CHAPTER VI

6.1 RESULTS AND DISCUSSIONS : ELECTRICAL CONDUCTIVITY

6.1.1 CONDUCTIVITY IN AIR AT ROOM TEMPERATURE WITH TIME.

The electrical conductivity (σ) of potato and apple was investigated in the laboratory atmosphere at room temperature after different intervals of time. Conductivity values so obtained by measurement are provided in table 1for potato and table 2 for apple. The variation of conductivity after different intervals of time for potato and apple are shown in figs. 11 and 12. Both for potato and apple it is found that the electrical conductivity first increases with time attaining a maximum value and then it decreases. In case of potato from an initial value of conductivity 0.37 (10^{-4})S/m it attains a maximum value of 2.00 (10^{-4})S/m after a time interval of 8400 secs. On the other hand apple attains a maximum value of conductivity 1.83 (10^{-4})S/m after a time interval of 2700 secs. from the initial value of 0.67 (10^{-4})S/m. Potato reaches a minimum value of conductivity of 0.89 (10^{-4})S/m after 13200 secs. while apple decreases to a minimum value of 1.05 (10^{-4})S/m after an interval of time 12300 secs.

All substances are more or less hygroscopic (i.e they can absorb moisture when present in the air containing water vapour or when wetted with water).Thus samples which are more porous will be more hygroscopic. The presence of small amount of water causes considerable increase in the conductivity of the samples depending upon their porous nature. This is because the impurities in the water dissociates into ions or the water with a high permittivity aids in the dissociation of the molecules of the matter itself. Moreover moistening changes the conductivity of the samples due to the formation of continuous films of moisture on the

surface of the sample [30] .The acidity affects the ionic movement in the sample during ohmic heating. It is thought that the difference between the electrical conductivity values of the samples at the same room temperature (29^0 C) might be also the result of the difference in the acidity of the samples [16 b].

Electrical conductivity depends on ions in solution. Ions found in plant tissue include potassium (K^+), proteins and organic acids, such as ascorbic acid and citric acid. Sugars and starch are uncharged molecules. Therefore the difference in the conductivity of potato and apple might be the difference in the concentration of ions in solution.

Food materials or biological materials can display large compositional variation, inhomogeneties and anisotropic structure. Ohmic heating enhances drying rates [7,8] and extraction yields[9] in certain fruits and vegetables. Electrical conductivity is influenced by temperature, particle size and concentration of the food system and location of the particle. Most engineering properties are significantly altered by the structural difference between foods [31]. Electrical conductivity increases when moisture content increases but decreases when starch concentration increases [24].

6.1.2 VARIATION OF ELECTRICAL CONDUCTIVITY WITH TEMPERATURE

Electrical conductivity of potato and apple was measured at different temperatures.Tables 3 and 4 gives the values of electrical conductivity at different temperatures for potato and apple respectively. From the plot of electrical conductivity versus temperature (fig.13) it is found that in case of potato the electrical conductivity first increases linearly with

temperature from 299 K to 307 K , then it shows a decreased value till a temperature of 325 K. Again from 338 K to 379 K the curve shows an enormous increase in electrical conductivity with a peak at 375 K of conductivity value 29.41 (10^{-4} S/m) and then it again decreases to 19.61(10^{-4} S/m) at a temperature of 379 K. The electrical conductivity values with decrease in temperature is also shown in the same plot. It is found that initially the conductivity first increases slightly as temperature decreases and then it shows a decrease with decrease in temperature upto 353 K as measured.

Apple on the other hand shows a linear increase in electrical conductivity value from a temperature of 301 K to 324 K, as shown in fig.14 . Again from 329 K to 334 K it shows a decrease in conductivity and increase from 339 K to 350 K. Finally conductivity increases from a temperature of 360 K to 373 K. With decrease in temperature from 373 K to 366 K the electrical conductivity values were found to decrease.

The increase in electrical conductivity values with temperature is due to reduced drag for the ionic movement [11,14] . Palanippan and Sastry[10] reported that electrical conductivity of the orange, carrot and tomato juices increased with temperature and decreased with solid content. Hence the decrease in electrical conductivity in the present work must be due to evaporation of the juices present in the samples during heating. Significant changes in the electrical conductivity with temperature were found by Kong et al [13]. Electrical resistance heating can intensify both heat and mass transfer[14]. Electrical conductivity decreases with temperature rise after bubbling starts [16b]. Fruit juices are acidic resulting in the potential for electrolytic hydrogen bubble formation [16b]. According to Kolbe and Flugstad [32]gas bubbles were the results of either water

boiling due to localized high current densities or the outguessing by-products of various oxidation / reduction reaction (eg. Hydrogen or oxygen gas). The drag for ionic movement increases when insoluble solids content increases and results in decrease of the electrical conductivity[10]. The acidity affects the ionic movement in the samples. The difference between the electrical conductivity values of potato and apple might be also the result of difference in the acidity of the samples. If air is occluded in the sample the air bubble will expand with temperature . As a result the bubble volume would increase with temperature. Thus air, which can be roughly considered to be of zero electrical conductivity will increase in area tending to reduce the conductivity of the sample[22].

A number of effects which occur during heating, such as starch transition and cell structure changes affect the electrical conductivity. In some cases the presence of an electric field induces enhanced diffusion of cell fluids in the sample which increase the rate of change of conductivity with temperature[33]. At high temperature structural changes results as a result of which the electrical conductivity shows increase and decrease values.

