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(R) ELECTRIC ENGINE PREHEATERS AND BATTERY WARMERS FOR DIESEL ENGINES

1. SCOPE:

The scope of this report is to acquaint and inform those concerned with cold weather operation of diesel powered machines and vehicles with the selection and application of electrically powered starting aids currently available.

It deals specifically with the design, function, and application of line voltage electrically powered engine preheaters and battery warmers.

2. REFERENCES:

SAE J226 Engine Preheaters

3. GENERAL:

Diesel engine starting becomes progressively more difficult as the ambient temperature drops below 40°F (4°C). To achieve successful engine starting, the engine combustion chamber temperatures must be sufficient to ensure that the air/fuel mix will ignite under full compression. However, low ambient temperatures affect combustion chamber temperatures for the following reasons:

a. The cylinder wall temperatures are low due to low coolant and block temperatures.

b. The air temperature entering the combustion chamber is at ambient temperature.

c. The cranking speed at low temperature is at a lower rpm because of the greater lube viscosity and decreased battery efficiency.

d. The fuel temperature reduced by low-ambient temperature will reduce combustion chamber temperatures.

3. (Continued):

Electric engine preheaters and battery warmers are one way of assisting in obtaining consistent successful starts under cold ambient starting conditions, assuming a source of electric power is readily available.

These cold weather aids are designed for permanent installation and are intended to be utilized during normal engine shutdown periods. Engine preheaters heat the engine block by way of raising coolant temperatures and by heating lube oil.

Ideally, engine preheaters should be sized so that they will produce engine temperatures allowing for consistant starting when energized for several hours from a cold-soak condition. Under certain conditions of limited wattage and severe cold conditions, the use of ether in conjunction with preheaters and battery warmers may also be required to achieve starting. An important benefit from the correct application and use of preheaters is a reduction in strain and wear caused to electric starting systems and key engine components.

The engine coolant preheaters should provide successful engine starting at temperatures in the -25°F (-32°C) range. At lower ambient temperatures, other preheaters will be required in conjunction with coolant heaters.

The engine preheaters can take several forms depending upon the engine application. The heater design depends on engine size and configuration and will generally fall into one of the following categories:

a. Coolant immersion type.
b. Oil immersion type.
c. External tank coolant type.

4. HEATER DESIGN AND CONSTRUCTION:

Electric engine preheaters have three basic components:

a. Heating element.
b. Heater casing or adaptor.
c. Power supply conductor.

4.1 Heating Element Consists of:

4.1.1 Tubular metallic sheath of steel, copper, stainless steel, or nickel alloy.

4.1.2 Resistance wire helix and terminal pin assembly, a specific length and gage or nickel chromium resistance wire, equipped with heavy gage wire, stainless steel or plated steel terminal pins welded to the helix.

4.1.3 Suspending medium, magnesium oxide powder, possessing high dielectric strength, high temperature stability and heat conductivity.

The heating element is generally assembled in the following manner:

The resistance wire helix and terminal pin assembly of a predetermined resistance value is suspended centrally inside a specific length of tube. A controlled flow of magnesium oxide powder is allowed to fill the remaining cavity to physically support and electrically insulate the helix. The assembly is then further compacted by reducing its tubular sheath diameter through a swaging or roll mill operation. Annealing is necessary to relieve work hardening stresses resulting from the previous operation. Bending and final forming are performed after annealing.

4.2 Heater Casing or Adaptor:

The heater casing or adaptor may take the form of a tank assembly, flange plate, or threaded adaptor. The heating element is affixed to one of these forms accordingly.

4.3 Power Supply Conductor:

The power supply conductor is usually a flexible grounding type electrical power supply cord. The length and gage of conductor, male cap configuration, and conductor jacketing can vary with the final application.

5. HEATER TYPES AND APPLICATIONS:

5.1 Coolant Immersion Type:

These units (see Figure 1) are designed to be inserted directly into the engine block coolant chamber. Ideally, the location of the heater insertion is at a point on the engine block that is low in the cooling system, where there is unrestricted coolant available, and where external mounting is unobstructed. The coolant circulates in the system by convection.

These units incorporate a tubular heating element of the type previously described. The element may be brazed or soldered to a threaded adaptor or plate which, in turn, may be assembled to a jacket plate or core hole adaptor. In addition, some units have tubular elements brazed or soldered to specifically designed bushings incorporating standard pipe thread sizes.

Coolant immersion heaters' dimensions and specifications are described in SAE J226.

Elements are kept to a minimum length with a recommended maximum watt density of 100 W/in^2 (15.5 W/cm^2) of element sheath surface.

When elements exceed approximately 7 in (17.75 mm) in overall length, element failure may occur due to engine vibration induced metal fatigue at point of solder.

