fuel consumption also indicates load severity on the engine by comparing it with the rated fuel rate associated with that rating. When this ratio is expressed as a percent, it is called load factor.

### **Diesel Engine Considerations**

On a given engine model, a power range capability is created by providing different engine configurations such as naturally aspirated, turbocharged and turbocharged-aftercooled. Some engines may have the aftercooler cooled with engine jacket water (JWAC). Some engines may have the aftercooler cooled with a separate lower temperature fresh water circuit (SCAC). Some engines may have the aftercooler cooled in an air-to-air cooling device (ATAAC). Emissions requirements many times determine the type of aftercooling used. Internally, these engines may differ significantly.

Naturally aspirated engines generally do not meet emissions regulations.

Increasing power output by injecting more fuel requires additional air for complete combustion and internal cooling. This requires additional mechanical strength of internal components and additional design features such as oil jet cooling for pistons. In any engine, the mass flow of air supplied to each cylinder determines the amount of fuel which can be efficiently burned. The entire engine must be designed for strength and durability at approved power levels.

Turbocharging, using energy from waste exhaust gas, provides an efficient means to increase air flow. The power rating of a turbocharged engine is usually limited by internal temperatures, turbocharger speed and structural limits. Compression of the air by the turbocharger increases air temperature.

An aftercooler between the turbocharger and intake manifold cools the hot compressed air. This increases air density and allows more air to be packed into the cylinder and more fuel to be burned. The rating is typically limited by internal temperature limits, turbocharger speed and structural limits.

Because turbochargers and aftercoolers provide more air to the engine, the engine fuel rate can usually be increased to use this extra combustion air. As a result, engine component loading or turbocharger speed become the limit on rating. Caterpillar diesel engines do not utilize turbochargers or aftercoolers as add-ons; rather, engines are designed and developed in all aspects for these higher loading levels. Then they are tested thoroughly to assure long life and satisfactory performance.

The air-fuel mixture that a naturally aspirated engine can draw into its cylinders is limited by the engine's breathing characteristics and atmospheric conditions. Therefore, an NA engine's load capability will be directly affected by altitude and ambient temperatures.

### **Turbocharging**

Turbocharging is an efficient means of increasing airflow and power output. It also allows the engine to be more tolerant of differences in altitude and ambient temperatures. However, air compression by the turbocharger increases air temperature.

### **Diesel Fuel Heating Value**

Fuel heating value affects the ability to achieve rated power output because fuel is delivered to the engine on a volumetric basis. Allowance should be made for lower heat content fuel (higher API than standard) where the power level is critical.

Fuel rates are based on fuel oil of 35° API {60°F (16°C)} gravity having an LHV of 18,360 Btu/lb (42,780 kJ/kg) when used at 85°F (29°C) and weighing 7.001 lb/U.S. gal (838.9 g/L).

### **Diesel Engine Rating Conditions**

Ratings are based on SAE 1995 standard ambient conditions. Ratings are subject to  $\pm 3\%$  Power Tolerance. Ratings are valid for air cleaner inlet temperatures up to and including 122°F (50°C).

**Note:** Horsepower shown on the performance curve for generator set applications may be slightly below the advertised horsepower to match a generator nominal output.

Engine performance is corrected to inlet air standard conditions of 99 kPa (29.31 in hg) dry barometer and 25°C (77°F) temperature. These values correspond to the standard atmospheric pressure and

temperature as shown in SAE J1995.

Performance measured using a standard fuel with fuel gravity of 35° API having a lower heating value of 42,780 kJ/kg (18,390 Btu/lb) when used at 29°C (84.2°F) where the density is 838.9 G/L (7.001 lb/US gal).

The corrected performance values shown for Caterpillar engines will approximate the values obtained when the observed performance data is corrected to SAE J1995, ISO 3046-2 & 8665 & 2288 & 9249 & 1585, EEC 80/1269 and DIN 70020 standard reference conditions.

### **Altitude Derating**

Each model and rating has established maximum altitude capabilities for lug and non-lug applications. For higher altitude operation, power settings must be reduced approximately 3% per 1000 ft. (305 m) above that rating's

altitude limit. Mechanically controlled diesel engines do not self-derate enough so that the fuel setting can be left unchanged. If they are not reset to appropriate power levels, naturally aspirated engines may smoke badly and turbocharged engines may suffer excessive thermal and mechanical loading, resulting in internal damage without giving external indication of distress. Engine derating curves are contained in the TMI.

### **Life Related to Load Factor**

Using an oversized engine contributes to longer engine life because it runs at a lower overall load factor. It also provides quicker response to sudden load changes. Load factor is the ratio of average fuel rate to the maximum fuel rate the engine can deliver when set at a rating appropriate for a particular application. This value is expressed as a percent.

## Diesel Engine Fuel Conservation

Rapidly increasing fuel prices coupled with decreasing fuel availability is receiving increased attention by contractors and oil companies.

Methods to reduce fuel consumption are under three sections:

- General Conservation Practices
- Minimizing Prime Mover Fuel Consumption
- Modifying Drilling Practices/Machinery to Reduce Prime Mover Fuel Consumption

### General Information

The amount of flywheel kilowatts (horsepower) produced by burning a liter (gallon) of diesel fuel depends on engine type, condition, and loading. If an engine is operated at more than half load, a liter (gallon) of diesel fuel can produce approximately 3.3–4 kW•h/l (17–20 hp-h/gal). In contrast, the same engine lightly loaded will only produce approximately 2.7–3.6 kW•h/L (14–18 hp-h/gal) or much less if operating at no load.

