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Field Implementation of *Pseudomonas fluorescens* for Bioremediation of Single-use Plastic Waste: A Biolayer in Landfill Liner System

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Abstract: Single-use plastic materials are enormously used for packaging daily essentials and sanitary products. Fifteen such packaging materials were identified and collected. Twelve batches of samples were buried in Twelve pits. *Pseudomonas fluorescens* in dextrose medium was applied to six pits, and six pits were subjected to natural degradation to serve as a control. The study was conducted for a period of six months, and samples were recovered after each month. Recovered samples were subjected to a weight loss study and Fourier Transform Infrared (FTIR) spectroscopy analysis. FTIR analysis indicated a shift of the peak towards the weaker side, disappearance of the peak, and reduction in bond energy change in all samples bioremediated with microbial solutions. Reduction in spectral energy associated with shifts in characteristic FTIR peaks was around 0.15 to 45%. Compared to weight loss techniques, FTIR analysis was effective in understanding biodegradation phenomena. CHNS analysis on the soil recovered from the pit revealed that the bioaugmentation technique has raised the C/N ratio of the surrounding soil existing in the pit to 4.5%, which was absent initially. The results signified that this technique could enhance the process of bioremediation of non-recoverable plastic waste to a greater extent.

1. INTRODUCTION

Many of the non-recycled plastic products after its useful life ultimately ends either in soil or water as a waste. More than hundreds of microbes have been identified to degrade plastic polymers (Arutchelvi et al., 2008; Shah et al., 2008; Kumar Sen and Raut, 2015; Montazer et al., 2018; Fesseha and Abebe, 2019; Bahl et al., 2020; Bardají et al., 2020; Merchant et al., 2025) . Microbes use plastic polymers as their source of carbon and mineralise them to carbon dioxide and water (Albertsson and Karlsson, 1990; Reddy et al.,2009; Pérez-García et al., 2025). The success of any scientific finding lies in its field-scale implementation. Earlier bioremediation studies were conducted on a laboratory scale in a controlled environment. Plastic-degrading microbes were isolated from the soil and water samples collected from the dumpsites (Dubey and Thalla, 2025; Iqbal *et al.*, 2025; Tirkey and Upadhyay, 2025). Field bioremediation studies were limited to the soil burial technique. The field studies were conducted by burying the plastic materials directly into the soil without introducing any potential bacterial strains (Orhan, Hrenović and Büyükgüngör, 2004; Vijaya and Reddy, 2008; Shovitri *et al.*, 2017; Tai *et al.*, 2019). The microbial species have to thrive in the existing environmental conditions along with native microbial species. In the present research, the field-scale implementation of bioaugmentation using *Pseudomonas fluorescens* to accelerate the process of plastic biodegradation was studied. The microbes were introduced into the field where fifteen different plastic packaging materials were buried. Based on the effectiveness of the field-scale study, a biolayer is proposed to be introduced in the design of engineered landfill system to enhance the process of biodegradation of plastic waste.

2. MATERIALS AND METHODS

The plastic materials considered for the degradation study are generally used for packaging and are made of HDPE, LDPE, polypropylene, and polylactic acid. Fifteen such wrapping materials of various products used in our daily routines were randomly selected. Particulars of these materials were mentioned in Table 1. Information on the polymer's origin was obtained from the resin identification code (RIC) printed by the manufacturer. Each plastic material was washed with isopropyl alcohol, then dried and cut into 2 cm x 2 cm pieces. These pieces were weighed to an accuracy of 0.1 mg and were attached to a mesh to facilitate easy recovery of the sample at the end of the biodegradation study. The study was conducted at VNR VJIET College, Hyderabad, Telangana, India. Initial characterisation of the soil collected from the field was performed. In the field, 12 pits of 0.5 m diameter and 0.7 m depth were dug. In each pit, meshes attached with plastic pieces were buried in triplicate at different depths to verify the repeatability of the procedure. Schematic layout of test pits considered in the study is given in Fig.1.

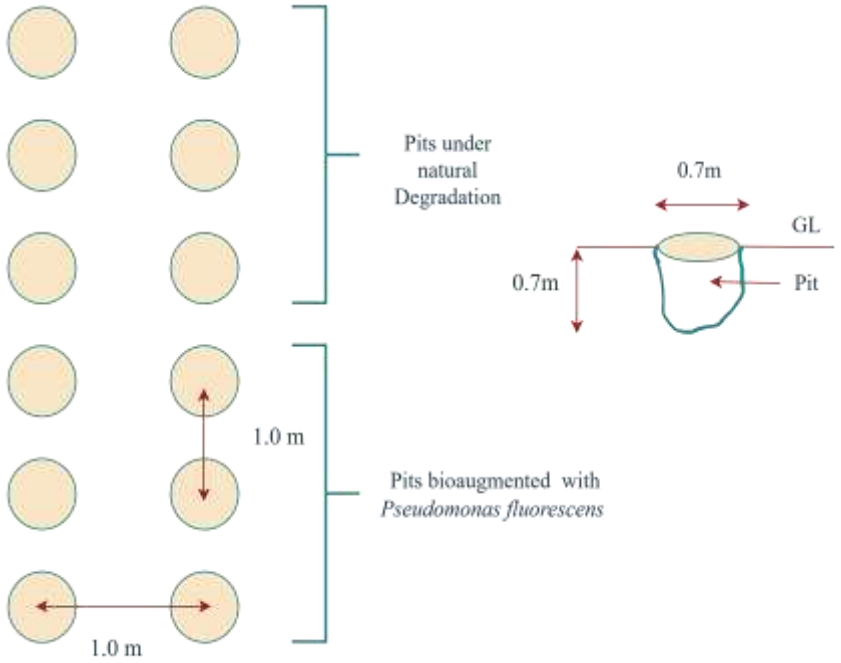


Fig. 1: Schematic representation of test pits of field biodegradation study

Table 1: Different types of single-use plastic materials subjected to field degradation

Label	Description	Type of plastic
1F	Detergent cover	HDPE
2F	Cloth-like white bag	PP
3F	Transparent Orange colored cover	LDPE
4F	Black and white parcel packaging	PP
5F	Transparent cover	HDPE
6F	Aerated Beverage label	PP
7F	Empty Milk packet	LLDPE
8F	Packaging cover	HDPE
9F	Carry bags from textile shop	PP
10F	Food packing silver wrapper	HDPE
11F	Empty oil packet	HDPE
12F	File cover	PP
13F	Shampoo cover	HDPE
14F	Biodegradable white carry bag	Polylactic acid
15F	Instant noodles wrapper	HDPE

Six of these pits were left for natural degradation. As the major objective of the study is to compare the performance of field bioaugmentation technique with natural degradation process, these pits were maintained as control instead of sterile control. The other six pits were bioaugmented with *Pseudomonas fluorescens*. 60 g

of *Pseudomonas fluorescen*s in dextrose medium (powder form), supplied by M/S SOM Phytopharma (India) Ltd., Hyderabad, was dissolved in 6 litres of water. *Pseudomonas fluorescens* is a harmless microorganism, and its biosafety level is 1 according to Canadian and Indian standards. 1 litre of the prepared bacterial solution was applied to each of the treatment pits uniformly throughout the depth. Moisture content of the pit was maintained constant by supplying water periodically. To avoid distrubances, at the end of each month, one pit subjected to natural degradation and another pit subjected to bioaugmentation were excavated. After recovery, the plastic film samples were cleaned with isopropyl alcohol. Percentage weight loss was calculated by comparing the initial and the weights of the sample after recovery, as given in equation (1). For each sample, the maximum amount of weight loss observed in six months of duration is considered.

$$\text{Percentage of weight loss} = \frac{w_a - w_b}{w_a} \times 100\% \qquad \ldots(1)$$

Here,

w_a and w_b are the weights of a plastic film before placing it inside the pit and after recovery.

