TRIZ Applied to Waste Pyrolysis Project in Morocco

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Abstract. The methods and technologies of waste disposal are characterized by a slow evolution. A system that can bring great benefits, in economic and environmental terms is pyrolysis. A technology that instead of burning waste, gets products for industrial use.
The technology offers many advantages, among which they allow drastically reduce the ashes deriving from the reaction compared to those deriving from normal combustion, it also produces reaction gases and oils that have a high calorific value and are suitable for conversion into other energy such as electricity, district heating or cold, compressed air.
In order to make this technology usable today we need an important scale up in response to the many pilot projects around the world.
In this article we can show some examples of how an Italian-French industrial group, active in pyrolysis has implemented TRIZ to develop a large-scale technology for urban waste recycling. In particular, the ongoing project in Agadir area in Morocco will be presented.
The project will be shown in the article and how the sponsoring company is using TRIZ to develop its technology worldwide.

Keywords. Triz – pyrolysis – Problem solving – Evolutive Tree

1 Introduction

In recent times, the quantity of the produced wastes has considerably increased: everyday over three million tons of waste are produced. As a result, the problem of their disposal has become a crucial point. Traditional methods, such as storage and incineration, are no longer effective and environmentally sustainable due to the high impact of the pollutants produced.

A less impactful alternative is represented by the pyrolysis, or the thermal decomposition of materials at high temperatures inside a not oxidant atmosphere.

Moreover, such process is able to generate products (i.e. gas, liquid and solid) with interesting qualities in terms of composition and heating value, with a relative distribution dependent on several parameters (e.g. time, temperature, waste composition).

Despite pyrolysis is a technology known for centuries, its application in the field of waste disposal is considerably newer and for this reason it is still under development and with huge industrial potential.

Since the most important feature of pyrolysis is the calorific value and the energy content of the exhaust gases, the comparison with a traditional incineration system is very significant. The comparison can involve the processed products, the required energy, the versatility and the dimensions of the plants. In general, while the products obtained from an incineration plant are only pollutants to be destroyed with a little advantage deriving from their combustion, those from pyrolysis are interesting resources for different markets (e.g. fuels). The process also requires less energy due to the to the low operating temperature, which is around 500-800 C°, unlike the 1000°C needed for the traditional combustions. Other advantages include the possibility of building the reactor with less valuable materials to save costs.

Today there are many pyrolysis technologies: Fluidized bed combustion, Cyclonic, Rotative screws, electric induction, microwave, laser-assisted and plasma assisted). Any technology can work with different operative parameters in a multitude of design variants.

Some of them are almost fully operative while others are still at experimental and, in general, the most important requirements driving their development are:

1) Ensuring the full disposal of a greater flow of raw materials, deriving by the increasing in the total production of waste.
2) Reducing the time required for processing the waste within the reactor or its residence time.

The two requirements are clearly in contradiction: the complete waste disposal in a pyrolysis reactor generally requires a long time for carrying out all the chemical reactions involved occurring inside the reactor, which typically imply large volumes of the reactor chamber for storing the entire mass of waste.

However, this problem cannot be solved by directly applying TRIZ separation principles, because of the lack of knowledge about the operative parameters and their combinations governing its functioning.

The contradictions work well when the conflicting parameters can be considered reasonably independent of each other, otherwise the formulation of the contradiction tends towards tautology, resulting therefore impossible to separate. During the heating with the thermal vector and immediately after in the cooling phases, the chemical reactions between the reactants and the continuous recombination of the products are very difficult to predict and describe, because they depend on hundreds of factors: it can almost be said that every chemical process has its peculiar dynamic! If we cannot start with a bottom-up approach, we can instead create contradictions starting instead from the results of field experiments. Hence the idea of collecting and organizing all the information on the subject with an evolutionary approach and in particular the evolutionary tree of Shpakovsky [1].

The starting point concerns the recovery of information through the collection and analysis of experimental results from the scientific literature. Through the Shpakovsky evolution tree, the recovered technologies were then classified. Therefore, the same tree is used to select the technologies and to visualize the operational parameters that come into conflict with each other in order to identify the physical contradictions. The structure of the paper is as follows: section 2 presents the state of the art on the operational parameters of pyrolysis, section 3 proposes the use of the evolutionary tree to organize information on pyrolysis technologies, section 4 draws conclusions.

