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The use of measurement uncertainty and precision data in conformity assessment of automotive fuel products

D. Theodorou *, F. Zannikos

National Technical University of Athens, School of Chemical Engineering, Laboratory of Fuels and Lubricants Technology, Iroon Polytechneiou 9, Athens 15780, Greece

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ABSTRACT

In order to use a test result to decide whether it indicates compliance or non-compliance, it is necessary to take into account the dispersion of the values that can be attributed to the measurand. When dealing with conformity assessment of automotive fuel samples against European Union specification limits, this dispersion may be represented by uncertainty estimates based on either standard method precision data (ISO 4259 approach) or within laboratory precision data (intermediate precision approach). The present work presents possible decision rules based on these approaches and directly related to the required or acceptable level of probability of making a wrong decision. Acceptance limits for 95% and 99% confidence levels are calculated for all the properties of automotive fuels. Moreover, the effect of different approaches for defining guard bands, different levels of confidence or different number of replicate measurements is investigated using the results of the analyses of 769 diesel fuel samples for the determination of sulfur mass concentration.

1. Introduction

The automotive fuels placed on market should comply with strict requirements introduced by relevant legislation. In European Union (EU), several directives [1,2] set technical specifications for fuels used with positive ignition engines (petrol) or with compression ignition engines (diesel). These directives aim at the reduction of direct and indirect health and environmental risks and are supported by documents prepared by CEN (European Committee for Standardization) such as EN 228:2008 [3] and EN 590:2009 [4] that specify requirements as well as test methods for marketed and delivered unleaded petrol and automotive diesel.

Evaluation of conformity with specified requirements should provide adequate confidence that the product under test fulfills (or not) these requirements [5], minimizing the risk of incorrect decisions, which often have financial consequences [6]. As no measurement is exact, the true value of any measured quantity or any errors associated with the measurement cannot be known exactly and the measurement result is actually only an estimate. This estimate should be accompanied by an uncertainty statement or a coverage interval, which summarizes the knowledge of the possible values of the measured quantity [7]. Therefore, the assessment of conformity with specified requirements, especially when the measurement result is close to a specification limit, is closely related to the probability density function of the measurement data and should be approached using the probability theory [8]. In these cases, appropriate decision rules may permit a control over the probability of taking the wrong decision [9].

In the present work an insight is given to the available approaches that can be used to support reliable decisions – expressed by a certain confidence level – in conformity assessment of fuels. These approaches are applied and compared for the assessment of conformity of automotive diesel fuel samples against the EU sulfur mass concentration

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* Corresponding author. Address: 57a Parnassou St, 15234 Halandri, Athens, Greece. Tel.: +30 2106525976.

E-mail address: dtheodoro@teemail.gr (D. Theodorou).

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specification. The results of the analyses of diesel fuel samples from 769 petroleum retail stations, monitored for fuel quality purposes, are used for the calculations.

2. Evaluation of conformity with specified requirements

The evaluation of conformity (or conformity assessment) has the objective to determine whether specified requirements relating to a product, process, system, person or body are fulfilled or not [5,8,10]. Often, a conformity test is involved in the activity of the conformity assessment, which actually has three distinct stages: measurement of the property of interest, comparison of the measurement result with the specified requirement (or tolerance limit) and finally, decision on the action that will follow. The measurement result has to be obtained using a validated procedure, which should guarantee its metrological traceability [11]. The subsequent comparison of the result with the specified requirements should be based on predefined decision rules, which are of key importance when the result is close to the tolerance limit. The decision rules take into account the measurement process variability (expressed as standard deviation or uncertainty) in order to determine acceptance and rejection zones or intervals [12,13]. Figs. 1 and 2 show acceptance intervals and their relation to the tolerance intervals defined by upper and lower specification limits, T_U and T_L, respectively. Fig. 1 shows a case which involves an acceptance interval constructed by reducing the tolerance interval on either side by a guard band of width, w (guarded or stringent acceptance). On the other hand, Fig. 2 shows a case which involves an acceptance interval constructed by increasing the tolerance interval on either side by a guard band of width, w (relaxed acceptance or guarded rejection) [14,15]. The guard bands are defined as the magnitude of the offset from a specification limit to the acceptance interval boundary [15]. The selected decision rules should minimize the consequences of an incorrect decision and are thus indispensably related to the determination of a minimum acceptable level of probability that the measurand lies within or outside specification limits [16].

There are two types of possible errors in the conformity assessment procedure, Type I and Type II. In Type I errors, conforming products are incorrectly rejected. Minimizing Type I error of a conformity assessment test means minimizing the probability of the measurand lying within specification when the test result is outside the specification limit. On the other hand, in Type II errors, non conforming products are incorrectly accepted. Minimizing Type II error of a conformity assessment test means minimizing the probability of the measurand lying outside the specification when the test result is inside the specification limit [13,17].

Guidance regarding the design and use of decision rules is provided by several documents [12,14,18–20]. Although many of them are sector specific, the principles they describe, may be applied in any kind of conformity assessment. Decision rules may be based either on the simple acceptance/rejection or on guard bands. Applying simple acceptance/rejection decision rules means that Figs. 1 and 2 would present a situation with guard bands of zero magnitude and acceptance and tolerance intervals that coincide with each other. This decision rule is insufficient as it can lead to high (up to 50%) probabilities of Type I and Type II errors when a measured value is close to the specification limit. These probabilities can be controlled or reduced by using acceptance intervals that differ by tolerance intervals. The acceptance interval can be inside the tolerance interval (Fig. 1) leading to reduced probability of false acceptance (Type II error). Alternatively, the acceptance interval may be wider than the tolerance interval (Fig. 2) leading to reduced of probability of false rejection (Type I error). The reduction of these probabilities is proportional to the width of the guard band, w. It has to be noted though, that the probability of Type I error is reduced at the cost of increasing the probability of Type II error and vice versa. Therefore the risks associated with making the wrong decision have to be taken into account when formulating decision rules [8,15].

3. Probability of conformity

Probability density function (PDF), $g_Y(\eta)$, may be employed to describe the dispersion of probable values η of a measurand Y about the best estimate y, given a measured value η_m. In many cases, this PDF is or can be approximated by a normal distribution, described by the Gaussian function:

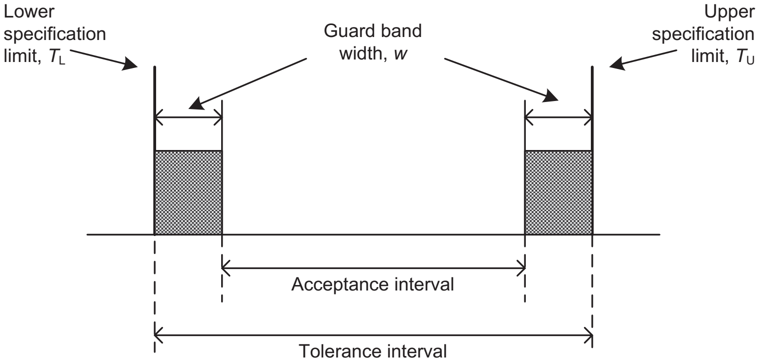

Fig. 1. Symmetric two-sided acceptance interval created by reducing tolerance interval, defined by the lower specification limit T_L and the upper specification limit T_U, on either side by a guard band of width, w (guarded or stringent acceptance).