CHAPTER 2

THE SUSTAINABILITY ISSUE ABOUT PLASTIC MATERIALS

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This article retakes decisions presented in the round-table about "Ecomaterials", which took place in 2017 SBDS + ISSD, in Belo Horizonte/MG, eliciting aspects about the plastic polymers production scenario related to environment issues, in virtue of the critics established throughout the last decades. Surely these debates are shortened, because these themes, which involve the plastic production area and the environment, are either complex and long. Therefore, this work comments some data and information which may give the reflections a path to follow from the perspective of productive sustainability in plastic polymers, citing as references the productive and the environment scenario, as well as the integration programs.

With the advent of industrialization, it was believed that the natural resources would be infinite. However, just a little time later, this reality would change to this environment shortage and overload scenario.

Regarding this, Mano et al. (2005) eliciting the Brundtland Commission, highlight that the depletion of natural resources derived from the excessive production and consumption would indicate the necessity of rethinking all the developmentalist dynamic, especially over the relations which involve the society and environment. This scenario is where it is possible to establish the necessity for reflections over the procedures that refer to the acquisition, usage and wasting of natural resources in a permanent and balanced way.

According to the Associação Brasileira da Indústria do Plástico (ABIPLAST, 2018), a city with three million people produces nearly 130,000 tons of solid waste per year. Part of this amount will be placed in any landfill or will be wasted in garbage dumps. It can be estimated that 48% of this total are residual materials which could be integrated, once again, to the productive systems and 18% of this amount are polymers (plastics and rubbers). The rest (52%) of the wastes is composed of varied organic materials. The mixture of industrialized and organic waste, derived from post-use, corresponds to the main environmental problem faced by big cities.

A huge part of the critics to the indiscriminate usage of the natural resources devolves upon the materials and their environmental relations — pollution rates. However, analyzing the life-cycle of the products, taking as a base the productive structures, it can be noticed the consumption of other natural resources, which happen seamlessly due to the difficulty of the quantity and quality measurement. Resources as energy, soil and water are essential for the operation of the productive systems.

Independently of the energy matrix, it can be summed up that around 20% of the worldwide energy is wasted with some technological problem or bad social habits. This loss comes from questions that involve industrialization, as 70% of worldwide energy production is settled in five microregions of the planet. Some data from the International Energy Agency (IEA) indicate that a huge part of worldwide energy is generated from nonrenewable sources (86%), while the renewable sources are only 14% of all production.

According to the Empresa de Pesquisas Elétricas (EPE) (BRAZIL, 2018), the energetic Brazilian matrix shows a framework more balanced, 43.5% of the energy generation is based in renewable sources, having as main the hydroelectric plants with 65.2%. The so-called “alternative” energies, as biomass, the solar and aeolian are 15% of the energy. It is estimated that 11.4% are wasted during the transmission and the consumption. The EPE indicates that the industrial sector showed an average of 6% of energy loss. The sectors of marketing and services show, together, 11% of the loss, while domestic consumption is around 15%. Nowadays, the Programa Nacional de Conservação de Energia Elétrica (PROCEL), established by the Ministério de Minas e Energia through the Presidential Decree No. 8/1993, is the main Brazilian program, which looks forward to conscientizing the society about the reduction on the waste and consumption of energy.

Of all natural resources, the one that has the hardest measurement in productive structures is linked to the soil usage. Kon (2000) comments that soil has an essential role in the industrial scenario, because it refers to aspects of localization and regionalization and, therefore, all the necessary infrastructure for the productive activity. According to the characteristics of soil and subsoil, the economic relations of occupation and exploration change, conditioning specific regions to a specific development program. As reported by Embrapa (2017), a huge part of the Brazilian soil (63%) is composed of public and private native forests, 30% is destined to farming, of which 21% are pasture and 9% are destined to agriculture, and only 3.5% represent the urban areas occupied by most of the Brazilian population, which walks along with huge part of industrial activity.

Soil degradation happens for natural (climate and geologic phenomenon) or unnatural reasons (polluting agents visible through the deposition of solid wastes or invisible through chemical agents, saturation by metal and others), which causes damage to the surface and subsequent layers. The environmental impact caused by extractives, miners and infrastructural modify the characteristics of the soils. The main reason of the urban soil degradation is the disordered occupation of the environmental protection area, hillsides, river streams and lakes. These facts request even more preventive management and corrective over the soil, through waste management, in order to contribute with the gains and life quality.