TABLE 1: Variation of electrical conductivity with time

POTATO

Log t (sec.)	Conductivity,$\sigma(10^{-4})$ S/m
0	0.37
3.03	0.55
3.14	0.53
3.18	0.69
3.24	0.67
3.30	0.89
3.33	1.07
3.37	1.14
3.41	1.23
3.47	1.33
3.70	1.60
3.92	2.0
4.0	1.78
4.01	1.60
4.03	1.07
4.06	0.89
4.09	0.94
4.12	0.89

TABLE 2 : Variation of electrical conductivity with time

APPLE

Log t (sec.)	Conductivity,$\sigma(10^{-4})$ S/m
0	0.67
2.48	0.94
2.78	1.47
3.43	1.83
3.48	1.67
3.52	1.53
3.53	1.47
3.56	1.36
3.59	1.26
3.62	1.22
3.65	1.18
3.68	1.15
3.71	1.11
3.78	1.08
3.80	1.05
3.95	1.10
4.0	1.11
4.03	1.08
4.05	1.05
4.06	1.11
4.08	1.08
4.09	1.05

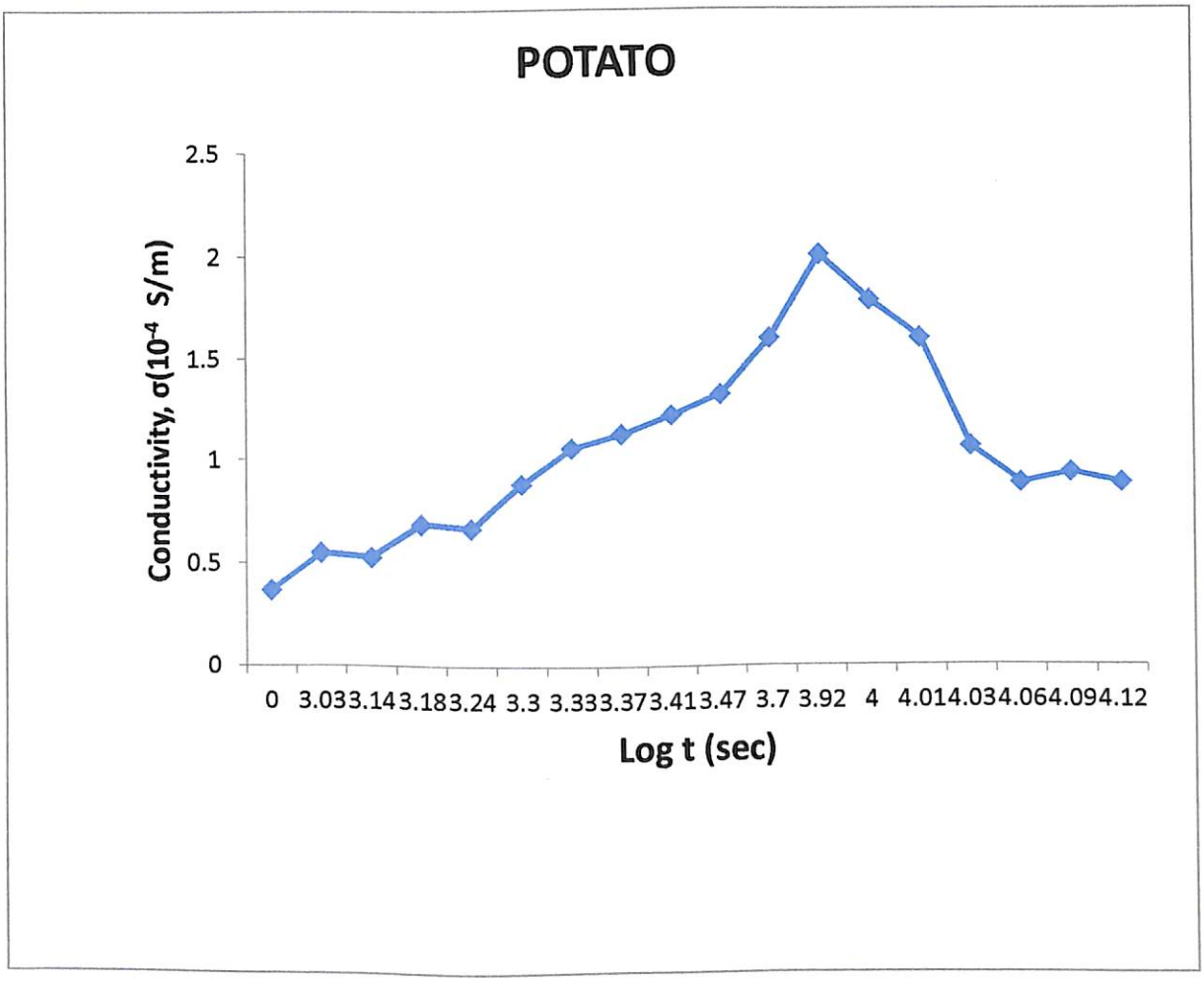

FIG. 11 : PLOT OF CONDUCTIVITY VS. LOG t

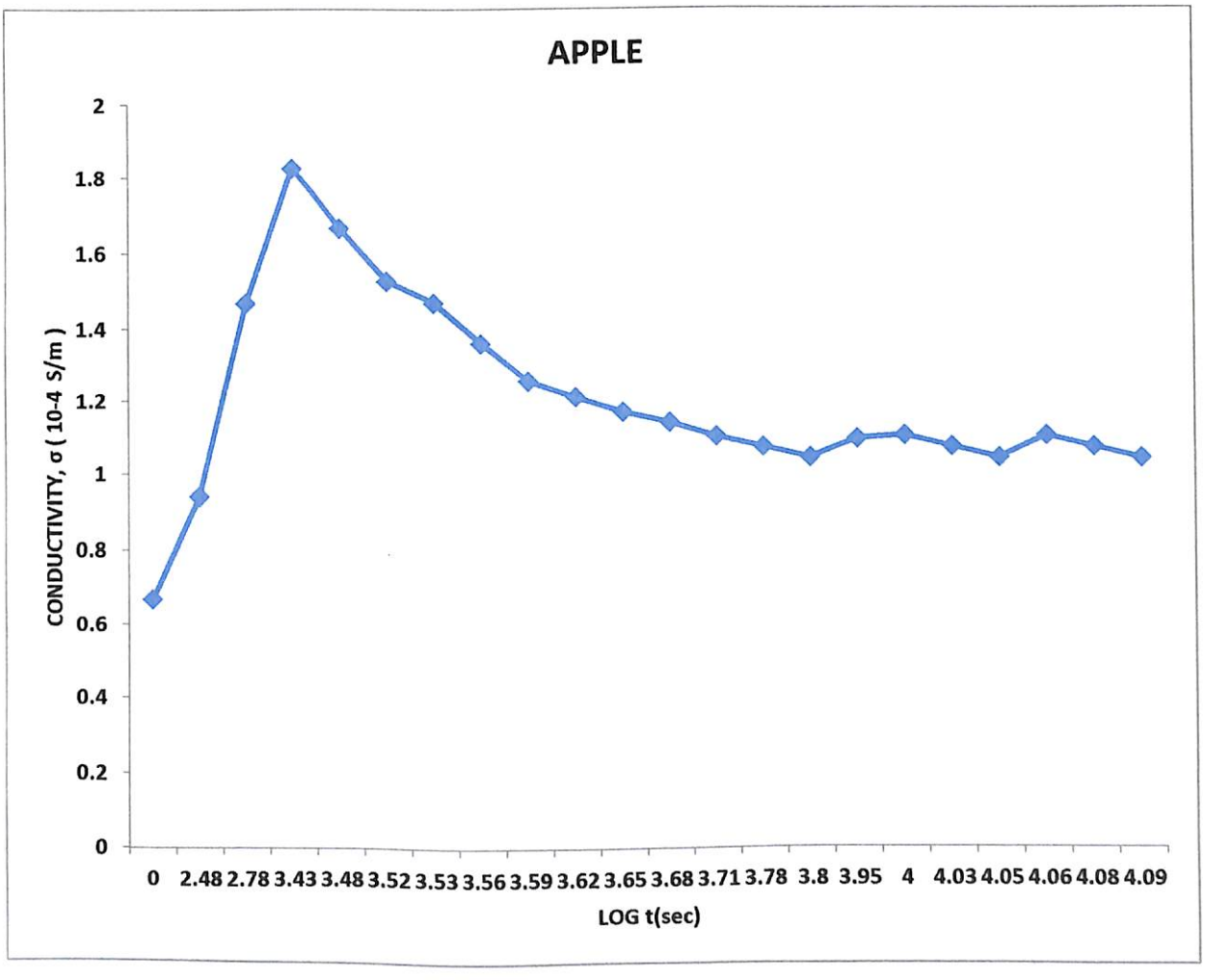

FIG. 12 : PLOT OF CONDUCTIVITY VS. LOG t

TABLE 3: Variation of electrical conductivity with temperature

POTATO

