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Odour Measurements in Textile Industry

Abstract
In this article, some selected problems associated with the measurements of odour in the textile industry have been presented. The notion itself and a qualitative model of this quantity are discussed. Basic methods of measurement and some measuring apparatus have been presented. Special attention has been paid to the creativity of these measurements.

Key words: *odour, textile industry, creative measurements.*

Introduction

Odour measurements are dealt with by a branch of metrology called odorimetry. Odour is an important quality of textile objects, especially those which influence odour formation inside rooms and in the vicinity of human beings. It is important not only for net curtains, drapes, linens or garments, but also for carpets, covers, tents, upholstery fabrics etc. Odour is also measured in many other industries, such as the chemical, food, oil and motor industries, as well as in animal breeding and environmental protection. Until recently the only methods used were organoleptic methods, based on human olfactory sensations. For a number of years attempts have been made at establishing a scientific objectivity of this measurement by constructing a variety of technical devices. Following the first enthusiastic reports about the possibility of measuring odour, it appeared that the problem had not in fact been solved. The evidence of this was a lack of correlation between the indications of the devices and the assessment of experts, the so-called sniffers [1]. At present, there are a number of well thought-out and mature constructions of measuring equipment units which yield comparable, numerical results; however most of them still requires the direct participation of a human in the measurement. This individual's task is to use their olfactory perception as an odour detector. So what does progress consist in, and where do the new problems result from? The material presented below is an attempt to answer this question.

Odour as an Object of Measurement

In general, an odour is a perceptive sensation caused by the stimulation of the olfactoreceptors by odoriferous substances. From the metrological point of view, odour is a feature of a portion of the air containing odorants, i.e. particles of gases, liquids and/or solids which stimulate the olfactory organ and its sense. Odorants act on the olfactoreceptors located in the nose mucosa, or more precisely in the olfactory epithelium covering part of the nasal cavity. These are two-pole neurons projecting over the surface of the epithelium and covered in a serous secretion. The receptors thus constructed generate neural impulses which spread along their axons to the olfactory bulbs of the brain. There, the axons branch off widely and are linked to the so-called mitral cells. The axons of these cells, in turn, form an olfactory path to the olfactory cortex placed in the telencephalon. It is here, in the part of brain called the olfactory lobe, that the analysis of odorous stimuli is made [34].

The olfactory sense is organised differently to our other senses, since many classes of receptors (each of which is stimulated by different groups of odorants) can be distinguished. This means that each class reacts to a different type of odour. This accounts for the existence of fundamental odours, characteristic of a given group of odoriferous substances. It can thus be concluded that substances of a similar structure should have a similar odour, which is not always the case [4]. At the same time, substances of a different structure happen to have similar smells, e.g. hydrogen cyanide and nitrobenzene. The relation between the kind of odour and the concentration of the odoriferous substance is a curious matter that makes the determination of the odour extremely difficult. How mysterious must be the phenomena occurring between the receptor and the brain lobe (or perhaps in the telencephalon itself), if at one time one can smell the lily of the valley and immediately after that the disgusting odour of fecal matter! This happens while inhaling indole, a substance used in the perfume industry [29].

There are two basic causes of the existence of a great variety of odours and the relevant troubles with their classification. The first, the physiological cause, consists in a rich and complicated structure of neural connections within the area of the olfactory bulbs; the other, of a physicochemical character, is the lack of any close relation between the chemical structure of odorants and their physical properties and the odour that they produce.

All the remarks presented above illustrate the statement that measurements of odour are counted among the most difficult tasks of metrology [14]. It appears that odour as an object of measurement requires the participation of a human in the measuring process, in the role of a unique measuring apparatus.

In the system-cognitive understanding of the measuring process [10,17], the performance of a measurement is closely linked with the modelling of the object under measurement; the knowledge of the mathematical model is a necessary and sufficient condition. Building a qualitative mathematical model of every object consists in specifying a set of affecting quantities *w* and output quantities *y*, which are the results of the measurement [26]. Following the decomposition, this model can be presented in the form [13]:

$$y = F\,(w_1\,,\, w_2\,, ...,\, w_{i+j+k}) \quad (1)$$

where:
y - one of the outputs,
F - the function of the real variables *i+j+k*.

