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Use of Photopyroelectric Film in Performing Quality Analysis for Food Matrix

Rushdi Kitaneh[(*a)], Ibrahim Afaneh[(a)], Hisham Hidmi[(b)], Abrar Al Za'tari[(a)]

(a) Alquds University, (b) Alquds Open University

(*) Corresponding author, Assoc. Prof. Dr. RushdiKitaneh, rkettaneh@staff.alquds.edu

Abstract – The Photopyroelectric film known as Polyvinylidenedifluoride film (PVDF) was used to invent a new technique for detecting food elements qualitatively and quantitatively. Several Food items, namely carbohydrates, proteins, fat, vitamins, and minerals, were involved. Several concentrations of the investigated materials were prepared in form of 0.1, 0.5, 1, 3, 5, 7, and 10%. The PVDF was found to be very effective in determining the concentrations and detecting the presence of several food elements, as in the case of NaCl, $CaCl_2$, Sucrose, and Tryptophan. The detection was in terms of full beam, while each item was measured at all investigated concentrations at specific wavelength. The results obtained showed very remarkable correlation between the measured food elements; NaCl, $CaCl_2$, Sucrose, and Tryptophan and the wavelengths; 720, 850, 1000, and 760nm, respectively. The real food samples consisted of eggs in the form of whole egg, egg yolk, and egg white and milk in the form of raw, pasteurized, and sterilized milk, and they were stored at different storage temperatures.

Keywords – Polyvinylidenedifluoride, Infra-Red, Quality Control, Filters, Food Technology.

I. Introduction:

Food is a word that can simply mean all substances people eat to sustain their life and to meet their body's basic needs, for growth, development and functions. Every single cell in our body depends on a continuous supply of calories and nutrients.

While Food is necessary to sustain life, this food has to be processed to insure it is microbiologically safe to eat, and also to transform unpalatable or unacceptable raw materials into attractive and desirable products, [1].

The first archaeological evidence of food processing shows that it first began in hunter-gatherer societies which had cooked by using open fire for meat, fish, and vegetables. Gradually, with the development of civilization, certain societies such as Egyptians societies had developed better food processing techniques, such as sun drying for meat, and grinding for cereal. So for thousands of years food processing kept evolving until this time of technological development. The entire food processing industry developed with electrical and technological revolutions, and food processing also became much faster in all areas, from coffee machines to food factory machinery [2].

Coupled with the speed in technological development, consumers' demands keep changing over time. These changes range from basic considerations such as improving food safety, shelf life, and reducing wastage, to demand for increasingly sophisticated foods having special characteristics in terms of nutritional value, palatability, and convenience. The actual product development process is determined by the interaction between consumer expectations and

demand, the technical capacity of the food producer, and emerging knowledge from food science research [3].

For the purpose of that issue, food quality should be determined. Food quality, defined by [4] as the degree of excellence of food, includes factors such as taste, appearance, and nutritional quality, as well as in bacteriological or keeping quality. Food quality goes hand in hand with food acceptability, and it is important that quality is monitored, both from a food safety standpoint and to ensure that the public likes a particular product and will come to select it. With this intention, food quality cannot be estimated until the food composition is determined, and that needs good methods to detect, which are called food analysis techniques.

Traditionally, analytical techniques have been classified according to their working principle. For example, they can be spectroscopic (e.g., mass spectrometry (MS); nuclear magnetic resonance (NMR); infrared (IR); atomic spectroscopy (AS)), biological (polymerase chain reaction (PCR); immunological techniques; biosensors), electrochemical (including also biosensors here), for separation (e.g., high-performance liquid chromatography (HPLC); gas chromatography (GC); capillary electrophoresis (CE); supercritical fluid chromatography (SFC)), for sample preparation (e.g., solid phase extraction (SPE); supercritical fluid extraction (SFE); headspace (HS); flow injection analysis (FIA); purge and trap (PAT); microwave-assisted extraction (MAE); automatic thermal desorption (ATD)), hyphenated (e.g., putting together separation and spectroscopic techniques), and so forth. Every technique provides specific information on the sample or components under study based on a specific physical-chemical interaction, and all have their own advantages and drawbacks when applied to food analysis as will be discussed below. An additional idea on the complexity of the number of techniques currently involved in food analysis can be obtained by developing a little more one of the above sub-disciplines. Considering the case of immunological techniques, they include the following ones: enzyme immunoassay (EIA), enzyme-linked immunosorbent assay (ELISA), immunodotting, radioimmunoassay (RIA), solid-phase RIA, liquid-phase RIA, immunoradiometric assay (IRMA), fluorescence: fluorescence immunoassay, enzyme-linked fluorescent immunoassay, fluorescence polarization immunoassay(FPIA), time-resolved fluorescence immunoassay (TRFI), and chemiluminescence immunoassay (CIA). Up to 27 techniques can be associated to immunological techniques [5].

