DENSITY MEASUREMENTS OF FOSSIL FUELS BLENDED WITH BIOFUELS TO DETERMINE TEMPERATURE CONVERSION FACTORS FOR LEGAL METROLOGY

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Abstract − In a national project preceding the European project EMRP ENG09 Metrology for biofuels, several fuel blends were investigated at the Physikalisch-Technische Bundesanstalt (PTB). Density data were measured for mixtures of fossil petrol with ethanol and for fossil diesel with biodiesel.

The volume concentration of the biofuels component varied between 0% and 100% to have data available for all possible mixtures. The data were measured in a temperature range between -10 °C and +50 °C. The measurement data were obtained by using a modified Anton Paar DMA 5000.

Keywords biofuel, density

1. INTRODUCTION

Biofuels are thought to be one way to reduce the CO_2 emission into the atmosphere. Commonly these fuels are plant-based and, thus, run under the name biofuels. The main groups of biofuels nowadays available at the market are ethanol, which can be blended with fossil petrol, and methyl esters of some oils, which can be blended with fossil diesel, e. g. rape seed oil or soy bean oil or palm oil.

The European directive 2009/28/EC [1] demands that "Each Member State shall ensure that the share of energy from renewable sources in all forms of transport in 2020 is at least 10 % of the final consumption of energy in transport in that Member State." Thus, usually a mixture of fossil fuels with biofuels is offered in most European countries with the percentage of biofuel growing from year to year.

To ensure proper trade and an adequate adaption of engines to such mixtures their material data have to be known with sufficient uncertainty. As liquid fuels are usually measured not as mass but as volume the knowledge of their density including its temperature dependence is a very important quantity. These data are used for a temperature conversion of the measured volumes to a standard volume at 15 °C.

Apart from the legal requirements the material data are important inputs for process control in automotive industries.

2. MEASUREMENT PROCEDURE

Density measurements were performed using a DMA 5000 by Anton Paar, modified to be able to measure down to -20 °C. The temperature dependence of the density was determined in each case in the temperature range between -10 °C and +50 °C. This was done by stepping the temperature in steps of 5 K from -10 °C to +50 °C for petrol and vice versa for diesel. The direction of the temperature scan was different at petrol blends and at diesel blends to minimize temperature effects on the material's parameter.

A typical difficulty of these experiments comes from possible changes in the composition in the investigated materials caused by evaporation effects. This is in particular for petrol blends the main source of bad reproducible results. For diesel fuels the beginning solidification at low temperatures can influence the material's parameters.

A considerable advantage of the device used in the present experiments is that its construction allows the nearly complete avoidance of evaporation effects.

The uncertainty of these measurements is smaller than 0,02 kg/m³.

3. MEASUREMENT RESULTS

Within the project at PTB the range of mixtures was not restricted to a percentage of biofuel at the 10 % level but the full range from 0 % biofuel content (pure fossil fuel) up to 100 % biofuel content (pure biofuel) was investigated to have data available in the case that the fraction of biofuel given by law will increase further.

The investigation covered blends of petrol (octane number 95) with ethanol, blends of diesel with rape seed methyl ester (RME), with soy bean methyl ester (SME), and with palm oil methyl ester (PME). The first two types of biodiesels are commonly available at the European market, PME is the most important biodiesel in the tropics and subtropics. Both the blends with summer quality and winter quality of the fossil fuels common in Germany were investigated.

3.1. Approximation of the temperature dependence of the density

One important issue of the studies was to infer a recommendation for the description of the temperature dependence of the density. Therefore, the description of the temperature dependence of measured data by the exponential description used up to now in legal metrology for the temperature conversion of volumes [2] was compared to polynomial approximations of first, second, and third order. These comparisons showed an excellent description of the temperature dependence of the density by a polynomial of third order with relative deviations between measured data and approximation at the 10^{-6} level. Furthermore diesel blends can be described very well by a linear approximation. The maximum relative deviation

between the measured data and the approximation is smaller than 10^{-5}. The linear approximation for petrol blends shows larger deviations, but the relative values are still below 10^{-3}.