The set *W* of the affecting quantities *w* contains *i* of the measuring quantities *x*, also known as input quantities, *j* of the quantities *c* constant during measurement and *k* disturbances *z*. In other words,

$$W = \{w_{i+j+k}\} = \{x_1,...,x_i,\, c_1,...,c_j,\, z_1,...z_k\} \quad (2)$$

where *k* is an unknown value.

If among the affecting quantities mentioned there is no time, then the model is of a static character. In a dynamic model:

$$y(t) = F\,[x_a(t),\, c_b,\, z_d] \quad (3)$$

where: a=1,...,i; b=1,...,j; d=1,...,k.

The latter formula results from an idealised character of the constant quantities and the fact that time has only a scheduling effect on the occurrence of disturbances. In the case of odour, time is always important, and hence the models presented in form (1) implicitly take it into account.

The input quantities in the odour model shown in Figure 1 are time and concentrations of odorants. However, it should be stressed that odour cannot be directly identified with the chemical composition. The constant quantities determining the conditions for making measurements are as follows: the volume of a gas sample, its temperature, the content of odourless substances and the distance from the source. In the model, there is a considerable number of disturbances. The following factors contribute to these disturbances: the individual psycho-physical qualities of the sniffers, a set of substances of concentrations below the discrimination thresholds of the apparatus, which actively - although frequently in an unknown manner - affect the fragrance, as well as unknown interactions between odorants.

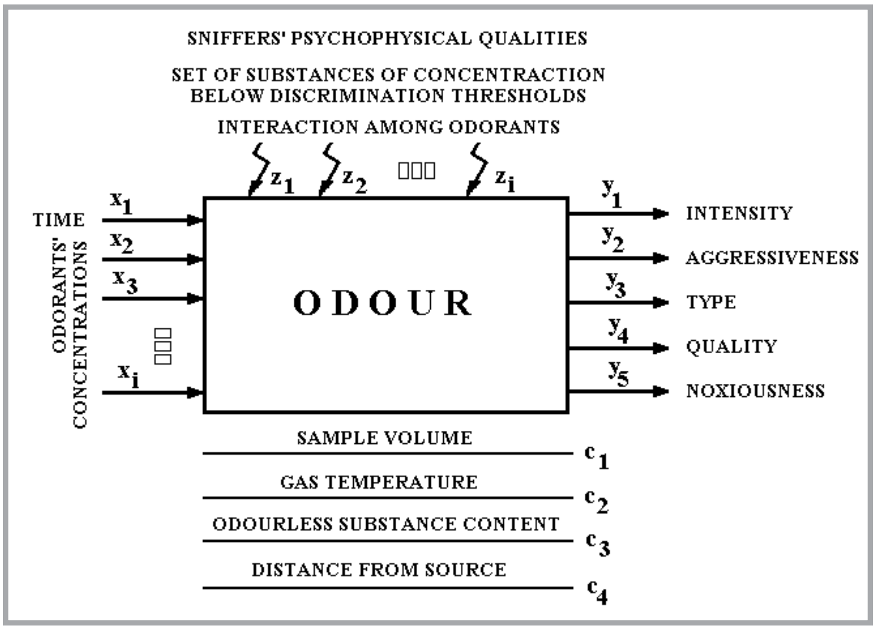

Figure 1. *A qualitative mathematical model of odour.*

Intensity, aggressiveness, type, quality and noxiousness are output quantities. Durability is also frequently defined. However, assuming that the model is of a dynamic character, the durability of each output quantity should be considered separately. Thus, it is more convenient to regard each of these quantities as a function of time.

Each of the output quantities is measured in a different manner. **Intensity** is defined as the multiplication factor of the discrimination threshold. It is expressed as a ratio of dilution to discrimination threshold [30], since the sample taken is gradually diluted in a controlled manner until the odour cannot be sensed by the sniffers. Thus, the value of this quantity is measured according to the quotient scale. The relationship between the intensity *I* and the concentration *C* of the single odorant is usually defined by a logarithmic relationship resulting from Weber-Frechner's law [15]:

$$I = k\,logC + b \quad (4)$$

in which *k* and *b* are the constants characteristic of the odorant. The simultaneous presence of more than one odoriferous compound makes the above relationship difficult to establish.