Engine fuel consumption data is stated as:

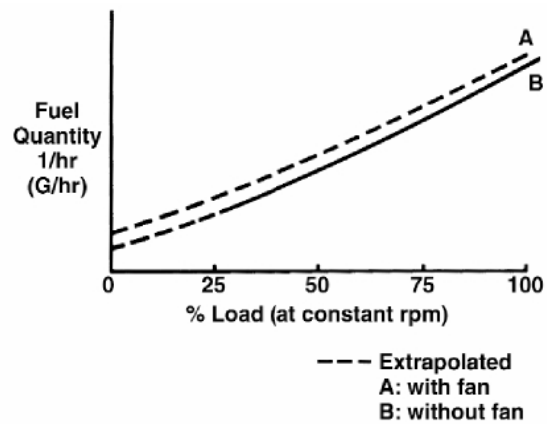
“Fuel quantity consumption per hour at various loads. This is expressed in L/h or gal/h.”

The engine burns fuel at no load due to the internal demands of water and oil pumps, friction losses, other mechanical devices, etc.

This accounts for a major part of the slope in B curve, **Figure 1**. These internal losses become a smaller portion of the total as the engine is loaded. Thus, the engine is more efficient.

Curve A, **Figure 1**, adds the power required to operate the radiator fan. It is not normally included in the engine’s fuel curve due to the wide selection of radiators used in the oil field.

Note that a radiator fan that takes 5% of the engine fuel consumption to drive at full load may take 16% of the engine fuel consumption at 20% load. The percentage would be much higher at no load.



**Figure 1**

### General Conservation Practices

Fuel will be saved by converting small diesel engine-driven auxiliaries, such as mud mix pumps, superchargers, etc., to electric motor-driven units. As an engine-driven device, these auxiliaries are the only load on that particular engine. Thus, when at light load,

fuel consumption per flywheel kilowatt (horsepower) delivered is high.

On rigs that require winterizing, engine exhaust and jacket water heat can be recovered and reduce boiler fuel consumption.

Take measures to prevent theft of fuel. Eliminate spillage and leakage losses.

Turn off auxiliary loads when not needed. Operation of unneeded auxiliary loads may represent up to 5-10% of total rig load.

### Minimizing Diesel Prime Mover Fuel Consumption

The following items should be considered in regard to prime movers. The secret is to get all the energy out of each drop of fuel and avoid fuel waste due to poor maintenance and adjustment.

Engine should be maintained to assure optimum fuel consumption. Exhaust smoke under steady-state conditions indicates incomplete combustion of fuel, hence, increased fuel consumption. It could be caused by such things as dirty air cleaner elements, dirty aftercooler cores,

turbocharger malfunctioning, incorrect fuel injection timing, faulty fuel injection nozzle, etc. A qualified serviceman should be called upon to provide a specific diagnosis.

Turbochargers may also not be properly matched to the engine. This can happen with engines that are operating at a speed other than that shown on the manufacturer’s nameplate.

In such cases an improper turbocharger match increases fuel consumption by 1–5%, in addition to creating other possible adverse operating conditions, i.e., excessive exhaust temperature, slower engine acceleration, etc.

Reduce radiator fan power requirements. Radiators of the same ambient capability can have great differences in fan power due to fan rpm and fan diameter differences. A large diameter fan at a lower rpm can deliver the same cfm, but at greatly reduced power demand.

Radiators are available with fans which draw 1.5 to 6% of the engine rating. The effect of radiator fan power is quantified in **Table 1**.

Increase in Rig Fuel Consumption Due to Radiator Fan				
Engine Load	5% Fan	2.5% Fan	Controlled Speed	Fan (2:1)
			5%	2.5%
20% to 40%	12% to 16%	6% to 8%	1%	0.5%
30% to 50%	10% to 14%	5% to 7%	1%	0.5%
40% to 60%	8% to 10%	3% to 6%	1.5%	0.75%
60% to 100%	5% to 8%	2.5% to 5%	1.5% to 3%	0.75% to 1.5%

**Table 1**

Considering that drilling engines spend much of their time at reduced load levels, a further reduction in fan power can be achieved by using a two-speed drive (electrical, mechanical or hydraulic) to operate fan. This savings is illustrated in **Table 1** under the column labeled Controlled Speed Fans. This column also reflects the fact that the engine does not operate all year round at design ambient conditions.

Controlled speed fan would run continuously at low speed until hot weather/high load conditions cause engine water temperature to rise, signaling the fan drive to run at high speed.

**CAUTION:** Controlled speed fans may be prohibited by some emission regulations.

A single-speed fan drive that is turned on or off may not be desirable. The radiator supplier would have to be consulted to determine if the radiator core can tolerate the repeated temperature cycling that occurs. When the fan is off, the radiator out-let water is at engine water temperature and will be cooled toward ambient as the fan turns on — particularly at light load. This temperature reduction causes the radiator core to contract. Repeated temperature fluctuations could result in premature core failure unless the radiator can accommodate these fluctuations.

When operating on cool or cold days, the radiator ambient capacity, in the low speed operation, will increase. A low temperature is always reached where the engine

can be cooled at full load with the fan in low speed operation. Therefore, during winter operations (and most summer operations) the fan may never operate in the high speed position. **Table 2** shows these approximate values.

Radiator Ambient Capability		
Engine Load	Fan Speed	Approximate Ambient Capability
100%	100%	125°F (52°C)
100%	50%	80°F (27°C)
50%	50%	125°F (52°C)

**Table 2**

For additional assurance of reliability, the two-speed drive can be arranged such that fan belts can be reattached to the engine crankshaft pulley if necessary.

Radiator louvers are a desirable feature in cold climates, but they do not reduce the fan power demand.

Use of a heavy distillate or crude fuel can reduce fuel costs. Fuel consumption will reduce in an approximate inverse proportion to the ratio of the heat content of this fuel to regular fuel. However, such a fuel cost reduction frequently results in increased engine operating costs. Depending upon contaminants or operational difficulties encountered, engine life could be severely reduced.