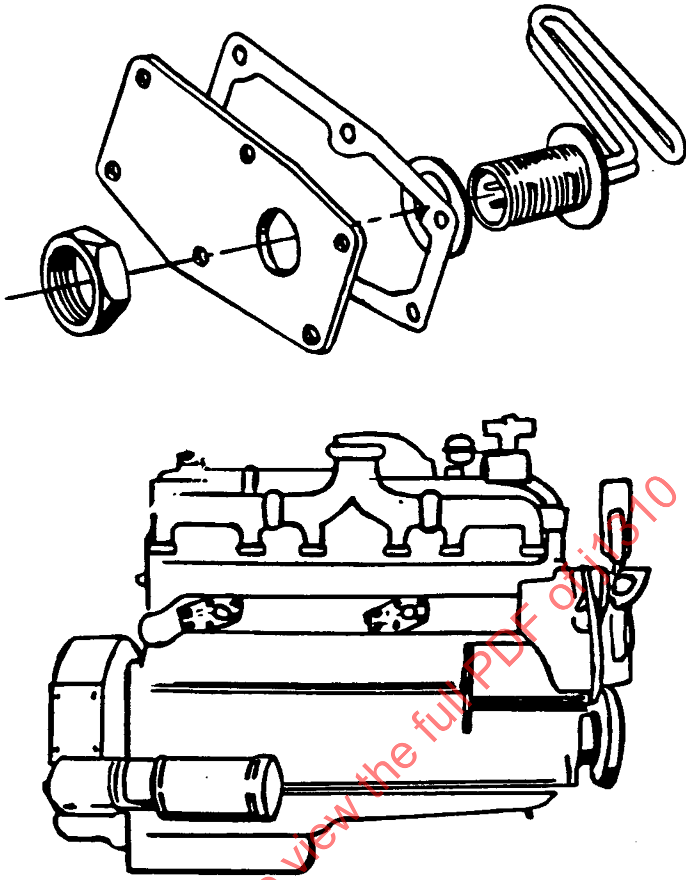

FIGURE 1

5.1 (Continued):

When watt densities exceed the recommended maximum, aeration of the coolant and/or steam pockets may occur. This may result in engine hot spots and premature heater failure. In addition, heaters displaying high watt densities or heaters installed in restricted coolant areas may result in calcification of the element and in poor circulation of heated coolant or premature element failure.

Coolant immersion heaters are available with heavy-duty three-wire grounded detachable power supply cord sets, usually 5 ft (1.5 m) or 6 ft (1.8 m) in length. They are also available with permanently attached cord sets.

When installing immersion engine preheaters, care must be taken to follow the manufacturer's installation instructions.

Little, if any, maintenance is required other than periodic inspection for coolant leaks around gasketed area or threaded fittings. Power supply cords should be inspected periodically for damage. Protective caps are available to cover the recessed terminal area of the heater should the power supply cord be disconnected for seasonal storage.

Coolant immersion heaters are available in wattages ranging from 750 to 2000 W, 120 or 240 V.

5.1 (Continued):

Some manufacturers provide dual heater kits, complete with special "Y" configuration power supply cord sets. Weather-proof flush-mounted male receptacle enclosures are also available for mounting on engine enclosures.

5.2 Oil Immersion Type:

These heaters (Figure 2) are used as supplements to coolant immersion heaters. They are used to raise or maintain the temperature of oil in the sump in order to reduce crankshaft friction drag (churning loss), and to prevent possible damage to crankshaft and connecting rod bearings as well as to cylinder walls and/or pistons.

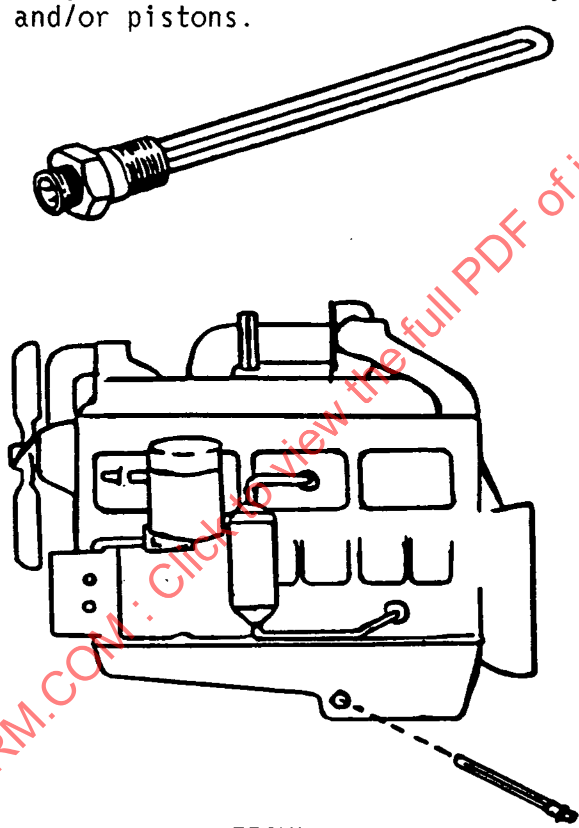

FIGURE 2

The point of installation is in the lower portion of the oil pan through a tapered pipe thread opening. This opening is either already provided or can be fabricated by welding or brazing on an adaptor provided by the heater manufacturer.

The oil is a relatively poor conductor of heat. The entire volume of oil in the sump is heated by convection. The recommended maximum watt densities range from 20 to 30 W/in^2 (3 to 5 W/cm^2) of sheath surface, depending on sheath material. Sheath materials include steel, plated steel, stainless steel, and aluminum. Consult the manufacturer for recommendations.

The control thermostats are available, which are mounted in a manner similar to the heaters. These are placed in close proximity to the heater and are usually used with high wattage units.

5.2 (Continued):

These heaters may also be controlled by thermostats, used in conjunction with coolant preheaters.

To prevent possible coking of the heater element operated in an ambient below -20°F (-30°C), recommended practice is to energize the oil immersion heater immediately after engine shutdown while the lube oil is still warm.

Power supply cords are of three-wire grounded type and may be either detachable or permanently fixed to the heater. Cords should be routed to minimize possible damage.

These heaters are available in 1/2, 3/4, or 1 in NPT sizes and wattage range from 150 to 600 at 120 or 240 V. Metric size threads are also available.

5.3 External Tank Coolant Type:

Also known as "side arm type," these units (Figure 3) consist of a tubular heating element fixed inside a tank complete with a coolant inlet and outlet, as well as a suitable power supply cord. These units are of a rugged construction and are offered in a wattage range from 1000 to 4000 in appropriate voltage, either 120 or 240 VAC. Higher wattages and voltages are available; consult manufacturers.

