University of Miskolc

Faculty of Material Science and Engineering

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Environmentally friendly recycling of metal cans and polymer bottles obtained from household waste

MSc Thesis Work

writer:

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… In the world of life, you are appreciating not less than a God. Now, in the kingdom of the dead, we love you as a king, so why all that sadness my Achilles…

-HOMER-

To my Father.

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Abstract

With progressing urbanization, household's waste management is becoming a major public health and environmental concern in urban areas. The current system in developing countries are doing all their categories of waste management systems to find the more environmentally friendly Waste Management Systems (WMS), by having established rules to limit the amount of Municipal Solid Waste (MSW) sent to landfill "because the landfill is still the primary destination for (MSW)], and have set drivers to establish more environmental sustainable technologies for dealing with the treatment of (MSW)"[1]. Municipal Solid Waste (MSW) consists of an organic fraction (wet waste: kitchen waste, food waste, straw, garden trimmings, sawdust, etc.) and a non-organic fraction (Dry waste: glass, plastics, metals, ash, stone and bricks, etc.). "The properties of waste differ immensely depending on many factors, such as the area of collection (rural, urban, industrial or commercial), seasonal variations and recycling levels" [2]. The management of the plastic fraction is one of the most debated issues in the discussion on integrated municipal solid waste systems. "The plastic in MSW is composed of plastic bottles made of polyethylene terephthalate (PET) or High-Density Polyethylene (HDPE), of soft plastic or plastic films made of Low-Density Polyethylene (LDPE) and of Hard Plastic made of HDPE"[3]. Through the above introduction about the mechanism of action of the factory, we can see that by taking an example the city center of Miskolc is the closest to understand the mechanism of recycling at the plant as well as to highlight on the device used for this purpose.

Chapter 1: Introduction and goals:

The increasing awareness of the environment has contributed to concerns regarding our life styles and our indiscriminate disposal of wastes. During the last decade there are many categories have been trying to address this complex problem, more aggressively to discussed the issue of solid waste and in particular plastic waste. "Because the Plastics have become an integral part of our lives. The amounts of plastics consumed annually have been growing steadily its low density, strength, user-friendly design and fabrication capabilities and low cost, are the drivers to such growth" [4]. "The routes of Plastic Solid Waste (PSW) treatment are detailed and discussed covering the schemes and technologies for the plastics such as; re-extrusion, mechanical, chemical and energy recovery, and because the Plastic Solid Waste (PSW) presents challenges and opportunities to societies regardless of their sustainability awareness and technological advances recent progress in the recycling and recovery of PSW are involves the re-introduction of clean scrap of single polymer to the extrusion cycle in order to produce products of the similar material" [5]. "Among various recycling methods, the chemical method, which converts waste plastics to useful hydrocarbons have been recognized as a promising approach. Presently, about half of the waste generated from factories as specific plastics, such as Polyethylene Terephthalate (PET), Polyvinyl Chloride (PVC), Polycarbonate (PC), Polypropylene (PP), polyethylene (PE)and Polystyrene (PS)" [6]**.** The goal for my topic of diploma work is how to recycling the polymer bottles more effectively which were originated from households waste, and is to monitor the type and the mass of waste polymer handling, and also to do a critical notes concerning with the applied technology in a plant around a middle sized city like Miskolc. Furthermore to know more about the effective recycling technology line or lines for Polyethylene Terephthalate (PET).

Chapter 2: Literature Review

2.1 The origin of households waste bottles:

"With increasing biomass of solid waste and growing demand for renewable resources"[7]. "Furthermore, as household waste composition analyses are often carried out routinely at regular or irregular intervals, the determination of food waste as separate waste fraction suggests itself and has been increasingly demanded by local authorities in recent years"[8], because it is "undertaken to evaluate the quantity and decomposition of household waste to identify opportunities for waste recycling" [9]. The techniques, facilities and treatment of waste management are developing because the improper waste management has led to various types of pollution and health issues. Due to the lack of infrastructure, financial, operational and technical resources, it has lead to an inadequate and inefficient level of provision at various levels of the waste hierarchy. "Therefore, privatization of solid waste management was initiated with the goal of attaining an integrated, efficient and technologically advanced management system capable of enhancing environmental quality through resource recovery and waste minimization without affecting the welfare of the public"[10]. Traditionally local government centered their urban solid waste management strategies on effective collection, transportation and disposal services. The primary objective was to protect and improve public health standards, because the increasing amounts of waste became socially unacceptable. "Therefore, a new perspective, entailing the reduction of waste through prevention, reuse, recovery, composition and recycling waste traders and recyclers contribute to more sustainable development by promoting cleaner urban neighboring"[11]. "For years industry and research craved for developing smaller form factor and increasing performance and speed, nonetheless always with one constant parameter"[12] searching for synthetic substance supposedly more precious than gold because it would unite all the positive properties of the conventional "natural" materials. "As the plastics were invented in the 19th

century and went into large-scale production in the early 20th, it seemed as though this vision had become reality, which apparently could be given all conceivable characteristics. It combined:

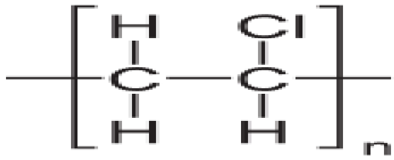
- Lightless.
- Strength.
- Transparency.
- Thermal insulation capacity.
- Light permeability.
- Loadbearing." [13].

2.2 The raw materials of the polymer bottles for recycling:

"The plastics among solid waste materials as the greatest threat to the environment mainly because plastic articles are not biodegradable. In order to react to the legislative pressure to ban plastic packaging, the plastic industry has been forced to intensify the efforts in developing efficient recycling processes as well as biodegradable materials" [14]. The raw materials of the polymer bottles for recycling. A post consumer's material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product, which can no longer be used for its intended purpose. This includes returns of material from the distribution chain. "This type of material is different from a "Pre-consumer material as defined in the same article of the standard, (i.e. a material diverted from the manufacturing waste stream"[15]."Newly developed biodegradable polymers and modifications of previously developed biodegradable polymers have enhanced the tools available for creating"[16], several types of polymers It formed a revolution in recycling operations. It led to reconsider and find a testing processes and solutions to take advantage as much as possible of these species. After recycling to reduce the negative impact on the environment.

Introduction OF polymeric materials:

Polyvinyl Chloride (PVC):



Polyvinyl chloride is a synthetic solid resin material, i.e. a plastic. It is also commonly known as vinyl. PVC has a complex molecular polymer structure that imparts its many useful characteristics. "Pure PVC is a bright white, fine-grained, powder or brittle solid. It is non-toxic and inert"[17]. "PVC it is the world's third-most widely produced synthetic plastic polymer, after polyethylene and polypropylene"[18]. PVC comes in two basic forms: rigid (sometimes abbreviated as RPVC) and flexible. "The rigid form of PVC is used in construction for pipe and in profile applications such as doors and windows. It is also used for bottles, other non-food packaging, and cards (such as bank or membership cards)"[19]. "Furthermore, the following table present the main applications of PVC... and the percentage of overall use in the table below" [20]:

Table .1: PVC lifetime in household applications

Use application	Percentage	Average life time
Buliding	57	1-10 (years)
Packging	9	1 (years)
Furniture	1	17 (years)
Other houshold appliances	18	11 (years)
Electric Electronic	7	21 (years)
Automotive	7	12 (years)

Produce of (PVC):

Two main processes are used to produce PVC:

- Suspension polymerization of VCM (80%).
- Emulsion polymerization (10%).

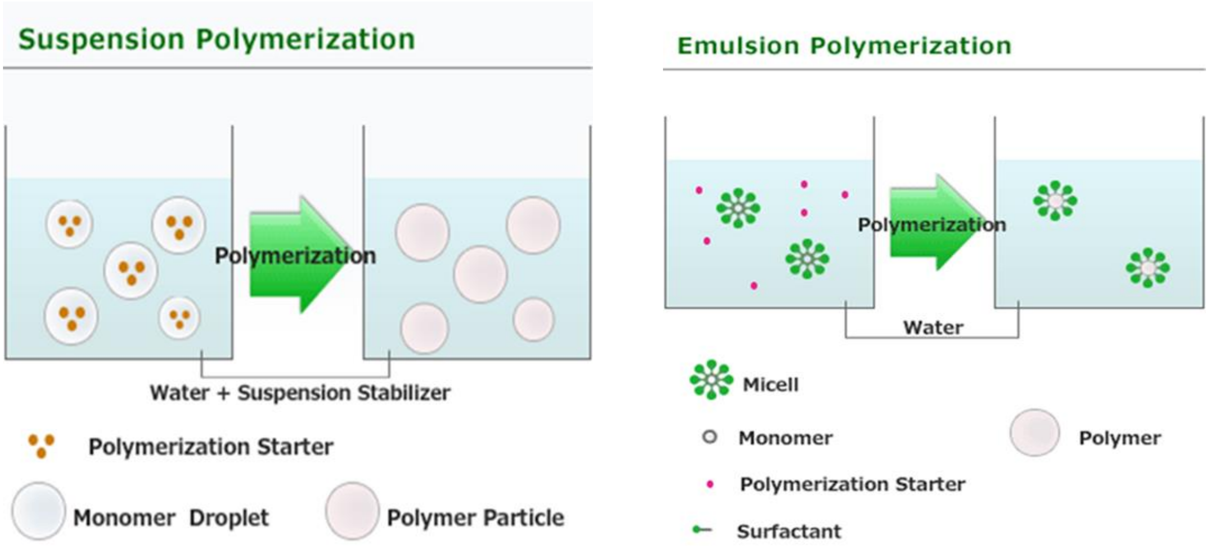
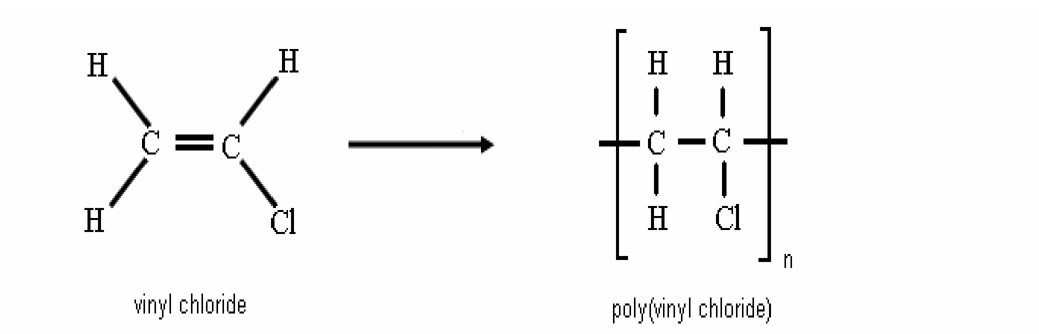


Fig.1. Scheme of suspension and emulsion polymerization of PVC

The production of VCM from ethylene and chlorine, or ethylene and HCl respectively, takes place to a great extent in closed industrial processes. Emissions of chlorine, ethylene, ethylene dichloride, HCl, VCM and chlorinated by-products including dioxins to the working environment or the outdoor environment can occur (air and water). "Several of these chemicals are well known toxic substances and strict emission control measures are therefore necessary. Several Community Directives apply to PVC and VCM production processes" [21].

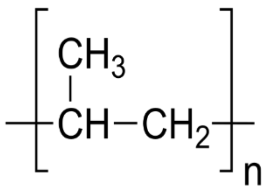
- "The Production of Vinyl Chloride from Ethylene and Chlorine:
  Ethylene + chlorine ----- EDC (ethylene dichloride)
  $$C_2H_4 + Cl_2 = C_2H_4Cl_2$$
- PVC is formed from vinyl chloride in a special heat driven plastics manufacturing process that polymerizes toxic short gaseous vinyl chloride monomers [C2H3Cl] into non-toxic solid PVC [(C2H3Cl)n] long polymer chains :



The waste management of (PVC):

Mechanical recycling, chemical recycling, incineration and landfilling they are in order to assess the technical aspects of the main waste management options for PVC waste" [22]. "The management of PVC waste should be assessed in the context of the strategy for waste management has confirmed the hierarchy of principles that prevention of waste shall remain the first priority, followed by recovery and finally by the safe disposal of waste. It is further stated that preference should be given, where environmentally sound, to the recovery of material over energy recovery operations. This general rule is based on the fact that material recovery has a greater effect on waste prevention than energy recovery. It will nevertheless be necessary to take into account the environmental, economic, and scientific effects of either option. The evaluation of these effects could lead, in certain cases, to preference being given to the energy recovery option" [23].

Polypropylene (PP):



"Polypropylene is a clear glossy film with a high strength and puncture resistance. It has a moderate barrier to moisture, gases, and odors; also, it has to water vapor, which is not affected by changes in humidity" [24]. "Polypropylene is currently one of the fastest growing polymers. Much of this growth is attributed to polypropylene’s ability to displace conventional materials (wood, glass, metal)" [25]. "Polypropylene is a strong lightweight thermoplastic that offers outstanding toughness, rigidity, and resistance to thermal deformation. Fabricators and designers value these characteristics and have come to consider polypropylene one of the most satisfactory thermoplastic resins for a wide range of applications. This unique material can be steam-sterilized or autoclaved without damage and resists environmental stress cracking when subjected to most chemical tests. Polypropylene is highly responsive to injection speed and pressure and sets up quickly in the mold, enabling molders to attain high production rates. This combination of performance properties gives polypropylene a position in the injection-molding field that is unique among thermoplastics. Polypropylene also demonstrates excellent chemical resistance, good abrasion resistance, good dimensional stability, and a high surface gloss on finished pieces. Several characteristics of polypropylene enable thin section oriented moldings to have virtually unlimited flex life, making it an excellent material for integral hinges in molded parts. These properties include" [26]**:**

- Fatigue resistance.
- Ultimate tensile strength.
- Ultimate elongation.

Chemical identification:

Generally, "Propylene is described as a volatile, colorless gas at room temperature. In addition, the additional identification information as shown in the (table 2).

Table.2: chemical identification of PP

Product Name	Propylene
IUPAC Name	PROPYLENE
Chemical Abstract Registry Name	1-PROPENE
Chemical Name	Propylene
Chemical Family	1-Alkenes
Chemical Abstract Registry Service Number	115-07-1
Chemical Formula	C3H6
Structural Formula	CH2CH=CH3
Synonyms	Propene
	Methylethane
	Methylethylene
	1-Propene
	1-Propylene
	UN1075
	UN1077
	C3 Hydrocarbon
	HSN 175

Chemical and physical properties of (PP):

"The important chemical and physical properties of propylene as summarized in the (table 3) below:

Table.3: chemical and physical properties of PP

Value	Property
Gas, Liquid Under Pressure	**Physical State**
Colorless	**Color**
Gassy/aromatic	**Odor**
C3H6	**Molecular Formula**
42.08	**Molecular Weight**
-53.84°F	**Normal Boiling Point (at 1 atmosphere)**
-301.46°F	**Melting Point**
197.15°F	**Critical Temperature**
667.18 psia	**Critical Pressure**
0.07042 ft3/lb	**Critical Volume**
0.281	**Critical Compressibility Factor**

14.56 lb/ft3 (1.9476 lb/gal)	**Critical Temperature, 197.15°F3**
1.46	**Gas Density (air =1)**
144.06 psia	**Vapor Pressure, 65.93°F3**
1.717 g	**Gas Weight (at 25°C and 760mm)**
0.3638 BTU/lb°R	**Ideal Gas Heat Capacity, 70°F3**
1.363	**Refractive Index, 77°F**
Insoluble	**Solubility in Water**
-185°C (-301oF)	**Solidifies**
-54.4°F	**Liquifies**
0.0085 centipoise	**Viscosity (vapor), 70°F**
201.36 BTU/lb	**Ideal Gas Heat of Formation**
-108°C = -162°F	**Flash Point**
717.6 cal/mol	**Heat of Fusion**
851° F	**Autoignition Temperature**
Explosive Limits in Air, Vol. %, 77°F, 1 atm	
2	**Lower**
11	**Upper**
Odor Threshold in Air	
270 - 600 ppm	**Detection**
418 ppm	**Recognition**

Production of (PP):

is a resin of the polyolefin family and is one of the most widely used plastics in the world today, with a density of only 0.9 g/cm3, it is also the lightest of the widely used thermoplastics. The low-density characteristic of PP is a key factor enabling lighter weighting of many end applications relative to using higher density materials. Light weighting and the resulting reduced material usages are often important drivers of Life cycle assessment (LCA) environmental impact results. Moreover, there are two techniques used for the production of polypropylene:

- *Liquid Propylene Pool Process (LIPP):*

The polymer is produced in a liquid pool of propylene by the inclusion of a Ziegler Natta catalyst, which forces the molecules of the monomer to align and join in a certain manner to enable long chain formation, or polymerization, into polypropylene. When long chain formation is sufficient, growth of the molecule is stopped via hydrogen, following this the catalyst is deactivated and resultant polymer separated from the liquid propylene (Fig 2).