Temperature(K) (Increasing)	Conductivity, σ (10^{-4}) S/m	Temperature(K) (Decreasing)	Conductivity, σ (10^{-4}) S/m
299	2.80	368	1.15
304	3.27	367	1.28
307	3.46	366	1.37
315	3.10	365	1.37
321	2.80	363	1.37
325	2.67	362	1.28
338	2.80	361	1.23
343	2.94	360	1.15
349	3.10	359	1.07
354	3.27	358	0.96
356	3.46	357	0.88
358	3.68	356	0.80
360	4.20	355	0.73
362	8.40	354	0.65
371	11.77	353	0.59
375	29.41		
379	19.61		

TABLE 4 : Variation of electrical conductivity with temperature

APPLE

Temperature(K) (Increasing)	Conductivity, σ (10^{-4}) S/m	Temperature(K) (Decreasing)	Conductivity, σ (10^{-4}) S/m
301	1.06	372	2.65
305	1.09	371	1.48
310	1.09	370	1.24
313	1.12	369	0.82
319	1.16	368	0.54
324	1.20	367	0.41
329	1.12	366	0.37
334	1.09		
339	1.12		
343	1.28		
346	1.43		
348	14.82		
350	16.10		
355	14.82		
358	12.77		
360	14.25		
363	15.43		
371	18.51		
372	28.49		
373	37.04		

