Applying risk analysis thinking in uncertainty estimation for LOI testing according to ISO 4589

A. A. Younis[1]* and Kh. El-Nagar[2]

[1]*Gas Analysis and Fire Safety (GAFS) Laboratory, National Institute of Standards (NIS).
[2] Material Testing and Chemical Surface Analysis Laboratory, National Institute of Standards (NIS).

*Corresponding Author E-mail: ahmed.abdeen@nis.sci.eg

Article Type: Research article.

Received on 28 May 2022, Accepted on 16 August 2022

Abstract

The limiting oxygen index (LOI) is the littlest oxygen concentration needed to let the ignition continue with a combination of oxygen (O_2) and nitrogen (N_2) gases at room temperature. Strategies for estimating the oxygen index are widespread and have numerous applications, beginning with innovative work testing, which characterizes the conduct of materials during burning, up to quality control of fabricated items. The fire tests depend on basic tests such as cone calorimetry (CC), LOI, and single burning item (SBI).

The LOI device classifies the materials into flammable and non-flammable. Many standards can be applied to oxygen index devices, but ISO 4589 is the most standard used in fire testing. The uncertainty was determined during the tests, which included quantitative and qualitative measurements. This manuscript was concerned with evaluating the contributions of available sources of errors included in the uncertainty budget and applying the risk analysis concepts to mitigate its effect on the expanded final uncertainties associated with the final results.

Keywords: Polyester fabric; LOI; Fire testing, Uncertainty; Risk analysis.

1. Introduction:

Polyester fabric or polyethylene terephthalate (PET) is a synthetic fabric that's usually derived from petroleum and composed of ester groups in a high percentage (85%), while a small percentage is concerned with terephthalic acid and dihydric alcohol [1]. It is characterized by high strength, easy washing, low cost, wrinkle resistance, and quick drying [2], so it is used in packaging, sportswear, home textiles, and automotive industries [3]. PET has a melting point between 240-29^{o}C, so it is easy to ignite, shrinking, more smoke emitted during combustion, and more ignite drops dripping [4]. The main problem with PET is fire spread with melted dripping [5]. There are many methods used to improve the ignition properties of PET as a direct reaction between urea and phosphoric acid in the presence of methyltrimethoxysilane (MTMS) to coat the specimen with a layer of urea phosphate [6]. The minimum concentration of oxygen, by volume percentage, in a mixture of oxygen and nitrogen introduced at 23^{o}C±2^{o}C will support the combustion of material under specified test conditions (ISO 4589-2). The average percentage of oxygen in the air is 20.9%, so the materials burning in the air are classified as flammable materials, while more than 25.0% are classified as flame retardant materials (Table 1) [7].

Table 1: Classification of materials according to LOI values.

Easy to ignite, easily flammable. (burns and the flame is spreading easily/rapidly).	LOI <18.0%
Burnable, flammable. (burns and will not self-extinguish).	18.0% < LOI < 22.0%
Slow burning, hard to ignite. (may burn slowly could also self-extinguish).	22.0% < LOI < 25.0%
Flame retardant fabric – flame resistant fabric (not burned- - self-extinguishing material)	LOI > 25.0%

The main factor effect in the ignition is oxygen. This factor can be measured using a limiting oxygen index (LOI) device, defined as the minimum percentage of oxygen in a blend of nitrogen and oxygen desired to keep specimen ignition. It was performed for different materials like wool, and plastics according to different standards [8 - 10]. The test is conducted by measuring the lower oxygen percentage needed for ignition and continues to share in many articles by fire technology specialists [11].

Our previous works [12, 13] had published specialists studying the flammability properties of different new coatings or composites, sharing the LOI test as the main test according to its significance [14]. The ISO 4589 standard is one of the most widely used standards in studying the flammable properties of different samples [15].This standard has four versions [16 - 19]. This test is correlated with other ignition tests such as; cone calorimeter [20], and small ignition test [21].

