Technical Information

# THERMOLON™
# MINERAL COATINGS

***Performance - Health - Environment***

# Technical Information

**Title:** Thermolon™ Mineral Coatings

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# PREFACE

Until today non-stick coatings were based on **organic** (carbon-containing) polymers. They mainly comprised PTFE or other fluoropolymers. Such polymers have many well-documented disadvantages in practical household use. For example, above 260° C fluoropolymers like PTFE are known to release a multitude of toxic and carcinogenic chemicals.

Manufacture, application and use of these fluoropolymers impacts on our health and safety as well as causing a build-up of perfluorinated persistent pollutants in the environment. PTFE dispersions are generally manufactured with the use of an artificial dispersant called PFOA, which is classified by the US EPA as a persistent organic pollutant. Moreover, it is classed as a "likely carcinogen”. Environmental contamination has reportedly caused PFOA to be found in the blood of 95% of the American population. As it is slow to be cleared from the body, average levels of PFOA in the population’s blood have reportedly increased decade upon decade.

In view of results from various animal and human studies, traditional non-stick coating manufacturers have been prompted under an EPA stewardship program to phase out PFOA from their products by the year 2015 and reduce emissions to zero.

The good news is that a new, completely safe non-stick surface is available – known as Thermolon™, it does not use any PTFE or PFOA at any stage in its manufacture or application.

Thermolon™ is **inorganic** (i.e. mineral in origin) and, therefore, offers a unique combination of properties:

- Hardness (up to pencil hardness 9H)
- High heat resistance (up to 450°C)
- Low coefficient of friction

Thermolon™ is a natural solution that is in accordance with International Food Contact Regulations such as those set by the U.S. Federal Dugs Administration (FDA) FDA CFR21 § 175.300 and the German LFGB §30 and §31.

***Thermolon™ is available now – you do not have to wait until the year 2015.***

# TERMINOLOGY

**Abrasion resistance** is a measure of the ability of a coating to withstand abrasion through contact with a rough (abrasive) material. It is often quantified in an Abrasion Test whereby a Scotch Brite pad under a specified force is reciprocated for a given number of cycles across the coating's surface and the decrease in coating thickness is recorded.

**Adhesion** of a coating is its ability to adhere to the surface of a substrate without being delaminated by mechanical force or thermal cycling.

**Acid and alkali resistance** is the ability of a coating to protect the substrate (metal underneath) from attack by acid or alkaline media. This is often quantified by the number of hours that a coated substrate can withstand being immersed in an acid or alkaline solution of stated concentration and temperature without the substrate underneath being impaired.

**APFO** - see entry under PFOA

**C8** - see entry under PFOA

**Carbon tetrafluoroide** ($CF_4$) is a gas that is released by decomposition of PTFE above 1,202°F (650°C). Inhalation at low concentrations may cause narcotic effects or other symptoms including dizziness, headache, nausea and loss of co-ordination.

**Carbonyl fluoride** ($COF_2$) is a fluorinated relative of the chemical warfare agent known as phosgene. It is a gas released when PTFE is heated above 824**°**F (440°C). Such a temperature can readily be attained or exceeded on a conventional domestic stove.

**Carcinogens** are substances that can cause cancer in humans or other animals.

**Ceramics** – mineral materials, which have traditionally been derived from the earth (e.g. from clays). Ceramic materials are completely food-safe and have been used to form ceramic items like pottery and glass for manufacture of for example cookware and tableware. Thermolon™ is a ceramic type of coating that is based on *Sol-Gel* technology.

**Chlorodifluoromethane** ($CHClF_2$) - raw material used in the production of PTFE and which is ozone-depleting.

**$CO_2$** (carbon dioxide) - a greenhouse gas that is produced by the generation of electricity from burning fossil fuels, which is considered to be a major contributor to climate change.

**Corrosion resistance** is the ability of a coating to protect the substrate (metal underneath) from corrosion. Resistance is often quantified by the number of hours that a coated substrate can be boiled in a 10% aqueous salt (NaCl) solution without the substrate being impaired or the coating being otherwise damaged.

**Curing** is the process of drying the coating during which the properties of the coated surface are developed. For conventional PTFE non-stick coatings, this process is carried out in a curing oven in which the peak oven (air) temperature may reach above 824°F (440°C). This process is highly energy-intensive. Therefore, the lower the curing temperature that can be used the greater the energy that can be saved – as with Thermolon™.

**Dispersion** is the term used to describe a liquid in which another liquid or solid material is finely suspended. For example, PTFE is a solid at room temperature, but the form in which it is used for manufacture of non-stick coatings is normally an aqueous dispersion. Owing to the fineness of the PTFE particles, the PTFE dispersion has a milky appearance. To prevent the particles of PTFE from agglomerating, a dispersion agent such as PFOA is added during manufacture.

**Flash-off** is an intermediate drying stage in applying a coating, the name implying driving solvent from a wet coating layer.

**Fluoropolymers** are a class of polymers where the molecular formula of the repeat unit in the polymer chain contains atoms of fluorine (F). The substitution of fluorine in the molecular structure makes the polymer relatively inert and heat resistant. One of the most common examples of a fluoropolymer is PTFE.

**Hardness** of a coating is a measure of its ability to resist damage by another material of a given hardness. A common way of quantifying hardness is on a scale of pencil hardness.

**HPF** (hexafluoropropene, $C_3F_6$) is a gas that is released from PTFE when it is heated above 680°F (360°C). It is classed as harmful by inhalation and irritating to the respiratory system.

**Inorganic** - compounds that are not based on carbon – such as minerals.

**International Food Contact Regulations** - an article used in food contact must comply with the “No Migration Principle”. This means that nothing from the articles can impart flavour, color, odor, toxicity or any other undesirable characteristic to food.

**Mid-coat** is a layer of a coating that is applied after the primer but before the top-coat. It is often used to impart strength (or reinforcement) to the coating and to form an interface between primer and top coat.

**Multi-layer coating** – conventional PTFE non-stick coatings require two or more layers in order to make them more durable. The disadvantage is that the more layers that are used, the more spraying operations that are involved. Each spraying operation involves losses of coating into the atmosphere, which makes the coating process less efficient and increases emissions of pollutants.