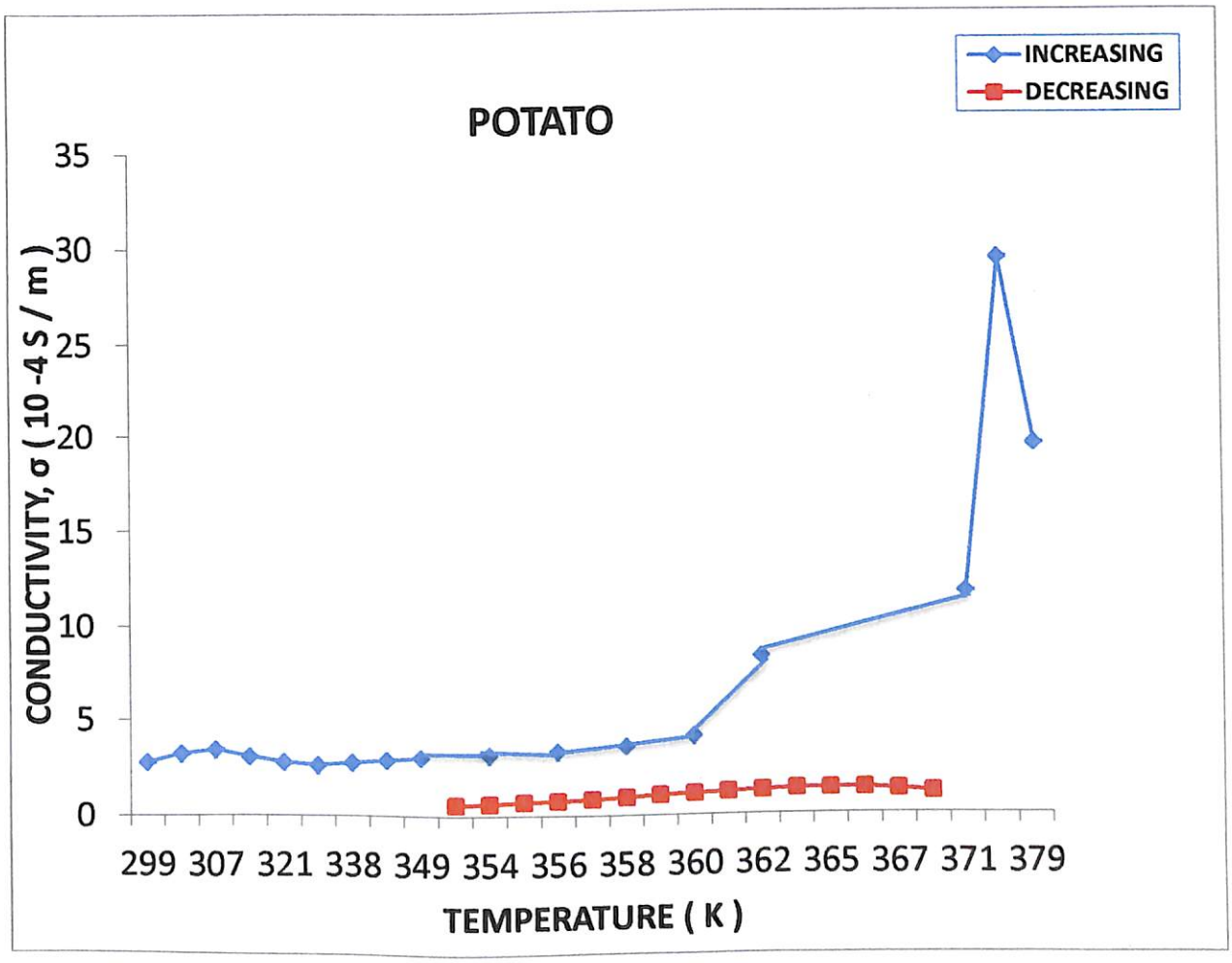

FIG.13 : VARIATION OF CONDUCTIVITY WITH TEMPERATURE

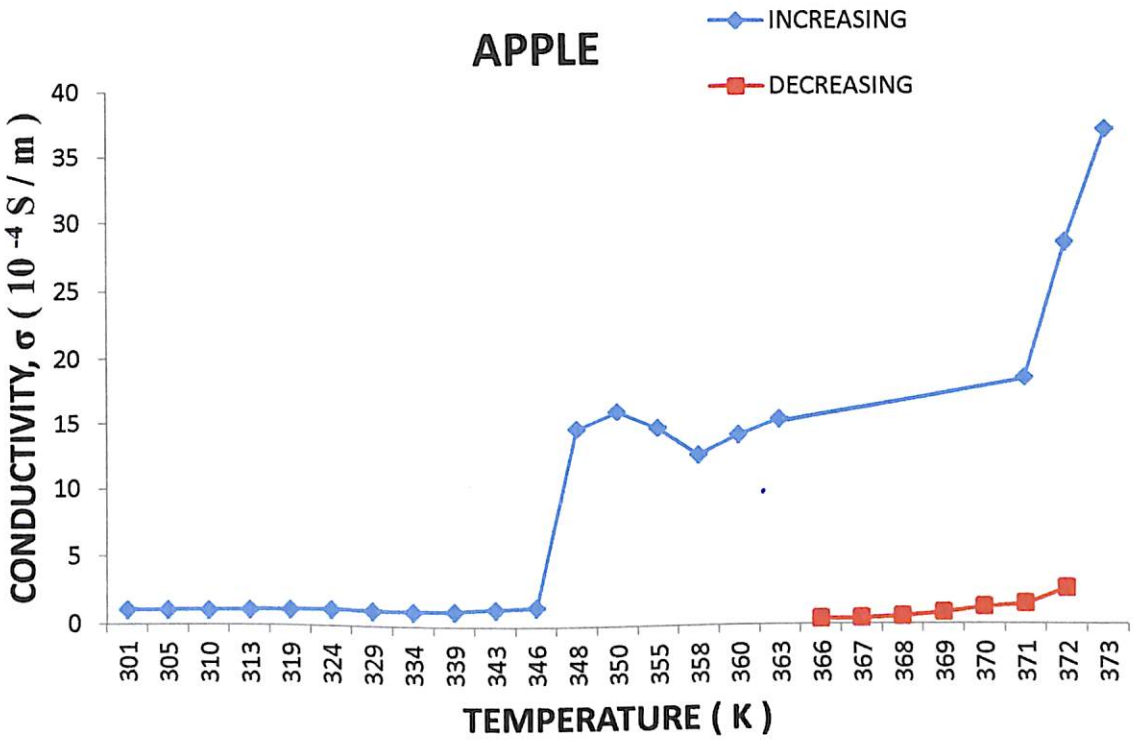

FIG. 14 : VARIATION OF CONDUCTIVITY WITH TEMPERATURE

6.1.3 CONDUCTIVITY AT DIFFERENT CONCENTRATIONS

Electrical conductivity of the samples (potato and apple) was measured by saturating it with NaCl solution of different concentrations at room temperature. Table 5 shows the variation of electrical conductivity at different concentrations. The variation of electrical conductivity with concentration is shown in fig.15. It is found that the electrical conductivity of potato is less than that of apple at the same concentration, but the nature of variation of conductivity is the same. The electrical conductivity is found to increase with increase in concentration up to a particular concentration and then decrease. For potato the electrical conductivity increases and attains a maximum value of 10.31×10^{-4} S/m at 5% concentration and thereafter it decreases with increase in concentration attaining a minimum value of 1.52×10^{-4} S/m at 31% concentration. In case of apple the maximum value of electrical conductivity is 17.54×10^{-4} S/m at a concentration of 5% and then it decreases with further increase of concentration attaining a minimum value of 0.67×10^{-4} S/m at 31% concentration.

