(REFEREED RESEARCH)

THE STUDY OF FLAME RETARDANCY AND THERMAL PROPERTIES OF SeaCell® FABRICS

SeaCell® KUMAŞLARIN TERMAL ÖZELLİKLERİ VE GÜÇ TUTUŞURLUK ÖZELLİKLERİNİN İNCELENMESİ

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ABSTRACT

In this study, the properties of flame retardant woven fabrics produced from the SeaCell®active and SeaCell®pure yarns, which are known as ecological and medical textile materials, were investigated. The yarns were produced from SeaCell® stapel fibres and then were woven into fabric. After dyeing, the fabrics flame retardants which has phosphorus–inorganic synergism and organophosphorus compounds (N-hydroxymethyl-3-dimethylphosphonopropionamide), were applied to the the SeaCell®active and SeaCell®pure fabrics, and later the flame retardant properties were determined before and after washing processes. In addition to that, thermal properties of the fabrics and the effects of flame retardants were studied.

The flammability of the flame retardant treated SeaCell®active and SeaCell®pure were characterized by using limiting oxygen index (LOI). Structural changes of the treated SeaCell®active and SeaCell®pure and the compounds were carried out by using thermal analysis methods of differential scanning calorimeter (DSC) and thermogravimetric analysis (TGA). After flame retardant treatment on the 100% SeaCell® fabrics, the LOI value of the sample with phosphorus–inorganic synergism reached to 31 % and after 15 successive washing the LOI value was 20%. On the other hand, while obtaining 28% LOI value with the application of the N-hydroxymethyl-3-dimethylphosphonopropionamide after 15 successive washing this was achieved only 26%. It was also observed that both DSC and TGA thermograms were verifies their results.

Key Words: Flame retardancy, Thermal properties, SeaCell® fabric, Antimicrobial fibres, Washing.

ÖZET

Bu çalışmada medikal ve ekolojik olarak bilinen SeaCell®active and SeaCell®pure ipliklerden üretilen kumaşların güç tutuşurluk özellikleri araştırılmıştır. SeaCell® staple elyaftan üretilen ipliklerden kumaşlar oluşturularak boyama sonrası SeaCell®active ve SeaCell®pure kumaşlara fosfor–inorganik sinerjik ve organofosfor bileşikleri (N-hidroksimetil-3-dimetilfosfonopropionamid) maddeleri kullanılarak güç tutuşurluk bitim işlemi uygulandı. Daha sonra yıkama öncesi ve yıkama sonrası güç tutuşurluk özellikleri incelendi. Buna ek olarak termal özellikleri ve güç tutuşurluk maddelerinin etkilerine bakıldı.

Güç tutuşurluk maddeleri uygulanan SeaCell®active and SeaCell®pure kumaşların Limit Oksijen İndeksi (LOI), diferansiyel taramalı kalorimetri (DSC) ve termogravimetrik analiz yöntemleri kullanılarak yapısal değişikler araştırıldı. %100 SeaCell® kumaşlara uygulanan güç tutuşurluk işlemi sonrası, fosfor–inorganik sinerjik maddesi ile LOI değeri %31, 15 yıkama sonunda ise LOI değeri %20 olarak elde edilmiştir. N-hidroksimetil-3-dimetilfosfonopropionamid maddesi ile yapılan uygulamada ise %28 LOI değeri elde edilirken 15 yıkama sonrasında %26 olarak tespit edilmiştir. DSC ve TGA termogramların birbirlerini desteklediği görülmüştür.

Anahtar Kelimeler: Güç tutuşurluk, Termal özellikler, SeaCell® kumaşlar, Antimikrobiyal lifler, Yıkama.

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1. INTRODUCTION

SeaCell® fibres are considered to be new materials for textile industry and are becoming more important within the range of fibres in textile consumption. In the production of SeaCell® the coarse crushed seaweed material is processed to fine seaweed powder by a specialized milling technology. Subsequently, the fine seaweed powder is mixed with the cellulose component of SeaCell® fibre. The seaweed content in the SeaCell® fibre is around 8 to 10 % (1,2).

SeaCell® fibre is known as the third generation of regenerated cellulosic fibre and is manufactured using the product and environmental friendly Lyocell technology with algae (3). The SeaCell® fibre production can be either SeaCell®pure (cellulose fiber containing seaweed) or SeaCell® active (cellulose fiber containing seaweed and enriched with silver) (4).

