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FUEL CONSUMPTION MEASUREMENT METHOD FOR VEHICLE POWERED REFRIGERATION UNITS BASED ON A CONCEPTION OF STANDARD VEHICLE ENGINE

(Description of the test)

Transmitted by the Government of the Czech Republic

This procedure describes the measurement method for the fuel consumption determination of vehicle powered refrigeration units, it means of the diesel vehicle engine fuel consumption increment when the unit is on.

The relevant measurement procedure guarantees the standard operating conditions of tested refrigeration unit and excludes the influence of all the random effects as for example of particular truck and truck engine type, particular test road & driver's style, indistinct real load (capacity) of the unit and the like. The basic principle is the test laboratory measurement of total input power indispensable to drive the unit and its recalculation on the fuel consumption of a standard engine.

Properly speaking, no vehicle powered refrigeration unit has its own fuel consumption. Its economy can be fully described by indispensable input power measured under well-defined conditions. The majority of customers, however, prefer to speak about the consumption of diesel oil, which is what they have to pay. For that reason it makes sense to deal with the fuel consumption in case of vehicle powered units as well.

Three standards
Three standards have been introduced and used to determine the fuel consumption increment induced by the operation of refrigeration unit:

- Standard diesel engine with standard specific fuel consumption $\mathbf{c_S}$ = 165 g/(kW. h).
- Standard vehicle alternator efficiency: $\boldsymbol{\varepsilon}$ = 50 %
- Standard diesel fuel specific density: $\boldsymbol{\rho}$ = 836 g/l.

Measurement of the input power needed to drive the unit
The most frequent arrangement is supposed: Refrigeration compressor or a special electric generator supplying refrigeration unit is driven from the vehicle engine crankshaft (usually by a belt drive). Using a suitable design of power pack in the test station, the torque $\boldsymbol{\tau}$ [N.m] &

operating rotational speed ***n*** [RPM] are measured and input power $\mathbf{P_1}$ [kW] on the shaft of the compressor or generator is calculated.

Concept of a standard engine
Introducing the concept of a standard engine, we can exclude the effect of a real truck type. Specific fuel consumption of such a standard engine is the key parameter in this case. Let's assume that the standard diesel engine has the standard specific fuel consumption $\mathbf{c_S = 165}$ **g/(kW . h)**.

Vehicle-powered unit taking also current of the standard (or auxiliary) vehicle alternator
There are also vehicle-powered units taking besides electric current of the standard (or auxiliary) vehicle alternator, or from vehicle batteries, usually to drive electric fans and blowers. In this case total input power **P** [kW] that vehicle engine has to deliver to refrigeration unit consists of compressor input $\mathbf{P_1}$ and of alternator input $\mathbf{P_2}$ for the fans:
$\mathbf{P = P_1 + P_2.}$

Regarding the shaft power $\mathbf{P_2}$ of a standard or auxiliary alternator determined from electric measurement, we have to deal with the efficiency of such vehicle alternators (usually 24 V dc, 100 A to 150 A). These alternators reach 60 % to 65 % efficiency at 1 500 RPM to 1 800 RPM, but this efficiency falls at higher alternator speed (to 45 % to 48 % at 6 000 RPM). 6 000 RPM is usual alternator operating speed. Reasonable alternator efficiency estimation for these calculations is **50 %**.

Alternator efficiency **ε** for these calculations is postulated 50 % (see one of the three standards mentioned above). Accordingly, if $\mathbf{P_{fans}}$ is total electric input needed to drive the fans, alternator shaft input $\mathbf{P_2 = 2 \times P_{fans}.}$

If **P** [kW] is the total refrigeration unit input power at specific operating conditions, when the unit gives cooling capacity **Q** [kW], then the fuel consumption by weight $\mathbf{C_{fw}}$ [g/h] of tested refrigeration unit can be calculated as

$$\mathbf{C_{fw}}\ [g/h] = \mathbf{P \times c_S = 165 \times P.}$$

Consumption by weight and by volume
The consumption by weight (measured in g/h) can be converted to the consumption by volume (measured in l/h) if one knows the specific density **ρ** of diesel fuel. This density varies from 830 kg/m^3 (winter) to 842 kg/m^3 (summer). Standard (mean) value of the specific density **ρ** = 836 kg/m^3 = 836 g/l has been used for purposes of this directive (the third of the standards
mentioned above).