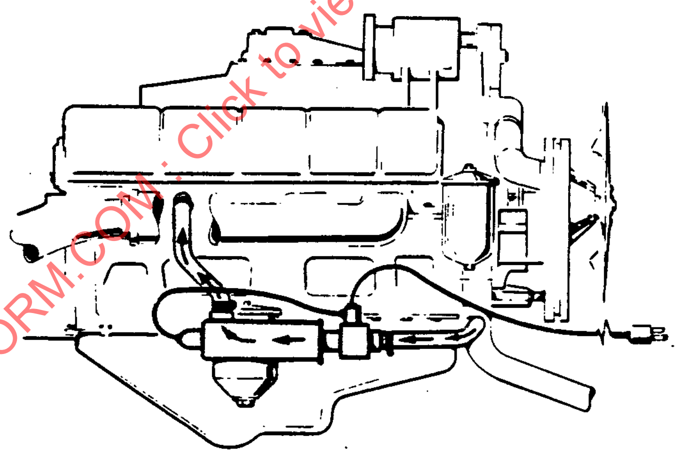

FIGURE 3

The tank heaters are universal in application and have the advantage of high wattage availability; however, they are more costly to purchase and install than immersion heaters.

Some heat loss is encountered compared to equivalent wattage immersion heaters, and this should be taken into account when selecting required wattage. A good rule of thumb is to select the next larger wattage size to compensate for these extra heat losses.

5.3 (Continued):

These units are intended to be mounted in close proximity to the engine, usually as low in relation to the cooling system as is practical. This should be even with or below the lowest point in the cooling system in order to provide a head of pressure to the heater inlet.

Tank heaters are plumbed to the engine by hoses or coolant lines of suitable diameter and material. Care should be exercised in the clamping and routing of the hoses to prevent abrasion damage from engine vibration, exhaust manifold contact, or contact with moving parts. These connections must be of high grade materials capable of withstanding severe physical and thermal shock. High-low temperature silicone or equivalent hose is recommended.

In operation, the coolant is drawn from a low point in the cooling system, for example, water in the tube or block drains through the heater inlet, is heated and flows by convection through the heater outlet to a high return point of entry into the engine cooling system, usually the cylinder head, high point in block, or thermostat housing. In addition, tank heaters are equipped with a one-way valve in the inlet area of the tank. This prevents short circuiting of the coolant flow during engine operation and also assists in promoting a flow or percolating effect. Because of the valve, units must not be energized during engine operation or immediate heater failure will occur. On standby units, heaters should be electrically interlocked with the starting electrics to prevent heater element or hose failure in the event of insufficient coolant flow due to air locks. These may be caused by restricted hoses or incorrect heater installation.

The recommended practice for tank heater installation is to utilize the largest diameter hose compatible with the heater inlet/outlet to achieve maximum flow. Avoid long runs of hose, kinks, or humps. At no point should the outlet hose be higher than the highest coolant level in the engine. The outlet hose should be a minimum of 6 in (15.25 cm) in length.

The auxiliary nonadjustable control thermostats are available for mounting in series with the heater inlet, thus sensing inlet coolant temperature. The temperature settings are available from 100 to 180°F in 20°F increments. Metric versions are also available.

These controls may also be used to control the lube oil heaters as well. Because of heater design and construction, particularly in larger sizes, it is inadvisable to mount these heaters directly to the engine as vibration may cause failure. Secure mounting to a frame member is recommended. Ensure protection from severe shock, splashing, and other physical damage.

Although not generally required, pumps are available for use with tank heaters and provide more efficient overall coolant heating. They are generally used on larger wattage units. Manufacturers can be consulted for their recommendation.

Maintenance for tank heaters should include periodic inspection of power supply cord, hoses, and hose connections. The element should be removed from the tank once a year for removal of scale or sediment.

6. SIZING OF ENGINE PREHEATERS:

There are three modes of heat transfer to be considered when preheating engines. These modes are: conduction, convection and radiation.

Because of the complexity of specific engine designs and the many variables and unknowns, it is extremely difficult to determine by formula the wattage requirements for engines. Wattage requirements can best be determined by actual field experience and test, or by testing conducted under simulated cold-weather conditions.

Some engine heater manufacturers have developed a rule of thumb for sizing wattages to diesel engines. This rule specifies that a 3 W/in^3 of displacement should provide adequate preheating under most conditions. Of course, this provides only a rough estimate.

The wattage requirements based on engine weight or coolant capacity may also be considered; however, the most important consideration should be the basic engine block's ability to free flow its coolant during the heater cycle. As previously mentioned, this can best be determined through testing.

Other engine heater manufacturers, in cooperation with original equipment manufacturers, have developed some general guideline charts for selection of heater wattages. (See Table 1.)

An important consideration in determining the wattage requirements for specific applications is the effect of windchill under cold ambient conditions. Where practical, precautions should be taken to shield engines and sump areas from the effects of wind during shutdown periods. The effect of windchill can be estimated from the windchill factor shown in the chart in the appendix (see Table 2). As an example, a 20 mph (32 km/h) wind at -10°F (-23°C) is equivalent to a temperature of -45°F (-43°C) with no wind. When specifying wattage requirements for engine preheaters, it is important to make certain that specified heater voltages match as closely as possible the nominal voltage of the intended electric service to be utilized. For example, a heater load designed for 240 V and utilized at 220 V will deliver approximately 85% of its rated output.