In both cases it is ensured, that a linear approximation of the temperature dependence of density allows a temperature conversion with an uncertainty smaller than 0,2 %, which is the maximum permissible error of the temperature conversion in Germany.

Based on these results it is recommended in the meantime, that in Germany the linear temperature conversion can be used for legal purposes.

3.2. Variation of the density for blends of fossil petrol with ethanol

The density of the pure fossil petrol studied in the PTB experiments was 742,31 kg/m³ for summer quality, and 733,89 kg/m³ for winter quality. When blending with ethanol the density increases nearly linearly up to a value of 794,0 kg/m³, the value for pure ethanol. These data were measured at 15 °C and are shown for this temperature in fig.1. There is a small enhancement in density compared to the linear approximation of about 1,5 kg/m³ at low ethanol contents (volume concentration up to 20 %). This enhancement was poorly reproducible and has to be investigated more carefully in the future. An anomaly can also be found in the thermal expansion coefficient showing a maximum in this range at an ethanol content of 10 %. We assume that there is a masking effect of the polar ethanol molecule by nonpolar hydrocarbon molecules causing this behaviour.

For low ethanol contents (smaller 20 %) the thermal expansion coefficient of the blends changes only by 2 %. This has to be compared with the difference between summer and winter quality of the fuels, which is 2 %, too. From this follows that for low ethanol contents it is possible to use the coefficients known for pure fossil petrol without exceeding the maximum permissible error for the conversion. To have temperature conversions within a maximum permissible error of 0,2 %, the deviation of the real thermal expansion coefficient from a nominal coefficient can be 5 % at maximum.
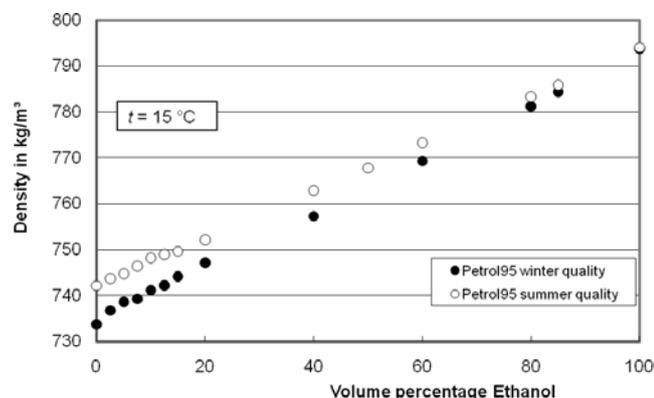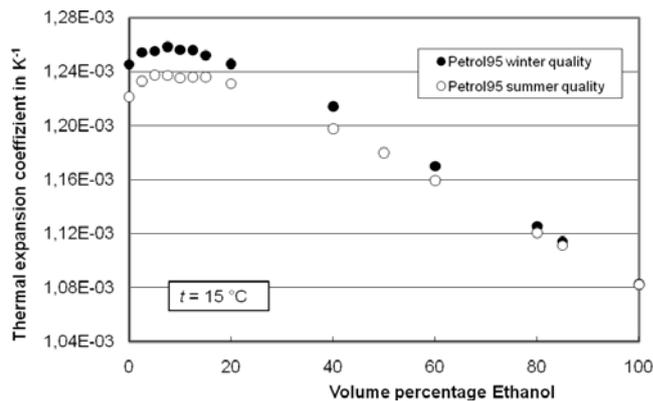

Fig. 2. Thermal expansion coefficient of the petrol-ethanol blends shown in fig. 1 at t = 15 °C.

However the change in the thermal expansion coefficient between E10 and E100 is 16 %. This is too large to cover this range of blends with one temperature conversion factor. Therefore, in Germany it was decided in March 2011 to split the range of blends into two intervals from 0 % to 40 % and from 60 % to 100 % with two different conversion factors. The intermediate range between 40 % and 60 % has not been covered yet, as there are no blends with such ethanol contents in the market.