FTIR analysis was then performed on samples recovered after 6 months of study. The test was directly performed on plastic films. CHNS analysis was performed on the soil samples collected from the field, before commencement of the process. After 6 months, soil samples from the control and bioaugmented pit near the mesh were also subjected to CHNS analysis to assess carbon levels. The samples were tested by preparing KBr pellets.

3. RESULTS AND DISCUSSIONS

3.1 Basic Characteristics of Soil

Soil collected from the field location was tested to understand its basic properties. The properties of the soil are given in Table 2.

Table 2: Basic Properties of soil collected from the study location

Properties	Standard Codes	Results/Values
Field dry density	IS: 2720 (Part 29): 1975	1.6 t/m^3
Water content	IS: 2720 (Part 2): 1973	7.4 %
Specific gravity	IS:2720 (Part 3):1980	2.66
Grain size distribution:	IS: 2720 (Part 4): 1985	Gravel - 5.6 %; Sand - 89.7 %
Sieve and Hydrometer Analysis		Silt - 3.3%; Clay - 1.4%
Soil classification	IS: 1498: 1970	Poorly graded sand (SP)
pH	IS: 2720 (Part 26): 1987	8.82 at 28.6˚C
Electrical Conductivity	IS: 14767: 1973	0.589 mS at 28.6˚C
Salinity	Probe method	0.286 ppt at 28.6˚C

3.2 Field Weight Loss Study

The rate of physical disintegration, expressed as percentage weight loss, was observed for all 15 samples at specified time intervals up to 6 months. The maximum percentage of weight loss observed during the study period for all 15 samples subjected to natural and bioaugmented degradation is shown in Fig. 2. Of the 15 samples, 9 have shown a higher amount of degradation in the presence of *Pseudomonas fluorescens*. A maximum degradation of 34% was observed with the bioaugmentation technique for the transparent cover made of HDPE. Two samples have shown equivalent degradation under both processes (6F and 9F). Samples 7F, 10F, 12F, and 15F exhibit greater weight loss during the natural degradation procedure. These samples were made from LLDPE, PP, and HDPE. The results of the field weight-loss study demonstrate the efficiency of *Pseudomonas fluorescens* in biodegradation under field conditions. However, a weight-loss study may not provide an accurate picture of plastic biodegradation. The samples were attached to the mesh using stapler pins. Physical damage to the material was reported upon recovery due to a stapler-punch hole and sharp particles in the soil.

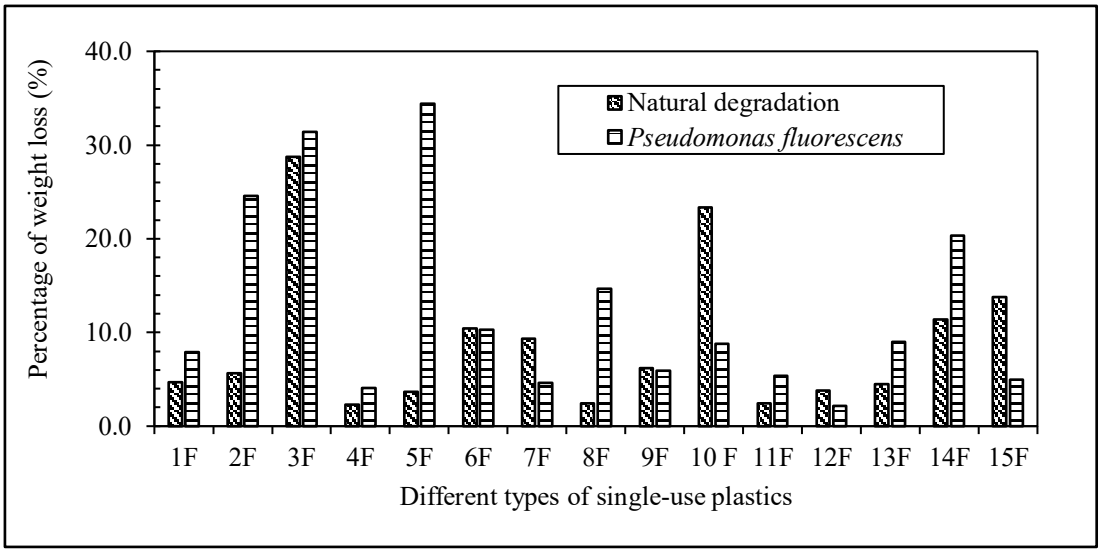


Fig. 2: Percentage of weight loss observed in the field degradation study

3.3 FTIR Analysis

To investigate the changes in the chemical bonds of polymeric hydrocarbon samples subjected to field bioaugmentation and natural degradation, FTIR analysis was performed on the samples recovered from the field after 6 months of degradation. FTIR spectra of all 15 samples with prominent peaks are shown in Figs. 3 to 17. In the FTIR spectra of samples subjected to bioaugmentation, shifts of peaks towards lower wavenumbers and the disappearance of certain peaks were observed compared with samples subjected to the natural process of degradation. In all the single-use plastic samples, peaks corresponding to C-H stretching of the plastic polymer were observed in the 3000-2850 cm^{-1} region. Peaks of C-H deformation were observed around 1500-600 cm^{-1}. Minor peaks due to carbonyl bonds were observed in some samples at 1900-1500 cm^{-1}. Various peaks were observed in the spectra of all samples, except in the spectra of the 6F and 9F samples. However, these two samples have also shown a shift of peaks towards lower wavenumbers.

