# Technological advancement in effective

# management of Low Level radioactive

# solid wastes

K.C. PANCHOLI

Homi Bhabha National Institute &

Nuclear Recycle Group, Bhabha Atomic Research Centre

Mumbai, India

Email: keyur@barc.gov.in

SUPRABHA

Homi Bhabha National Institute &

Nuclear Recycle Group, Bhabha Atomic Research Centre

Mumbai, India

S. AGARWAL

Homi Bhabha National Institute &

Nuclear Recycle Group, Bhabha Atomic Research Centre

Mumbai, India

M. MASCARENHAS

Beam and Technology Group, Bhabha Atomic Research Centre

Mumbai, India

A. SHARMA

Beam and Technology Group, Bhabha Atomic Research Centre

Mumbai, India

C.P. KAUSHIK

Homi Bhabha National Institute &

Nuclear Recycle Group, Bhabha Atomic Research Centre

Mumbai, India

**Abstract**

In India, Low Level (LLW) Solid Radio-Active Wastes (RAW) contributes more than 90% of the total RAW generated from regular Operation and Maintenance of a typical Nuclear Fuel Cycle facilities. The volume generated from a typical nuclear facility ranges from 200 to 600 m3 depending on type and number of the facilities at a site. These wastes, in general are segregated as combustible, compressible and non-compactable/compressible based on the processing considerations. Predisposal processing is an essential task for optimal utilization of Near Surface Disposal Facility (NSDF) to contain the radioactivity and isolation from the environment meeting regulatory guidelines. Combustible waste forms viz. Cellulosic. Rubber and Plastics, contributes about 50-60% of the total VLLW and LLW solid wastes. Predisposal steps employed for these combustible radioactive solid wastes are compaction, melt densification and incineration based on type of waste forms. Cellulosic waste is incinerated using oil/diesel fired incinerator. Rubber and plastics wastes are compacted using hydraulic compactor and plastic wastes having thermoplastic behavior is processed through melt densiﬁcation mode achieving volume reduction factor (VRF) of 30-40, 3-4 and 3-10 respectively. Rubber and plastic wastes mainly PPEs, contributes about 70-80% of` the total combustible waste. As advancement in technology with high temperature based processing of these wastes, has certain advantages to nullify formation of toxic compounds like dioxin and Furans. The plasma based process having ease of higher temperature availability, is seen as the promising solution for management for all type of combustible radioactive wastes. To achieve higher volume reduction for rubber and plastic wastes, an engineering scale Plasma pyrolysis based incineration demonstration setup of 25 kg/hr capacity has been commissioned at Bhabha Atomic Research Centre (lndia) utilizing in-house developed 30 kW DC air plasma source. After lab studies and simulated waste trails, the setup was commissioned with actual radioactive waste. More than 2000 kg waste has been successfully processed through the setup in various trials. VRF achieved for all combustible type of waste forms is ranging from 30-40. The paper highlights waste processing aspects, laboratory scale study for waste decomposition and demonstration of plasma processing of solid RAW.

