# The Application of Plasma Technology in Packaging

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## Abstract:

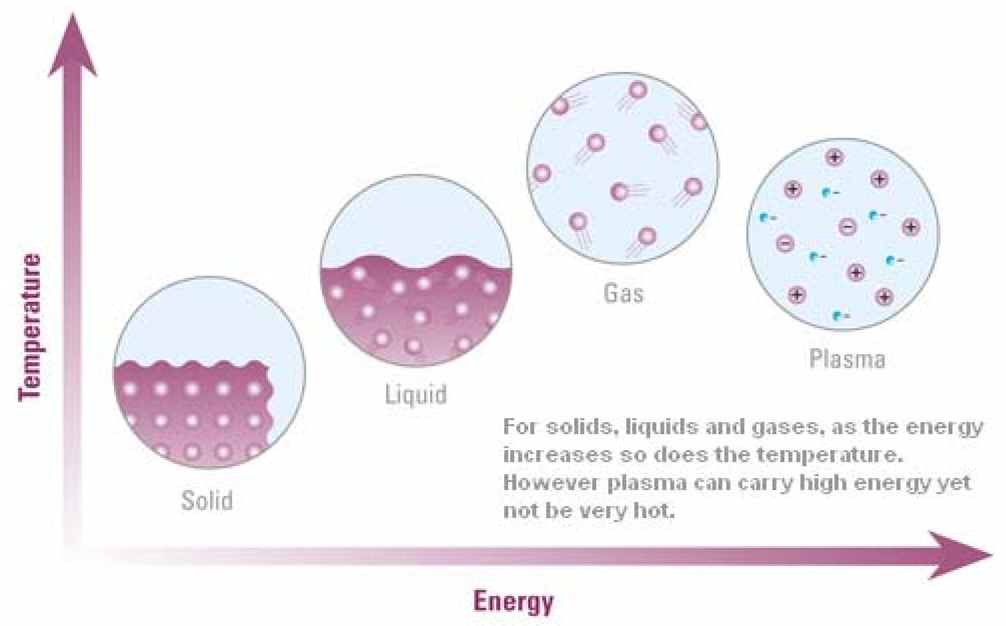
Throughout recent years the idea to use plasma technology to modify materials has been at the forefront. The use of plasma to sterilize packaging has become increasingly popular. Plasma has also been adopted to surface treat materials, increasing their wettability. This opens a wide variety of doors; anywhere from better printing, to bonding unlike materials during dual-injection molding. Lastly, plasma has given the packaging industry the ability to add a thin layer of material to a substrate, allowing it to share qualities of both materials. Packaging has an amazing opportunity to fully implement the plasma treatment process, and to become a leader in plasma technology.

## **Introduction:**

Plasma is defined as “A fourth state of matter distinct from solid or liquid or gas and present in stars and fusion reactors… ‘particles in space exist in the form of a plasma.’” [1] This daunting definition could lead one to believe that this is a science fiction theory to likes of which your best reference would be from the movies Star Wars, Star Trek, or possibly your nearest Martian. Though recently the use of plasma has become very prevalent; it can now be found in every thing from your neighbors Plasma TV to the neon sign displaying a $10.99 deal at your local pizzeria. [2] As the most abundant form of matter becomes more common in everyday society, it is inevitable that packaging research and development teams take this opportunity to broaden the application abilities of something so unique and intriguing as plasma. [3] Through plasma technology, the packaging industry is becoming capable of three unique abilities: (1) To remove all unwanted ‘organic contaminants,’ (2) Surface treating, or activating a material to gain an increased wettability quality, and (3) The deposition of substrates onto a material, adding desired new qualities. [6]

Over 90% of the known universe is made up of plasma. [4] It is created when heat energy is added to a gas. This addition of energy causes the atoms to lose their electrons, leaving both the charged nuclei (ions) of the atom and its electrons in a plasma state. This ionized gas is both kinetically and electrically charged. [1] Of the four states of matter, plasma is the only state that can carry energy, but remain at a ‘cool’ temperature. This allows the use of plasma’s reactive characteristics without the dangerous aspect of large amounts of heat energy. [4] Figure 1 loosely displays the unique distribution of energy to temperature in contrast to the other states of matter.