2 State of the art

The process of the pyrolysis is too complex because of the multitude of involved parameters (e.g. temperature, time of reaction, typology and granulometry of the processed material) and the nature of their mutual correlations affecting the quality (e.g. heating value) and the quantity of the obtained products (i.e. gas, liquid and solid).

In addition, today, a lack of knowledge still persists, as testified by the interest of the scientific community in proposing always new experiments, and by the many contradictory obtained results.

On a practical level, this lack is detectable on the insufficient flexibility of the numerous commercial and semi-commercial plants of pyrolysis, which are forced to work in too narrow ranges of function for not compromising the performances.

For this reason, we carried out an analysis of the existing technologies, both from patent and papers and an analysis of the operative parameters based on the experimental results of the test from scientific literature.

The research of the technologies of pyrolysis has been carried out on patents and papers on the international databases (i.e. Espacenet, SCOPUS and Google Scholar) by using generic keywords (i.e. “pyrolysis” and “gasification”), as shown in table 1.

The result shows that the number of documents is very high, both as regards the number of scientific articles and the number of patent documents. The goal was to extract correlations between physical-chemical parameters of the pyrolysis process in order to be able to set contradictions.

2.1 Analysis of the operative parameters

The first parameter searched in the document pool is the temperature at which the pyrolysis process takes place. According to [2], each chemical reaction of each element of the pyrolyzed waste has a precise threshold value. In general, we noticed how the increase of temperature leads to an increase in the gases produced, while the fraction of liquids and solids is reduced even if with different quantities [3].

Another main parameter is the reaction time which substantially discriminates the two main pyrolysis mechanisms: the fast, which occurs in a few seconds (less than 5) and the so-called "traditional", which times are always longer than 10 minutes. A lot of authors (e.g. [4]) studied the combination between temperature and time of reaction by deepening the effects deriving from the heating rate and the permanence at the peak temperature.

Also, the raw material within the reactor, the shape of the reactor and the agitation mechanism of the raw material can strongly influence the reaction (e.g. [5]).

This framework is then complicated by the comparison of the influence of these parameters on different feeding materials (e.g. rubber, wood, paper), by their shape of aggregation (e.g. dust or pellet) and by the percentage of the contained humidity (e.g. [6]).

The analysis of the product also considers other evaluations in addition to the quality and the quantity of the products, such as the reactivity of the ashes, or its ability to keep suspended in the produced gas (e.g. [4]).

Figure 1 summarizes different correlations between the operative parameters and the obtained products found in literature. As can be seen, there is no correlation factor between the increase in temperature and the modification of the percentages of pyrolysis products. The different processed materials, even very similar to each other, behave in unpredictably: some improve with the increase in temperature while others get worse. These dynamics have been identified for most of the analyzed literature and for all types of parameters.

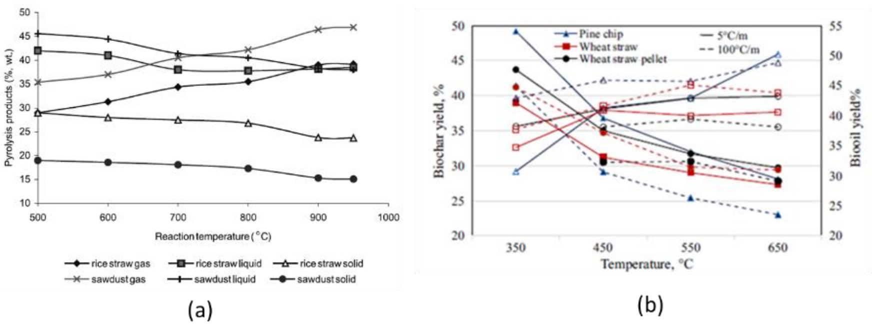

Figure 1: Different influences of the operative parameters on the pyrolysis products from literature (a – [7] Chen et al., 2003, b – [6] Roy and Dias, 2017).

3 Proposal

The collected technologies have then been related to those regarding the operative parameters and then they have been organized through the logics of the evolutive theory and the tree of Shpakovski (i.e. [1]).

