Evaluation of Films for Packaging applications in High Pressure Processing

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Abstract

Food treatments implying high pressures used pre-packaging systems; consequently it appeared necessary to validate different packaging films able to be used in such processes. Two different packaging films from AMCOR FLEXIBLES have been evaluated:

- **VIROFLEXAL**: BOLSA 80 MICRAS, coextrusion PA/PE (20/60µm)
- **RILTHENE**: SEMI 20/60 MICRAS, laminate PA/PE (20/60µm)

Three different physico-chemical characterizations have been developed for the evaluation of films behaviour after High Hydrostatic Pressure (HHP):

1. Mechanical properties (tensile strength and sealing strength),
2. Oxygen permeability,
3. Migration, through the contact with four food simulating liquids FSLs (water, acetic acid 3%, ethyl alcohol 10%, iso-octane).

Two different pressures values (P = 400MPa and 500MPa) have been tested, with a duration of 15 min, at ambient temperature (+20°C) and only one pressure (P =200MPa) for the experiments at low temperature (T= -20°C) with the same duration (15min).

The selection of such values can be justified taking into account that experimental conditions as a temperature close to +20°C and a pressure between 400 and 500MPa are appropriated to inactivate bacteria and different others micro-organisms. Due to the efficiency of the association of hydrostatic pressure processing and low temperature (HHP/LT) [1, 2], the same films have been tested under high pressure processing (200MPa) but at negative temperature (-20°C).
1. Introduction

During these last twenty years, Pressure parameter was developed in food-processing due to different contributions: improvement of the shelf-life, preservation of the flavour or/and texture, reduction of the enzymatic activity, inactivation of contaminant micro-organisms [3-6]. Such applications can be considered as the results of research works initiated during the first part of the XXth century in particular by P.W. Bridgman in U.S. [6] and J. and J. Basset in France [7].

The development of such processes in Biosciences is due to the difference of energy associated to the application of pressure, as thermodynamical parameter, compared to that developed by temperature [8], pressure appearing as a “soft tool”.

The second step was the evaluation of high pressures in biological processes [9]. Different researches have been developed for testing different processes involving pharmaceutical applications associating the inactivation of micro-organisms to the preservation of the therapeutic activity [10, 11]. In the major high pressure applications both in food processing or involving pharmacology, the products are treated as pre-packaged in flexible or semi-rigid packaging materials in order to prevent contact between the pressure transmitting fluid and the treated material (food or pharmaceutical product). In such cases the behaviour of films used for packaging during the high pressure treatments appears an important goal for developing industrial high pressure processes [12].

Different studies have been carried out previously on different films demonstrating that the package have to present sufficient flexibility to compensate the complete compression of the head space and the limited volume reduction of the food inside the packaging materials [13].

The selection of the correct packaging material is important. The pouches have to be flexible while maintaining physical integrity and suitable barrier properties. The flexible polymeric films should be closed by heat seal, compatible with the HP process [14, 15].

Three major interactions between food and packaging materials can occur and could affect the quality of the biological product: sorption, permeation, and migration.

The sorptions of organic component from a food product or pressure transmitting fluid by packaging material have been studied. Polymeric pouches, after HHP showed no significant change in the sorption behaviour, compared to before hydrostatic pressure, which is not the case for the metallized films [16, 17].

The permeation, corresponding to the barrier properties in particular oxygen barrier and water vapour barrier, protects the quality of the high pressure treated foods, can be affected by the high pressure treatment [18].

The migration properties using four food simulating liquids FSLs (water, acetic acid 3%, ethyl alcohol 10%, iso-octane) recommended by the European rules [19] is important to determine the quantity of components susceptible to be transfer from the polymer to the food (global migration limit).

High pressure processing on certain plastic packaging pouches may cause damage. The package is susceptible to fracture, may distort or present delamination for multilayer films. HHP could alter the adhesion between the layers of the multilayer film. The delamination presents air pockets between constituent sublayers and occurs in particular when the individual layers of multilayer structure show widely differing compressibility and resilience behaviour [18, 20].

