ASBESTOS DESTRUCTION PROCESSES: THE ITALIAN EXPERIENCE AS CASE OF STUDY

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SUMMARY: According to recent policies related to the reduction of waste to landfill, since 2013 the EU Parliament is promoting and supporting research for sustainable alternatives to treat Asbestos Containing Wastes (ACWs) and to limit their landfilling. Moreover, on 28 January 2015, an Opinion of the European Economic and Social Committee (EESC) pushed all European Countries to the total removal of all used asbestos and all asbestos containing products; thus, asbestos removal, management and destruction has to be a priority target of the European Union. In particular, measures are encouraged to prepare action plans for the safe removal of all asbestos and ACWs, as a priority of the European community by 2028. This paper summarizes the status of the most important and innovative asbestos destroying processes, providing main operating parameters, advantages, and disadvantages. In this way, the ACWs become a secondary raw materials, which could be reused. Starting from the Italian experience, reported, analysed and discussed, other countries regulations have been evaluated evidencing as in many cases no specific rules exist. The extensive literature analysis , encourages further studies in the field. If the research will overcome the drawbacks highlighted in this paper, the industrial and social acceptance of asbestos destroying processes will considerably increase.

1. INTRODUCTION

Asbestos is one of the most harmful occupational carcinogens, causing more than 100,000 deaths per year. Exposure to airborne asbestos fibers is held responsible for half of the deaths from occupational cancer (caused by mesothelioma, asbestos-related lung cancer and asbestosis).

Estimated worldwide consumption of asbestos minerals decreased from approximately 2 million tons in 2010 to slightly less than 1 million tons in 2018. China, the world's leading asbestos consumer, used 570,000 tons of it in 2015 [1,2]. Asbestos-cement products are expected to continue to be the leading global market for asbestos. The world leaders in raw asbestos production for 2015 and 2016 were Russia, China, Brazil, Kazakhstan and India, according to a 2017 report from the

Table1. World Mine Production and Reserves (MINERAL COMMODITY SUMMARIES 2019).

World Mine Production and Reserves			
	Mine production [tons]		**Reserves [tons]**
	2017	**2018**	
United States	-	-	-
Brazil	160,000	100,000	12,000.000
China	125,000	100,000	96,000.000
Kazakhstan	193,000	220,000	Large
Russia	690,000	650,000	110,000.000
World total (rounded)	**1,168,000**	**1,070,000**	**large**

U.S. Geological Survey. The extraction of the mineral by the countries mentioned is downhill, while the natural reserves of the mineral still remain enormous [3] (Table 1).

Many countries have already banned asbestos mining and its marketing (European Community, Japan, etc.) and are now engaged in remediation actions and ACW (Asbestos Containg Waste) management. Historically, Europe has always and massively used this substance, and more than 50% of asbestos marketed worldwide in the period 1920-2000 was utilized in Europe. Consequently, Europe bears most of the global asbestos-related disease. While the European population accounts for only 13% of the world's population, the European region has been registered most of the asbestos-related deceases with about 56% of the global deaths for mesothelioma and 41% for asbestosis. In this context, since 2005 the European Commission ("EC") has banned the marketing and use of products or substances containing asbestos.

The removal and reclamation of Asbestos Containing Materials (ACM), mainly used in construction and technical supplies, represent a sector of great health and environmental concern. The management of ACW, in particular, represents a critical issue, due to its risk and the resulting attention that both government and the public opinion pay to it [4]. Attention to ACW's final destination has therefore shifted in recent years from disposal to recovery.

Recovery usually include two different types of asbestos destruction processes:

1. treatments completely modifying the crystal/chemical structure of asbestos so that the resulting waste poses no health hazard,
2. treatments reducing fibers release from ACW, without changing the crystalline/chemical structure of the asbestos or partially modify it.

Asbestos destroying processes differ according to the type of process used (chemical, thermal, biological and/or mechanical) and to the nature of byproducts.

The European Patent Office has registered about 50 patents, 13 by Italian companies. Most of these patents protect processes that are still in laboratory or experimental scale. However, in a few cases, companies have presented a preliminary industrial project, accompanied by operational schemes, tables and diagrams.