**Organic** – compounds that contains carbon (C) in combination with other elements

**Non-stick coatings** for cookware or bakeware are materials that are applied to the substrate (metal) to prevent the sticking of food during cooking and to render them easy to clean after cooking. Non-stick coatings commonly contain PTFE or silicone oil to aid the release of food from the surface. Thermolon™ is an example of a non-stick coating that contains neither PTFE nor silicone oil.

**PFiB** (perfluoroisobutene) is a gas released from PTFE when heated above 824°F (440°C). It is ten times as toxic as phosgene, which is a chemical warfare agent. Inhalation of this gas can cause pulmonary edema and can lead to death.

**PFOA** (Perfluorooctanoic acid) sometimes referred to as "C8" or APFO, is used as a dispersant in manufacture of PTFE and other fluoropolymer dispersions. It is highly persistent in the environment and is very slow to be eliminated from the human body. Currently there is concern because reports show that PFOA can now be detected in the blood stream of most Americans, but the mechanism by which it enters the body is not entirely understood. PFOA is currently considered as a likely carcinogen.

**Polymers** are natural or synthetic long chain molecules composed of a simpler molecule (or repeat subunit) linked together to form a material which, depending on the type of subunit and length of the chain, can be designed with specific mechanical and physical properties.

**Primer (or base coat)** - the first layer of coating that is applied to the substrate.

**PTFE** (Polytetrafluoroethylene) is a fluoropolymer comprising repeat units of a simpler molecule called tetrafluoroethylene forming the structure $-[CF_2-CF_2]_n-$
(n is the number of times that the unit is repeated in the chain). PTFE is widely used to impart non-stick properties to cookware coatings because of its low coefficient of friction. Its temperature stability, however, is limited 260°C when used for food-contact applications.

**Release properties** of a coating refer to the degree to which food does not stick to the surface during or after cooking. It is often assessed by tests such as frying eggs or caramelizing sugar inside coated cookware under a standard test conditions.

**Sol-Gel** – materials formed from small inorganic (mineral) particles suspended in *Solution* that *Gel* together to form an inorganic matrix. Thermolon™ is an example of a Sol-Gel technology.

**Scratch resistance** is the ability of a coating to withstand scratch markings when sharp implements are applied with motion and force to the surface.

**Substrate** refers to the material of the article that is to be coated.

**Temperature resistance** refers to the maximum temperature to which a coating may be subjected before physical or chemical changes occur, rendering the coating unfit for further use.

**Thermolon**™ is a non-stick mineral coating based on Sol-Gel technology with superior release properties but contains absolutely zero PTFE (and zero PFOA) and no silicone oil.

**TFE** (tetrafluoroethylene, $CF_2$-$CF_2$) is a highly flammable, colorless gas that is insoluble in water. It is used as the basic building block of PTFE. When PTFE is heated above 680°F (360°C) TFE is released. TFE is classed as a reasonably anticipated human carcinogen.

**Top-coat** is the layer of a coating that is applied directly onto the primer (in a 2-coat system) or onto the mid-coat (in a three layer system).

**Toxic** - substances that are capable of causing harm or death by chemical means.

# 1. THERMOLON™

## 1.1 Mineral (Inorganic) versus Organic Coatings

Thermolon™ is an **inorganic** (mineral based) coating comprised predominantly of the elements silicon (Si) and oxygen (O) combined – i.e. materials that originally come from sand.

Traditional coatings such as PTFE are predominantly **organic**, which leads to inefficiencies in formulation, application and weaknesses in durability. The disadvantages and hazards posed by PTFE are discussed in subsequent sections.

The following is a comparison of Thermolon™ with traditional organic coatings such as PTFE.

| ***APPLICATION BENEFITS:*** | Organic coating ***(e.g. PTFE)*** | Thermolon coating |
|---|---|---|
| Easy application | YES | YES |
| Low curing temperature | NO | YES |
| Increased line capacity | NO | YES |
| No PFOA | NO | YES |
| No PTFE | NO | YES |
| Single step spraying | NO | YES |
| Single step curing is possible | NO | YES |
| ***ENVIRONMENTAL BENEFITS:*** | | |
| Lower $CO_2$ emission (60%) | NO | YES |
| Mineral vs organic coating | NO | YES |

## 1.2 Thermolon™ Values

Thermolon™ is a *Values-innovation* that offers best performing mineral (i.e. inorganic) coatings that are:

- Guaranteed healthy and safe for food contact use
- Outstandingly durable
- Environmentally-friendly

## 1.3 Thermolon™ Characteristics

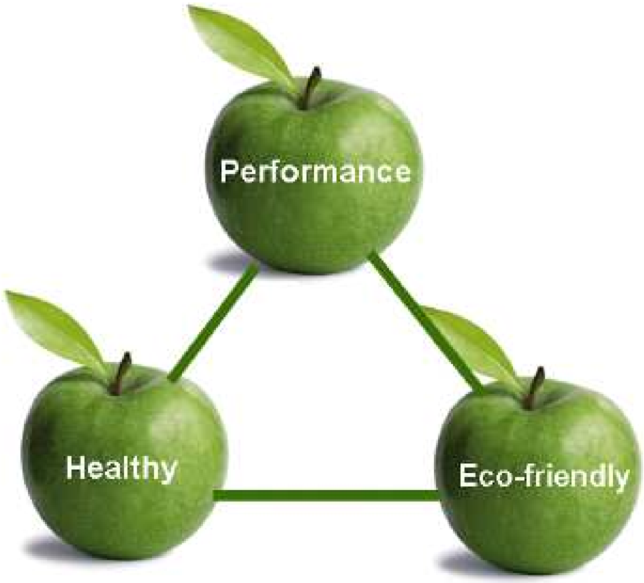
Thermolon™ is a leading-edge technology based on a Sol-Gel process resulting in coatings with the following characteristics.