SeaCell® fibres have many health advantages to users with excellent physical properties. Especially, the SeaCell® active has an antibacterial and fungicidal effect, therefore, is generally used for textiles to heal wounds (5,6).

On the other hand, the flame-retardant finish is highly required for the textile fibers for the security of the human life since they are extremely flammable. Shigeko et.al (7) have performed successive studies on flame-retardant finishes and related investigations of cellulose and polyester fibers, as well as of cotton–polyester blended fibers, from both fundamental and practical standpoints. There are four main chemical groupings of flame retardants, which are inorganic (e.g. aluminium trioxide and magnesium hydroxide), nitrogen-based organic, organop-hosphorus (e.g. phosphate esters) and halogenated flame retardants. Flame retardants are further divided based on durability; depending on their fastness to laundering, flame retardants can be classified as non-durable, semi-durable, or durable (8).

Different types of flame retardants will impede combustion by varying mechanisms and at different stages of combustion. Flame retardancy mechanisms and examples of flame retardants which work within that mechanism reducing the evolved heat to below what is needed to sustain combustion (inorganic and organic phosphorus-containing agents, aluminium hydroxide). There are different flame retardancy mechanisms, which improve the decomposition temperature inherently flame resistant fibres (e.g. aramids), modify pyrolysis process to promote char formation (barrier between flame and polymer) and decrease flammable volatiles (phosphorus and nitrogen containing flame retardants), interfere with flame chemistry (halogenated flame retardants often in synergy with antimony) and isolate the flame from the oxygen supply (halogenated flame retardants by releasing hydrogen halide and hydrated flame retardants by releasing water) (9).

There are concerns surrounding the toxicity of flame retardants since the combustion products are released into the environment. Researchers do not know or understand what the long-term risks of having traces of these chemicals in the body or environment is (10).

In this study the mechanism of a commercially successful flame retardant. N-hydroxymethyl-3 dimethylphosphonopropionamide and phosphorus–inorganic synergism were used for flame retardancy finishing of SeaCell® active and SeaCell®pure.

The flammability of the flame retardant treated SeaCell®active and SeaCell®pure was characterized by using limiting oxygen index (LOI). Thermal analysis methods were employed such as differential scanning calorimeter (DSC) and thermogravimetricanalysis (TGA).

2. MATERIAL AND METHOD

2.1 Material

In this study 100% SeaCell®active and 100% SeaCell®pure fabrics were produced from SeaCell® fibres supplied as a staple fibre which was spun into yarn.
The fabrics were made of plain weave structure and in weight of 130 g/m^2 with 30 thread/cm in weft density, and 30 thread/cm in warp density. Woven fabrics were then dyed as below.

2.2 Method

The woven SeaCell®active and SeaCell®pure fabrics were first bleached H_2O_2 with soda ash at pH 7,5.

Later the woven SeaCell® active and SeaCell® pure fabrics were dyed according to the weight of fabric with 2 % of colour yield which are Remazol Brillant Blue RSP (DyStar) and the liquor ratio was 40:1. Glauber's salt 13g/L, soda ash 50g/L were added to the dye liquor.

After the dyeing process, cold washing off and 70oC of warm washing off were carried out. Subsequently fabrics were neutralized with acetic acid and anionic washing (1g/L of washing substances, liquor ratio 40:1 for 20 minutes, 95oC) and then finally rinsed with 70oC of warm and cold.

As it is well know, flame retardants are divided based on durability or main chemical groupings. Depending on their fastness to laundering, flame retardants can be classified as non-durable, semi-durable, or durable. Therefore in this study the flame retardants were chosen durable (based on organophosphorus) and semi-durable (phosphorus–inorganic).

The flame retardants which have phosphorus–inorganic synergism and N-hydroxymethyl-3-dimethylphospho-nopropionamide structure were applied to the %100 SeaCell® active and SeaCell® pure fabrics. Both dyed fabric was padded at 70 % wet pick up with solutions containing 350 g/L N-hydroxymethyl-3-dimethylphosphono-propionamide, 30 g/L resine, 30 g/L crosslink agent 22 g/L phosphoric acid 5 g/L wetting agent, dried at 120oC for 40m/min speed, cured at 175oC for 60s at the specified times and temperatures, rinsed in running water, and finally dried.

