Fuel consumption of vehicle powered refrigeration units

How to measure it?
Test method proposal

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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.

What does it mean fuel consumption of a vehicle-powered unit?

Fuel consumption of vehicle powered unit =
vehicle engine fuel consumption increment when the unit is on.

In addition to the refrigeration unit properties, it generally depends on a whole range of external parameters:

- ambient and in-box temperatures
- set point and actual refrigeration capacity
- particular truck type and truck engine type
- test track and driver's style
- insulation properties (K-value) of the isothermal box

We have to eliminate influence of these external parameters and to determine the fuel consumption depending only on the refrigeration unit properties.

How not to proceed

Seemingly easy way of fuel consumption measurement:

- Install the unit on a truck
- Measure **primary** consumption of the truck (unit off) on a test road
- Measure **aggregate** consumption of the same truck (unit on) on the same test road
- Difference in both consumptions (**aggregate - primary**) equals consumption of tested unit.

Drawbacks of this “seemingly easy way”:

- One can hardly influence operating conditions (ambient temperature above all).
- It is difficult to measure refrigeration capacity of the unit on a going truck.
- Results are connected with all the above mentioned external parameters (particular truck type, particular test road & operating conditions, driver’s style).
- No information about real load (capacity) of unit.

Suitable to a very limited extend only for comparison tests, no “absolute” results, no characterization of general features of the unit.

Therefore, how to proceed?

It is beneficial to organize all the measurements under well defined conditions in a test station and to exclude the influence of a specific truck type.

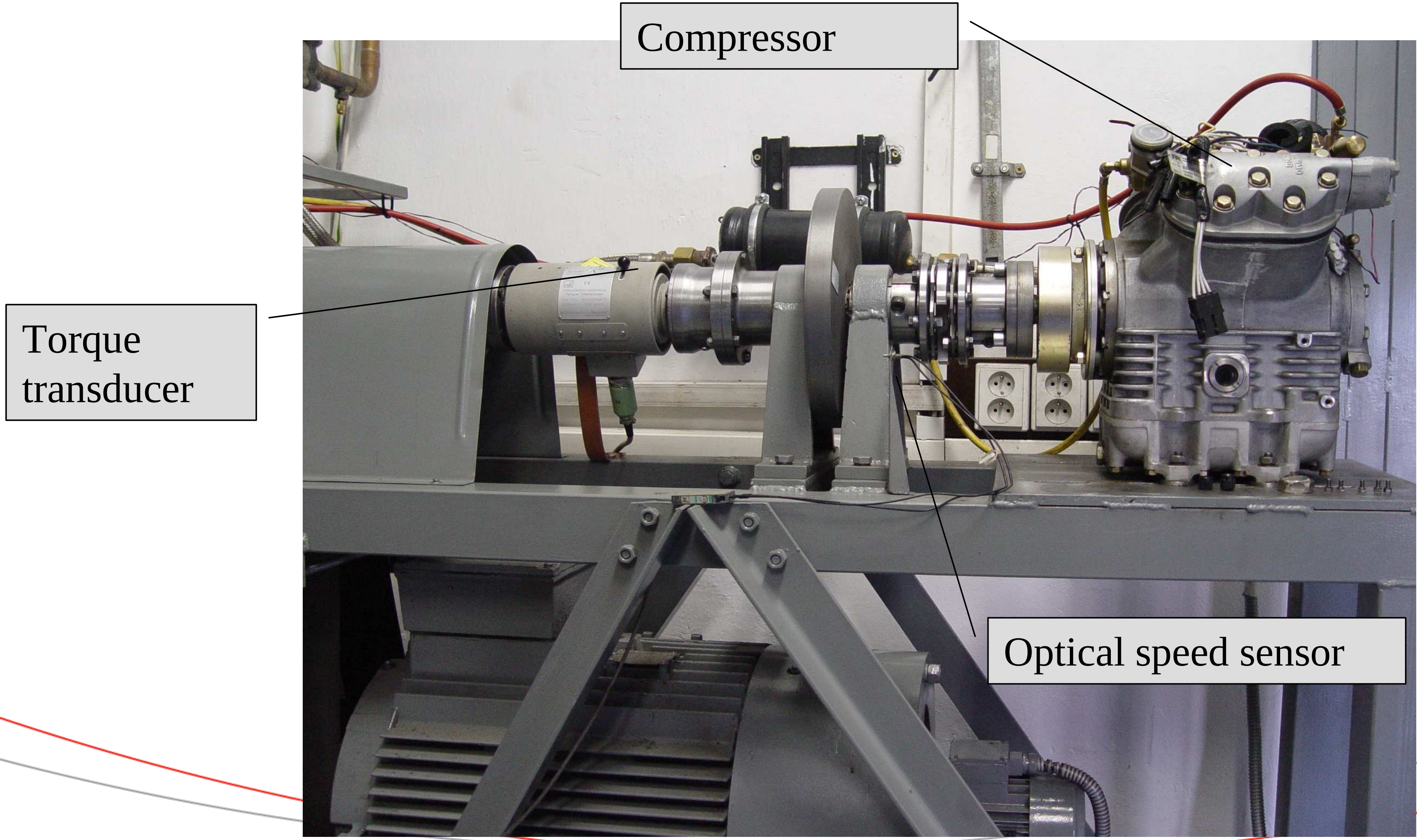
It means to be focused on the refrigeration unit itself, to measure its input power and to recalculate it on the fuel consumption of a standard engine.