- PTFE-free
- Zero PFOA / APFO / C8 (or anologues thereof)
- Highly temperature resistant (up to 450°C)
- No toxic fumes released when over-heated
- Extremely hard (up to 9H)

***In contrast, no PTFE coating can claim <u>any</u> of the above features!***

## 1.4 Thermolon™ Performance

Thermolon™ is first and foremost a high **performance** mineral coating that has **environmentally-friendly** and **healthy** characteristics:




It features:

- Good **non-stick**
- Extreme durability
- Scratch and abrasion resistance
- Corrosion resistance
- Food-contact compliance (e.g. FDA CFR21 § 175.300; German LFGB §30 and §31)
- Zero-PTFE and no PFOA
- Low Carbon footprint

***With a lower curing temperature and faster processing times, Thermolon™ has a significantly lower carbon footprint in comparison with PTFE (Section 5.3)***

## 1.5 Thermolon™ Next Generation

The rapid market uptake of Thermolon™ in 2007 proved that there is a genuine demand for healthier non-stick coatings. Our success spawned many imitators who boasted similar claims and who on occasions even “borrowed” our brand image.

In 2009 Thermolon stamped its authority on the market as the innovative leader in mineral coatings with the introduction at the Ambiente Housewares Show of its “next generation” product. Called ***Thermolon™ ROCKS***, this coating provided a quantum leap forward in durability and cooking performance.

Not satisfied with this, we harnessed what we learned in developing the ROCKS technology to upgrade our existing range of mineral coatings, taking them far in advance of the imitators who had sprung up in our wake.

Below is a comparison of performance of our original ***Thermolon™ Endurance*** (shown here as Endurance1) versus the new ***Thermolon™ Endurance2***, ***Thermolon™ ROCKS*** and one of the more successful of our imitators.

**BS Reciprocal Abrasion Test (BS7069 : 1988)**
Note: For the following data, a force of 4.5 kg was used (instead of the usual 1.5 kg force)

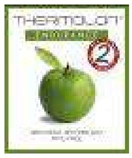
| Coating | No. Abrasion Cycles (4.5 kg force) | Dry Film Thickness (DFT) |
|---|---|---|
| Endurance1 | 6,000 | 30 µm |
| Endurance2 | 32,500 | 33 µm |
| **ROCKS** | **59,000** | 40 µm |
| Imitator | 5,000 | 34 µm |

***Thermolon’s next generation coatings leave the competitors far behind!***

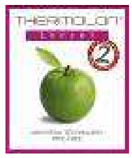
## 1.6 Thermolon™ Product Range

Thermolon's R&D Centre is continually developing new products that stretch the benchmark for mineral non-stick coatings. Our product portfolio comprises:

**Thermolon™ Endurance2** – superior non-stick performance combined with exceptional coating endurance for demanding kitchen uses

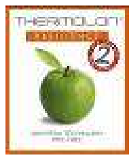


**Thermolon™ Expert2** – a durable non-stick performance for frequent use



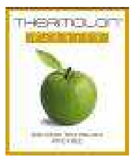
**Thermolon™ ROCKS** – our extra tough coating with unrivaled scratch and abrasion resistance reaches a new level in non-stick performance

**Thermolon™ Resilience2** – engineered for stainless steel and clad materials



**Thermolon™ Exterior** – this decorative and functional coating is ideal for cookware and bakeware exteriors as it is protective, high-heat resistant and easy to clean

**Thermolon™ Flexity** – a mineral coating that is flexible and, therefore, perfect for absorbing thermal dilatations, bending etc…



| **Thermolon™** | **Endurance2** | **Expert2** | **ROCKS** | **Resilience2** | **Flexity** |
|---|---|---|---|---|---|
| Substrates | Stainless Steel or Alu | Stainless Steel, Alu, HA | Stainless Steel, Alu, HA | Stainless Steel | Various Metals |
| Hardness | > 9 H | > 9 H | > 9 H | > 9 H | 8 H |
| Safe temperature | > 450ºC | > 450ºC | > 450ºC | > 450ºC | > 450 ºC |
| Flexibility | Limited | Limited | Limited | Limited | Excellent |

Note: HA = Hard Anodized Aluminum

## 1.7 Thermolon™ Manufacture and Composition

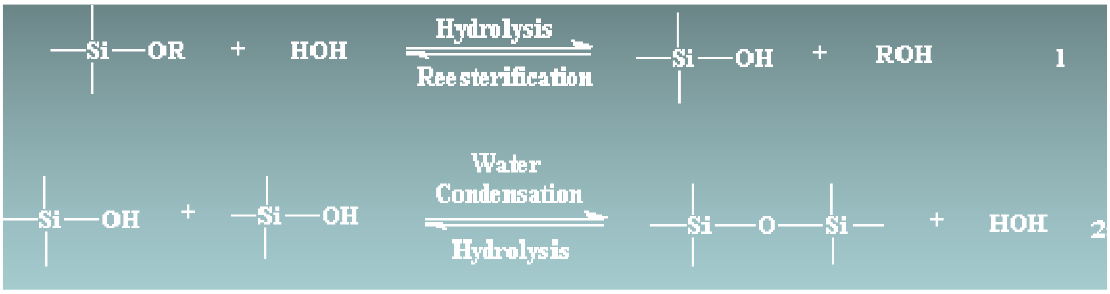
The exact composition of Thermolon™ is of course a trade secret. However, we can disclose some generic information as follows.

Thermolon™ is based on silica, which of course originally comes from sand. The elemental composition of the coating is predominantly silicon (Si) and oxygen (O). All raw materials comply with the requirements of international food contact regulations.

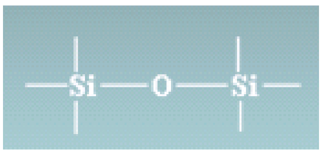
The process by which Thermolon™ is manufactured occurs at ambient temperatures and pressures. Obviously we cannot disclose exact process conditions.

Nevertheless, in simplified terms the first step is a hydrolysis reaction (1).

This is followed by a condensation reaction (2) in which a simple molecule is eliminated.




After applying the coating, it is cured at a temperature in excess of 180°C. Curing is a process in which cross-linking occurs to form a three dimensional matrix:




*Matrix formation*

.