Many authors intended to estimate the uncertainty associated with the final testing consequences of textile materials [22 - 26]. Uncertainty can be characterized as an A parameter related to the result of a measurement that describes the scattering of the values that could sensibly be credited to the measure [27]. Uncertainty might be raised from various sources, e.g., the incomplete definition of the test, an imperfect realization of test methodology, sampling, the effect of environmental conditions, personnel bias, instrumental resolution and drift, the standard used, approximations, and assumptions incorporated in the measurement method. It can be assessed overall methodology considering all methodical and arbitrary mistake sources [28].

This work aimed to evaluate uncertainty parameters associated with LOI measurement and define the risk of each one to avoid the high risk and in turn, increase the test capabilities (accurate result with the lowest uncertainty).

2. Experimental

Substrate

The fabric used in this test was PET supplied from Elmahala Elkobra factory, Egypt. The fabric was 110 g/m^2 with a thickness of 0.4mm±0.01mm. PET fabric was thoroughly washed with non-ionic detergent for 30min at 40^{o}C and finally rinsed with distilled water.

Limiting Oxygen Index (LOI) Test

The LOI values were determined according to the standard ISO 4589 [16]. This test was performed using a Rheometric Oxygen Index Instrument (Rheometric Scientific Ltd, Model No.: 16000, UK) [29]. This test was achieved in the presence of a gas mixture of nitrogen (N_2) and oxygen (O_2) at ambient temperature. The specimen (31 specimens) in the dimension of 15.0cm × 5.0cm × 0.1cm were cut, held vertically, and exposed to a direct flame (propane gas) for 30 s from the free edge. Results were gained after consuming a length of 5cm of a sample or 180 s from the specimen according to Equation (1) [30].

$$LOI = 100 \text{ X } [O_2] / [O_2 + N_2] \quad (1)$$

where $[O_2]$ and $[N_2]$ are the concentrations of oxygen and nitrogen gases at ambient temperature, respectively.

Schema used to calculate uncertainty

To precisely estimate the sources of uncertainty all parameters associated with all possible sources of errors should be considered. Table 2 includes all possible sources of uncertainty [31].

Table 2: Sources of errors.

Source of error	Details
Repeatability to indicate the precision /standard error (uncertainty type A)	For 33 replicates.
Reproducibility [32]	On different days using the same sample and equipment (33 replicates each).
Accuracy	The deviation from the average of 33 replicates of the homogeneous sample.
Uncertainty of data logger calibration	From the calibration certificate of the data logger.
Purity of Oxygen gas	Specification from the gas producer.
Uncertainty of timer	From calibration certificate of timer.
Uncertainty of dimensions	From calibration certificate of ruler/thickness gage used for measuring length, width, and thickness
Personnel	Application of flame (5 s) Initial O_2 Start/stop the chronometer Burned length
Environmental conditions	Ambient temperature 23±2^{o}C
Sample conditioning prior to the test	Fabric sample conditioning before the test to get the stable dimensions and moisture content Temperature=23±2^{o}C, RH= 50±5%
Equipment	As example, Equipment resolution and drift Gas mix velocity Ignitor diameter Rod for films/fabric Flowmeter Timer Gas pressure

3. Results and discussions

As per the ISO 4589 test method, a small test specimen is upheld vertically in a combination of nitrogen and oxygen streaming upwards through a straightforward chimney stack (Figure 1) [17].