Both dyed fabric was also padded at 70 % wet pick up with solutions containing 250 g/L phosphorus–inorganic synergism 2 g/L wetting agent, dried at 100oC for 40m/min speed, cured at 165 oC 12 m/min at the specified times and temperatures, rinsed in running water, and finally dried for phosphorus–inorganic synergism is (11).

2.3 Measurements

Limiting oxygen index (LOI) values of the untreated and treated fabrics were determined on the A JD-14 oxygen index tester. Any fiber with a LOI value of 21% or lower will effortlessly ignite and burn in the presence of air. LOI values of 26-28 are indicative of fibers which are flame retardant.

Additionally the treated fabrics which washed 15 cycles of washing according to the BS EN ISO 6330:2001 +A1: 2009 procedures were measured according to the ASTM standard method D2863-00 (12).

Table 1. Abbreviations used in the experimental work

Abbreviation of the fabrics	Fabrics and applications
SA	100% SeaCell®active raw fabric
SAB	100% SeaCell®active bleached fabric
SAD	100% SeaCell®active dyed fabric
SAH	100% SeaCell®active fabrics treated with N-hydroxymethyl-3 dimethylphosphonopropionamide
SAH15	After 15 cycles of washing of 100% SeaCell®active fabrics treated with N-hydroxymethyl-3 dimethylphosphonopropionamide
SAC	100% SeaCell®active fabrics treated with phosphorus–inorganic synergism
SAC15	After 15 cycles of washing of 100% SeaCell®active fabrics treated with phosphorus–inorganic synergism
SP	100% SeaCell®pure raw fabric
SPB	100% SeaCell®pure bleached fabric
SPD	100% SeaCell®pure dyed fabric
SPH	100% SeaCell®pure fabrics treated with N-hydroxymethyl-3 dimethylphosphonopropionamide
SPH15	After 15 cycles of washing of 100% SeaCell®pure fabrics treated with N-hydroxymethyl-3 dimethylphosphonopropionamide
SPC	100% SeaCell®pure fabrics treated with phosphorus–inorganic synergism
SPC15	After 15 cycles of washing of 100% SeaCell®pure fabrics treated with phosphorus–inorganic synergism

TGA studies were carried out under nitrogen atmosphere at a heating rate of 10oC/min using a Pyris1 thermal analyzer (Perkin Elmer) (13). DSC studies were carried out under nitrogen at a heating rate of 10 oC/min using a DSC-4000 (Perkin Elmer) instrument.

3. RESULTS AND DISCUSSION

LOI values, the thermogram graphics of the Thermogravimetric Analyse (TGA) and Differential Scanning Calorimetry (DSC) of the untreated and treated fabrics were shown and discussed in this section.

The results on the LOI values show that flame retardancy treatment in both SeaCell®active and SeaCell®pure fabrics raised the samples' flame retardancies (see Table 2, Table 3).

Table 2. Limiting oxygen index (%) of 100% SeaCell®active fabrics treated with N-hydroxymethyl-3 dimethylphosphonopropionamide (SAH) and phosphorus–inorganic synergism (SAC) flame retardants at different phosphorus content and their results after 15 cycles of washing

Abbreviation of the fabrics	LOI (%)	% Increase
SA	17.88	-
SAB	19.79	-
SAD	19.72	-
SAH	28.81	46
SAH15	26.34	33
SAC	31.30	59
SAC15	20.71	5

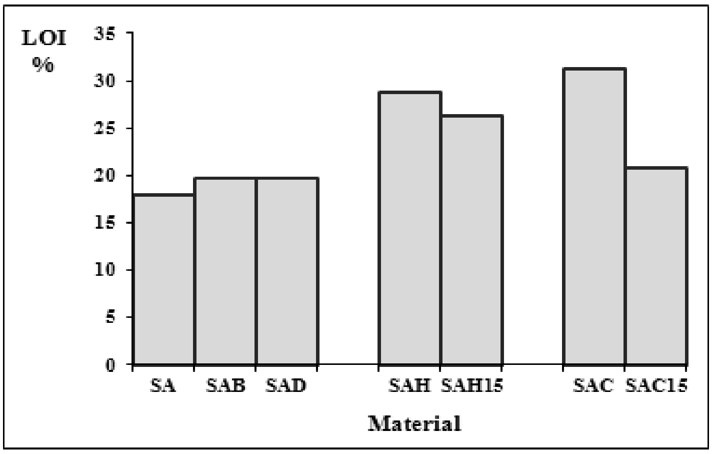

Figure 1. LOI (%) of 100 % Seacell® active fabrics treated with SAH and SAC flame retardants and after their 15 cycles of washings