***In other words, the building block of Thermolon™ is predominantly sand!***

# 2. PTFE

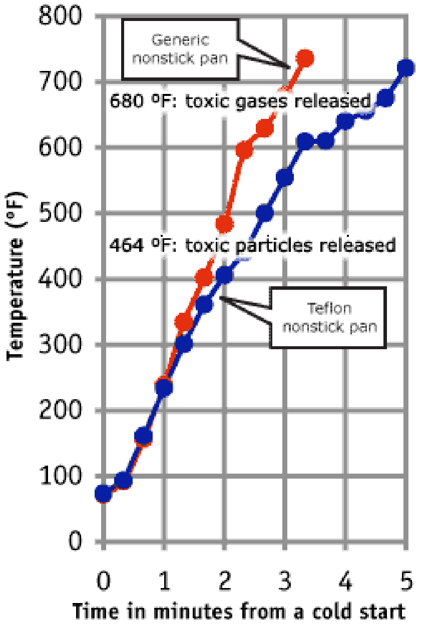
## 2.1 Properties of PTFE

PFTE (Polytetrafluoroethylene) is a soft and waxy fluoropolymer that is widely used in non-stick coatings due to its extremely low frictional properties.

However, the main drawback of *PTFE non-stick coatings is the* *maximum use temperature*, which according to the US FDA is just 260 °C.

Although PTFE manufacturers claim that: *typical cooking temperatures are much lower*, independent tests show that a frying pan can easily reach a temperature of 390°C or higher in just a few minutes on a conventional stove ►

**Figure 1: Teflon pans on stovetop burners easily reach temperatures that produce toxic particles and gases**




Source: University Food Safety scientist and Environmental Working Group. Tests conducted on May 12 and 13, 2003.

- At a temperature of **240°*C***, release of PTFE particles has been observed
- By **290°*C*** emission of ultra-fine oxidized particles can occur
- At **360°*C*** a cocktail of toxic and carcinogenic gases is given off
- Between **360-600°C** there is release of TFE (tetrafluoroethylene), a reasonably anticipated human carcinogen
- Above **360-650°C** there is emission of HFP (hexafluoropropene)
- Above **440°C** $COF_2$ (carbonyl fluoride) is released - a fluorinated derivative of phosgene, a chemical warfare agent
- Above **440°C**, PFiB (perfluoroisobutene, a warfare agent 10 times more toxic than phosgene) is detected
- Above **650°C**, decomposition releases carbon tetrafluoroide ($CF_4$)

**PubMed** (a service of the National Library of Medicine and the National Institute of Health) warns:

> *"Any industrial or household activity in which PTFE is heated above 350-400 degrees C puts nearby workers or residents at risk of illness and is to be avoided without strict industrial hygiene controls."*

## 2.2 Manufacture of PTFE

In contrast to Thermolon™, manufacture of PTFE involves five steps that are hazardous and which may have a negative impact on health, workers' safety and the environment:

For example, hydrofluoric acid (HF) is produced from the reaction of sulfuric acid with calcium fluoride:

| | | | | | |
|---|---|---|---|---|---|
| I. | $CaF_2$ | + | $H_2SO_4$ | → | 2 HF |
| | (Calcium fluoride, or fluorspar) | | (Sulfuric acid) | | (Hydrofluoric acid) |

***HF is one of the strongest and most corrosive acids known to man!***

The next step is a ***high temperature* reaction** – i.e. it has a high energy demand.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| II. | $CHCl_3$ + | 2 HF | → | $CHClF_2$ | + | 2 HCl | ***(600 °C)*** |
| | (Chloroform) | | | (Chlorodifluoromethane) | | | |

***Chloroform*** *(otherwise known as Trichloromethane or TCM) is a* known carcinogen.

***Chlorodifluoromethane*** *is also known as Freon, Arcton-22 or HCFC-22, an* ozone-depleting refrigerant gas.

III. Chlorodifluoromethane ($CHClF_2$) is then heated in super-heated steam at a pressure of **6 bar** and temperature of **900 °C**, which results in production of difluorocarbene ($:CF_2$). This is a highly energy-consuming process.

IV. **:**$CF_2$ then dimerizes (joins with itself) to form tetrafluoroethylene (**TFE**):

2 ($:CF_2$) → $CF_2=CF_2$ + higher polymers + **perfluoroisobutylene**
(**TFE**) (**PFiB**)

**TFE** is hazardous material and a suspected carcinogen;

**PFiB** is ten times more toxic than mustard gas

V. Emulsion polymerization of **TFE** occurs in water containing an initiator and emulsification agent (usually **PFOA.**)

**PFOA** (Perfluorooctanoic acid) or **C8** is highly persistent in the environment, is reported to be found in the blood of 95% Americans (including unborn fetuses) and is considered by the scientific advisory board to the US EPA as a likely carcinogen.

***Manufacture of PTFE is a process involving hazardous chemicals of a corrosive, toxic, carcinogenic and polluting nature.***

***As PTFE manufacturing involves high temperatures and pressures, it already has a big Carbon Footprint even before it is applied to your cookware!***

## 2.3 PFOA Emitted from Non-stick Cookware?

As noted in Section 2.2, PTFE dispersions are manufactured by a process that involves emulsion polymerization of TFE (tetrafluoroethylene) in water. During this process a dispersing agent (generally **PFOA**, otherwise known as **C8**) is used.

As the U.S. Environmental Protection Agency notes:

- *PFOA is a synthetic (man-made) chemical that does not occur naturally in the environment*

Although most of the PFOA is removed from PTFE dispersions following manufacture, small but measurable amounts (generally in range 10-50 parts per million) remain in PFTE paints that are handled by the workers in factories of coating suppliers and by operatives on cookware coating lines all around the world.

Although manufacturers of PTFE coatings claim that PFOA is completely decomposed in the curing oven, the break-down products are simply smaller **perfluorinated organic molecules** that can escape into the environment.

Moreover, major manufacturers of non-stick cookware coatings admit that when PTFE is overheated, one of the breakdown products happens to be PFOA.

Studies show that traces of PFOA can now be detected in the bloodstream of most of the American population and can be found in the wider environment.

Moreover, PFOA accumulates in the body and is reported to pass through the placenta into the unborn child in pregnant women.

- As recently as February 2006, EPA's Science Advisory Board voted to approve a recommendation that PFOA should be considered a **likely carcinogen**

Currently, scientific studies are being carried out to determine how PFOA enters the body and the extent of its dangers to our health.

In the meantime, manufacturers of PFTE non-stick coatings are being prompted by the EPA to phase out use of PFOA by the year 2015.

Since the introduction of Thermolon™, there has been a sea-change in the market. Major manufacturers of conventional coatings have subsequently introduced a selection of zero-PFOA non-stick coatings into their offerings. However, to the best of our knowledge, none of these manufactures have yet stated clearly what they have used as a replacement for PFOA.