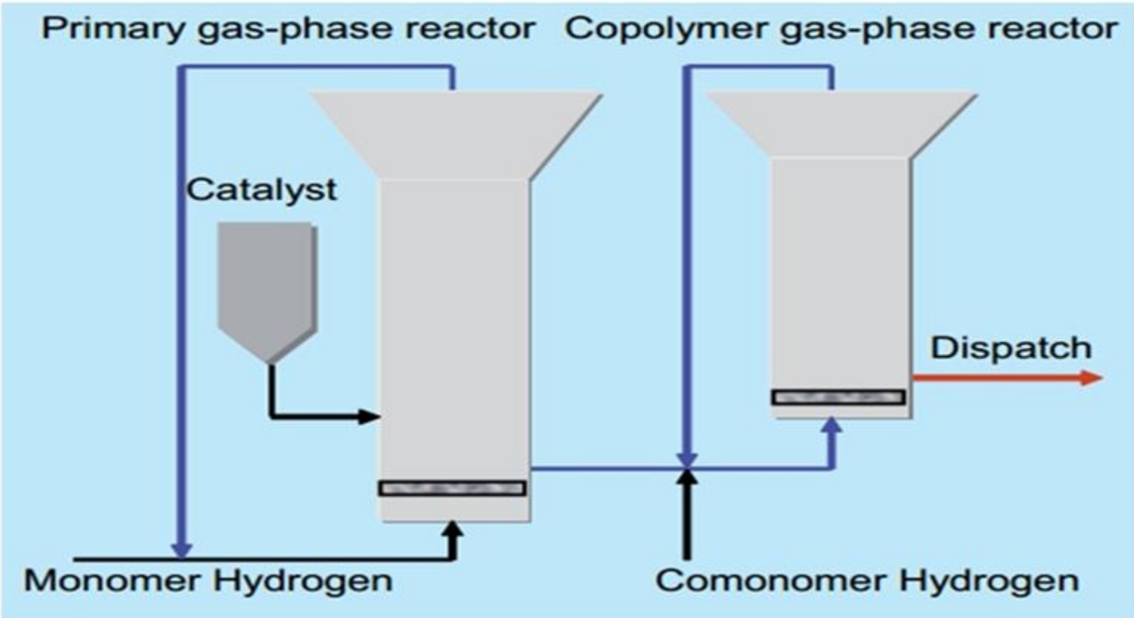


Fig.2. Scheme of (LIPP) PROCESS

- *Gas Phase Polymerization:*

A gas phase reactor is essentially a fluidized bed of dry polymer particles maintained either by stirring or by passing the propylene monomer gas at high speeds through it. As with the LIPP process, high activity specialty catalysts used in the polymerization of the gaseous monomer into polypropylene. Pressures are usually relatively low at ~2MPa and temperatures are usually in the range 60 – 800C (Fig 3). In both processes, the polypropylene leaving the reactor is in a fine powder form. This powder is then mixed with various chemical stabilizing and performance additives, fed to an extrusion compounding machine which melt mixes the materials and forces the melt through dies where it is cut into pellets, the molten pellets are then cooled using water then packaged for sale [27].

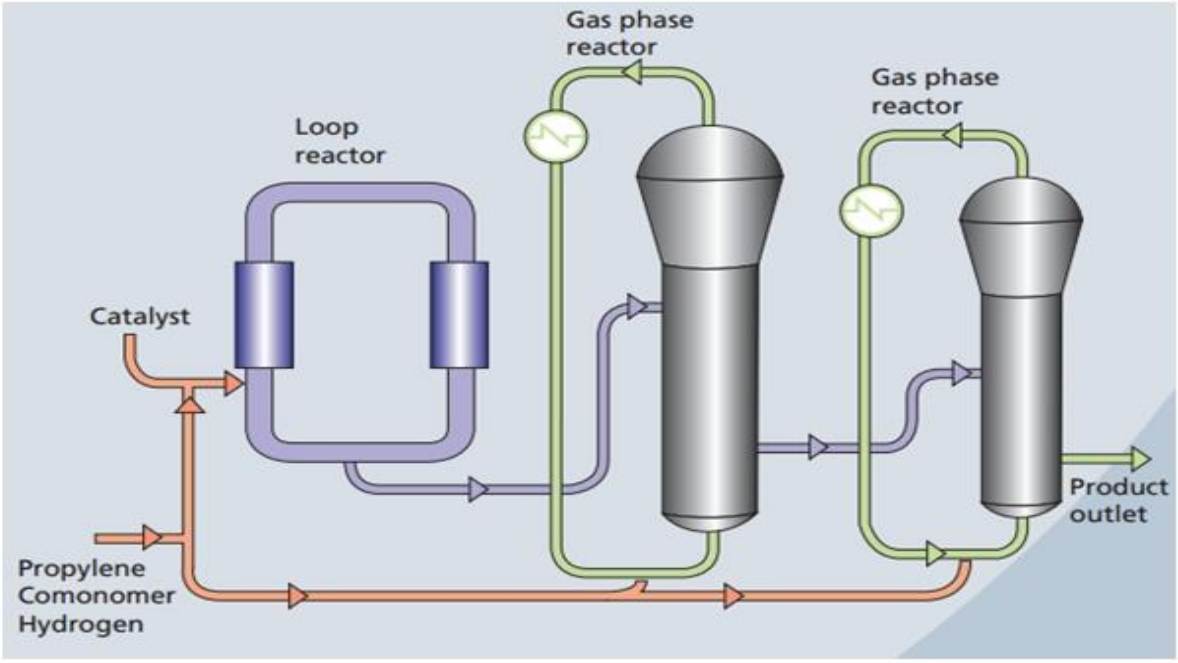
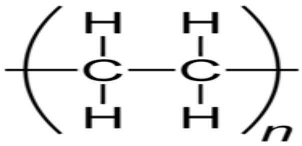


Fig.3. Scheme of Gas phase process

Polyethylene (PE):



"The word polyethylene means" repeating units of ethylene". These invisibly tiny parts of ethylene (monomer) are the building blocks for polyethylene during production. Polyethylene (PE) is a thermoplastic polymer, which can be melted to a liquid and remolded as it returns to solid state.PE is chemically synthesized from molecules that contain long chains of ethylene monomer. It can be produced through radical polymerization, anionic addition polymerization, ion coordination polymerization or cationic addition polymerization. This is because ethane does not have any substituent groups that influence the stability of the propagation head of polymer"[28]. "Polyolefins is same polyethylene" [29] "and also it is such as polypropylene, and their copolymers have excellent bulk physical/ chemical properties, are inexpensive and easy to process. Polyethylene in particular holds a unique status due to its excellent manufacturer, and user-friendly properties. Polyethylene does not possess such as printability, hydrophobicity, roughness, lubricity, selective permeability and adhesion of microorganisms, underscore the need for tailoring the surface of this valuable commodity polymer"[30]. "Polyethylene is the most widely utilized synthetic polymers. There are many scientific, industrial and commercial reasons for this enormous consumption, such as good chemical resistance, zero toxicity, bio-acceptability, good physical and mechanical properties, low cost, ease of fabrication, good raw material availability and low environmental impact based on the product's properties. Polyethylene can be commercially classified into" [31] (Fig.4):

- *"High-density polyethylene (HDPE):* High Density Polyethylene has almost no branching and thus has stronger intermolecular forces. It is produced mainly in slurry and gas-phase polymerization processes. HDPE is a white opaque solid**.**

- *Low-density polyethylene (LDPE):* Low-Density Polyethylene has random long branching, with branches on branches. It is produced mainly in high-pressure polymerization processes. LDPE is a translucent solid" [32].

Fig.4. the photo of two type of PE

Production of High Density of Polyethylene (HDPE):

- *"Hostalen A Typical Slurry Process:* The Hostalen process consists of two continuous stirred-tank reactors (CSTR) that can be operated in parallel or in series, depending on which grade of polymer is required. The process is designed to produce either unimodal (broad or narrow molecular weight distribution polymer) or bimodal polymer by using Ziegler-Natta catalysts. For bimodal polymer production, a high concentration of hydrogen in the first reactor and a low concentration of hydrogen plus a small amount of co-monomer in the second reactor is used. The ethylene concentration in the second reactor is much higher than the first reactor (Fig 5).

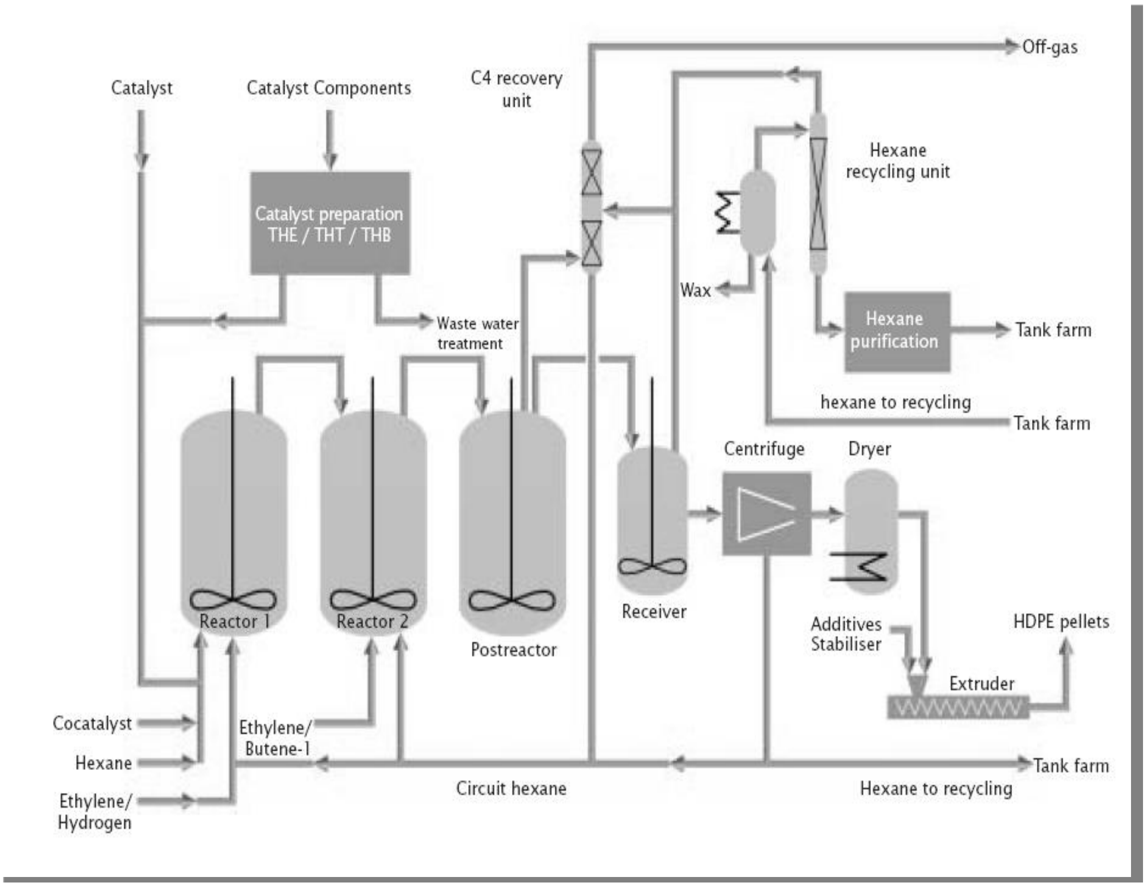


Fig.5. Scheme of **(**Hostalen A Typical Slurry Process)

- *Innovene G: A Typical Gas-phase Process:*

In this process, the catalyst and co-catalyst are fed to a slurry stirred-tank reactor in which pre-polymerization occurs. Pre-polymerization under mild conditions helps to prevent hot spots or the production of fines which is caused by high heat generation and growth stress inside the particles. The pre-polymer is transferred to a dryer where hot nitrogen evaporates the solvent. Then the pre-polymer powder, as a catalyst for the main polymerization reactor, is fed continuously to the fluidized bed reactor. The fluidization reactor comprises two main parts: a cylindrical part and a disengagement part. The cylindrical part is equipped with a gas distributor in order to fluidize the content of the bed. The disengagement part reduces the velocity of flowing gas and consequently disengages the polymer particle from the outgoing gas. Cyclones are installed to remove fines coming from circulated gas from the top of the reactor. Fines from bottom of the cyclones, which are usually quite active, are returned to the reactor for further polymerization. Circulating gases from top of the cyclones are passed through a heat exchanger(s) and then mixed with a certain quantity of fresh feeds to fix the composition of components in the reactor. Finally, the gases are compressed and returned to the bottom of the reactor. Ethylene as a monomer, butene-1 or hexene-1 as co-monomer, hydrogen as a chain transfer and nitrogen as an inert gas are introduced at different points of the circulating-gas pipe in order to achieve perfect mixing and to prevent condensation, which could damage the blades of the compressor or block the holes of the gas distributor. The circulating gas fluidizes the bed and removes the heat of reaction (fig 6)" [33].

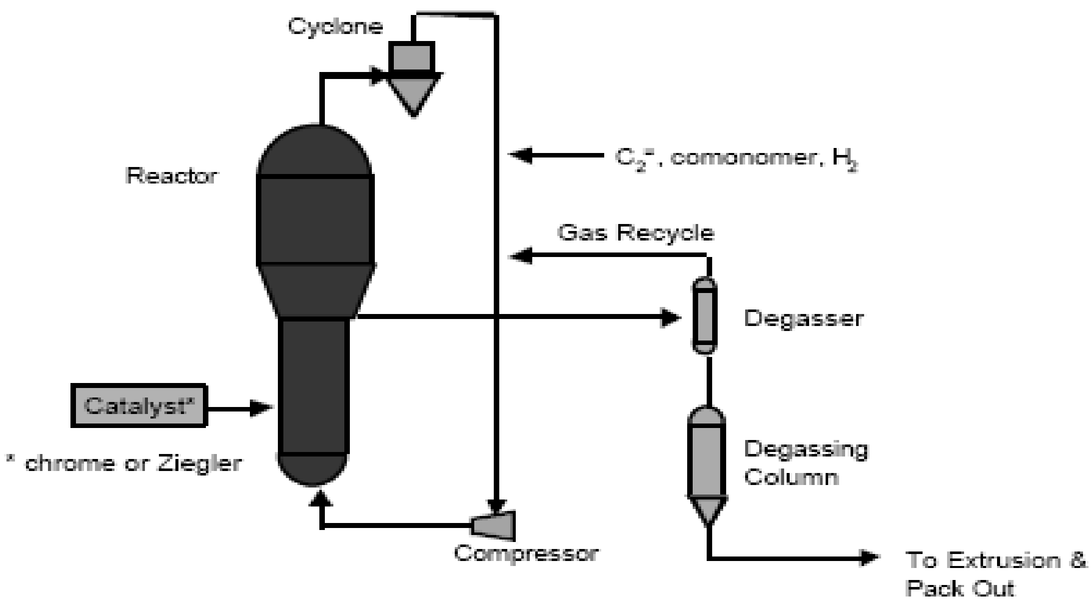
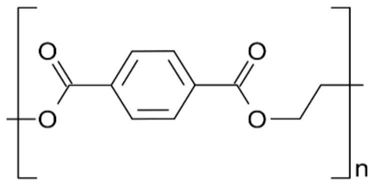


Fig. 6. Scheme of (Innovene G: A Typical Gas-phase Process)

Polyethylene terephthalate (PET):



"The plastic products have revolutionized the way we live. Polyethylene terephthalate (PET), is an acronym for polyethylene terephthalate, which is a long-chai polymer belonging to the generic family of polyesters [34]. PET is cheap and common polyester plastics used throughout the world in the manufacturing of bottled drinks, containers for foodstuffs, and fibers used in clothing" [35]. (PET) has become the plastic packaging of choice for many food products, particularly beverages like bottled water and carbonated soft drinks. The scientific testing of PET is based on two key principles: establishing that there is a minimal amount of transfer of substances between the plastic packaging and the food, and establishing that any substances that may transfer from the plastic to the food do not pose a risk to human health [36]. "Polyethylene is characterize as a semi-crystalline polymer, made up of crystalline regions and amorphous regions. Crystalline regions are those of highly ordered, neatly folded, layered (in parallel) and densely packed molecular chains. These occur only when chains branching off the sides of the primary chains are small in number. Within crystalline regions, molecules have properties that are locally (within each crystal) directionally dependent. Where tangled molecular chains branching off the molecular trunk chains interfere with or inhibit the close and layered packing of the trunks, the random resulting arrangement is of lesser density, and termed amorphous. An abundance of closely packed polymer chains results in a tough material of moderate stiffness. Polyethylene Terephthalate (PET) has become the material of choice for many new applications in the food and beverage, medical and pharmaceutical, household and chemical, and electronic and automotive markets. The end-use applications of PET are found in rigid and flexible packaging, composite molded structures, tapes and discs of various kinds. The fabrication processes include injection molding, blow molding, extrusion, thermoforming, and film orientation. The ease of fabrication, the quality of the fabricated products, and the end-use properties are all-dependent on basic material properties and specific responses during the various steps of each of the processing methods used to convert PET pellets into the desired final product" [37].

The properties of (PET):

Thermal and mechanical properties of (PET):

- "Polyethylene Terephthalate’s (PET) properties are particularly sensitive to its processing history. Processing affects the extent of crystallinity. Mechanical stretching and melt flow history influence the extent and structure of crystalline domains in the semi-crystalline polymer. Typical processing parameters include the rate of cooling and the amount of stretch. Both influence crystallization differently. Isolating the contribution from stretch or thermal crystallization is valuable for identifying the relationship to mechanical properties.

- The interdependence of chemistry, processing conditions, microstructure and properties is an important aspect in the engineering of polymers; it is the ability to control the microstructure through changing the process provides a means for selecting microstructure, and thereby affecting the properties. With wide spread application of semi-crystalline polymers (e.g. PE, PP, and PET), establishing the relationship between microstructure and properties is essential for efficient material use.
- Polyethylene terephthalate (PET) is an aromatic semi-crystalline polymer with applications in the field of textiles, packaging, and engineering molding. Crystallinity and molecular orientation affect the modulus of PET. Because of its slow crystallization rate and strain sensitive characteristics, PET can be engineered to have a distinctive microstructure, and thereby distinctive properties.
- Modeling properties requires comprehensive microstructure information (crystal size and percent crystallinity, because Crystallinity measurements of PET is subject to the process history and the technique used) of the polymer" [38].

The physical properties of (PET):

- "As the most typical thermo plastic polymer in polyester family, polyethylene terephthalate (PET) has been widely applied in various fields such as packaging, textile, and engineering composites due to its cost effectiveness, excellent moisture/gas barrier properties, mechanical strength, and good process ability" [39].
- "PET exhibits interesting physical properties (morphology). PET is classed as a semi-crystalline polymer and when heated above 72C° changes from a rigid glass-like state into a rubbery elastic form where the polymer molecular chains can be stretched and aligned in either one direction to form fibers, or in two directions to form films and bottles.

- If the material melt is cooled quickly, while still held in the stretched state, then the chains are frozen, with their orientation remaining intact. Once set in this stretched state the material is extremely tough and confers the properties we see in a typical PET bottle.
- If the PET is held in the stretched form at temperatures above 72C°, it slowly crystallizes and the material starts to become opaque, more rigid and less flexible. It is then known as crystalline PET or CPET. In this form, it is capable of withstanding higher temperatures and can be used for trays and containers capable of withstanding moderate oven temperatures.
- The PET described so far is the simplest typical product. However, many modifications are introduced to develop specific properties for the various packaging applications and to suit particular manufacturing equipment why, because the main reasons for its popularity are the properties of glass-like transparency coupled with adequate gas barrier properties for retention of carbonation. In addition, it exhibits a high toughness/weight property ratio which allows lightweight, large capacity safe unbreakable containers (<1.5L)" [40].
- "PET is hygroscopic, meaning that it absorbs water from its surroundings. However, when this "damp" PET is then heated, the water hydrolyzes the PET, decreasing its resilience. Thus, before the resin can be processed in a molding machine, it must be dried. Drying is achieved through the use of a desiccant or dryers before the PET is fed into the processing equipment (table below)" [41].