Table 3. Limiting oxygen index (%) of 100% SeaCell®pure fabrics treated with N-hydroxymethyl-3 dimethylphosphonopropionamide (SPH) and phosphorus–inorganic synergism (SPC) flame retardants at different phosphorus content and their results after 15 cycles of washing

Abbreviation of the fabrics	LOI (%)	% Increase
SP	19.3	**-**
SPB	19.86	-
SPD	19.86	-
SPH	28.91	45
SPH15	26.10	31
SPC	31.80	60
SPC15	20.50	12

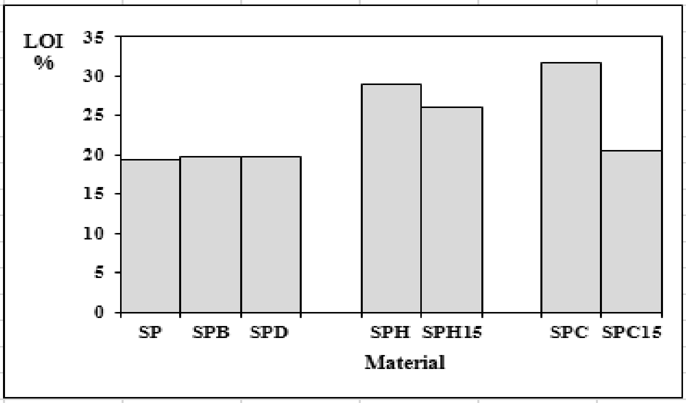

Figure 2. LOI (%) of 100 % SeaCell® pure fabrics treated with SPH and SPC flame retardants and after their 15 cycles of washings

It can be seen from the Table 2 and Table3 that bleaching and dyeing processes do not change the flame retardancy of the fabrics.

Table 2 and Table 3 shows that when 100% SeaCell®active and 100% SeaCell®pure fabrics were treated with phosphorus–inorganic synergism retardant have increased the LOI values of about 31 %. However, after the 15 cycles of washing it was observed that the materials seem to lose its effect by 20 %. Limiting oxygen index (%) values of 100% SeaCell®active and 100 % SeaCell®pure fabrics which were treated with N-hydroxymethyl-3 dimethylphosphonopropionamide (SAH) have shown LOI value of ~ 29 %. After the 15 cycles of washing LOI value was down to 26 %.

The decomposition temperature reduces and the amount of char formed increases with the SAH (34%) and than SAC (14%) as shown in Figure 3. Increased char formation could lead to improved flame retardance of the treated fabric. Overall, the N-hydroxymethyl-3 dimethylphosphonopropionamide (SAH) treated fabrics have shown little bit better thermal stability than the SAC treated fabrics.

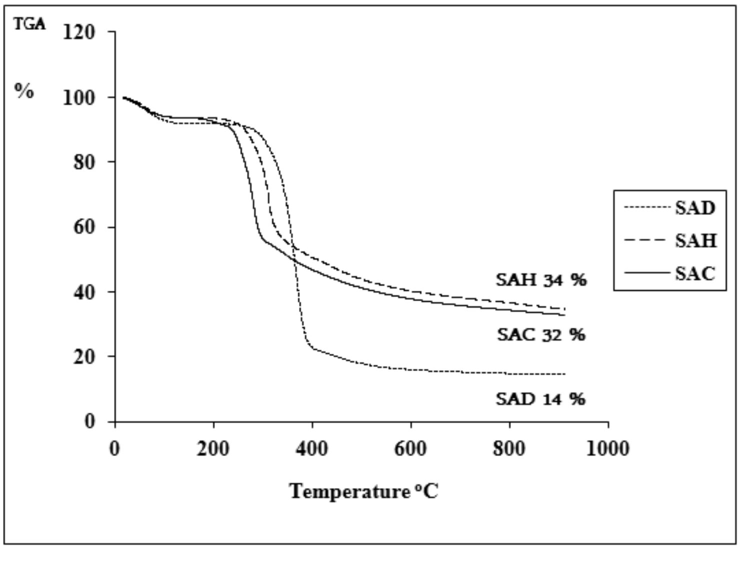

Figure 3. Thermal stability of 100% SeaCell®active fabric treated with different flame retardants: dyed 100 % SeaCell®active (SAD); 100 % SeaCell®active dyed fabric treated with N-hydroxymethyl-3 dimethylphosphonopropionamide (SAH); 100% SeaCell®active fabric dyed treated with phosphorus–inorganic synergism (SAC)