Test equipment
The test shall be carried out inside the ATP test station under ATP test conditions (0 °C/+30 °C, possibly also -20 °C/+30 °C). If the dc electric current from vehicle alternator supplies fans and blowers separately, then this current has to be measured at standard alternator voltage 24 V dc or 12 V dc.

In that way, vehicle powered refrigeration unit fuel consumption measurement can be carried out as a normal part of ATP capacity test of the refrigeration unit installed on an isothermal

body of a truck or installed on a special calorimeter inside the test station. In any case the tested unit should be supplied from a special power pack, not from the engine of the truck located inside the test station.

Measuring instruments
Power pack equipped with a strong enough electric motor capable to drive either refrigeration compressor or electric generator of tested unit. It is advantageous to supply this electric motor from a frequency inverter to have possibility to control the speed of the compressor or of the electric generator continuously.

Torque transducer (part of above mentioned power pack) for the torque measurement on the shaft of the compressor or electric generator.

Optical speed sensor (part of above mentioned power pack) for the rotational speed measurement on the shaft of the compressor or electric generator.

In case of a unit taking besides electric current of the standard or auxiliary vehicle alternator:
- another power pack with the auxiliary vehicle alternator;
- usual meters of electric values for the measurement of total electric input $\mathbf{P_{fans}}$ needed to drive the fans.

Test recordings
The recordings shall be printed; they shall include at least the following:

- Date of the test;
- Identification of the transport equipment tested;
- Operating conditions of tested refrigeration unit (for example 0 °C/+30 °C according to the ATP test conditions);
- Refrigeration capacity **Q** [kW] of tested unit measured according to the ATP standards.
- Torque $\boldsymbol{\tau}$ [N.m] and rotational speed $\boldsymbol{n}$ [RPM] measured on the shaft of compressor (or electric generator), and calculated input power $\mathbf{P_1}$ [kW];
- Battery voltage, total electric input current and total electric input power $\mathbf{P_{fans}}$ [kW] needed to drive the fans (in case of a unit taking besides electric current of the standard or auxiliary vehicle alternator, or from vehicle batteries);
- Calculated alternator shaft input $\mathbf{P_2}$ [kW] = $\mathbf{2 \times P_{fans}}$;
- Total input power **P** [kW] that vehicle engine has to deliver to refrigeration unit;
- Fuel consumption by weight $\mathbf{C_{fw}}$ of tested refrigeration unit (calculated as $\mathbf{C_{fw}}$ [g/h] = **P** x $\mathbf{c_s = 165}$ x **P)**;
- Fuel consumption by volume $\mathbf{C_{fvol}}$ of tested refrigeration unit (calculated as $\mathbf{C_{fvol}}$ [l/h]= $\mathbf{C_{fw} / 836}$);

– Specific fuel consumption $\mathbf{c_{fvol}}$ (consumption by volume reduced to 1 kW of refrigeration capacity): $\mathbf{c_{fvol}}$ [l/(h. kW)] = $\mathbf{C_{fvol}}$ /**Q**
  Specific fuel consumption is the quantity suitable to compare economy of the units of unlike refrigeration capacities.

– Name of the person in charge of the test;

– Identification of the measuring apparatus.

Preparation of the test
Standard installation for the refrigeration capacity test with one less common feature: It is a vehicle-powered unit whose supply in the test laboratory has to be provided from a special power pack.