***Every single article that is made with the use of PTFE dispersions contributes to the amounts of Perfluorinated Compounds (PFC) that are manufactured and then processed, thus providing opportunity for PFCs to enter the "Chain of Contamination"***

***Even if PFOA or other perfluorinated dispersion agents are eliminated from final products and if emissions from its manufacture and handling are reduced to zero by 2015, Perfluorinated Acids may still be formed (albeit in small quantities) when PTFE is overheated!***

# 3. COOKWARE COATING COMPARISON

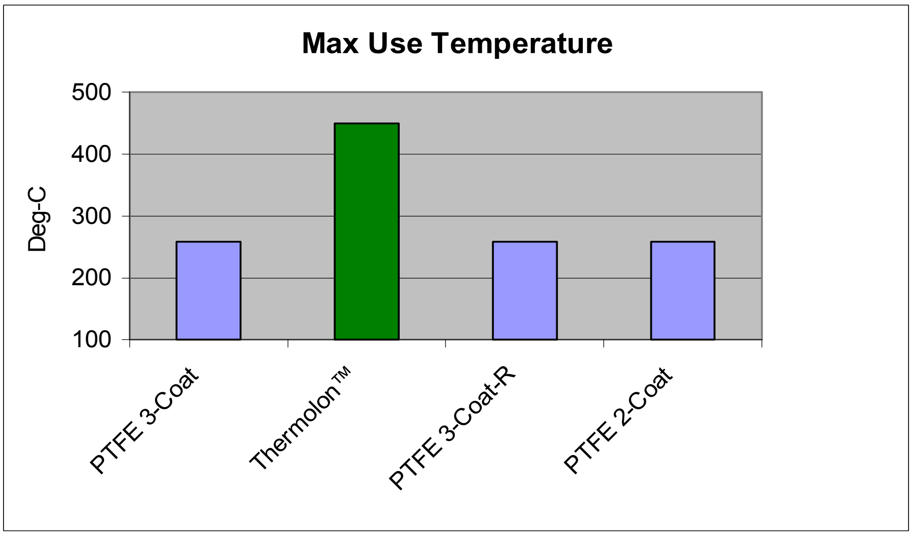
## 3.1 Temperature Resistance

In the table below, Thermolon™ is compared with famous brands of traditional non-stick coatings on the market (although we do not mention specific brands here).

| Coating | Contains PTFE? | Max Use Temp (°C) | Hours Res 426°C (hrs) |
|---|---|---|---|
| PTFE 3-Coat | Yes | 260 | 1 |
| **Thermolon™** | **No** | **450** | **> 26** |
| PTFE 3-Coat-R* | Yes | 260 | 1 |
| PTFE 2-Coat | Yes | 260 | 1 |

**Note*: R refers to reinforced coating*

Because of the PTFE (**organic**) content of the traditional coatings, the temperature resistance is limited by food contact regulations to just 260°C. In contrast, Thermolon™ because of its **inorganic** composition can resist up to 450°C.



- When PTFE-coated fry pans were placed in an oven at 425°C for 26 hours the coatings were thermally decomposed →

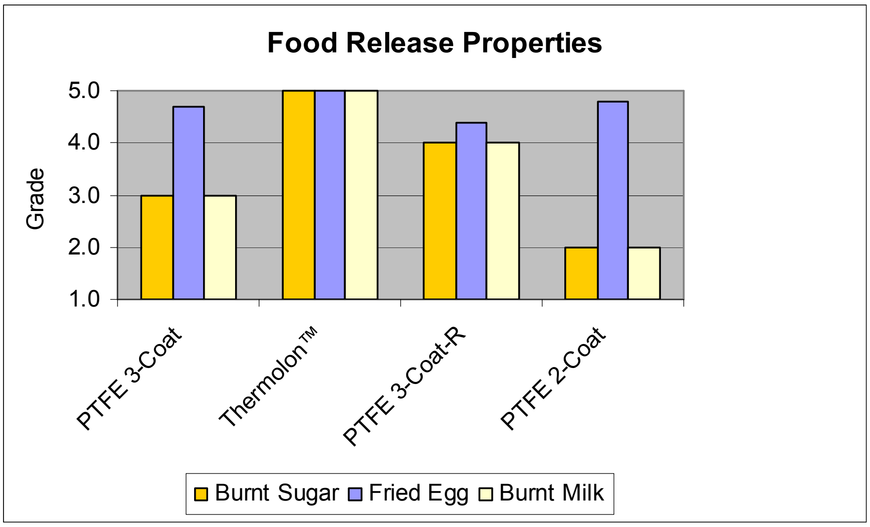
    - PTFE-coated pans were not fit for purpose after test

- In comparison, a GreenPan™ coated with Thermolon™ showed no change in color (or any other coating defects) →

    - GreenPan™ could still be used for frying a pancake without using any oil
    - Independent test report confirms that there is no measurable loss in weight and no toxic fumes emitted when Thermolon™ is heated up to 460°C

## 3.2 Release Properties

We examined famous brands of traditional non-stick coatings on the market (noted in Section 3.1) and compared the non-stick properties for a range of food types.

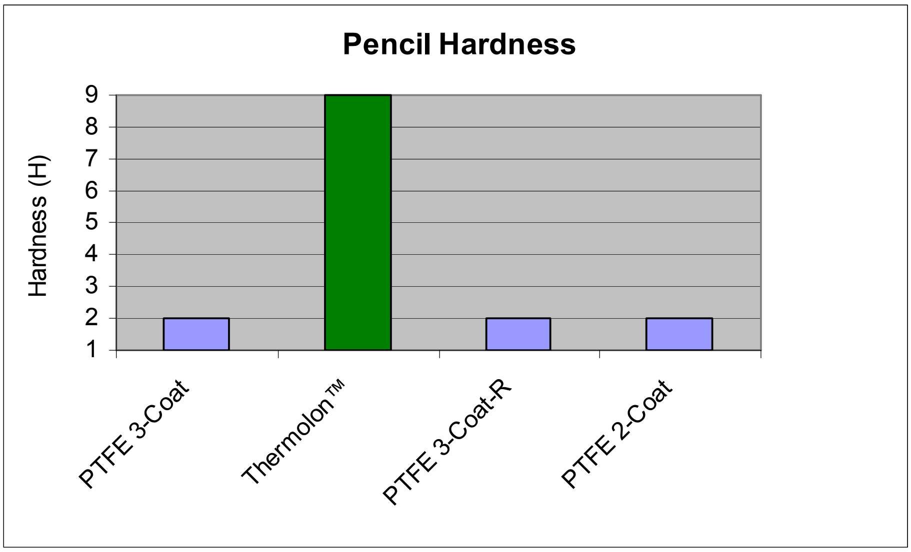



*<u>Note</u>: *Grade **5** denotes perfect release with no residues;*
*Grade **1** denotes food stuck to surface and unable to clean*