Flexible plastic structures which are resilient and elastic behaviour are best suitable for processing prepackaged foods by HHP; they were especially resilient and invariant in their sorption, permeation, migration and mechanical behaviour. If plastics are combined with metallized film (aluminium), they are greatly affected in their barrier properties and partially in their mechanical properties (delamination), because of the different elasticity factors. Structures of multilayer films containing inorganic layers such Al₂O₃ or SiO₂ show even though some superficial damages like disruption of the recoverage, delamination and wrinkles, which did not affected mechanical properties [21, 22]. For all these reasons, the materials packaging used in HHP treatment are principally polymeric multilayer films.
EVOH is the principal plastic used in multilayer structure, usually between polyethylene or polypropylene. It is the most extensively studied concerning the effect of pressure on the packaging because EVOH films present an excellent barrier to oxygen and aroma compounds and they also have high chemical resistance to organics compounds [23].

Our study concern another type of polymer without EVOH, constituted of polyamide (PA) and polyester (PE) assembled in two layer films PA/PE used in food industries by GAIKER (20µm polyamide layer and 60µm polyethylene layer). The film VIROFLEXAL is elaborated by coextrusion and the film RILTHENE by lamination.

Only three works concern this type of multilayer film PA/PE.

One work concerns films elaborated by SOPLARIL, VACOPACK and CHEMOSVIST, Dobias [24] demonstrated that the most important effect of HHP was found for loss of heat sealability of material film and for a modification of global migration into ethanol and/or isooctane.

The second work, from Lambert et al. [18] on films elaborated by SOPLARIL, showed that only one package demonstrated incompatibility with HHP because of delaminations. The other pouches showed any significant mechanical changes, in terms of barrier properties, migration or integrity after HHP treatment.

The third work, from Le Bail et al. [25] on films elaborated by CRYOVAC, showed that HHP treatment minimally affects the mechanical strength and water vapour permeability was not significantly affected. This author has showed that the depressurization rate has any significant influence.

2. Materials and Methods

In this study, two different packaging films prepared by AMCOR FLEXIBLES have been evaluated: VIROFLEXAL and RILTHENE.

The characteristics of such films are given on Table I.

Table I: Characteristics of the two packaging-films selected for evaluation after high pressure processing at ambient temperature or high pressure processing/low temperature treatments

| Type of package | Composition | Fabrication process |
|-----------------|-------------|---------------------|
| VIROFLEXAL      | PA/PE       | coextrusion         |
|                 | (20/60µm)   |                     |
| RILTHENE        | PA/PE       | lamination          |
|                 | (20/60µm)   |                     |

The selected parameters governing the treatment were not only high pressure processing in hydrostatic conditions at ambient temperature but also low temperatures (LT), due to the influence of negative temperatures associated to high pressures on the inactivation of micro-organisms [1, 2].

Three main physico - chemical characterizations have been selected in order to evaluate the behaviour of packaging films before and after the treatment (HHP or HHP/LT):

(i) Mechanical properties, in particular the tensile strength and the sealing strength,
(ii) Oxygen permeability,
(iii) Migration properties using different liquid phases simulating different media (distillate water, acetic acid 3%, ethyl alcohol 10% and iso-octane) recommended by the European rules (n°85/572, n°90/128, n°93/8, n°97/48 and n°02/72).

In order to manage high pressures and/or low temperatures, specific equipment designed through a partnership between NFM Technologies – Framatome Clextral and the High Pressure Centre (ICMHB/CNRS site of ENSCPB – University of Bordeaux) has been used for such a study [1]. This
equipment, due to its specific design, is able to generate high pressures up to 800MPa and to use low
temperatures till -20°C in a volume close to 3 litres and in addition such equipment is appropriated for
developing short cycling processes.

The samples were placed in the compression chamber and first subjected to hydrostatic
pressures with selected values as: 200, 400 and 500MPa and ambient temperature (+20°C).

When low temperatures were associated to high pressures (HHP/LT), the selected temperature
value representative of this process was: -20°C.

In all cases the duration of the treatment is constant (15mn.) and pressure-increasing rate was
selected close to 375MPa/min.

At ambient temperature, water can used as pressure transmitting medium but at low-temperature
it is impossible. For this reason the pressure transmitting fluid is ethylene glycol for all experiments at
negative temperature but also at ambient temperature for our study.

3. Physico-Chemical characterizations before and after high pressure treatments

The characterizations of the physico-chemical properties are made according to the specific
international standards for each of the analyses, at ambient pressure and ambient temperature.