– install the tested unit on the calorimeter body complying with the ATP installation instructions concerning all the needed sensors;

– install the refrigeration compressor (or electric generator) on the power pack complying with the installation instructions of the torque transducer manufacturer;

– in case of a unit taking besides electric current of the standard or auxiliary vehicle alternator, or from vehicle batteries, install another power pack with the auxiliary vehicle alternator;

– interconnect refrigerant hoses (if refrigeration compressor is installed on the power pack) or electric cables (if electric generator is installed on the power pack) with tested unit;

– in case of a unit taking besides electric current of the standard or auxiliary vehicle alternator, connect dc electric supply of the fans;
– connection and activation of the data acquisition system depends on the data acquisition and control systems used in the particular test laboratory.

Progress of the test
Find out nominal speed of the compressor or of the electric generator from the data of the unit manufacturer, set this rotation speed on the power pack and switch on the power pack.

In case of a unit taking besides electric current of the standard or auxiliary vehicle alternator, switch on the second power pack with the auxiliary alternator. Set suitable alternator speed (usually 6 000 RPM) and set accurately the alternator voltage **U** = 24 V dc (or 12 V dc).

Switch on the tested unit and measure its refrigeration capacity **Q** under ATP test conditions. After the temperatures are balanced and the capacity **Q** is measured, read the compressor (or electric generator) torque and rotation speed, possibly also the electric current **I** from the second power pack.

Record all the measured values and calculate total input power **P**, and fuel consumptions $\mathbf{C_{fw}}$ by weight and $\mathbf{C_{fvol}}$ by volume.

Use following relations to calculate individual intermediate and final results:

$\mathbf{P_1}$ [kW] = 1/1000 x $\boldsymbol{\tau}$ [N.m] x 2π/60 x $\boldsymbol{n}$ [RPM]

$\mathbf{P_{fans}}$ [kW] = 1/1000 x **U** [V] x **I** [A]

$\mathbf{P_2}$ [kW] = 2 x $\mathbf{P_{fans}}$ [kW]

P [kW] = $\mathbf{P_1}$ [kW] + $\mathbf{P_2}$ [kW]

$\mathbf{C_{fw}}$ [g/h] = 165 g/(kW. h) x **P** [kW]

$\mathbf{C_{fvol}}$ [l/h] = $\mathbf{C_{fw}}$ [g/h] / 836 [g/l]

$\mathbf{c_{fvol}}$ [l/(h. kW)] = $\mathbf{C_{fvol}}$ [l/h] /**Q** [kW]

Interpretation of the test results

The fuel consumption of the unit shall be presented only together with other critical data: Refrigeration capacity **Q**, temperature conditions (for example 0 °C/+30 °C), compressor or electric generator speed ***n***, auxiliary alternator speed, voltage **U** and current **I**.

In practical operation, we can expect lower fuel consumption because the unit usually doesn't operate permanently with its nominal capacity. After the pull down stage, the temperature inside the cooled compartment decreases, and the input power (together with the fuel consumption) of the unit decreases too.

Definitions[1]

Definitions	Remarks
Vehicle powered unit: a transport refrigeration unit driven by vehicle engine.	Vehicle powered refrigeration units use vehicle engine as primary source of energy, they don't have its own internal engine. Refrigeration compressor or, in case of electric units, a special electric generator is usually installed on the vehicle engine block and powered from the engine crankshaft. Other arrangements are also possible. Standby operation (vehicle stationary, vehicle engine off, refrigeration unit is supplied electrically from public network) is often used too.
Vehicle powered unit fuel consumption: diesel vehicle engine fuel consumption increment when the refrigeration unit is on.	As vehicle powered unit hasn't its own engine, it is not quite easy to measure "its fuel consumption". Properly speaking, vehicle powered unit has no direct fuel consumption. On the other hand, such a unit in operation loads vehicle engine, which comes through the increased vehicle engine fuel consumption.
Standard diesel vehicle engine: Imaginary vehicle engine made-up for the use of this instruction.	Standard diesel vehicle engine with unified (or standard) specific fuel consumption 165 g/(kW. h) enables to exclude the influence of individual real engines. This concept excludes influences of various engine types and it makes it possible to gain fuel consumption results depending only on the parameters of the tested refrigeration unit.
Compliance with ATP means that equipment must meet the specific conditions (see the remarks) in order to comply with ATP.	They belong to a series in which a ***model*** has undergone a complete test of the equipment (body and unit), or more generally separate tests of the body and the unit. These tests shall be carried out in an ATP-recognized laboratory and certified by the issue of the relevant test report(s). - They are certified by the competent authority.
Standard alternator efficiency is a constant efficiency 50 % defined for the use of this instruction.	Some vehicle-powered units take also current of the standard or auxiliary vehicle alternator usually to drive electric fans. Such alternators reach 60 % to 65 % efficiency at 1 500 RPM to 1 800 RPM, but this efficiency falls at higher alternator speed (to 45 % to 48 % at 6 000 RPM). 6 000 RPM is usual alternator