Figure 1:



[4]

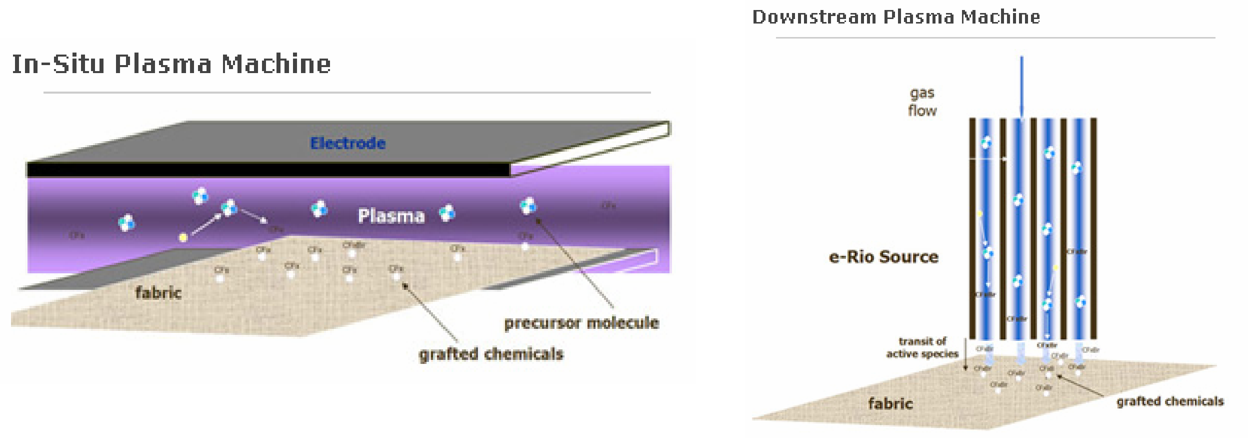
**How the technology works:**

Plasma is created through the addition of energy to a chosen gas. This energy is usually induced through electric fields with either direct or alternating currents. The known ‘useable’ gases for this process are “Oxygen, Hydrogen, Argon, Nitrogen, Fluor containing gases and their mixtures.” However, as research continues, more gases are becoming available and useful. [5]

There are two types of plasma application, vacuum and atmospheric. Vacuum technology, or In-Situ, as described by Apjet Inc. (a leader in plasma products)[6] introduces a gas with “high frequency electrical discharge under low pressure to treat the surface of various shaped products.” [7] The lower pressure described is approximately 0.05mbar - 12mbar (or 5Pa – 1200Pa). [5] Within the chamber there is an electrode to provide an “electrical discharge” of energy to excite the plasma and begin the modification of the material. The total process can last from as little as 2 seconds to as much as 2 minutes depending on desired results. [7] A multitude of different vacuum technology machines are available, from a rotary machine to a simple tray like application that resembles a household microwave (refer to Figure Extra-1 at the end of the this paper for visuals.) [5] A basic model, represented in Figure 2, explains the In-Situ (or vacuum) process.

The other available process is an atmospheric plasma treatment. This “produces a plume similar to a conventional Bunsen burner flame.” [6] This process can maintain a relatively cold temperature, usually between 50°C to 300°C (122°F to 572°F) when using a cold flame technique. [6] The ‘plume’ of plasma can be used in a free-hand format, or a design that utilizes a flat flame that remains uniform over set distance. The flat flame, or FlatJet, allows for easy scale-ups and could possibly be added to a packaging line. Figure 2 displays both vacuum and atmospheric processes. [6] (Figure Extra-2 at the end of this paper provides a picture of both a plasma vacuum machine and a FlatJet produced by Apjet, Inc.)

<u>Figure 2:</u>



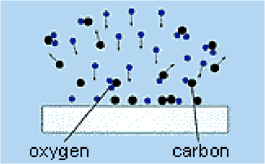
*Vacuum / Low Pressure Application*

*Atmospheric Application*

There are pros and cons to both plasma processes. The initial concern for both pieces of equipment would be the cost to run the machine, and the amount of gas needed to run an application. Apjet, inc. explains that the vacuum process “requires less gas flow and consumes less power” when compared to atmospheric plasma treatment. On the other hand, an atmospheric application allows the user to bombard the substrate, or material, with different amounts of plasma in different areas for a specified outcome. [6] Although, if the atmospheric equipment is stationary, such as in a FlatJet [6] on a line, the application can result in an uneven distribution of plasma in the vertical and horizontal areas of the material. Under these circumstances the use of a vacuum method might be recommended. [8]

## Uses and current applications in packaging:

***Cleaning:***

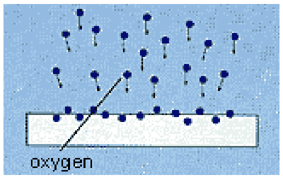


[5]

