RESULTS

4. RESULTS

4.1. MONITORING THE DEGRADATION OF POLYMER FILMS IN URINE

Monitoring the degradation of urine pH is a critical parameter to evaluate the degradation of polymers (Experiments I and II). In Experiment I, it was discovered that the degradation of all polymers resulted in a decrease in the pH of alkalized urine (Fig. 11), with the most change observed in urine where PVOH films were stored, up to 47.2%. The average pH drop was less than one pH unit, with the least change observed in urine where PP films were stored. For Experiment II, a non-significant decline ($p<0.05$) in the pH of urine was observed from day 2 to day 4 for 0.05 mm films stored at 20 °C, but a significant decline ($p<0.001$) was noted from day 4 to day 8. The decline in pH was also significant ($p<0.001$) at every sampling day for PLLA film samples at 45 °C and different thicknesses of PLLA films at both 20 °C and 45 °C.

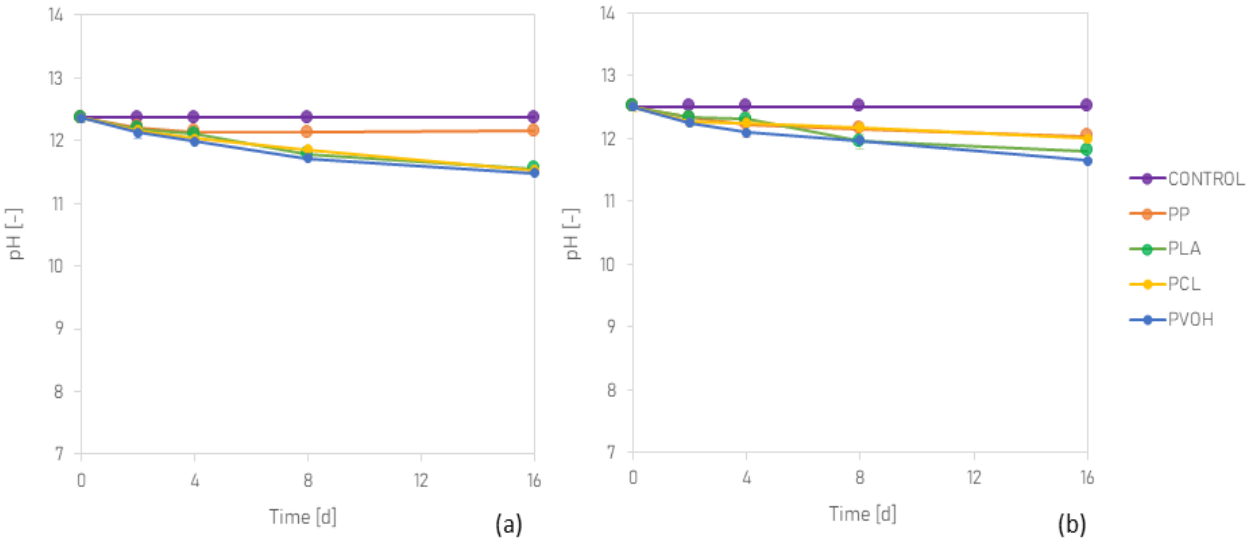

***Figure 11**: Change in pH of $Ca(OH)_2$ dosed (a) CF 1 urine and (b) CF 2 urine, over sixteen days due to degradation of different polymers: polypropylene (PP), polylactic acid (PLA), polycaprolactone (PCL) and polyvinyl alcohol (PVOH). Polymer films of 2 cm diameter and 2 mm thickness were placed in 80 mL urine at 20 °C for 16 days and destructively sampled on every sampling day. The data was collected for duplicates (n=2) and the standard deviation was in the range of ± 0.007-0.1 (too small to be visible in the curves) (Experiment I).*

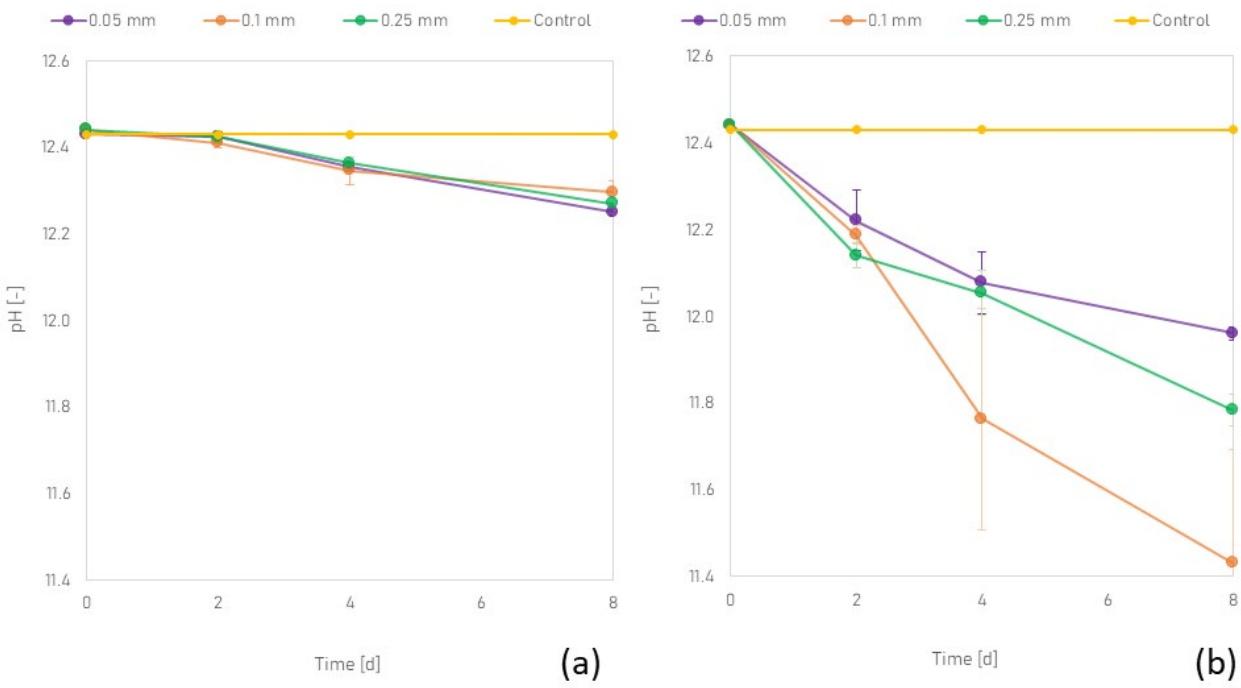

***Figure 12**: Change in pH of $Ca(OH)_2$ dosed urine in the presence of PLLA films of different thicknesses (0.05, 0.1, and 0.25 mm) at (a) 20 °C and (b) 45 °C for eight days. PLLA was fabricated into films with different thicknesses (0.05 mm, 0.1 mm and 0.25 mm) and stored in $Ca(OH)_2$ dosed urine for eight days (Experiment II).*

Another crucial parameter to monitor polymer degradation is the rise in COD . In Experiment I, the initial COD of CF 1 urine and CF 2 urine was 6.12 g L^{-1} and 9.86 g L^{-1}, respectively (Fig. 13). The degradation of the polymers over time increased the COD concentration of urine. In contrast, there was no change in the COD concentration of urine in the controls. After sixteen days, the degradation of polymers in CF 2 urine was higher than in CF 1 urine, as indicated by the greater overall increase in COD in CF 2 urine. The degradation of PVOH films in urine resulted in the largest increase in COD after sixteen days, whereas, urine with PCL films showed the minimum increase.

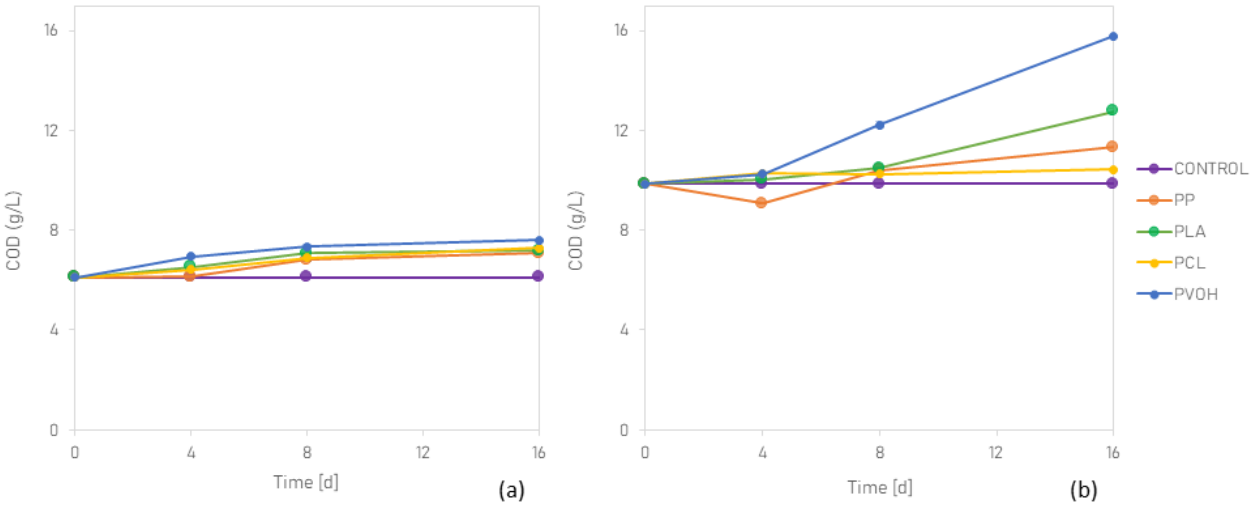

***Figure 13**: Change in pH of $Ca(OH)_2$ dosed (a) CF 1 urine and (b) CF 2 urine, over sixteen days due to degradation of different polymers: polypropylene (PP), polylactic acid (PLA), polycaprolactone (PCL) and polyvinyl alcohol (PVOH). Polymer films of 2 cm diameter and 2 mm thickness were placed in 80 mL urine at 20 °C for 16 days and destructively sampled on every sampling day. The data was collected for duplicates (n=2) and the standard deviation was in the range of ± 0.007-0.1 (too small to be visible in the curves) (Experiment I).*

The quantification of polymer degradation was accomplished through molecular weight analysis using GPC (Experiments I and II). It was observed that all polymer films experienced a decline in both the number average and weight average molecular weights after being stored for sixteen days in CF 2 urine (Table 6). Among the films, PVOH films showed the most notable degradation, as evidenced by the reduction in molecular weights (36.7% and 47.2% for number average and weight average, respectively), followed by PLA films (25% and 12.2% for number average and weight average, respectively).

***Table 6**: Change in number average (M_n), weight average (M_w), calculated poly dispersity index (PDI) and degradation (D %) of polymer films stored in Concentration Factor 2 $Ca(OH)_2$ dosed fresh urine at 20 °C after sixteen days obtained by GPC (Experiment I).*

Polymer film	Retention time (min)	M_n (Da)	M_w (Da)	PDI	D % for M_n	D % for M_w
Virgin PP	7.8	2600	44700	1.6	-	-

PP in CF2 urine (Day 16)	7.3	24600	40200	1.6	7.5	10
Virgin PLA	5.9	131500	188600	1.4	-	-
PLA in CF2 urine (Day 16)	6.1	98600	163600	1.6	25	13
Virgin PCL	7.2	27000	40000	1.4	-	-
PCL in CF2 urine (Day 16)	7.2	27000	42600	1.5	0.2	-6.7
Virgin PVOH	6.1	126600	151700	1.1	-	-
PVOH in CF2 urine (Day 16)	8.36	80100	80100	1	36.5	47

In Experiment II, it was observed that PLLA films stored at 45 °C showed greater degradation than those stored at 20 °C (Table 7). Specifically, the 0.05 mm films stored at 45 °C exhibited a degradation of 25% and 13.2% (number average and weight average, respectively), while the films stored at 20 °C showed a degradation of 3.8% and 19.5% (number average and weight average, respectively).