The starting point of this logic are the Laws of Technical System of Evolution [8] and the related patters, which are the most general trends for describing the evolution of technical systems and they are reported to be one of the most used TRIZ tools within the case studies from literature [9]. During the years, the Laws have been applied in several fields, and, in particular, along with the evolutive trees, they have been exploited for classifying technical systems according to their level of evolution [10].

The first pattern (Evolution Toward Increased Ideality) is based on the assumption that every system has both useful and harmful effects and it is used for classifying the systems in order to maximize their ratio of useful to harmful effects and approach ideality. The second pattern (Stages of Technology Evolution) is a sort of an S-curve for mapping the technological maturity of the systems. The third pattern (Non-Uniform Development of System Elements) explains that different systems could evolve by their different schedules, since they are affected by different constraints during different period. The fourth pattern (Evolution Toward Increased Dynamism and Controllability) states that the evolution of the systems passes through the increasing of their dynamism and controllability. The fifth pattern (Increased Complexity, Then Simplification) explains that there is an initial tendency to add functionalities to the systems, by increasing their complexity, and then to divide them into simpler systems that provide the same, or more, functionality. The sixth pattern (Evolution with Matching and Mismatching Elements) states that evolving system elements are matched or mismatched to improve performance or compensate for undesired effects. Seventh pattern (Evolution Toward the Micro-level and Increased Use of Fields) explains that technological systems tend to transition from macro- to micro-systems, and that different types of energy fields are used to achieve better performance and control during this transition. The last pattern (Evolution Toward Decreased Human Involvement) explains that evolution of the system passes through the decreasing of the human involvement.

Their improvements and combinations have been proposed by several authors.

[11] found hidden patterns in technological evolution by exploring the relationships between the evolution of products from the point of view of TRIZ's patterns of evolution and new emerging information technologies (semantic web, data mining, text mining, theory of chaos and evolutionary algorithms).

[12] proposed an algorithm to perform functional analysis for building a network of evolutionary trend for a given technical system and they integrated it with well known models for function representation (e.g. Energy Material Signal -EMS- model).

[13] proposed an automated method for identifying TRIZ evolution trends from patents which consists of extracting binary relations of verb, nouns and adjectives from patents using natural language processing, defining a 'reasons for jumps' rule base that arranges trend-specific binary relations for trend identification, and determining specific trends and trend phases by measuring semantic sentence similarity between the binary relations from patents and the binary relations in the rule base.

[14] presents a forecasting novel model to acquire innovative ideas more easily to design eco products, followed by evaluation of whether the new design is more effective than currently available ones in the concept design stage based on TRIZ evolution patterns, in which the index system of case-based reasoning connects the innovative idea to cases located in a database to accelerate the process.

[15] identified promising patents for technology transfer by adopting TRIZ evolution trends as criteria to evaluate technologies in patents, and Subject–Action–Object (SAO)-based text-mining technique to deal with big patent data and analyze them automatically

[16] explained how they can be used to construct a technology road-map that profiles the life curves of considered technical system. In particular, the author used the patterns of evolution to define the fuzzy edge of what we will be tomorrow compared with what we are today.

Among all these approaches, one of the most simple and immediate way to organize information, especially for novice designer, is the work about the evolutive trees carried out by Shpakovski (2006). The peculiarity of this approach consists in using the so-called "Evolution Tree" – an organized set of technical system evolution patterns - to structure technical and patent information. The result is a certain hierarchy of actions, as shown in figure 2, performed during the system transformation, as well as the hierarchy of evolution patterns formed as a result of each of these actions:

1) Introduction of new or segmentation of existing objects, processes, fields and forces.
2) Coordination the shape, size, and properties of the surfaces with the internal structure of the system's elements, process parameters, fields, and forces,
3) Dynamization of sets of objects, processes, fields, and forces.
4) Providing controllability of the system's elements,
5) Coordination the action of the system's elements.

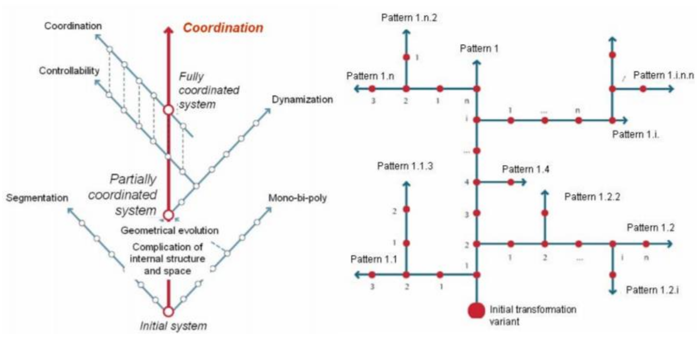

Figure 2: (a) Hierarchy of actions aimed at the transformation of the system's elements and (b) the structure of the Evolution tree (Shpakovski, 2006).