Measurement of the input power needed to drive the unit

- Let's suppose the most frequent arrangement: Refrigeration compressor or electric generator is driven from the engine crankshaft by a belt drive.

- Using a suitable design of power pack in the test station, we can measure the torque τ [N.m] & operating rotational speed ***n*** [RPM] and calculate input power **P [kW]** on the shaft of the compressor or generator.

An example of a test stand



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 **c_s = 165 g/(kW . h)**.
- If **P [kW]** is the compressor or generator shaft input power at specific operating conditions, then we can calculate fuel consumption **C_f** of the refrigeration unit

$$C_f\ [g/h] = c_s \times P = 165\ .P$$

Numerical example No 1

Electric refrigeration unit (supplied from a generator driven by the truck engine) has the capacity **Q** =10.4 kW at 0 ℃/+30 ℃.
This unit takes input power **P** = 9.5 kW from the truck engine; this input power covers entire input of the unit, i.e. input of refrigeration compressor + input of all fans + input of whatever possible further consumers.

Then, its standard fuel consumption

$$\mathbf{C_f = 165 \times P = 165 \times 9.5 = 1.57 \times 10^3\ g/h}$$

We can introduce also the specific fuel consumption $\mathbf{c_f}$ (consumption reduced to 1 kW of refrigeration capacity):

$$\mathbf{c_f = C_f/Q = 1.57 \times 10^3/10.4 = 151\ g/(h.kW)}$$

Specific fuel consumption $\mathbf{c_f}$ is the quantity suitable to compare economy of the units of unlike refrigeration capacities.

Vehicle-powered unit taking also current of the standard (or auxiliary) vehicle alternator

Typical example: truck unit with an open compressor driven mechanically by truck engine and with all the electric fans (24 V dc) supplied from vehicle battery (= from vehicle alternator).

In this case total input power **P** 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:

$$P = P_1 + P_2$$

Vehicle-powered unit taking also current of the standard (or auxiliary) vehicle alternator

Regarding alternator shaft power $\mathbf{P_2}$, we have to deal with the efficiency of vehicle alternators (usually 24 V dc, 100 A to 150 A) used to supply for example fans and blowers. 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 %**.

Accordingly, if $\mathbf{P_{fans}}$ is total electric input needed to drive the fans, alternator shaft input $\mathbf{P_2 = 2 \times P_{fans}}$ and vehicle engine has to deliver total input power

$$P = P_1 + 2 \times P_{fans}.$$

Numerical example No 2

A small vehicle powered refrigeration unit with electric fans supplied from vehicle battery has cooling capacity **Q** = 3.39 kW at standard conditions (0/+30 ℃, compressor speed 2 400 RPM). It consumes compressor input P_1 = 1.7 kW and in addition to 27.4 A at 12 V dc. Thus P_{fans} = 27.4 x 12 = 0.33 kW.

Consequently **P** = P_1 + 2 x P_{fans} = 1.7 + 2 x 0.33 ≅ 2.36 kW.

Then, its standard fuel consumption

$$\mathbf{C_f = 165 \times P = 165 \times 2.36 = 389\ g/h,}$$

and the specific fuel consumption $\mathbf{c_f}$ (consumption reduced to 1 kW of cooling capacity):

$$\mathbf{c_f = C_f/Q = 389/3.39 = 115\ g/(h.kW)}$$

Fuel consumption
by weight & by volume

It is easy to convert the consumption by weight (measured in g/h) 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). Let's use some standard (mean) value of the specific density

$$\rho = 836\ kg/m^3 = 836\ g/l.$$

Then for example (taking results of example No 1)

C_f **= 1.57 x** 10^3 **g/h** (by weight) corresponds to

1.57 x $10^3/836 \cong$ **1.9 l/h** (by volume)

or

$c_f = C_f/Q$ **= 151 g/(h.kW)** (by weight) corresponds to

151/836 $\cong$ **0.18 l/(h.kW)** (by volume)**.**

Recapitulation (1)

3 standards introduced:

- **standard vehicle engine: c_s = 165 g/(kW . h).**
- **standard vehicle alternator efficiency: 50 %**
- **standard diesel fuel specific density: 836 g/l**

- **It is essential to measure the fuel consumption C_f of refrigeration units in a test laboratory under well defined conditions and at standardly loaded units.**
- **Proper conditions:**
  0 ℃/+30 ℃ and -20 ℃/+30 ℃ (ATP conditions)
- **If fans and blowers are supplied separately by the dc electric current from vehicle alternator, then this current has to be measured at standard alternator voltage 24 V dc or 12 V dc.**

Recapitulation (2)

- **The introduction of "standard vehicle engine" with standard specific fuel consumption c_s = 165 g/(kW . h), the introduction of standard alternator efficiency 50 %, the measurement of total input power that the unit absorbs and its recalculation to the fuel consumption enable to exclude the effect of particular vehicle engine, vehicle type, driver's style, test track, insulation properties (K-value) of the isothermal box and of indefinite ambient conditions.**

- **Mean (standard) specific density of diesel fuel ρ = 836 kg/m^3 = 836 g/l enables the expression of the consumption also by volume.**

- **Specific fuel consumption c_f is the quantity suitable to compare economy of the units of unlike refrigeration capacities.**

Comment

This test procedure – if generally accepted – will enable to report reliable and mutually comparable fuel consumption data of vehicle powered cooling units. As it is based on the measurement of total input power at nominal refrigeration capacity, resulting (standard) fuel consumption will represent a value close to maximum thinkable fuel consumption of such a unit.

However, 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 input power (together with fuel consumption) of the unit decreases too.