***Table 7**: Change in number average (M_n), weight average (M_w), calculated poly dispersity index (PDI) and degradation (D %) of PLLA films stored in $Ca(OH)_2$ dosed fresh urine at 20 °C and 45 °C after two days obtained by GPC (Experiment II).*

Film	**Retention time (min)**	**M_n (Da)**	**M_w (Da)**	**PDI**	**D% for M_n**	**D% for M_w**
Control 0.05 mm	5.96	132000	189000	1.4	-	-
0.05 mm at 20 °C in urine (Day 2)	6.10	127000	152000	1.1	4%	19.5%
0.05 mm at 45 °C in urine (Day 2)	6.18	99000	164000	1.6	25%	13%

The presence of moisture can also contribute to the degradation of polymer films, as demonstrated by the quantification of weight loss and swelling of the films (Experiment I). Water-swellable polymers, such as PVOH, absorb water before disintegrating, resulting in increased swelling. Among the films, PVOH films exhibited the highest swelling (142% in CF 1 and 135% in CF 2), while PVOH and PLA films experienced the greatest weight loss. Specifically, PLA films lost 30% (CF 1) and 33% (CF 2) of their original weight and PVOH films lost 15% (CF 1) and 27% (CF 2) (Fig. 14).

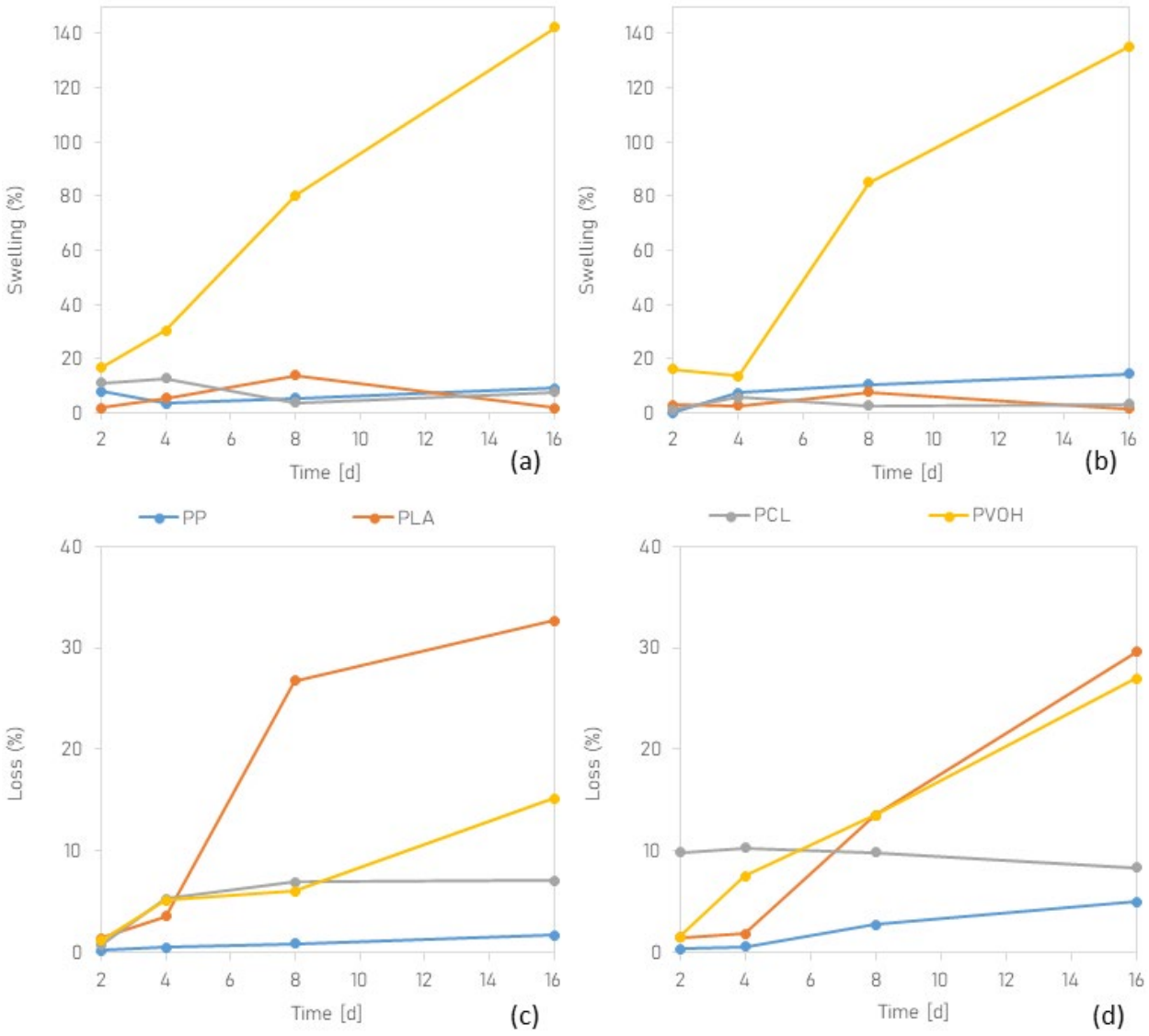

Figure 14: *(a, b) Percentage swelling and (c, d) percentage weight loss (c, d) of polymer films made from polypropylene (PP), polylactic acid (PLA), polycaprolactone (PCL) and polyvinyl alcohol (PVOH) and stored in (a, c) concentration factor (CF)1 and (b, d) CF2 $Ca(OH)_2$ dosed urine. Swelling is a measure of water intake by the polymer relative to its initial weight, weight loss is a measure of the reduction in weight of the polymer due to degradation relative to its initial weight. Values obtained in single measurements (Experiment I).*

XRD was utilized to assess the degradation of semi-crystalline polymers in urine with an alkaline pH (Experiment II). The initial crystallinity index (X_c) of the PLLA film was 44.6%. After being immersed in Mili-Q water for 8 days at 20 °C and 45 °C, there was little to no change in the X_c of the 0.5 mm films. The X_c of the 0.5 mm films immersed in $Ca(OH)_2$ dosed fresh urine for two days decreased to 33.4% at 20 °C and 33.9% at 45

°C, while the X_c of the 0.1 mm PLA films increased to 59.3% at 20 °C and decreased to 39% at 45 °C. The X_c for the 0.25 mm thick films immersed in $Ca(OH)_2$ dosed fresh urine for two days at 20 °C was 45.7%, while the X_c at 45 °C was 43.3% (Fig. 16).

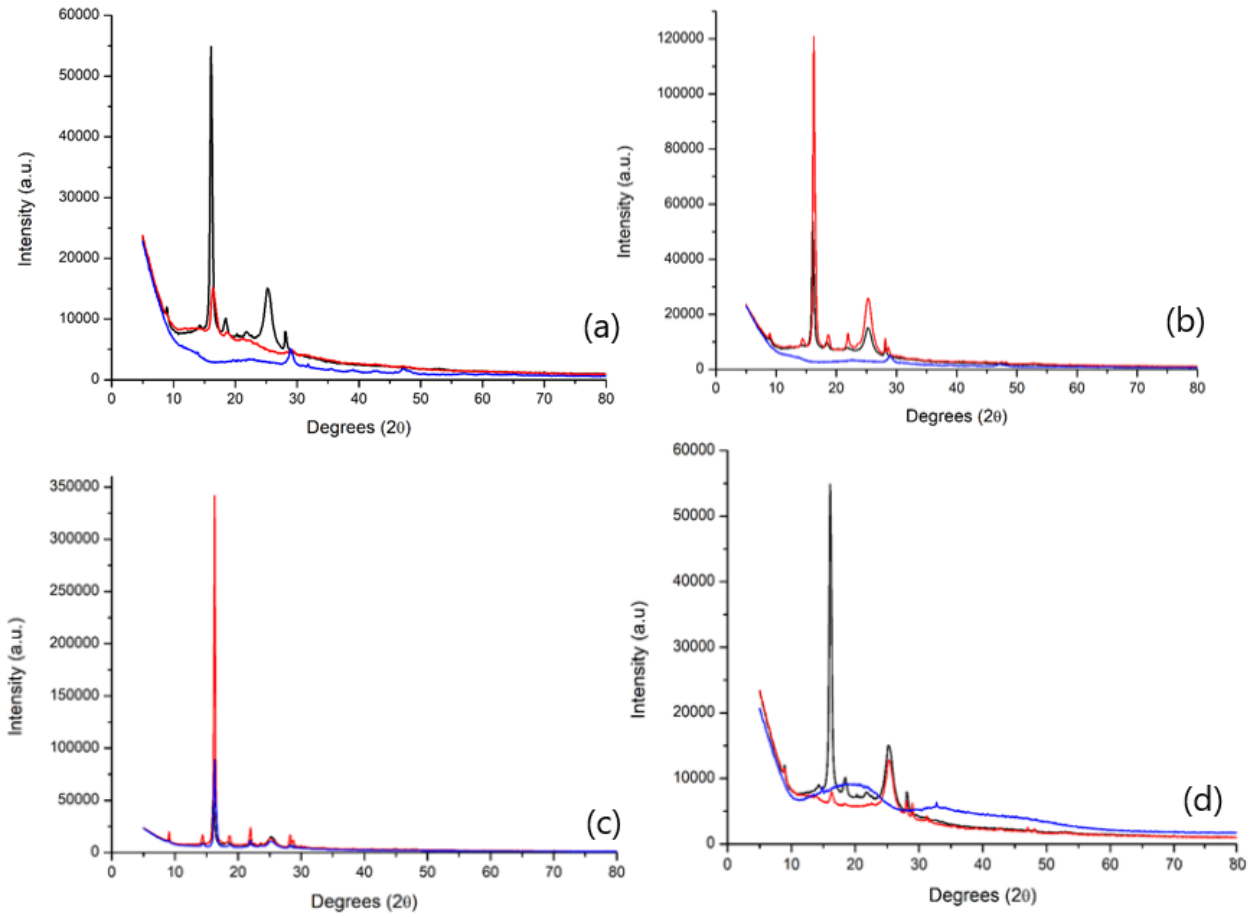

Figure 15: *PXRD curves in the range 2Θ = 10-70° of PLLA films degraded in $Ca(OH)_2$ dosed fresh urine (day 2) (a) 0.05 mm, (b) 0.1 mm (c) 0.25 mm (d) 0.05 mm film degraded in Mili-Q water (day 8) [Black = virgin PLLA, Red = 20 °C, Blue = 45 °C] (Experiment II).*

