Contract No:

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OSR 45-24 (Rev 1-20-2009)

Calculation Cover Sheet

Project/Task N/A	Calculation No. M-CLC-H-02758 Rev. 5	Project/Task No. N/A
Title Standby Diesel Generator Fuel Consumption Calculation	Functional Classification SC	Sheet 1 of 7
	Discipline MECHANICAL	
Calculation Type ☒ Type 1 ☐ Type 2	Type 1 Calc Status ☐ Preliminary ☒ Confirmed	
Computer Program No. ☒ N/A	Version/Release No. N/A	
Purpose and Objective This calculation will determine the minimum fuel quantity to ensure a Standby Diesel Generator can meet the required eight hours of continuous operation at the maximum expected steady state load of 574 KW determined per the Standby Diesel Generator Load Study.	DC/RO Date	

Summary of Conclusion

The changes implemented in this calculation require a minimum fuel quantity of 461 gallons to ensure a Standby DG can meet eight hours of continuous operation at the maximum expected steady state load of 574 KW per the Standby Diesel Generator Load Study.

Revisions

Rev #	Revision Description
5	Revised fuel consumption in conservative manner based on expected changes to ASTM D975 that includes API gravity value increasing to API 42 for diesel fuel. Resultant reduction in energy content will impact fuel consumption req'd to meet requirements.

Sign Off

Rev #	Originator (Print) Sign/Date	Verification/Checking Method	Verifier/Checker (Print) Sign/Date	Manager (Print) Sign/Date
5	JM 8/22/12	☐ Design Check (GS/PS only) ☒ Document Review ☐ Qualification Testing ☐ Alternate Calculation ☐ Operational Testing	8/22/2012	8/22/12
		☐ Design Check (GS/PS only) ☐ Document Review ☐ Qualification Testing ☐ Alternate Calculation ☐ Operational Testing		

Additional Reviewer (Print) N/A	Signature	Date
Design Authority (Print) James A. Mullner		Date 8/22/12.
Release to Outside Agency (Print) N/A	Signature	Date

Security Classification of the Calculation

Unclassified.

1.0 Table of Contents

2.0 References

1. SRS Engineering Standard Guide, 15591-G, Rev. 1, dated 11/17/09 – SRS Requirements for Diesel Fuel Quality.
2. ASTM D975, Standard Specification for Diesel Fuel Oils.
3. VPF AC05522A, Sheet 15, Rev. D, Diesel Fuel Oil Day Tank.
4. ANSI/HI 9.8-1998, American National Standard for Pump Intake Design.
5. API Technical Data Book, 4th Edition, Chapter 14, Combustion.
6. Bureau of Standards (NIST) Miscellaneous Publication No. 97- Thermal Properties of Petroleum Products.
7. Biodiesel Handling and Use Guide (4th Edition), NREL/TP-540-43672, National Renewable Energy Laboratory, US Department of Energy, 2009.

3.0 Introduction

This calculation determines the minimum stored fuel oil quantity to ensure continuous operation of a DG for eight hours to provide standby electrical power to the facility at the maximum expected steady-state load per ref. (5) in the event of a loss of utility power without refilling its respective tank.

The facility requires that the fuel oil day tank for each DG shall be filled within the required time after a shutdown. Facility operators procedurally verify the fuel level for each fuel oil day tank to be greater than or equal to the TSR-required minimum level. The fuel tank level calculation, which provides a tank calibration chart including uncertainty, is the basis for which to verify fuel level as documented per procedure in ref.

It should be noted that revision (1) of this calculation incorporated changes due to concerns identified in DOE Assessment 2009-000987 (DG Fuel Issue No. 2009-0039) as addressed by HMD Engineering in STAR item 2009-CTS-003502 (action items 10 and 11). This ensured the appropriate variables were considered for impact on fuel consumption, e.g., grade no. 2-D, S-15 ultra low sulfur (ULSD) diesel fuel, Biodiesel, API Gravity, etc., per site level guidance in ref. (7). In addition, changes incorporated in revision (1) resulted in a total rewrite.

A significant aspect of this revision will incorporate anticipated changes in ref. which will eventually result in the API gravity value of API 38 increasing up to API 42. This is discussed in ref. Consequently, this change will further reduce the heat content of the diesel fuel and require more fuel to meet the load requirements. In the previous revisions, the impact of using ULSD, biodiesel and increase from API 35 [as shown in OEM fuel consumption data per ref. (4)] to API 38 were conservatively estimated using industry experience and a rule of thumb per ref. This revision will more specifically determine the impact of these factors using a calculation from ref. (12) and data from ref. (13).