It is equally important to make certain that the total wattage load will not overload the rated capacity of the electric service to be utilized. External power supply circuits should be suitably protected by means of circuit breakers and/or ground fault interruption devices in accordance with local electrical codes.

TABLE 1 – Wattage Selection Chart

	Medium Duty Diesels (Small V's, In-Line 4's)	Heavy Duty Diesels (Small V8's, In-Line 6's)	Heavy Duty Diesels (Large V8's)	Super Heavy Duty (Industrial and Off-Highway Engines)
32 to 0°F (0 to –18°C)	750 or 1000 watt coolant immersion or 1000 watt coolant tank and 150 watt oil immersion	1000 watt coolant immersion or 1500 watt coolant tank and 150 watt oil immersion	1000 watt coolant immersion or 2000 watt coolant tank and 150 watt oil immersion	(2) 2000/115 coolant tank or (1) 4000/230 coolant tank and 300 watt oil immersion
0 to –30°F (–18 to –34°C)	1000 watt coolant immersion or 1000 watt coolant tank and 150 watt oil immersion	1500 watt coolant immersion or 2000 watt coolant tank and 300 watt oil immersion	1500 watt coolant immersion or 2250/115 coolant tank or 2500/230 coolant tank and 300 watt oil immersion	(2) 2000/115 coolant tank or (1) 4000/230 coolant tank and 300 watt oil immersion
–30 to –60°F (–34 to –51°C)	1500 watt coolant immersion or 1500 watt coolant tank and 300 watt oil immersion	2250/115 coolant tank or 2500/230 coolant tank and 300 watt oil immersion	4000/230 coolant tank and 300 watt oil immersion	(2) 2000/115 coolant tank or (1) 4000/230 coolant tank and 300 watt oil immersion

	115 volts	230 volts
$\frac{\text{watts}}{\text{volts}}$ = necessary amps	20 amp fuse, max wattage 2300 25 amp fuse, max wattage 2875 30 amp fuse, max wattage 3450.	20 amp fuse, max wattage 4600 25 amp fuse, max wattage 5750 30 amp fuse, max wattage 6900

TABLE 2 - Windchill Factor

Wind Velocity mph (km/h)	Temperature Degrees °F (°C)															
	+30 (-1)	+25 (-4)	+20 (-7)	+15 (-9)	+10 (-12)	+5 (-15)	0 (-18)	-5 (-20)	-10 (-24)	-15 (-27)	-20 (-29)	-25 (-32)	-30 (-34)	-35 (-37)	-40 (-40)	-45 (-43)
10 (16)	+20 (-7)	+14 (10)	+8 (-13)	+2 (-17)	-4 (-20)	-10 (-23)	-15 (-26)	-21 (-29)	-27 (-33)	-33 (-36)	-39 (-39)	-45 (-43)	-50 (-46)	-56 (-49)	-62 (-52)	-68 (-56)
15 (24)	+13 (-11)	+7 (1-14)	0 (-18)	-6 (-21)	-12 (-24)	-18 (-28)	-25 (-32)	-31 (-35)	-38 (-39)	-44 (-42)	-50 (-46)	-57 (-49)	-63 (-53)	-69 (-56)	-75 (-59)	-81 (-63)
20 (32)	+9 (-13)	+2 (-17)	-5 (-21)	-12 (-24)	-19 (-28)	-25 (-32)	-32 (-36)	-39 (-39)	-45 (-43)	-52 (-47)	-59 (-50)	-66 (-54)	-72 (-58)	-79 (-62)	-85 (-65)	-92 (-70)
25 (40)	+5 (-15)	-2 (-19)	-9 (-23)	-17 (-27)	-24 (-31)	-30 (-34)	-37 (-38)	-44 (-42)	-51 (-46)	-58 (-50)	-65 (-54)	-72 (-58)	-78 (-61)	-86 (-66)	-93 (-69)	-99 (-73)
30 (48)	+3 (-16)	-5 (-21)	-12 (-24)	-20 (-29)	-27 (-33)	-33 (-36)	-41 (-41)	-48 (-44)	-55 (-48)	-63 (-53)	-70 (-57)	-77 (-61)	-83 (-64)	-91 (-68)	-98 (-72)	-104 (-76)
35 (56)	0 (-18)	-7 (-22)	-14 (-26)	-22 (-30)	-29 (-34)	-36 (-38)	-44 (-42)	-51 (-46)	-58 (-50)	-66 (-54)	-73 (-58)	-81 (-63)	-87 (-66)	-95 (-71)	-102 (-74)	-109 (-78)
40 (64)	-1 (-18)	-9 (-23)	-16 (-27)	-24 (-31)	-31 (-35)	-38 (-39)	-46 (-43)	-53 (-47)	-61 (-52)	-69 (-56)	-76 (-60)	-84 (-64)	-91 (-68)	-98 (-72)	-105 (-76)	-112 (-80)

These temperatures shown are approximate due to varying humidity.

Note: Windchill as defined by the climatic research unit of the United States War Department, expresses the rate at which the body of an inactive human would lose heat if placed out of doors in the shade under given conditions of temperature and wind speed.

It should be noted that cooling cannot take the temperature of an object to a point lower than the recorded temperature. However, when there is a strong wind, exposed objects dissipate heat more rapidly.

7. BATTERY WARMERS:

The batteries deliver full cranking power when fully charged at 80°F (27°C); however, this is not the case when they are subjected to colder temperature.

As can be noted in Figure 4, a battery at full charge can deliver only approximately 26% of its rated cranking at -20°F (-29°C), demonstrating that as temperatures decrease engine cranking power requirements increase.