Table.4: The physical properties of PET

Properties	Values
Yong's Modulus	2800-3100 MPa
Tensile strength (σt)	55-75 MPa
Ealastic limit	50-150%
Notch test	3.6 KJ/m²
Glass transition temperature(Tg)	67-81C°
Vicat B	82 C°
Linear expansion coefficient (α)	0.00007 per K
Water absorption	0.16
Meting point	>250°C
Boiling point	>350°C (decomposes)
Density	1.38 g/cm³.
Solubility in water	Practically insoluble
Molar mass	variable

Aluminum (Al):

'Besides other factors to be taken into account in every engineering application, aluminum purity is a very important parameter, which can limit its use in many cases. It is well known that many properties of aluminum can be changed by adding even very small amounts of other elements. The presence of increased its hardness cause considerable changes in electrical conductivity of the pure metal, etc. Determination of trace elements is therefore often of extreme importance. Many industrial applications demand high purity grade aluminum where the content of impurities must be kept extremely low. The impurities in aluminum used in the food and chemical industry, nuclear reactor technology, for electric conductors, electric condensers, Due to its physical and mechanical characteristics, compatibility, resistance against corrosion and radiation damage and favorable nuclear properties (low neutron absorption cross-section and rapid decay of neutron induced radioactivity (T = 3.2 m) aluminum is widely used in nuclear technology"[42]. "The aluminum and its alloys from structural engineering point of view. The first building structures made of aluminum alloy appeared, when concrete, masonry and steel were the main materials used for civil engineering structures. The aeronautical industry was one of the first fields, which benefited of the aluminum alloys physical properties, so much used because there are no other metallic materials, which can compete with it" [43]. "Aluminum pure and commercial aluminum primary, it is produced in a variety of grades, normally ranging from 99% to better than 99.999%. There are three different types, corresponding to different production methods, can be distinguished:

- *Commercially pure aluminum:* is the metal that comes from the reduction of (Al_2O_3) in the electrolytic cell and it is the bulk of the commercial production. It may contain up to (1%) impurities and very seldom exceeds (99.9%) purity.
- *Refined aluminum:* is produced by electro refining the commercially pure metal in the three layers cell.
- *One refined aluminum:* is produced by zone refining and, with proper starting material and technique can produced metal with less than one (ppm) impurities.

The properties of (Al):

Thermal properties:

- *Melting point:* The melting point is very sensitive to purity and all the values measured on metal less than 99.99% are at least 1-2K^o too low. Moreover, when the melting point is effected by impurities, the commercial metal usually has range of solidification, the upper freezing point being 0.5-1^o lower than pure metal. The most accurate determinations on aluminum 99.99% give a melting point of 933.4K^o, and this or the rounded off figure of 933K^o(1220F^o), is the generally accepted value. Even in aluminum better than 99.99% purity melting starts at the grain boundaries, but is doubtful if it happens below the melting point.

The melting point of aluminum increases slightly less than linearly with pressure.

- *Boiling point:* The early values for the boiling point around (2300K°) are definitely too low. Values ranging from 2700 to 2800K are much more probable and value of 2570 can be accepted as reasonable, the maximum boiling rate for aluminum is 0.7 $*10^{13}$ atoms/sec, above this rate, aluminum explodes. Moreover the boiling point is affected by impurities the commercial metal usually has a range of solidification, the upper freezing point being 0.5-1 lower than the pure metal.

- *Heats of fusion and sublimation:* The values for heat of fusion at 933K° fall within the range 342-405KJ/gr, with 390KJ/gr and 10.5KJ/gr, as most probable, the values for the heat sublimation at 298K° (25C°) range from 10,400 to 12900 KJ/gr, with 11,900KJ/gr and 324KJ/gr. As most probate from these values the heat of vaporization can be calculated at 11,400KJ/gr (310KJ/gr) and the entropies of fusion, vaporization and sublimation at 11400KJ/gr (310KJ/gr), and the entropies of fusion, vaporization and sublimation at 112,312 and 325KJ/gr. /K°, respectively. Comparison of data for high purity and commercial metal indicate that the difference in the values for the heats and entropies due to the presence of impurities is less than the error of determination" **[44]**.

The physical properties of (Al):

- "*Crystal structure:* It is the results of the arrangement of atoms during the solidification process" [45]. "When metals change from the molten to the solid state, they assume crystalline structures. The atoms arrange themselves in definite ordered symmetrical patterns, which metallurgists speak of as "lattice" structures"[46]. "Aluminium is a metallic material, composed of atoms, which are arranged in a specific three-dimensional array - a crystal. The way in which the atoms of all materials are bonded is determined by their atomic structure (FIG 7)" [47].

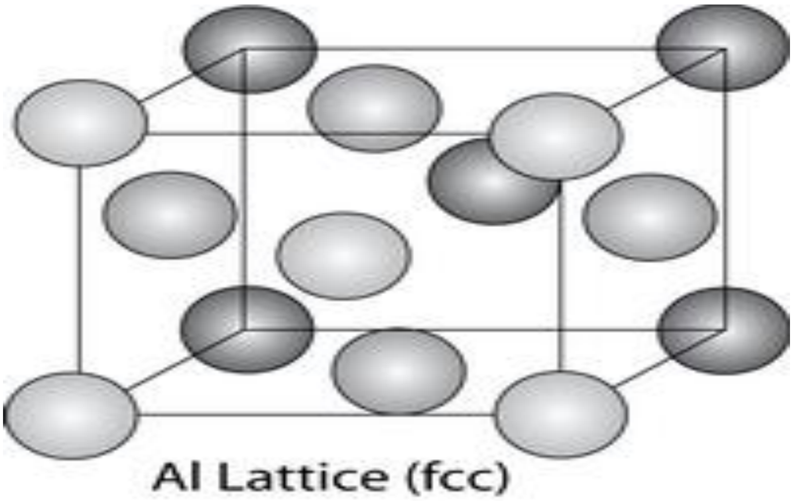


Fig. 7. Scheme of atomic structure of Al

- *"Atomic structure:* According to present concepts, the Aluminum has the atomic number 13 this means that an aluminium atom is composed of 13 electrons, each having a unit negative electrical charge, arranged in three orbits around a highly concentrated nucleus having a positive charge of 13. The three electrons in the outer orbit give the aluminium atom a valence or chemical combining power of (+3) (fig 8)" [48].

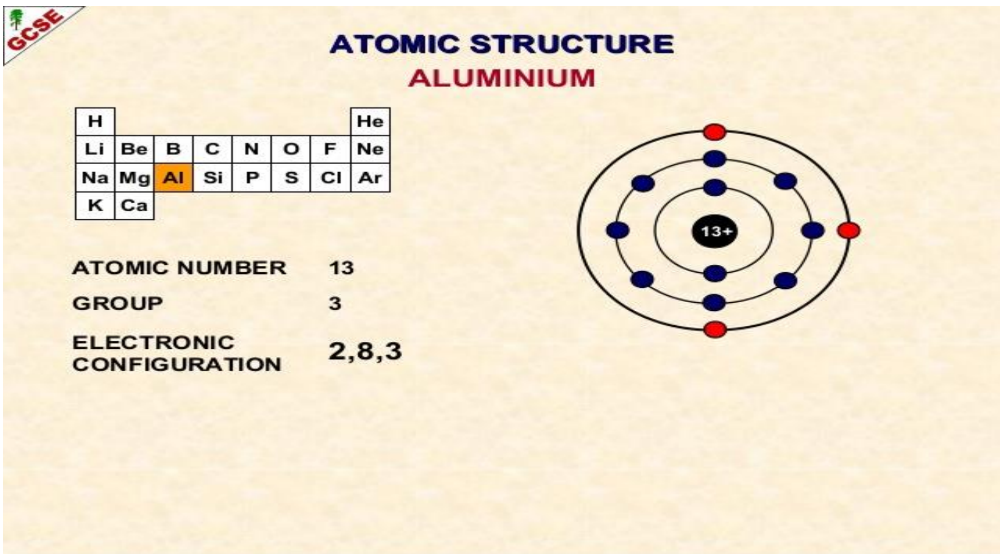


Fig. 8. Scheme of atomic structure of Al

- *"Density:* The relative lightless of Aluminum is one of its outstanding characteristics. The relationship between the density of an alloy and its composition usually approaches linearity closely enough to justify calculating density as the sum of the density contributions of each element. The conditions under which the density of an alloy is determined should be specified, because the effects of many of the above factors are minimized when the alloy is annealed, the densities of alloys in this condition are readily comparable**.**

- *Non-magnetic property:* Much attention has been paid to improve the magnetic properties, which leads to a decrease in the energy consumption. As improved magnetic properties are realized through the control of chemistry, grain size and texture, several new products with low core loss and high induction have been developed by precise control of the chemistry and mill-processing [49]. Aluminium and its alloys are very slightly paramagnetic, as it has a magnetic permeability (m) slightly greater than one. The magnetic susceptibility χ (Chi), degree of magnetization/ applied magnetizing force, of 99.99 % purity aluminium is only 0.623 x 10-6, which for practical purposes is regarded as non-magnetic. The magnetic susceptibility is not sensitive to strain hardening, but varies slightly with temperature. The low magnetic characteristic of aluminium is of value in military ship structures where it has advantages of lightness and lower cost over other non-magnetic metals. It is also used to advantage in electronic equipment for screening where it may also double as heat sinks, usually in the form of finned extruded profiles. Special techniques have been developed to deposit thick layers of aluminium without the need for protective lacquering; these give very good shielding results and the non-magnetic properties ensure consistent operation over the life of the product" [50].

Recycling of the Aluminum (Al):

"The environmental soundness of aluminium is often questioned because of the large consumption of energy and use of problematic auxiliaries for the primary production. Other factors for which the environmental profile of aluminium is especially sensitive are processing and net-consumption of the material. The environmental profile of products made from aluminium, or other materials, is defined by:

1. The amount of material used for providing a function in comparison with other materials or with a reference,
2. Environmental characteristics of manufacturing processes applied to the material.
3. Account for recycling and avoided production of metal, which is saved by recycling"[51]. The environment soundness keep pushing the questioned; why recycling Aluminum Why Aluminium must be recycled? .Because Aluminium is 100% and infinitely recyclable. Every ton of recycled aluminium allows saving 2.3 tons of bauxite. Moreover, recycling this material needs 20 to 25 times less energy than manufacturing it from raw materials. It is therefore a win-win situation: it saves natural resources and it saves energy! 30% of all the aluminium produced therefore comes from recycling fig (9).

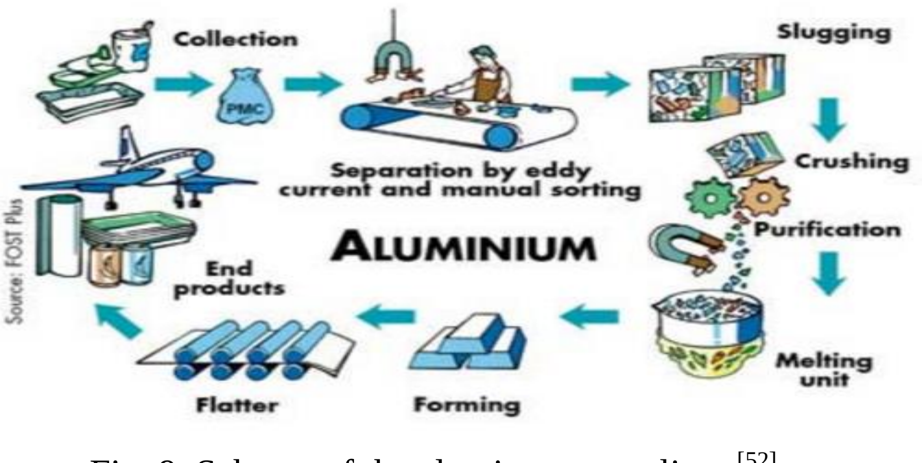


Fig. 9. Scheme of the aluminum recycling. [52]

2.3 Recycling technology of PE and PET:

"In the past years parallel with the rapid urbanization across the world, the production of municipal solid waste (MSW) correspondingly increased quickly. Sanitary landfill is always accepted as the preferred method for the ultimate disposal of MSW owing to its economic advantages and simplicity of operation. In the disposal process, due to the complex function of the physical, chemical, and biological processes occurring naturally in wastes. These things generally contain high amount of total ammonia nitrogen (TAN) and organic matters [expressed as chemical oxygen demand (COD) and biological oxygen demand (BOD)]" [53]. "Moreover, the recycling rates have been static or increased only marginally in recent years, although local recycling programs have captured more volumes of recyclable materials, and also it's very important to evaluate development of a new approach in its Beyond Waste Plan, to shift from focusing on “end-of-the-pipe” waste management techniques to “looking more comprehensively at how materials that would otherwise become waste can be more sustainably managed through the State’s economy"[54]. "Therefore, the technology of recycling has been carried out to assess the general waste management and effectively manage the plastic bottles by identifying practical means and introducing recycling as cleaner production tool to achieve sustainable development goals"[55]. "From these, causes and the main causes represented by increasing in the plastic bottles waste. Due to rapid development of plastic consumption in the developing countries. When this large captive market taking into account the leveling of the plastics," [56]. Therefore, the plastic bottles as waste materials with a high amount in the environment led to pressure on the world's major markets, as an important necessity to build up factories deal with the large amount of waste plastic bottles. The (TECHNOFER) factory as recycling equipment's and machinery dependent on these circumstances, which has special use of mechanical processes that approximately highlight values. To study the possibilities and experience in the use of mechanical processes. In (TECHNOFER) factory there are lines used as main topic to start the process of recycling for (PE) (fig.10. A), and (PET) (fig.10.B)

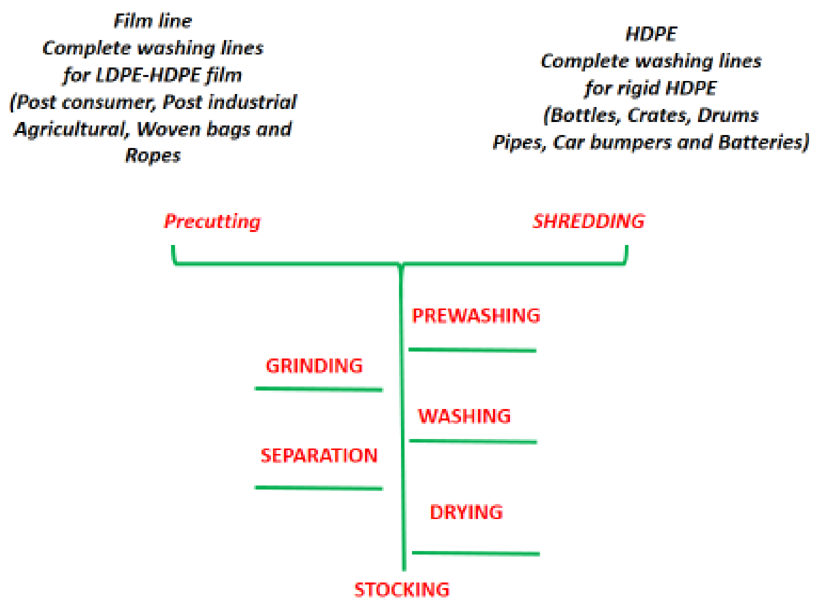


Fig.10. A. scheme of the PE- recycling line

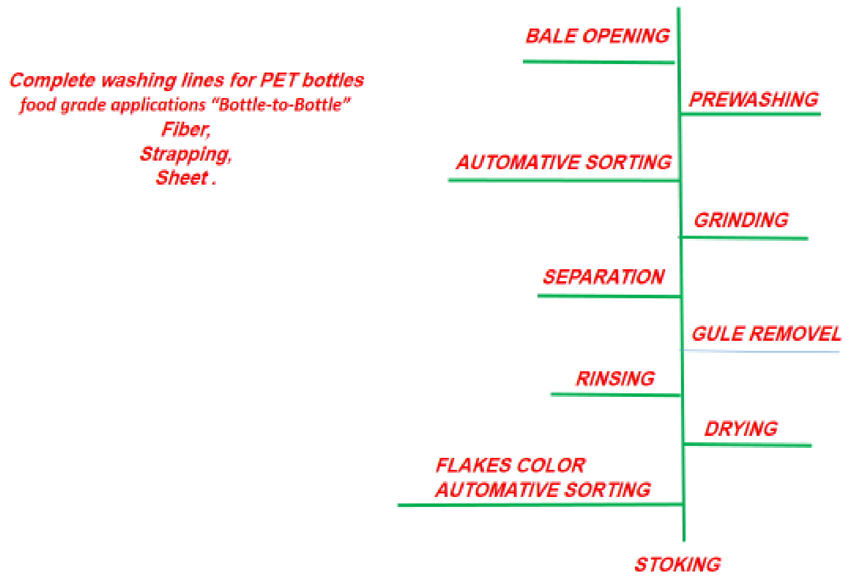


Fig. 10. B. scheme of the PET- recycling line

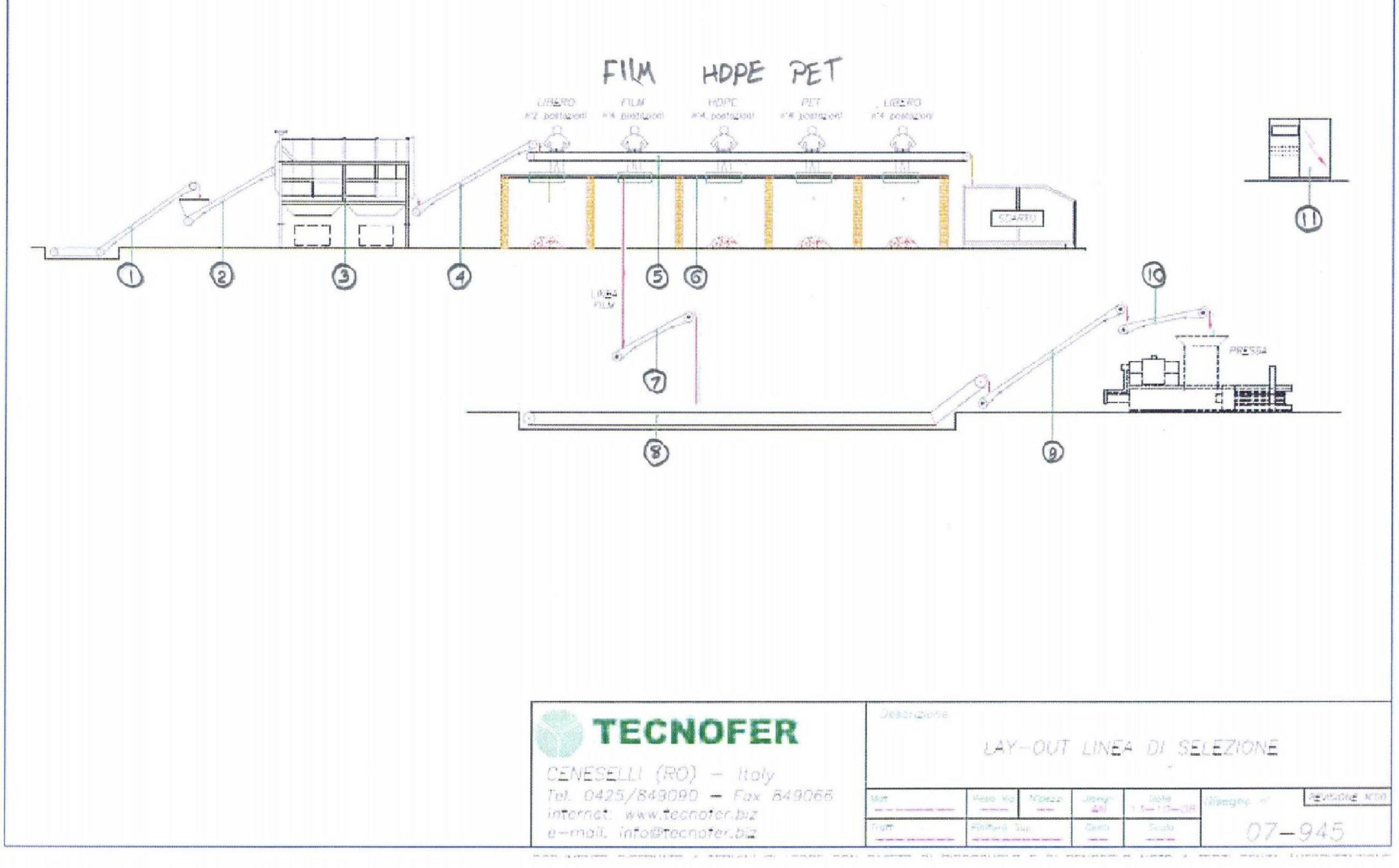
In addition, the factory of (TECHNOFER), independent on the amount of waste materials which need to recycling it. For there are the integrated system for plastic, recycling consists of:

1. First: stocking and sorting plant, total area (MQ 12500) indoors and stocking area (MQ 4800).when the sorting (fig 11) plant for plastic materials have :
    - Input product: heterogeneous plastics coming from urban collection, industrial waste, packing from supermarkets and from agriculture.
    - Output product: pre-sorted plastics according to their polymeric family and color partially separated from foreign and contaminated bodies and then baled and ready to be sent to the process of recycling.

2. Second: recycling plant including water treatment line, total area (MQ 12500) and indoors and stocking area (MQ 2000).

In addition, for recycling plants for the main polymeric families is the general line that one is deals with the recycling of plastic from the packing of post-consumer (fig. 12).provided by the factory to process recycled polyethylene:

Fig. 11. Scheme of the sorting plant in TECHNOFER factory



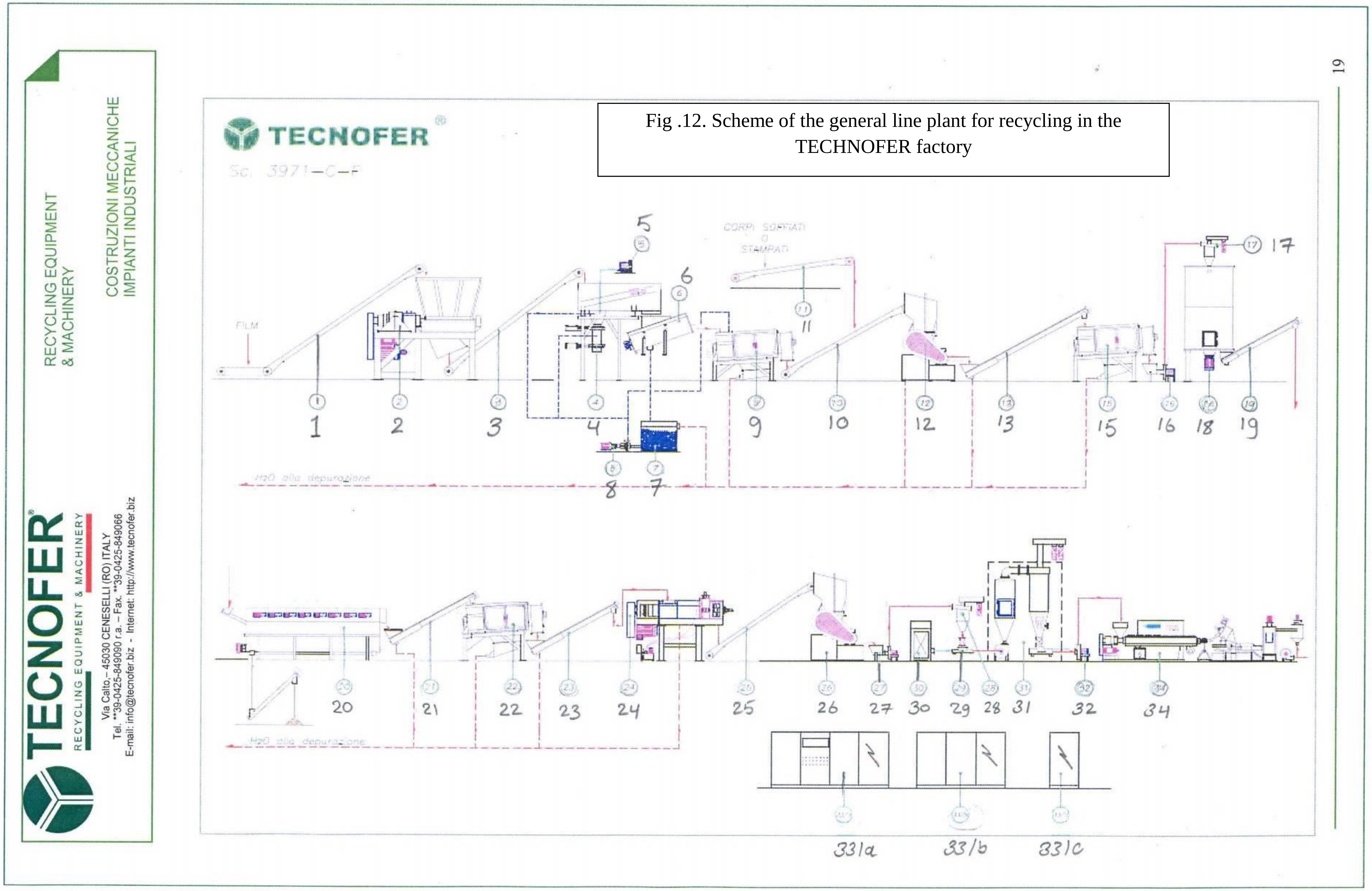


Fig .12. Scheme of the general line plant for recycling in the TECHNOFER factory

When the numbers in the (Fig.11.) refer to: 1.*Conveyer belt:* A belt conveyor is a system of pulleys with a long loop of fabric or other material stretched between them. Usually at least one of the pulleys is motorized to pull the belt along with it. It used to conveniently move the waste of materials that want to recycle it, objects from one part of a processing facility to another. *2. Conveyer belt. 3. Rotating Trommel:* is mainly used for treating high-contaminated PET bottles and other rigid plastic containers/bottles that need to be pre washed before feeding the washing plant. *4. Conveyer belt. 5. Conveyer belt:* in this stage, it is receive the direct film waste from separator. It used to conveniently move the waste of materials that want to recycle it. *6. Picking cabin 7. Conveyer belt. 8. Conveyer belt. 9. Horizontal Conveyer belt. 10. Screw press:* The machine is installed at the end of the film washing lines for drying the material. The drying system is based on the mechanical squeezing, made by a worm working inside holed cylinders. The machine discharging final part is fitted with hydraulic locks that slow down the feeding of the product. In a way the material becomes compacted, partially melt and consequently the water is removed.*11. The Electric Panel.* In addition, the numbers in the (Fig.12) refers to *1. Conveyer Belt. 2. Wash Shredder:* The single-shaft continuous shredder is used to pre-cut high-contaminated materials. it is a very reliable machine, and its maintenance can be done at very long intervals. The machine works with a combined action cut-tear of the product.*3. Conveyer Belt. 4. extracting system for the film flake. 5. steam generator 6. Pre- Washing Tank:* The pre-washing tank has the function to settle and separate stones and heavy metals in the pre-washing phase, which could damage the following machines. *7. Combineation of waterpower pressure. 8. Air Insufflation system. 9. Horizontal Centrifuge:* has been designed to wash high-contaminated medium or big flakes of film or other materials, which come from a primary shredder or from a grinder. The centrifugal effect is based on mechanical friction combined with the use of a big quantity of water in order to guarantee a very good cleaning effect of the product. For less contaminated materials, this machine can be used as 'dry separator". The heavy-duty inner rotor turns at high speed, and its dedicated geometry makes it possible to avoid blockings with medium-size pieces too. Contaminants and dirty water are then ejected through a holed screen and collected in the discharging stainless steel hopper.*10. Conveyer Belt. 11. Blown Molded Bodies. 12. Grinder:* The Grinder is used to grind flexible or rigid materials with or without water *13. Drainage Auger:* the grinder is normally contain the drainage auger at variable revolutions. As a normally provided with a dosing extraction *15. Caps Removel Machine. 16. Electric fan. 17. Electric fan. 18. Storage Flake Silo:* The series of storage silos for Film flakes storage silos are intermediate "lungs" to grant constant dosing and production on some machines. They are normally provided with a dosing extraction AUGER at variable revolutions. The Film storage silos are available in different dimensions and containment capacities, to suit any production needs. *19. Conveyer Belt. 20. Washing Tank:* The washing tank is used to settle and separate ground plastic materials, having regular size, by density. Each tank is customized basing on the material to be treated, and is equipped with a double discharge system, working continuously, for both floating and sinking material. *21. Drainage Auger. 22. Horizontal Centrifuge. 23. Conveyer Belt. 24. Screw Press:* The machine is installed at the end of the film washing lines for drying the material. The drying system is based on the mechanical squeezing, made by a worm working inside holed cylinders. The machine discharging final part is fitted with hydraulic locks that slow down the feeding of the product. In a way the material becomes compacted, partially melt and consequently the water is removed. *25. Conveyer Belt. 26. Grinder. 27. Electric Fan. 28. Electric Fan. 29. Rotary valve. 30. Hot Air Generator:* The hot washing system used in plastic recycling lines is able to treat plastic materials (like washed PET flakes) contaminated with substances, very difficult to be removed, as glue, oil, etc. This batch system is very flexible, in fact by changing the processing factors like temperature, residence time and detergents all type of contaminants can be removed. Besides this principal function, the machine is able at the same time to remove the fine particles of PET and the polyolefin residues. By the feeding AUGER with hopper the material (washed PET flakes) passing through the feeding screw is introduced alternatively in the mixing tanks where it stays together with hot water (approx. 85°-90°C) and, if needed, detergents for a certain amount of time, in order to remove the contaminants (glue and/or oil). Different models are available to suit any production needs. *31. Drying Unit. 32. Electric Fan. 33. Control Panel. 34. Extroder with Agglomerator:* The Agglomerator for plastic films of series APF 400 is an innovative machine, designed to replace the traditional drying and discontinuous densification systems. His machine was designed and manufactured in order to increase the throughput per hour of the conventional extruders having restricted screw-feeding capacity with thin material even if equipped with forced feeding, as well as to grant a better quality of the final granules. The machine works by means of a screw compacting the material and generating, only with mechanical friction so without any additional heating equipment, an increase of the temperature, enough to reach the agglomeration point [57].

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Recycling of polyethylene terephthalate (PET):

"For creating recycled plastic materials from waste plastic materials are described. A recycled plastic material contains at least a primary polymer, a secondary polymer and residual additives. The properties of the recycled plastic material can be controlled by selecting the types of waste plastic materials used the recycling feed, determining the types and amounts of recycled plastic material recovered from a separation process and blending the recycled plastic material with other materials"[58]. "PET plastic packaging industry has demonstrated its commitment to environmental responsibility through recycling. Prior to the introduction of the PET soft drink bottle on grocery shelves, PET bottle manufacturers and consumer product companies worked with private recycling companies to demonstrate that this new packaging material could be recycled, a major concern for new packaging, given the popularity of recycling" [59]. "There are main types of PET-recycling:

- Chemical recycling.
- Mechanical recycling" [60].

Chemical recycling of (PET):

"The (PET) has excellent features such as heart resistance, weather resistance, mechanical resistance and transparency"[61], "so when the chemical recycling back to the initial raw materials purified terephthalic acid (PTA) or dimethyl terephthalate (DMT) and ethylene glycol (EG) where the polymer structure is destroyed completely Chemical recycling of PET will become cost-efficient only applying high capacity recycling lines Such lines could only be seen, if at all, within the production sites of very large polyester producers. Several attempts of industrial magnitude to establish such chemical recycling plants have been made in the past but without resounding success. The two reasons for this are at first the difficulty of consistent and continuous waste bottles sourcing in such a huge amount at one single site and at second the steadily increased prices and price volatility of collected bottles" [62]. "A process for the chemical recycling of post consumption (PET), which includes the steps of performing the depolymerization of polyethylene terephthalate, based upon a hydrolysis reaction, which causes a rupture in of the ester bonds formed between the polymer precursors of terephthalic acid and ethylene glycol at the time of polymerization to recover terephthalic acid and ethylene glycol" [63]. "The prior art has contemplated the recycling of PET and other polyesters by means of various techniques and processes, among which that known as "recycling materials" is on of the simplest consisting of the collection cleaning, grinding and granulation of the waste polymer, to incorporate it thereafter to the production of different items that need not comply with high quality and/or purity standards; hence the field of application of this recycling technique is certainly narrow. Furthermore the chemical recycling (depolymerization), which comprises breaking the polyester chains. In the regard an important number of chemical processes to depolymerize PET or other polyesters can be found in the prior art, such processes being classified as follow:

- **Glycolysis.**
- **Alcoholysis.**
- **Hydrolysis.**

Glycolysis:

Regarding glycolysis, it consists of degrading the polyester with diols such as ethylene glycol to temperature conditions from about 1800 to 250Cº.When PET is decomposed via this process, the products obtained are mainly bis (hydroxyethyl) terephthalate (BHET) and ethylene glycol (EG) which is incorporated to the reacting media. One of the drawbacks in glycolysis is that high temperatures are required to perform it, which entails an important consumption of energy at an industrial scale" [64]. "Glycolysis depolymerizes

PET to bis (hydroxyethyl) terephthalate (BHET) with ethylene glycol or other glycol and hydrolysis to terephthalate acid (TPA) under the promotion of acidic or basic conditions" [65]. "The glycolysis of PET with EG was carried out in the presence of a catalyst - sodium bicarbonate. NaHCO3 dissolves well in EG which ensures penetration into PET structure and increases glycolysis rate. It is an ecofriendly catalyst for glycolysis, preferable to those containing heavy metals. Generally, the process can be described with (Fig 9). After the end of the process, two fractions were separated from the glycosate on the basis of their different solubility in water. Numerous experiments were carried out until fractions of acceptable yield and molecular mass were achieved" [66].

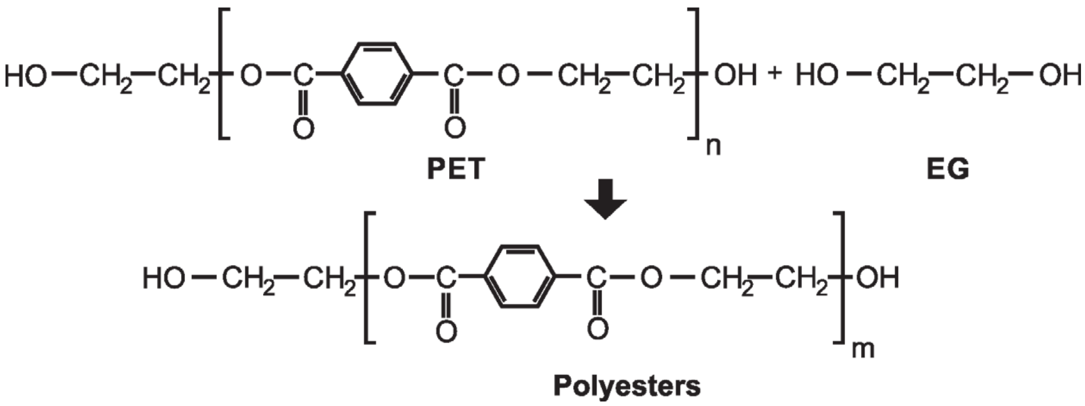


Fig. 13.Scheme of PET glycolysis with ethylene glycol.