4.0 Inputs and Assumptions

- The fuel consumption rate at the nameplate rating of 725 kW Prime (continuous duty) is 56.7 Gal./Hour with radiator fan, per the vendor engine data sheet, ref. (4). This assumes use of ASTM D975 diesel fuel oil grade no. 2-D, S-500 (also referred to as "No. 2 Diesel" or "DF-2") as described in ref. (8) and (9). In addition, Engineering will assume this rate was determined using the high heating value per ref. for ASTM D975 No. 2 diesel fuel with a High Heating Value per ref.

- The maximum expected steady-state load for DGs is 574 KW, as documented in ref. (5). This value will be used to determine fuel consumption rather than the 254-19H DG nameplate rating of "725 KW Prime"(continuous duty).

- The following variables as described in ref. (7) will be incorporated into this calc;

    - ASTM D975 grade no. 2, S-15 (15ppm sulfur), ULSD fuel – has less heat content (BTU/Gal.) than grade no. 2 diesel S-500 (500 ppm sulfur) which was assumed in revision (0) of the calculation. This conservative 5% reduction in heat content for S-15 will result in an approximate 5% increase in fuel consumption for same DG output power. The 5% reduction in heat content for ULSD fuel is captured within the calculated net heat of combustion for API 42 diesel fuel and is therefore not required separately in the fuel consumption rate calculation as used in previous revisions of this document. Note: For the net heat of combustion calculation, the 15 ppm sulfur content is considered negligible as well as the water content factor, which is maintained at less than 0.05% by volume.

    - ASTM D975 grade no. 2, S-15, Biodiesel blend (B5) fuel – Biodiesel is basically a fuel derived from vegetable oils or animal fats. The B5 designation refers to a blend of 5% Biodiesel with 95% grade no. 2-D diesel. The potential changes in fuel consumption due to properties such as heat content in Biodiesel have not been quantified by industry or engine manufacturers. A conservative consideration of 1.0% reduction in heat content per ref. (14), however, will result in an approximate 1% increase in fuel consumption for the same DG output power

    - API Specific gravity – the present range for fuel delivered per Site Contract is API 30 – 39 per ref. (8). An expected loss of heat content per degree rise in API gravity in conjunction with assuming a maximum value of API 42 will result in an increase in fuel consumption for the same DG output power.

    - Unusable quantity of diesel fuel as documented below. This accounts for the fuel level required above the centerline of the fuel supply line per ref. (6) to prevent fluid vortex and the fuel below the centerline of the fuel supply line which is the heel as shown in ref. (10).

    - Recommended head space in FO Day tank in the range of 5% to 15% of tank capacity to allow for expansion of the stored fuel.

    - Parasitic Loads – The fuel consumption rate per the vendor, ref. (4), takes into account all attachments, including radiator fan which are considered as parasitic loads.

5.0 Analytical Methods and Calculations

The method utilized to develop this calculation will be a manual calculation to specify the fuel consumption rate and incorporates data from references (4), (12) and (13).

The amount of fuel required for the DG to operate eight hours continuously at the maximum expected steady state load can be determined as shown below. Per ref. (4), the fuel consumption rate is 56.7 gal./hr at 100% of nameplate rating and 42.8 gal./hr. at 75% (544 KW). Therefore the calculated fuel consumption rate, including variables described in Section 4.0, would be interpolated as follows;

$$\frac{56.7 - x}{725 - 573.13} = \frac{56.7 - 42.8}{725 - 544}$$

$$56.7 - x = \frac{151.87}{181} \times (13.9)$$

$$56.7 - x = 11.66$$

x = 45.04 gal./hr. fuel consumption rate at maximum expected steady state load.

The impact of using no. 2 diesel fuel with an API gravity value up to API 42 will be calculated per the equation for net heat of combustion (14A1.3-3) at 60 degrees F from ref. (12) as shown below. This will determine the Low Heating Value for ASTM D975 No. 2 Diesel Fuel with an API gravity value of API 42. This is in contrast to the assumption of High Heating Value of API 35 No. 2 diesel fuel which therefore provides additional conservatism to this variable. This calculation assumes a negligible amount of sulfur, water content or impurities.