The measurements of the properties concerning mechanical behaviour (delamination or fracture,
tensile and sealing strength), oxygen permeability and migration are following:

3.1 Tensile strength

Tensile strength in both the machine direction (MD) and the transverse direction (TD) was
measured using a tensile tester equipped with a sensor 2000N. The speed of the tensile tester was
200mm/min. The sample size was: width=15mm, thickness=0.080mm. The results are the average of
10 samples for each treatment expressed as MPa.

3.2 Sealing strength

Sealing strength in both the machine direction (MD) and the transverse direction (TD) was
measured using the same a tensile tester. The speed of the tensile tester was 100mm/min. The sample
size was: width=15mm, thickness=0.080mm. The results are the average of 10 samples expressed as
MPa.

If some delaminations are observed, electron microscopy will be used for the comprehension of
the origin.

3.3 Oxygen barrier

Oxygen permeability was measured by anemometric gas permeability tester Systech 8000 in
compliance with regulation ASTM D3895. Measurements conditions were 23°C and 0% humidity. Each
result (in cm³/m²/24h) was repeated several times.

3.4 Global migration

Measurements of the global migration were carried out following the AFNOR XP ENV
1186-1 regulation. Packages were in contact with simulating liquid phases for 10 days at 40°C. Due to
the difficulty to evaluate migration with olive-oil and following the second amendment of EEC
Directive 82/711 and EEC Directive 85/572, olive-oil was replaced by iso-octane. Each result (in
mg/dm²) was the average of three different measurements.
4. Experimental results

4.1 Evolution of mechanical properties

The results of mechanical behaviour (tensile and sealing strength) were statistically analyzed using analysis of variance (ANOVA). This test is able to evaluate results of two or more samples. Samples are evaluated as a function of a quantitative variable (tensile strength, sealing strength etc…). This allows detecting differences in the mean values. The ANOVA test has been done by the F of Fisher-Snedecor. F calculated < F theoretical, then the variations are homogeneous and changes are not significant.

The samples (width=15mm, thickness=0.080mm) for the mechanical measurement were cut out from pouches tested with water inside.

At +20°C, two different pressure values have been tested (400MPa and 500MPa), the duration of the treatment being constant (15min.).

At -20°C, only one pressure value was tested (200MPa), the duration of this treatment being maintained at 15min.

The tensile and sealing strength was measured in two directions: machine direction (MD) and transverse direction (TD).

4.1.1 Measurement of tensile strength

Table II gives the resulting values of the tensile strength values before and after high pressure processing treatments for two high pressure treatments 400MPa and 500MPa, at +20°C for a constant duration 15min.

Table II: Tensile strength values before and after HP treatment (400MPa and 500MPa, 15min., +20°C) for VIROFLEXAL and RILTHENE in two directions (MD) and (TD)

|                  | VIROFLEXAL                      |               | RILTHENE                      |
|------------------|---------------------------------|---------------|-------------------------------|
|                  | MD                              | MD            | MD                            |
| no treatment     | P = 400 MPa                     | P = 500 MPa   | P = 400 MPa                   |
| 24.4 ± 3.7       | 23.9 ± 3.2                      | 26.8 ± 3.2    |
| TD               | P = 400 MPa                     | TD            | P = 500 MPa                   |
| 17.4 ± 3.6       | 20.1 ± 3.8                      | 24.5 ± 1.3    |

Table III gives the resulting values before and after HHP treatment values at -20°C for only the pressure value P=200MPa tested duration 15min.
Table III: Tensile strength values before and after HP treatment (200MPa, 15min., -20°C) for VIROFLEXAL and RILTHENE in two directions (MD) and (TD)

|         | MD          | MD          | TD          | TD          |
|---------|-------------|-------------|-------------|-------------|
| VIROFLEXAL | no treatment | P = 200 MPa | no treatment | P = 200 MPa |
|         | 28.6 ± 1.8  | 22.7 ± 1.8  | 24.3 ± 2.4  | 17.4 ± 2.3  |
| RILTHENE | no treatment | P = 200 MPa | no treatment | P = 200 MPa |
|         | 47.2 ± 10.3 | 48.6 ± 2.2  | 33.2 ± 4.0  | 35.0 ± 4.1  |

4.1.2 Measurement of sealing strength

Table IV gives the resulting values of sealing strength values before and after high pressure processing treatments for two high pressure treatments 400MPa and 500MPa, at +20°C for a constant duration 15min.