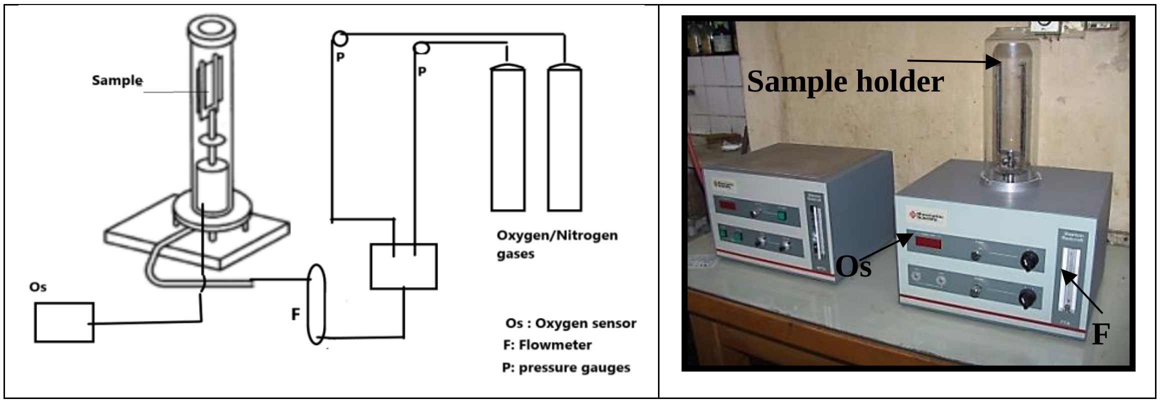


Figure 1: The Schematic diagram and photo of the limiting oxygen index (LOI) equipment.

The free end of the specimen is flamed, and the following consuming behavior of the specimen is noticed to compare the period for which burning continues, or the length of specimen burnt, with specified limits for such burning. The base oxygen fixation is assessed by testing a progression of specimens in various oxygen concentrations. Otherwise, three test specimens are tested using the significant oxygen concentration for comparison with a specified minimum oxygen index value, at least two of which are required to extinguish before any relevant burning criterion is exceeded. In this research, we utilized fabric that agrees with the standard test technique (i.e., thickness up to 10.5 mm, moreover, an apparent density greater than 100 kg/mm^3 [16].

The used method can provide a sensitive measure of the burning characteristics of materials under specific controlled laboratory conditions and may be valuable for quality control purposes. The outcome results depend upon the shape, orientation, and isolation of the test specimen and the ignition conditions. The results obtained from test specimens of various thicknesses or by utilizing different ignition procedures may not be comparable, and no correlation with combustibility conduct under other fire conditions is inferred [17].

By analyzing the main requirements of the standard test method for each part of the test and equipment, we can conclude the following Table 3 [17]:

Table 3: Equipment part and its requirements.

Equipment part	Requirements
Test chimney	• The preferred dimensions of the chimney are 450mm minimum height and 95mm minimum diameter. • The upper outlet shall be restricted as necessary by an overhead cap having an outlet small enough to produce an exhaust velocity of at least 90 mm/s from that outlet. • The chimney support may incorporate a leveling device and indicator, to facilitate vertical alignment of the chimney and a test specimen supported therein. A dark background may be provided to facilitate the observation of flames within the chimney.