Electrical conductivity profiles in both samples were found to be sensitive to salt concentration. Electrical conductivity is influenced by concentration, temperature ,particle size of the sample system and location of the particles. With increase in concentration the conductivity increases due to increase in the number of ions contributing towards conductivity. Zareifard et al[2] further found that electrical conductivity decreases as particle size or concentration increases. The decrease in electrical conductivity may be due to the increase in viscosity of the sample juice with concentration which decreases the mobility of the ions[19].

TABLE 5 : Electrical conductivity at different concentrations of potato and apple

CONCENTRATION (%)	CONDUCTIVITY σ (10^{-4} S/m) POTATO	CONDUCTIVITY σ (10^{-4} S/m) APPLE
0	1.47	4.27
4	5.05	9.52
5	10.31	17.54
10	2.17	3.33
12	1.92	2.65
18	1.79	0.56
31	1.52	0.67

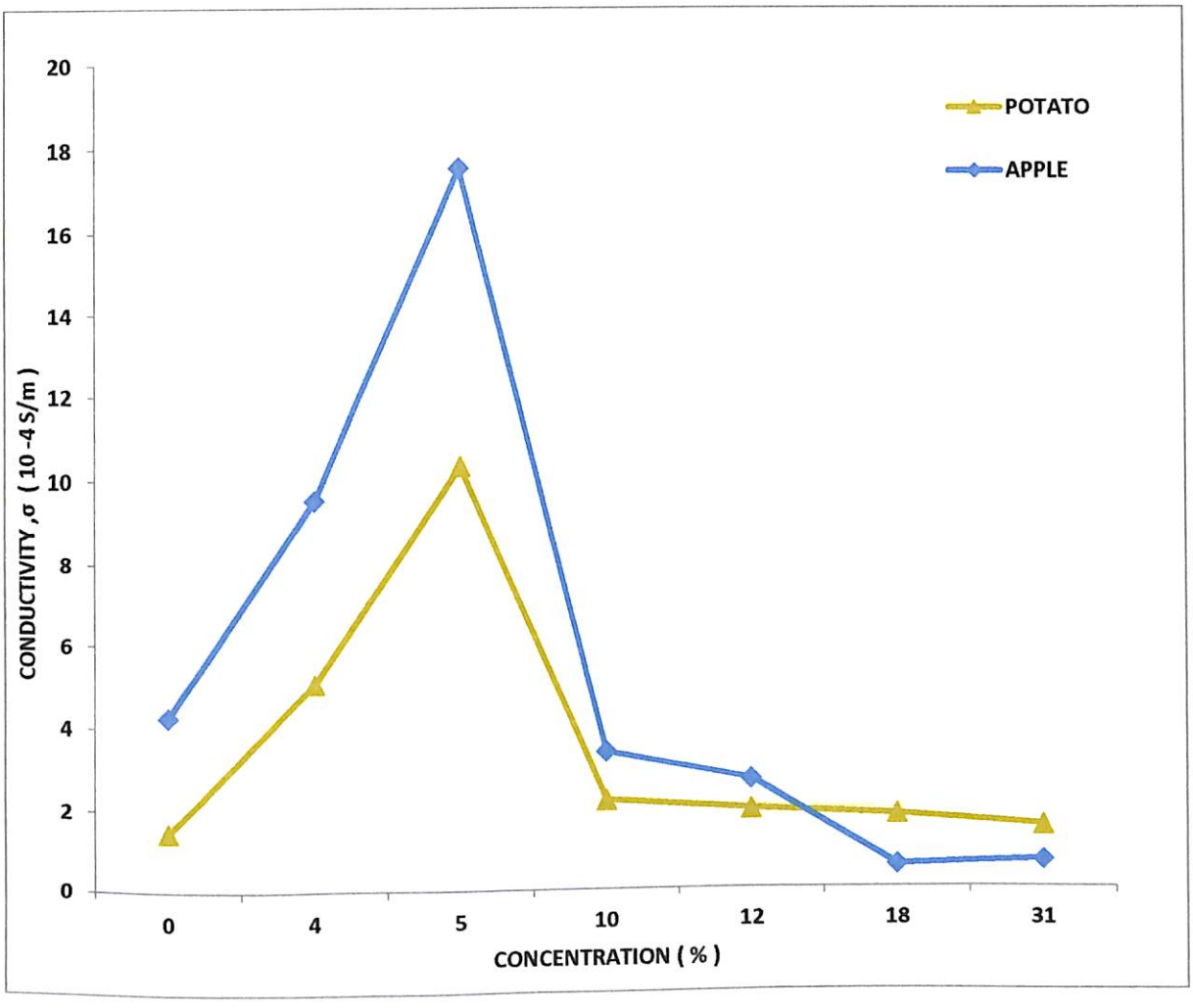

Fig. 15 : PLOT OF CONDUCTIVITY WITH CONCENTRATION FOR POTATO AND APPLE

6.1.4 CONDUCTIVITY AT DIFFERENT CONCENTRATIONS WITH TEMPERATURE

Samples of potato and apple were saturated with NaCl solution of different concentrations and their electrical conductivity measured at different temperatures. Tables 6 and 7 shows the electrical conductivity at different concentrations with temperatures. The fig.16 shows the plot of electrical conductivity versus temperature at different concentrations for potato. It is observed that electrical conductivity at concentrations (%) 0.1 and 0.23 shows an initial increase and then the curve becomes non linear showing decreasing and increasing values. While at concentrations (%) 0.27, 0.31, 0.36 and 0.45 the curves show an initial decrease and then increasing and decreasing nature. Fig.17 shows the plot of electrical conductivity versus temperature at different concentrations for apple.It is found to show similar variation as potato. At concentration 1.38% it initially shows an increase and then a decrease and increase of electrical conductivity values. While at concentrations (%) 0.38, 0.68,0.80,1.00, 1.13 and 1.54 the curves initially shows a decrease and then the same nature of increasing and decreasing electrical conductivity values as potato. The electrical conductivity profiles were found to be sensitive to salt concentrations. The increase in conductivity values with increasing temperature is due to increase in the mobility of the ions. The non linear nature of the curve is a result of salt equilibration during the heating process[34].The change in the electrical conductivity pattern when temperature increased at different concentrations confirms that starch gelatinization that occurs during heating alters the electrical conductivity. During heating phase change, dehydration and starch gelatinization affects the electrical conductivity of the samples[24].