A fuel analysis is certainly recommended. This should be compared to permissible and

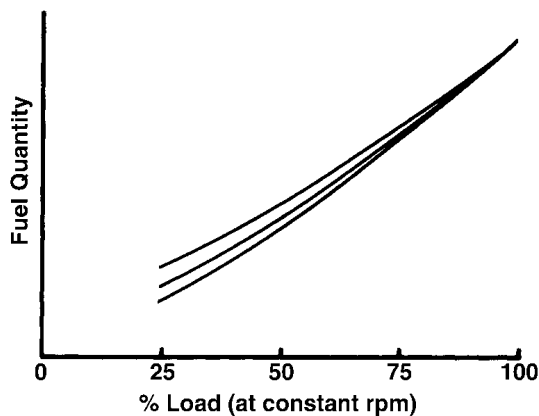
recommended fuel specifications which can be provided by the engine supplier. Fuel treatment equipment may be commercially available that conditions fuel to meet permissible or recommended fuel specifications. It may be necessary to start and stop the engine on diesel fuel.

Used lube oil can be blended into the fuel supply when proper precautions are taken. However, the reduction of fuel consumption would be in the range of 0.5% — and, fuel filters would have to be changed more frequently. It also discolors the fuel so that it cannot be returned to the supplier.

### Modifying Drilling Practices & Machinery

The first drilling practice to be discussed is the number and size of engines used to power a rig. An SCR rig will be assumed.

The importance of engine sizing is shown by engine fuel curves, **Figure 2**.



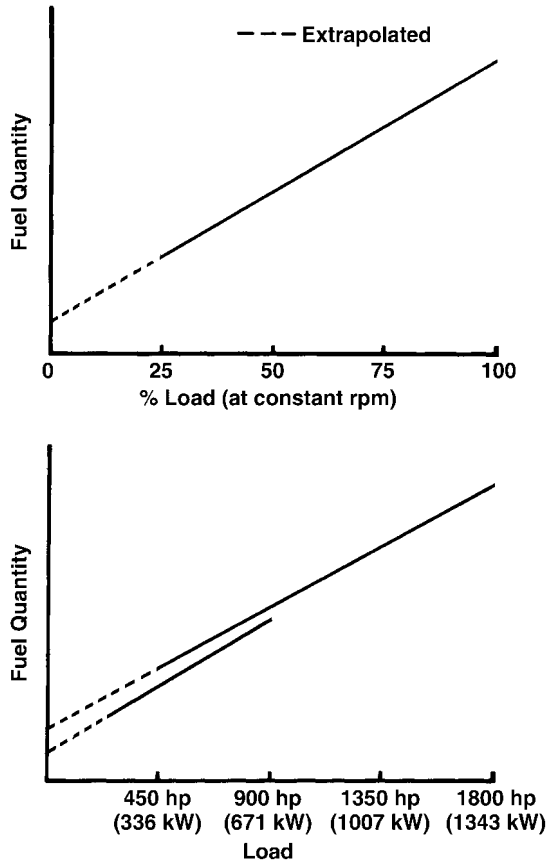
**Figure 2**

The curve is not flat. More importantly, this is a curve for a given prime mover. Such curves are not the same for all manufacturers and/or models. In a given engine family, a V8, V12, and V16 will not have identical fuel curves. Between engine manufacturers, a V8, V12, and V16 will also differ. Fuel curves give testimony to engine configuration differences such as aspiration-type, fuel-type and engine size.

**Figure 2** represents such variations. All these engines, for purpose of dramatizing the comparison, have the same full load fuel consumption.

An additional point is illustrated in **Figure 3**. The fuel quantity vs. percent load chart shows that two engines have the same fuel curve. The fuel quantity vs. kW (hp) chart shows that these same two engines have dramatically different fuel rates at specific load points; this indicates the engines are different sizes.

This understanding of fuel curves leads to the following conclusion: When using fuel consumption as one of the criteria in selecting engine sizes, types and quantities, fuel consumption at normal operating loads is of greatest importance. An approximation of engine load versus time at various well depths is also required.



**Figure 3**

In drilling applications, the well profile data is required to establish the basis for estimating engine fuel consumption. Well depth and fuel cost are values you provide.

The well profile itself can be based on your experience, on-site evaluation, documented by data recording systems or a combination of all of these.

It is suggested that separate drilling activities should be tabulated for each diameter hole being drilled, hoisting time and a grouping for nondrilling times such as logging and waiting on cement. Refer to **Table 3**.

Top Hole	days	hp
Drilling	days	hp
Drilling	days	hp
Tripping	days	hp
Wait, Misc.	days	hp

**Table 3**

Calculating or estimating fuel consumption requires the following:

- Engine fuel curves — tabulated in the same format (and down to no load operation).
- An actual or typical well profile that plots power required versus days of operation.
- A format to calculate and display the required information.

Refer to the Introduction Application & Installation Guide for Caterpillar petroleum engine fuel consumption data.

Engine operating techniques reflect the fuel consumption consequences of the number of engines in operation. Caterpillar recommends operating engines efficiently, but the consequences of operating more engines than required should be explored.

Engine operating techniques are tabulated under three headings:

- Run all engines — regardless of need.
- Run one engine more than required — this prevents a power interruption or reduction if a generating unit should go off the line.
- Run minimum number of engines — realizing that a temporary power reduction or out-age will occur if a generating unit should go off the line.