It is essential that steps be taken to ensure that adequate battery capacity is available under severe cold conditions. Electric battery warmers can offer a solution if auxiliary electric power is available. This power may be on board or off; however, it is usually the off-board type, and therefore, these heating devices are generally used for standby use.

When utilizing electrically powered battery warmers, it is recommended that special attention be given to the design and construction of an insulated battery box (Figure 5). This box can be fabricated from heavy gage sheet metal with rigid foam insulation applied to the outer surfaces, or it may be of double-walled foamed-in-place urethane construction.

7.1 Battery Warmer Types and Application:

There are several types of electrically powered battery warmers currently in use. These are:

7.1.1 Plate Type: This unit (Figure 6) employs a metal sheathed tubular element of "U" shape sandwiched between heavy gage sheet metal plates and equipped with an integral control thermostat. This unit is mounted directly under the battery. The unit is available in 200 W-115 V or 230 V size 6 x 9 x 5/8 in (15.2 x 22.8 x 1.6 cm).

7.1.2 Mat Type: This unit (Figure 7) is comprised of a heavy gage rubber material, incorporating a serpentine pattern resistance wire element imbedded in the center area of the material. The unit relies on low watt density radiant energy to heat the battery and is intended to be mounted directly under the battery. An auxiliary thermostat option with 80°F (27°C) open setting is available.

The unit is available in two sizes:

a. 8-1/2 x 11 x 1/8 in - 50 W - 115 V (21.6 x 27.9 x 0.3 cm)
b. 11 x 10 x 1/8 in - 75 W - 115 V or 230 V (27.9 x 50.8 x 0.3 cm).

7.1.3 Strip Heaters: Commercially available strip heaters (Figure 8) can be employed for heating batteries. These are generally of higher watt densities. Care must be exercised to ensure that they do not come into direct contact with the battery casing. It is advisable to mount these units on the inside wall of the battery box. These units are available in various sizes, wattages, and voltages.