The planet has a surface covered of 71% of water, of which 2.6% is freshwater and somewhat of this half is literally liquid. It is summed up that a quarter of this total shows some kind of contamination by organic material excess, heavy metals among other problems which request even more investment in treatments and purification, aiming to fit it to the domestic, agricultural and industrial consumptions. As reported by data of the Ministério do Meio Ambiente (2017), water consumption in Brazil shows 70% of its activities in farming and cattle, 22% acting in the industries and 8% for domestic consumption.

The main environmental problem about the water is related to its waste. Some technologies allow the reuse of water and some other need special treatment before its waste due to its high concentration of solid particles or chemical agents derived from its productive process. The main problems in the domestic consumption are the waste and the lack of treatment. It can be evaluated that 40% of the whole fresh water is wasted either by failures in the distribution system or for wrong usage, just like 48% of the Brazilian houses have no sanitary treatment for wasting used water (BRAZIL, 2017).

Agricultural activities have as main problems in the usage of water resources to the contamination of the water table and of rivers by agricultural defenders, offsetting of waterways with the deforestation or the replacement of the native forest among others, despite the social economic production value.

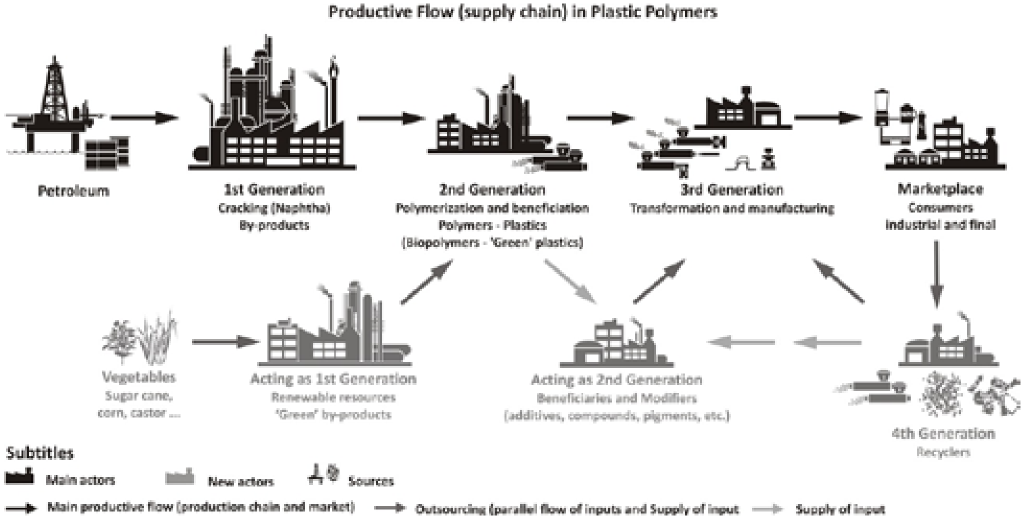
THE PLASTIC POLYMERS PRODUCTIVE SCENARIO

The productive structure in polymers is built by an unfolding in the petrochemical string from the supply of naphtha plots, or from the natural gas to the high-end industries (first generation). This segment is made of feedstock producers destined to the second-generation industries, formed by resin producers and some other derivative. Such products are destined to third-generation industries, constituted by companies which process manufactured products.

The existing relations in the polymers productive flow in Brazil does not present significative differences if compared to existing countries with higher rate of industrialization. However, the process segment shows some critic situations, if compared to other players. In general, the polymers supply chain string shows distinguished competences in its levels, determining specific actions in relation to the companies' stance. During the first stages, the competences are based in the access to basic feedstock in the massive production and in the cost reduction. As the flow develops itself, these competences turn to figure over other attributes, like: scope production, innovative capacity (including design), partnership formation, logistics and distribution, marketing actions, among some other aspects, granting to the included companies some unique strategic conditions (CERQUEIRA; HEMAIS, 2003).