Test specimen holder	• Suitable for supporting a specimen vertically in the center of the chimney. • For self-supporting materials, the specimen shall be held by a small clamp that is at least 15mm away from the nearest point at which the specimen may burn before the extent-of-burning criterion is exceeded. For supported film or sheet test specimens, the specimen shall be supported by both vertical edges in a frame equivalent, with reference marks at 20mm and 100mm below the top of the frame. • The profile of the holder and its support should preferably be smooth to minimize the induction of turbulence in the rising flow gas.
Gas supplies	• Comprising pressurized sources of oxygen and/or nitrogen not less than 98% (m/m) pure and/or clean air [containing 20.9% (V/v oxygen], as appropriate. • The moisture content of the gas mixture entering the chimney shall be <0.1% (m/m) unless the results have been shown to be insensitive to higher moisture levels in the gas mixture. The gas supply system shall incorporate a drying device, or provision for monitoring or sampling the gas supply for moisture content unless the moisture content of the gas supplies is known to be acceptable. • The constituent gas supply lines shall be linked in a manner that thoroughly mixes the gases before they enter the gas distribution device at the base of the chimney, so that the variation in oxygen concentration in the gas mixture rising in the chimney, below the level of the test specimen, is < 0.2% (V/V). • It should not be assumed that bottled oxygen or nitrogen will always contain < 0.1% (m/m) of water; moisture contents of 0.003% (m/m) to 0.01% (m/m) are typical for commercial supplies as filled bottles of purity 2.98% (m/m), but as such bottled gases are depressurized to below about 1 MPa, the moisture content of the gas drawn off may rise above 0.1% (m/m).
Gas measurement and control devices	• Suitable for measuring the concentration of oxygen in the gas mixture entering the chimney with an accuracy of ±0.5% (V/V) of the mixture and for adjusting the concentration with a precision of ±0.l% (V/V) of the mixture when the gas velocity through the chimney is 40 mm/s ± 2 mm/s at 23ºC±2ºC. • Means shall be provided for checking or ensuring that the temperature of the gas mixture entering the chimney is 23ºC±2ºC. If this involves an internal probe, its position and profile shall be designed to minimize the induction of turbulence within the chimney. Systems of measurement and control that have proved satisfactory include the following: a) needle valves on individual and mixed gas supply lines, a paramagnetic oxygen analyzer that continuously samples the mixed gas, and a flowmeter to indicate when the gas flow through the chimney is within the required limits; b) calibrated orifices, gas pressure regulators, and pressure gauges on the individual gas supply lines; c) needle valves and calibrated flowmeters on the individual gas supply lines.
Flame igniter	• Comprising a tube that can be inserted into the chimney to apply to the test specimen a flame issuing from an outlet of 2mm ±1 mm diameter at the end of the tube. • The flame fuel shall be propane, without premixed air. The fuel supply shall be adjusted so that the flame will project 16mm & 4mm vertically downwards from the outlet when the tube is vertical within the chimney and the flame is burning within the chimney atmosphere.
Timing device	• Capable of measuring periods up to 5 min with an accuracy of ±0.5 s.

Fume extraction system	• Providing sufficient ventilation or exhaust to remove fumes or soot expelled from the chimney without disrupting the gas flow rate or temperatures in the chimney. If soot-generating materials are being tested, the glass chimney may require cleaning to maintain good visibility, and the gas inlets, inlet screen, and temperature sensor (if fitted) may also require cleaning to function properly. Suitable precautions should be taken to protect personnel from noxious materials or burns during testing or cleaning operations.
Calibrate the equipment parts	Calibrate the equipment parts (flowmeters, oxygen sensor, nitrogen sensor, pressure gauges, thermometer).
Sampling	Obtain a sample sufficient for the preparation of at least 15 test specimens. The sample shall be taken, if relevant, in accordance with the material specification, otherwise in accordance with IS0 2859-1 or IS0 2859-2, as applicable. For a material for which the oxygen index is known to be within k 2, 15 test specimens may be sufficient. For materials of unknown oxygen index, or which exhibit erratic burning characteristics, between 15 and 30 test specimens may be required.

Determination of test uncertainty is not simple; as a result, it combines of qualitative and quantitative measurements. This article highlights the main uncertainty parameters needed to ensure test results' accuracy (trueness and repeatability) and proposes a method to calculate and estimate test uncertainty. Evaluation of the uncertainty associated with final results after amendments have been mentioned in Table 4.

Table 4: ANOVA statistical analysis for the obtained results**.**

S.N	Day 1	Day 2			
	LOI %	LOI %			
1	17.8	17.8	**Within-group 1**		
2	17.8	17.7	**Average**	17.83	%
3	17.9	17.7	**Variance**	0.002	%
4	17.8	17.8	**Stdev**	0.05	%
5	17.8	17.8	**Relative Stdev**	0.0027	
6	17.9	17.8	**Repeatability**	0.0005	
7	17.9	17.8	**Degree of Freedom**	32	
8	17.9	17.8	**Number of replicates**	33	
9	17.8	17.7	**Range**	0.1	
10	17.8	17.8			
11	17.9	17.9	**Within-group 2**		
12	17.9	17.9	**Average**	17.80	%
13	17.9	17.9	**Variance**	0.004	%
14	17.8	17.8	**Stdev**	0.06	%
15	17.8	17.8	**Relative Stdev**	0.0036	
16	17.8	17.8	**Repeatability**	0.0006	
17	17.8	17.8	**Degree of Freedom**	32	
18	17.8	17.8	**Number of replicates**	33	
19	17.8	17.8	**Range**	0.2	
20	17.8	17.8			