2. LEGISLATIVE GAP CONCERNING INDUSTRIAL PLANTS FOR DESTROYING ASBESTOS

The importance of developing industrial plants for destroying asbestos to reduce landfills and soil consumption is clear as it will be beneficial to society as whole; however, there is presently no clear legislation anywhere in the world for these types of industrial plants when it comes to health and safety of the working and living environment. The few number of technical standards with clearly defined intervention parameters leads, at international and national scale, the public authorities not to authorize them. Thus, Regional and Local Administrators avoid direct responsibility and are not confronted with negative public opinion. In fact, the majority of the population adopts the NIMBY principle, "not in my backyard", particularly in high-density areas where neighborhood and mothers committees often oppose the construction of such plants [6-10].

From the technical point of view, we highlight the main technical data that output material must have, required by some legislation for the approval of industrial plants for destroying asbestos (e.g.: Italian legislation) [5]:

- absence of asbestos fibers under examination at least with SEM,
- total concentration ≤ 0.1% of category 1 or 2 carcinogens,
- it must not generate hazardous waste,
- non-asbestos fibrous materials (length/diameter ratio ≥ 3) with an average geometric diameter < 3 microns must not exceed 20% vol.

Considering all of the above and the public opinion concern, it’s clear that an international or national regulation are required for the management of ACW. The current waste management system, based on a few small and authorized landfills is considered unsuitable by the progressive increase in ACW production, encouraged by international legislations.

3. INDUSTRIAL PLANT FOR DESTROYING ASBESTOS: THERMAL TREATMENT

These industrial plants for destroying asbestos aim to reduce the waste impact on the environment and to transform it into energy or recoverable products [6].

In Europe patents have been issued for a thermal treatment based on plasma torch technic, operating at very high temperatures in the absence of oxygen. An industrial plant based on one of these patents, operated in France from 1992 to the end of 2018, allowing asbestos to be permanently destroyed and the exploitation of the processed byproduct as a totally inert secondary raw material. Through a thermal-chemical reaction, the waste reaches fusion at 1500 °C / 2732 °F: the asbestos fibers structure (both amphiboles and chrysotile) is thus destroyed, and the product of fusion is extracted from the furnace trough a semi-continuous ingot casting air-cooled. The high temperature melts the asbestos fibers, which are transformed in non-fibrous minerals, thus eliminating the toxicity [9-15]. This process, turning asbestos waste into inert material, also allow taking over responsibility for the waste from producer and owner by supplying a treatment certificate. From a public health and environmental perspective, the process offers full and permanent elimination of the risk of toxicity of ACW. This asbestos destroying process by plasma torch provides 4 steps: Waste preparation, Vitrification of asbestos, Smoke treatment and finally the evacuation/valuation of secondary materials. At the moment it is in maintenance but it is expected to reopen in 2022. Considering this, in paragraph 5 some prevention measures are indicated by the authors which, if adopted, would significantly contribute to an upgrade in terms of Security.

4. INDUSTRIAL PLANT FOR DESTROYING ASBESTOS: BIOCHEMICAL TREATMENT

In Italy a process has been patented for destroying asbestos based on biochemical treatment realized studying the action of lichens. Some studies realized by the University of Bologna have shown that *lichenic hyphae* secrete oxalates-containing substances, leading to an alteration of the crystal structures. A procedure has been developed, which involves ultrasound and oxalic acid. Finally, the microbiological treatments involve the use of specific bacteria. For example, the lactic acid produced by both *Lactobacillus Casei* and *Lactobacillus Plantarum* causes the disintegration of the brucite layer (crystallographic plane) of Chrysotile. The aforementioned treatments can produce secondary raw materials, often in the form of inert materials suitable for construction/public works, or to produce fertilizers and insulations. The patent has been sold to different companies [6,15]. One of them is going to realize an experimental plant located in the South of Italy and in particular in Regione Puglia. This experimental plant has been authorized by regional authorities to treat about 5 ton/year. At the moment it is not operating yet. Another company obtained a patent that allows the use of a different kind of food waste, not only milk waste. The treatment process should develop in two phases: the first by mixing ACW with acid PH food waste to decompose the cement structures at environmental temperature; the second transforming the asbestos fibers into Mg, Ni, Mn and silicate ions using a hydrothermal process at 170 °C / 338 °F. In this way it should be possible to easily extract metals electrically for sale as secondary materials making the process economically viable. In this way, from two types of waste (ACW and food waste) it should be possible to obtain new secondary materials. A third company presented a new patent, improving the other ones, which led to the development of a preliminary project for an industrial plant. This project provided the truck to enter in the confined area (static and dynamic) where two workers with hand pallet truck must place the big bags on automated shelving and self-registered on a special database managed by a Control System.