It is possible to notice that, in the last decades, the plastic polymers supply chain presents new actors in the productive flow, from the supply of hydrocarbons derived from renewable sources to the production of the so-called "green plastic". It can be ascertained the occurrence of new enterprises destined to the modification of plastic property, the insertion of groups and social agents destined to the recycling, as well as the development of computational technologies applied to the materials and polymerics process, as it is shown in Figure 1.

Figure 1 – Representation of the plastic supply chain strings and new insertions in the productive system



Source: Elaborated by the author.

These insertions in the plastic productive system feed the idea of a productive network, incorporating actors that belong to other productive flows in an outsourcing way, since there exist many interrelation points in feedstock, products and service supply. This characteristic is easily noticed when analyzing the third generation, once it corresponds to the convergence in the whole productive system.

Among the variety of results taken of this complex structure, the work relation must be highlighted, because a huge part is settled in the process segment, where the economic profile is built by micro- and small enterprises.

Despite the mechanical process, this sector is characterized as intensive in labor; while the segments of first and second generation are focused in automation and are intensive in technology.

FROM DIVERSITY TO SPECIFICITY

For slightly more than a hundred years, the material science has studied the polymers in order to increase its productive and application performance. Polymers are organic macromolecular substances obtained by the minor molecules (monomers), which give birth to the “molecular chains” started by means of physical or chemical actions — polymerization (MANO; MENDES, 1999). Polymers form a group of materials hugely significant for industrialized economies, as it shows many properties and characteristics. They are plastics, rubbers, fiber, composites and cellars, which allow huge variety of applications, replacing the usage of traditional engineering materials (wood, metal and glasses).

Currently, plastics can be qualified in five evolutive stages: natural plastics, modified natural plastics, thermosetting synthetic plastic, thermoplastic synthetic plastic and bioplastics. The transitional period between thermosetting and thermoplastics made this diversity and expansion in these materials.

Since the 1960s, the focus on plastic development has been in the improvement of the plastic performance. This has happened through new synthesis processes, new modifiers agents' integration, as well as the upgrading in the productive processes, allowing gain of properties and rentability increase (LOKENSGARD, 2013). During the last decades of the 20th century, it could be noticed that a lot of plastics got in some kind of technological maturity, while some others were yet developing.

The diversity of plastic kinds took the way of convergence; in other words, less varieties with more applications, which resulted in the focus and consumption increase of some specific polymers, for example: polypropylene (PP), polyethylene (PE), poly(ethylene terephthalate) (PET) and polystyrene (PS). Some other plastics had their demand increased aiming to focus in specific segments in the market, as well as other plastics had their demands increased due to the focus on specific market segments, such as: the acrylonitrile-butadiene-styrene (ABS) in electronic equipment, poly(vinyl chloride) (PVC), in the civil engineering sector and polycarbonate (PC) in the automotive sector. These conditions made the stagnation or productive reduction of some polymers, such as styrene-acrylonitrile (SAN) and the poly(methyl methacrylate) (PMMA).

As a result of this evolutive scenario, there was an increase in the productivity rate, so that the basic resources loss and the waste of feedstock decreased considerably, establishing "clearer technologies". This technological development would make possible the expansion of the plastic market, not only geo-economically, but, mainly, in new segments of products, resulting in a bigger consumption of plastic materials.

THE CONTINUOUS EVOLUTION

The polymers science established a bunch of classificatory values that approach physical, chemical and even economic aspects of these materials. Some groups influence directly the productive systems, such as: the classifying towards the fusibility, the mechanical behavior, the structure, the composition and, furthermore, as can be seen in Mano and Mendes (1999), from the International Union of Pure and Applied Chemistry (IUPAC) definition. Yet, this work will approach only the aspects which guide the classifying towards the plastic occurrences and its evolutionary unfolding over natural and synthetic plastics.

Natural plastics

Natural plastics were an active part of the industrial production until the birth of synthetic polymers. This decline was caused by the growing demand and the technological evolution of the industrialized products, which used to request quantities and properties that were superior to the ones obtained from the natural polymers. These polymers are generated by spontaneous reactions (biogenesis) and are presented as fiber, plastics (resin) and some elastomers derived from vegetal species — polysaccharide, cellulose, latex, lignin — or that come from animals — proteins, casein, chitin, etc. (MANO; MENDES, 2013). Several of these polymers are processed in natura, while others went through chemical modifications, gaining mechanical properties in the transition range between elastic and plastic regions. From the 1980s on, there has been a resumption of interest for these materials with the intention to the "ecological footprint", mainly from those derived from vegetal resources.