21	17.8	17.8
22	17.8	17.8
23	17.8	17.8
24	17.8	17.8
25	17.9	17.9
26	17.9	17.9
27	17.9	17.9
28	17.9	17.8
29	17.8	17.7
30	17.8	17.9
31	17.8	17.8
32	17.8	17.7
33	17.8	17.8

Between-groups	
SS	0.02
DoF	1
Average LOI =	17.82%

Table 4 shows the Analysis of variance for the repeatability and reproducibility using excel Microsoft software. The degree of freedom within each group of data was 32 (number of replicates n=33) two sets of measurements were analyzed on two different days to calculate the reproducibility (two sets of data). Sort of statistical information is obtained from ANOVA analysis, namely: the average of each group of data, standard deviation, degree of freedom, relative standard deviation (relative to the average), repeatability, and reproducibility (ISO 21748:2017).

To evaluate the uncertainty as indicated in Table 5 we calculated the uncertainties, including uncertainty type A (repeatability U_A) and uncertainty type B (Uncertainty budget). The value of each parameter was taken as relative values (relative to the average LOI and the actual values used).

Table 5: Uncertainty budget calculation.

Symbol	Source of Uncertainty	Value (relative)	Probability Distribution	Divisor	CI	(UI)^2
U_A	Precision (Type A evaluation)	=0.0036	Normal	1	1	1.30E-05
U_{rprod}	Precision (Type A evaluation)	=0.02	Normal	1	1	4.00E-04
Ugas_pres	N_2Gas pressure gauge 0.15Mpa	=0.01/0.15	Rectangular	1.73	1	1.49E-03
	O_2Gas pressure gauge 0.15Mpa	=0.01/0.15	Rectangular	1.73	1	1.49E-03
U_{ruler}	U ruler-Calib (±0.037 mm)					
	Ruler (sample length 120 mm & line at the top of sample 50 mm)	=0.037/120	Normal	2	1	0.00E+00
	Ruler (sample width 50mm & line at the top of sample 50 mm)	=0.037/50	Normal	2	1	1.00E-07
	Ruler (line at the top of sample 50 mm)	=0.037/50	Normal	2	1	1.00E-07
	Igniter height (ruler) 16 mm	=0.037/16	Normal	2	1	1.30E-06
	Adjust O_2 Pressure on the instrument 0.1Mpa	=0.03/0.1	Normal	2	1	2.25E-02
	Adjust N_2 Pressure on the instrument 0.1Mpa	=0.02/0.1	Normal	2	1	1.00E-02
	Flowmeter 0.2 LPM (used for O_2)	=0.03/0.2	Normal	2	1	5.63E-03