“To obtain molecular cleanliness there is not a more effective method than plasma.” [9] In this process plasma bombards the surface of a substrate, and the reactive particles within the plasma chip-away and remove all organic material. In the picture above, oxygen plasma is bombarding a substrate polluted with carbon. [9] This application has become increasingly prominent in the medical packaging industry. Cleaning using plasma offers the sterility of more intense methods, while operating at a lower temperature. The ability to maintain a lower temperature through sterilization gives companies the opportunity to easily sterilize packaging material sensitive to high heat. [10]

Another current application in the packaging industry is the sterilization of aluminum foil on the line. “Placing the foil for an extended period in an annealing oven… can affect the structural properties of the material adversely.” [4] In contrast, when sterilized with plasma, the foil exhibits no adverse affects that would have occurred if an annealing, or chemical process was used. [4] The limitless applications of plasma cleaning, through low heat and aggressive speed, give the packaging industry the ability to continue to grow immensely and efficiently.

### ***Surface Treatment / Activation:***



[5]

The second application of plasma is to surface treat a material. Using oxygen plasma, as depicted above, the oxygen nuclei are charged and voluntarily react with the material. This reaction increases the surface energy of the substrate, allowing for greater bonding strength. [11]

A study conducted by IDS packaging undoubtedly displays the power of plasma surface treatment. This study pretreated LDPE film using atmospheric plasma treatment (APT). They then monitored and recorded results over a 17 day period based on the longevity of the treatment (measured in dynes/cm, Figure 3), and the strength of the adhesion using 3M 800 acetate film acrylic adhesive tape (measured in lbs/in., Figure 4.) [12]

This study concluded that APT can “significantly improve the surface tension and adhesion of LDPE film” in comparison to both corona treatment (a competing treatment), and no treatment at all. [12]

Figure 3:

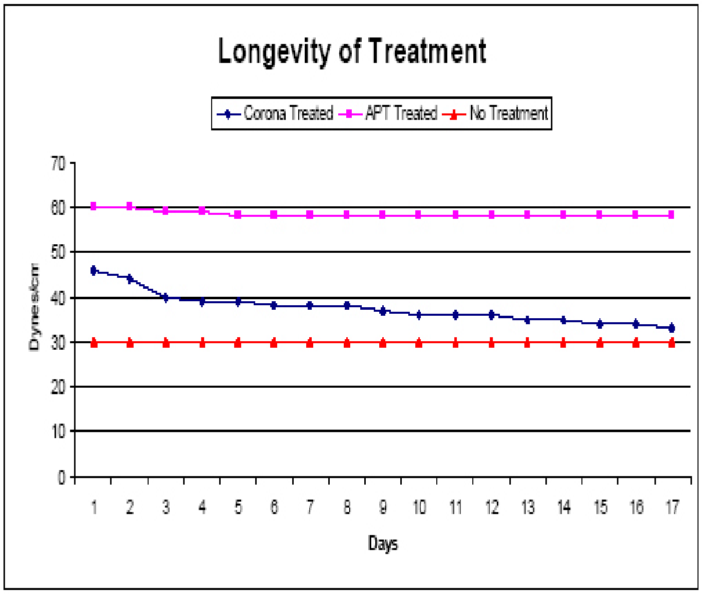
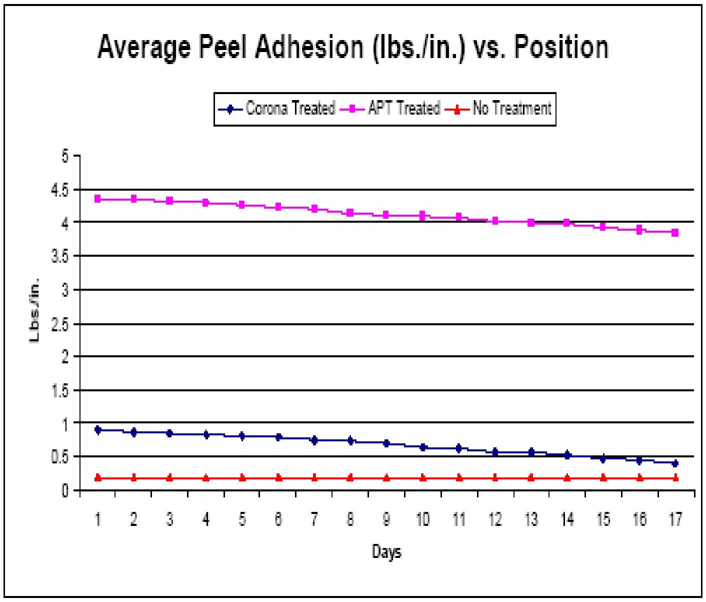