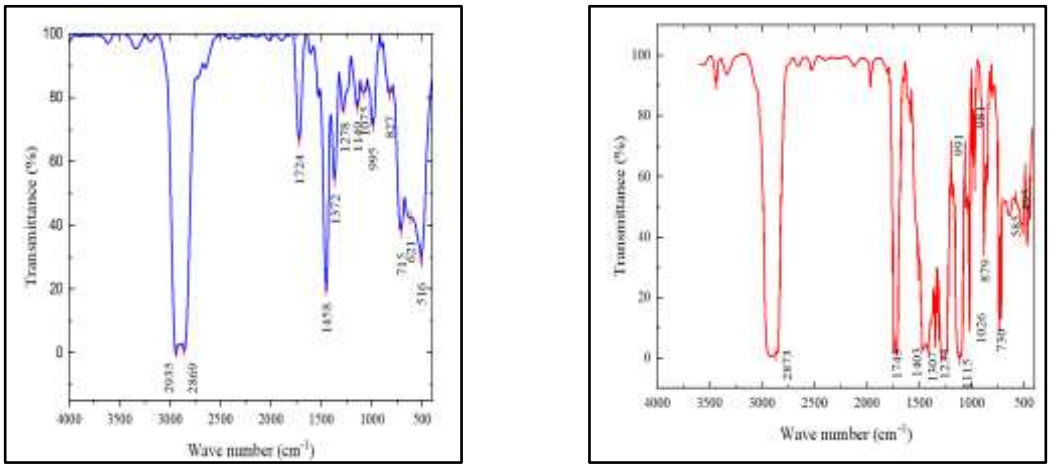
In the bioaugmented samples, reduction of base width of the wide peak, disappearance of peak in C-H region (3000-2850 cm^{-1}) with respect to natural degradation were witnessed in samples 1F, 2F, 12F, 13F and 15F. For the purpose of analysis, the plastic film samples are categorised into different groups based on the origin of the polymeric material with which it is manufactured. The peaks are identified based on the information available in standard literature of FTIR spectroscopy (Coates, 2000; Stuart, 2004; Silverstein, Webster and Kiemle, 2005; Smith, 2011). Changes in spectral peaks are as follows.

3.3.1 FTIR Spectra of HDPE Samples

HDPE has a linear structure, which accounts for its higher density. The material is generally stiff, tough, and opaque (Crawford, 2002; Emblem, 2012). Samples 1F, 5F, 8F, 10F, 11F,, and 15F are films made from HDPE polymer, and the spectral peaks after 6 months of bioremediation study under natural and PF bioaugmented conditions are shown in Figs. 3 to 9. Characteristic spectral peaks of virgin HDPE film include double peaks between 2950-2800 cm-1 representing CH2 asymmetric and symmetric stretching, a pair of split peaks at 1400-1300 cm-1 due to C-CH3 bending, and another set of split peaks around 730-700 cm-1, as reported in the literature. After 6 months of bioremediation, along with these peaks, from the Figs. 3 to 17, many other peaks are also observed. This is because the samples considered in the present study are commercial wrappers that

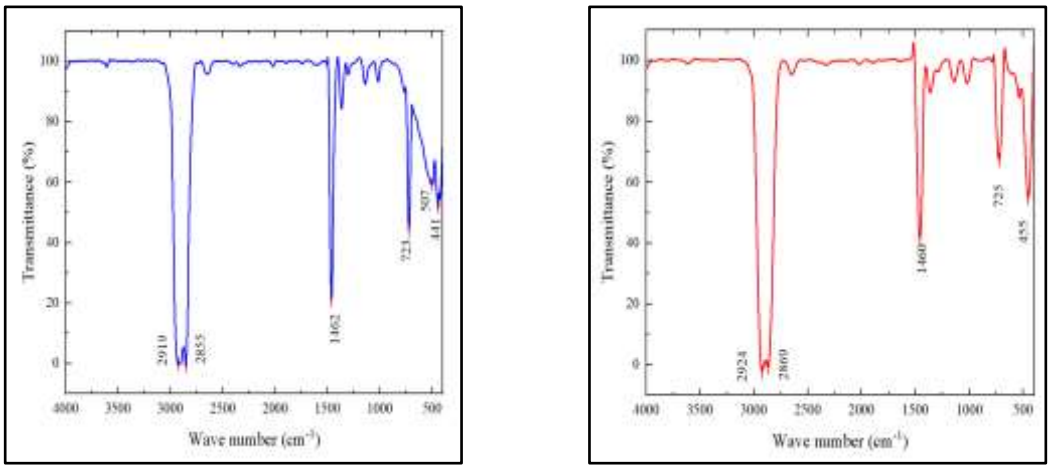
contain antioxidants, surface coatings, additives, colour dyes, and other composite substances. Hence, to investigate microbial activity relative to natural degradation, all spectra from the bioaugmented batch are compared with those of samples subjected to natural degradation.

In Fig. 3 of sample 1F, which is a detergent wrapper, the peak wave numbers got shifted towards the weaker side, and the double peaks in the C-H region became blunt, and a single significant peak appeared. A new peak at around 981 cm-1 corresponding to HDPE oxidation was observed (Stuart, 2004). Peaks shown in Fig. 4 of the 5F sample are identical to those reported by various researchers (Gulmine et al. 2002; Smith, 2011, 2021; Chaudhary and Vijayakumar, 2020). A weak band observed at 507 cm^{-1} in Fig. 4a of natural degradation was absent in the bioaugmented sample due to microbial activity. In Fig. 5, in addition to CH2 stretching and C-CH3 bending, peaks corresponding to the OH bond and weak bands representing carbon triple and double bonds are present. It shows that the material contains HDPE along with other polymeric units. In this case, as a result of bioaugmentation, the broad band from 1500 to 1440 cm^{-1} with a triple peak narrowed to two prominent peaks, and a reduction in peak wavenumbers was observed.



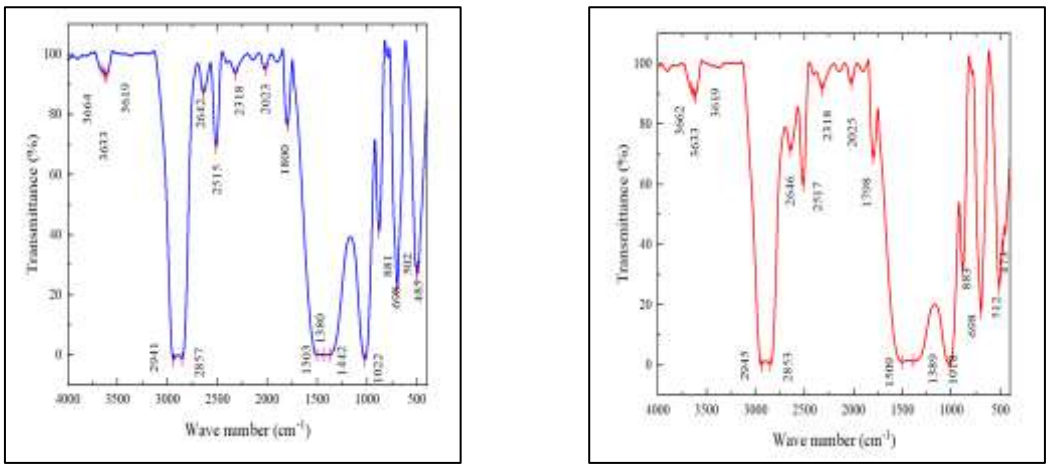
a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