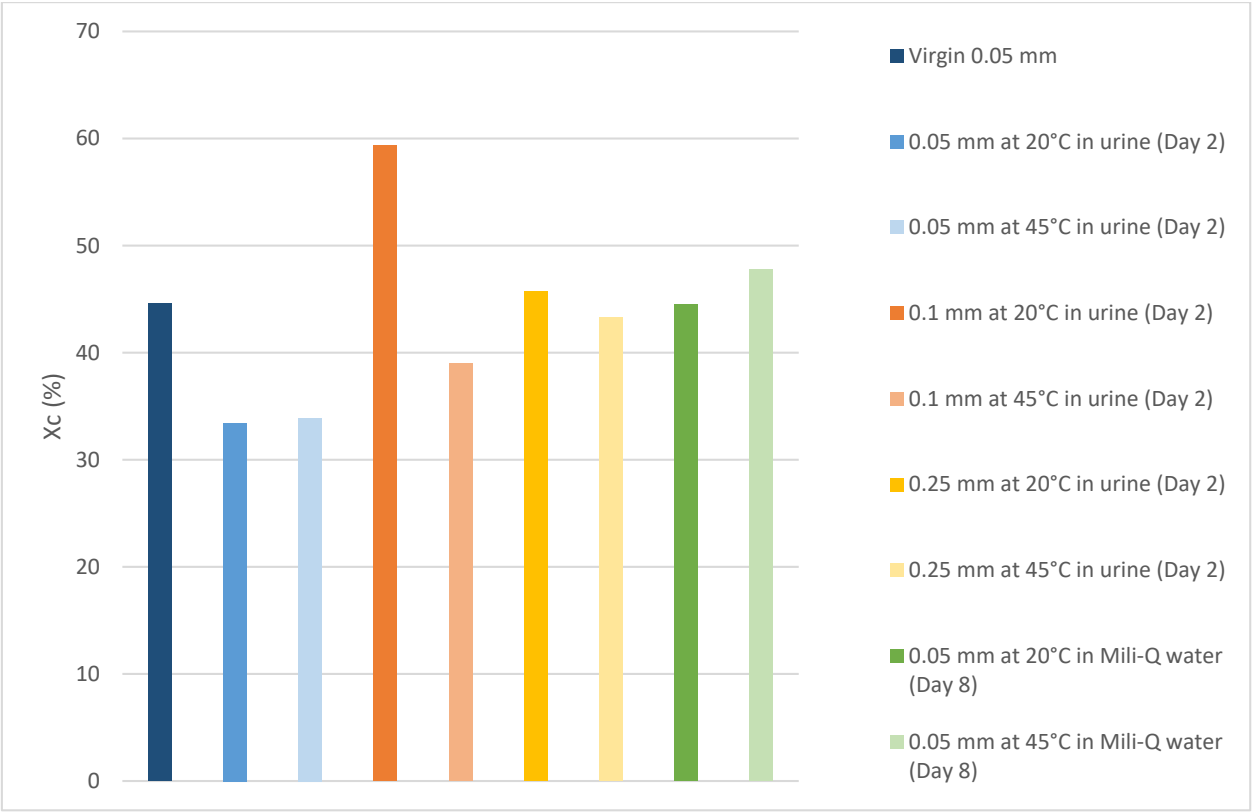

Figure 16: *Degree of crystallinity (X_c) of different PLLA films [Urine samples on day 2, Mili-Q water samples on day 8]. X_c was calculated by dividing the area under the peaks by the total area under the XRD curves (Experiment II).*

The visual evaluation also showed signs of degradation of the polymer films. Evaluating the pictures of the PLLA films from every sampling day showed signs of degradation (Experiment II). Degradation was more in the PLLA films stored at 45 °C than at 20 °C. The films stored in urine also degraded faster than the films stored in Mili-Q water (Fig. 17).

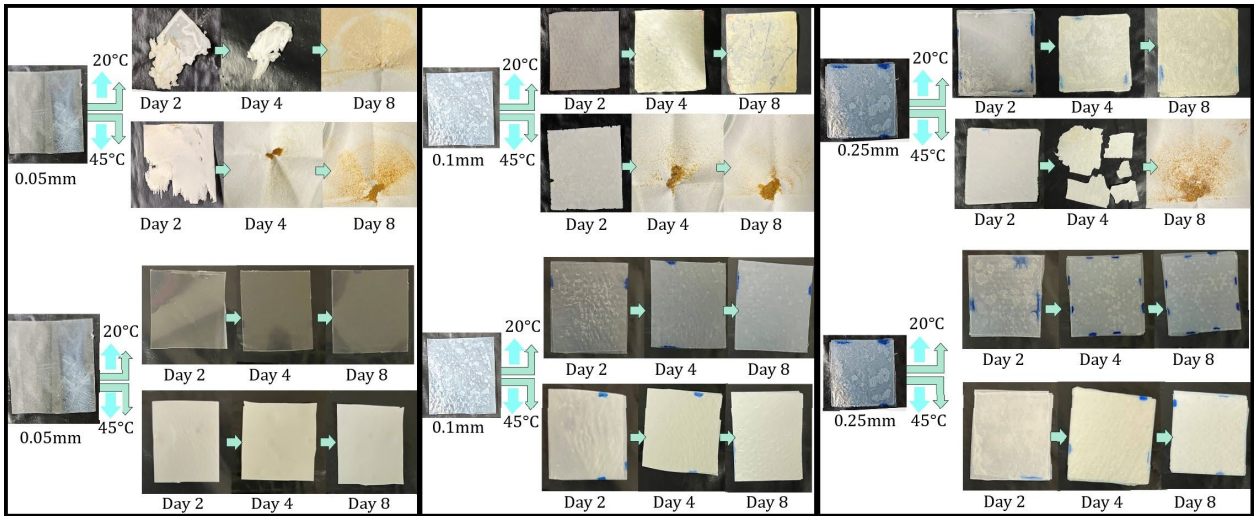

***Figure 17**: Degradation of PLLA films stored in $Ca(OH)_2$ dosed fresh urine (top row) and Mili-Q water (bottom row) and stored for different periods (day 2, 4 and 8) and at different temperatures (20 °C and 45 °C). The films were collected after passage through a filter paper with pore size 3-5 µm, dried at 40 °C for 24 hours and stored at room temperature (Experiment II).*

Fig. 18 (a) shows a one-layered pouch with 0.2 g KOH encased within while Fig. 18 (b) shows the same pouch after 2 days in CF 1, pH 14 urine (Experiment III). The breakdown of the pouches was faster in pH 14 urine as compared to pH 11 urine. The one-layer pouch was completely broken down in CF1, pH 14 urine by day eight and formed a white residue (Fig. 19 (b)) which is likely to be KLa while the 2 layered pouches still had not completely broken down (Fig. 19 (a)). The 3 layered pouch was intact.

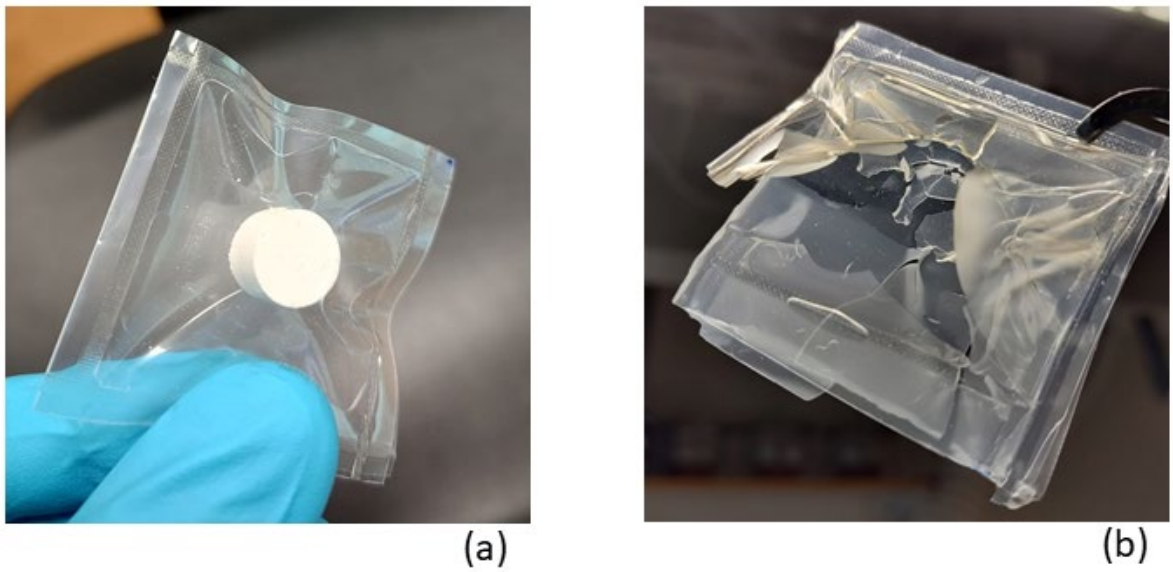

Figure 18: *(a) A one-layered PLLA pouch encased with a KOH pellet made by heat sealing two 0.05 mm thick identical films, (b) the same pouch after 2 days in Concentration Factor / pH 14 urine (Experiment III).*

Figure 19: *(a) a two-layered pouch in Concentration Factor 1/ pH 14 urine after eight days. The pouch is broken down but still structurally intact releasing some amount of KOH in the urine, (b) a one-layered pouch in Concentration Factor 1/ pH 14 urine after eight days. The pouch has completely broken down and formed a white immiscible residue, likely to be KLa (Experiment III).*

The 2 layered pouches were completely broken-down by day twenty-four and day thirty-two in pH 11 and pH 14 respectively while the 3 layered pouches were only partially broken down till day thirty-two in both the pH.

The scanning electron microscopy (SEM) images at 1000x or 2000x magnification provide a detailed analysis of the polymer degradation in urine. The virgin polymer films exhibited smooth morphology with only minimal defects, except for PVOH, which had various imperfections due to the solvent escape during the solution polymerization process (Fig. 23 (a)) (Experiment I). After storage in CF 1 or CF 2 urine at 20°C for 16 days, all the polymer films displayed visible imperfections (Figs. 20-23). The PLA films showed signs of structural breakdown with visible deposits, which were likely a mixture of degraded polymer and precipitates formed in the urine (Fig. 21 (b) and (c)). The PCL

films exhibited marginal swelling after storage in alkaline urine for 16 days (Fig. 22 (b) and (c)).