Symbol	Source of Uncertainty	Value (relative)	Probability Distribution	Divisor	CI	(UI)^2
	Flowmeter 0.2 LPM (used for N_2)	=0.03/0.2	Normal	2	1	5.63E-03
U_{O2}	Oxygen Index set value (20.9%)	=0.42%/20.9	Normal	2	1	0.00E+00
	UO_2resl (0.1%)	=0.1/20.9	Rectangular	1.73	1	7.60E-06
	UO_2 Drift	--	Rectangular	1.73	1	
U_{time}	Utime-Calib (00.0093s)					
	Sample ignition time (30 s)	=0.0093 /30	2	1	1	1.00E-07
	Burning time (s) to the mark	=0.0093 /60	2	1	1	
	Utime-resol (0.01s)	=0.01/2	Rectangular	1.73	1	8.40E-06
U_{temp}	Ambient Temperature (23±2ºC)	=0.40/23	Normal	2	1	7.56E-05
	Utemp-resol	=0.005/23	Rectangular	1.73	1	0.00E+00
	Utemp-Drift	--	Rectangular	1.73	1	
U_{RH}	Ambient RH (50±5º%)	=1.70/50	Normal	1.73	1	3.86E-04
	Utemp-resol	=0.005/20	Rectangular	1.73	1	0.00E+00
	Utemp-Drift	---	Rectangular	1.73	1	1.30E-05
Uc	Combined Uncertainty	$= \pm \sqrt{(UA)^2 + (Urprod)^2 + (Ugas\text{-}pres)^2 + (Uruler\text{-}calib)^2 \ldots\ldots etc}$ = 0.0476126				
Uexp	Expanded Uncertainty	=Uc*2 (for C.L. 95%) =0.0476126*2=0.095225187~0.095				

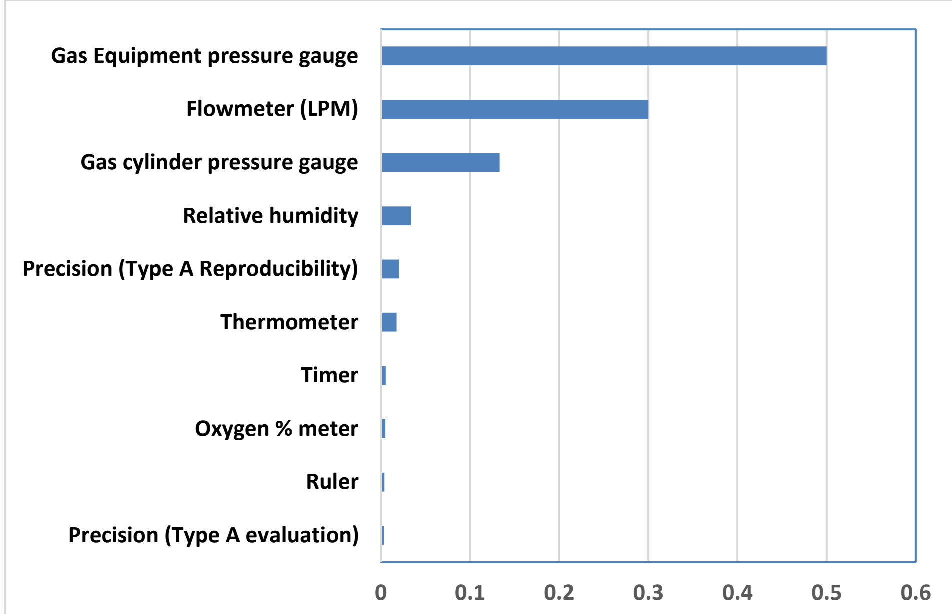
Final results

- Average 17.82% ± 0.095 (coverage factor =2 for Confidence level 95%).

By grouping the uncertainty sources and evaluating each contribution, we get the following Table 6. This table reveals that the contribution of the gas equipment gauge is the highest value, followed by the flowmeter, gas cylinder gas pressure, relative humidity, reproducibility, and final minor values for the timer, oxygen meter, and ruler. Regardless of the oxygen concentration sensor's risk, it gives the final result. When considering the time of burning to the 50 mm mark, especially for the synthetic fabric (PET), the uncertainty of time might present a high risk. By increasing the oxygen concentration needed to start burning the sample, the relative uncertainty becomes low contribution due to the measured oxygen concentration comes as a dominator when calculating the relative value.

Table 6: Uncertainty contribution from each parameter (risks).