***Only the GreenPan™ coated with Thermolon™ performed perfectly on release of a range of different food materials – i.e. fried egg; burnt milk and burnt sugar***

## 3.3 Hardness

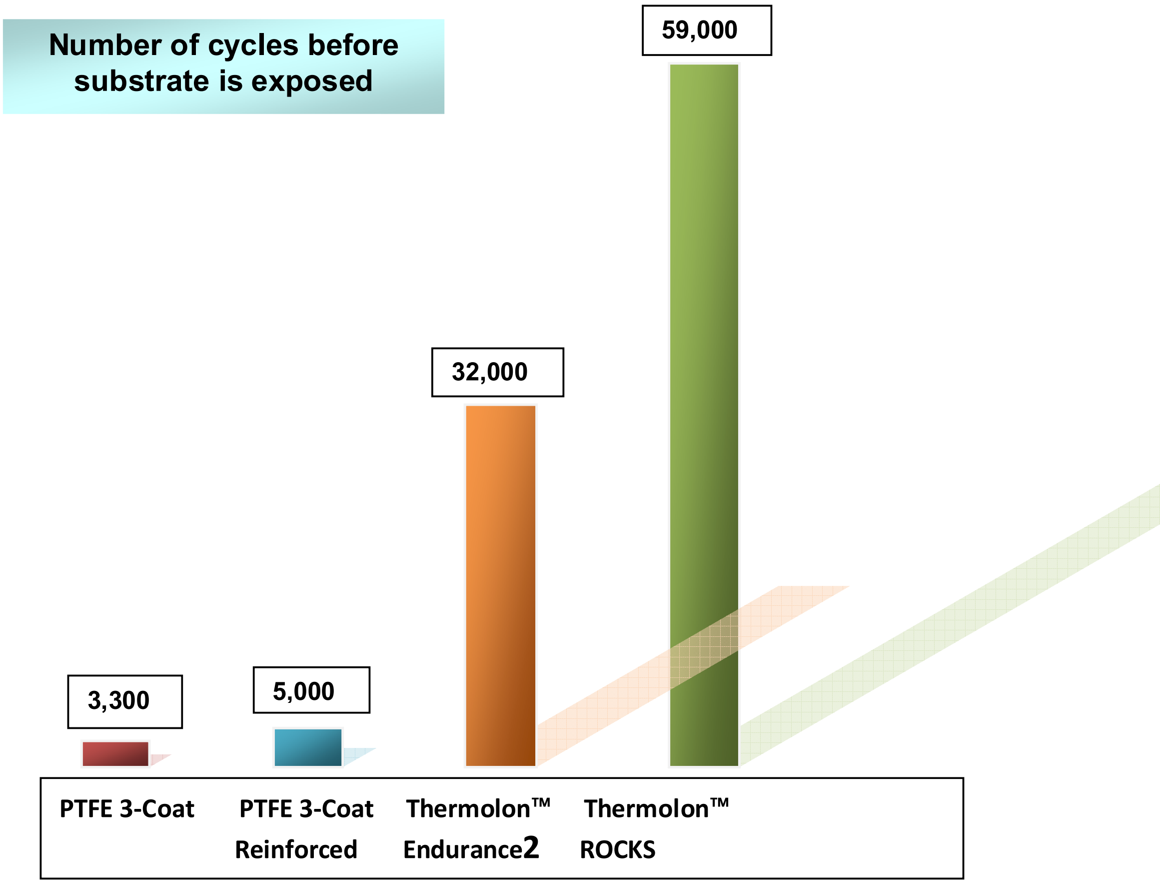
The same leading brands of traditional non-stick coatings as in the preceding section were compared with Thermolon™ in terms of pencil hardness.




- Thermolon™ retains it's hardness of 9 H even up to 200°C (or above).
- PTFE coatings by virtue of their soft, waxy nature have a low harness
    - PTFE softens even further when heated

## 3.4 Abrasion Resistance

The same leading brands of traditional non-stick coatings as in the preceding section were compared with Thermolon™ in terms of abrasion resistance (Reciprocal Abrasion Test; BS7069 : 1988; 4.5 kg force; 3M 7447 Scotch-Brite abrasive pad).




- ***Thermolon™ ROCKS and Endurance2*** have a high abrasion resistance, which is achieved by only a single layer with no hard filler materials added
- PTFE, even with a high level of hard reinforcement material, has inferior abrasion resistance in comparison with Thermolon™

***Thermolon™ provides a unique combination of:***

- ***Safety in use***
- ***Heat resistance***
- ***Hardness***
- ***Wear resistance***

## 3.5 Impact Resistance

In 2009 Thermolon improved its decorative/protective coating, known as Thermolon™ Exterior (mainly on the outside of cookware and bakeware) by enhancing its impact resistance. The aim was to prevent cracking or delamination of the coating in the event of impact.

The following picture shows that a steel ball of mass 500 g can be dropped onto a coated metal substrate (4 mm forged aluminum) from a height of 1,500 mm before there is any damage (cracking or peeling) to the coating. (Normally the pass criterion for such an impact test is 500 mm).