"The present disclosure describes toner comprising a portion of resin comprising a polyethylene terephthalate oligomer represented in a way of Based toner as an example of the glycolysis process:

- *Based toner:* Oligomeric PET can be obtained by glycolysis of PET products, such as, plastic bottles, which are pelleted and depolymerized, that is, digested, with a glycol to form PET oligomers and/or monomers, which are polyol compounds. The PET oligomers can be mixed with a polyacid or polyester, or an anhydride reactant, with optional catalyst, to yield a polyester polymer for use in toner. "PET oligomers," (or grammatic forms thereof) as used herein comprise an oligomer of ethylene terephthalate which can have a molecular weight of from about 400 (the approximate weight of an ET dimer) to about 5,000 g/mole. Oligomeric PET can be derived by glycolysis of existing PET (poly (ethylene terephthalate)) materials, such as, bottles, such as, those holding carbonated beverages, juices and waters, and so on. The consumer PET materials prior to depolymerization generally have a number average molecular weight of from about 5,000 to about 500,000 g/mole. The PET oligomers, which comprise two or more ET residues and monomers, are polyols that can be used to make polyester resins for use in toner. PET oligomer also includes the ET monomer obtained in the depolymerization reaction. Toner particles of interest can comprise a polyester resin. A composition can comprise more than one form or sort of polymer, such as, two or more different polymers, such as, two or more different polyester polymers composed of different monomers. The polymer can be an alternating copolymer, a block copolymer, a graft copolymer, a branched copolymer, a cross-linked copolymer. PET sources include, for example, films, such as, materials, cloths and so on, with a more commonly available source being spent liquid containers. For example, empty bottles, such as, clear or colorless bottles that do not carry bottle colorants, can be washed, dried and shredded into a granular or pellet form, for example, pellets of a size of about 3 mm by about 3 mm by about 1 mm. The pellets can be treated in a depolymerization reaction, such as, partial glycolysis by heating under nitrogen with a catalyst in an organic diol, such as, an alkylene glycol, such as, ethylene glycol, propylene glycol, butylenes glycol, and pentylene glycol and so on. Suitable catalysts are known, such as, titanium phosphate, metal acetate, such as, zinc acetate, solid super acids, ionic liquids and so on. Following reaction, the products obtained are ET, PET oligomers and alkylene glycol monomer, where the number average molecular weight of the oligomeric PET can be from about 200 (the approximate weight of ET) to about 5000 grams per mole, from about 400 (the approximate weight of an ET dimer) to about 3500 g/m, from about 600 (the approximate weight of an ET timer) to about 2000g/mole. The PET oligomers can be reacted with diacid or diester monomers, such as, anhydride forms thereof, as known in the art and as taught herein, with an optional catalyst, to produce polyester polymers, which can be used to substitute for a portion of the resins commonly found in toner. The remainder of the resins comprises those known in the art and which are taught herein" [67].

Alcoholysis:

Alcoholysis processes depolymerize PET to dimethyl terephthalate (DMT) with liquid or gaseous methanol. Methanolysis under normal conditions can be carried out at relative mild temperature and pressure. However, the reaction rate is very slow, and some divalent metal catalysts such as zinc, lead, and manganese acetates, are required to enhance depolymerization rate"[68]. "Therefore, these recycled products would be effectively unable, when the development of a chemical recycling process has begun Taking into consideration, as an example for that process is:

- *Methanolysis in Supercritical Methanol:* increasing collection volume of post-consumer PET bottles, depolymerizing post-consumer PET bottles into monomers for use as feed stocks for manufacturing PET resin [1, 2], utilizing supercritical methanol intends to establish an ideal recycling system consisting of a recycle flow from PET bottles to PET bottles (so called B to B (Bottle to Bottle) recycling) while minimizing the consumption of natural resources and the generation of wastes by making this process practicable. By recycling process flow as shown in (fig.14)

Flow sheet of a PET recycling system). And by the process outline flow sheet (fig 15) which consist of mainly 4 sections, (the PET bottle shredding section, the depolymerization with supercritical methanol section, the separation and purification section and hydrolysis section). Postconsumer PET bottles are flaked by the PET bottle shredding section. PET flakes are sent to the depolymerization with supercritical methanol section. In this section, the PET flakes are depolymerized into diethyl terephthalate (DMT) and EG by methanolysis in supercritical methanol" [69].

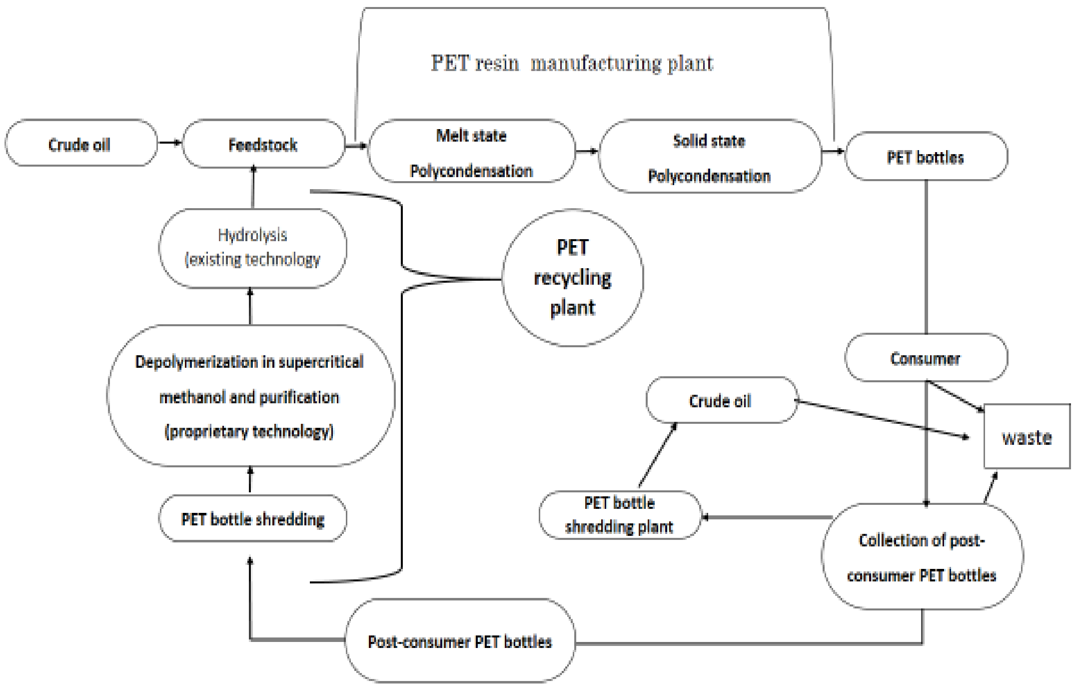


Fig. 14. Scheme of the Flow sheet of a PET recycling system.

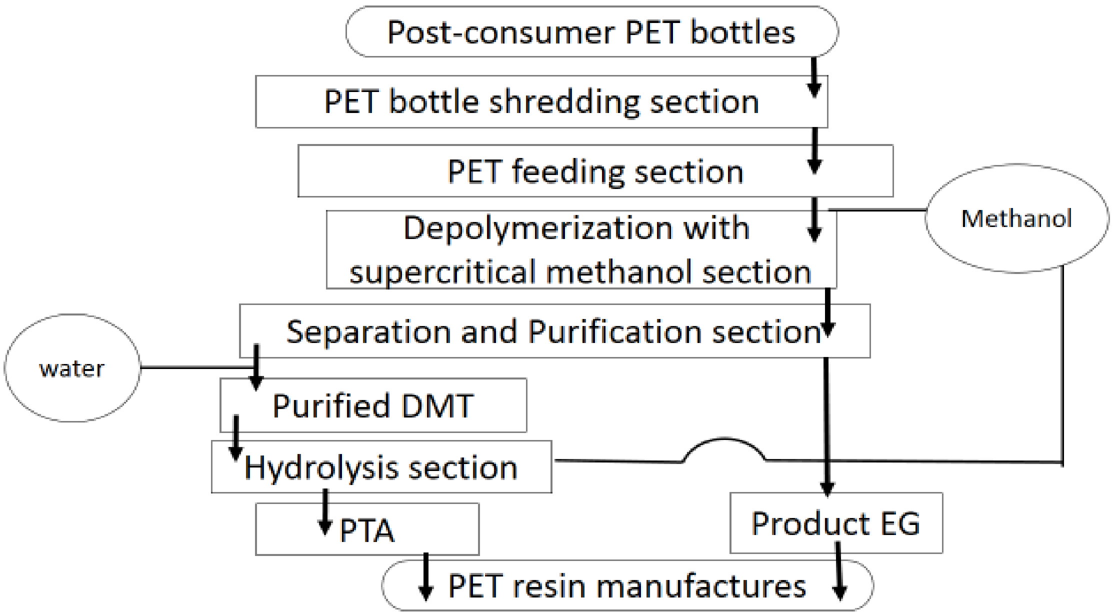


Fig. 15. Scheme if the outline flow sheet of the process.

Hydrolysis:

"Is one of the interested chemical recycling of polyethylene terephthalate (PET), is based on the concept of depolymerizing the condensation polymer through solvolytic chain cleavage into low molecular-weight products, which can be purified and reused as raw materials for the production of high-quality chemical products. Depending upon the depolymerizing agent. Neutral hydrolysis. Neutral hydrolysis is typically carried out contacting scrap PET with water or steam at a pressure of (1-4 MPa) and temperatures of (473-573 K). The main products formed are ethylene glycol (EG) and terephthalic acid (TPA). TPA is separated from the post reaction mixture by filtration, while a substantial volume of diluted EG is recovered through extraction or by distillation (Fig. 16)" [70].

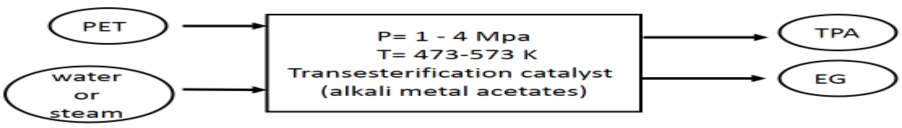


Fig. 16. Scheme of the distillation to removed EG

"The method of chemical recycling of polyethylene terephthalate waste to terephthalic acid and ethylene glycol it is consider as an example for the Hydrolysis process. The recycling of polyethylene terephthalate waste to terephthalic acid and ethylene glycol is usable for chemical recycling of waste mixtures of polyethylene terephthalate products, especially drink bottles, packaging foils and photographic film containing up to 30% of contaminating admixtures, to monomeric materials suitable for Polycondensation to new polyethylene terephthalate materials (PET). The purpose being its depolymerization, which consists of a continuous series of repeated steps:

- *Separation:* of the polyethylene terephthalate component of the input material by its conversion to brittle form through crystallization, grinding and subsequent sifting. Wherein the crystallization of the polyethylene terephthalate component of the input material in this step of the process being is carried out by tempering the input material to a temperature in the range of (140) to (190.degree). Centigrade for a period of (15) to (60 minutes).
- *Continuous two-stage hydrolysis of the polyethylene terephthalate:* carried out in the first stage by feeding steam to the polymer melt, and in the second stage, by the reaction of the products of the first stage of hydrolysis with ammonium hydroxide. Wherein the first stage of polyethylene terephthalate hydrolysis in this step of the process is carried out by means of reactive extrusion in an extrusion reactor, which consists of a double-screw extruder, with the screw length representing at least 25-times their diameter (L/D.gtoreq.25), and a follow-up static mixer at the reactor outlet.

- *Precipitation of terephthalic acid*: from an aqueous solution of the second-stage hydrolysis products by an inorganic acid, which is chemically stronger than terephthalic acid, and its separation by means of filtration.

Wherein the products of the first stage of hydrolysis in step of (continuous two-stage hydrolysis of the PET) of the process are delivered from the extrusion reactor outlet to a second-stage reactor where they react with the surplus of ammonium hydroxide aqueous solution, resulting in terephthalic acid and ethylene glycol.

- *Rectification:* separation of ethylene glycol from a solution of the products of the second stage of hydrolysis, after the separation of terephthalic acid. Characterized by the fact that wherein said inorganic acid in step (Precipitation of terephthalic acid) is selected from the group consisting of hydrochloric acid, phosphoric acid and sulfuric acid" [71].

The mechanical recycling of (PET):

"Polyethylene terephthalate composite materials based on polyethylene terephthalate intended for manufacture of single-layer containers in form of bottles and containers for various purposes, with improved barrier properties" [72]. "In mechanical recycling (fig. 17), the waste bottles are recycled directly as polymer feed through the process of grinding, cleaning, separating, dehydrating, drying, and re-melting. The waste bottles collected in domestic regions have lower quality than those of foreign countries because those have much more contaminants such as labels, general wastes, etc. Therefore, the cleaning process is very important to increase the physical and mechanical properties of recycled PET flakes. In chemical recycling they are depolymerized to give chemical intermediates (monomers or oligomers), which can then be re-polymerized. Total depolymerization process to monomers such as methanolysis is more tolerant of contamination while it is more expensive than glycolysis. For this reason, the glycolysis process is widely used for thermoplastic polymers such as PET and Polyurethane (fig. 18). Chemical recycling process allows any contaminants bound to the polymer chain to be removed by purification of the monomers and oligomers while mechanical recycling process can separate inorganic contaminants and therefore the organic contaminants are remelted in extrusion process. The mechanical properties and long-term degradation properties of recycled PET yarns are known to be lower than virgin PET yarns due to the contaminants coming from non-PET bottles, labels and caps (fig. 19)" [73]. "Used recycling of industrial and domestic waste of polyethylene terephthalate (PET) to obtain a composite material with high performance for manufacture of articles of structural and general purposes, to which the increased requirements for dimensional accuracy are imposed. A method of recycling PET waste includes its grinding, heating to the melting point and treatment. Treatment is carried out by mixing with crushed waste of followed by granulation. Technical result consists in simplifying method of recycling PET waste, reducing the number of stages, reducing energy consumption and obtaining composite material from PET waste with high technological and operational properties" [74].

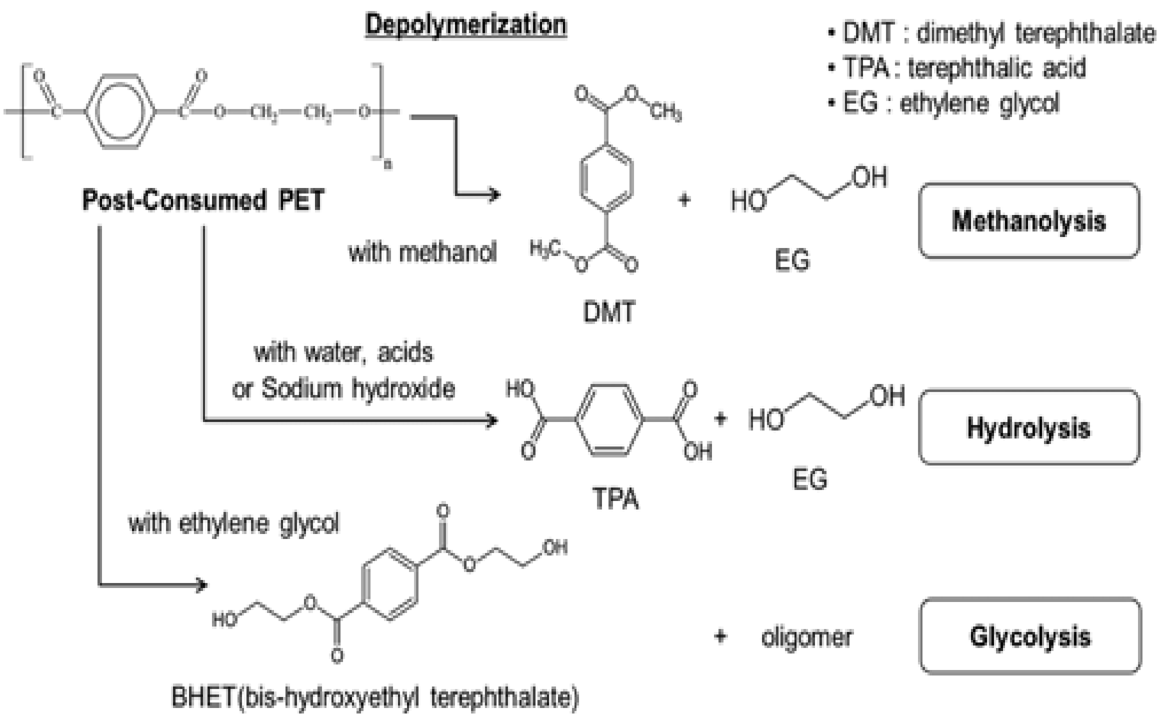


Fig .17. Scheme of the chemical recycling process.