The process involved that the big bags or other packaging were sent to the hoppers and the recovery of the pallets. The mills mince the waste to a grinding of <10 cm. The plant provided, in the next step, a densimetric table for the separation of packaging plastics, which would remain in suspension and would be aspirated and managed through big-bags in landfills. Through a cup auger, the milling waste should be distributed on a further densitometric plane for iron removal. Then, the iron should be collected in hermetic boxes and subsequently sold. After that, the waste should go in a hammer mill to reduce the size to about 20mm and then in another rotating mill to reduce it to < 1mm. The material should be subjected to a first attack with acids with CO_2 production (treated in the stripping tower). The remaining material containing high concentrations of asbestos should be subjected to a second reactor with temperatures of about 400 °F and 6-7 bar of pressure with production of hydrogen for sale. The plant also should be provide the production of methanol, iron and magnesium salts for sale. This process should make it possible to produce 50 kg of secondary material per ton of waste treated. The secondary material produced should consist in a mud useful for agriculture. The system should provide a frequent washing of all surfaces in the depression area, built on a floating grilled floor with collection and treatment of all the water beneath it. Various personal and environmental monitoring were planned.

Biological asbestos treatment plants are going to be realized in some Italian Region and with different industrial layout and there are already specific authorization for their starting activity. The prevent some diseases for workers or environmental contamination consistent with this kind of industrial plant, the Italian National Institute for Insurance against Accidents at Work (INAIL) produced some instructions and safety measures reported in the following.

5. INAIL INSTRUCTIONS AND SAFETY MEASURES

INAIL coordinates and provides financial support to research plans regarding all aspects of health and safety in the workplace. The research develops cutting-edge new operating procedures, methodologies, equipment, systems, and insights, paying considerable attention to the complex issue of asbestos [15]. In particular, the Department of Technological Innovations and Safety of Plants, Products and Anthropic Settlements (DIT) works to develop methods, procedures and models for risk assessment in the presence of hazardous substances released by production materials and processes, both in the workplace and living environment. Thus, the Department identifies measures for risk mitigation, the protection of workers and the safeguard of residential communities. In this framework, the asbestos research team prepares technical reference documents at the national and international level, in collaboration with Public Authorities, Research Bodies and universities to diffuse a culture of safety in working areas. Following the authors report the main cautions to adopt for workers safety of those thermal and biological industrial plants.

5.1. Facility layout

A continuous fence, with 24/24 hours video surveillance, must be built all around the facility. The whole area must be identified by appropriate signs, specifically to prevent and prohibit entrance by outsiders, indicating asbestos risk, and requiring a compulsory use of Persona Protective Equipment (PPE). All people entering the industrial plant must wear PPE, also including external operators or Public Authorities. Suitable kits of PPE must be kept inside the receiving area so that truck drivers can use it promptly in case of breakage evidence on the incoming packaging or accidents.
A suitable area must be designed for the scheduled cleaning of vehicles and equipment, to be carried out by means of aspiration system with absolute filters – particularly inside the operator's cockpit.

A decontamination procedure must be provided to adopt for vehicles that unload damaged packages, to carry out in correspondence of the vehicle washing platform. A statically and dynamically confined area under negative pressure must be foreseen, in order to safely carry out the repackaging and emergency operations.

The different plant areas must never communicate directly but only across air lock, it's preferable for different areas to be identified through colored elements and, finally, the entrance and the receiving area, plus the unloading area, temporary storage and automated storage must be continuously monitored in order to guarantee the continuity of the process.