In this regard, anon- destructive technique has been developed for enhancement of food composition and pathogen detection with less time, cost and more accuracy. These conventional methods require laboratories, high-cost equipment, and professionals. Moreover, complicated procedures for sample preparation and long analysis times are needed, thus preventing rapid detection and implementation in white electronics found in stores and homes. The limitations above have restricted their widespread use in food processing, transportation, marketing, and preservation in various food industries [6].

Scientific background:

Photopyroelectric technique:

In recent years there has been a surge of interest in investigations of materials - solids and liquids - using photothermal diagnostic techniques, which use lasers as precisely controlled optical heat sources. The development of lasers as convenient and powerful sources of localized energy has contributed greatly to the success of photothermal techniques over the conventional methods. The photothermal effects are generated by the deposition of energetic beams via direct heating provided by thermal deexcitations or by other non-thermal deexcitation processes like photoelectric, photochemical, luminescence and energy transfer processes, which result in indirect heating of the sample. If the excitation is modulated, the corresponding time and space dependent temperature variations developed in the sample

give rise to a variety of effects and most directly to temperature increase of the sample, which constitutes the basis of a distinct experimental technique known as photopyroelectric (PPE) effect. The pyroelectric effect consists of the induction of spontaneous, rapid polarization in a non-centrosymmetric, piezoelectric crystal as a result of temperature changes in the crystal. The measurements of the pyroelectric effect first appeared shortly before World War I. The use of pyroelectric detectors for the detection of infrared radiation was suggested early by [7]; however, the practical pyroelectric detectors have been developed only over the last two decades. Historically, the search for pyroelectric materials has been focused on their infrared radiation detection and their efficient high-frequency response. It is surprising that the sensitivity and the unique intrinsic capability of thermal sensors based on the pyroelectric effect to respond very rapidly to thermal excitations has not been exploited with photothermal phenomena until recently, [8].

[9] showed that in their study by considering the one-dimensional heat diffusion problem of Fig.1, where light, with intensity I_0 and angular modulation frequency $\omega=2\pi f$, is impinging on the upper surface of medium 2, which absorbs light on its surface with optical absorption coefficient b.

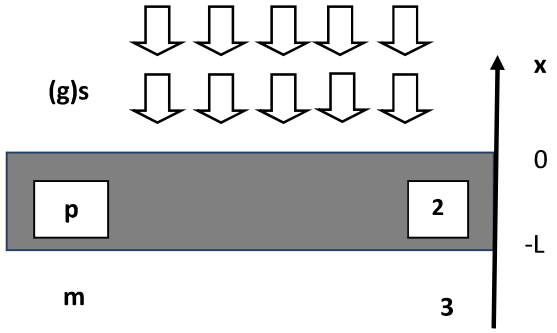


Fig.1 Schematic representation of the onedimensional heat diffusion model with surface absorption on the pyroelectric element.

The corresponding coupled differential equations for the one-dimensional heat diffusion are:

$$\frac{\partial^2 T_1}{\partial x^2}-\frac{1}{\alpha_1}\frac{\partial T_1}{\partial t}=0, \qquad 0\le x$$

$$\frac{\partial^2 T_2}{\partial x^2}-\frac{1}{\alpha_2}\frac{\partial T_2}{\partial t}=-\frac{\beta I_0\delta(x)}{2k_2}\left[1+e^{i\omega t}\right], \qquad -L\le x\le 0$$

$$\frac{\partial^2 T_3}{\partial x^2}-\frac{1}{\alpha_3}\frac{\partial T_3}{\partial t}=0, \qquad -L\le x<\infty \qquad (1)$$

where T_i (i=1, 2, 3) is the temperature distribution inside medium i; σ_2 is the complex thermal diffusion coefficient for medium 2, which is defined as $\sigma_2=(1+i)(\pi f/a^2)^{1/2}$, and a_2 , k_2 , and L are the corresponding thermal diffusivity, thermal conductivity and thickness, respectively. Solving this system of equations with the proper boundary conditions of heat flux and temperature continuity at all interfaces, it is easy to show that the temperature distribution inside medium 2 is given by:

$$T_2(x,t)=\frac{I_0\beta d(1+y_{12})}{4K_2\sigma_2}\frac{\left[e^{\sigma_2 x}-y_{23}e^{-2\sigma_2 L}e^{-\sigma_2 x}\right]}{\left[1+y_{12}y_{23}e^{-2\sigma_2 L}\right]}e^{i\omega t} \qquad (2)$$