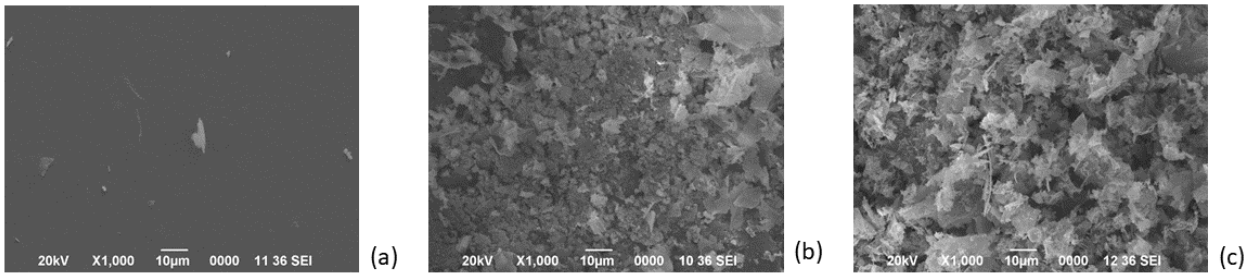

***Figure 20**: Scanning electron microscope (SEM) images at 1000x magnification of (a) virgin polypropylene (PP) film and PP film stored in (b) CF 1 and (c) CF 2 $Ca(OH)_2$ dosed fresh urine at 20 °C for 16 days (Experiment I).*

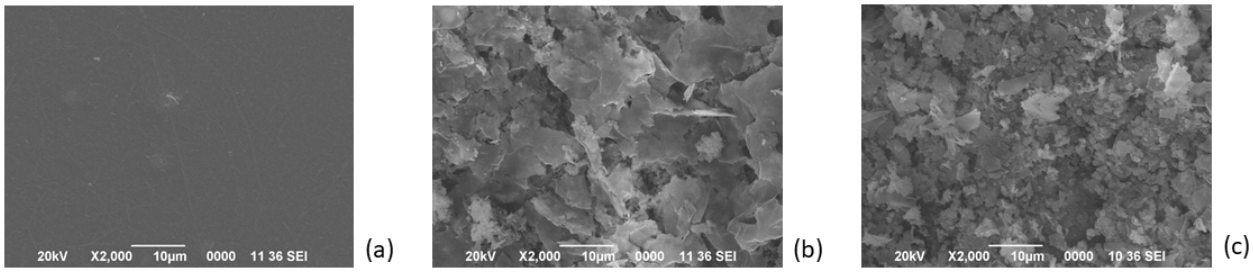

***Figure 21:** Scanning electron microscope (SEM) images at 1000x magnification of (a) virgin polylactic acid (PLA) film and PLA film stored in (b) CF 1 and (c) CF 2 $Ca(OH)_2$ dosed fresh urine at 20 °C for 16 days (Experiment I).*

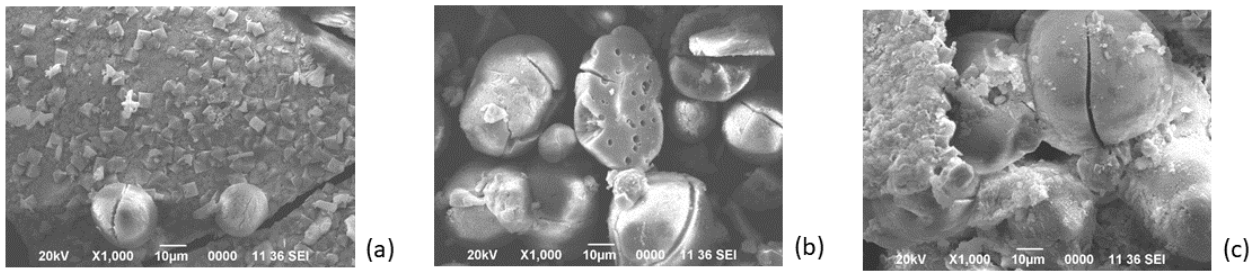

***Figure 22**: Scanning electron microscope (SEM) images at 1000x magnification of (a) virgin polycaprolactone (PCL) film and PCL film stored in (b) CF 1 and (c) CF 2 $Ca(OH)_2$ dosed fresh urine at 20 °C for 16 days (Experiment I).*

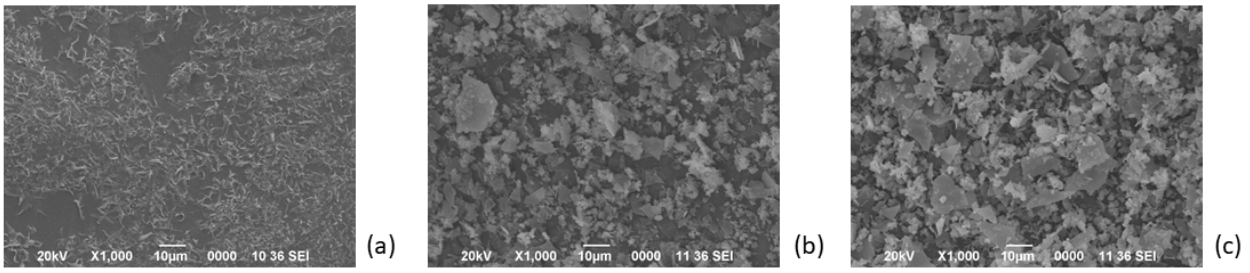

***Figure 23**: Scanning electron microscope (SEM) images at 1000x magnification of (a) virgin polyvinyl alcohol (PVOH) film and PVOH film stored in (b) CF 1 and (c) CF 2 $Ca(OH)_2$ dosed fresh urine at 20 °C for 16 days (Experiment I).*

4.2. IDENTIFYING THE BY-PRODUCTS

The Fourier transform infrared (FT-IR) spectra were utilized to identify the by-products formed during the polymer degradation (Experiments II, III, and IV). Experiments II and III investigated the degradation of PLLA in the presence of excess calcium and potassium in the urine while Experiment IV assessed the degradation of KPAc and NaPAc due to repeated absorption and extraction of moisture.

The FT-IR spectra of the virgin PLLA (black curve in Fig. 24 and 25) exhibit the characteristic peaks of PLLA, such as a broad peak around 3400 cm^{-1} and sharp peaks at 2900 cm^{-1}-2800 cm^{-1}, 1600 cm^{-1} and 1050 cm^{-1} (Deka et al., 2023). However, new peaks were detected in the FT-IR spectra of PLLA films placed in $Ca(OH)_2$ dosed fresh urine for two days (Fig. 24 (a)), indicating the formation of new functional groups. The FT-IR spectra of the PLLA films immersed in Mili-Q water for eight days also showed various new peaks (Fig. 24 (b)), although no visible structural changes in the films were observed. Broad peaks around 1500 cm^{-1}-1000 cm^{-1} indicate the formation of carboxylate (-COO) group.

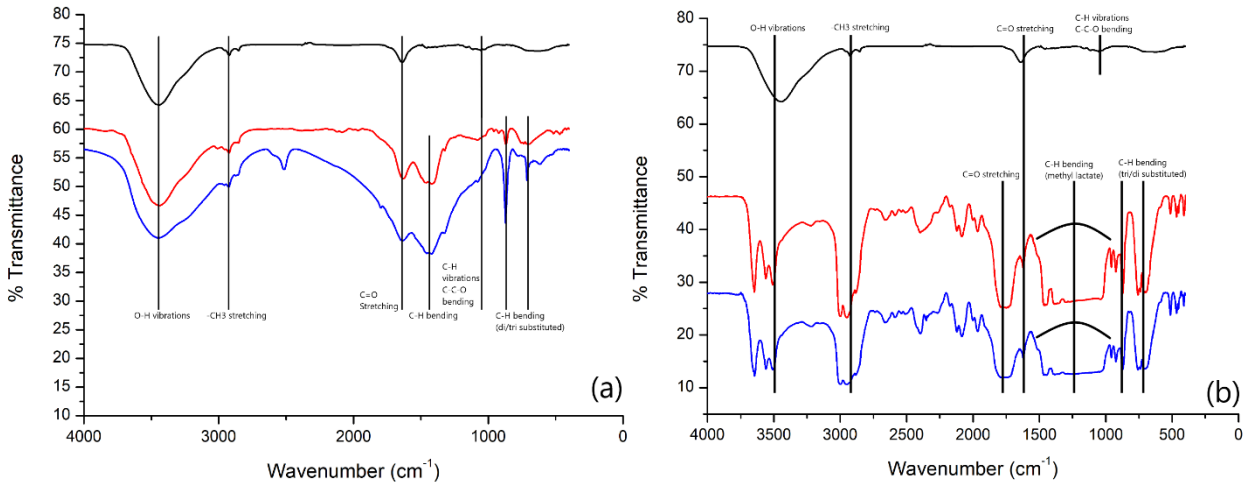

***Figure 24:** FT-IR spectra from 4000 cm^{-1} - 400 cm^{-1} (a) 0.05 mm film degraded in $Ca(OH)_2$ dosed fresh urine (day 2), (b) 0.05 mm film degraded in Mili-Q water (day 8) [Black = virgin PLLA, Red = 20 °C, Blue = 45 °C] (Experiment II).*

The FT-IR spectra of PLLA pouches stored in NaOH dosed urine revealed new peaks (Experiment III). The peaks around 850 cm^{-1} and 600 cm^{-1} are attributable to the C-C bending of the lactate group, while the peaks around 1500 cm^{-1} to 1300 cm^{-1} indicate the formation of lactate salts. The FT-IR spectra of the PLLA pouch stored in pH 11 NaOH dosed urine without KOH pellets for sixteen days showed a mostly flat curve, except for the peaks for –CH vibrations at 3400 cm^{-1} and $–CH_3$ stretching at 2700 cm^{-1} to 2600 cm^{-1}.

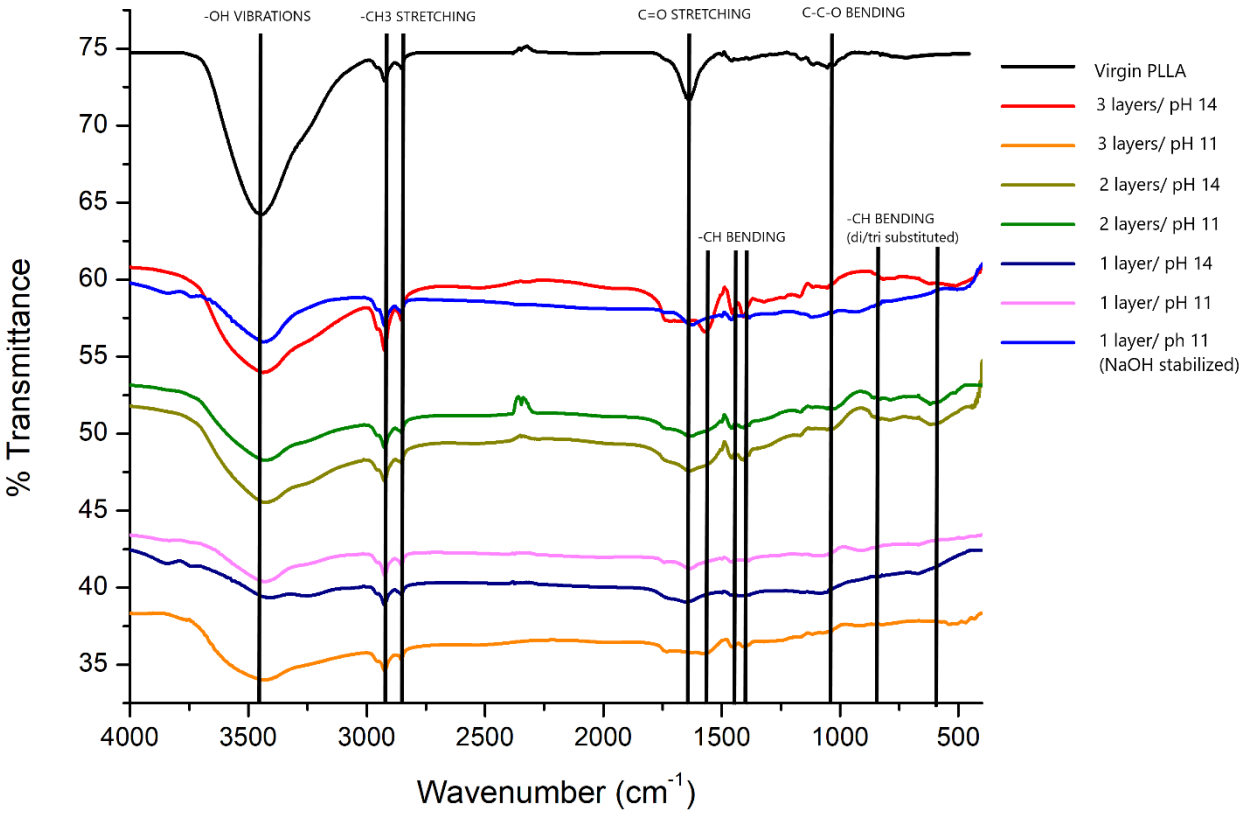

Figure 25: *FT-IR spectra from 4000 cm^{-1} - 400 cm^{-1} of degraded PLLA pouches and residue. The semi-degraded pouches and residue were obtained by filtering the urine through a Grade 390, Ahlstrom Munksjö filter paper. It was then dried at 40 °C for 24 h (Experiment III).*

The FT-IR spectra of fresh SAPs exhibited all the characteristic peaks of polyacrylates (black and red curves in Fig. 25), such as a broad peak around 3350 cm^{-1} and sharp peaks around 2800 cm^{-1}, 1700 cm^{-1}, 1450 cm^{-1} and 1050 cm^{-1} (Karagöz & Yücel, 2020)(Experiment IV). However, new peaks were detected in the FT-IR spectra of the reused SAPs (blue and green curves in Fig. 26), indicating the formation of new functional groups. For instance, the sharp peaks around 3000 cm^{-1} demonstrate a shift in

the $–CH_3$ bond stretching. The sharp peaks around 1750 cm^{-1} are due to C=O stretching, and 1400 cm^{-1} is due to $–CH_3$ or $–CH_2$ bending.

