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Enhancing the capability through recycling: Doubling the world's largest muon telescope with almost-buried iron tubes

ABSTRACT

The GRAPES-3 experiment, housing the world's largest muon telescope at 2200 m above sea level in Ooty, is designed to study cosmic-ray effects on Earth. To double the telescope's capability, we have refurbished nearly the same number of proportional counters using iron pipes that are over half a century old. Before their utilization, these pipes were almost-buried 2300 meters underground at the Kolar Gold Field experiment following its decommissioning. The present work outlines various methods employed for repurposing these pipes, using several non-destructive characterization techniques, including X-ray Diffraction (XRD), Infrared Spectroscopy (IR), Scanning Electron Microscopy (SEM), and Energy Dispersive X-ray (EDX) techniques, to identify iron-bearing phases and conversion products. The results obtained from these instrumental techniques have been presented. This extension of the experiment serves as an exemplary demonstration of reducing, reusing, and recycling the iron tubes that would otherwise be discarded on a large scale.

Keywords:*Material characterization; Sustainability; Proportional counter; Recycling; Muon*

1. INTRODUCTION

History should guide the future, else it loses its relevance, confining itself to academia. The Kolar Gold Field experiment [1], which employed a deep underground mine (2300m below the ground) as a cosmic ray neutrino observatory, concluded in 1992 due to the potential closure of the mine for environmental and economic reasons, leaving behind a substantial amount of iron tubes [2]. Interestingly, these iron tubes have the potential to be reused as proportional counters, a type of gaseous ionization detector in the measurement of muon component of extensive air showers, making it the most cost-efficient method. Similar counters were used in the Akeno Air Shower Array managed by the Osaka City University group [3], with identical cross-sectional area and wall thickness (10 cm × 10 cm and 2.3 cm, respectively).

Accordingly, in the early nineties, approximately 7500 counters were transported to Ooty (2200m asl), a popular hill station in the Nilgiris district of Tamilnadu (shown in Figure 1).

These tubes constitute two varieties, most of them zinc galvanized (GST; with ~0.1mm zinc coat) and the rest mild steel tubes (MST). Initially, we used half of those tubes to construct the World's largest muon telescope as part of the GRAPES-3 experiment [4-10], leaving behind the rest to remain stacked for all these years (Figure 1b shows present status). Extensive features of the existing muon telescope as part of the GRAPES-3 experiment with the many physics perspectives are well-documented in literature [11-20]. More recently, a proposal has been made to double the size of the telescope area. These tubes have undergone extensive chemical reactions, making it necessary to understand their status before their use in the experiment. We have used extensive cleaning, following designated protocols, to prepare them for evacuation as proportional counters described elsewhere [20], while extending the present telescope to double its area [19].

Comparison of the X-ray microanalysis, qualitative and semiquantitative data obtained by SEM/EDX, together with the study and interpretation of image SEM (obtained by secondary electrons and backscattered electrons detectors) and micrography video images, the latter obtained by metallographic light microscope [24]. These are the competitive techniques with X-ray

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fluorescence spectrometry (XRF), X-ray diffraction spectrometry (XRD), electron probe microanalysis (EPMA), inductively coupled plasma mass spectrometry (ICP-MS), or inductively coupled plasma atomic emission spectroscopy (ICP-AES), and particle-induced X-ray emission (PIXE) [21-24, 27]. Most of these techniques are often combined with Mössbauer spectroscopy, which is considered a fingerprint technique for identifying iron-bearing phases in the studied samples [21, 22, 26-28].

Figure 1.A view of the transportation of steel pipes by road from the underground KGF laboratory to Ooty, the current site of the GRAPES-3 experiment. Inset (a) shows the arrangement of the counters in the 2300-meter-deep underground laboratory prior to their relocation. Inset (b) shows the current condition of the counters incorporated into the newly designed large-area trackingmuon telescope

The GRAPES-3 experiment, housing the world's largest muon telescope at 2200 m above sea level in Ooty, is designed to study cosmic-ray effects on Earth [6-15]. To double the telescope's capability, we have refurbished nearly the same number of proportional counters using iron pipes that are over half a century old [1-5]. The present work outlines various methods for repurposing these pipes, including implementing custom-made vacuum manifolds and utilizing a few helium leak-detection systems [18-20]. We examined these iron tubes using several non-destructive characterization techniques, including X-ray Diffraction (XRD), Infrared Spectroscopy (IR), Scanning Electron Microscopy (SEM), and Energy Dispersive X-ray (EDX) techniques, to identify iron-bearing phases and conversion products [21-30]. The results obtained from these instrumental techniques have been presented. This extension of the experiment serves as an exemplary demonstration of reducing, reusing, and recycling the iron tubes that would otherwise be discarded on a large scale.