## INTRODUCTION

Operation and Maintenance (O&M) of nuclear and radiological facilities generates accountable amount of Solid Radio-Active Wastes (RAW) which are above the exempt or clearance level, i.e., Very Low Level Waste (VLLW), Low Level Waste (LLW) but less than Intermediate Level Waste (ILW) and High Level Waste (HLW) [1,2]. Management and safe disposal of these radioactive wastes is a big challenge faced by nuclear industry all over the world [1,2]. Though R-3 concept (Reduce, Reuse and Recycle methods) is well practiced to minimize the waste volume generation, still a good amount of VLLW and LLW require processing for volume reduction before their eventual disposal [3,4]. The waste amenable for direct disposal as well as processed waste, after applicable conditioning processes, is disposed in the engineered disposal modules of Near Surface Disposal Facility (NSDF), to contain the radioactivity and isolation from the environment meeting regulatory guidelines [4]. The volume generated from a typical nuclear facility ranges from 200 to 600 m3 depending on type and number of the facilities at a site [3-5]. In India, solid RAW of VLLW and LLW nature contributes more than 90% of the total solid RAW generated from regular O&M of a typical closed nuclear fuel cycle facilities [5]. These wastes, in general are segregated as combustible, compressible and non- combustible/ non-compressible based on the processing considerations. Various constituents of the combustible O&M radioactive waste are mostly comprising of, cellulosic (*i.e.*, paper, boiler suits and lab coat), plastics (*i.e.*, Shoe covers, sample bottles, sheets) and rubbers (*i.e.,* surgical and post-mortem hand gloves). Rubbers and plastics, contributes about 50-60% of the total VLLW and LLW solid wastes, which amounts to about 70-80% of` the total combustible waste [5]. Though direct disposal is a very simple and energy-less waste disposal option, direct disposal of waste requires unacceptably more land space. Appropriate volume reduction techniques are to be deployed to achieve maximum possible reduction of volume of waste amenable for disposal to NSDF [3-5]. In the present paper, we report the conventional practices in practice for volume reduction, and technological advancement by installation of plasma based system for management of VLLW and LLW combustible waste forms, viz. cellulose, rubbers and plastics. The mass and volume reduction during pyrolysis process have been understood through laboratory scale muffle furnace study. Results of plasma pyrolysis based incineration of solid combustible nuclear waste from the nuclear facilities are also summarized along with disposal of residual ash with proper conditioning in cement matrix.

### Conventional practices for volume reduction

Compaction, melt densification and incineration are being practiced for volume reduction based on type of waste forms, with achievable volume reduction ranging from 3 for compaction to more than 30 for incineration [4,5]. Compaction, for rubber and plastic (non-thermo plastics) type waste results in volume reduction factor (VRF) of 3-5, where as in melt densification for thermo plastic type waste (e.g. High Density Poly Ethylene-HDPE) results in VRF of about 3-10. Incineration of cellulosic material results in effective VRF of about 30-40 [5]. Typical compaction, melt densification and conventional incineration systems are shown in Fig.1. Incineration process can effectively treat combustible waste materials in oxygen-rich atmosphere with very small volume, reach in inorganics, results as residual ash [5]. Conventional incineration of cellulosic wastes is in practice. Such incineration is not preferred for rubber and plastic wastes due to associated lower operating temperatures of around 800-900 0C which may result in discharges of toxic gases like Dioxin and Furans [5-9]. It needs intense heat source with higher temperature, like plasma environment, for effective processing of such wastes [6-10].

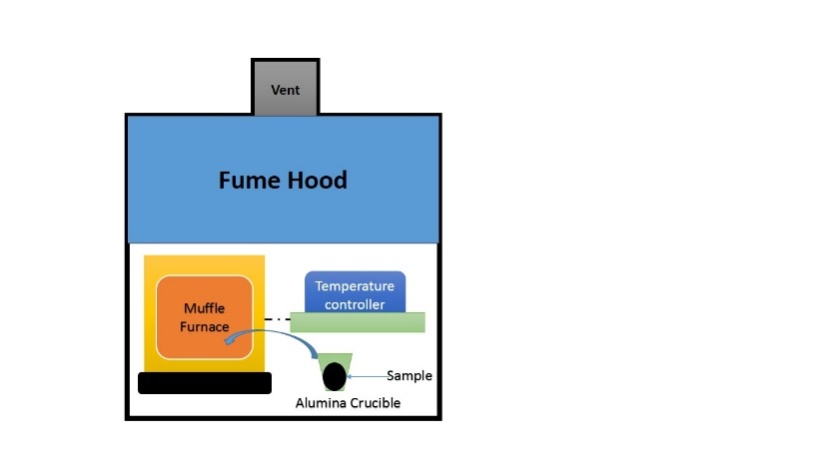
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| *Fig.1 Volume reduction techniques for combustible O&M wastes (VLLW & LLW)* |