***Thermolon™ Exterior -***
***even at drop height 1,500 mm, metal substrate deforms,***
***but the coating does not crack or delaminate***

# 4. MANY USES OF THERMOLON™

Thermolon's mineral coatings can be applied in many applications where one or more of the following properties are required:

- High heat resistance
- Hard surface yet high impact resistance
- Exceptional wear resistance
- Good corrosion resistance and/or anti-fouling properties
- Stain resistance and good clean-ability cf. a vitreous enamel
- Low coefficient of friction
- Higher heat transfer coefficient cf. an organic coating

Examples of just some of the current applications of Thermolon™ include:

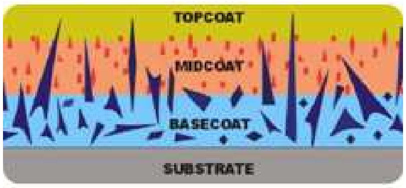
# 5. APPLICATION

## 5.1 Application of PTFE Coatings

PTFE coatings comprise **multiple layers** in which **hard filler** (reinforcement) materials tend to be added to enhance abrasion resistance.

Application therefore requires several stages (**Section 5.4**):

1 Spraying of a Base Coat (1st Spray Booth);
2 Drying of the Primer in a oven;
3 Spraying of Mid-coat (2nd Spray Booth);
4 Spraying of Top-coat (2nd or 3rd Spray Booth).




*Multi-layer PTFE coating*

Three or four different ovens are required for the process, each of which demands energy:

1 Pre-heating oven - prior to spraying Primer;
2 Primer Flash Off oven for drying Primer at 120-150°C;
3 Flash off zone for Mid/Top coat (sometimes requires a separate oven);
4 Curing oven ~430-440 °C (~35 minutes) - the most energy-demanding stage!

- The speed at which the PTFE-coated cookware passes through the curing oven is relatively slow (e.g. only 0.7-0.8 m/minute through a 28 m oven).

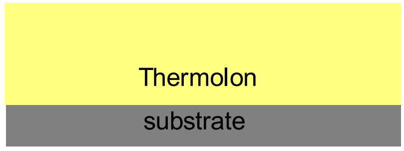
  - **A combination of high curing temperature and slow throughput results in high energy consumption (large Carbon Footprint) for PTFE coatings!**

- Application of PTFE non-stick coatings exposes workers to the risks of spraying PTFE paints that contain PFOA in two or three different spray booths.

- After curing, workers may also be exposed to the decomposition products of PFOA, namely smaller perfluorinated molecules.

## 5.2 Application of Thermolon™

Thermolon™ is a **single-layer** coating →




Application is therefore simpler and far more efficient in comparison with PTFE because Thermolon™ requires only the following stage:

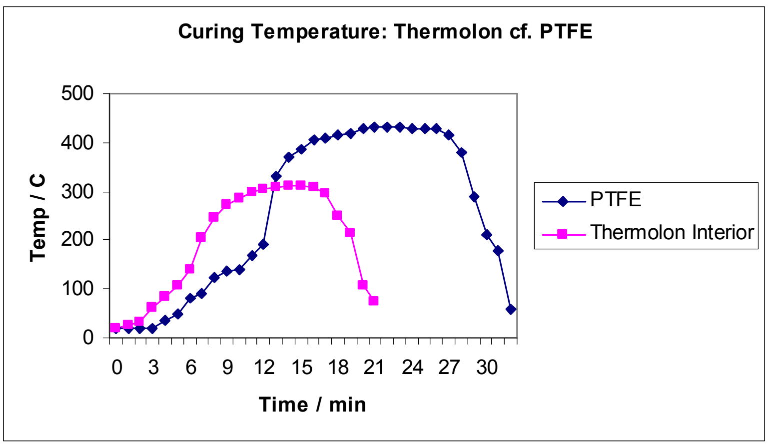
1. Single stage spraying (one spray booth only)

Two ovens are set to substantially **lower temperatures** in comparison with those for PTFE.

1) Pre-heating oven - prior to coating (~70°C)
2) Curing oven ~300-320 °C (~21 minutes)

- The speed at which the coated cookware passes through the curing oven can be up to **50% faster** (e.g. 1.2-1.4 m/minute through a 28 m oven).

  - Combination of low curing temperature and faster throughput results in substantial energy savings as may be seen from the curing temperature curves below.




*Curing Oven Profile for (i) 3-layer PTFE and (ii) THERMOLON™.*
*Oven line speed: 0.8 m/min for PTFE; 1.2 m/min for Thermolon™.*
Data courtesy of Anotech International (HK) Ltd (Chief R&D, Kurt Blondeel)

## 5.3 Thermolon™ Reduces $CO_2$ Emissions

Thermolon™ saves energy and, therefore, reduces $CO_2$ emissions because:

- Thermolon™ is cured at a significantly **lower peak temperature** in comparison with PTFE, thus reducing energy consumption;

- Speed through the curing oven for Thermolon™ is **50% faster** (~1.3 m/minute in comparison with typical values of 0.7-0.8 m/minute for PTFE coatings);

- With conventional cookware coatings, the PTFE non-stick interior is cured first; then an exterior decorative coating (usually a silicone-polyester) is applied and cured in another pass through a second oven;

- With Thermolon™, as both Thermolon™ Non-stick (interior coating) and Thermolon™ Exterior (decorative coating) are cured together in **one single pass** through the curing oven, the **energy saving can be up to 60%**.

Independent studies by RMIT University (Australia) and Tianjin University (China) quantified the savings in energy and $CO_2$ emissions as follows.

- 1,000 fry pans (24 cm diameter) equates to a coated area (interior + exterior) of **140 $m^2$**

- Thermolon™ curing:
  - Diesel oil required for curing 1,000 fry pans coated with Thermolon™ (interior and exterior coated) = **59.3 L**
  - Associated emissions approx. **156 kg $CO_2$**

- PTFE curing:
  - Diesel oil required for curing 1,000 fry pans coated with PTFE + Exterior = **179.7 L**
  - Associated emissions approx **473 kg $CO_2$**

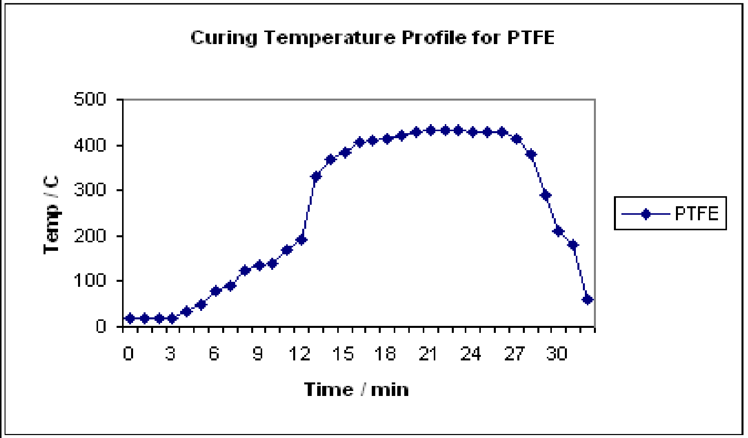
- **Reduction in emissions:**
  - **Approx. 317 kg $CO_2$ per 1,000 fry pans coated in Thermolon™**