Fig. 3: FTIR Spectrum of field sample - 1F



a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

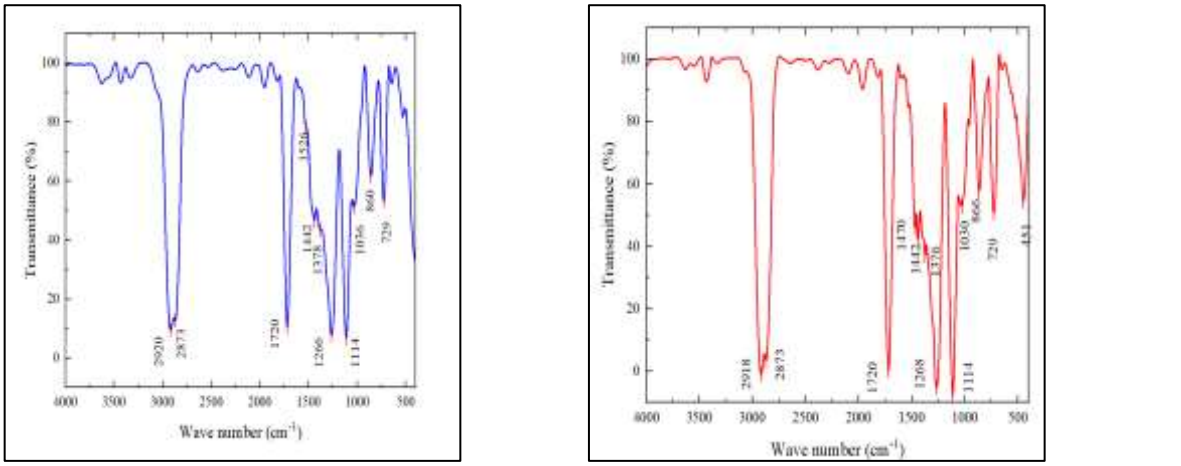
Fig. 4: FTIR Spectrum of field sample - 5F



a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

Fig. 5: FTIR Spectrum of field sample- 8F

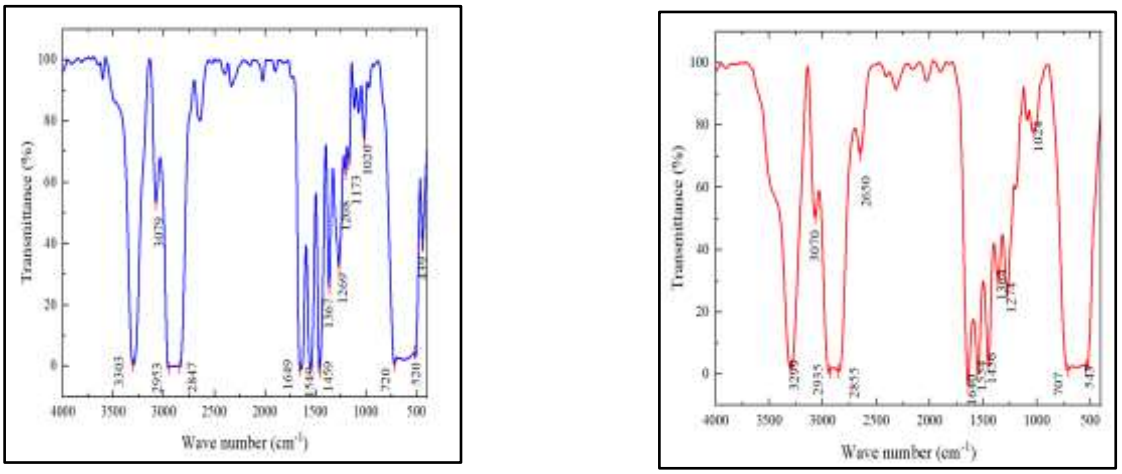
The major spectral change observed in the peaks of sample 10F, other than the shifting of the peak, is the reduction in the appearance of the peak at 1526 cm^{-1} in the bioaugmented sample, which is observed in the naturally degraded sample, as given in Fig. 6.



a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

Fig. 6: FTIR Spectrum of field sample - 10F

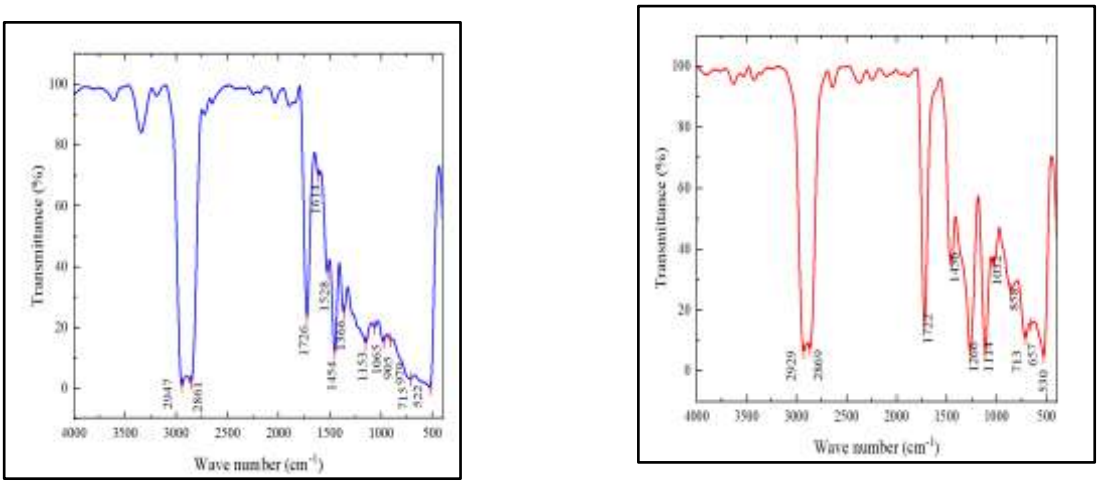
In Fig. 7, the significant bands representing HDPE are the OH group at 3600-3300 cm-1, the aromatic C=C band at 1649 cm-1, C-O stretching at 1269 and 1208 cm-1, and C-O-C stretching at 1173 cm^{-1}. The major change resulting from bioaugmentation, as shown in Fig. 7 b, is the absence of peaks at 1173 cm^{-1} and 1208 cm^{-1}. It should be noted that the peak intensities in the functional group region have decreased.



a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

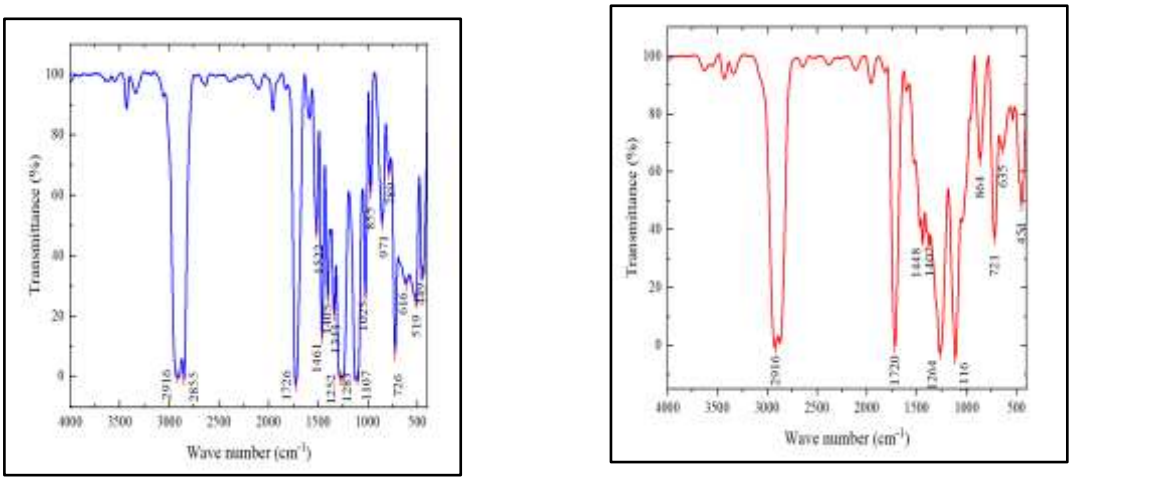
Fig. 7: FTIR Spectrum of field sample - 11F