Synthetic plastics

Synthetic plastic participation in the industrial activities has begun with the resin phenol-formaldehyde, also known as "bakelite" by the end of the 19th century. During the following decades, the plastic industry would be consolidated with the emerging of new materials. Since the 1930s, the plastic industry had a significant increase in its quality and quantity, with the incorporation of the thermoplastic polymers to the manufacture, which has replaced the natural and the thermosetting plastics.

Although synthetic plastics conquered the productive scenario, there is a bunch of critics about its environmental performance, mainly related to biodegradation, once the thermoplastics, even being chemically stable, has a slow degradation, either for physical or chemical reactions, creating "microplastic" particles.

New categories

Bioplastics form a plastic category which aims the friendship with the environment. The European Bioplastics qualifies biobased, plastics that are partially derived from renewable sources, and biodegradable, plastics that can be easily integrated to the environment. The IUPAC defines biobased polymers the ones derived from monomers obtained from the same biomass. The American Society for Testing and Materials (ASTM) says that the biobased polymers are materials "[...] whose carbon in its composition comes from renewable sources and not from fossil source [...]" (ASTM *apud* MEI, 2016, p. 31, our translation). Currently, bioplastics are applied in several disposable materials, loads of them using conventional technologies or technologies of additive manufacture. However, its demand is still limited to some market segments in virtue of its properties.

Plastics show qualitative subdivisions due to their properties, whatever they may be: general usage plastic (commodities), produced in large scale, and engineering plastics (pseudo-commodities or specialties) produced in smaller scale and destined to products that require better properties or higher performance. Advanced plastics include those that are structural composites applied for usage in extreme conditions and require strict environmental control during the whole process, as well as self-adapting intelligent plastics and nanoplastics, which are actually being developed technologically.

PLASTICS: SOLUTION OR ENVIRONMENTAL PROBLEM?

Nowadays, not considering the contribution of plastics to the worldwide productive scenario may be an immeasurable strategic mistake in social, economic and technological aspects. This is because the plastic industry is not limited to producing low-value products, which usually have short life-cycles. The industry also has its high-value segments, including the human segment, such as hospital equipment, besides producing a bunch of products destined to electronics; civil engineering, transport and some others segments, which contribute to social and individual well-being. Such insertion in almost all the market segments and products categories stemmed from the technological relation between the plastic material and the productive processes. This fact resulted from innovative actions, which made possible the reduction of costs, democratized the access to loads of goods, decreased the consumption of basic resources, among social benefits, making this group of materials a symbol of the industrial society.

However, the World Trade Organization (WTO), along with other international organs, shows the environmental damages made by plastic residues derived from the usage and wrong waste, which is possible to highlight the "invisible pollution", made by the degradation of plastics in the environment leading to the existence of "microplastic".

The World Wide Fund for Nature (WWF, 2019) developed the *Global Plastics Report*, which studied the worldwide plastic garbage in the environment and highlights that only 14% of the whole plastic produces is taken for recycling, while the rest is discarded, and a huge part ends up impacting the sea environment.

The growing demand for plastic products requires more consistent policies about the control of these materials. In the document *The State of Plastics*, made by the United Nations Environment Programme (UNEP, 2018), the environmental responsibilities are endorsed and have been discussed since the 1970s, which are: government actions by means of law about the consumption and waste of solid residues; companies actions by means of innovation programs, based in replacement, fitting or incorporation of less impactful to environment materials; and individual actions, related to the environment education, aiming at the conscientization for consumption and mainly the waste of plastics.

Especially in Brazil's case, it is highlighted by the WWF study that the relationship between recycling and transformation are not significant, conditioning Brazil to the 4th bigger plastic garbage producer. However, to face the numbers shown by WWF, it can be noticed that the plastic consumption *per capita* corresponds to the double indicated by studies by public and private institutions, such as ABIPLAST, CNI, IBGE, which determine that the consumption has kept itself in 83 lb/year, lower than the values shown by Argentina (97 lb/year) and by Chile (112 lb/year), and way too low if compared to the United States of America with their 326 lb/year and the 304 lb/year shown by Europe (ABIPLAST, 2018), as the national plastic recycling rate corresponds to 25.8% of the whole plastic transformed from short life cycle products. The results difference shown suggests the usage of specific methodologies for defining criteria and data collection by the organs previously named. Therefore, lies with the reader the responsibility of the reflection about the data above.