2. EXPERIMENTAL DETAILS

X-ray diffraction (XRD) patterns were obtained for both samples using a Bruker-made X-ray diffractometer with a wavelength (λ) of 1.54Å, scanning at 5° per minute with a scanning range from 10° to 60° to confirm structural identification (D8 advance ECO XRD systems with SSD160 1D Detector) [25, 29, 30]. The SHIMADZU-IR Tracer-100 spectrometer was utilized to record Fourier Transform Infrared (FTIR) spectra of the samples in the wavenumber range of 4000 cm^{-1} to 400 cm^{-1}. This provides information about the complex formation between metal and oxygen bonds and details different vibrational modes of the oxides and metal-metal bonds. The surface morphology of the samples was examined using a Carl Zeiss field emission scanning electron microscope (FESEM) coupled with an EDAX system [29, 30].

3. RESULTS AND DISCUSSIONS

The XRD pattern shows major iron oxide lines for the sample MST. However, there are multiple patterns for GST, mostly indicating Fe-Zn lines with variable composition.

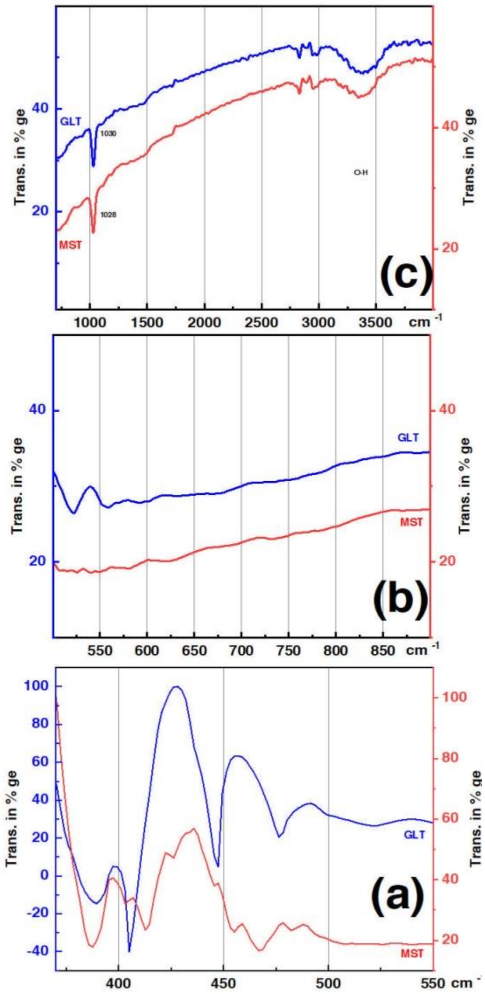

Figure 2. FTIR spectra for MST and GST samples in the 400-4000 cm-1 range. (a) shows the bands in the fingerprint region till 550 cm−1. (b) Shows the 500-900 cm-1, and (c) shows the bands in the region 900 cm-1 to 4000 cm-1 range. The majority of changes are visible in the lower band of the fingerprint region

Figure 2 shows the complex formation and vibrational modes of chemical bonds for MST and GST samples discussed by the FTIR spectrum. Figure 2(a) shows the bands in the fingerprint region till 550 cm^{-1}. Interestingly, this lower region is rich in features, clearly distinguishing between two types of tubes. Figure 2(b) shows the extension to 900 cm^{-1}, and a strong band was observed at 530 cm^{-1} for the GST sample, which is absent in the case of the MST sample. Figure 2(c) shows the spectra's extension till 4000 cm^{-1}. The presence of hydroxyl bond of O-H stretching vibrations can be attributed to a wavenumber range of 3600-3200 cm^{-1} and due to the presence of goethite (α-FeOOH), though it is difficult to quantify from FTIR spectra, being more as a qualitative technique [25, 29, 30]. The presence of peaks at around 2800-3000 cm^{-1} indicates the possible presence of C-H stretching vibration at 2926 cm^{-1}. A strong band was also observed around 1030 cm^{-1} for both types of tubes.