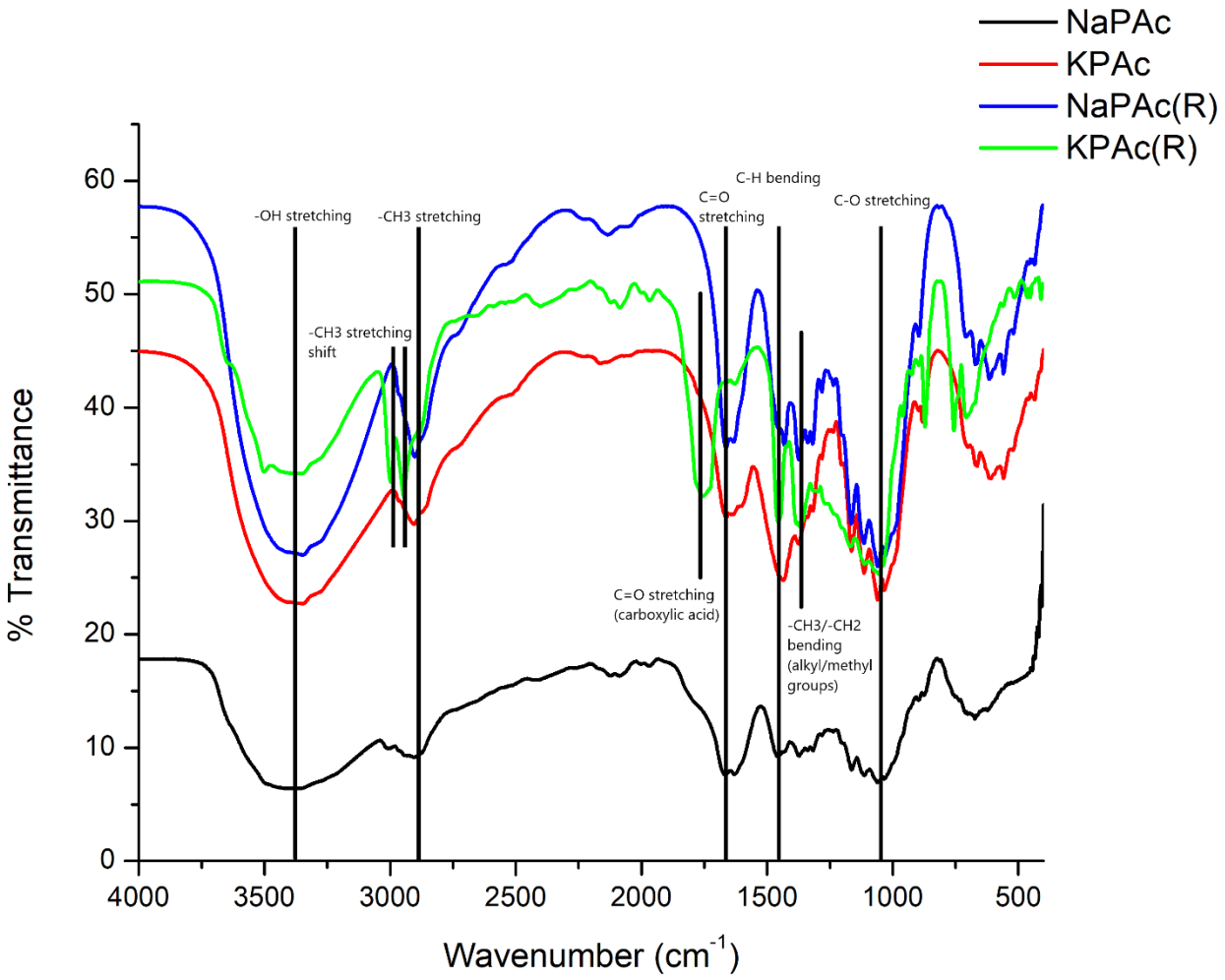

Figure 26: *FT-IR spectra from 4000 cm^{-1} - 400 cm^{-1} of Potassium Polyacrylate (red= fresh, green= reused) and Sodium Polyacrylate (black= fresh, blue= reused). The reused polymer samples absorbed moisture during a 12-hour urine dehydrating cycle and then heated at 60 °C for 4 hours to dehydrate the SAPs. It was repeated 8 times (Experiment IV).*

Inductively coupled plasma optical emission spectrometry (ICP-OES) was used to determine the changes in cation density in urine after storing PLLA films for eight days (Experiment II). The results showed a 43% decrease in Ca concentration and an 8.3% decrease in Na concentration (Fig. 27).

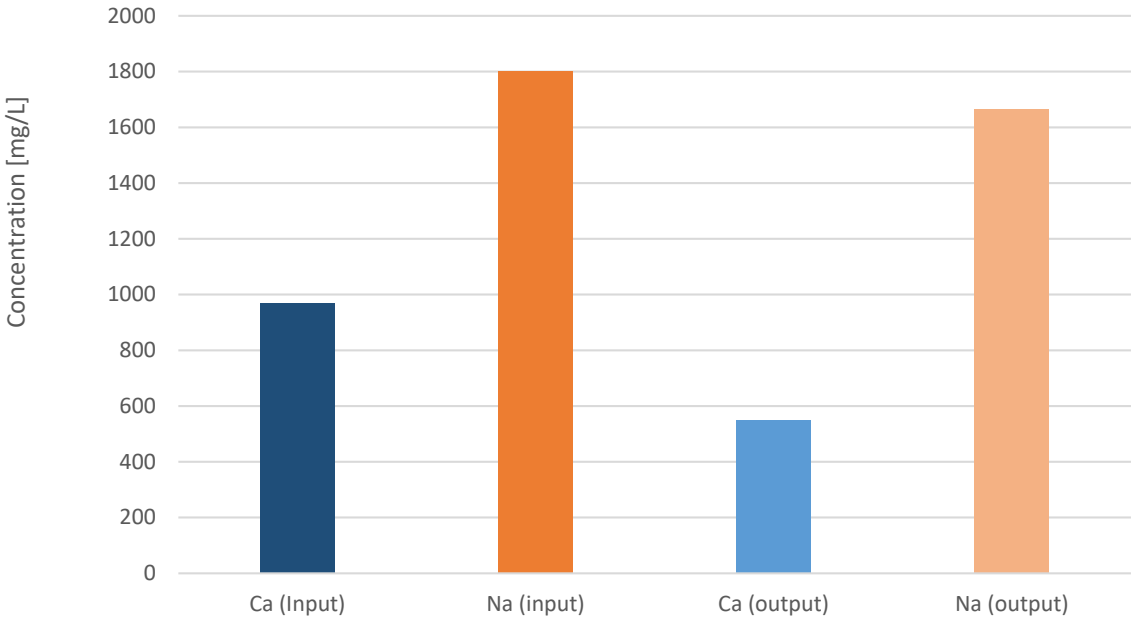

Figure 27: *Input and output concentration of calcium (Ca) and sodium (Na) in $Ca(OH)_2$ dosed fresh urine at 20 °C according to ICP (Experiment II).*

The energy-dispersive X-ray (EDX) analysis of the degraded PLLA films in urine showed the introduction of various new elements (Experiment II). The EDX analysis of the virgin PLLA films showed the presence of only carbon and oxygen, while the degraded films had 12.5% Ca (20 °C) and 28.5% Ca (45 °C) in them (Fig. 28).

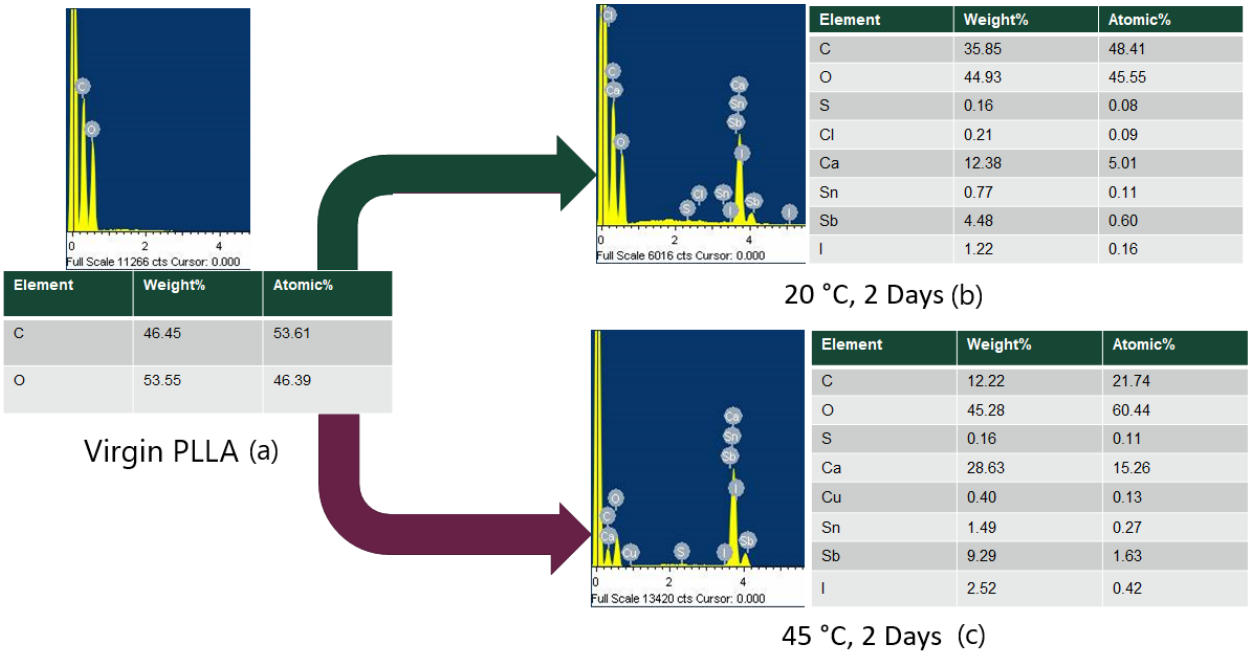

Figure 28: *EDX data for (a) virgin 0.05 mm PLLA film, (b) 0.05 mm film stored in $Ca(OH)_2$ dosed fresh urine at 20 °C and (c) 0.05 mm film stored in $Ca(OH)_2$ dosed fresh urine at 45 °C (Experiment II).*

The formation of KLa in urine can be quantified using Eq. 11, which follows Eq. 8. The amount of KLa formed is correlated with the pH and number of layers in the pouches (Fig. 29). The results indicate that pouches with the same number of layers and stored in the same CF urine formed more KLa at pH 14 compared to pH 11. For instance, three-layered pouches stored in CF 10/pH 14 urine formed more KLa than those stored in CF 10/ pH 11 urine after thirty-two days. Additionally, the number of layers affects the amount of KLa formed, with more layers resulting in higher KLa formation when stored in similar CF and pH of the urine. For example, two-layered pouches formed more KLa than one-layer pouches at pH 14/ CF 10 urine at the end of the thirty-two days (Table S7 of SI).