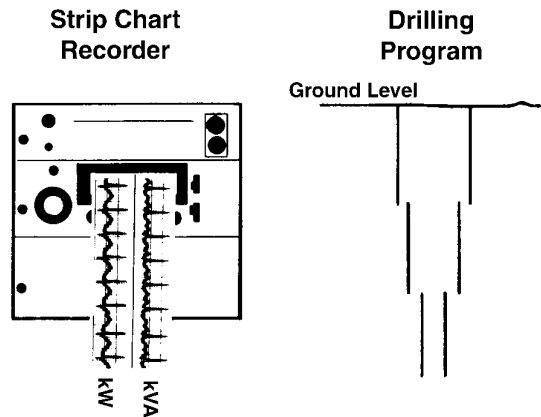
Generally, tripping hp (tripping out, tripping in and running casing) for the entire well averages 10 to 20% of the drawworks rated hp. Any operating auxiliary load has to be added.

Wait and miscellaneous time is spent, throughout the entire well, waiting on cement, logging and other operations.

The profile also assumes no generator limitations were encountered which would have required more engines running than indicated.

It is a known fact well profiles vary widely. Specific well profiles should be utilized if more results that are accurate are required. It may be necessary to record kW and kVA values on some drill rigs to gain reliable representative data. Refer to **Figure 4**.

### Drill Rig Load Profiles



**Figure 4**

### Engine Sizing versus Generator Sizing

The engine operating technique recommended in this guide may spark objections and/or demand qualification.

It could be argued that an SRC rig, operating within its power limit, is already performing efficiently. This statement requires a word of caution — the SCR system’s power limiter or overload control activates for either kW or kVA overloads. A rig operating with the power limiter light on does not mean the engines are being efficiently operated. Larger kVA generators (or other remedial action) may be needed because generators may be at kVA limit and engines at only 30 to 50% load.

A difficulty in efficiently sizing and operating an SCR or DC rig is the common assumption that “x” amperes represents “y” power; this is not true.

This fact is represented by system power factor. If power factor is 1.0, then “x” amperes represents “y” power. At power factors below 1.0, power is less than the amperes indicate.

A power factor from 0.3 to 0.9 on an SCR rig, under steady-state conditions, is evidence that generator sizing is important. During hoisting, power factor varies from 0.0 to 0.95.

Casually speaking, the engine supplier’s concern regarding power factor is that engine power capability cannot be utilized due to generator limitations during low power factor operation. This necessitates running additional engines. Running of additional engines increases rig fuel consumption and unnecessarily increases annual hourly usage of engines and total operating costs.

There may be cases where the minimum number of engines cannot be operated because of a high generator kVA requirement.

Before examining these variables, it is first necessary to review some characteristics of DC motors.

### **DC Motor Characteristics**

The rpm of DC motors is primarily controlled by the voltage to the motor (recognizing that motor type — series, shunt — and control system — field weakening, etc. — are related factors).

Ampere draw of the motor controls torque output of the motor.

In other words, torque comes from the interaction of magnetic fields and the strength of these fields is proportional to amperes, not to DC voltage. Therefore, kilowatt (horsepower) load on a DC motor is the product of volts and amperes and can be expressed as:

$$\text{kW (DC Output)} = \frac{V \times A}{1000}$$

$$\text{hp (DC Output)} = \frac{V \times A}{0.746 \times 1000}$$

Input power would be higher in inverse proportion to motor efficiency.

This leads to the realization that a DC motor can work hard at low rpm (draw high amperage and produce high torque) and not load the engine (but load the generator) when operating at low DC voltage/low rpm.

### **DC Motor Effects On Generator Selection**

DC motors do not have power factor identified with them. However, their DC amperes come from an AC generator with an SCR system providing rectification. This AC current does have power factor associated with it.

The speed/voltage characteristic of the DC motor is thus the major determinant of the system’s power factor.

**METHOD TO CALCULATE AC GENERATOR pf DUE TO DC MOTORS**

1. Determine DC kW
  - from meter
  - or formula 
$$kW_{DC} = \frac{V \times A}{1000}$$
2. Determine AC Amp of DC motor
  - use formula 
$$AC_{amp} = DC_{amp} \times 0.816$$
3. Determine kVA
  - use formula 
$$kVA = \frac{AC\ Volts \times AC\ amp \times 1.73}{1000}$$
4. Determine pf
  - use formula 
$$pf = \frac{kW\ (from\ Step\ 1)}{kVA\ (from\ Step\ 3)}$$

**Figure 5**

**Note:** System power factor is a weighted average of the DC motor system’s effect on the generator’s power factor and that of the AC auxiliary load. The AC auxiliary load generally is only about 20% of the DC load, so its effect on power factor is minimal.

regardless of DC power. Operating a DC motor at high rpm reduces ampere load, therefore kVA.

On the rotary table, this means keeping the draw-works transmission in as low a gear as possible.

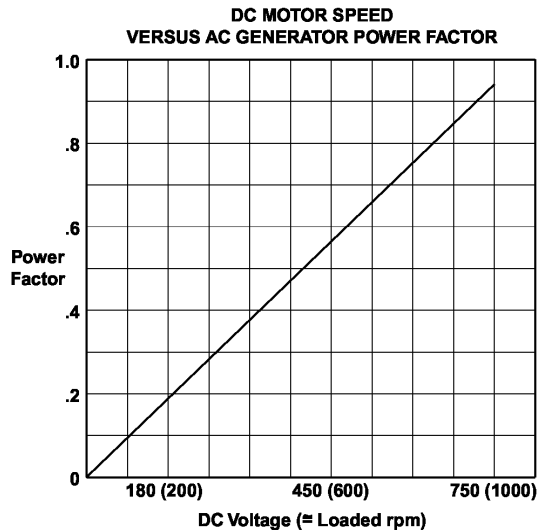
**Figure 5** shows a method to calculate AC generator power factor due to current draw of a DC motor powered through an SCR system.

**Figure 6** graphs the effect of motor rpm (or DC voltage) on the power factor of the driving AC generators. For a constant rpm (DC voltage), power factor is the same from no load to full load.