5.2. ACW Storages areas

ACW (compact or friable) must be packaged and stored inside temporary/preliminary storages, which have to be statically and dynamically confined under negative pressure. Specific access and exit procedures must be envisaged. Temporary deposits must be kept clean. Therefore, adequate and frequently cleaning procedures and PPE should be adopted by operators; these procedures must be established and planned. In the event of an accident (broken big-bags, etc.), clean the entire surfaces in the surrounding area using a high vacuum cleaner and wet procedures.

Waste must be stored in homogeneous classes (preferably according to the European LoW), divided by suitable barriers.

The packaging must be appropriately marked (preferably according to European LoW), in order to uniquely and clearly identify the type of waste inside. It is therefore essential, once the ACWs have been characterized, to label each package with the following information: name and address of the waste producer, waste code (preferably European LoW), description of the waste, physical state and the corresponding hazard symbols (H350: may cause cancer; H372: causes damage to organs through prolonged and repeated exposure).

The name of the waste and the related code must be printed in clearly legible and indelible characters. All ACW must be unloaded inside the storage area with intact packages, so as to avoid fibers dispersion. In exceptional cases, such as when broken packages are received, they shall be re-packaged as soon as possible inside the plant, possibly before unloading, in order to avoid undue exposures or in the specific confined static and dynamic area under negative pressure with an economical surplus for the waste producers.

The location of ACW within the storage site must be automatic and mapped in a data base continuously updated. A correct handling and storage of each ACW pallet/package has to be performed.

5.3. Workers' safety measures

Exposed workers must use all the Personal Protective Equipment (PPE) provided in the presence of asbestos, and particularly those related to the respiratory tract, with a protection factor adequate to the concentration of airborne asbestos, concerning the airways protection, we recommend different mask considering the worker task and the air fibers concentration, but always a mask with P3 filters. Mask must be worn under the hood so as to allow the correct decontamination procedures while leaving the workplace (the mask is the last PPE to be removed under the shower of the Personal Decontamination System), PPE, to be used during emergencies, must include insulating respirators to ensure protection to a concentration of airborne asbestos fibers greater than 1 f/cm3. It is recommended the use of following PPE: gloves, disposable overalls non-woven fabric (with hood under the helmet and seams covered by insulating tape) and rubber footwear or waterproof work boots (to be cleaned very well with water at the end of the shift and to be left at the work site). Footwear must be worn inside the trousers of the overalls and sealed with insulating tape. The same seal must be made between the gloves and the cuffs of the suit. The use of disposable shoes is to be avoided. A four or five-step Personal Decontamination System should be realized adjacent to the confined statically and dynamically area.

5.4. Air filtration

It is necessary to establish the specific values of depression and air exchange for each single area, in order to size properly the extraction systems. The indoor air should be conveyed by a suitable suction system and pass through a system of pre-filters before being sent to the final HEPA filter to ensure the latter is not clogged. Good maintenance and cleaning of the processing area where dust or ash are eventually produced (specific procedures). Replacement and recycling of the air filters in the system (HEPA, bag filters, etc.) have to be carefully scheduled, as well as issuing of procedures about labeling of exhausted filters and PPE; establish if they are intended to be treated inside the industrial plant for destroying asbestos or not. Due to the particular working conditions, it is necessary to carefully evaluate the air conditioning, so as to obtain a correct indoor microclimate considering PPE use and to design of dedicated paths and specific safety procedures for workers in charge to transport the exhausted air filters from chimney and PPE.