$$\text{Hc 60 (net)} = 16{,}796 + 54.5(G) - 0.217(G)^2 - 0.0019\,(G)^{3;} \quad \text{(where G = API value of 42)}$$

$$\text{Hc 60 (net)} = 16{,}796 + 54.5(42) - 0.217(42)^2 - 0.0019\,(42)^3$$

$$\text{Hc 60 (net)} = 16{,}796 + 2{,}289 - 382.79 - 140.77$$

$$\text{Hc 60 (net)} = 18{,}561.44 \text{ BTU/lb.}$$

To determine the fuel consumption rate, this value is converted to units of BTU per gallon by using the specific gravity as determined by the following equation then converted to density as follows;

API 42 Diesel Fuel Specific Gravity at 60^0 F = 141.5 / (API + 131.5) = 141.5 / (131.5 + 42)

API 42 DF Sp. Grav. at 60^0 F = 0.81556 (Water Density at 60^0 F is 8.34lb./gal);

API 42 DF Density at 60^0 F is equal to 0.81556 x 8.34 lb./gal. = 6.802 lb./gal.

Net Heat of Combustion is (18,561.44 BTU / lb.) x (6.802 lb./gal.) = 126,252 BTU/gal.

5.0 Analytical Methods and Calculations (continued) -

The net heat of combustion (low heating value) for API 42 diesel fuel as calculated above is shown to have

9.04% less heat content than API 35 diesel fuel with a net heat of combustion of 139,400 BTU/gal. from ref(13). The values from this table for API and Net Heating Values of Petroleum Products) are accurate to

The fuel consumption rate that incorporates the calculated impact of using ASTM D975 No. 2 diesel fuel with B5 biodiesel content and an API 42 value is then determined as follows;

Fuel Consumption Rate (gal/hr) = (45.04 gal./hr.) x B5 variable (1%) x Increased API variable (10%)

45.04 x 1.01 x 1.10 = 50.0394 gal./hr.; rounded up to 50.1 gal./hr.

Each FO Day Tank is equipped with a fuel supply line as shown in reference (10) that is approximately 2-3/4 inches above the bottom of the tank. The following formula can be used to determine the height (S), above the centerline of the day tank fuel supply inlet pipe, that a liquid must be maintained to prevent fluid vortex, reference (11);

$$S(\text{in}) = D(\text{in}) + 0.574\frac{q(\text{USgpm})}{D(\text{in})^{1.5}}$$

D = 0.824 inches (internal diameter of 3 /4" schedule 40 pipe)
q = 1,260 Liters/hr, 5.54 gals./ min., Max. fuel flow to transfer pump [per Att. 8.5 of ref. (6)]

$$\mathbf{S}\ (\text{in}) = 0.824 + [\ 0.574 \text{ x } 5.54 \text{ x } \frac{1}{0.824^{1.5}}\ ]$$

$$\mathbf{S}\ (\text{in}) = 5.1 \text{ inches}$$

Therefore a minimum of 5.1 inches of fuel is required above the centerline of the fuel supply inlet pipe in the day tank to ensure that no air (which could choke out the engine) enters the fuel supply line due to fluid vortex. To accomplish this, 2.75 inches is added to account for the height of the supply pipe above the bottom of the FO day tank.

To ensure that adequate fuel can fill this ¾" supply pipe, at least 7.85 inches of fuel must remain in the bottom of the tank to prevent fluid vortex. Per reference (2), this value can be interpolated to be a quantity of 60.01 gallons of fuel.

The amount of fuel required to prevent vortex is the amount of fuel above the centerline of the fuel supply line. In addition, the amount of fuel below the centerline of the fuel supply line is the heel. The total of these values is approximately 60 gallons which is considered unusable. Therefore, total fuel required in the day tank to provide eight hours of continuous operation at maximum expected steady state load is as follows;

(50.1 gals./hr.) x (8 hrs.) = 400.8 gallons + 60.0gallons = 460.8 gallons; rounded up to 461 gallons.

6.0 Results

Taking into account the variables as described in Section 4.0, the fuel consumption rate is calculated to be 50.1 gals./hr. for the maximum expected steady state load as determined per the DG load study, ref. (5). This fuel consumption rate requires 461 gallons of fuel in the day tank to allow for eight hours of continuous operation at the maximum expected steady state load. This amount includes the 60 gallons of unusable fuel that encompasses the quantity of fuel to ensure no fluid vortex occurs during operation.

7.0 Conclusions

The maximum expected steady state load for a single DG per the load study, ref. (5), is 574 KW. Consequently, a minimum quantity of 461 gallons of diesel fuel is required in a fuel oil day tank to provide eight hours of continuous operation at this maximum expected steady state load for its respective DG.