**System Power Factor Improvement**

The best way to improve system power factor is to ensure that DC motors are run at as high an rpm as possible.

Every DC ampere presents a 0.85 kVA load on the generator,



**Figure 6**

ROTARY TABLE OPERATION				
114 hp (85 kW) at DC Motor	rpm at	DC Amp =	pf at	kVa
	960	118	.9	922
	860	131	.8	104
	750	151	.7	12-
	640	177	.6	140
	530	214	.5	168
	425	267	.4	208
	325	349	.3	300
	210	540	.2	420
	150	756	.14	640

**Table 4**

1600 hp (1194 kW) TRIPLEX MUD PUMP 140 Strokes Maximum 120 Strokes Rated							
Customer Needs 300 gpm @2500 psi = 515 hhp (18.9 L/s @ 17237 kPa = 384 HkW)							
		DC Motors Gear for 140 spm			DC Motors Geared for 100 spm		
Liner Size	Required Pump Strokes	Motor rpm	AC pf	AC kVa	Motor rpm	AC pf	AC kVa
5 (127)	97	690	.66	577	970	.92	419
5 ½ (140)	81	579	.56	690	810	.76	502
6 (152)	68	486	.45	822	680	.64	598
6 ½ (165)	58	414	.40	966	580	.55	701
6 ¾ (171)	54	385	.37	1035	540	.51	753
7 (178)	50	357	.34	1118	500	.47	813
7 ¼ (184)	47	336	.32	1189	470	.44	864
7 ½ (191)	44	314	.30	1274	440	.35	1079

**Table 5**

To illustrate the effect of rpm, assume a rotary table is operating under the following conditions:

$$\text{rpm} = 30$$

$$\text{Torque} = 20,000 \text{ lb-ft (27 138 N}\bullet\text{m)}$$

$$\text{Power} = 114 \text{ hp (85 kW)}$$

Regardless of the rpm of the driving DC motor, engine load will stay at 114 hp (neglecting losses). However, motor rpm will change the kVA (pf) and, therefore, the size of generator required. This is illustrated in **Table 4**.

In the extreme case of 150 rpm, it does not take a large engine to produce 114 hp (85 kW), but it does take a large generator to produce 640 kVA.

This phenomena of increasing AC generator kVA as the DC motor slows down may seem unexpected, but it is just another way of saying that DC motor amperes are increasing as the DC motor is required to provide the same power at lower rpm (lower DC voltage).

If DC motors are operated at half DC voltage or less, an alternative method of raising AC generator power factor is to operate both drawworks motors in series; assuming this option is available from the SCR system supplier. This doubles the voltage out of the SCR system and proportionally raises the power factor. System speed, however, is limited to half the motor speed.

The same considerations apply to mud pumps. Operating speed should be as high as possible. If pumps must be operated at less than half

speed (rather than putting in smaller liners) the SCR system supplier may be able to supply equipment to allow the motors to operate in series.

When mud pumps are purposely oversized to reduce cost of fluid end maintenance, the mud pump will run much lower than rated strokes. In that case, specify a motor drive system ratio such that motors run at or near their rated rpm. Both mud pump drive types are shown in **Table 5**.

In summary, required engine power can be determined by knowing only load demand (based on **Table 6** and **Table 7**). However, generator sizing also requires knowing equipment speed. The kVA values in **Table 7** are for constant power levels but with various equipment rpms.

Load While Drilling				
	hp/kW	kVa		
		Minimum	Average	Maximum
Rt MP1	114/85	92	209	640
	515/384	577	966	1274
	629 hp (469 kW)	669	1174	1914
+	Auxiliary load			
Rt = Rotary Table MP1 = #1 Mud Pumps				

**Table 6**

Accordingly, definitive rules for sizing generators cannot be provided. Estimates of generator sizing are shown in **Table 7**.

<b>Generator Sizing</b>	
<b>Engine Size hp (bkW)</b>	<b>Generator kVA</b>
600 (450)	750-1000
800 (670)	1100-1300
1200 (900)	1500-1800
1500 (1120)	1600-2000
2000 (1490)	2000-2500

**Table 7**

This discussion illustrates that operating a rig in power limit does not ensure efficient engine utilization. The goal is to operate the minimum number of engines without encountering generator limitations.

#### **Drawworks Capability**

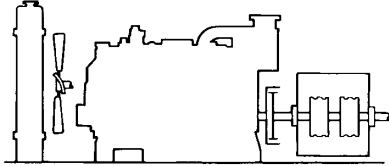
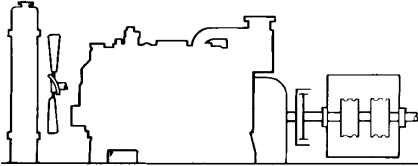
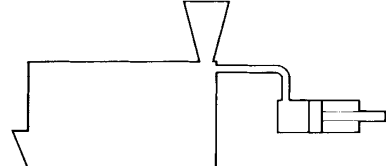
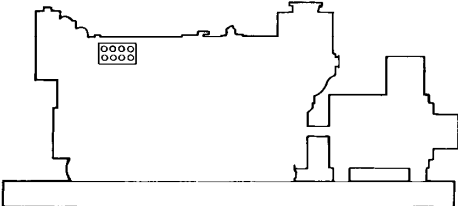
Another argument regarding the engine operating technique recommended by this guide relates

to underpowering. An operator may claim that using one engine during deep drilling causes the drawworks to be underpowered.

Many times rig operating personnel are reluctant to operate a minimum number of engines under deep hole conditions. They express the concern that, should they need to operate the drawworks in a hurry, one engine would not be able to "come off bottom," and time would be lost while starting additional engines.

With proper equipment selection, this issue can be partially overcome. The key to understanding this possibility is to draw a distinction between drawworks power and drawworks torque. Static hook load capacity is determined by generator kVA, not engine power.