The misuse of the plastics in wastable products, electronic gadgets, packages, among others, have contributed for a mistaken view, partial and restrictive about the plastic usage. Besides that, the application of specific plasticizers, colors and dyes, modifying agents or mineral chargers may contribute to toxic effects towards either the environment or the human being at all.

Aiming to avoid this kind of problems, various countries have established a restrictive law about the usage of these feedstocks, including Brazil, through their own law, which keeps control over the production, application and elimination of these feedstock in the plastic composition.

Another discussed aspect was that toxicity of plastics refers to petrol and the carbon liberation. However, the part which comes from petrochemical, in other worlds, the naphtha, corresponds to 4% of the whole refined petrol, destined to the production of polymers, besides detergents, wax, among other products.

ECOEFFICIENCY AND ECOEFFECTIVENESS

The plastic industry is a sector extremely dynamic and willing to change, because it is liable to the market demands and the productive government. This characteristic is present in all the productive line, but it highlights in the transformation segment because it can also be used in virtue of the specific requests of the upstream or by imposition of the downstream.

Currently, it has been noticed some environmental requirements established by client-companies towards the plastic transformers, attending the markets expectations. This condition obligates the companies to think about their strategic actions in general. In this sense, can be highlighted the guidelines of ISO 14000 series, for the development of "ecoefficient" programs. This concept has guided the productive activities from the Environmental Management System (EMS) looking for improving the performance and usage of resources and feedstocks (SEIFFERT, 2007). In general, the EMS actions are related to the energetic control, the waste reduction, the reuse of feedstock, to the replacement of polluting agents, the techniques normalization and to the social integration.

Therefore, even though EMS holds together important contributions to the productive routines, its proactivity is questionable when we talk about the reduction of the environment harm.

The plastic recycling

For the third plastic generation, ecoefficiency is shown through the energetic consumption, the reduction and losses and through the recycling itself. There are some considerations about this context, mainly with the aspects which refers to recycling. The Environmental Protection Agency (USA, 2017) defines recycling as "[...] the collect, benefit, processing, commercialization and usage of the materials considered garbage". The recycling corresponds to a technological group which allows the recovery of materials from the industrial waste or derived from post-usage.

However, resulting from the taxes of shear stress during the transformation process, there is loss of molecular weight (*Mw*), which makes the recovered material need a certain quantity of new plastic or additives to recover part of its properties. This aspect makes the cost of the recycled product "better" than the "virgin" plastic. Therefore, the consumption of plastic products is the condition *sine qua non* to enable the technic and economic over the recycling, establishing a continuous production cycle and a fair and necessary value to the circular economy.

These plastic recycling systems might be aligned with the properties, composition and origin of the available technological resources. They will be classified by operational levels, just like primary recycling (in house), secondary (mechanical), tertiary (chemical) or quaternary (energic).

The so-called "R functions" in the productive context to reduce, reuse and recycle were associated with the function to reintegrate, rethink and refuse, determining a new level in the ecological perception of plastics. This group of activities was called eco-effectiveness, which encompasses a concept previously proposed by McDonough and Braungart (2014), who said that planned actions establish a continuous cycle of integration between production and recycling.

Certainly, plastic recycling has contributed with socioenvironmental actions, allowing not only the reintegration of solid wastes to the productive system, but also preserving the natural resources and stimulating entrepreneurial actions based in technological innovation.

SUSTAINABILITY IN PROCESS

Nowadays, the plastic transformation technologies form a range of options to the manufacturing of products or components. This range is a result of efforts that made the technologies even more dynamic throughout the productive line. The technological diversity allows a variety of forms, dimensions and production scales. All these aspects establish a productive scenario which is favorable to the production of tools and plastic products.