***On an estimated worldwide market of 250,000,000 fry pans, if Thermolon™ replaced traditional cookware coatings, the anticipated reduction in emissions would be greater than 79,250 tons $CO_2$!***

## 5.4 COMPARISON BETWEEN PTFE & THERMOLON™ APPLICATION

| | Conventional Application | Thermolon™ Application |
|---|---|---|
| | **INTERIOR (PTFE) COATING :** | **INTERIOR (THERMOLON™) COATING :** |
| 1. | **Degrease substrate** | **Degrease Substrate** |
| 2. | **Sand blast substrate** | **Sand blast substrate** |
| 3. | **Place substrate onto coating line** | **Place substrate onto coating line** |
| 4 | **Pass through air blast chamber to blow away dust/particles** | **Pass through air blast chamber to blow away dust/particles** |
| 5. | **Pans pass through a pre-heating oven set to 30-40°C** | **Pre-heating oven can be switched off**<br><br>Instead, prior to spraying of Thermolon™ the substrate passes through the flame of a gas torch for temperature adjustment. |
| 6 | **Apply Primer in Spray Booth 1**<br>Usually there are 3 spray guns to deliver primer to the interior base and interior side walls | **Apply Thermolon™**<br>**Single spray booth**<br>Use 3-4 spray guns directed at the substrate interior to deliver base coat |
| 7. | **Pans Coated with Primer Pass Through Flash-off Oven**<br>Set oven at 120-150°C | **Flash-off the coating until it is touch dry**<br>**Set oven at 110-120°C** |

| | | |
|---|---|---|
| 8. | **Spray Mid Coat in Spray Booth 2A**<br>Optimum temp. of substrate prior to mid-coat application is 35-45°C | **There is no mid-coat with Thermolon™**<br>Spray Booth 2A is eliminated in the case of Thermolon™ |
| 9. | **Spray Top Coat in Spray Booth 2B**<br>Top coat is sprayed on top of the wet mid-coat<br>(i.e. no intermediate drying) | **There is no top-coat with Thermolon™**<br>Spray Booth 2B is eliminated in the case of Thermolon™ |
| 10. | **Short Flash Off Zone before Curing Oven**<br>Allows for evaporation of low-boiling solvents from mid/top coat | **Thermolon requires no further flash-off**<br><br>Thermolon Coating is already touch-dry, so this area only serves as an exit<br>from the redundant Spray Booth 2 |
| 11 | **Curing Oven**<br>In general PTFE interior coatings must be cured before the exterior Coating is applied<br><br>Curing oven is set such that the temperature is ramped slowly through temperature stages. | Pans coated with Thermolon™ pass directly to exterior coating line.<br>(There is no curing required at this stage.) |



| | | |
|---|---|---|
| | PTFE must be cured such that substrate reaches peak of ~ 426°C for around 5-6 mins.<br><br>Total time spent in curing oven is around 31-32 mins<br><br>**Combination of high peak temperature and long dwell time results in high energy consumption!** | |
| | **EXTERIOR DECORATIVE COATING :**<br><br>**High Temperature Paint Application** | **EXTERIOR DECORATIVE COATING :**<br><br>**Thermolon™ Exterior Application** |
| **12** | Once PTFE coating has been cured, the pans are sent round another coating line where two or three spray guns are used to apply the exterior (decorative/protective) coating. | Pans are passed from interior coating line directly to exterior coating line without the need for curing the interior coating first!<br>**This saves a considerable amount of energy** |
| **13.** | There may be a short flash off required before the coating is cured, especially if the exterior coating is applied as a 2-coat with colored primer plus a high gloss (clear metallic) top coat | There is no further Flash-off as the interior coating is already touch dry |

**14.**

**Curing of Exterior Coating**
Exterior coatings are normally cured at a lower temperature cf. curing temperature required by a PTFE coating. This is why the interior coating is normally applied and cured first - then exterior is applied as a second operation.

Peak curing temperature for silicone-polyester exterior paints is normally ~250-260°C for 10 min

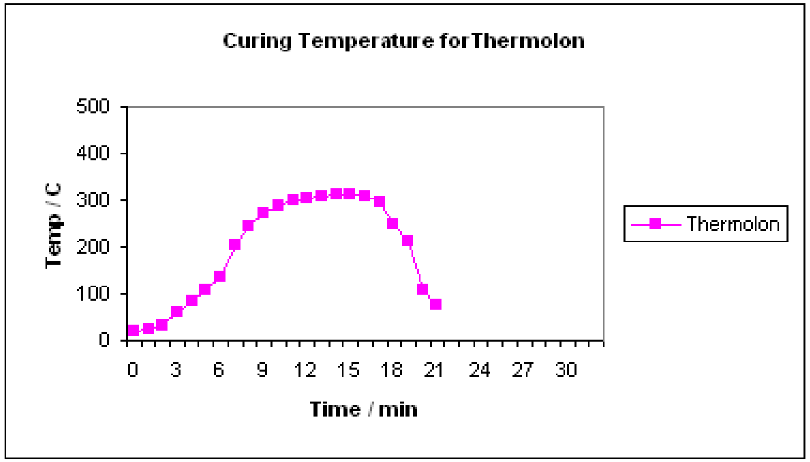
Total dwell time in second curing oven is around 20 min

**Energy is wasted because:**
The pan has now passed <u>twice</u> through an oven (Steps 11 & 14)

Additional curing stage for the exterior coating is a heavy energy requirement

**Curing of Thermolon™ Interior & Exterior Coating.**

**Single Pass through just one curing oven**




**Energy is saved because:**
(a) There is only one pass through the oven per pan with Thermolon™
(b) Peak curing temperature for Thermolon™ is 320°C (cf. 426°C for PTFE)
(c) Dwell time in oven for Thermolon™ is only around 20.8 min