Lemark Services
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[redacted]

June 3, 2021

RE: Data Analysis for Company/PCM Test Trailers

Dear M[redacted]

Lemark Services was asked to review the data provided from the testing done April 12th and April 13 at the Company facility, in xxxxx, Florida. Our findings are noted below:

A. Data provided for this analysis:

1. There is Reefer History Grid provided by ORBCOMM. The data tracks various run parameters for a control trailer, and two test trailers.
2. A test summary provided by Phase Change Solutions; the power point is titled Apollo Smart Unit (ASU) Pilot Project Analysis.
3. ASU 1 and ASU 2 data logger outputs
4. Diesel Engine Start Stop Data

B. Findings:

1. The scope of this study was to understand the mechanism for the apparent reduction in energy usage while charged ASUs were loaded on reefer trucks, and to quantify the possible cost savings of having ASU's or PCM panels installed in the truck.
2. During the analysis it was determined that the PCM cubes are sized as follows
   a) ASU1-Gen 1 Panel with 170 BTU storage per panel.
      (1) 3.9 ton-hr
      (2) 46,800 BTU (stored as latent heat (in the phase change)
      (3) Additional sensible energy is stored, up to 36,000-43000 BTUs, depending on the charging freezer temperature.
   b) ASU2- Gen 1 Panel with 350 BTU storage per panel.
      (1) 4.375 ton-hr
      (2) 52,500 BTU (stored as latent heat (in the phase change)
      (3) Additional sensible energy is stored, up to 36,000-43,000 BTUs, depending on the charging freezer temperature.
3. Using the ASHRAE 2014 Handbook for Refrigeration systems, the UA value (overall heat transfer coefficient multiplied by the area of a truck), is 150 BTU/(hr-deg F)
   a) For a truck cooled to 0 deg F on an 80 deg day, the heat load is: 12000 BTU/hr
   b) The loads vary based on ambient temperature and the refrigerated truck target temperature.

4. Carrier Refrigerated (reefer) trailers:
    a) Typical refrigeration system on a Carrier truck is a maximum of 21,000 BTU/hr
    b) Takes .3 to .38 gal/hr to run their reefrer trailers.
5. Calculated cost to cool a PCM ASU using an average cost of $4 per gal for diesel and $.07 per kw-hr for electricity.
    a) Using the annual walk-in efficiency factor (AWEF) which is "a ratio of the total heat, not including the heat generated by compressors, the operation of refrigeration systems, removed, in Btu, from a walk-in box during a one-year period of usage for refrigeration to the total energy input of refrigeration systems, in watt-hours, during the same period."
    b) Minimum AWEF (Btu/W-h) of a unit cooler with a net capacity (qnet) of: ≥ 15,500 Btu/h is 4.15.
    c) Charge a PCM using electric $.50
    d) Charge using diesel in a carrier trailer is about $6 due to most of the energy being used to cool the empty trailer itself.

C. Theory of how the ASUs specifically and PCM material generally save diesel fuel.

1. For Company the typical load temperature swing is up to 10 deg F.
    a) This is equal to approximately 342,000 BTUs absorbed by the load on a 38,000 lb loaded trailer, with the load allowed to heat up 10 deg F during the trip.
    b) Not all loads will heat 10 deg F.
2. On a long trip a cube may be able to store between 1/8 and ¼ of the BTUs required to keep the trailer in temperature specification.
3. The reefer truck evaporator fans are off when the diesel/electric generator is off on the reefer truck.
4. The ASU appear to provide additional air movement in the interstitial space between the truck walls and the refrigerated load. This movement along with a small portion of the ambient energy being transferred into the ASU, cause the air to remain below the thermostat target temperature, and therefore the diesel electric generator does not activate as often or for as long as in the control trailer.
5. These tests did not include any heat of respiration from the refrigerated foods, as would happen if the trailer was filled with fresh food.

CI. Results:

1. The average ambient temperatures during each test:
    a) Control Trailer: 81 deg F
    b) ASU1 Trailer: 76 Deg F
    c) ASU2 Trailer: 77 Deg F

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2. Based on degree days (Average Daily Temp – Set point (34 deg)) the energy required to cool each trailer is expected to be:
    a) Control Trailer: 169,200 BTU/24 hr period
    b) ASU1 Trailer: 151,200 BTU/24 hr period
    c) ASU2 Trailer: 154,800 F BTU/24 hr period
    d) Note the expected additional energy required in the control trailer is about 11% more than in the ASU1 trailer and 9% more than the ASU2 Trailer.
3. The fuel required for each test.
    a) Control Trailer: 8.2 gal
    b) ASU1 Trailer: 1.0 gal (Control is 820% higher)
    c) ASU2 Trailer: 3.0 gal (Control is 273% higher)
        (1) Note ASU2 was removed from the freezer and sat on the 50 deg F loading dock for approximately 8.5 hrs. before being placed on the test trailer with refrigerated product.
4. Approximate fuel and electricity cost for each test:
    a) Control Trailer: Fuel only: $32
    b) ASU1 Trailer: Fuel and Elect: $4.50
    c) ASU2 Trailer: Fuel and Elect: $12.50

E. Summary:

This test data showed that when the ASUs with the phase change materials were loaded on the trucks, they had a large effect on the fuel saved. In one case over 700% savings on energy costs, and in other case 256% savings on energy costs.

The ASUs phase change material load, along with their circulation capabilities, appear to be cooling the air in the interstitial space between the load and the walls and roof of the trailer. Over the test period approximately ½ of the required energy is being pulled into the ASU units and the other half is drawn into the refrigerated load and the reefer evaporators. The addition of the precooled ASU dramatically reduced the energy load to the reefer evaporators and thus dramatically reduced the diesel fuel usage.

Further testing will have to be done to verify the exact ratios of energy being drawn out by the reefer evaporators and the amount of energy absorbed by the precooled load itself, versus the ASU, or panels if installed on the ceilings and upper walls of the reefer trailer. I would expect the fuel usage to be reduced in a similar manner for both the ASU fitted truck and the panel fitted trucks if they are precooled in a similar manner.

If you have further questions about the points noted above, please call me for clarification.

Regards,

Christopher M. Hahn P.E., P. Eng

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