Source of uncertainty	Relative value
Precision (Type A evaluation)	0.0036
Precision (Type A Reproducibility)	0.02
Gas cylinder pressure gauge	0.133
Ruler	0.004
Gas Equipment pressure gauge	0.500
Flowmeter (LPM)	0.300
Oxygen % meter	0.005
Timer	0.0055
Thermometer	0.0176
Relative humidity	0.03425



To define the risk resulting from uncertainty sources as indicated in Table 5 and compare the value of each one as an indication of the degree of impact and risk on the degree of confidence accompanied with the final results (considering the degree of confidence 95% using coverage factor = 2). By comparing each uncertainty source/risk with budget uncertainty, the uncertainty risks were found in the following order: Gas equipment, pressure gauge>Flowmeter> relative humidity> Reproducibility> Thermometer>timer> oxygen meter>ruler> repeatability (Type A).

According to these risks from the uncertainty contribution values in Table 6 (considered as the risk register), we have to avoid and mitigate the higher ones to decrease the budget uncertainty values that decrease the confidence in the final average results.

4. Conclusion

Polyester can be melted in the range 260-285°C. One of the dangers of polyester, when exposed to fire, is that it will melt on the human body causing, different types of burning. The percentage of C, H, and O produced from the polyester's combustion will decrease as the temperature increases; this leads to an increase in the production of CO and CO_2, which decreases the oxygen percentage around the specimen during the ignition, so the specimen is extinguished at once. The results and relative uncertainties that arise from pressure gauges, flowmeters, and relative humidity indicate that they are the major risk and uncertainty contributions when compared. Risks resulting from the studied uncertainty sources were investigated, and the highest risks were found from the uncertainty of pressure gauges and flowmeters. All users of the standard method ISO 4589 shall mitigate/eliminate the uncertainty from these two sources to increase the confidence and the accuracy of the final results.

5. Acknowledgment

The authors gratefully acknowledge the funding provided by the National Institute of Standards (NIS), Tersa, Giza, Egypt.

6. References

[1] Lee S.M. Dictionary of composite materials technology, Technomic publishing Co. Inc., Lancaster, Pennsylvania, (1989).
[2] Younis A.A. Flammability properties of polypropylene containing montmorillonite and some of silicon compounds, Egyptian Journal of Petroleum, 26(1), p. 1-7 (2017).
[3] Lerdkajornsuk P., and Charuchinda S. Study on flame retardancy and anti-dripping of polyester fabric treated with bentonite, diammonium hydrogen phosphate and aluminum hydroxide, Journal of Metals, Materials and Minerals, 20(2), p. 63-70 (2010).
[4] Awaja F., and Pavel D. Properties of Recycled-Polyethylene Terephthalate/Polycarbonate Blend Fabricated by Vented Barrel Injection Molding, European Polymer Journal, 41, p. 1453–1477 (2005).
[5] Zhao H.B., Chen L., Yang J.C., Ge X.G., and Wang Y.Z. A novel flame-retardant-free polyester: cross-linking towards self-extinguishing and non-dripping, Journal of Material Chemistry, 22(37), p. 19849–19857 (2012).
[6] Younis A.A. Optimizing of mechanical, thermal and ignition properties of polyester fabric using urea and phosphoric acid, Journal of Industrial Textiles, 49(6), p. 791-808 (2020).
[7] https://www.daletec.com/limiting-oxygen-index-relevance-for-your-choice-of-ppe/ (access date 8/8/2022)
[8] ASTM D 2863: Measuring the minimum oxygen concentration to support candle - like combustion of plastics (Oxygen Index), (2017).
[9] BS 2782-0: Methods of testing plastic introduction, (2011).
[10] NF T 51-071-2: Plastics – Determination of burning behaviour by oxygen index – part 2: Ambient-temperature test, (2002).
[11] Younis A.A. Evaluation flammability, mechanical and electrical properties of polypropylene after using zinc borates and montmorillonite, Journal of Thermoplastic Composite Materials, 35(2), p. 177-191 (2022).
[12] Younis A.A., and El-Wakil A.A. New composites from waste polypropylene/eggshell characterized by high flame retardant and mechanical properties, Fibers and Polymers, 22(12), p. 3456-3468 (2021).
[13] El-Alfy E.A., Younis A.A., Samaha S.H., Salama A.M., and Hashem M. Eco – Friendly Flame Retardant Via Self Assembly Coating, Egyptian Journal of Chemistry, 60(4), p. 479-489 (2017).
[14] Younis A.A., El-Nagar Kh., and Nour M.A. Part I: Characterization of flammability behavior of polyester fabric modified with sol-gel, International Journal of Chemistry, 5(2), p. 38-46 (2013).
[15] Younis A.A. Flame retardancy, mechanical properties and antibacterial activity for polyester fabric coated with a sol-gel coating and pomegranate rind, Fibers and polymers, 20(12), p. 2594-2603 (2019).