SEM/EDX techniques and metallographic interpretation are well-suited to the object of study as they are conducted on small samples prepared as metallographic test tubes and, therefore, minimize work time and handling. The chemical, qualitative, and semiquantitative analysis has made it possible to characterize different elements.

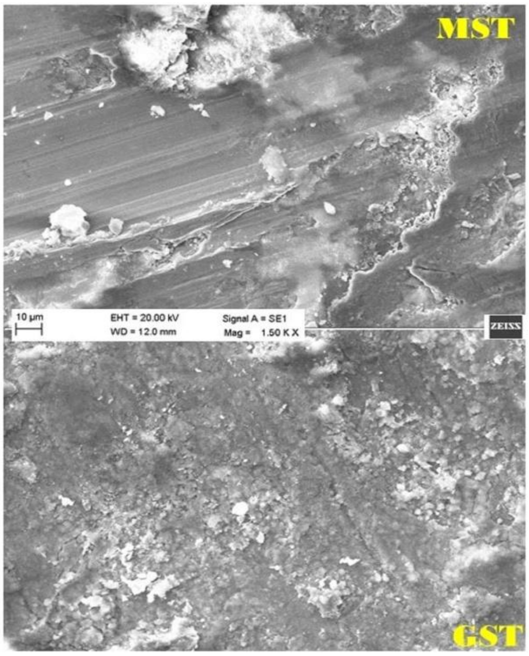

Figure 3. SEM images obtained using a secondary electron detector for the samples: (a) MST and (b) GST. In the case of MST, the presence of more impurities suggests oxidation of the iron. The zinc-galvanized sample shows a more uniform appearance with relatively less oxidation

Figure 3 shows the SEM images obtained by the secondary electron detector of the samples (a) MST and (b) GST. In the case of MST, more impurities indicate oxidization of the iron. Uniform and relatively less oxidization is evident for the zinc-galvanised sample.

Figure 4 shows the distribution of elements and a map of various components in MST (left column) and GST (right column). Iron and oxygen are the dominant elements for MST (matrix element), whereas the presence of zinc (minor element) in a significantly higher proportion is visible for the GST sample.

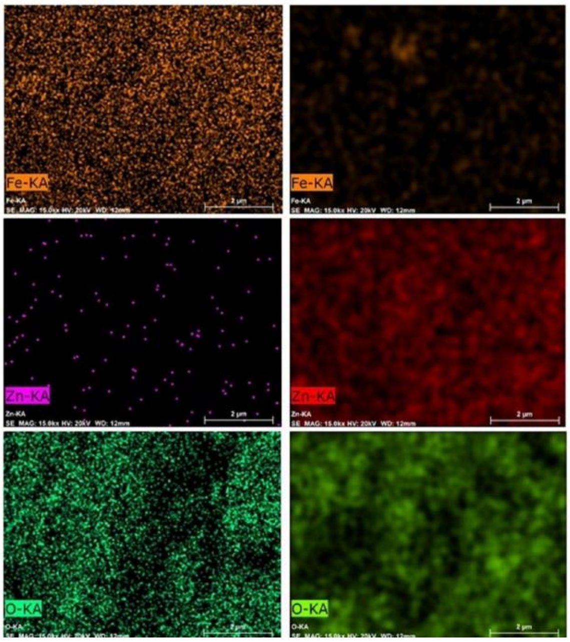

Figure 4. Distribution and map of various elements in MST (left column) and GST (right column). Iron and oxygen are the major dominant elements in MST, whereas a significantly higher proportion of zinc is visible in the GST sample.