The current Brazilian scenario of transformation shows the following overview: extrusion 54.6%, injection 31.4%, blowing 8.9%, thermoforming 1.6%, rotomolding 0.8%, lamination/pultrusion (composite) 1%, compression 0.4%, and other processes 1.3% (ABIPLAST, 2019; CERQUEIRA, 2018). In general, these technologies show energic consumption by transformed ton and other technologies, as well as the consumption of water. Despite this advantage, it can be noticed that the Brazilian industrial park was showing low values in productivity, as the average is around 85% of the productive capacity.

Huge part of these technologies shows different characteristics in process, some are totally automatized, while others are very dependent of human resources. The same way, there is a variety in the generation of process waste.

For thermoplastics, the injection channels, trimmings, wastes come back to the production (in house recycling). This is the reason why the conception and development of the project are important, considering all of these machine parameters, in terms of molds and matrices. Today, some projection programs allow a bunch of parametric analysis about the form and process of products with the goal of maximizing the efficiency of the process and with the lower consumption of resources and feedstock.

The thermosetting shows a lower number of processes; however, even with the inferior taxes, the conformation of this material group incurs in significant rates of wasting, mainly in feedstock per processed ton. Depending on the technology and the productive qualification, some processes may present loss in the order from 18 to 25% of the resources applied (CERQUEIRA, 2018). However, thermosetting plastics have a longer durability, for presenting a longer life cycle, decurrent from its physical and chemical properties. Nevertheless, the indication of this group must be very well analyzed in virtue of these significant environmental problems, because resins, in its majority, are processed using charges, which limit them to energic recycling.

CONCLUDING REMARKS

According to a research made by the Organization for the Cooperation and Economic Development (OCED), Brazil, despite being among the ten biggest worldwide economies, shows very low competitive rates. Among other reasons of this economic dichotomy, lies the lack of synergy between the actors who compound the productive structures, limiting the actions destined to social technology innovation.

While the country exports a huge volume of commodities in feedstock and agricultural derived, the results with the exportation of manufactured products represents only 10.4% of national gross domestic product (GDP) (IBGE, 2019). This aspect has been aggravating in the last ten years, due to its subsequent falls in the Brazilian industrialization process, showing an average decline tax around 0.8%. This aspect shows that the Brazilian industrial productive structures are extremely fragile, either in the inner scenario or in their participation in the global economy.

Brazil shows supply chain and productive networks of significant importance for industrial development; however, the conjectural problems in the transformation industry can be noticed. This economic segment, besides sticking together part of the human resources (work posts), is what adds the most value to the productive line, because it establishes relations of all the consumer lines.

Specifically for the plastic polymers productive line, many initiatives destined to improvement of the productive processes in virtue of the environmental issues can be seen, which goes from the informatized systems adoption for the products development, to environment management systems, which involves government, social and companies' actions aiming to improve or, even better, to balance the industrial growth with the environmental conservation.

For this, the creation of integrated incentive programs to technological innovation and social action destined to the refinement of the whole plastic productive line is encouraged. From them, the following programs can be highlighted: (1) basic resources control with the goal of reducing or eliminating wastes during the productive process; (2) incentives to recycling, reverse logistic and plastic materials recycling, aiming at the replacement of the linear economy to the circular economy; (3) integration of bioplastics in products that have a short life cycle, just like packing, disposables and others; (4) strategic partnership formation for developing innovations about plastics along with sustainability values; (5) scientific and technological capacitation and for the professionals involved with projects of plastic management; (6) stimulus to social actions destined to generating income from the usage of plastic waste; and (7) environmental education for the conscious consumption and correct waste of plastic.

Researches focused on innovation of products and processes, besides contributing to individual wellness, have been giving satisfactory answers to plenty of environmental issues. This affirmation can be confirmed, directly, when identifying the plastic *per capita* consumption, which keeps relations with the human development index (HDI). According to the Plastics Europe Institute (2013), countries that show higher taxes of plastic products consumption tend to have a higher HDI, while countries with a lower consumption of plastic products show lower development index. This condition also deserves respect as they are directly linked to the educational aspects of income equal distribution.

To conclude, it is important to have a different perception of the productive line and plastic production in the sustainability context. For this, it is necessary to have an environmental education, which may contribute to the constitution of a society more responsible and committed with ecological values, aiming the total social development.

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