Table IV: Sealing strength values before and after HP treatment (400MPa and 500MPa, 15min., +20°C) for VIROFLEXAL and RILTHENE in two directions (MD) and (TD)

|         | MD          | MD          | TD          | TD          |
|---------|-------------|-------------|-------------|-------------|
| VIROFLEXAL | no treatment | P = 400 MPa | no treatment | P = 400 MPa |
|         | 20.7 ±1.9   | 19.0 ± 3.4  | 17.5 ± 1.3  | 15.9 ± 2.6  |
| RILTHENE | no treatment | P = 400 MPa | no treatment | P = 400 MPa |
|         | 20.3 ± 2.5  | 20.8 ± 5.1  | 12.6 ± 1.6  | 14.7 ± 2.2  |

Table V gives the resulting values before and after HHP treatment at -20°C for only the pressure value P=200MPa tested duration 15min.
Table V: Sealing strength values before and after HP treatment (200MPa, 15min., -20°C) for VIROFLEXAL and RILTHENE in two directions (MD) and (TD)

|                  | MD  | TD  |
|------------------|-----|-----|
| VIROFLEXAL       |     |     |
| no treatment     | 26.2 ± 1.1 | 25.3 ± 2.0 |
| P = 200 MPa      | 26.5 ± 3.7  | 24.9 ± 2.2 |
| RILTHENE         |     |     |
| no treatment     | 34.3 ± 1.9  | 27.0 ± 2.1 |
| P = 200 MPa      | 31.8 ± 1.1  | 25.6 ± 1.5 |

4.1.3 Conclusions concerning the strength values after HHP treatments at ambient temperature (+20°C)

4.1.3.1 Tensile strength
Concerning tensile strength at 400MPa and +20°C, the films VIROFLEXAL and RILTHENE present no significant modifications. But at 500MPa and +20°C if the film VIROFLEXAL maintains its tensile strength value, the film RILTHENE is affected by this HHP treatment, the mechanical tensile strength decreasing mainly in the transverse direction (TD).

4.1.3.2 Sealing strength
Involving sealing strength at 400MPa and +20°C, the films VIROFLEXAL and RITHENE present no significant variation. At 500MPa and +20°C, the sealing strength values concerning the film VIROFLEXAL, seems not affected compared to that observed for RILTHENE.

4.1.3.3 Discussions
Dobias et al.[24] showed that the HHP treatment (600MPa, 60min., +20C) doesn’t affect the mechanical properties (tensile strength MD and TD, sealing strength MD and TD) for two films PA/PE 100µm (SOPLARIL), and PA/PE 80µm (CHEMOSVIT), but the film PA/PE 90µm (VACOPACK) is affected by these conditions.
Le Bail [25] showed that HHP treatment (200, 400, 600MPa, 10min., +10°C) doesn’t affect the mechanical properties with rapid depressurization and slow depressurization for the film PA/PE 59µm (NOD 259: CRYOVAC).
The study of Lambert et al. [18] showed that the HHP treatments (200-500MPa, 30min., 20°C) have no significant change on the tensile strength and heat-seal strength of films PA/PE (RSD100, RSE100, RC302), within the allowable deviations of 25% (norm of SOPLARIL).
This study shows that only the film VIROFLEXAL (PA/PE (20/60µm) elaborated by coextrusion) is compatible for HHP treatment at +20°C if pressure is above 500MPa. The manufacture of the multilayer films is important consider the mechanical properties.
4.1.4 Conclusions concerning the strength values after HHP treatments (200MPa) at negative temperature (-20°C)

4.1.4.1 Tensile strength

At -20°C and normal pressure (0.1MPa), the film RITHENE is affected by the low-temperature and ambient temperature treatment compared to the tensile strength values at normal pressure and ambient temperature. The film VIROFLEXAL is less affected in the same conditions.

At high hydrostatic pressures (200MPa) and negative temperature (-20°C), the tensile strength properties of VIROFLEXAL are modified but for RILTHENE they are not affected.

4.1.4.2 Sealing strength

At negative temperature (-20°C) and normal pressure (0.1MPa), the film RILTHENE is affected compared to the evolution of the sealing strength values at ambient temperature (+20°C) but VIROFLEXAL seems less affected.

At negative temperature (-20°C) but under high hydrostatic pressure (200MPa), the films RILTHENE and VIROFLEXAL are not affected compared to the sealing strength values at normal pressure (0.1MPa).