A different scale of intensity is also used. It is an ordering six-degree scale, in which particular degrees are ascribed the following denotations of odour: 0 - imperceptible, 1 - very weak, 2 - weak, 3 - perceptible, 4 - distinct, 5 - intensive, very distinct.

Aggressiveness [28] is related to the discomfort of inhaling odours perceived as unpleasant. This is assessed according to the multi-degree ordering scale. Ammonia of different concentrations is sometimes used for comparison. This quantity is most often determined during measurements associated with the assessment of the effect of large breeding farms [30] and textile factories (especially finishing mills) [9] on the environment.

Type of odour is described verbally and differently in a different branch. The following words can serve as examples of such terms: 'floral', 'almond', 'hop', 'caramel', 'foul', 'pungent', 'maize' etc. When the more detailed characteristics of the odour must be described in scientific research, a more extensive description of the type of odour is given. For example, to define tetrohydrofuranoids and pyranoids, the following terms have been used: 'sweet, interesting, pleasant, similar to the odour of the orange rind'. The odour of rose-oxide, in turn, has been described as 'very characteristic, green, penetrating, slightly resembling the odour of the rose and geranium' [22].

In the perfume industry, the **quality** of odour is described; in standardisation documents it has been evaluated (among other ways) in a six-degree scale (from zero to five). This is a notion connected with the possibility and manner of reproducing the odour of, for example, a flower. The following terms are ascribed to the particular degrees of quantity: strange (not floral), does not resemble the flower, resembles the flower to a small degree, slightly resembles the flower, resembles the flower, is perfectly associated with the flower. Odour is also described by means of a feature called hedonistic quality [33], which is related to the permissible time of exceeding the threshold concentration of the sensibility expressed, in per cent, as a part of a year. Attempts at the determination of this feature are at a stage of preparation of the standard project.

There have also been attempts to measure the **noxiousness** of odour [20], which can also be defined as a number of complaints of a given population over a definite period of time. This feature is indirectly connected with aggressiveness, but is defined in a different manner.

Measuring Methods and Apparatus

The use of purely electronic devices measuring odour without human participation is not satisfactory [24]. They react to one or a small number of odorants, and are sensitive to substances that do not smell, hence to those that are not odorants. Most devices employed for industrial measurements of the odour of different products are based on gas chromatography, but even modern constructions require the observer's direct, manual participation in the measurement. This also applies to the attempts at the application of mass spectrometers. The human nose remains the best detector of odour. Therefore, in most of the methods of odour measurement presented below, the evaluation of experts - sniffers - is still more or less directly used. Sometimes they use certain technical means that facilitate this assessment [2]; however, they will often base their opinions only on their general olfactory sensations, e.g. when assessing perfume products. These are always subjective and depend on a number of factors, such as psychophysical qualities, instantaneous condition, the fatigue caused by a long-lasting assessment process, etc. On the other hand, only a human can determine all the output quantities in a model, while no apparatus is capable of evaluating, e.g. the type of odour. It should also be remembered that sniffers have limited possibilities; a human can detect over 1000 different odours but can identify only a small proportion of these. Teams of experts are organised into so-called panels, consisting of three to over ten people. The odour is generally stored in balls of cotton placed in sealed containers.

A popular device for the assessment of odour is the so-called dynamic olfactometer [24], which can also be called a meter of olfaction sensitivity. The device makes it possible to transfer definite samples of air to the sniffer's nose. Measurement is frequently made by a group of 4 to 16 sniffers, who are successively presented with samples of increasingly high odorant concentrations. The sample in which the majority of the panel will sense a definite smell constitutes a point of reference for further measurements. This concentration is called 'dilution-to-threshold' (DT), and corresponds to the mean threshold of the panel's excitability. Further measurement consists in the comparison of successive samples of air with DT. This device is considered expensive and the measurement itself time-consuming. Matrix devices are an example of recent attempts at scientific objectivity of odour measurement. Their basic part are matrices of chemical gas sensors of a varied character, whose task is to create an image of the odour as a characteristic set of results of detecting the presence of different chemical compounds. Sensors are now constructed in the form of an integrated sensor matrix in the MOSFET and fuzzy neural networks technology [7,8]. A more interesting construction is that of matrix sensors made of conducting polymers [16], which have high sensitivity and low power consumption. Compared with the conventional MOS technology, polymer sensors do not need to be made in special types for particular chemical compounds, since the sensor matrices can be used to provide the characteristic response patterns to the presence of a specific odorant. This is considered essential in a situation when the odour is a rich mixture of components, which is always the case when assessing foodstuffs or perfume products. Polymer sensors have already found use in a number of devices, such as in the olfactometers of Neotronics or Alpha MOS. However, a discussion on the correlation between the results yielded by them and the sensation of the human nose is still continuing [11].