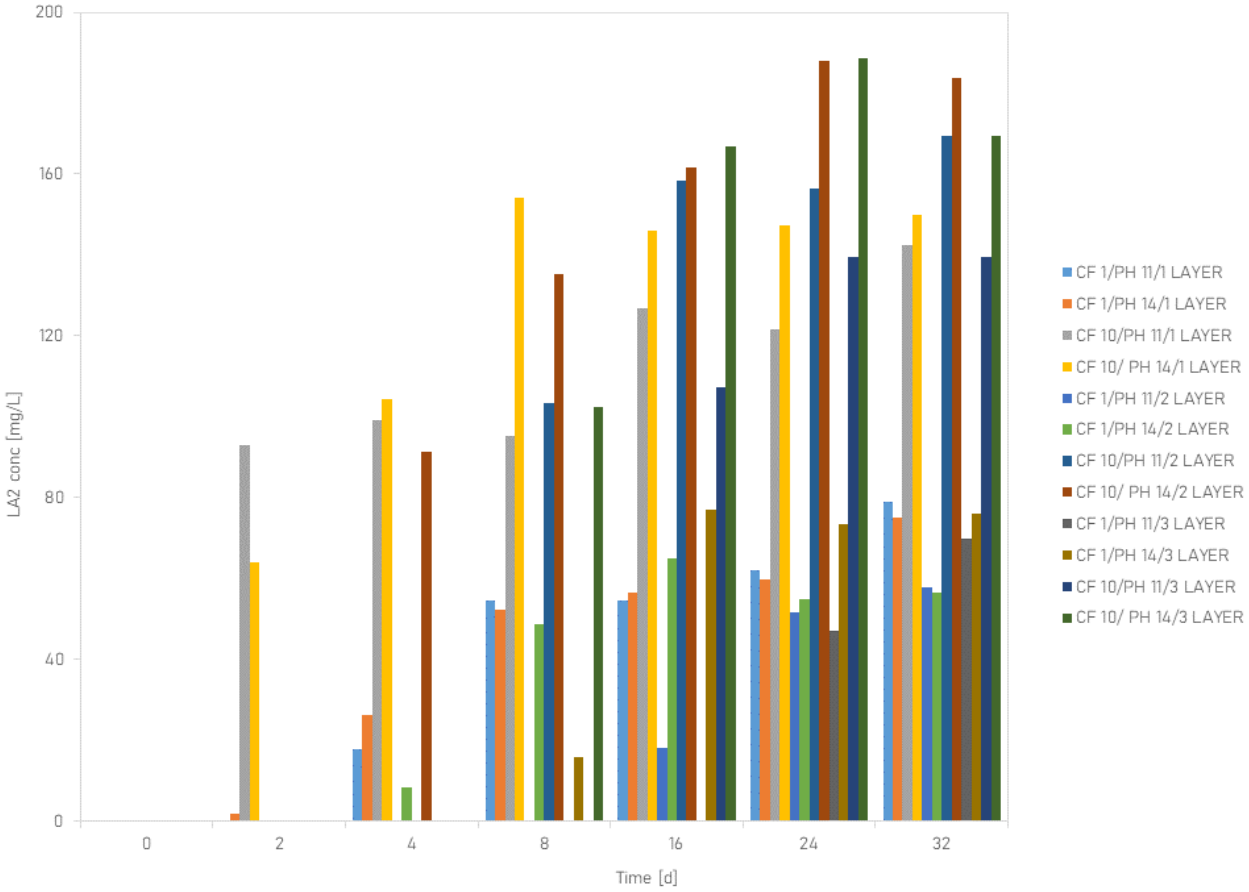

Figure 29: *Amount of Potassium Lactate (KLa) formed in the urine calculated using equation 4. KLa is formed when the KOH in urine reacts with Lactic Acid (LA) which is formed when PLLA degrades in urine.*

4.3. BUFFERING THE pH OF THE DEHYDRATING URINE

Experiment III examined the ability of the PLLA pouches packed with 0.2 g of KOH to passively dose chemicals and buffer the pH of dehydrating urine over longer durations. The pH of pH 11 urine increased to 12.55 and the pH of pH 14 urine increased to 14.4 due to the KOH pellets (Fig. 30). The increase in the pH was notable. However, over time, there was a slight decline in the pH after the rise due to the KOH pellets (Table S4 of SI). The decline in pH could not be attributed to the formation of carbonic acid, as the chambers were airtight. Instead, it might be due to lactic acid or potassium lactate.

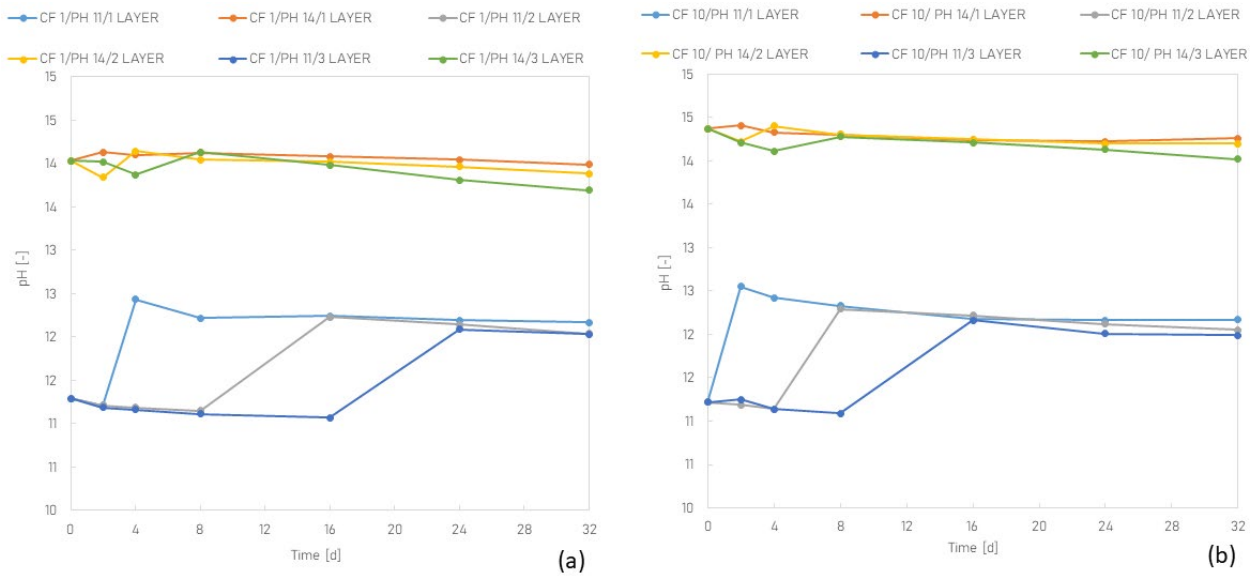

Figure 30: *Change in pH of NaOH dosed fresh urine (a) Concentration Factor 1 urine and (b) Concentration Factor 10 urine, over thirty-two days due to degradation of polymer pouches and release of encased KOH pellets. 0.2g KOH was encased in each polymer pouch and placed in 100 mL urine and destructively sampled on every sampling day (Experiment III).*

The initial pH of the alkalinised urine (CF 1) was 11.95 (Experiment IV). CF 1 urine was dried to CF 1.25, 2, 2.5, and 5 in both circular and linear alkaline urine dehydration setups. The pH of the CF 5 urine was 11.64 (using KPAc) and 11.68 (using NaPAc) in the circular setup, and 9.73 (using KPAc) and 9.65 (using NaPAc) in the linear setup (Fig. 31).

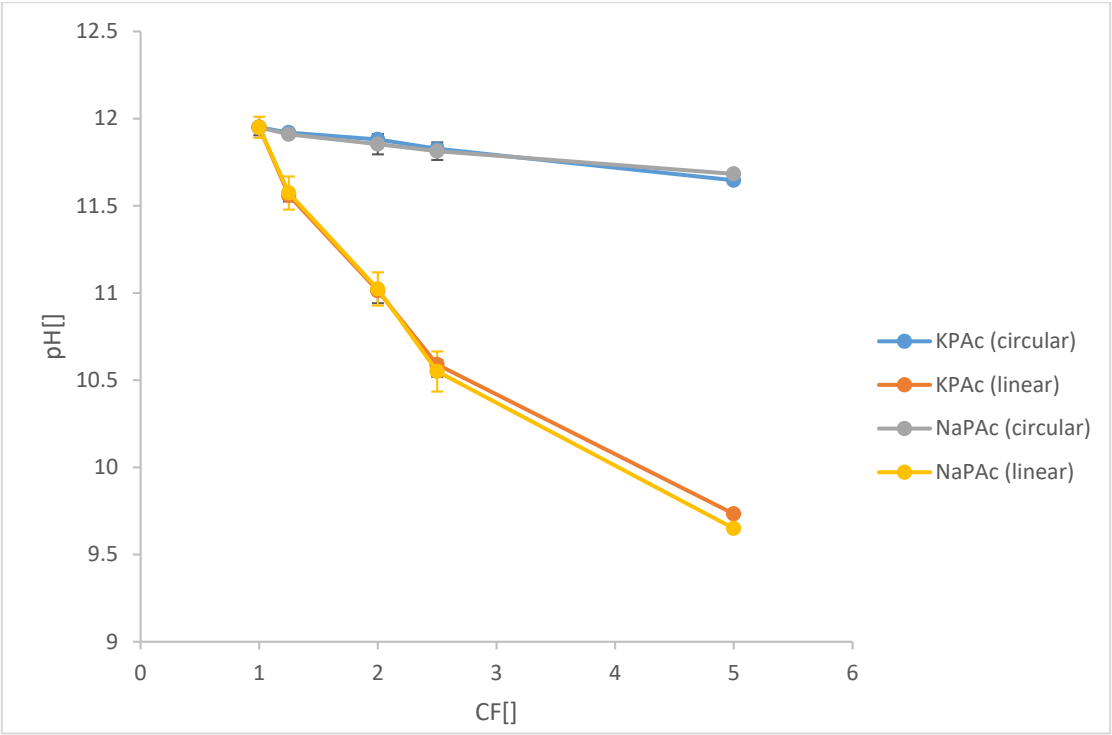

Figure 31: *pH of urine dehydrated in circular (airtight) and linear alkaline urine dehydration setups using Potassium Polyacrylate (KPAc) and Sodium Polyacrylate (NaPAc) Super Absorbent Polymers. 50 g alkaline urine with 11.95 pH was dehydrated to concentration factors 1.25, 2, 2.5 and 5 in a* circular *and* linear *setup and the pH was measured (Experiment IV).*

4.4. RECYCLING WATER FROM DEHYDRATING URINE

In experiment IV, the moisture absorption and extraction from circular urine dehydrating setup using SAPs were assessed. The drying rate of both circular and linear systems was calculated by measuring the time it took for 50 g of urine to dehydrate from CF 1 to CF 5 (Table S9 of the SI). The average drying rate of the circular system was 0.00087 kg/day/m^2 (using KPAc) and 0.0008 kg/day/m^2 (using NaPAc), while the linear system's drying rate was 0.0015 kg/day/m^2. It is important to note that the drying rate increased proportionally with the amount of urine in the drying chamber (Fig. 32).