### Advance technology

Thermal plasma based application for management of hazardous industrial and medical wastes has been studied and reported [10-22]. The waste processing in oxygen deficient environment is called pyrolysis, controlled oxygen environment process is called gasification, while excess oxygen environment is called incineration [14-22]. Plasma pyrolysis based incineration system, having higher than 1000 0C environment in waste processing zone, can overcome the limitations of the conventional incinerators with spontaneous decomposition of toxic compounds [6-9, 15-17]. At such higher temperatures in pyrolysis, the organic material is decomposed in oxygen deficient conditions, resulting into lower molecular gaseous compounds like CO, H2, CH4, etc. [15-17], which can be further combusted in the secondary combustion chamber with exothermic reactions in excess oxygen environment. Application of plasma incineration for radioactive waste management has also been studied [23-24]. Not much literatures available for plasma pyrolysis based incinerator for radioactive wastes. Pyrolysis also provide advantage of very low flue gas exit velocity in process chamber, due to lower mass flow rate, and hence very low carry over possibility of particulates along with exit flue gases.

## Laboratory scale pyrolysis study with resistive furnace

Prior to taking up plasma pyrolysis based system operation and to understand the results from pyrolysis process for all combustible waste forms, i.e. cellulosic, rubber and plastics, initially a lab scale study was conducted in resistive heating muffle furnace. A typical muffle furnace setup used for the study is shown in Fig.2 (a). Environment in the furnace was controlled to simulate pyrolysis condition with ~ 3-4% of stoichiometric equivalent oxygen available in the furnace. Various samples treated as simulated waste are enlisted in Table 1. All runs were done with same samples quantity and treated up to 800 0C, maximum available temperature of the setup. The results of the study are given in Fig.2 (b), as weight reduction ratio and volume reduction ratio, derived as ratios of weight and volume reduction factors of each waste type to the observed value for mixed cellulosic wastes, respectively. It is observed that weight and volume reduction ratio for all waste types is lower than value for cellulosic waste incineration. It is also observed that mixed rubber wastes have the lowest values followed by HDPE type of wastes, mixed wastes and PVC wastes in increasing order. This may be due to effect of strong polymeric bonds presence in rubber and HDPE compounds. For better weight and volume reduction of such wastes, i.e. for nearly complete destruction of polymeric waste forms, more higher temperatures with intense heat source, like plasma, can be beneficial.

TABLE 1. Composition of different pyrolysis batches

|  |  |
| --- | --- |
| Batch | Contribution of sample in percentage |
| 1 | Mixed Cellulosic  Mixed rubber hand gloves  Poly Vinyl Chloride (PVC) shoe cover  High Density Poly Ethylene (HDPE) |
| 2 |
| 3 |
| 4 |
| 5 | Equal portion of feed from batch 1-4 |

|  |  |
| --- | --- |
| M:\PhD\Papers\IAEA Conference paper-2021\Muffle furnace setup.tif   1. *A Typical laboratory setup* | 1. *Observations from the study* |
| *Fig.2 Laboratory scale decomposition study for weight and volume reduction in pyrolysis condition* | |

## Plasma pyrolysis based incineration system

Based on observations from laboratory studies, a plasma pyrolysis and incineration setup, of 25 kg/hr capacity (Fig.3), has been developed and installed at Bhabha Atomic Research Centre, India [25]. Chamber is designed to process waste using the intense heat from indigenously developed 30 kW DC non transferred type air plasma torch (Fig.3). The torch is operated using 50 kW IGBT based power supply unit. Plasma is ignited using high frequency spark using Argon as initial plasma gas. Later on, air is supplied to sustain plasma plume and Argon supply is cut off. Air supply, including leakages into the system contributes ~ 5% of the stoichiometric requirement nearing the pyrolysis condition in the plasma chamber. Overall temperature in the pyrolysis chamber has been >1000 0C, whereas, plasma plume (Fig.3) provided in the chamber could have plume temperature >1500 0C. The core of plasma can achieve temperature equal or more than 10,000 0C.



*Fig.3 Plasma pyrolysis based incineration system and 30 kW DC non transferred air plasma torch*

The gaseous products from plasma pyrolysis are allowed to react with excess air supply to give exothermic combustion reaction in after combustion chamber which is followed by elaborate wet off gas treatment system including quencher and scrubbers for preventing recombination possibilities of Dioxin and Furans as well as removal of other polluting gases [25]. In the secondary chamber, heat source for preliminary heating mode is diesel fired burner. Temperature in the secondary chamber is maintained at > 1000 0C with the flue gas residence time > 3 sec. Flue gas exit mass flow rate from plasma pyrolysis chamber will be less than 20 % of the value for similar capacity stoichiometric air supplied incinerator chambers. The lower exit velocity helps in reducing carryover from processing chamber.