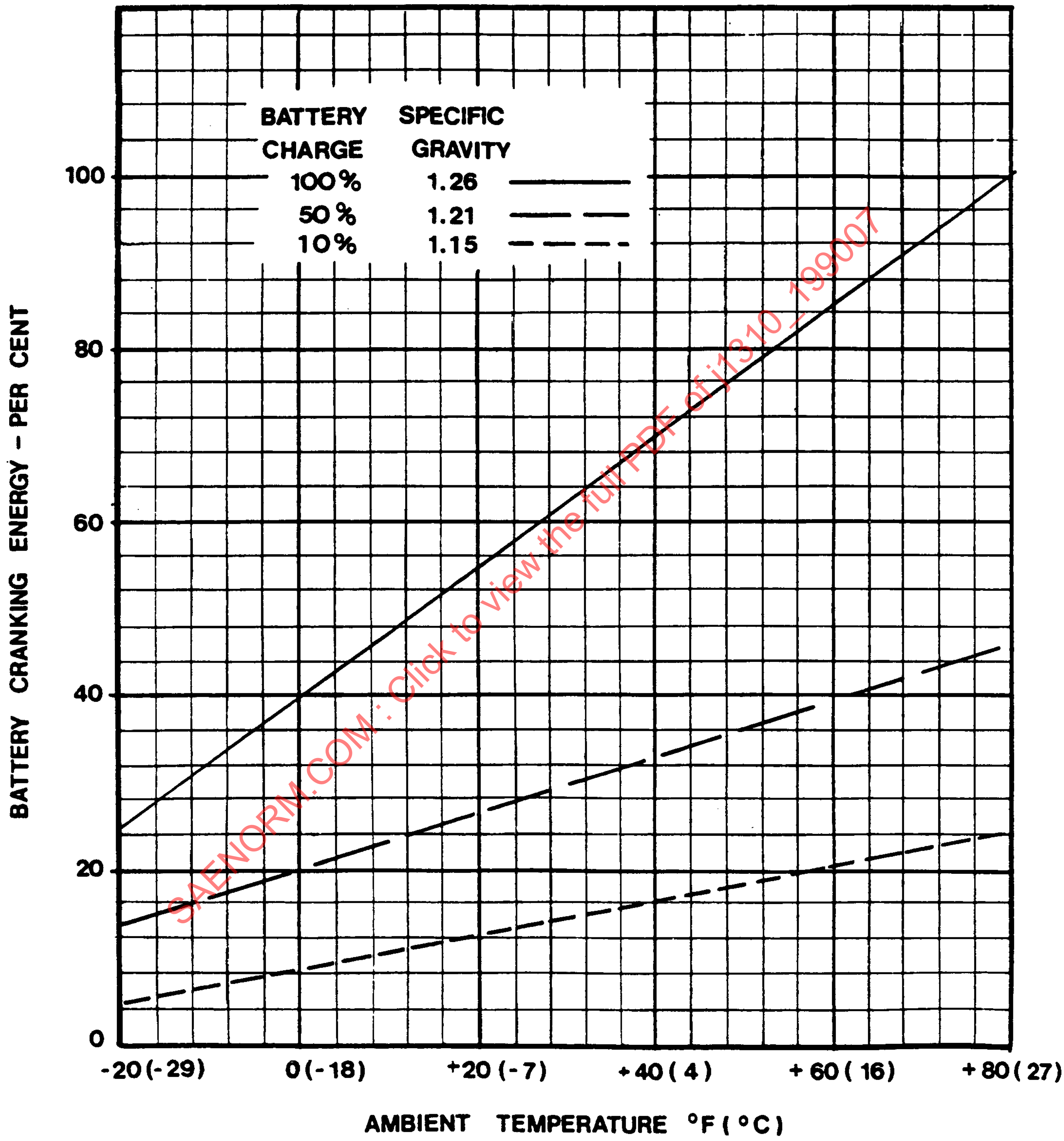

FIGURE 4 - Effect of Ambient Temperature on Battery Cranking Energy

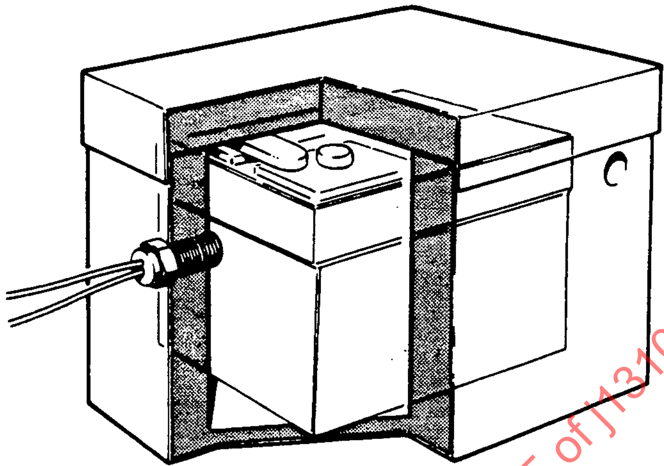

FIGURE 5

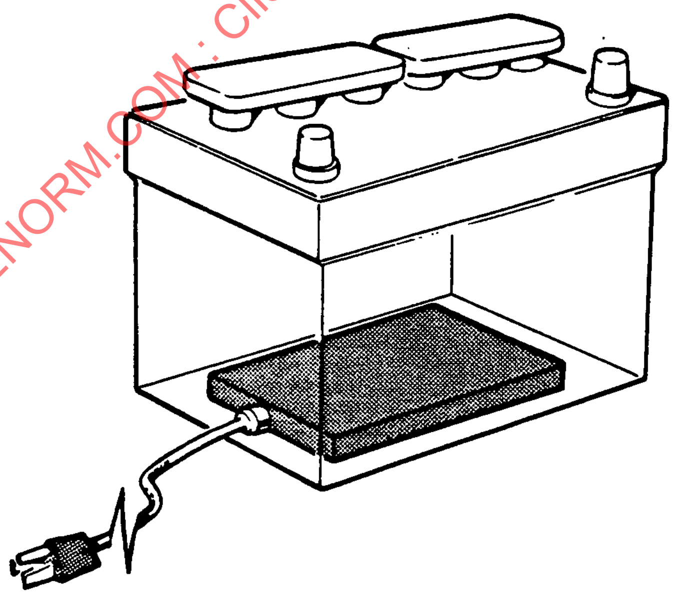

FIGURE 6

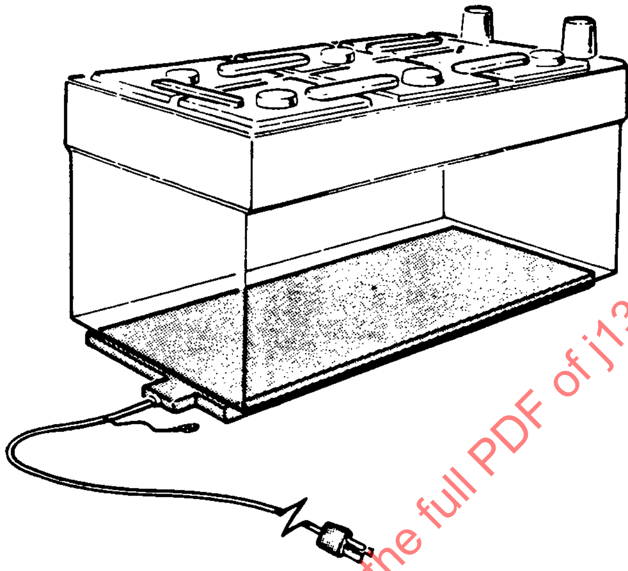

FIGURE 7

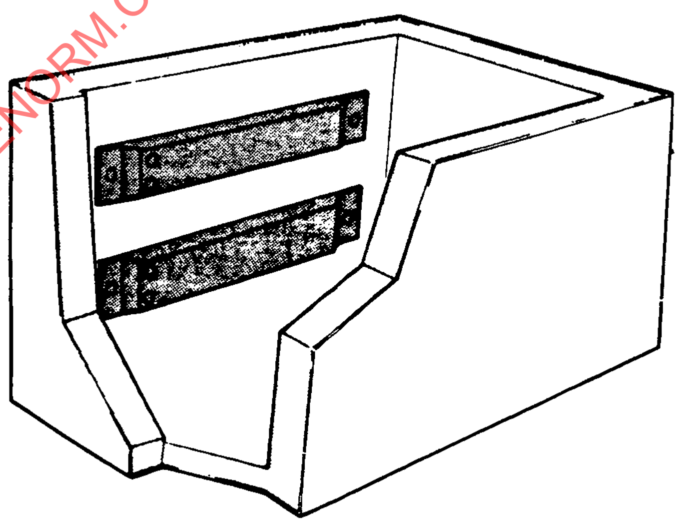

FIGURE 8

7.1.4 Blanket Type: Flexible construction (Figure 9) comprised of a heavy aluminum foil element assembly of low watt density, complete with fiberglass insulation on one side, enclosed in a heavy gage acid-resistant plastic sheath. The unit is provided with ties and is intended to be installed tightly around the sides of the battery or batteries. This unit has the advantage of integral insulation.