**Starting Torque Comparison**

Drive Type	Torque When Coming Off Slips	Engine Load When Coming Off Slips
	Low	High*
Direct Drive		
	Rated	Rated
Torque Converter		
	Rated	NIL**
Steam		
	Rated	NIL**
DC/SCR		

**Figure 7**

This was discussed earlier under DC motor characteristics where it was pointed out that motor torque comes from the strength of motor magnetic fields.

To dramatize the stall torque characteristics, it is useful to compare torque characteristics of several drives when coming off slips, such as mechanical, torque converter, steam and DC (SCR). Refer to **Figure 7**.

The surprising data shown in **Figure 7** is that developing rated torque on a DC motor at the moment when coming off the slips does not load the engine. The engine is loaded in proportion to the speed to which the motor is accelerating. Thus, the electric drive is comparable to a steam rig.

Ideally, an electric rig will initially accelerate the traveling block, when coming off the slips, at a constant rate regardless of power capability of the engine. This constant rate is determined by generator kVA capacity. Motors will accelerate at this constant rate to the rpm at which developed power equals engine capability. The SCR system kW limit will then begin to reduce motor ampere draw. The motor will now accelerate at a slower rate or maintain a constant rpm, depending on load.

These factors are illustrated by using a hypothetical hoisting

scheme. This drawworks has the following characteristics:

1492 kW (2000 hp) Capacity  
Two 746 kW (1000 hp) Motors

	Each Motor	
	At Rated rpm	At Stall Conditions
DC amp	995	1200
AC amp	812	979
KVA	845	1020
kW (hp)	746 (1000)	0

**Table 8**

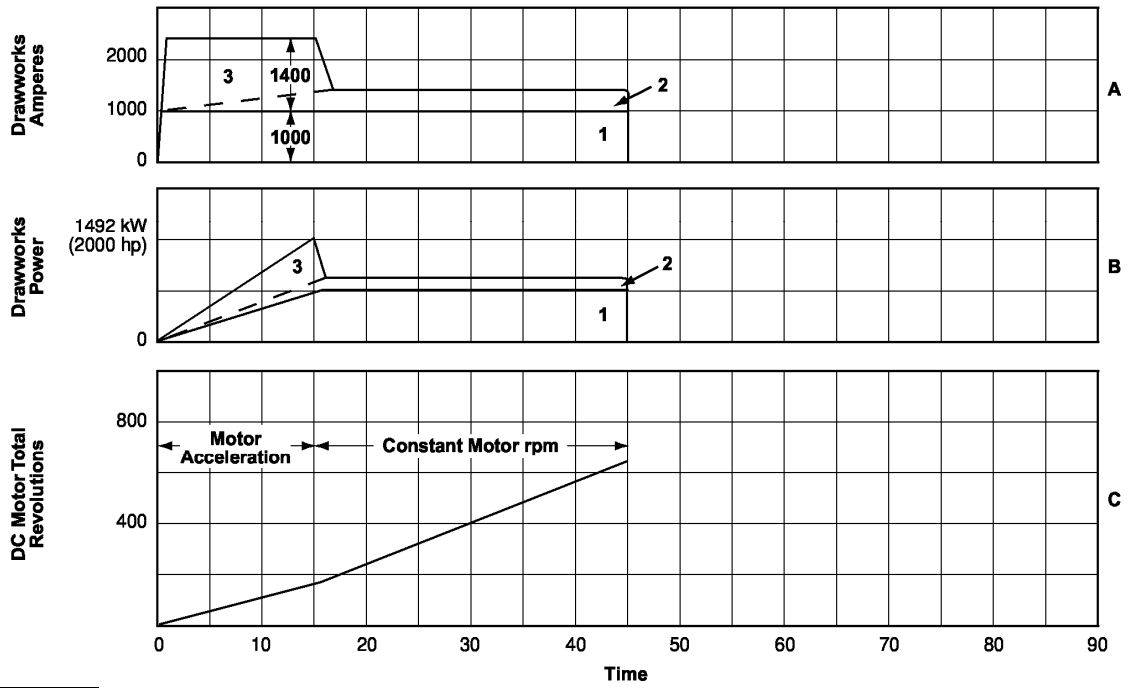
**Figure 8** plots drawworks current, power, and hoisting time for a heavy load. Total time to pull a stand of pipe is 45 seconds. (This is not based on actual calculations but is sufficient to illustrate the desired phenomena.)

In Part A of **Figure 8**, note that drawworks DC amperes are indicated as doing three things:

1. Hold weight of pipe against gravity under static or constant rpm conditions.
2. Overcome hole friction.
3. Accelerate pipe.