TABLE 6: Electrical conductivity at different concentrations with temperature

POTATO

Concentration:	0.1 %	Temperature (K)	0.23 %	Temperature (K)	0.27 %
Temperature (K)	Conductivity $\sigma \times 10^{-4}$ S/m		Conductivity $\sigma \times 10^{-4}$ S/m		Conductivity $\sigma \times 10^{-4}$ S/m
297	0.24	297	2.84	297	3.37
299	0.36	299	3.25	300	3.03
300	0.34	301	2.84	305	2.76
333	0.32	304	2.53	308	2.53
343	0.30	307	2.27	315	2.33
352	0.32	311	2.07	339	2.53
357	0.36	313	1.89	342	2.76
358	0.38	318	1.75	344	3.03
360	0.54	327	1.89	352	3.37
363	0.90	337	1.75	353	3.03
366	1.80	345	1.62	355	2.53
373	2.70	351	1.52	356	2.17
375	1.34	353	1.42	358	1.78
377	1.08	354	1.34	361	1.68
379	0.90	355	1.26	362	2.02
380	0.77	359	1.34	363	2.33
382	0.62	360	1.52	364	2.76
		361	1.62	365	3.37
		362	1.89	367	4.33
		363	2.07	368	5.05
		367	2.84	372	4.33
		369	3.25	373	4.33
		373	3.25		

Table 6 (contd.)

Concentration :	0.31 %	Temperature (K)	0.36 %	Temperature (K)	0.45 %
Temperature (K)	Conductivity $\sigma \times 10^{-4}$ S/m		Conductivity $\sigma \times 10^{-4}$ S/m		Conductivity $\sigma \times 10^{-4}$ S/m
297	2.27	295	6.25	295	7.69
303	2.02	299	4.46	299	5.13
306	1.82	302	3.91	300	3.85
309	1.65	304	3.91	302	3.08
315	1.52	306	3.47	304	2.56
317	1.40	317	3.47	310	2.20
335	1.65	331	3.47	313	2.56
342	1.82	343	3.91	318	3.08
343	2.02	357	4.46	325	3.85
348	1.65	368	2.84	331	5.13
352	1.30	373	3.47	352	1.71
353	1.14	353	1.54	363	1.21
354	1.92	364	2.27	355	2.20
365	2.60	356	2.56	368	2.02
357	3.08	370	2.27	358	3.85
373	2.60	360	5.13	367	7.69
		373	7.69		

TABLE 7: Electrical conductivity at different concentrations with temperature

APPLE

Concentration:	0.38 %	Temperature (K)	0.68 %	Temperature (K)	0.80 %	Temperature (K)	1.0 %
Temperature (K)	σ x10^{-4} S/m		σ x 10^{-4} S/m		σ x 10^{-4} S/m		σ x 10^{-4} S/m
294	19.61	294	26.32	298	10.87	296	15.63
300	1.51	302	5.85	300	7.25	304	12.50
307	1.40	310	2.92	308	5.44	323	12.50
319	1.31	315	3.1	309	7.25	331	15.63
343	1.31	322	3.29	323	7.25	334	20.83
353	1.31	326	3.51	325	10.87	339	31.25
368	1.23	331	3.76	335	10.87	357	31.25
369	1.15	338	4.05	353	7.25	371	12.50
373	1.09	351	3.76	356	5.44	373	10.42
		365	3.51	358	4.35		
		368	3.29	363	3.62		
		371	3.10	365	3.11		
		373	2.92	366	2.72		
				368	2.42		
				369	2.17		
				370	1.98		
				371	1.81		
				372	1.55		
				373	1.45		

Table 7 : (Contd.)

Concentration:	1.13 %	Temperature	1.38 %	Temperature	1.54 %
Temperature(K)	σ x10^{-4} S/m	(K)	σ x10^{-4} S/m	(K)	σ x10^{-4} S/m
295	13.16	296	5.16	296	0.85
297	2.92	301	10.31	300	0.81
302	3.29	306	5.16	324	0.81
307	3.76	310	3.44	325	0.85
315	4.39	319	2.58	339	1.88
321	5.26	333	2.58	351	2.42
327	6.58	343	2.58	353	2.83
333	8.77	347	3.44	356	1.13
339	13.16	358	5.16	361	1.41
343	26.32	364	10.31	362	1.54
351	13.16	369	10.31	365	1.70
363	26.32	373	10.31	366	1.88
367	13.16			369	2.12
373	13.16			370	2.42
				371	2.83
				373	2.12