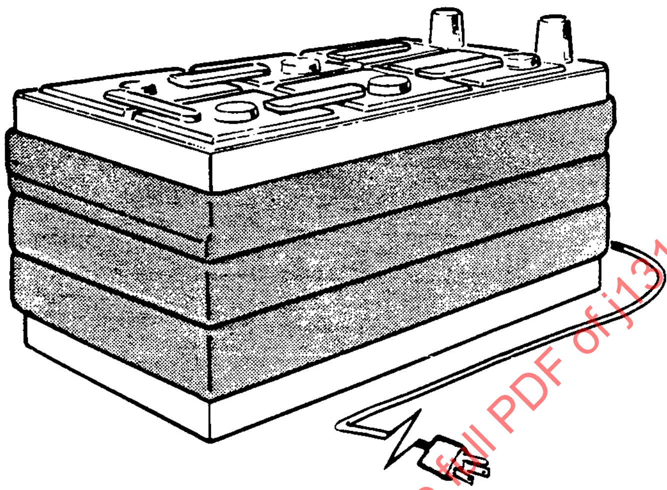

FIGURE 9

The unit is available in two models:

a. 80 W - 120 V - 5-1/2 x 36 x 3/4 in (13.9 x 91.4 x 1.9 cm)
b. 160 W - 120 V - 5-1/2 x 72 x 3/4 in (13.9 x 182.9 x 1.9 cm).

The (R) is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. If the symbol is next to the report title, it indicates a complete revision of the report.

APPENDIX A

A.1 TYPICAL WIRING DIAGRAMS:

Figure A1 represents a typical wiring diagram for engine preheaters and lube heaters.

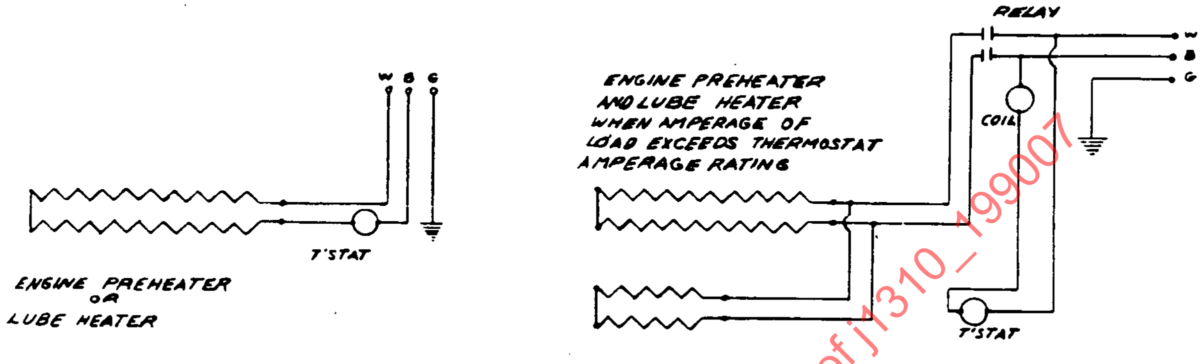

FIGURE A1 - Typical Wiring Diagrams

A.2 TEMPERATURE RISE CURVES FOR TYPICAL DIESEL ENGINES: (See Figures A2, A3, A4, and A5)

These curves are based on mathematical analysis with constants derived from laboratory test results. Data for the graphs shown in Figures A4 and A5 was calculated with zero wind. The final engine temperature is the sum of the temperature rise and ambient temperature.