The Headspace method [32] is used for taking a sample of the air in strictly defined and reproducible conditions. It allows the sample to be transported to a chromatograph for a quantitative analysis of the chemical composition of the sample taken [22]. In the case of measurements of odours, partition gas chromatography using conductometric detectors of the presence of odorants plays the most significant role.

CharmAnalysis [3] combines the elements of gas chromatography and olfactometry (System GCO). An appropriately prepared sample of odoriferous air is supplied to the sniffer, who operates a push-button pressing it when s/he senses an odour, and keeps it pressed until the odour disappears or its feature changes; a computer records the times of these pressings. A sample is prepared by being diluted with filtered, odourless air using a constant factor 2 or 3. This yields a set of 7 to 10 dilutions, in which concentrations of the odorants are equal to 1, 1/3, 1/9, 1/27, etc. of the original concentration. The sample must be diluted until no odour can be sensed. A reverse situation may happen when an input extract is weak and must be con-

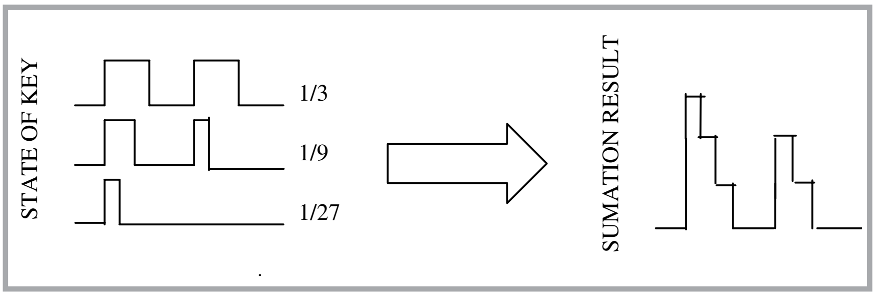

Figure 2. *Formation of a charm-chromatogram for one odour in the CharmAnalysis System.*

centrated to make the detection of all significant components possible. The portions of the samples thus prepared are injected into the stream of inert carrier gas moving inside a long chromatographic column, in which the mixture is separated into components supplied to the olfactormeter.

The pressings of the button cause rectangular impulses to be plotted as a function of retention time, and the duration of one impulse exactly corresponds to the time of flow of one odour (Figure 2). The diagrams concerning particular dilutions are summed up and integrated. The device can also be used to characterise the portions of the air containing several different odours. As a result, a diagram similar to a chromatogram is formed; it is called a 'charm-chromatogram'.

Odour Measurements in Textile Industry

Investigations carried out recently around the world lead to the common awareness that odour has a fundamental influence on people's general comfort and even on their health. This influence can be as much of a positive as of a negative character. For example, the reassuring effect of lavender and the harmful influence of ammonia on humans is known. This is why it is very important to create the possibility to form an appropriate odour in rooms and in the environment immediately surrounding people. This especially concerns textile products, which in the form of underwear, clothes, bedclothes, sheets, blankets, and textile furnishing of living rooms of all kinds accompanies humans day after day without interruption.

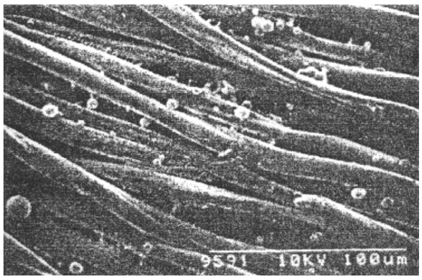

Figure 3. Aromatic fibre. Product of Kanebo Ltd.