In Fig. 8, the prominent changes as a result of bioaugmentation are the disappearance of the C=C aromatic ring stretching peak at 1614 and 1528 cm^{-1}. The functional group peaks in the fingerprint region (1500-500 cm-1) have predominantly shifted. Sample 15F has also experienced similar changes in the fingerprint region as depicted in Fig. 9 due to biodegradation of polymeric material. The number of peaks has also decreased.



a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

Fig. 8: FTIR Spectrum of field sample - 13F

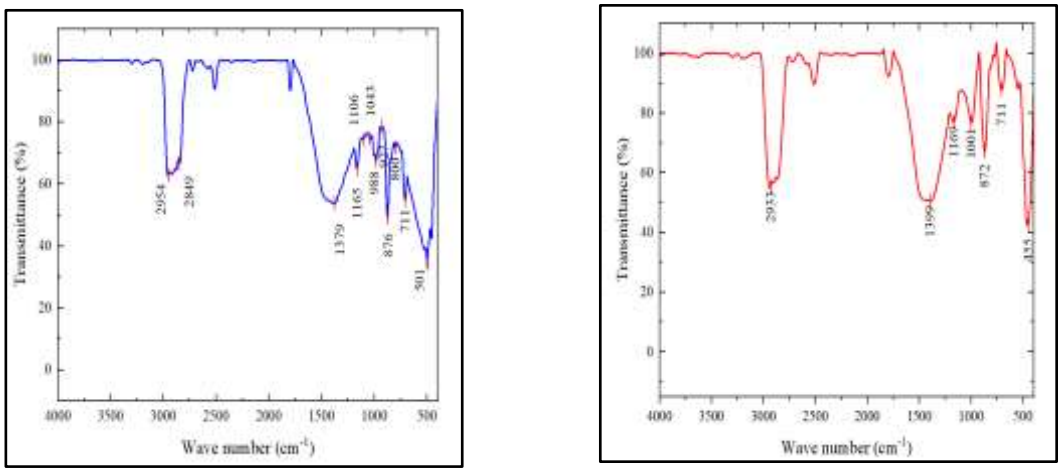


a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

Fig. 9: FTIR Spectrum of field sample - 15F

3.3.2 FTIR Spectra of Polypropylene Samples:

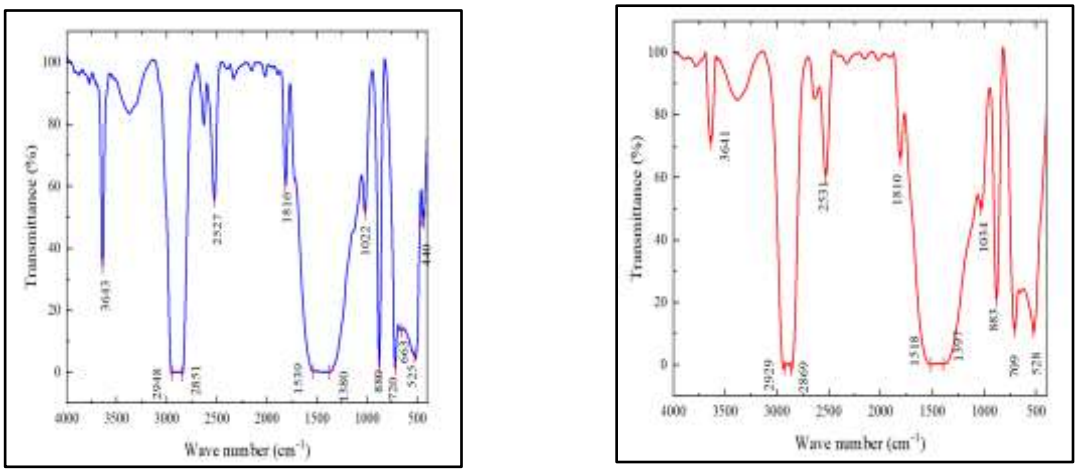
Sample 2F is made out of cloth-like non-woven polypropylene material.. It is worth noting that bags made from these materials are used as a replacement for polyethene carry bags after the plastic ban in many places. This material is also made out of synthetic polymer and is equally non-degradable under natural conditions. In Fig. 10, after biodegradation, the peak at 2849 cm^{-1} corresponding to the symmetric stretching of CH_2 becomes less intense.



a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

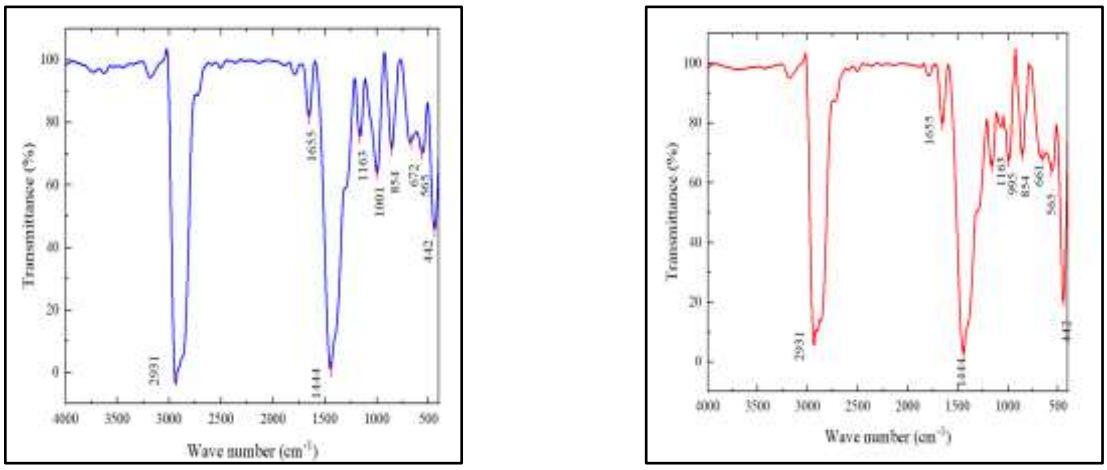
Fig. 10 : FTIR Spectrum of field sample - 2F

Fewer peaks are observed in the fingerprint region (1500-500 cm-1) in the HDPE samples. In Fig. 11, the overall spectrum shows a reduction in peak wavenumbers. The peaks of the weaker band region at 663 and 440 cm^{-1} were absent in bioaugmented samples. The spectral peaks of samples 6F and 9F showed only a reduction in peak wavenumbers at the end of the bioaugmentation study, as shown in Figs. 12 and 13.