The system was tested and commissioned in phase wise manner. Initially the setup was tested with various combination of simulated wastes in different trials. After successful trials, actual radioactive waste was processed through the setup at the rated capacity of 25 kg/hr. Waste was packed in standardized cardboard boxes for uniform feeding condition. Various combination of waste feeds were processed (Table 2). In total more than 2000 kg of actual radioactive waste, having contact dose less than 0.2 mGy/h, has been processed successfully. Temperature inside the chamber cavity observed during continuous processing of waste was 1200-1350 0C, which is higher than observed values for conventional incinerators and adequate for spontaneous decomposition of toxic gases, like dioxin and furans [6-9]. VRF achieved for all type of wastes was more than 30 and weight reduction factor (WRF) observed was between 18-25, where cellulosic waste gave most VRF and WRF than the rubber and plastic wastes. Relative values of volume and weight reduction for each waste type with respect to cellulosic waste is also summarized in Table 2.

Observations from engineering scale plasma system has shown improved values than observations during the laboratory scale resistive furnace study, indicating effectiveness of the plasma system. The environmental discharges during the plasma setup runs, after elaborate flue gas management system, were monitored at regular interval and observed to be meeting the national regulator guidelines. Activity in discharge were also monitored continuously and observed to be Below Detection Limit for all runs.

TABLE 2. Details of waste processed and observations from plasma pyrolysis-based incinerator

|  |  |  |  |
| --- | --- | --- | --- |
| Feed waste  Type | Waste  composition | Ratio of Reduction factors with respect to mixed cellulosic wastes | |
| Weight reduction ratio | Volume reduction ratio |
| Mixed Cellulosic | Cotton PPE3 [Higher %] + mops with wooden plug+ papers+ Cardboard box | 1  (as reference) | 1  (as reference) |
| Mixed Rubber and plastics | Postmortem hand gloves+ PVC\* + surgical hand gloves (equal weight) + cardboard box | 0.78 | 0.82 |
| Mixed Cellulosic, rubber and plastics | Cotton ppes+ paper + mops+ cardboard box (~ 70%)  + postmortem hand gloves + PVC + surgical hand gloves (~ 30%) | 0.89 | 0.96 |

*\*PVC: Poly Vinyl Chloride*

## Management of residues from the incinerators

Residual ash having very small volume from each run was collected in standard 200 litres drums. After adequate quantity of ash collected per drum, the ash was immobilized in the cement matrix before eventual disposal to the NSDF. Product properties was evaluated for integrity and stability aspects. Leach rate of the order of 10-4 g/cm2/day was noticed which is quite acceptable for cemented waste products. Mechanical strength for the product was ensured to have strength more than 35 kg/cm2, the limit set for indirect measure of product integrity under disposal conditions. The immobilized ash drums were disposed in engineered disposal modules of NSDF having multi-tier defence in depth concept. The disposal sites have elaborated surveillance schedule in place for environmental survey as well as water & soil sample analysis, in line with international practices. Surveillance results observed are well within the acceptable limits set by regulatory authorities indicating adequate confinement of the disposed wastes.

## Conclusions

From the advanced technological study, it is understood that plasma has very potential application as a uniform process for all potentially contaminated radioactive combustible waste forms. The plasma pyrolysis based incineration technology, indigenously developed at Bhabha Atomic Research Centre, India, has been found much suitable for radioactive waste processing at rated processing rate. End products from the process, i.e. flue gases and ash, are managed effectively meeting environmental disposal criteria. The surveillance results of NSDF show quite good integrity of disposal packages and engineered disposal modules. Based on the feedback and encouraging results from this plasma based setup operational runs, enhanced capacity plant (50 kg/h) is being setup for management of combustible VLLW and LLW wastes at nuclear and radiological facilities of the country.

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