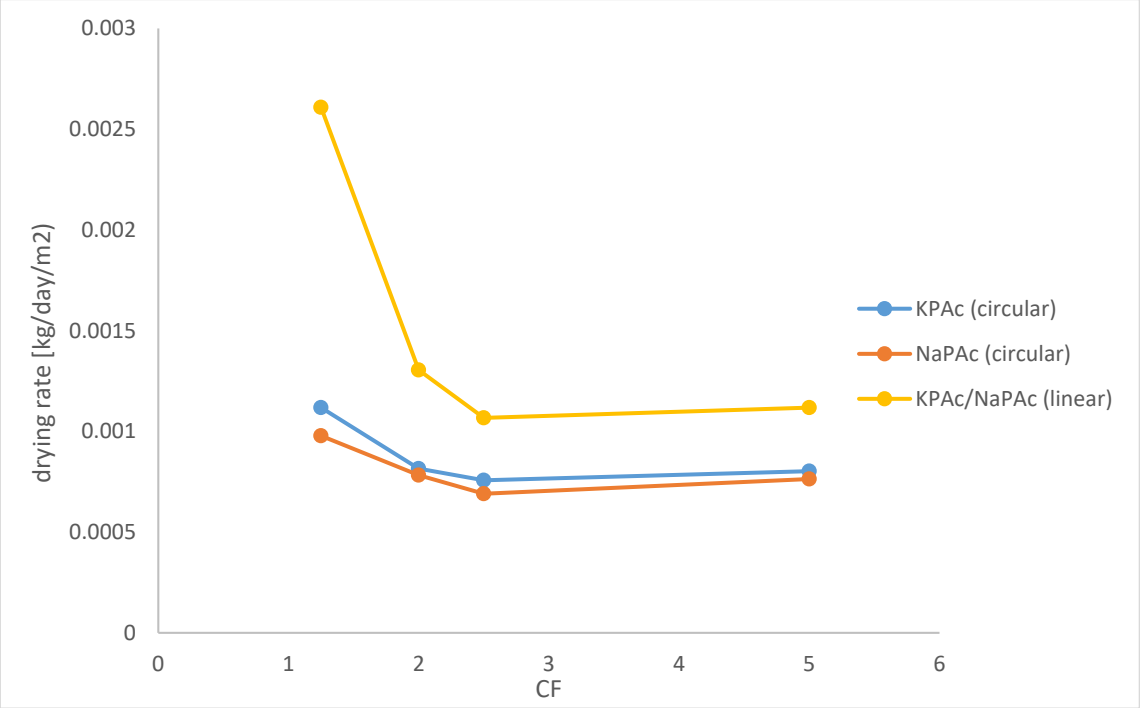

Figure 32: *Drying rate of urine dehydrated in circular (airtight) and linear alkaline urine dehydration setups using Polyacrylate (KPAc) and Sodium Polyacrylate (NaPAc) Super Absorbent Polymers. 50 g alkaline urine was dehydrated to concentration factors 1.25, 2, 2.5 and 5 in a circular and linear setup and the drying rate was measured based on the time taken to reach the specific CF (Experiment IV).*

The circular setup took 10 hours 15 minutes (using KPAc) and 9 hours 45 minutes (using NaPAc) to dehydrate 50 g urine from CF 1 to CF 5 (Fig. 33). The linear systems (using both KPAc and NaPAc) took 7 hours to dry 50 g of urine to CF 5.

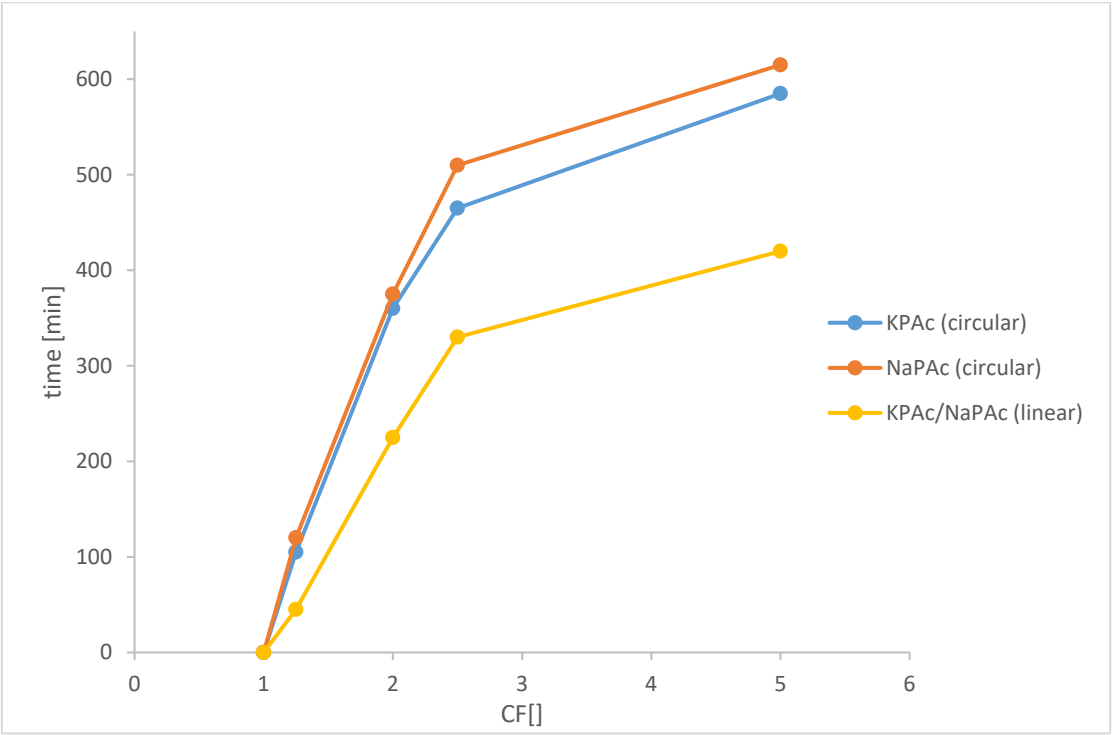

Figure 33: *Time taken for urine to dehydrate in circular (airtight) and linear alkaline urine dehydration setups using Polyacrylate (KPAc) and Sodium Polyacrylate (NaPAc) Super Absorbent Polymers. 50 g alkaline urine was dehydrated to concentration factors 1.25, 2, 2.5 and 5 in a circular and linear setup and the time taken was measured (Experiment IV).*

During each 12-hour drying cycle, 46 g of moisture was dehydrated from 50 g of urine (Table S10 of the SI), leaving 4 g as the total solid content of the urine. KPAc absorbed more than 42 g of moisture in the first four cycles of reuse (Fig. 34), while NaPAc absorbed more than 40 g of moisture in the first three cycles. In the fifth cycle, both KPAc and NaPAc absorbed 37 g of moisture, and in the final cycle, they absorbed 32 g of moisture each. When KPAc and NaPAc were mixed in a 1:1 ratio, they absorbed more than 40 g of moisture for the first five cycles, but only 30 g in the last cycle. In terms of absorption percentage, KPAc had a higher initial absorption rate compared to NaPAc. However, after the fourth cycle, KPAc had a decline in the absorption rate, whereas NaPAc had a higher absorption percentage after the fourth cycle. The mixture of KPAc and NaPAc had a higher overall absorption percentage than either of the SAPs until the seventh cycle.

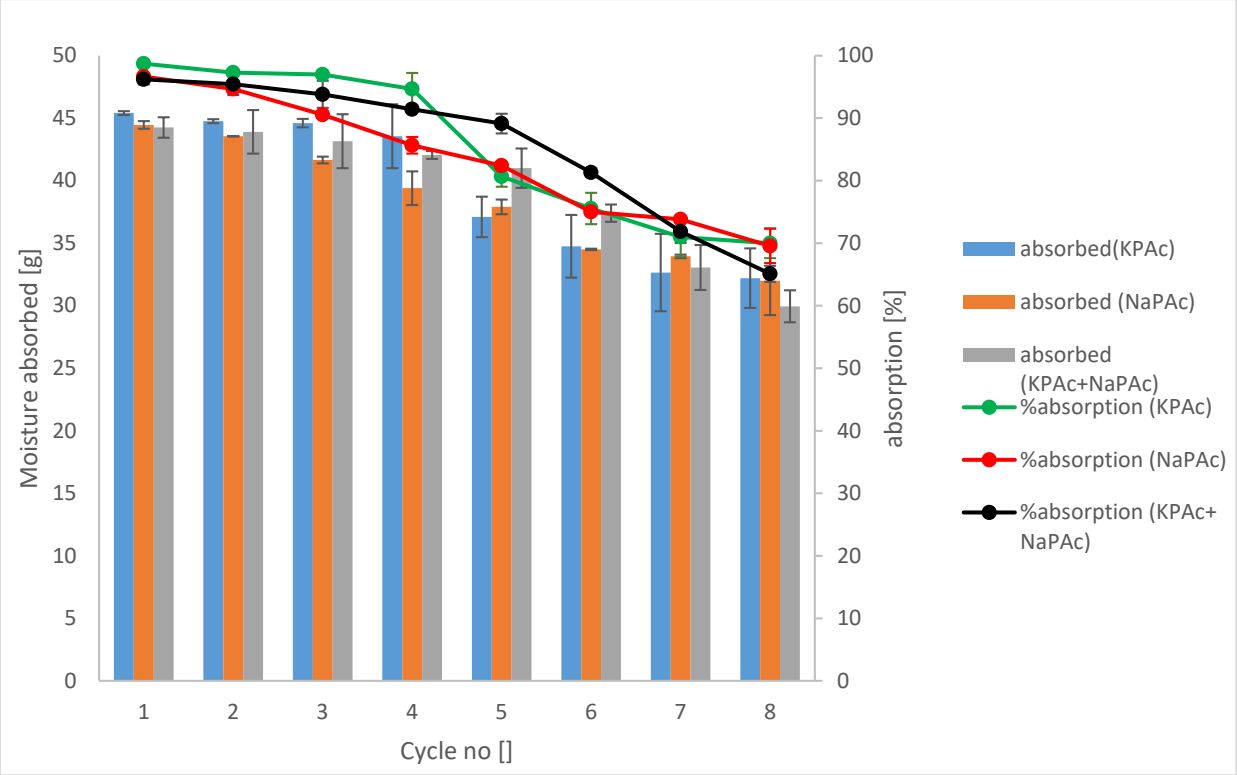

Figure 34: *Moisture absorbed by Potassium Polyacrylate (KPAc) and Sodium Polyacrylate (NaPAc) Super Absorbent Polymers during dehydration of urine in a circular (airtight) setup. 50 g alkaline urine was dehydrated in 12-hour cycles eight times and the amount of moisture absorbed by the SAPs were weighed (Experiment IV).*

The SAPs were subjected to moisture extraction using a rotary evaporator. Among the three SAPs, KPAc demonstrated the highest average water extraction percentage of 98% across all eight cycles. In comparison, NaPAc achieved an average water extraction percentage of 94%, while the 1:1 mixture of KPAc and NaPAc recorded a water extraction percentage of 95%. KPAc's water extraction percentage remained consistent throughout the cycles, ranging from 99% to 96% (Fig. 35). On the other hand, NaPAc's water extraction percentage fell below 90% for the last two cycles, ranging from 98% to 89.5%. Similarly, the mixed SAP's water extraction percentage was below 90% for the last two cycles, ranging from 98.5% to 90%.