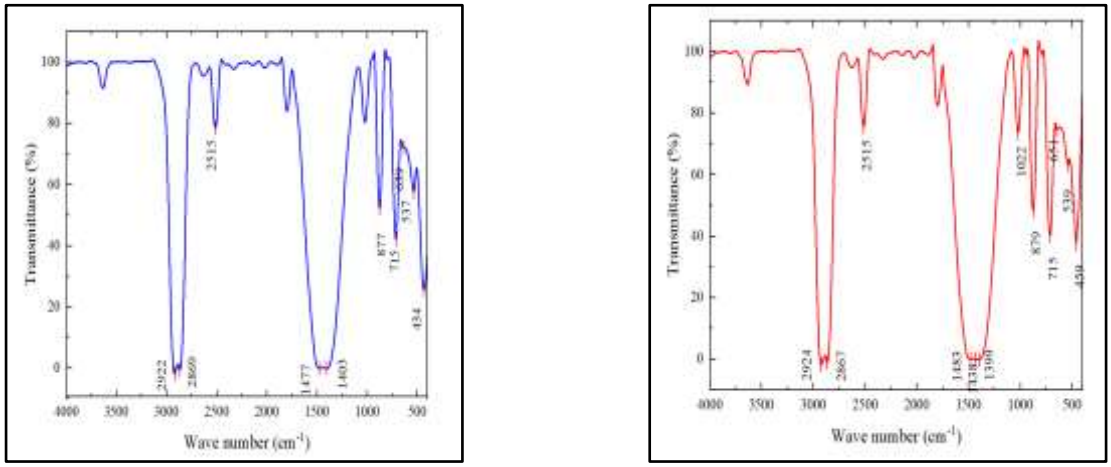
a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

Fig. 11: FTIR Spectrum of field sample - 4F



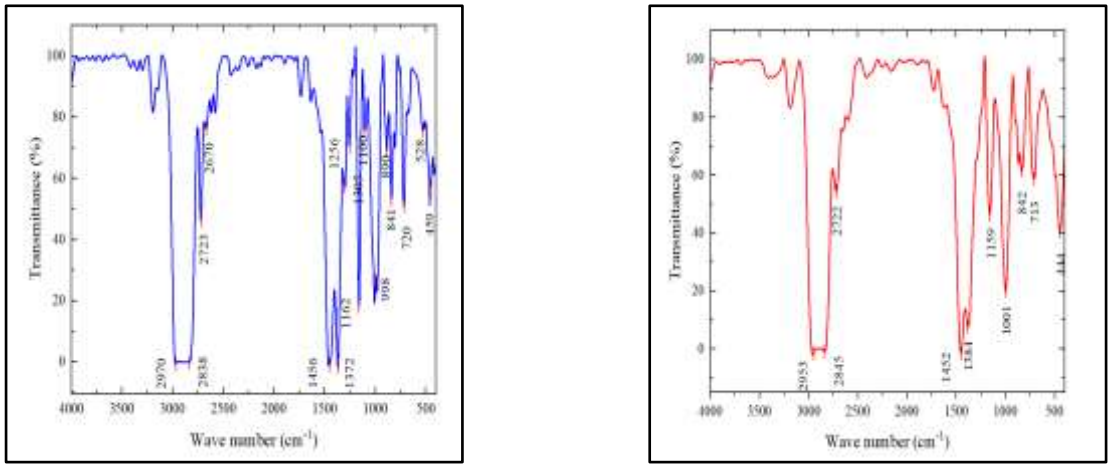
a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

Fig. 12: FTIR Spectrum of field sample - 6F



a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

Fig. 13: FTIR Spectrum of field sample - 9F



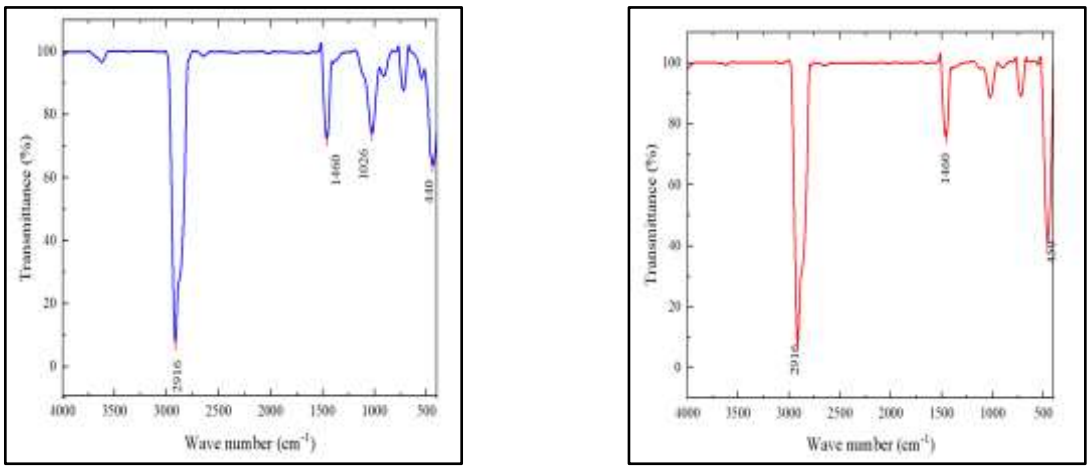
a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

Fig. 14: FTIR Spectrum of field sample - 12F

Sample 12F is comparatively harder than the polymer considered in the present study, and its spectral variations are given in Fig. 14. Similar to samples 13F and 15F, the number of prominent peaks in the fingerprint region has reduced. A side peak at 2670 cm^{-1} in the sample subjected to natural degradation is due to the presence of impurities and can be discarded.

3.3.3 FTIR Spectrum of LDPE Sample

The structure of LDPE contains a long chain of carbon atoms with complex side chains (Crawford, 2002; Montazer, Najafi and Levin, 2020).This results in the lower density of the polymeric material. Sample 3F is a transparent thin carry bag made out of LDPE, and its spectral variations due to bioaugmentation are given in Fig. 15. A peak at 1026 cm^{-1} of C- C skeletal vibrations has become comparatively less intense in the bioaugmented sample.

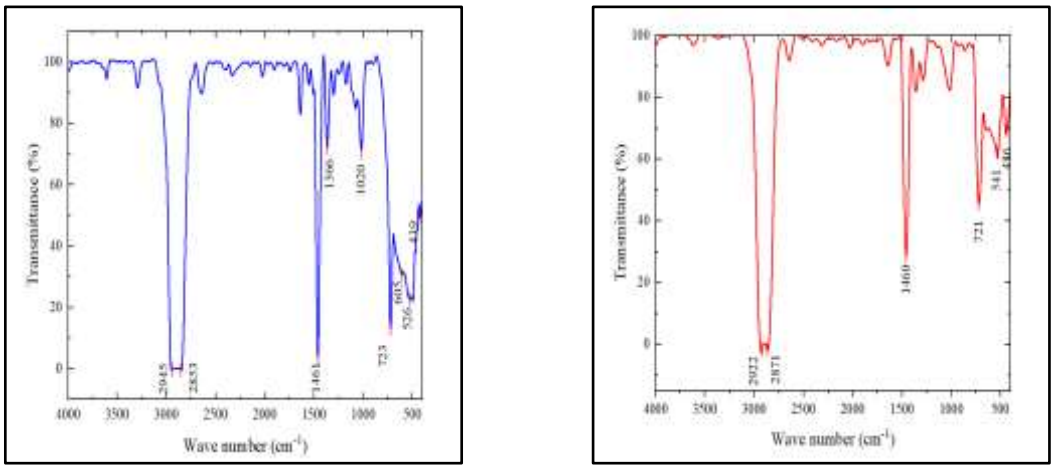


a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

Fig. 15: FTIR Spectrum of field sample - 3F

3.3.4 FTIR Spectrum of LLDPE Sample:

In comparison to LDPE, the side chains of LLDPE are short, and its density is slightly greater than that of LDPE. By comparing the FTIR spectra given in Fig. 16 after degradation study, peaks due to CH_2 bending at 1366 and cm^{-1} a peak at 1020 cm^{-1} due to C-C skeletal vibrations become less intense in the bioaugmented sample.