The manufacture of aromatic fibres designed for such everyday textile products as bedclothes, apparel, curtains, and draperies appeared to be a very good solution. The Cripy 65 fibre, developed after intensive research conducted in Japan [30] and manufactured in the Mitsubishi Rayon Laboratories [23], can be mentioned here

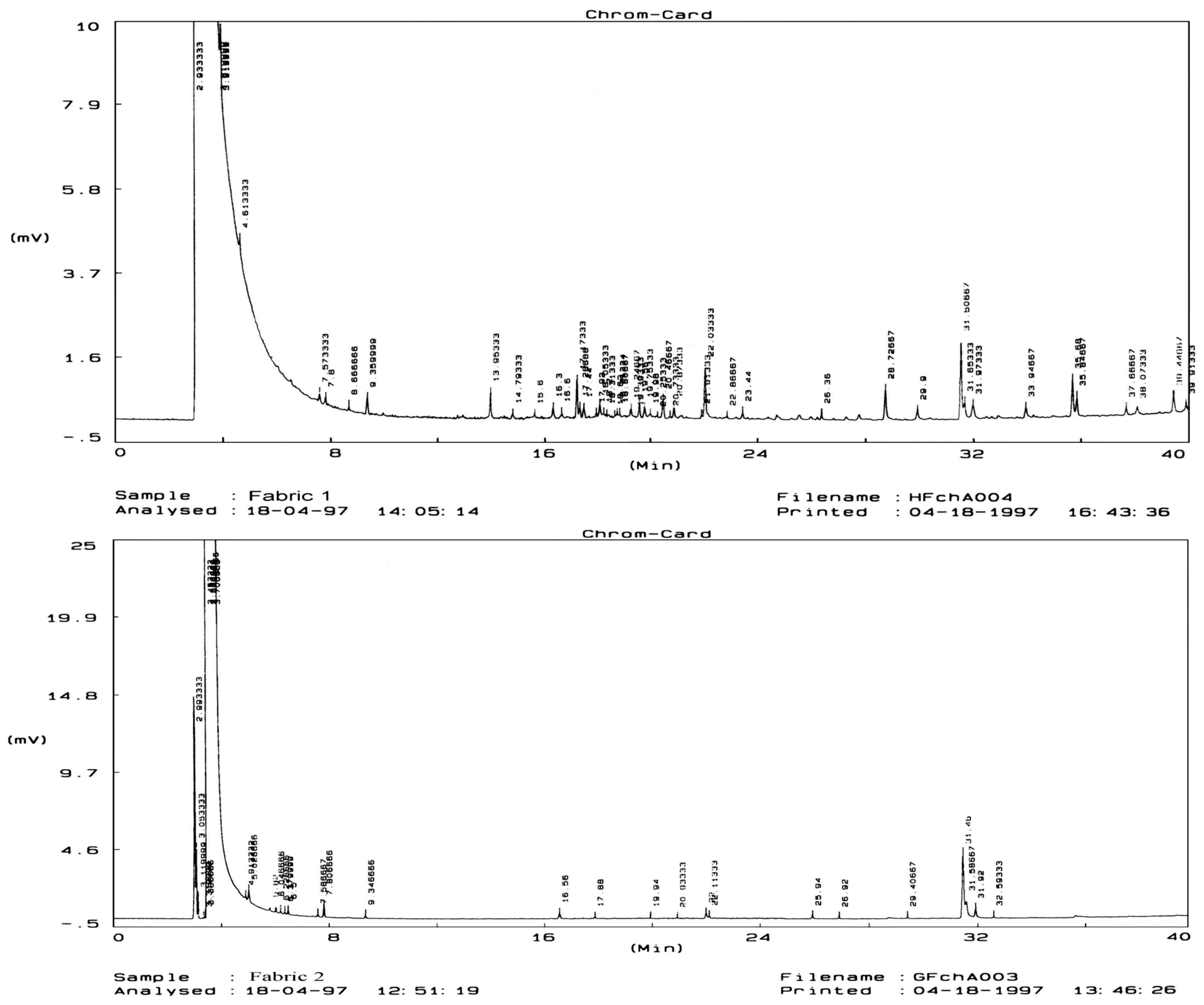

Figure 4. Odour chromatograms of two fabrics; fabric 1 - 58 odorants, fabric 2 - 32 odorants.