[16] ISO 4589-1: Plastics — Determination of burning behaviour by oxygen index — Part 1: General requirements, (2017).

[17] ISO 4589-2: Plastics — Determination of burning behaviour by oxygen index — Part 2: Ambient-temperature test, (2017).

[18] ISO 4589-3: Plastics — Determination of burning behaviour by oxygen index — Part 3: Elevated-temperature test, (2017).

[19] ISO 4589-4: Plastics — Determination of burning behaviour by oxygen index — Part 4: High gas velocity test, (2021).

[20] ISO 5660-1: Reaction-to-fire tests — Heat release, smoke production and mass loss rate — Part 1: Heat release rate (cone calorimeter method), (2002).

[21] EN ISO 11925-2: Reaction to fire tests – ignitability of products subjected to direct impingement of flame – part 2, (2010).

[22] Nermin M.A., Seddeq H.S., Elnagar Kh., and Hamouda T. Acoustic and thermal performance of sustainable fiber reinforced thermoplastic composite panels for insulation in buildings, Journal of Building Engineering, 40, p. 102747 (2021).

[23] El-Nagar Kh., Shehata A.B., Long S.E., Kelly W.R., and Jacqueline L.M. Detection of total mercury in cotton matrix, Elixir Applied Chemistry, 44, p. 7287-7291 (2012).

[24] Lima N.N., Conni M., Green P., and Barbieri M. Measurement Uncertainty for Printed Textiles, 2018", Colour and Visual Computing Symposium (CVCS), pp. 1-6 (2018).

[25] El-Nagar Kh., Amer M., Mekawy Y., and Mahmoud E. Development of Viscosity Transfer Standards from Chitosan/gelatin Mixtures, MAPAN - Journal of Metrology Society of India, 25(4), p. 253-259 (2010).

[26] Akmar A.B., Lahmer T., Bordasd S.P.A., Beex L.A.A., and Rabczuk T. Uncertainty quantification of dry woven fabrics: A sensitivity analysis on material properties, Composite Structures, 116, p. 1–17 (2014).

[27] ISO/IEC 17025: General requirements for the competence of testing and calibration laboratories, (2017).

[28] United Kingdom Accreditation Service (UKAS), Expression of uncertainty in testing, LAB 34, Edition 1, (2001).

[29] Younis A.A., Mohamed S.A.A., Samahy M.A., and Abdel Kader A.H. Novel fire-retardant bagasse papers using talc/cyclodiphosphazane and nanocellulose as packaging materials, Egyptian Journal of Petroleum, 30(1), p. 25-32 (2021).

[30] Younis A.A. Treatment of plywood from burning by synthesis a new protective coating through sol-gel, Elixir Applied Chemistry, 65, p. 20196-20200 (2013).

[31] Guillaume E., Yardin C., Aumaitre S., and Rumbau V. Uncertainty evaluation of oxygen index determination according to ISO 4589-2, Journal of Fire Sciences, 29(6), p. 499-508 (2011).

[32] ISO 21748: Guidance for the use of repeatability, reproducibility and trueness estimates in measurement uncertainty evaluation, (2017).