3.1 Application of the evolutive theory to pyrolysis

Within the obtained evolutive tree in figure 3, the pyrolysis technologies have been divided into different groups based on the trends involved and ordered based on them. Trends act on two hierarchic levels of detail.

The main vertical branch considers the different modes of interaction between the heat vector and the raw material to be subjected to pyrolysis, considering in particular the activation energies of the pyrolytic combustion. The direction of the path follows the "Transition from macro to micro level" evolutionary law. At the bottom of the evolution the heat transfer is limited to one single surface of the raw material, then with 2 or many surfaces till to move to a new level of granularity with an interaction with small parts of raw material and finally to a total decomposition in small particles. In the same way, the same tendency can also be observed on the thermal vector that begins with a hot surface, breaks down into different surfaces and then into an increasing number of parts (small spheres) until it takes the form of micro plasma molecules. The secondary horizontally branches collect main variants from the different pyrolysis technologies. A short selection of inventive principles was used to organize and hierarchize these variants according to an evolutionary type criterion (#1 Segmentation, #3 Local quality, #5 Merging, #7 Nesting, #14 Spheroidality, #17 Another dimension).

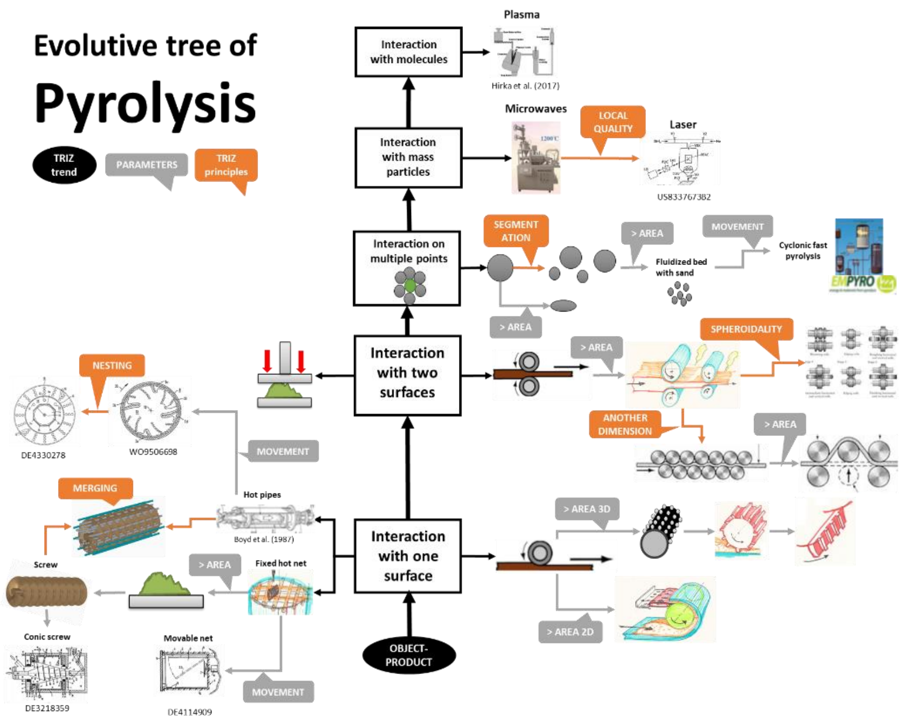

Figure 3: The proposed evolutive tree for organizing the technologies for the pyrolysis.

3.2 Idea generation

The starting point of the problem-solving activity was the hot screw reactor produced by the company. Among the many contradictions faced in the process of improving the screw technology, we take for example the one aimed at improving productivity in terms of the quantity of raw material processed. One of the possible ways to improve it is to increase the temperature of the heating mantle. However, this modification seriously undermines the seals of the system, which must have well-controlled thermal expansions to prevent the entry of oxygen into the inert environment. Otherwise serious safety problems may occur; more generally, there are complications in terms of overall structural resistance and a deterioration in the useful life of the plant. A physical contradiction has been set identifying two situations, the "current cold" one which does not guarantee a high productivity and a "warmer" one that gives problems of resistance and tightness, which is showed in figure 4.