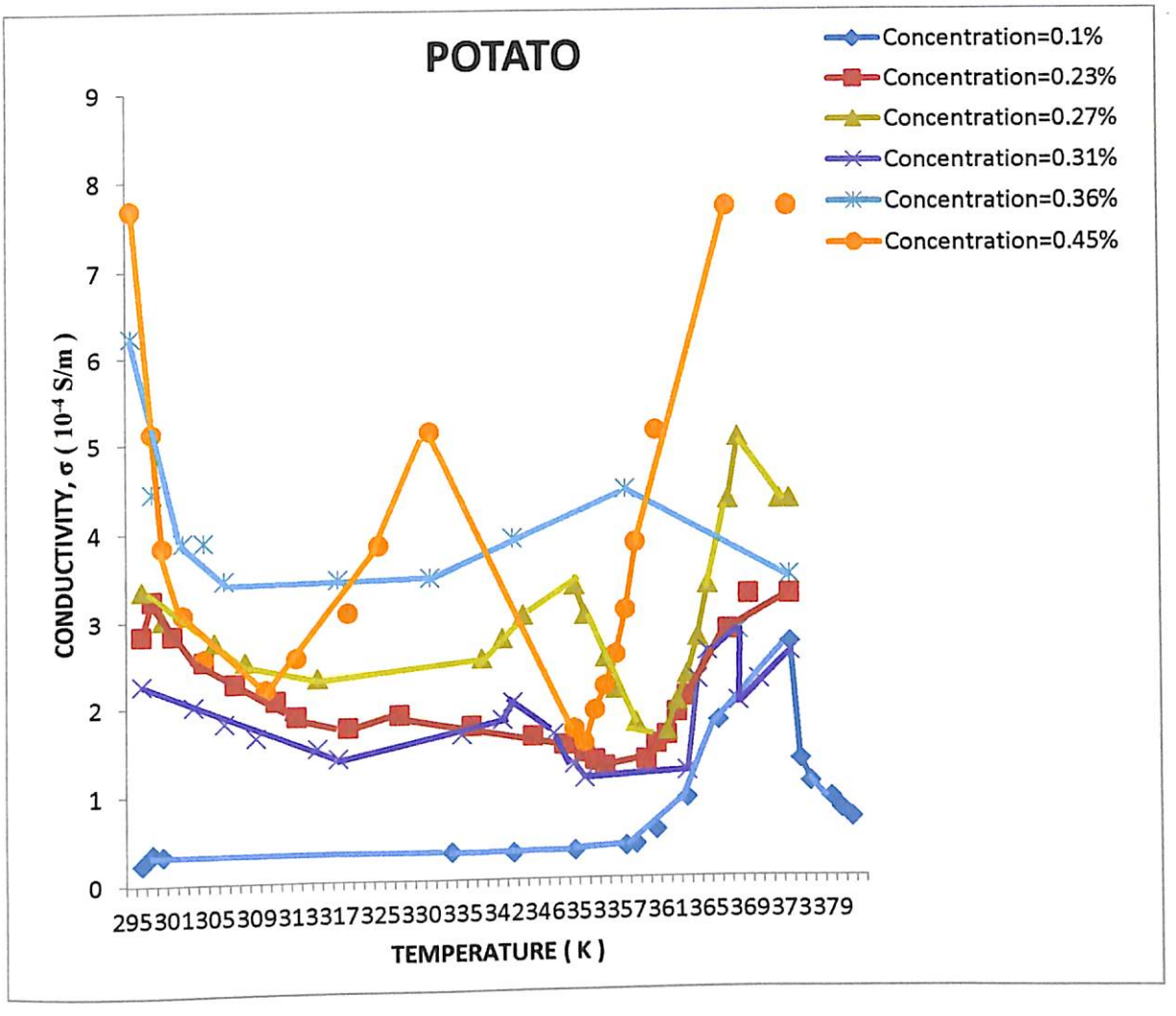

FIG.16: PLOT OF CONDUCTIVITY VERSUS TEMPERATURE AT DIFFERENT CONCENTRATIONS

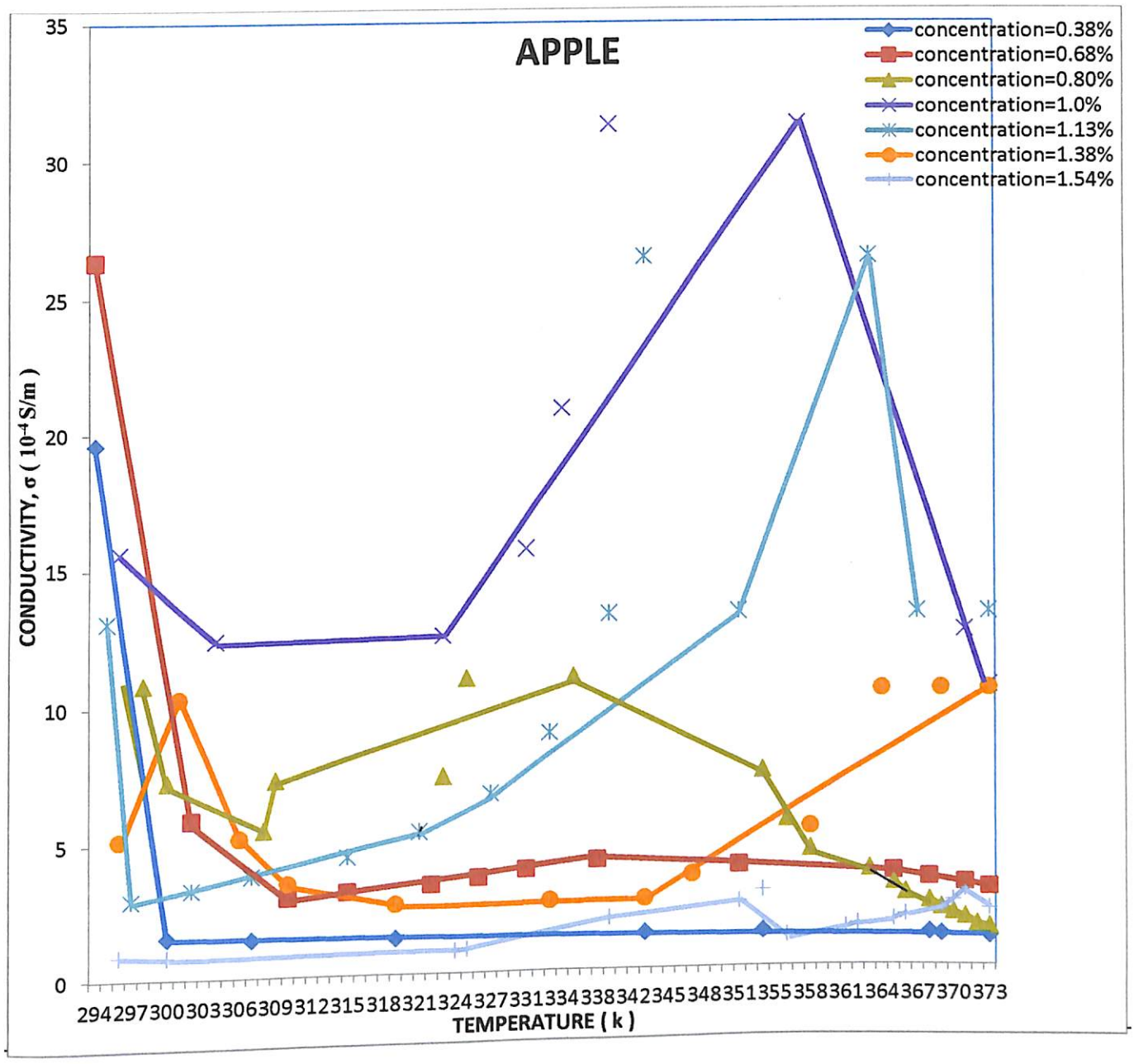

FIG. 17 : PLOT OF CONDUCTIVITY VERSUS TEMPERATURE AT DIFFERENT CONCENTRATIONS

6.1.5 TEMPERATURE VERSUS TIME

The plot of temperature versus time for potato and apple is shown in fig.18 and table 8 gives the values of variation of electrical conductivity with time. It is found that in the time interval 0 to 120 seconds the temperature increases slightly for potato and thereafter till 540 seconds there is an abrupt increase of temperature. In case of apple