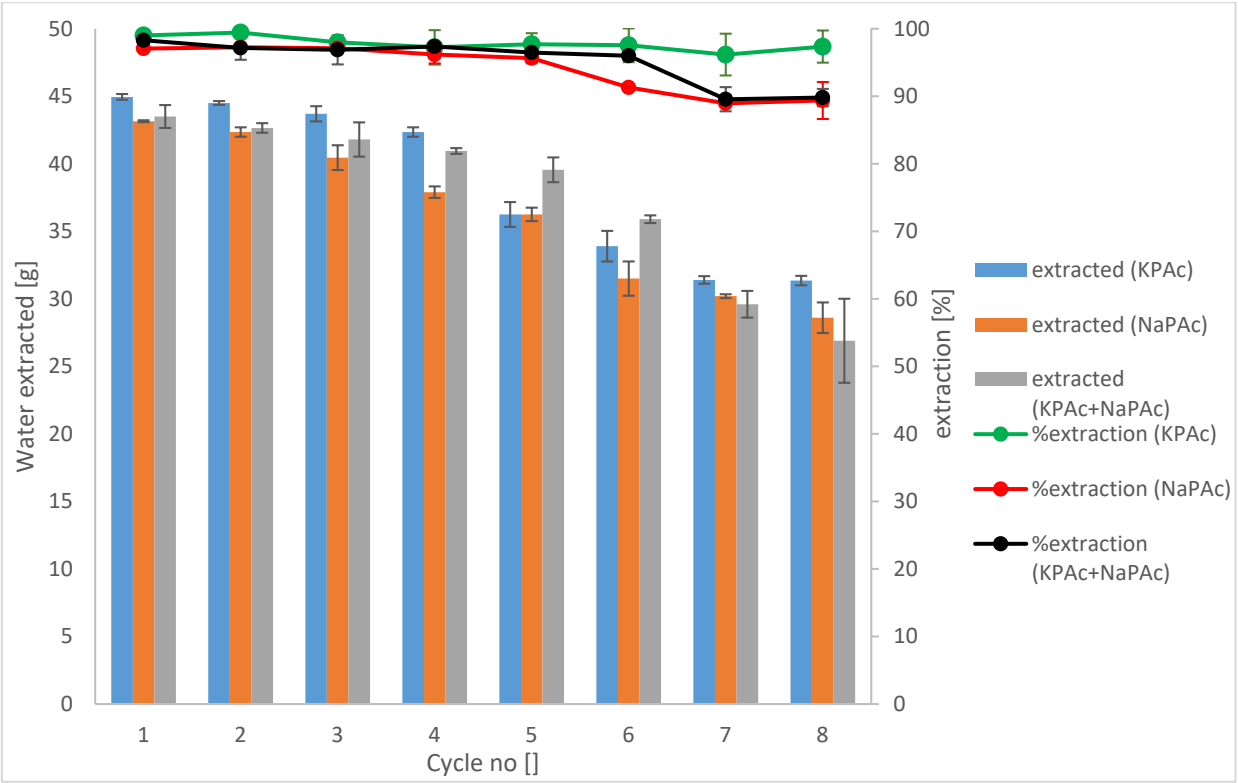

Figure 35: *Water extracted from Potassium Polyacrylate (KPAc) and Sodium Polyacrylate (NaPAc) Super Absorbent Polymers after absorbing moisture during dehydration of urine in a circular (airtight) setup. 50 g alkaline urine was dehydrated in 12-hour cycles eight times. Water was extracted from the SAPs using a rotary evaporator (Experiment IV).*

4.5. REMOVAL OF ORGANIC METABOLITES

For the 255 OMs detected in urine and extracted water (Experiment IV), 219 were detected in urine, while 108 were detected in the extracted water. Among the 108 OMs detected in the extracted water, 13 were completely removed, and 5 were removed by more than 80% of their concentration after being treated with activated carbon for 30 minutes. The detected OMs were categorized into 8 superclasses, 24 classes, and 46 subclasses based on the Human Metabolome Database (Djoumbou Feunang et al., 2016). Most of the detected OMs belonged to two superclasses: lipids and lipid-like molecules (n=78) (molecular weights > 400 g mole^{-1}) and organic acids and their derivatives (n=85) (molecular weight < 200 g mole^{-1}).

The concentration of ΣOMs in urine was measured at 2.15 g L^{-1}. Among the various organic compounds present, organic acids and their derivatives were the most prevalent, contributing 45.2% of the total mass, followed by organic oxygen compounds at 33.74%

and benzenoids at 14.9%. On a mass basis, the major metabolites were glucose (32.9%), hippuric acid (13.34%), citric acid (10.23%), lactic acid (3.7%), creatinine (3.6%), 5-oxoproline (3.16%), phenylacetylglutamine (2.31%), creatine (2.11%), and glycine (1.98%).

The concentrations of ΣOMs in water extracted using KPAc and NaPAc were reduced by 99.26% and 99.23%, respectively, to 0.015 g L^{-1} and 0.016 g L^{-1}. After being treated with activated carbon for 30 minutes, the concentrations of ΣOMs in the extracted water were reduced to 0.01 g L^{-1} for both KPAc(F) and NaPAc(F), representing a 99.5% reduction in concentration (Table. 8 and Table. 9).

The removal of OMs also reduced the COD of the extracted water (Experiment IV). The COD of CF1 urine was 6.2 g L^{-1}. The recycled water had 74 mg L^{-1} and 80 mg L^{-1} COD for NaPAc and KPAc, respectively. For the water treated with activated carbon, the COD was 25 mg L^{-1} for both SAPs.

Table 8: *Concentration, Mass contribution (%) and removal (%) of the superclass of the organic metabolites (top 10 mass contribution % wise) detected in urine, recycled water (NaPAc (W), KPAc (W)) and recycled water treated with activated carbon (NaPAc (F), KPAc (F)) for 30 minutes. NaPAc = Sodium Polyacrylate and KPAc = Potassium Polyacrylate (Experiment IV).*

	Concentration (g/L)						% removal			
Superclass of metabolites	**Urine**	**NaPAc (W)**	**KPAc (W)**	**NaPAc(F)**	**KPAc(F)**	**Mass Contribution (%)**	**NaPAc (W)**	**KPAc (W)**	**NaPAc(F)**	**KPAc(F)**
Organic Acids and derivatives	0.9701	0.0126	0.0125	0.0071	0.0076	45.2	100.0	100.0	100.0	100.0
Organic oxygen compounds	0.7240	0.0000	0.0000	0.0000	0.0000	33.7	85.7	88.8	83.2	87.5
Benzenoids	0.3192	0.0001	0.0001	0.0000	0.0000	14.9	86.9	91.2	83.3	89.3
organic nitrogen compounds	0.0732	0.0013	0.0013	0.0012	0.0011	3.4	98.7	98.7	99.3	99.2
Organoheterocyclic compounds	0.0378	0.0004	0.0004	0.0001	0.0003	1.8	98.2	98.2	98.4	98.4
lipids and lipid-like molecules	0.0113	0.0016	0.0013	0.0019	0.0014	0.5	100.0	100.0	100.0	100.0
Nucleosides	0.0024	0.0003	0.0002	0.0004	0.0003	0.1	98.9	98.9	99.7	99.2
Total	**2.1380**	**0.0163**	**0.0158**	**0.0107**	**0.0108**					

Table 9: *Concentration, Mass contribution (%) and removal (%) of the specific organic metabolites (top 10 mass contribution % wise) of the organic metabolites detected in urine, recycled water (NaPAc (W), KPAc (W)) and recycled water treated with activated carbon (NaPAc (F), KPAc (F)) for 30 minutes. NaPAc = Sodium Polyacrylate and KPAc = Potassium Polyacrylate (Experiment IV).*

(N.D.: Not Detected), (LOD: Limit of Detection)

		Concentration (g/L)						% removal		
Metabolites	**LOD (µM)**	**Urine**	**NaPAc (W)**	**KPAc (W)**	**NaPAc(F)**	**KPAc(F)**	**Mass Contribution (%)**	**NaPAc (W)**	**KPAc (W)**	**NaPAc(F)**	**KPAc(F)**
Glucose	22.5	0.7047	N.D	N.D	N.D	N.D	32.8	100.0	100.0	100.0	100.0
Hippuric acid	0.128	0.2863	N.D	N.D	N.D	N.D	13.3	100.0	100.0	100.0	100.0
Citric acid	31.1	0.2196	N.D	N.D	N.D	N.D	10.2	100.0	100.0	100.0	100.0
Lactic acid	2.783	0.0811	0.0004	0.0001	0.0003	0.0005	3.8	99.5	99.9	99.6	99.4
Creatinine	0.151	0.0772	0.0072	0.0072	0.0000	N.D	3.6	90.6	90.6	100.0	100.0
5-Oxoproline	1.239	0.0680	0.0015	0.0014	0.0015	0.0014	3.2	97.8	97.9	97.8	97.9
Phenylacetyl glutamine	0.163	0.0498	N.D	N.D	N.D	0.0000	2.3	100.0	100.0	100.0	100.0
Creatine	0.012	0.0454	0.0011	0.0012	0.0010	0.0010	2.1	97.6	97.4	97.9	97.8
Glycine	2.312	0.0425	N.D	0.0001	0.0001	0.0001	2.0	99.9	99.8	99.9	99.8
Total		**1.5745**	**0.0102**	**0.0100**	**0.0028**	**0.0030**					

4.6. THERMODYNAMICS OF THE CIRCULAR URINE DEHYDRATING SETUP

The energy demand to dehydrate urine in the circular setup was calculated (Experiment IV) and it was found to be 19,200,00 kJ L^{-1}. However, in an ideal setup, only 106.2 kJ energy is needed to dehydrate 45 g of urine. The 200W pump when used continuously for 12-hour cycles uses 8640 kJ of energy. Thus, 8533.38 kJ of energy is lost every 12-hour cycle to dehydrate 45 g of urine. The efficiency of the system, η was 0.012. Energy was lost in the form of heat via conduction and convection in the setup. The heat lost via conduction was 6780 kJ (through the walls of the drying chamber to the surroundings) while the heat lost via convection was 2500 kJ (from the pump to the surroundings).