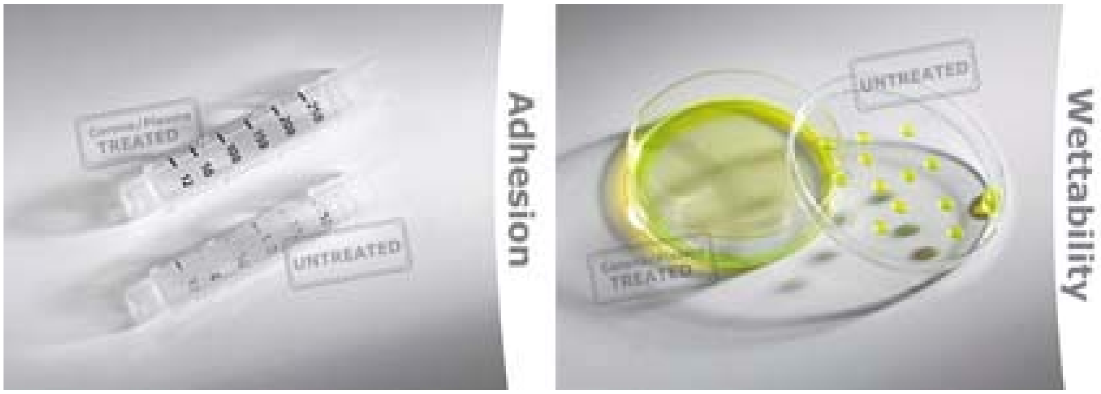
Figure 4:



Studies performed by other institutions, such as Enercron, a leader in surface treatment equipment, resulted in similar conclusions. Enercron pretreated “polypropylene nonwovens” using APT. The pretreated and untreated (control) materials were then printed with an identical graphic. Peel tests were then performed on both types of treated material. The outcome proved that the untreated material resulted in “total adhesion failure,” while the material treated with APT remained with nearly 100% of the graphic intact. Other tests on a variety of other materials, concluded in similar results.

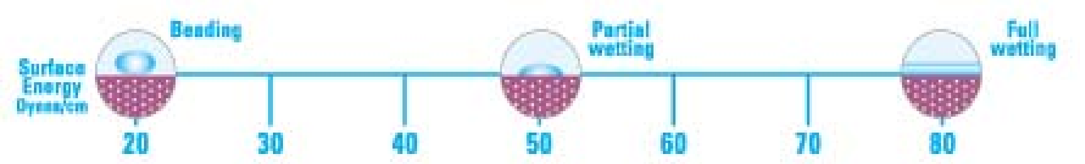
As the results show, plasma treating can greatly increase the surface energy of a material. In Figure 5, Tantec provides an intriguing visual of the before and after treatment of plasma on plastics. Figure 6 explains the visible measurement of wettability; this information can be applied to better understand the petri dish in Figure 5. [4]

Figure 5:



[4]

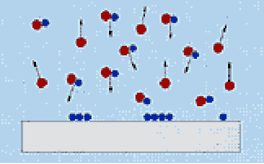
Figure 6:



[4]

The petri dish has become much more hydrophilic than before plasma treatment. Plasma treating materials allows for applications in almost unlimited packaging arenas. New qualities applied to a material by plasma could be functional in glue applications, painting, printing, and even double-shot injection adhesion between two unlike materials (making them more susceptible to bond). Currently this treatment is used on everything from printing on bottle caps to creating for a better bond in tamper evident seals. All this and more becomes available when plasma treating a material. [4]

***Deposition:***



[5]

Although the basics of this process have been understood for over 100 years, this property of plasma is still one of the most unique. [13] Using plasma as the transport mechanism and the catalyst, one material can be deposited (in a very thin layer) onto the surface of another material; thereby transferring some of its qualities. [6] The mechanism is simply shown in the graphic above. By using plasma to excite the initial material, the secondary material has the opportunity to bond with the first, creating a thin, layered effect. Dependant on the desired attribute, the second material is chosen. [4] Below, Figure 7 displays a list of secondary materials that can be used with a plasma treatment to gain a desired quality on a substrate. (Courtesy of Apjet, Inc.)[6]