in the time interval from 0 to 180 seconds the temperature increases gradually and from 180 to 540 seconds there is a rapid increase of temperature.

The heating method affects the temperature distribution inside a food and directly modifies the time temperature relationship for enzyme deactivation[35].

TABLE 8 : VARIATION OF TEMPERATURE WITH TIME

TEMPERATURE (K)	POTATO TIME (SEC)	APPLE TIME (SEC)
295		0
297	0	
298	120	
299		60
302		120
304		180
311		240
325		300
332	300	
340	360	
344		360
357	420	420
367	480	
370		480
375	540	

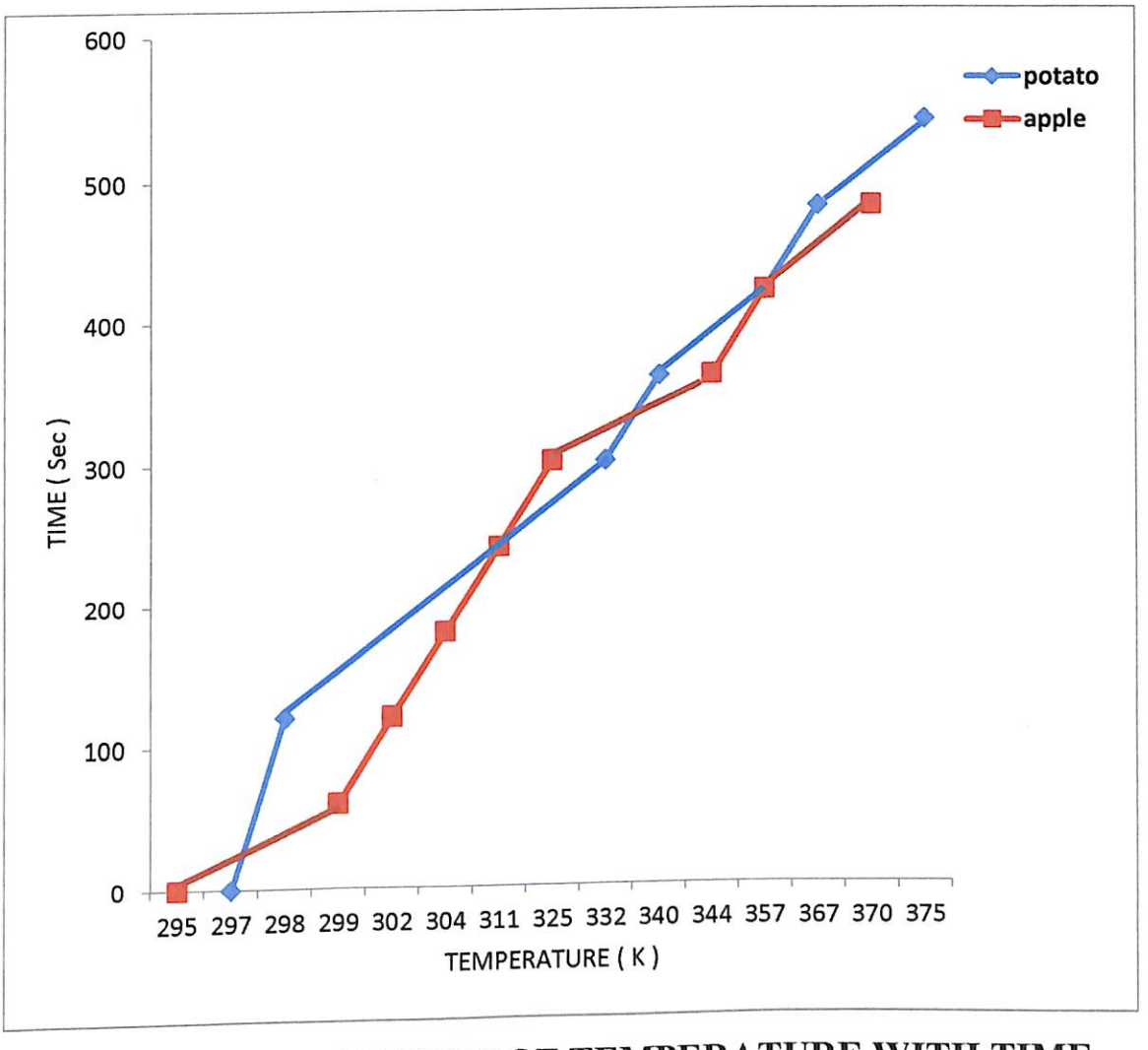

FIG. 18 : VARIATION OF TEMPERATURE WITH TIME