4.1.4.3 Discussions

Below 210MPa, the melting point of water decreases inversely with pressure, reaching the minimum melting temperature value, near -21°C, at about 210MPa.

Only the work by Fradin [26] has been found in the literature concerning the resistance of packaging material during HHP treatment (200MPa, 15min., +20°C), for the application in HHP treatment assisted thawing of foods. His study concerns six different packages and only one film with the structure PA/PE 100µm (SOPLARIL) using foods initially in a frozen state (-18°C). He observed a delamination on packaging materials containing air and not under vacuum conditions.

This study shows that only the film RILTHENE (PA/PE (20/60µm) elaborated by lamination) is compatible for HHP treatment at -20°C, but the mechanical properties are affected by the negative temperature.

4.1.5 Conclusions concerning the strength values after high pressure treatments

In conclusion versus its mechanical properties, the film RILTHENE appears as the best candidate as packaging film for high pressure treatment (200MPa) at negative temperature (-20°C) but it is necessary to underlined that such mechanical properties are affected compared to the observed values at ambient temperature.

Concerning the behaviour of mechanical properties under high pressures (400 and 500MPa), the film VIROFLEXAL (PA/PE (20/60µm) elaborated by co-extrusion) appears the best candidate as packaging film at ambient temperature (+20°C).

4.2 Evaluation of the oxygen permeability after HHP treatment at ambient temperature (+20°C) or negative temperature (-20°C)

4.2.1 Results

At high pressures (400 and 500MPa) and ambient temperature (+20°C) the film VIROFLEX presents a lower permeability than for RILTHENE and any modification versus pressure is observed for both.

At high pressures (200MPa) but at negative temperature (-20°C), the films VIROFLEXAL and RILTHENE present no modifications compared to that observed at ambient pressure.

Table VI gives the values corresponding to oxygen permeability (cm³/m²/24h) after different treatments of the packaging films.
Table VI: Evolution of the permeability to oxygen versus the experimental treatment (temperature, pressure) (values expressed in cm³/m²/24h)

|                  | VIROFLEXAL +20°C/0.1MPa | VIROFLEXAL -20°C/0.1MPa | VIROFLEXAL +20°C/400MPa | VIROFLEXAL -20°C/500MPa | VIROFLEXAL -20°C/200MPa |
|------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| VIROFLEXAL       | 37.6 ± 1.8               | 34.8 ± 1.2               | 37.1 ± 2.4               | 39.0 ± 0.8               | 37.9 ± 1.2               |
| RILTHENE +20°C/0.1MPa | 46.7 ± 3.4               | 42.7 ± 1.4               | 49.2 ± 1.2               | 43.4 ± 1.2               | 47.8 ± 5.7               |

4.2.2 Discussions
Lambert et al. [18] demonstrated that the variations of oxygen permeability for the films RSD100 and RC302 after HHP treatment (500MPa, 30min., 20°C) exceed allowable deviation of 12% (norm of SOPLARIL) but these levels of permeability were still compatible with food products. The film RSE100 after HHP treatment (500MPa, 30min., 20°C) didn’t exceed allowable deviation of 12%.

However, Dobias et al. [24] showed that HHP treatment (600MPa, 60min., +20°C) does affect water vapour permeability for films PA/PE 100µm (SOPLARIL), PA/PE 80µm (CHEMOSVIT) and film PA/PE 90µm (VACOPACK).

Le Bail et al. [25] showed that HHP treatment (200, 400, 600MPa, 10min., +10°C) doesn’t affect water vapour permeability with rapid depressurization and slow depressurization for the film PA/PE 59µm (CRYOVAC).

There are no global rules for the permeability, which depends on the films PA/PE.

4.3 Evaluation of Global migration after HHP treatment at + 20°C and HHP-LT treatment (-20°C)
Global migration has been evaluated both versus the high pressure parameter (400 and 500MPa) at ambient temperature (+20°C) and also versus the high pressure parameter (200MPa) but at negative temperature (-20°C).