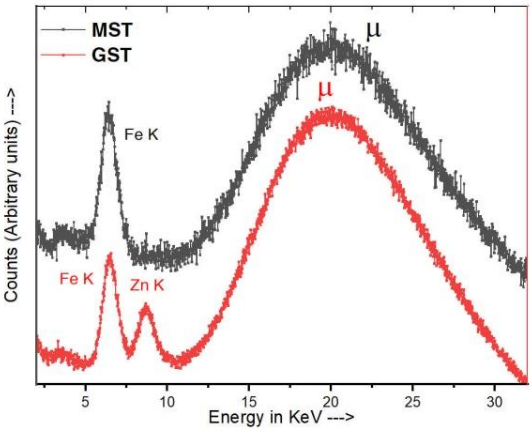

Figure 5. Spectra of pulse height distributions obtained from MST (in black) and GST (in red). The additional zinc K X-ray lines are evidence in GST spectrum. The muon peak at ~20 keV is visible in both spectra

Figure 5 shows the spectra of pulse height distributions obtained from MST (in black) and GST (in red), where the notable differences between the energy loss distribution from the representative MST and GST are evident. MST shows the K_α emission lines of Iron (6.4 keV) and Muon (~20 KeV) loss, whereas GST shows the additional emission line Zinc K_α (8.6 keV), indicating zinc-coated surface [13], complementing the SEM and EDAX outcome.

Figure 6. A view of the present-day GRAPES-3 experimental site. The new muon station is located nearby in a single hall. The old muon stations, situated a bit farther away in four different halls, use the similar KGF counters built more than a quarter-century ago.

Figure 6 shows the picture of the new muon station, while the older ones are far away, built from the same set of steel tubes a quarter century ago [4-6]. Further away are the plastic scintillator detectors, which are visible as white triangles for studying several other features of the cosmic ray spectrum as part of the GRAPES-3 experiment [5-7].

4. CONCLUSIONS AND FUTURE PLAN

In this preliminary report, we revisit the history of a large number of steel counters transported from the KGF underground mine to the mountain-top GRAPES-3 experiment at Ooty. After following a specific cleaning procedure [20], we studied two representative sample tubes, namely MST and GST, using various characterization techniques and presented their outcomes. This study, conducted for the first time on such old samples undergoing varying degrees of chemical changes, yielded promising results. The samples were analyzed using various techniques, including x-ray diffraction, infrared spectroscopy, scanning electron microscopy, and energy dispersive x-rayto identify the major iron-bearing phases and their possible conversion products after exposure to air pollutants in the natural Ooty climate for more than three decades.

While the present world is actively spreading awareness about reducing, recycling, and reusing existing resources, this movement has only gained momentum over the past decade. However, the visionary pioneers of the erstwhile Kolargold field experiments and the present-day GRAPES-3 experiment began implementing well-thought-out ideas more than three decades ago, when the concept of sustainability had yet to take root in many fields. A more detailed and extensive report will be presented to the global community in due course.

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IZVOD

POBOLJŠANJE KAPACITETA RECIKLAŽOM: UDVOSTRUČAVANJE NAJVEĆEG MUONSKOG TELESKOPA NA SVETU SKORO ZAKOPANIM GVOZDENIM CEVIMA

Eksperiment GRAPES-3, u kojem se nalazi najveći muonski teleskop na svetu na 2200 metara nadmorske visine u Utiju, osmišljen je za proučavanje efekata kosmičkih zraka na Zemlju. Da bismo udvostručili kapacitet teleskopa, obnovili smo skoro isti broj proporcionalnih brojača koristeći gvozdene cevi stare preko pola veka. Pre upotrebe, ove cevi su bile gotovo zakopane 2300 metara pod zemljom u eksperimentu Kolar Gold Field nakon njegovog prestanka rada. Ovaj rad opisuje različite metode koje se koriste za ponovnu namenu ovih cevi, koristeći nekoliko nedestruktivnih tehnika karakterizacije, uključujući rendgensku difrakciju (XRD), infracrvenu spektroskopiju (IR), skenirajuću elektronsku mikroskopiju (SEM) i tehnike energetski disperzivnog rendgenskog snimanja (EDX), kako bi se identifikovale faze koje sadrže gvožđe i proizvodi konverzije. Rezultati dobijeni ovim instrumentalnim tehnikama su predstavljeni. Ovo proširenje eksperimenta služi kao primerna demonstracija smanjenja, ponovne upotrebe i reciklaže gvozdenih cevi koje bi inače bile odbačene u velikim razmerama.

***Ključne reči**: Karakterizacija materijala; Održivost; Proporcionalni brojač; Reciklaža; Muon*

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