5.5. Workplace asbestos monitoring

Personal monitoring must be carried out on the most exposed operators for each activity or area (acceptance, loading, storing, etc.), with a frequency established in cooperation with the Local Health Authority; recommended sampling and analysis procedures are as follows: personal sampling with low-flow sample pumps, with a total of at least 480 sampled liters at a rate of 2–3 l/min. Filters must be made out of Mixed Cellulose Esters (MCE) of 25 or 47 mm, and analyses conducted via Phase Contrast Optical Microscopy (PCOM). Results must be available within 24 hours of sampling; if the filters analysis show that the threshold limit value for asbestos in working area (0.1 f/cm3 - Directive 2003/18/EC) have been exceeded, it is necessary to take the measures laid down in the above mentioned laws and adopt the precautionary measures indicated for alarm situations. Environmental asbestos monitoring must be effected: 1- before the work to know the environmental background values; 2 – on standard process and plant operations; 3 – post-processing to evaluate the remediation of the area at the end of the production cycle. Eextensive environmental monitoring must be carried out for each activity or area, also considering the preferential winds direction in the outdoors areas of the industrial plants and outside the facility perimeter. The sampling frequency will be agreed with the Local Health Authority. Sampling parameters are: high-flow sample draw pumps, drawing at a rate of 8–10 l/min, at least 3,000 sampled liters, filters made out of MCE (25 or 47 mm). In in-door areas they must be realized by PCOM analyses and in out-door area by SEM, TEM or STEM; if filters analyses exceed 0.02 f/cm3 by PCOM or 0.002 f/cm3 by SEM-TEM-STEM, some measures for "alarm case" must be taken. Furthermore, Local Health Authority should be immediately notified. These samplings must also be carried out every time an emergency situation occurs. It is advisable to carry out an environmental sampling inside the clean changing room (the uncontaminated area of the PDS), whenever there are emergencies or significant tearing of the packaging. Finally, as regards the threshold environmental limit value for airborne asbestos, it is recommended 0.002 f/cm3 inside the indoor remediated areas, 0.002 f/cm3 in outdoor areas of the industrial plants and 0.001 f/cm3 for urban areas, in compliance with the value issued by WHO (2000 - Air Quality Guidelines for Europe);

5.6. Evaluation of the quality of the product

Analytical verification of the absence of pollutants other than asbestos in the exit phase, which otherwise would require disposal in landfills. Planning of sampling on incoming materials and final products: frequency / number, pollutant to be researched, sampling points, points, homogenization, etc. Control analysis and tests carried out by the Local Health Authority.

5.7. Management of emergencies

The pre-alarm/alarm thresholds, relating to both the external and internal areas, must be highlighted, together with the emergency safety measures to be adopted, to reduce the dispersion of airborne asbestos fibers it is necessary that some tools are readily available on site for emergencies, such as a manual vacuum cleaner with absolute filters and a fog cannon.

6. CONCLUSIONS

In recent years, a significant increase in the production and disposal of ACW has been registered. In this context the authors highlight that worldwide there are too few landfills authorized for the disposal of such waste (with insufficient volumes still available) or industrial plants for destroying asbestos an industrial scale. The lack of industrial plants dedicated is determined by non-specific legislation and by few safety standards. It should be effected changes and additions aimed at defining at least:

- the Public Administrations involved in the authorization procedures,
- the Control Bodies responsible for environmental and workplace safety and compliance with product quality,
- methods and procedures for sampling and analysis of environmental matrices (air, water, soil) and of the materials produced by inerting treatments.

Taking into account the high degree of degradation of ACMs, often put in place in the 70-90s, the need to reclaim and remove such materials becomes increasingly strong which, upon their removal, become waste containing asbestos to be disposed of. Taking this into account it becomes even more necessary to dispose of more asbestos treatment industrial plants, specifically in Europe where the full density population and few space to be destined for landfills.

For a careful planning of waste management activities and transformation processes the authors put in evidecnce the importance of a preventive analysis of the various sources of risk and of the dangerous actions inherent in each operation. A correct planning of the interventions leads, in addition to the drastic reduction in the number of accidents and all the legal and economic consequences that derive from them, also an indirect effect such as the improvement of the interoperability between the various companies involved and the working atmosphere in the same company (greater constructive dialogue between managers, coordinators of activities and supervisors or operators). With this aim, the authors highligt the importance of a preparatory consultancy between the companies operating in this field and the Public Authorities encharced of industrial plants authorization, also involving priority the Governmental Bodies encharged for workers and living envirnoment safety. This paper can be thus considered aa a useful reference on an international scale for operators in the sector.

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