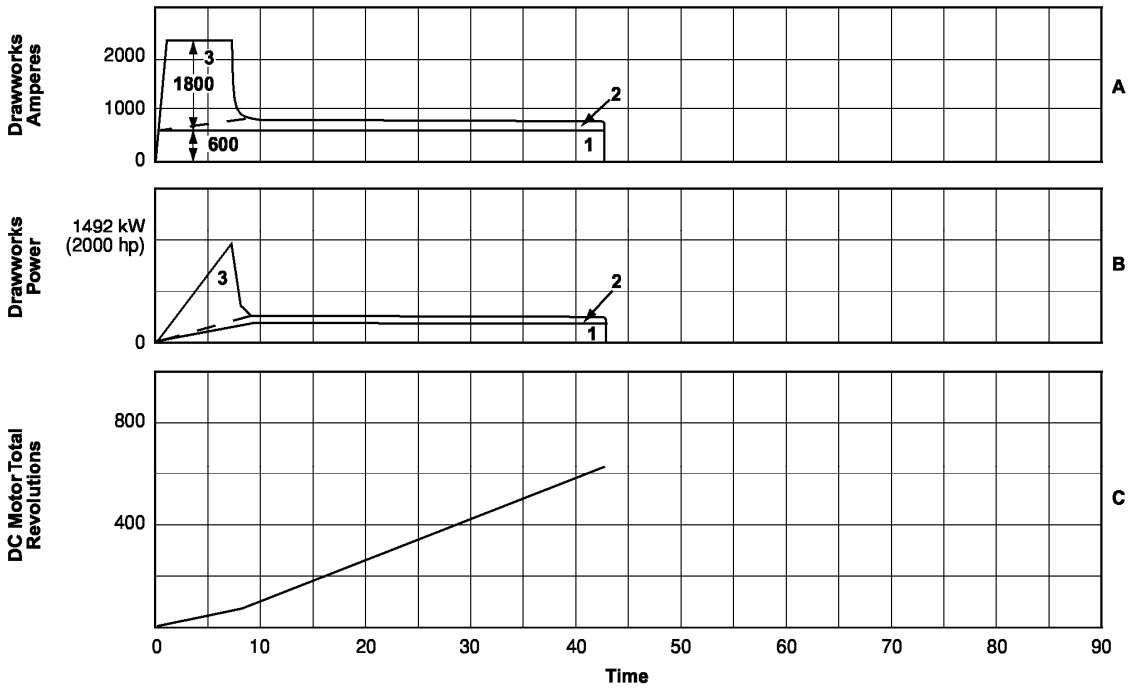
(Note that on a mechanical or torque converter rig, it would also be necessary to accelerate the engines.)

### Drawworks Under Heavy Load



**Figure 8**

### Drawworks Under Light Load



**Figure 9**

In this example, 1000 amps are required to hold the weight of the pipe. The remaining 1400 amps are initially available to accelerate pipe.

In Part B, drawworks power is indicated as being proportioned among the same three functions. Note that drawworks power starts at zero and reaches rated power after 15 seconds. Once the drawworks motor reaches rated rpm, the kilowatts (horsepower) drop (and motor amps) to that required for a constant speed condition.

If we accept 45 seconds as a reasonable estimate of heavy load hoisting time, we can count the DC motor revolutions as shown in Part C. For this transmission gear and lines strung, it takes 632 turns of the motor to pull pipe the required 90 ft. (27.4 m). Note that during acceleration, pipe is being lifted, although at a slower rate.

To perform according to **Figure 9**, the draw-works has to be fully powered both with horsepower (kilowatts) and kVA (amps), which would be two 3512s with 1250 kVA generators.

**Figure 9** shows the drawworks under a lighter load condition but in the same drawworks gear.

Note that acceleration time has been reduced from 15 seconds to 7 seconds due to the combination of having 1800 amps available for acceleration as compared to the 1400 amps in the previous example, and due to the lighter load to

accelerate. Hoisting time has been reduced only 3 seconds, from 45 seconds to 42 seconds. Part C indicates this by counting motor revolutions.

**Figure 10** shows an underpowered drawworks with the same heavy load as in **Figure 8**. The drawworks is now powered by one 3512 and a 1250 kVA generator.

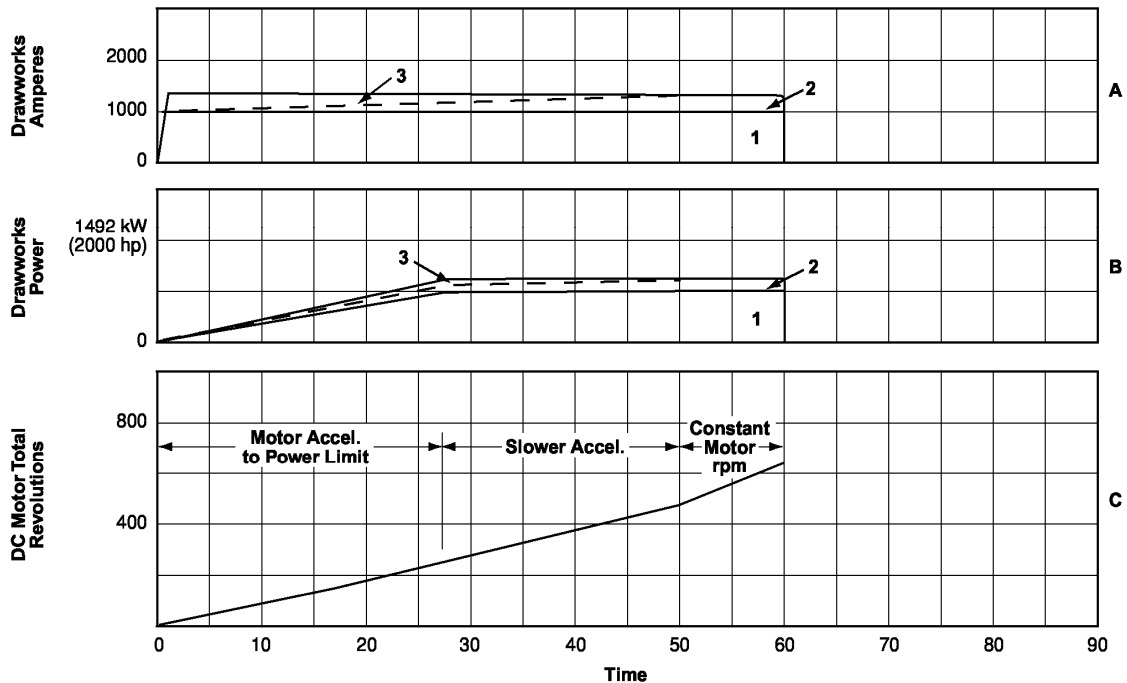
1250 kVA translates into 1470 DC amps. Comparing **Figure 8**, Part A, to **Figure 10**, Part A, we see that this under-torqued drawworks has only 470 amps available for acceleration while the fully powered drawworks has 1400 amps available for acceleration. Therefore, this under-torqued drawworks will accelerate much slower than before.