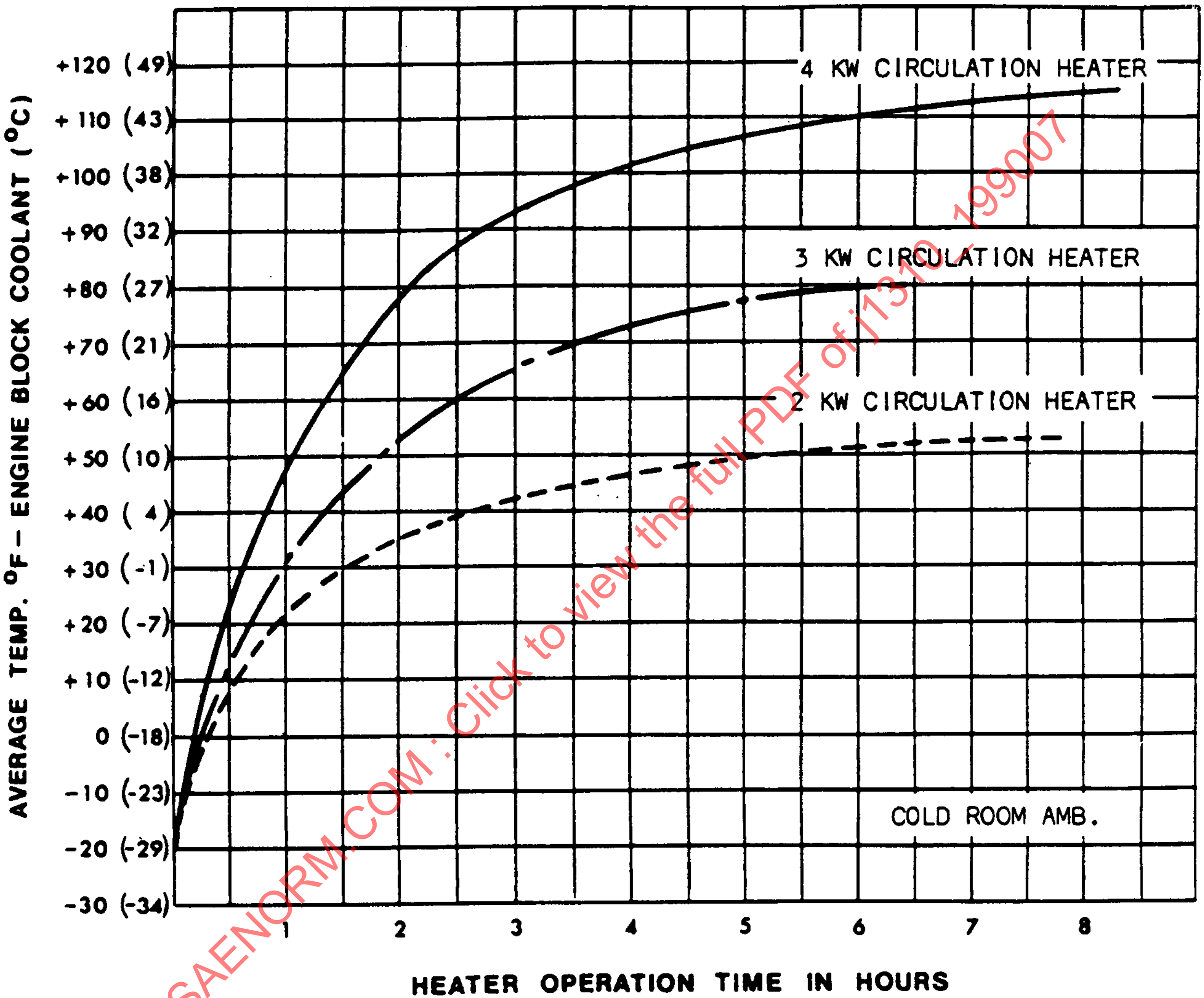

FIGURE A2 - Temperature Rise Curve - Circulation Heater Installed on Engine - Typical In-Line 6-Cylinder Diesel Engine, 855 CID (14 L)

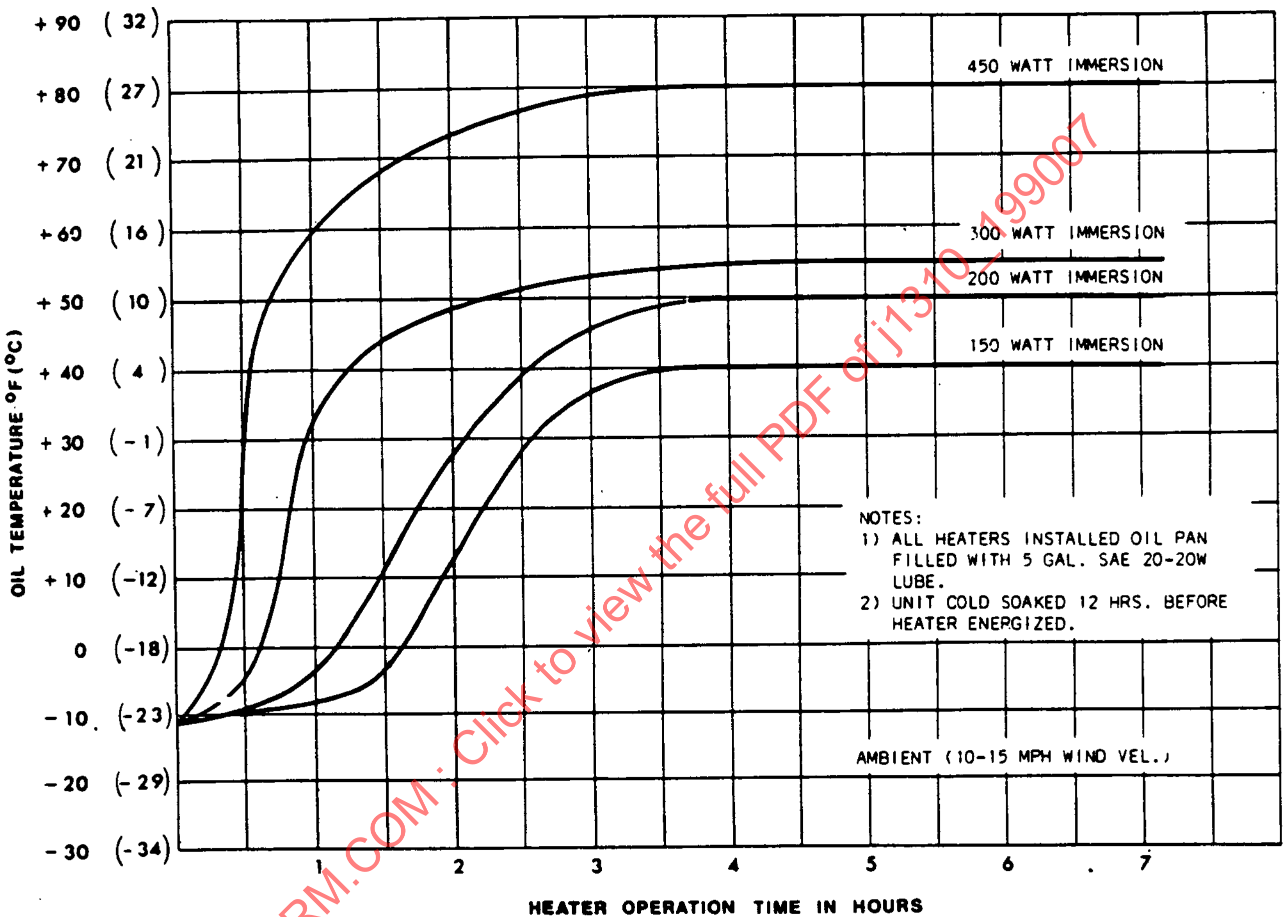

FIGURE A3 - Temperature Rise Curve - Oil Pan Heater
Installed in Typical Diesel Engine