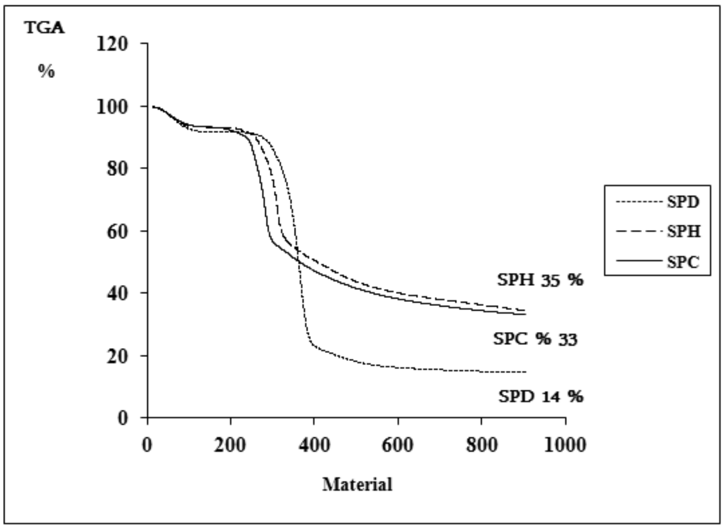

Figure 4. Thermal stability of %100 SeaCell®pure fabric treated with different flame retardants: dyed 100 % SeaCell®pure (SPD); 100% SeaCell®pure dyed fabric treated with N-hydroxymethyl-3 dimethylphosphonopropionamide (SPH); 100% SeaCell®pure dyed fabric with phosphorus–inorganic synergism (SPC).

The decomposition temperature and the amount of char formed is higher from the N-hydroxymethyl-3 dimethylphosphonopropionamide treated fabric (SPH) (35%) and (SPC) (33%) than that from SPD (14%) as shown in Figure 4. Increased char formation could lead to improved flame retardance of the treated fabric. Overall, the treated fabrics (SPH) have shown little bit better thermal stability than the SPC treated fabrics.

From the Figures 5 and 6, N-hydroxymethyl-3 dimethylphosphono-propionamide treated fabrics of 100% SeaCell®active and 100% SeaCell®pure show two endothermic peaks and an exothermic peak. The first endothermic area around 100oC is a loss of water present in 100 % SeaCell®active and 100% SeaCell®pure, and the second endotherm at~267°C was considered as acid catalyzed dehydration. At 294°C exothermic peak reveals the decomposition of 100 % SeaCell®active and 100% SeaCell®pure.

The DSC spectra of phosphorus–inorganic synergism treated 100% SeaCell®active and 100% SeaCell®pure showed two endothermic peaks at around 100oC and 244oC, respectively. And also exothermic peaks at ~273°C. Again at 100 oC loss of water, 244 oC acid catalyzed dehydration and 273°C decomposition occurs.