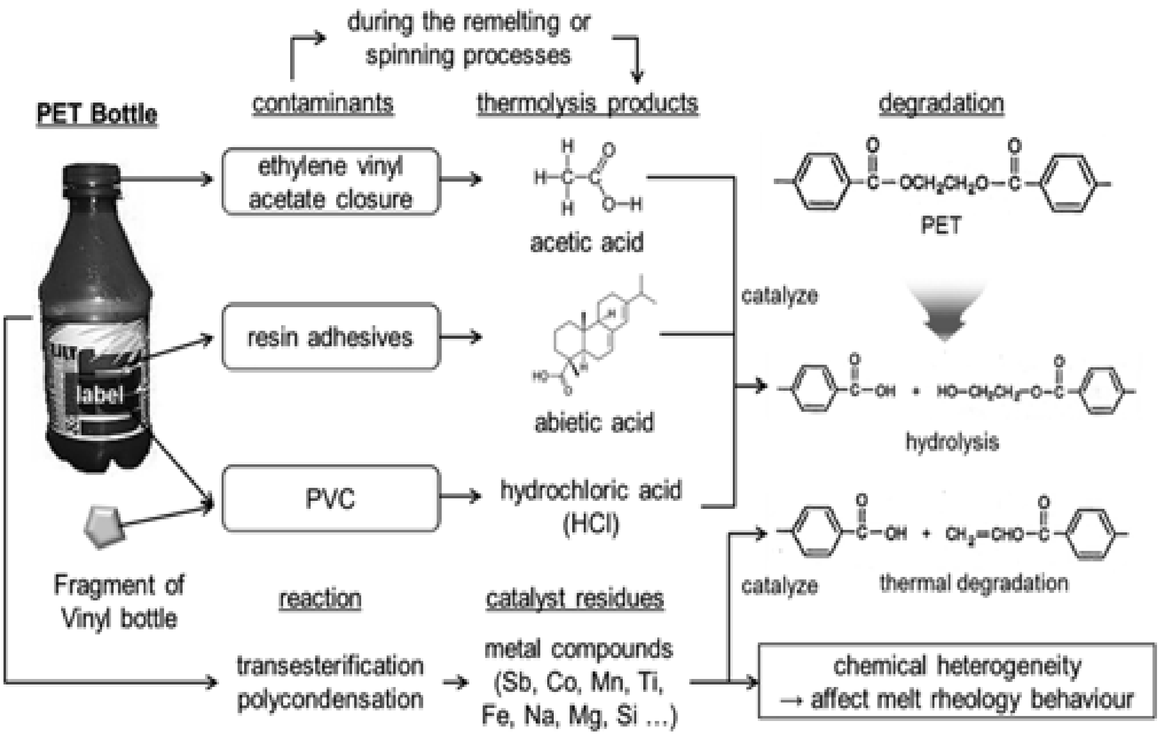


Fig. 18. Scheme of Effect of contaminants on the degradation of recycled PET

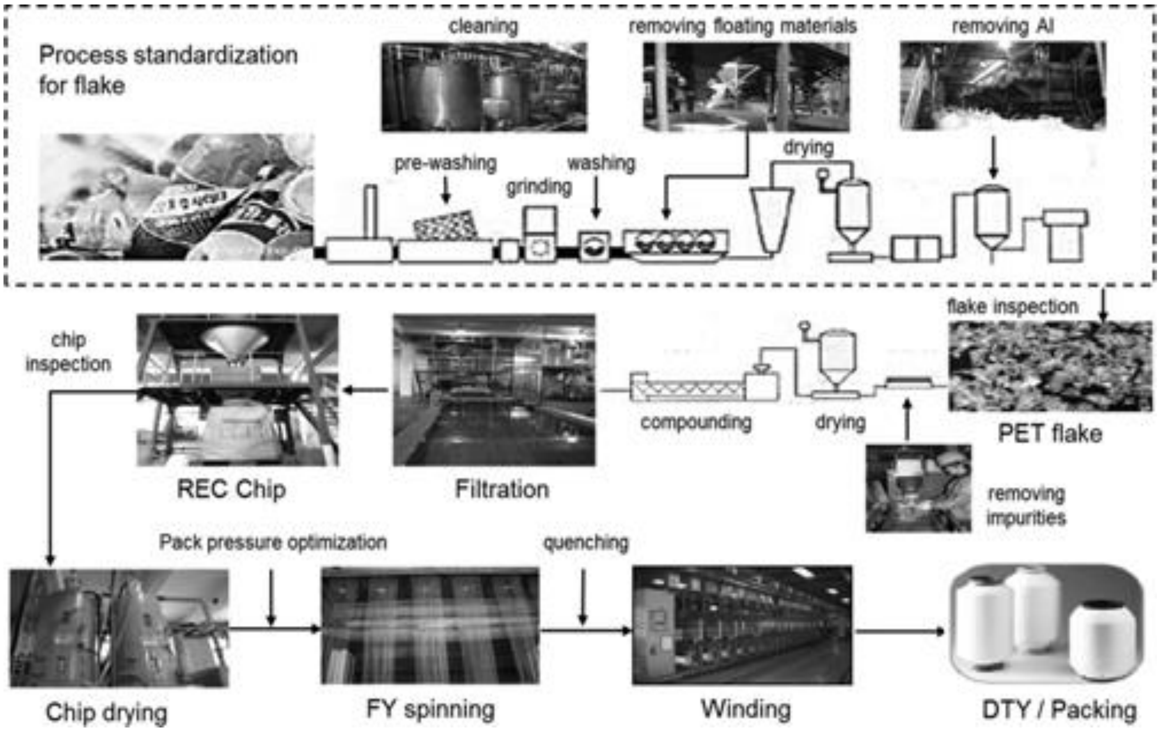


Fig. 19. Scheme of the mechanical recycling process of PET

Chapter 3: Collection mode and selection of household waste in MIREHUKÖZ [1]

3.1 Description of MIREHUKÖZ activity in waste collection and separation:

It represent the theme of our work as sample to study the recycling process for waste household bottles, As this plant operates on industrial waste usually contains a very high proportion of recyclable materials such as PE, PP, PET, Al, wood, paper and films, which are separated by mechanical sorting. The process begins with the feeding stage, which include delivering the wastes from city center of (Miskolc) with big bags. After that, there are three stages for recycling:

1. *First stage (separation by shape)* (fig.20-I): the household waste is sieved in the separator machine (BALLISTIC SEPARATOR) which separates the household waste to (rest materials), and in this stage the separator is separate these materials by (DRUM SIEVE) that is allows dimensional sorting of incoming material into two or more fractions. They can be placed individually or in cascade (primary and secondary screen) to obtain successive sorting refinements, the drum screen (or rotating sieve) essentially consists of a rotating cylinder with perforated walls. Rotation is maintained through rubber wheels by one or more electric motors powered by frequency converters (variable speed). The drum screen, depending on the size and shape of the holes of the inner metal walls, can perform the function of a sieving drum; therefore remove undesired fractions (scrap, powders, and unrecoverable sizes) or the function of a sorting drum, in which the goal is to divide the incoming flow into two or more fractions. Furthermore, it sends to (SORTING CABIN) that effective of a material stream into different fractions:

[1] *(Miskolc Regionális Hulladékgazdálkodási Közszolgáltató) = Regional Waste Management Service of Miskolc*

- Rolling and heavy materials, e.g. hollow bodies, plastic bottles, stones, wood, cans and steel sections
- Flat and light materials, e.g. films, textiles, paper, cardboard boxes and fibrous products
- Screened fraction – various grit sizes can be separated according to paddle perforation
- Optimal distribution to NIR (near-infrared) acceleration belt directly downstream
- Early removal of any glass
- Adhesions on materials are shaken off

In addition, some of these material separate goes to (BALLER) and some of them separate by (MAGNETIC SEPARATOR) type (UI.Pulaskiego 9/ 87-100. Torun) which separate it into (FERROUS and NON-FERROUS materials).

2. *Second stage (separation by material)* (fig.20-II)**:** the separation in this stage that the (BALLISTIC SEPARATOR) by Near Infra-Red separator technology (NIR SEPARATOR), which it means the separator are able to detect and sort a wide range of materials, and also able to separate paper, polyethylene (PE), and polyethylene terephthalate (PET) to the different type from different material flows regarding colors because only a segregation system can ensure that the waste will be treated according to the hazards of the waste and that the correct disposal routes are taken and that the correct transportation equipment will be used . (BALLISTIC SEPARATOR) have an integral conveyor belt system, which conveys the materials underneath an illumination and detection unit. This unit of the Sliding belt conveyor. The sliding belt conveyor is particularly suitable for recycling plants with medium-heavy sorting streams. With a conveying distance depends on the needing of work, it is designed for miscellaneous material streams and has a reverse function. Individual

designs allow applications as an accelerating conveyor upstream of (NIR device), as a sorting conveyor or as an articulated conveyor.

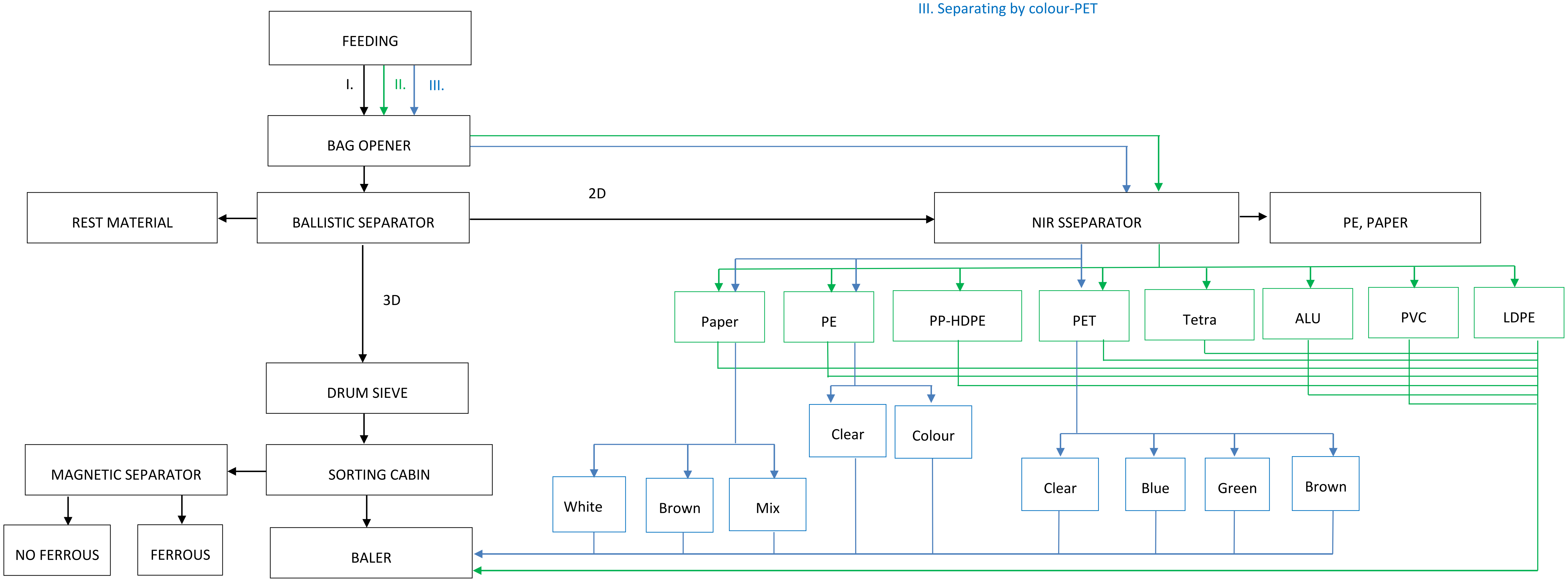
3. *Third stage (separation by colors)* (fig.20 III)**:** the (BALLISTIC SEPARATOR) is separate the materials like, polyethylene (PE), polyethylene High- Density (PE-HD), polyethylene Low-Density (PE-LD), polypropylene (PP), polyethylene terephthalate (PET) and another waste materials. Because the goal of the reason for this distribution in the division of material is to examine packaging options, especially for food products, in light of their environmental impact, along with looking at current and projected changes in packaging, and the effects these may have on our environment

(Fig. 20)

I. Separating by shape

II. Separating by material

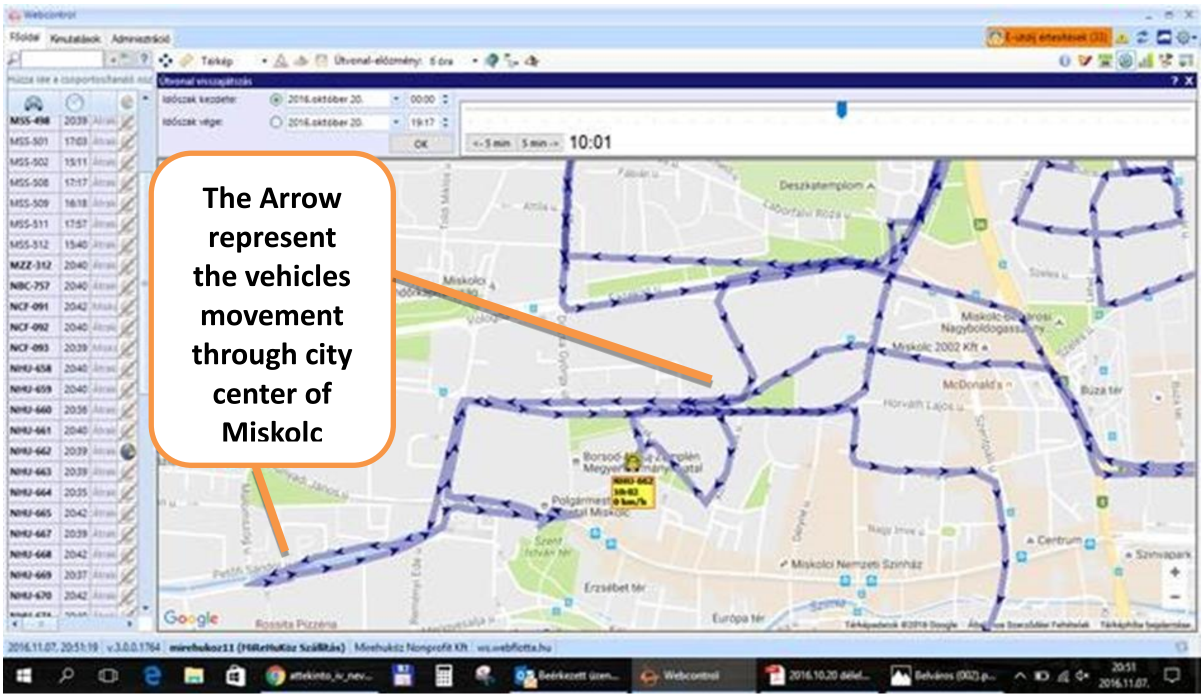
III. Separating by colour-PET



The plant of (Mirehuköz) provides for theses stages above, numbers of very important keys factors represented by the following:

- *Stage 1:* vehicles for waste collection and number (21 cars) (fig 21), specially designed for this purpose. Main mission is to collect waste from the city and taken to the location of the plant (fig.22).

Fig. 21. The photo of the Model of the vehicle used to transport households waste in (Mirehuköz) factory**.**



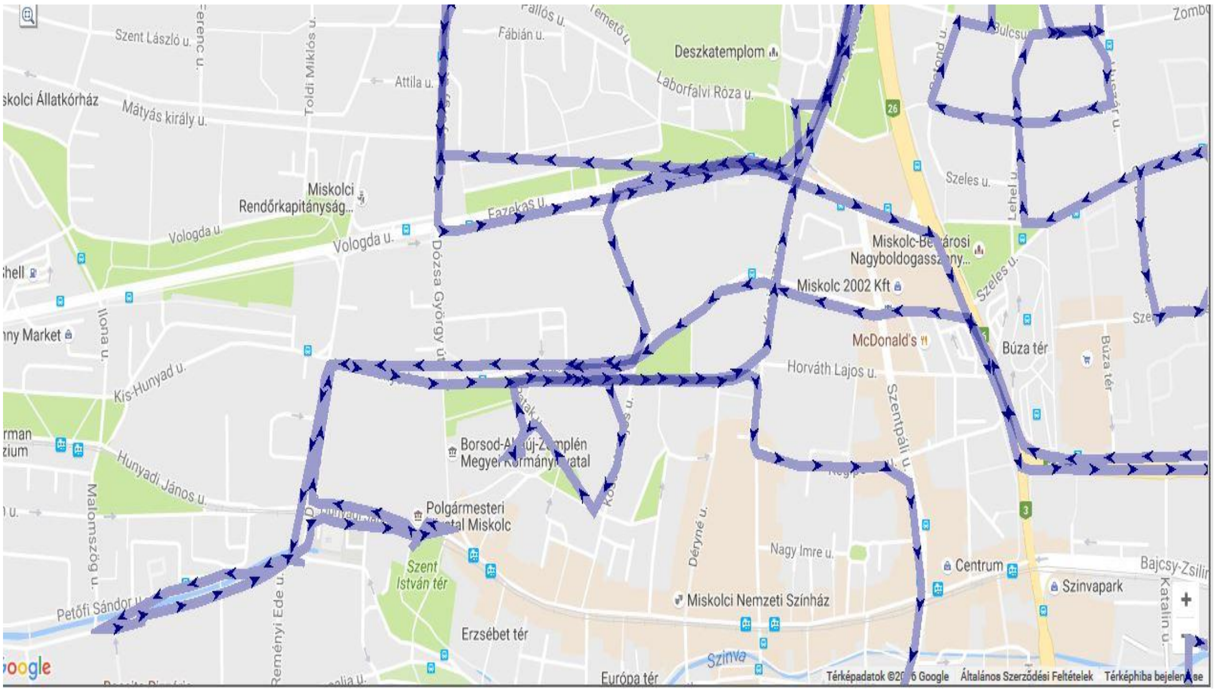


Fig .22. The photo shows the road of the households waste vehicles in the city center of Miskolc city by (GPS)

- *Stage 2:* after that; the contains of the cars are emptied in Place (square shape) inside the factory of (Mirehuköz) is equipped with this purpose, where the roof is closed, in addition the height of the place about (6m), width and a length (50m) (Fig.23)

Fig. 23. The photo of the place inside factory for unloaded the collector vehicles

- *Stage 3:* the vehicles bring the households waste to unload inside that closed place where the other process begin the sorting operations (fig 24).

Fig. 24. The photos of the household's waste

- *Stage 4:* Private machine start to transfer the households waste into room, where there workers as separator hand divided these wastes into (PET, PP, PE, Al, Paper and another waste) (Fig 25). after that, It is assembling what has been sorted separately in small reservoirs beneath the screening room (Fig.26)

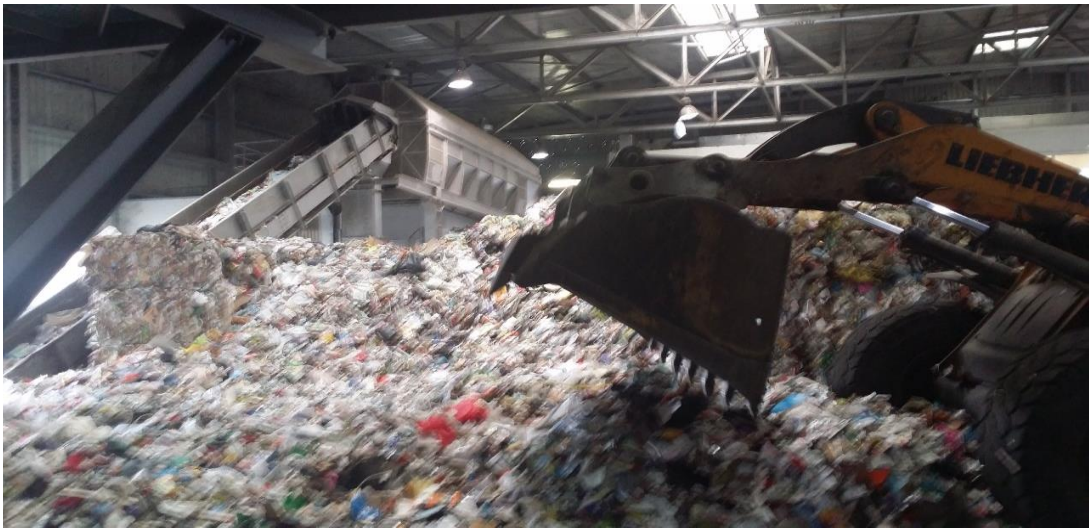


Fig. 25. The photo of the waste materials

Fig. 26. The photo of sorted separately in small reservoirs beneath

- *Stage 5:* In this stage, there are special vehicle what has been sorted and separated, to bring into another machine to compress it and transfer it to recycling (fig 27).