After an estimated 25 seconds, the horsepower will build to the rating of the engine. Acceleration will now continue at a slower rate as the SCR system power limiter or overload control phases back the SCR system. This reduces generator amps sufficiently to hold generator and engine at full load. Note the engine is not loaded for approximately 25 seconds.

Therefore, the total trip time could be about 60 seconds. This time is broken down as follows:

- O – X seconds Acceleration to engine power limit
- X – Y Acceleration at slower rate
- Y – Z Constant rpm

### Drawworks Underpowered



**Figure 10**

Figure 11 overlays Figure 8, Figure 9 and Figure 10. Part A shows the important variable is the percentage of available DC amperes available for acceleration. Oversize generators provide increased acceleration torque; therefore, the faster the drawworks accelerates, the sooner the engine can be loaded. Oversize generators come close to providing identical drawworks performance as that obtained with additional engines operating.

For these figures to be totally representative, available engine power and generator kVA should be reduced by the online auxiliary loads left running.

In summary, oversized generators not only provided for operation of

mud pumps at reduced power factors, but they also reduce the need to fully horsepower the drawworks, as long as the drawworks is close to being fully torqued.

#### Power Outage Concerns

An additional concern expressed by some drilling personnel is the domino effect. That is, if the load is equal to one and one-half engines, they prefer to run three engines. Operators may believe that if only two engines were operated, the loss of either of the two generator sets would overload and stall out the remaining generator set.

This does not happen with modern SCR systems due to the power limiter or overload control built into

the SCR system. This controller will phase-back one or more of the SCR-controlled loads sufficiently to prevent engine or generator overload.

**Other Considerations**

With optimum usage, engines accumulate fewer hours per year but at a somewhat heavier load.

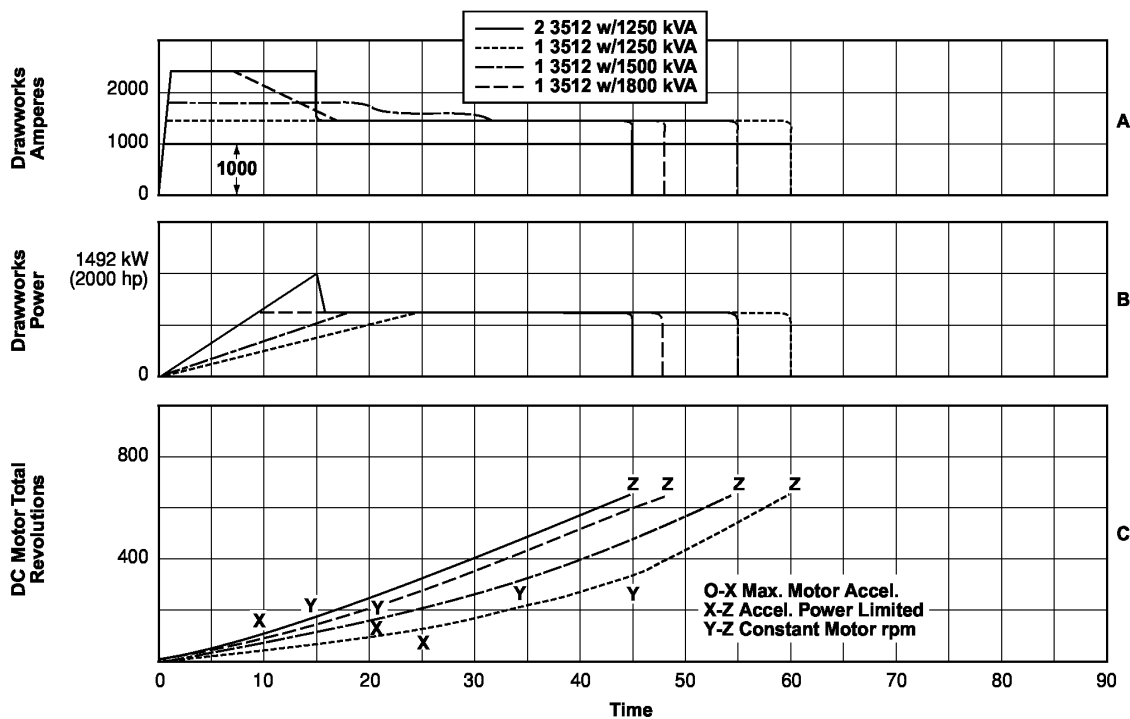
This heavier load may result in a somewhat lower time between overhauls as expressed in engine service meter hours. However, time

between overhauls as expressed in calendar years will be greater.

Additionally, there will be conditions where engines are presently so lightly loaded that the increase in load may still leave the engine moderately loaded and service life will be only slightly affected.

A final benefit of increasing engine load is that the resulting warmer jacket water temperatures greatly aid in combating harmful effects of some fuel contaminants.

**Drawworks with Oversized Generator**



**Figure 11**

During deep drilling, where the investment in the well is accumulating to a considerable amount and uncertainty regarding the exact nature of downhole conditions is also increasing, it is a general practice to operate with 80% or less engine load.

### **Diesel Engine Fuel Conservation Summary**

The main means available to improve fuel conservation are:

- Use electric motor-driven auxiliaries.
- Use engine heat on winterized rigs.
- Prevent theft of fuel.
- Eliminate spillage and leakage losses.
- Turn off unneeded auxiliaries.
- Keep engines properly maintained.
- Reduce radiator fan power requirements.
- Operate the minimum number of engines.
- Size system for operating kVA.
- Operate DC motors in series.
- Increase motor rpm.
- Utilize oversize generators for improved hoisting and mud pump performance.