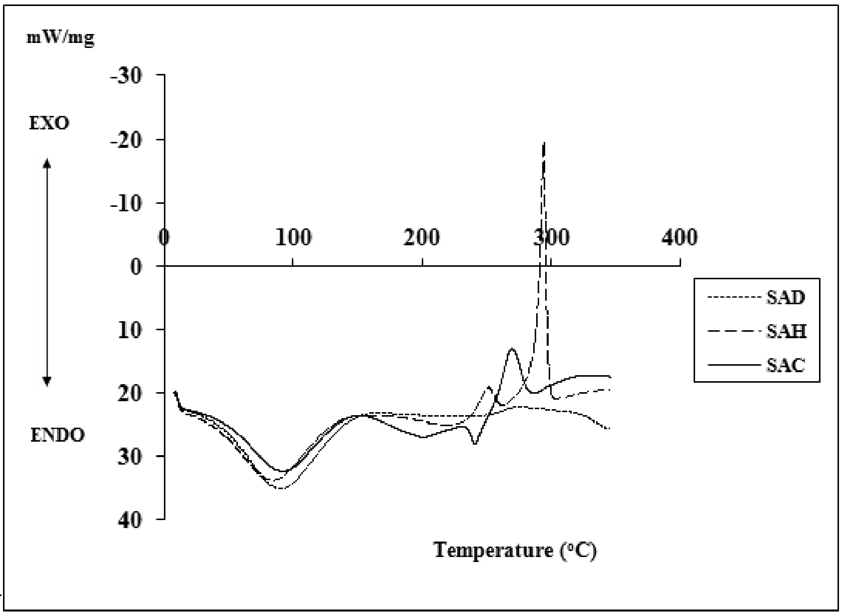

Figure 5. DSC spectra of 100 % SeaCell®active fabrics treated with different flame retardants: 100 % SeaCell®active dyed (SAD); 100 % SeaCell®active dyed treated with N-hydroxymethyl-3 dimethylphosphonopropionamide (SAH); 100 % SeaCell®active dyed and treated with phosphorus–inorganic synergism (SAC)

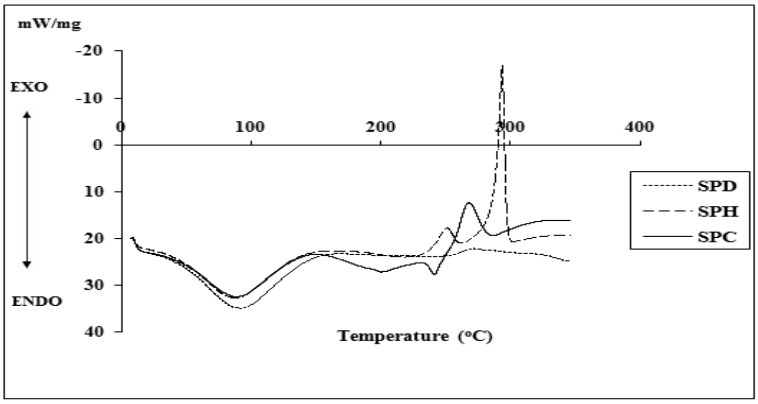

Figure 6. DSC spectra of 100 % SeaCell®pure fabric treated with different flame retardants: 100% SeaCell®pure (SPD) dyed; 100% SeaCell®pure dyed and treated with N-hydroxymethyl-3 dimethylphosphonopropionamide (SPH); 100% SeaCell®pure dyed fabrics treated with phosphorus–inorganic synergism (SPC)

4. CONCLUSIONS

1. The findings of this study make a useful contribution to the textile technologists and researchers as it has not been observed any related literature on the flame retardants of SeaCell® fabrics so far.

2. Pyrolysis was occurred earlier temperature and accelerated the char formation. It can be said that the char produced decreases the fuel within the flame and hence reduces the flammability and it acts as a barrier in between and therefore, it can be said that a flame retardant of 100 % SeaCell®active and 100 % SeaCell®pure is achievable.

3. TGA curves indicated that SeaCell® fabrics decomposed in a maximum rate lower than cotton materials (370 oC) found in literature. This may be due to the content (made from Alginat and Lyocell) of SeaCell® fiber itself.

4. TGA decomposition temperatures are similar to results seen in DSC thermograms.

5.The LOI values were around 19.7 % for both100 % SeaCell®active and 100 % SeaCell®pure dyed fabrics and LOI values were increased to 31.3 % with the flame-retardant application for the phosphorus–inorganic synergism. This is a 60 % increase when compared to dyed fabric. Furthermore, after the 15 cycles of washing its LOI value reduced to 20% and hence no flame retardancy left on the fabric.

6. Similarly LOI values with the N-hydroxymethyl-3 dimethylphosphono-propionamide treated fabrics were reached to 28% and this is an increase of 45% when compared to that of dyed fabric. Additionally, after the 15 cycles of washing their LOI values were about 26% and they retained the flame retardancy after the washing. Hence, the LOI values of SeaCell® fabrics were obtained likewise to cotton (28%) and to Lyocell (29%).

Especially SeaCell®active materials can be used to prevent infection spreading, odor release, and contaminations that are dangerous to human health, also deterioration of textile properties caused by microorganism activities and to reduce the risk of death and injury from fire at hospitals, schools etc.

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