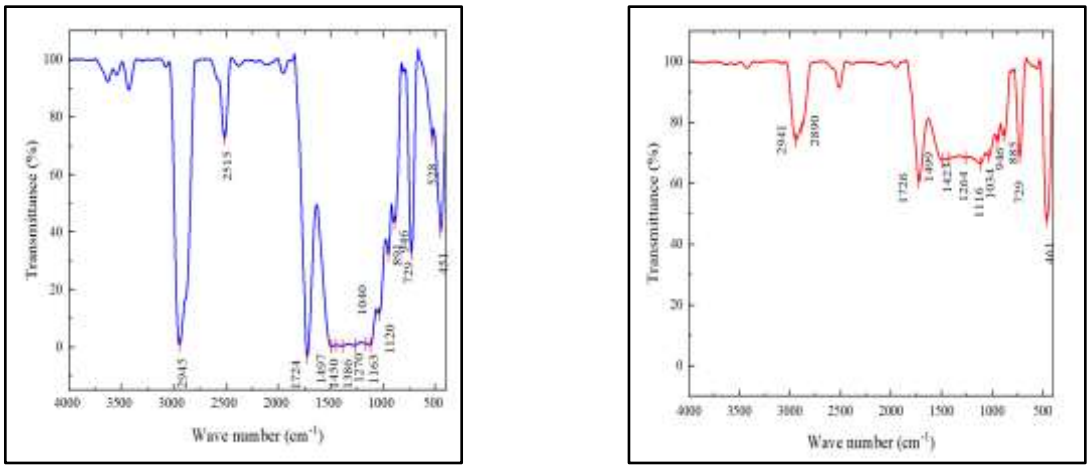


a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

Fig. 16: FTIR Spectrum of field sample - 7F

3.3.5 FTIR Spectrum of Polylactic Acid Sample

Polylactic acid is a biodegradable polymer derived from natural substances that contains lactic acid (Shah et al. 2008; Bahl et al. 2020; Chamas et al. 2020; Wei and Wierckx, 2021). There is a considerable reduction in the intensity of overall spectral peaks of the bioaugmented sample in comparison to the sample subjected to natural degradation, as observed in Fig. 17, due to a reduction in the thickness of the film. The sample is biodegradable under natural conditions.



a) Natural degradation b) Bioaugmented with *Pseudomonas fluorescens*

Fig. 17: FTIR Spectrum of field sample - 14F

As given by Singla et al. (2012), the material has several closely spaced peaks in the fingerprint region. A peak at 1386 $cm^{-1,}$ indicating CH_2 rocking and another peak in the weak band region at 528 cm^{-1} are degraded in the bioaugmented sample.

The major changes in the FTIR spectral peaks of bioaugmented and naturally degraded samples are given in Table 3.

Table 3: Summary of FTIR Analysis

Sample ID	Major FTIR Peak Changes after Bioaugmentation	Key Spectral Observation
1F	Shift of peaks to lower wavenumbers; double C–H peaks became blunt; new peak at ~981 cm^{-1}	Evidence of HDPE oxidation and weakening of C–H bonds
2F	Reduced intensity of CH_2 symmetric stretching peak at 2849 cm^{-1}; fewer peaks in fingerprint region	Partial degradation of polypropylene
3F	Reduced intensity of C–C skeletal vibration peak at 1026 cm^{-1}	Structural weakening of LDPE chains
4F	Overall reduction in peak wavenumbers; disappearance of weak bands at 663 and 440 cm^{-1}	Loss of weaker functional groups due to biodegradation
5F	Weak band at 507 cm^{-1} disappeared in treated sample	Microbial activity altered HDPE-associated bands
6F	Only peak shifting toward lower wavenumbers observed	Limited but detectable molecular alterations
7F	CH_2 bending and C–C skeletal vibration peaks became less intense	Reduction in polymer chain integrity
8F	Broad triple peak in 1500–1440 cm^{-1} narrowed to two peaks; reduced peak positions	Significant alteration in methyl-related bands
9F	Only reduction in peak wavenumbers observed	Minor spectral changes indicating slow degradation
10F	Disappearance of peak at 1526 cm^{-1}	Decrease in functional group intensity
11F	Peaks at 1173 and 1208 cm^{-1} disappeared; reduced intensity in fingerprint region	Loss of C–O–C and C–O stretching bands
12F	Reduced number of peaks in fingerprint region; i peak at 2670 cm^{-1} absent	Structural simplification after biodegradation
13F	C=C peaks at 1614 and 1528 cm^{-1} disappeared	Major changes in fingerprint region and aromatic structures
14F	Overall reduction in spectral intensity; degradation of peaks at 1386 and 528 cm^{-1}	Natural biodegradability enhanced under bioaugmentation
15F	Disappearance/ of peaks in fingerprint region; reduced number of peaks	Overall weakening of polymeric material

3.3.6. Bond Energy Change of Field Samples

The energy of an organic bond is directly proportional to its wave number. The higher the wave number, the stronger the bond. From the spectral analysis of the sample subjected to natural degradation and bioaugmentation, it is observed that each material exhibits variations across different peaks. Commercially utilised polymeric packaging materials contain various chemical bonds in addition to virgin polymeric bonds. To account for all the changes occurring across the entire spectra of samples subjected to natural degradation and bioaugmented with PF, the bond energy change of each spectrum was calculated as explained using the peak wavenumbers above the threshold height, following equation (2) (Smith, 2011), and is depicted in Fig. 18.

$$E = hc\upsilon \quad (2)$$

where E is energy change in Joules, h is Planck's constant of 6.626×10^{-34} Joule second, c is speed of light (3×108 m/s), and υ is wave number (m^{-1})

The change in bond energy for all the bioaugmented samples was lower than that for samples subjected to natural degradation. This indicates the technique's efficacy under field conditions. Sample 8F has the highest bond energy due to the presence of a greater number of methyl-related bands in the high-frequency region. The largest decrease in bond energy with respect to the natural degradation process was observed in the 15F sample, at around 45%. This sample was found to be made out of HDPE. The reduction in bond energy change with respect to the natural degradation process ranges from 0.85-45%, 0.15-44%, 17%, 24%, and 9% for HDPE, PP, LDPE, LLDPE, and PLA samples. The samples made of the same polymeric material have shown different degrees of decrease in the bond energy change. This is attributed to the fact that each sample was manufactured differently for various commercial wrapping purposes, with different thicknesses, colour prints, and surface coats.