The uncertainty of the overall migration expressed mg/dm²; it is obtained from the formula:

\[ A = \sqrt{\frac{\sum (x_i + \bar{x})^2}{n-1}} + E^2 \]

A: constant=2
n: number of tested samples
x: value of overall migration
\( \bar{x} \): mean value of overall migration
E: maximum value of the error from the equipment employed in the overall migration

Table VII gives the main obtained results.
Table VII: Overall migration values (expressed in mg/dm²) versus both parameters: high pressure (400 and 500MPa at +20°C) and high pressure (200MPa at -20°C)

| SAMPLE      | TREATMENT               | WATER | ACETIC ACID 3% | ETHYL ALCOHOL 10% | ISOOCTANE |
|-------------|-------------------------|-------|----------------|-------------------|-----------|
| VIROFLEXAL  | Untreated               | <0.3  | <0.1           | <0.3              | 4.1 ± 0.7 |
|             | HP treated 2000 bar     | <0.9  | <0.5           | <0.5              | 4.4 ± 0.9 |
|             | +20°C, 15 min           |       |                |                   |           |
|             | Untreated               | <1.2  | 0.7 ± 0.2      | 0.7 ± 0.5         | 4.3 ± 0.3 |
|             | HP treated 4000 bar     | <1.2  | 0.6 ± 0.3      | 0.4 ± 0.4         | 4.3 ± 1.3 |
|             | +20°C, 15 min           |       |                |                   |           |
|             | HP treated 5000 bar     | <0.6  | 0.7 ± 0.2      | <0.8              | 4.3 ± 0.6 |
|             | +20°C, 15 min           |       |                |                   |           |
| RILTHENE    | Untreated               | <0.4  | <0.5           | <0.2              | 2.7 ± 0.8 |
|             | HP treated 2000 bar     | <0.1  | <0.2           | <0.7              | 2.9 ± 1.2 |
|             | +20°C, 15 min           |       |                |                   |           |
|             | Untreated               | <1.2  | <2.6           | 0.6 ± 0.4         | 2.7 ± 0.5 |
|             | HP treated 4000 bar     | 0.3 ± 0.1 | 0.7 ± 0.3 | 0.6 ± 0.2         | 2.6 ± 0.9 |
|             | +20°C, 15 min           |       |                |                   |           |
|             | HP treated 5000 bar     | <0.2  | <0.5           | <0.9              | 2.7 ± 0.2 |
|             | +20°C, 15 min           |       |                |                   |           |

Whatever (i) the nature of the packaging, (ii) the pressure values (200, 400 or 500MPa) and (iii) the temperature (+20°C or -20°C), the global migration values are not modified (taking into account the variations compatible with the legislation). These results show quite clearly that the films are not affected by HHP treatment and could be used.

The same results was demonstrated by Lambert [18], the values before and after treatment (500MPa, 30min., 20°C) are similar for the films PA/PE RSD100, RSE100 and RC302.

However, Dobias [22] showed that HHP treatment (600MPa, 60min., +20°C) affect the global migration into 95% ethanol and into iso-octane for the three films PA/PE 100µm (SOPLARIL), PA/PE 90µm (VACOPACK) and PA/PE 80µm (CHEMOSVIT).

There are no global rules for the behaviour of films PA/PE concerning the migration with FSLs.

5. General Conclusions, Discussions and Prospective

The selection of correct packaging material is very important, as the packaging material needs to be flexible enough to resist compression forces while maintaining physical integrity and suitable barrier properties. Generally, the packages constituted with EVOH and PVOH have been shown its compatibility with HHP treatment.

This study on films PA/PE shows that no global rules can be given, each package has to be tested under HHP treatment with the pressure required by the industrial application.

We have observed that the most important aspect of packaging in HHP treatment is the volume of head space to avoid delamination. Air is very compressible under high pressure, the deformation strains on the packages would be more important.

Concerning the development of food processing under high pressure at ambient temperature
(+20°C) the film VIROFLEXAL seems a good candidate. Due to the upper pressure level able to be developed in the near future (600MPa) – such a film must be tested in such extreme pressures conditions.

Concerning the potential developments of packaging films in Pharmacological processes involving negative temperatures: -20°C (in order to improve the inactivation of resistant microorganisms, in particular Staphylococcus Aureus) the film RILTHENE could be the best candidate. For evaluating the potentialities of such film, two different types of tests must be developed in the near future: (i) the behaviour of the RILTHENE properties at higher pressures (400, 500MPa), (ii) the evaluation of its properties versus cycling high pressure processes (due to the strong efficiency of such processes in the inactivation of spores).

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