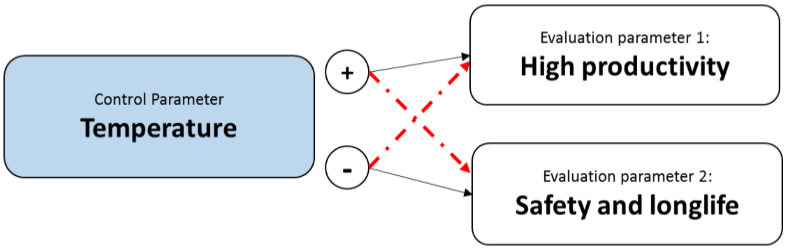

Figure 4: One physical contradiction affecting the hot screw reactor.

For solving this contradiction, we have then applied the principle of the separation in space identifying the operative zones of Control Parameters inside the screw structure. As shown in figure 5, the parts in contact with raw materials have to reach a high temperature, in order to ensure a more efficient pyrolysis, while seals have to be maintained at a lower temperature for guarantee safety.

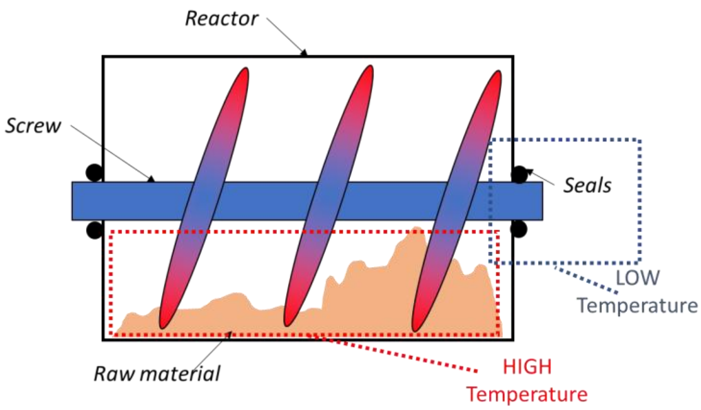

Figure 5: An application of the spatial Separation principle.

We have then applied principle n°14 – Spheroidal, and in particular its suggestion about the introduction of spheres within the technical system.

The derived solution, please refer to figure 5, is made by the same reactor where the screw is heated at same “low” temperature (i.e. 400°C), and the introduction of hot spheres with a high temperature (i.e. 1000°C), which are moved by the contact with screw rotation within the reactor.

4 Conclusions

The subject of pyrolysis is of great interest at present. Despite the great experimental interest, the laws that govern it have not yet been well circumscribed. The study of the available literature on pyrolysis has identified the lack of information as the biggest obstacle to conduct a more classic TRIZ approach: the initial representation of the process through totally reliable models of physics and chemistry prevents the formulation of equally reliable contradictions. Hence the risk of investing in solutions that may not be sufficiently effective. However, the vast literature is an important resource that has been exploited by the authors to extract those correlations that, considered individually, are certainly true as they are tested. The shape of a rector and its operating parameters, we know that they have produced a certain result even if we are not able to understand exactly which process dynamics took place within it.

Hence the choice to work at a high level of detail. The evolutionary graph has proved to be a very versatile tool, able to give order to the enormous amount of material available, to guide research according to a reasonable criterion; it has also proved to be a valid communication tool to discuss the client and overcome it as to resolve some contradictions that were evolutionarily more advantageous than others that on paper without other criteria could have seemed so interesting.

The tree also offered a valuable contribution to systematizing the technological hybridization process, resulting simple and orderly. It has been also used for formulating physical contradiction like the one shown in the paper showing the transition from a warm mantle technology with a screw to technology integrated with hot spheres.

A hybridization project of some pyrolysis technologies is ongoing. It concerns a plant in Morocco that will be built in the next 3 years at Agadir. It will have to process more than 1000 tons of solid urban waste per day with an innovative technology in a plant that will also be a showcase of green technological solutions involving solutions for exhaust heat storage, energy production and treatments foe ashes and pollutants.

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