A smaller decrement in the biodegradable PLA sample is due to the sample having undergone considerable changes during natural degradation, and relatively fewer variations were observed under bioaugmented conditions. It must also be noted that the bond energy change of biodegradable plastic is greater than that of other synthetic polymers. Hence, the change in bond energy does not indicate whether the material is degradable.

It only compares the changes and loss of bond strength in a material before and after degradation. As the weight-loss technique accounts only for physical changes, only 9 samples were reported to degrade better than in the natural process. In the case of FTIR analysis, internal changes at the molecular level were investigated. Hence, this gives a better picture of the bioremediation process. As the FTIR spectra of samples recovered after 6 months were compared in Fig. 18, it may not be meaningful to include error bars.

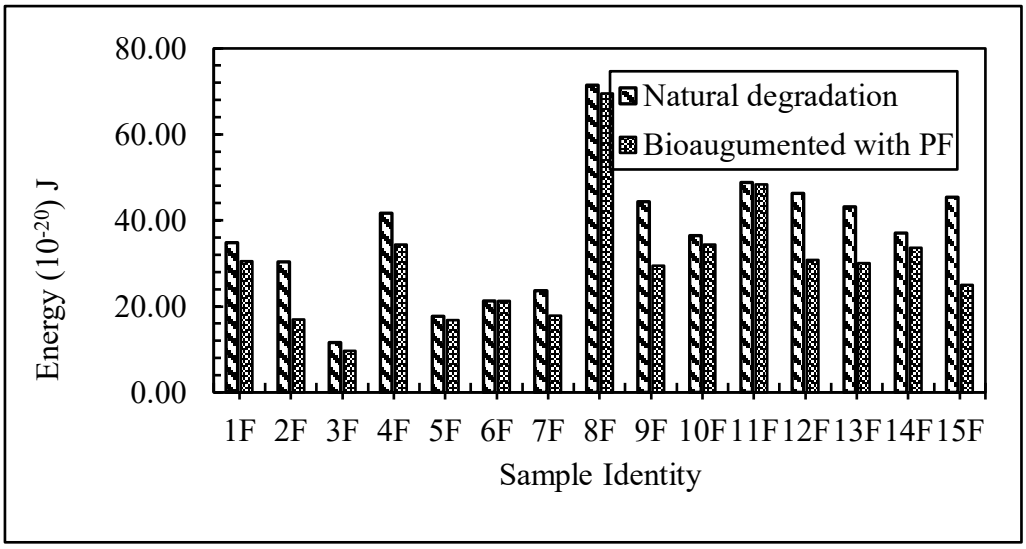


Fig. 18: Bond energy change of field samples from the FTIR spectral peak

3.4 CHNS Analysis

As the soil obtained from the site is homogeneous, CHNS analysis was directly performed on the oven-dried samples. CHNS analysis of the samples recovered from the site before the commencement of the test, from the control pit and from the pit bioaugmented with PF after 6 months are given in Table 4. Initially, the soil collected at a depth of 0.7 m before the commencement of the study contained no traces of carbon. No carbon was observed in the control pit even after 6 months of treatment. The carbon content of the pit bioaugmented with PF was 1.92%. This can be attributed to biomass deposited by microbial activity. The presence of biomass resulting from biodegradation was also accounted for by Ardisson et al. (2014).

In the field study, the soil before the commencement of the study had no carbon content. Soil samples collected after 6 months of bioaugmentation were tested for carbon levels after removing buried plastic films and were

found to have increased due to the deposited biomass from the bioaugmentation technique. Due to microbial activity in the bioaugmented pit, the C/N ratio of the sample increased to 4.5%, which was initially absent.

Table 4: CHNS Analysis of field samples

S. No.	Soil Samples	N (%)	C (%)	H (%)	S (%)
1	Before treatment	0.49	0	0.73	0.42
2	Control pit after 6 months	0.56	0	0.81	0.23
3	PF treated pit after 6 months	0.43	1.92	0.64	0.15

4.7 Proposal of Biolayer in Landfill Liner System

Fig. 19 shows a schematic diagram of the biolayer proposed for the landfill liner system. In an engineered landfill, unrecoverable waste is disposed of daily, forming a daily cell. The daily cell is covered with a soil-like fraction present in the landfill, referred to as daily cover (Warmadewanthi et al. 2021). This daily cover can be bioaugmented with potential plastic-degrading microbes, forming a biolayer. In the present study, bioaugmentation with *Pseudomonas fluorescens* was found to be effective in the bioremediation of plastic wastes. Many such plastic-degrading microbes that are within biosafety level 1 must be studied under a landfill environment. The technique can then be extensively implemented in engineering landfills on a large scale. However, challenges associated with large-scale implementation, including environmental variability, microbial survivability, long-term monitoring and operational feasibility must be further studied.

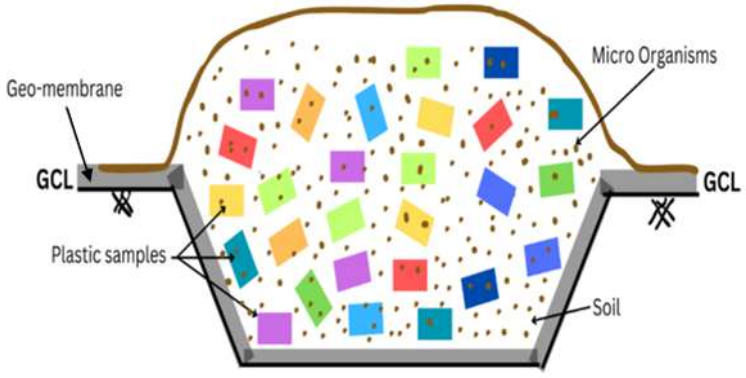


Fig. 19 : Proposal of biolayer in landfill liner system

5. CONCLUSIONS

The study involved a preliminary investigation of a field-scale bioaugmentation technique using FTIR analysis. The following conclusions are derived from the present research work.

- Bioaugmentation using *Pseudomonas fluorescens* has enhanced the degradation of polypropylene material by a maximum of 4.3 times and that of polythene-based material by 9.3 times in terms of weight loss percentage.
- It has also been observed that the FTIR study gives a better representation of the bioremediation process than the field weight loss study. FTIR spectra of bioaugmented field samples indicate the absence of C-H peaks and a shift of major peaks towards the weaker side.
- For the same type of base polymer, degradation rates vary in different samples of the same classification in both the weight loss study and FTIR bond energy calculations.
- After field bioaugmentation using *Pseudomonas fluorescens*, the carbon level and C/N ratio of the soil have increased to 4.5%, which was absent before treatment.

The success of the bioaugmentation process in the field under open atmospheric conditions signifies that this technique can be used to design a biolayer in an engineered landfill system. Field-scale bioaugmentation technique can be further investigated using CO_2 evolution studies, thermal characterisation technique, molecular weight measurement and SEM analysis.

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