[1] Words in ***bold italics*** are given definitions.

	operating speed. Reasonable alternator efficiency estimation for the shaft power calculations from measured electric power is 50 %.
Fuel consumption by volume of the tested refrigeration unit is diesel vehicle engine fuel consumption increment measured in l/h when the unit is on.	It is more usual to express vehicle fuel consumption in litres (by volume) than in g or in kg (by mass, possibly weight). Using the specific density **ρ** of the fuel, reciprocal conversion is easy.

Definitions	Remarks
Fuel consumption by weight of the tested refrigeration unit is diesel vehicle engine fuel consumption increment measured in g/h when the unit is on.	Standard diesel vehicle engine consumes 165 g/h of diesel fuel per each kW of output power (according to the definition). If the refrigeration unit needs **P** kW to operate at given conditions, then the product (165 x **P**) represents that part of the total engine consumption, which is connected with the operation of refrigeration unit.
Specific fuel consumption is the value suitable to compare economy of the refrigeration units of unlike refrigeration capacities.	When comparing economy of the refrigeration units of unlike refrigeration capacities, mere indication denominated in l/h tells nothing. In such a case, consumption by volume reduced to 1 kW of refrigeration capacity is a useful criterion.

Abbreviations and units

Abbreviation	Meaning	Unit

Three standards introduced in this instruction

$\mathbf{c_S}$	Standard specific fuel consumption of the standard diesel vehicle engine.	g/(kW. h)
ε	Standard vehicle alternator efficiency.	%
ρ	Standard diesel fuel specific density.	g/l (or kg/m^3)

Other values and units used in this instruction

τ	Torque measured on the shaft of the refrigeration compressor or on the shaft of the electric generator supplying tested unit.	N.m
n	Angular (rotational) speed measured on the shaft of the refrigeration compressor or on the shaft of the electric generator supplying tested unit expressed in technical units.	min^{-1} (or RPM)

$\mathbf{P_1}$	Calculated input power on the shaft of the refrigeration compressor or on the shaft of electric generator supplying tested unit.	kW
$\mathbf{P_{fans}}$	Total electric input needed to drive the fans of the tested unit (applicable only in case of refrigeration units taking besides electric current of the standard or auxiliary vehicle alternator).	kW
$\mathbf{P_2}$	Shaft power of a standard or auxiliary alternator (determined from electric measurement at nominal voltage taking into account alternator efficiency **ε**).	kW
P	Total input power that vehicle engine has to deliver to the tested refrigeration unit.	kW
Q	Cooling capacity of the tested refrigeration unit under defined (ATP) test conditions.	kW
$\mathbf{C_{fw}}$	Fuel consumption by weight of the tested refrigeration unit (diesel vehicle engine fuel consumption increment when the unit is on).	g/h
$\mathbf{C_{fvol}}$	Fuel consumption by volume of the tested refrigeration unit.	l/h
$\mathbf{c_{fvol}}$	Specific fuel consumption suitable to compare economy of the refrigeration units of unlike refrigeration capacities (consumption by volume reduced to 1 kW of refrigeration capacity).	l/(kW.h)