Fig. 27. The photo of storaged and selected material for recycling in MIREHUKÖZ

In addition to the above, the (Mirehuköz) factory Provides the plant for sorting the waste that comes through about (136 workers as a hand separator), (37 workers as a staff office). Moreover, the total number of workers in this factory is about more (200). Polymers, paper or films are subsequently inspected at manual sorting stations for quality optimization. It is therefore possible to easily market the individual fractions. The plastic fractions produced by means of near infrared equipment can be varied. The recycling of plastic bottles into a flake or pellet product has precipitated a demand for highly pure fractions suitable for washing and granulation processes. The material entering the system is in the form of baled or loose mixed plastic bottles with contamination, the input mostly constituting PE, PP, PET, and Al, wood, paper and films, which have been separated through conventional material recovery systems or source segregation. The material is processed in a pretreatment plant and divided into the required streams and the purity. The separated streams are then baled or transported to the bales are opened and the bottles are individualized, contaminants such as metal, fines, film and paper are removed in the first part of the process. The second stage separates plastic bottles by polymer and color using near infrared technology. The layout and quantity of scanners is individually designed for each work requirements. The task of each scanner can be changed and therefore gives the plant flexibility. The plant can be designed to remove the desired polymer types and colors. The separated fractions are stored in automatic bunkers, buffering and transferring material directly to a washing plant for granulation or baled for plastic buyers. Creating plastic fractions of this quality dramatically increases the value of the material and enables the production of a high quality washed flake or pellet.

3.2 Technical background of waste selection in MIREHUKÖZ:

The (Mirehuköz) factory used, and in depended on these data, the (STADLER STT2000) as a machine for this purpose. The (STADLER STT2000) is a ballistic separator, its used for separation of the material stream into three fraction 3D rolling, fines and 2D flats, to get the results as a 3 extracted fractions:

- **3D:** different plastic containers, ferrous and non-ferrous materials.
- **Fines:** materials, which are smaller than the paddle perforations.
- **2D:** paper, cardboard and film (fig. 28)

Fig. 28. The scheme of STADLER STT 2000 screen separator in MIREHUKÖZ

1. Input Material Types: (Light packaging, mixed paper, cardboard, film, bottles and Detergent bottles). 2. Removal of flat, light 2-D Fraction and that its: (Film, Paper, Cardboard, Textiles and fiberous materials).3. Removal of screened fraction. Removal of rolling 3-D Fraction: Plastic Containers, Bottles, Stone, Wood, Cans and Ferrous materials

The properties of the (STADLER STT2000)

1. *Capabilities:* Effective sorting of a material flow into various fractions**:**

- Rolling and heavy materials, e.g. containers, plastic bottles, stones, wood, cans and other metal items.
- Flat and light materials, e.g. films, textiles, paper, cardboard and fibrous products.
- Screen fraction – various grain sizes can be separated depending on paddle perforation.

- Gives an even distribution on NIR (near-infrared) acceleration belt positioned directly downstream.
- Early removal of any glass present.
- Adhesions on materials are shaken off.

1. *Possible adjustments:* The special basic principle of function and flexibility to the (STADLER STT2000) that's is the machine consists of a set of six paddles rotating its works against each other (Fig. 29) With the adjustment of the inclination of the paddle surface the ballistic separator can be adapted to deals with incoming material. The greater the angle of inclination of the screen surface the more the material will fall into the rolling fraction and the cleaner the flat fraction is and vice versa.

2. *Variability:* by the Multi-stage systems (fig. 30). The areas of application of the ballistic separator are very variable with quick and easy integration into a wide variety of large and small plants. By combining several screen surfaces above or behind each other, the ballistic separator can cope with a wide variety of challenges. Higher material throughputs and exact degrees of separation can be easily achieved with multi-stage systems. Depending on requirements, various material flows can be produced.

Manual angle adjustment

Fig.29. scheme of possible adjustments.

Stage1

Stage2

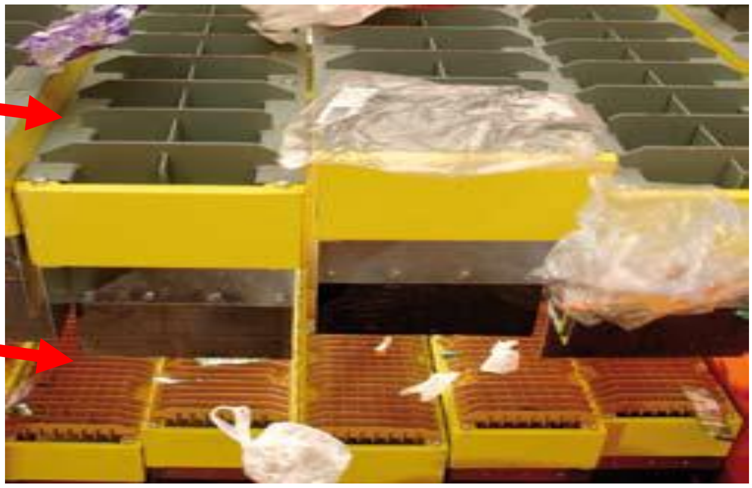


Fig. 30. Scheme of the variability

3. *Various screen size:* which screening drums classifying a material stream into different particle sizes, creating a consistent (homogeneous) mix of different materials and separating composite materials (agglomerates) (fig. 31), represent it. The screening drum consists of a sturdy steel frame (sectional steel) and the drum housing with the respective guide plates for feeding the material, for the residues and screened fraction(s). A hood prevents dust from escaping and is also used for connection to the dust extractor provided on site. The centerpiece of the screening drum is the rotating drum body. The drum body is made of steel plate and sectional steel and it has welded on and machined travelling rims for its guidance and support. The drum body is driven using friction wheels, which ensure quiet running, and eases operational demands on the running rings**.**

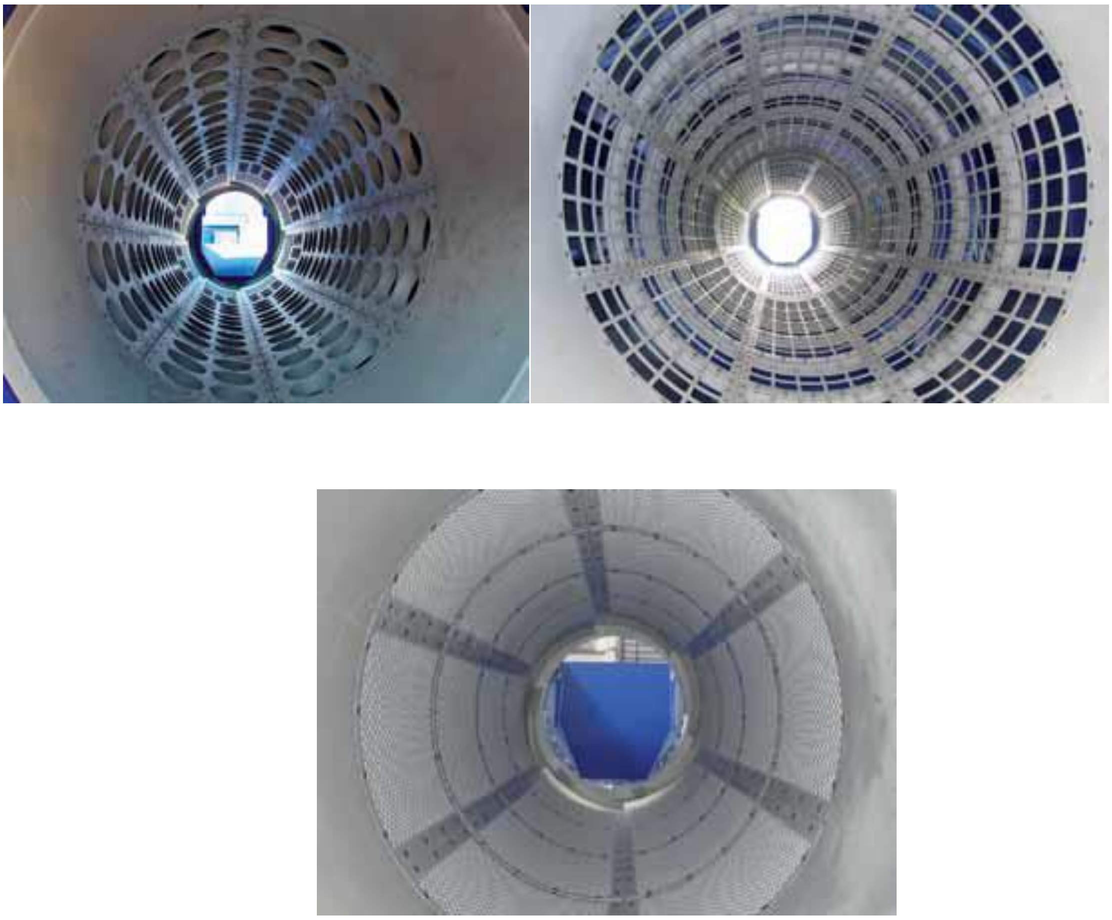


Fig. 31. "Scheme of various screen size for STADLLER"

Furthermore the (STADLER STT2000) with perforations in various sizes and forms fractions can be screened in various grain according to work requirements. Organic materials in domestic waste are separated by the oscillating movement and is screened off through the paddle perforations (fig. 32) with perforations in various sizes and forms according to your requirements.

Fig.32. Scheme of the various size of screen according to the work

3.3 Selective collected waste analysis:

The measurements were adopted in the research material on an important source, is the study of the results that have been collected, measured and studied as following:

- *The basic data for own measurement:*

i) The total population in Miskolc city (N) = 157.567

ii) The total area of Miskolc city (AT) = 236 km^2

iii) The total inner area of Miskolc city (Ai) = 58.02 km^2

iv) The closed garden area of Miskolc city (Ag) = 176.66 km^2

v) Overall population density of Miskolc city (δ) = 742

- The basic calculation for own measurement independent on the above basic data:

i) The inner land population (δ) = $\frac{N}{A_i} = \frac{157567}{58.02} = 2715 \frac{1}{km^2}$

ii) The city center area (fig. 33) (A_c) = $\ell \times \ell_2$ = 0.5 x 0.5 = 0.25 km^2

Fig. 33. The photo of Miskolc map from Google, shown on it the City center

iii) The center of the total population (N_c) = A_c x δ_c= 0.25 x 2715 1/km^2= 678 km2

iv) The vechile capacity (M_{cv}) = 1300 kg

v) Pumped mass input for MIREHUKÖZ in a week from city centre $\dot{M} = \frac{M_{CV}}{t_{week}} = 1300 \frac{kg}{week}$

vi) The waste material input ($\dot{m}$) amount in a week per person :

$$\dot{m} = \frac{\dot{M}_{cv}}{N_c} = \frac{1300}{678} = 1{,}9 \frac{kg}{week}$$

So in (Mirehuköz) factory from an area of about (0.25/ km^2) it is almost the total area that has been covered from Miskolc city center (about200-250 houses) inhabiting above about (approximately 600 families) Where they represent a sample to study the material that is put up as a household's waste. It was collected (712/ kg) from household's waste, and divided in a large trash bags intended for this purpose, ranging weights depending on the circumstances in the factory between (30-59 kg) and isolated in a special place inside the factory (fig.34).

Fig.34. Photo of the big bags contain the households wastes

Later, I separate by hand the contents of large bags, and collected by classification to polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), and Aluminum (Al) in side small bags (fig .35)

Fig.35. Photo of the small bags for the separation materials

Fig. 36. Photo of the weight device

They are weighed by a special balance (fig.36), to find out the weight of materials that are to be recycled (mentioned above) (fig.37)

Fig.37. Photo of the Materials that have been weighing

After these operations show us, after a full study of the process of separation by hand, that there is variation in the proportions of the materials that have been separated table(5) and representative graphically in (fig.38) :

Table 5: Distribution of waste types and its weight during pilot scale Measurement

Tape of waste	Separation By Hand/KG
PET	***156***
PE	***104***
PP	***56***
Al	***18.5***
Paper	***377.5***
Total weight	***712***

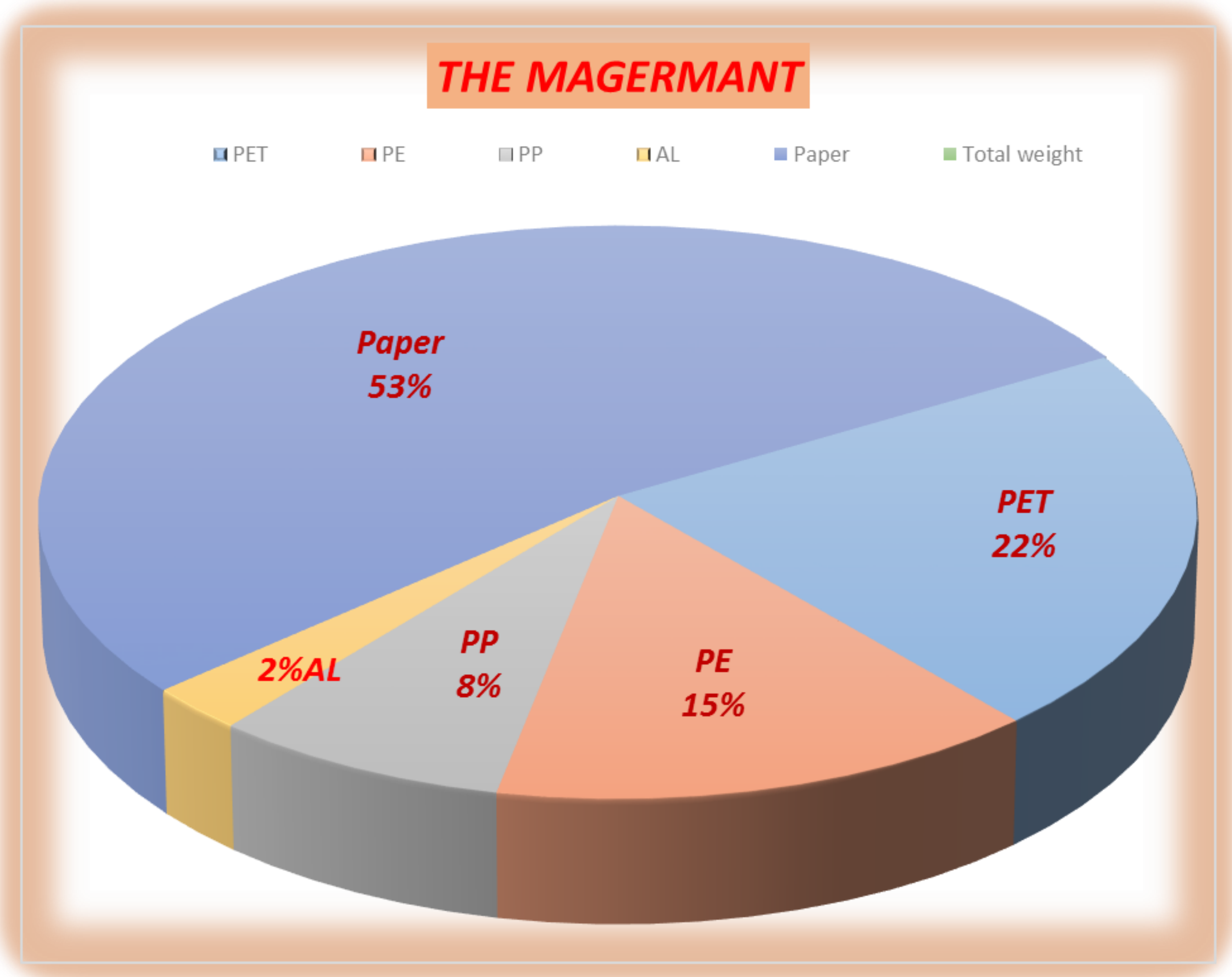


Fig. 38. Scheme show the amount of materials with graphically shape

In addition, for the materials for which are to be recycled (PET, PE, PP, and Al) table (6) and representative graphically in (fig.38):

Table. 6: show the waste materials for recycling

Tape of waste	Separation By Hand/KG
PET	156
PE	104
PP	56
AL	18.5
Total weight	334.5

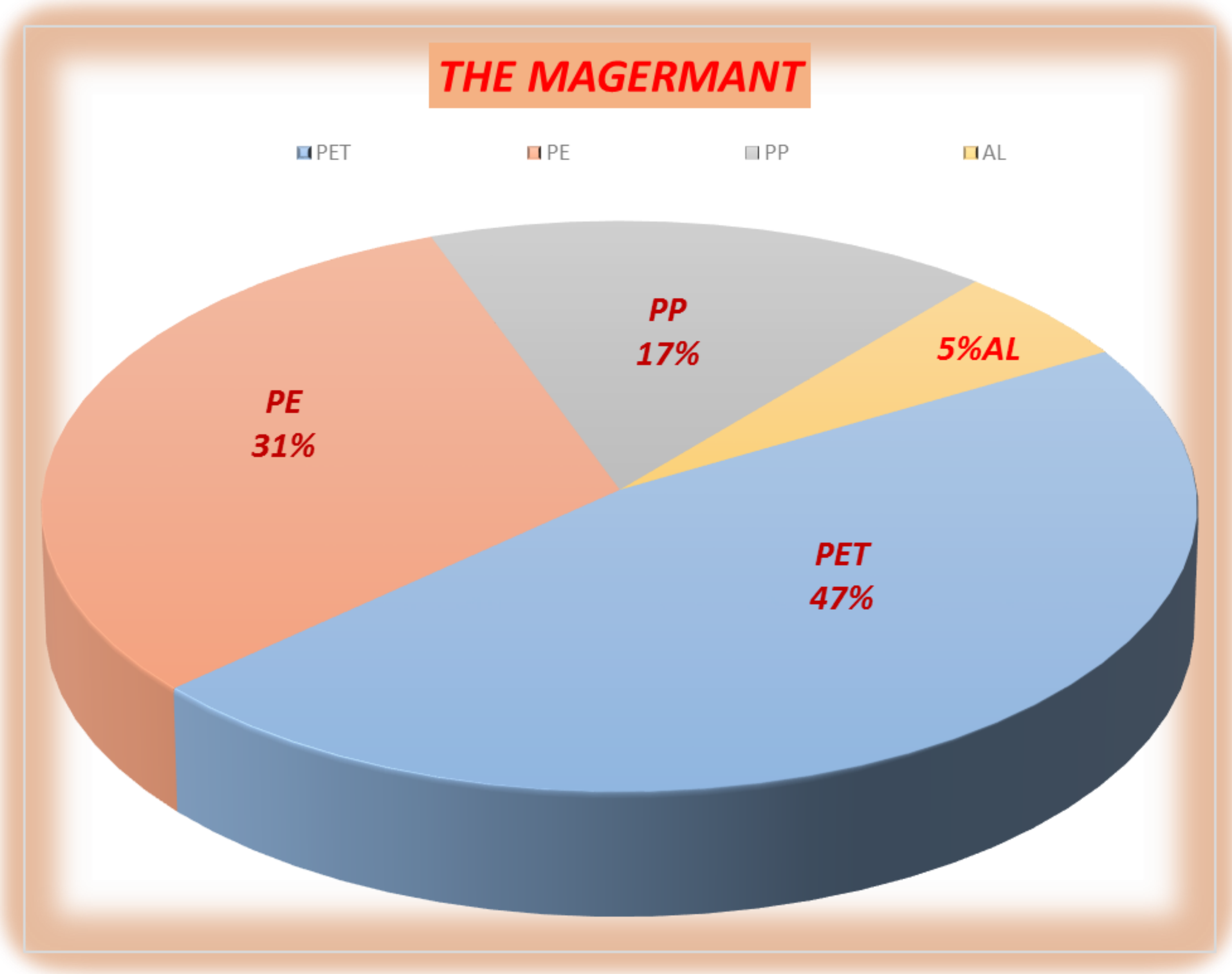


Fig. 39. Scheme show the show the amount of materials for recycling with graphically.