3.3. Variation of the density for blends of fossil diesel with RME

The situation with diesel-biodiesel blends is much easier to handle than that with petrol. The density of the blends increases at first order linearly with the biodiesel content. There is a small deviation from this linear behaviour resulting in a density decreasing of maximum 0,5 kg/m³ for a biofuel percentage of 50 %. The thermal expansion coefficient of the summer quality is nearly unchanged when blending with RME, the deviations are in the order of 0,2 %. This result has again to be compared with the difference in the thermal expansion coefficients between summer and winter quality of the pure fossil diesel which is 4 %. As already discussed in section 3.2., a difference of 5 %
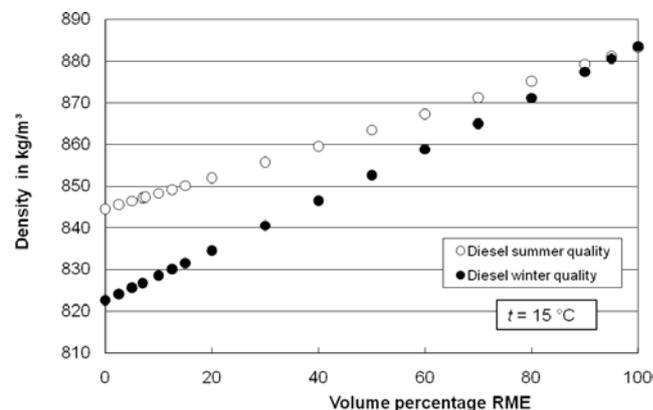

Fig. 1. Density of petrol-ethanol blends at t = 15 °C.

Fig. 3. Density of diesel-biodiesel (RME) blends at t = 15 °C.
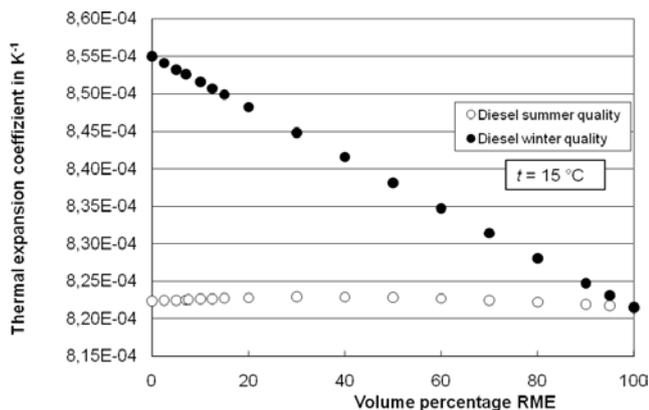
Fig. 4. Thermal expansion coefficient of the diesel-biodiesel blends shown in fig. 3 at $t = 15$ °C.

between the thermal expansion coefficient of the fuel and the nominal temperature conversion factor is acceptable in order to to stay within the maximum permissible error. This means, a change of the temperature conversion coefficient is not necessary when switching from fossil diesel to blends with RME. Quite the contrary the situation becomes more convenient, as the real thermal expansion coefficients of summer and winter qualities converge when using blends.

3.4. Biodiesel other than RME

In addition of RME the studies at PTB covered also SME and PME. The densities of RME and SME differ only by 2 kg/m³. The measurements results obtained with SME blends are very similar to those obtained with RME and therefore are not discussed separately.

The palm oil methyl ester PME has a density which is 7 kg/m³ smaller compared to the one of RME. Its thermal expansion coefficient is 2.4 % higher. Consequently, the thermal expansion coefficient of the blends varies by this amount of 2,4 %. But this still allows to work with the temperature conversion factor of fossil diesel as already shown for RME and SME.

4. CONCLUSION

From the studies of the density of fossil fuels and their blends with biofuels and their temperature dependences can be inferred that there is no urgent need to introduce new rules for the temperature conversion of measured volumes of these fuels.

The changes in the conversion factors of diesel-biodiesel blends are sufficiently small that one can stay within maximum permissible errors of 0,2 % without using new factors.

Petrol-ethanol blends with low ethanol percentage below 40 % do also not demand for a new conversion factor. The only exception is when using ethanol rich blends like E85. In this case a new conversion factor has to be used.

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