Figure 7:

| **Application (ability)** | **Material (secondary)** | **Substrate (initial)** |
|---|---|---|
| Oxygen Barrier coatings | $SiO_2$, $Al_2 O_3$ | PET, silicon wafer, steel, glass |
| Optical coatings | $SiO_2$ , $TiO_2$ | Glass, Plastics |
| Hard coatings | $Al_2 O_3$ , $TiO_2$ , $Cr_xO_y$ | Steel, Aluminum, Plastics, silicon wafers |
| Ashing | Photoresist | Silicon |
| Polymer hydrophilization | Polar groups, defluorination | PET, Teflon, Plastics |
| Water and oil repellent textiles (Ultrahydrophobic surfaces) | $-CF_3$ and $–CF_2$ – surface | Cotton, PET, Kevlar |

[6]

The idea of adding layers to increase the qualities of a material is exciting news in the packaging industry. Many companies now offer increased barrier properties through the addition of a metallic layer onto their materials. [14] In addition, if a company wants increased barrier properties on their soda bottle, some suppliers now offer the addition of PVDC to PET bottles with on-line capabilities through the use of plasma treatment. [15] These applications are merely a few of the current uses, some even directly attached to the manufacturing line.

## Conclusion:

Although packaging has begun to incorporate plasma technology, there are still a large number of uses that have currently been untapped. Plasma treating a material can provide tremendous advantages to a package. Plasma becomes inevitably popular as its benefits are explained. Plasma technology uses relatively low heat, and is extremely quick when compared to its competitor processes.  As explained, plasma treating a surface can rid the material of all unwanted organic matter, creating a sterilized surface. If a material is surface treated with plasma, its surface energy can greatly increase and show an exceptionally better wettability quality. This increased wettability can provide a package with an increased strength in which to adhere to ink, adhesive, or even another material. Furthermore, plasma’s deposition ability gives the packaging industry the tools to create materials with desirable qualities by adding a thin layer of a second material. All three applications make the research of plasma technology an opportunity that the packaging industry cannot overlook.

<u>**References:**</u>

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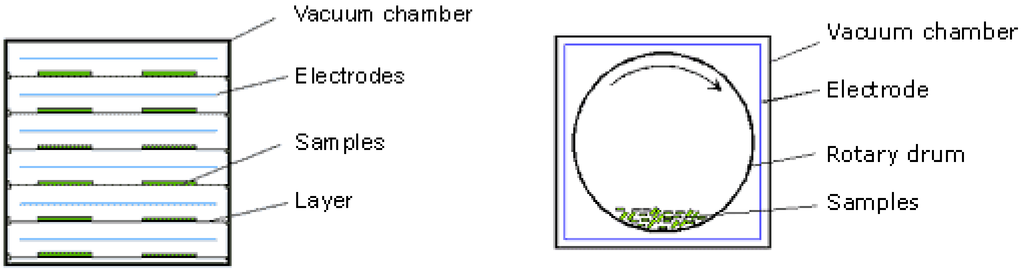
**Further Information:**

Figure Extra-1

*Some of the available styles of Plasma Vacuum Treatment Machinery*
**Pictures courtesy of diener electronic [5]**

*Multi-Tray-System* *Rotary drum system*



*System for large formparts* *System for foil treatment*

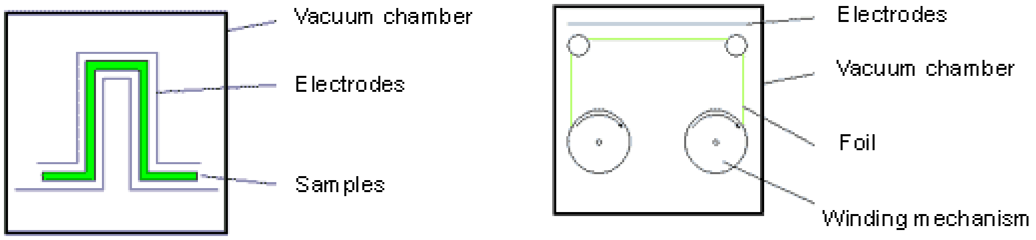
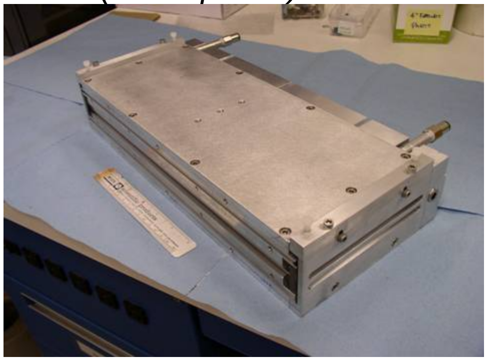


Figure Extra-2:

*Low-Pressure Plasma System*
*(Vacuum)*

[5]

*Flat Jet by Apjet, Inc. System*
*(Atmospheric)*



[6]