In addition, because of the minimal aluminum content of the collected material, and also depend on its amount as waste collected material, it is not worth to build direct metallurgical recycle line for metal can application in MIREHUKÖZ (fig. 40). Due to economic importance of aluminum, worth to compress and sell it as raw material for metallurgical factory exists in Europe.

Fig. 40. Photo of the compress waste of Aluminum in MIREHUKÖZ factory

3.4 Theoretical technology set up for PE, PET recycling in middle sized city:

During my practice in MIREHUKÖZ the most important thing in that line is the one from it can we create constructed offer line, which it will be near to deals with the results of our measurement for (PE) and (PET). When the composition of the set up device as a line to recycling the PE as following:

1. *Conveyer belt:* To transfer the waste of PE as an automatic feeding.
2. *Metal separator:* To take off the metal which mixed with this waste of PE
3. *Shredder:* It is very important part on the (Theoretical) line, because it represents the beginning of the recycling process through pre-cut all the contaminated films, pallets of wood, cans...etc. that maybe still related with PE waste material. In addition, for that, it is consider a very reliable machine, and its maintenance can be done at very long intervals.

4. *Sink flow tank:* It works as a (protector) for our (theoretical) line for recycling, by using the water and air injection to floating the plastics parts and deals with those parts of plastics, which are contaminated by earth or by other contaminant, to avoid the changes in their specific weight.
5. *Screw press (for de-water):* It is the first unit of drying in the theoretical line for recycling PE. The main base on this machine puts at the end line of film washing or the (sink flow tank) because this machine depend on the mechanical squeezing as the based for the drying system. In addition for that, it is represented the way that the materials becomes compacted partially melt and consequently the water is removed.
6. *Air transportation:* For transfer the flakes of the PE through bibs above the screw press unit.
7. *Hot air supplier:* This unit represents the second unit for drying during the transportation by air.
8. *Cyclone for powder separation:* It is the economic unit. The function of this unit is to emphasize the air filter of the problems during the work on the purification of materials, such as high temperature, moisture, and sticky or abrasive powders.
9. *Filter for air:* It is a method of removing particulates from an air, gas or liquid stream, without the use of filters. It involves the use of rotational effects and gravity to separate mixtures of solids and fluids.
10. *Screw press:* For preparing the recycling material to the next step, the screw press is used to convert the rotation of small movement of greater force.
11. *Extruder:* In this unit, the rotation of the screw conveys the PE waste material foreword heated parallel. Through this operation this

unit will be convert the PE waste material into small area inside it, to prepare that waste material of PE to melting.

12. *Laser filter (LUMA company):* It consider very special filter for that purpose, it consists of filter screen (two circular plot) parallel arranged, which through it the melting of the waste materiel of PE will moving slowly to the cutting by special rotating knives in side this unit.
13. *Grinder:* It is also known As the Removal Machine in recycling, because it is used for grind the elastic or rigid material, whether the water or without water.
14. *Screen:* Which is used to separate composite materials of waste materials of PE
15. *Static centrifuge:* It is considered as a washing cleaner has been designed to wash high-contaminated medium or big flakes of film or other materials, which come from a primary grinder.
16. *Silo tank:* It is consider the continuity machine because it is use to grant constant dosing and production for the recycling line.
17. *Silo bags:* It represents the last line of production. That has been extracted from the recycling line. Also, represent keeping the final product.
18. *Control panel (PLC):* In this unit as a (Programmable Logic Controller) used to control of the input and output during the operation of the recycling, and consider very useful because it depend upon a customer program.

So all these (18 units aforementioned), as a theoretical line for recycling PE, showing in the (Fig.41) below:

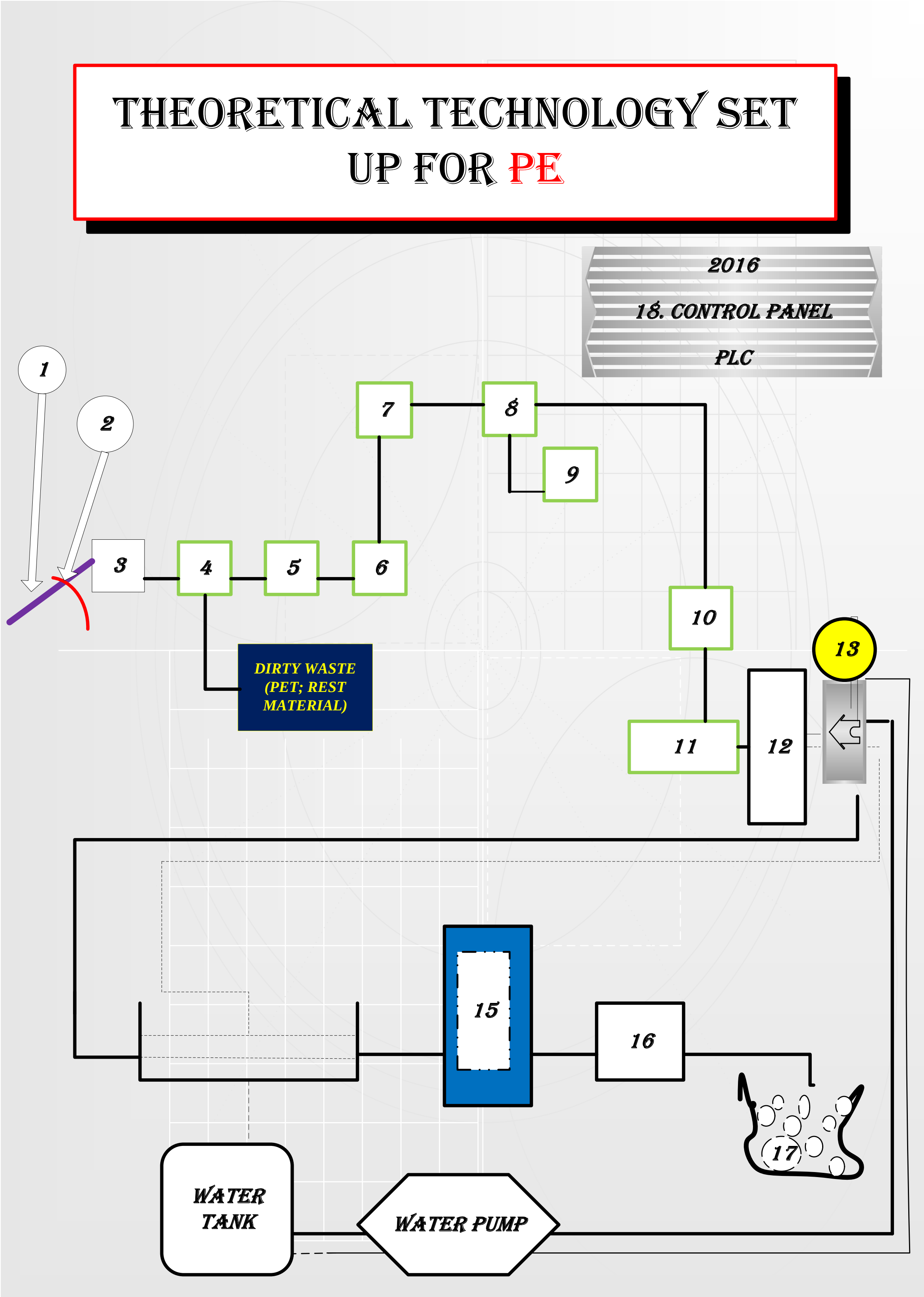


Fig.41. Scheme of the offer theoretical line for recycling PE

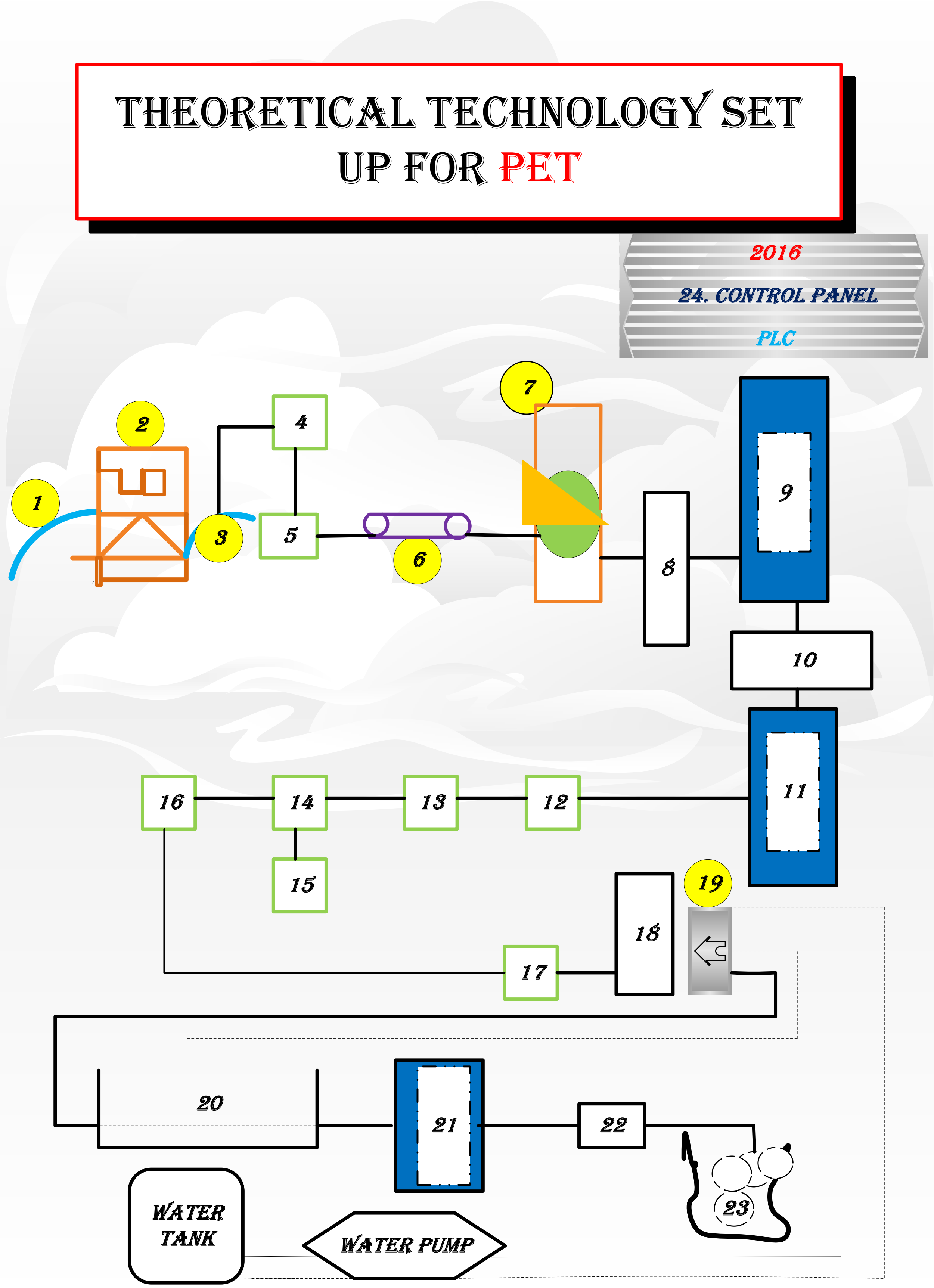


Fig.42. Scheme of the offer theoretical line for recycling PET

When the numbers in the (fig. 42) refer to

1. *Conveyer belt:* To transfer the waste of PET as an automatic feeding.
2. *Caps Removel machine:* The work of this unit, separating caps, labels and rings from the bottles, and it can change and facilitate the current line for recycling process of PET. Moreover, this unit is consider it is environmental friendly saving energy and water, because bottles processed in that machines goes out much cleaner and without any caps, labels and rings. This way of processing, makes final product of the raw material from the waste of PET clean without any contamination.
3. *Conveyer belt:* To transfer the materials of PET after cleaning it.
4. *Metal separator:* To take off the metal which mixed with this waste of PET.
5. *Rotating Trommel:* This unit is a big drum, work as a Trommel screen to deal with all the rubbish that related with PET waste material, by tumbles all the rubbish during this unit.
6. *Horizontal conveyer belt:* It is an output conveyor belt turntable.
7. *Grinder:* It is consider the (Removel machine) in line for recycling, because it is used for grinding the elastic or rigid material, whether the water or without water.
8. *Wash cleaner:* It is a tank for washing the waste material of PET, this unit work to separate the other material from PET by density and is equipped with a double discharge system, working continuously, for both floating and sinking material.
9. *Horizontal centrifuge:* It is work as a drying separator machine, and it is important unit in line of the recycling PET waste material, because it represent less contaminated material for PET waste by wash high-contaminated medium or big related materials with PET, that come from grinder. Moreover, this unit is based on mechanical friction combined

with the use of a big quantity of water in order to guarantee to improve a good cleaning effect of the product.

10. *Washing tank for the floating PET:* Which is used for treating the remaining of the PET material after these operations.
11. *Horizontal centrifuge:* It is work as a drying separator machine, and it is important unit in line of the recycling PET waste material, because it represent less contaminated material for PET waste by wash high-contaminated medium or big related materials with PET, that come from grinder. Moreover, this unit is based on mechanical friction combined with the use of a big quantity of water in order to guarantee to improve a good cleaning effect of the product.
12. *Air transportation:* For transfering the flakes of the PE through bibs above the screw press unit.
13. *Hot air supplier:* This unit is represented as the second unit for drying during the transportation by air.
14. *Cyclone for powder separation:* It is economic unit. The function of this unit is to emphasize the air filter of the problems during the work on the purification of materials, such as high temperature, moisture, and sticky or abrasive powders.
15. *Filter for air:* It is a method of removing particulates from an air, gas or liquid stream, without the use of filters. By using the rotational effects and gravity to separate mixtures of solids and fluids.
16. *Screw press:* For preparing the recycling material to the next step, the screw press in this function, is to convert the rotation of small movement of greater force.
17. *Extruder:* In this unit, the rotation of the screw conveys the PE waste material foreword heated parallel. Through this operation this unit will be convert the PE waste material into small area inside it, to prepare that waste material of PE to melting.

18. *Laser filter (LUMA company):* It is a very special filter for that purpose, it consists of filter screen (two circular plot), its parallel arranged , which through it the melting of the waste materiel of PE will moving slowly to the cutting by special rotating knives in side this unit.
19. *Grinder:* It is consider the (Removel machine) in line for recycling, because it is used for grinding the elastic or rigid material, with water or without water.
20. *Screen:* Which is use to separating composite materials of waste materials of PE
21. *Static centrifuge:* It is consider as a washing cleaner has been designed to wash high-contaminated medium or big flakes of film or other materials, which come from a primary grinder.
22. *Silo tank:* It is consider the continuity machine because it is use to grant constant dosing and production for the recycling line.
23. *Silo bags:* It is represented the last line of production. That has been extracted from the recycling line. Also, represent keeping the final product.
24. *Control panel (PLC):* In this unit as a (Programmable Logic Controller) used to control of the input and output during the operation of the recycling, and considered very useful because it depends on a customer program.

Chapter 4

4. Summary and results

Firstly, I have to mention, that during my thesis work I had the first practical experience in recycling technologies. My home city is facing many environmental problems as well in this Engineering territory. This situation forced me to face my engineering activity to recycling of polymers, especially for polymer bottles. Miskolc, as a second home city, showed friendly circumstances to understand more about the importance of environmental friendly recycling of polymers. I could understand the selective collected materials importance, and the validity of this work done e.g. in MIREHUKÖZ. On the base of my experience and the collected knowledge, I could built the following thesis in summary and final results of my thesis work. Under this line, one can find the most important result in thesis points I could reach in my own work.

Selective collected metallic and the polymeric materials has extreme importance not only in the environment protection process, but it has a huge economic importance as well. To protect and collect the pre-selected materials can be used as raw materials in that manner to reach minimal extra profit, or run the total system without extra economic help. To reach this status, it is necessary to use up to date primer and recycling technology as it was described in chapter 2.

In a middle-sized city as Miskolc, one can understand, that do not have to recycle all of the collected materials in one industrial site. It is worth to select, and reduce the volume of the collected materials, and worth to ask logistic help to reach appropriate recycle plant (e.g. REMAT for PE products). I explained and evaluated all of the technology elements in MIREHUKÖZ to reach economical process run. I wrote my picture based analysis in chapter 3.1.

By my hand, I made selection of the collected materials in order to know more about the specific content of selective collected waste. I gave the fundamental share diagrams in the chapter 3.2.

In the selective collected materials PE, arise as foils and film from packaging. PET material for recycling comes from bottles. Paper also arises in large amount for energetic re-use. Metals can be found in rare in selective collected waste see diagram in Fig. 34.

On the base of my own experience in MIREHUKÖZ, I discovered that MIREHUKÖZ do not have enough information about the concrete connection of inhabitants and collector vehicle route in the city. I built a calculation of the selected materials mass flow from the basic input data for further evaluation, and to do approximation for the size of recycle plant. This calculation is given in chapter 3.3.

On the base of my pilot scaled materials measurements, I can suggest not to build metallurgical factory for collected metal cans. The content of aluminum in selective collected materials even in a middle-sized city is only 2.6 % of the total mass flow coming from the households.

The volume of collected PE and PET lead me to build a simple theoretical technology line for PE and PET recycling. At the end of my thesis work, I explained twin developed block diagrams for technology line for PE and PET. These lines are shown in chapter 3.4. In Fig. 39-40.

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