as an example. This hollow fibre contains flavouring extracts in its structure which yield a sufficiently intensive and durable fragrance. The aromatic substances are displaced in four longitudinal channels arranged at angles of 90 degrees around the central hollow channel. A polyester fibre manufactured at Kanebo Ltd (Figure 3) can be an example of a fibre of opposite action, aimed at removing unpleasant odours. This fibre is applied in the production of stockings and everyday clothes. A fibre which possesses very strong fungicidal properties and at the same time is able to effectively suppress unpleasant odours is similarly offered by the Tejin company [25]. This fibre is manufactured as a core-crust system in which the crust consists of a co-polymer of ethylene and acrylic acid, and the core can be made, for example, of polyester. Additionally, the core contains pulverised copper. This structure possesses the possibility to chemically assimilate the odorant, whereas the regeneration of the structure is achieved over the period of washing and drying. Aromatic substances can also be placed in microcapsules dispersed uniformly over the cross-section area, which forms such durable connections that the flavour ceases only to an unimportant degree and over long periods of use.

Odour is also a very important element of technological processes in the textile industry. Many finishing departments exist, in which the so-called open processing methods have been used up to now; these are characterised by the use of acetic acid, formic acid and sodium hypochlorite, which all cause sharp smelling effects. A finish application of a different kind, such as antimite finishes, is an example of other processes which results in a long-lasting characteristic smell markedly distinguished by users. Smell also has marketing importance, as it is the first feature estimated after entry into a shop with textile products, fabrics or clothes.

For smell estimation of raw materials and textile products and for an analysis of the efficiency of odour removal, objective measurement methods of this quality are necessary. The measure of odour, similar to the measurement of many other textile properties, proved a very difficult and troublesome problem. The emanation of odour from fibres depends not only on their temperature but also on their humidity. The intense smell of damp wool fibres and wool products (which ceases after their drying) is a well known feature. An important problem is the smell emanating from nonwovens destined as filtration insertions for protecting the upper respiratory tracts. A problem of similar or even greater importance is the odour emitted by floor coverings and furnishing materials. All tests of the above mentioned fabrics demands the necessity of temperature and humidity stabilisation over the time of measurement. Odour is a feature of the volume of a given air sample, and not of the tested textile, which is only the emitter of the smell. Taking this into account, it is evident that not only is the manner in which a sample of fibres or fabrics is taken for the test very important, but also the sampling method of collecting a preset air volume at a given distance from the odour source.

An attempt at odour estimation was carried out at the Faculty of Textile Engineering and Marketing of the Technical University of Łódź [9]. An aromatic finish was applied to a draping manufactured of polyester fibres. Two kinds of finish, one containing an iris flavour and the second with a lavender flavour, were applied to the final product. The finish was applied by immersing the curtain in an acetone solution to which the flavour ingredients were added. The smell intensity and durability were estimated according to the triangle test [6]. The lavender flavour was more durable, and the smell of lavender was perceptible even after two washing processes and some weeks of use. However, it should be stressed that the method of flavour application described yields smaller durability than the use of aromatic fibres.

Tests with the use of the Headspace method and a chromatograph were also carried out at the Technical University of Łódź. Two samples of cotton fabrics were prepared. The first was in direct contact over 15 minutes with a fabric which had absorbed a Johnson odorant ('Autumn Flowers'). The second fabric was placed at a distance of 10 cm from the flavoured fabric. The measurement results of chromatographic tests are shown in Figure 4. The comparison of the chromatographs showed a significant difference between both fabrics. The first fabric absorbed 58 components of the flavour composition, whereas the second absorbed only 32. What is more, the amounts of the particular components were much greater in the first fabric than in the second. A precise identification of the chemical content of the absorbed components was not possible for both fabrics because the concentrations of the odorant were too small. Further tests carried out proved that, in general, the odour measurement of textiles demands an increase in the odorant concentrations which is only possible by using special devices, for example, with such devices equipped with the 'CharmAnalysis' measurement system. Observations made during this investigation confirmed that 'pure' chromatography has unfortunately only small usability for odour estimation. Independent of the reasons mentioned above, this results from the features of the disturbing factors of the measurement model and the impossibility of making an explicit relation between odour impressions and the human sense of smell. Another cause is the creative character of odour measurement.

Creativity of Odour Measurements

The measuring process always proceeds in a three-element measuring system, made up of an object of measurement, a measuring device and an observer. According to the definition described in [13], the measurement is an identification of a mathematical model of an object [19] (performed in definite conditions and at a definite accuracy). The definition is a generalisation of the classical one which refers to parametric identification only. In the author's opinion, the identification is parametric during routine measurements as usually carried out. Besides this, creative measurements are performed [18,12] in which structural identification takes place. The creative measurement is performed without a fully defined structure of the model of the object under study; it has properties of a scientific research. Such a case occurs during the first measurement of the object feature which has not yet been defined. The question of the 'first measurement' [12] consists in the definition of the object and formulation of a hypothesis of the existence and the structure of its model. Activities carried out then, such as planning and making the measurement, comparing the results with the expected features of the object model, and evaluating the differences and the model adequacy, are equal to making a scientific investigation [21,31]. Thus it can be stated that the character of the 'first measurement' departs from successive measurements made following the confirmation of the adequacy of the model. A creative element can be seen in this, which makes it different from the routine one. The main feature of creative measurement is that a human observer with appropriate metrological and methodological qualifications is needed to participate in the measuring procedure. Most odour measurements show the same feature because they are carried out with the help of sniffers who are able to assess all the input quantities of a model of odour. Each time, a new model of this quantity is created in their consciousness. The model contains limited information on the set of odorants and the time that has passed since the formation of the odoriferous mixture. The use of odourmeters and olfactometers is also closely related to the work of sniffers. Matrix devices are the only example of apparatus which allows a partial routine measurement. It should be remembered, however, that they have limited possibilities and are capable of evaluating neither the type nor the quality of odour. Gas chromatography, in the positive meaning of this word, is the closest to 'routinisation'. To make a chromatogram play the role of a standard, long-lasting and costly investigations are necessary. These should result in an adequately extensive library of chromatograms corresponding to all odours, including chemically active odourless substances. At present this seems impossible, and the sensitivity of the method is the decisive limitation. Hence the best solution with present-day technology is a combination of chromatography principles and human skills, as is the case with CharmAnalysis.

To perform the measurement in a fully routine manner, a complex identification of the qualitative mathematical model shown in Figure 1 should be made. To do so, the knowledge of all the forms of the function and values of the parameters in the system of equations is necessary.

$$\begin{aligned} y_1 &= F_1(x_1,\ldots,x_i), \\ y_2 &= F_2(x_1,\ldots,x_i), \\ &\ldots\ldots \\ y_6 &= F_6(x_1,\ldots,x_i) \end{aligned} \qquad (5)$$

on condition that

$$c_1 = \text{const}, \ldots, c_4 = \text{const} \qquad (6)$$

Such identification is impossible, due to the definition of odour which appeals to subjective human feelings.

Summary and Conclusions

Odour is one of the most important features of textile objects, especially of flat textiles. It is very important to develop new methods and instruments for measuring the odour of textiles, because the result could decide its market value.

The decisive majority of odour measurements require the use of teams of experts, since the present-day electronic devices find a limited use because of the great number of odorants. Matrix devices which use scoured neuron networks appear to be the greatest hope. By comparing a number of measuring methods, it can be stated that a combination of gas chromatography and olfactometry, into a system of CharmAnalysis, for example, can be the most universal solution.

Odour is a quantity whose measurement manifests the features of creative measurement. This results from the fact that there is no parametric, quantitative model of this object. Such a model may be created when the conditions for artificial, reproducible representation of human reaction to sensual stimuli are laid down. It seems, however, that in spite of considerable progress in the analysis and formation of neural networks, it will be a long time until such a model can be formed.

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Received 05.09.2002 Reviewed 29.11.2002