In this equation βd is the absorbance of the infinitesimal surface layer of material 2, where total light absorption takes place; y_{12} and y_{23} are thermal coupling coefficients, defined by $y_{ij}=(1-e_i/e_j)/(1+e_i/e_j)$, with e_i being the thermal effusivity of medium i. From Eq. (2) the spatially averaged temperature inside medium 2 is:

$$T_2(f)=\frac{\beta I_0 d(1+y_{12})(1-e^{-\sigma_2 L})}{4Lk_2\sigma_2^2}\left[\frac{1-y_{23}e^{-\sigma_2 L}}{1+y_{12}y_{23}e^{-2\sigma_2 L}}\right]e^{i\omega t} \qquad (3)$$

Considering that medium 2 is a pyroelectric transducer, with the induced voltage proportional to its thickness-averaged temperature rise, it is evident that the voltage signal can be written as:

$$v_2(f)=\frac{G(f)\beta I_0 d}{4Lk_2\sigma_2^2}(1+y_{12})(1-e^{-\sigma_2 L})\left[\frac{1-y_{23}e^{-\sigma_2 L}}{1+y_{12}y_{23}e^{-2\sigma_2 L}}\right]e^{i\omega t} \qquad (4)$$

The function G (f), called the transfer function, represents the frequency response of the sensor and the electronics. By considering two different materials for medium 1 (gas (g) or a transparent liquid (s) in Fig. 1), the following two equations are obtained:

$$v_p^g(f) = \frac{G(f)\beta I_0 d}{4Lk_p\sigma_p^2}(1+y_{gp})(1-e^{-\sigma_p L})[\frac{1-y_{pm}e^{-\sigma_p L}p}{1+y_{gp}y_{pm}e^{-2\sigma_p L}}]e^{i\omega t} \quad (5a)$$

$$v_p^s(f) = \frac{G(f)\beta I_0 d}{4Lk_p\sigma_p^2}(1+y_{sp})(1-e^{-\sigma_p L})[\frac{1-y_{pm}e^{-\sigma_p L}p}{1+y_{sp}y_{pm}e^{-2\sigma_p L}}]e^{i\omega t} \quad (5b)$$

Taking the ratio of these two equations we obtain

$$R(f) = \frac{v_p^g}{v_p^s} = \frac{(1+y_{gp})[1+y_{sp}y_{pm}e^{-2\sigma_p L}]}{(1+y_{sp})[1+y_{gp}y_{pm}e^{-2\sigma_p L}]} \quad (6)$$

It is clear that this normalization procedure eliminates the transfer function and some other parameters, which could complicate the analysis. Equation (6) involves only the thermal response of the materials under examination. When the pyroelectric element is thermally thick at large enough modulation frequencies, it is clear that *R* reaches the asymptotic value,

$$R_{TG} = \frac{(1+y_{gp})}{(1+y_{sp})} = \frac{1+(e_g/e_p)}{1+(e_s/e_p)} \quad (7)$$

Taking into account that gas thermal effusivity, e_g, and the effusivity of the pyroelectric sensor, e_p, usually satisfy the relation $e_g \ll e_p$, it follows from Eq. (7) that

$$R_{TG} = 1 + \frac{e_s}{e_p} \quad (8)$$

Where e_s is the thermal effusivity of the liquid under study. From Eq. (8) the thermal effusivity for a liquid can be found, once the asymptotic value $R_{TG}$is known, from the relation,

$$e_s = e_p(R_{TG} - 1) \quad (9)$$

The constant R_{TG} can be obtained for a given transparent liquid, by taking the signal ratio R_{TG} from the pyroelectric sensor in the thermally thick regime in two different situations: one with the bare sensor, and the other with the liquid sample in place.

Polyvinylidene difluoride (PVDF):

Polyvinylidene difluoride (PVDF) is an Electro-active fluoro-polymer exhibiting a wide variety of characteristic mechanical and electric properties, such as piezoelectricity (the largest among the synthetic polymers), pyroelectricity, nonlinear optical property [10]. It has excellent chemical resistance and solvent resistance, high abrasion resistance, high dirt shedding, low flame and smoke characteristics, low permeation to most gases and fluids (extremely important for mil-grade Micro Electro Mechanical Systems (MEMS) applications), high dielectric strength & volume resistivity, high thermal stability, resistant to gamma and e-beam radiation, high mechanical strength at elevated temperatures. It is readily processable, formable and weldable, with superior melt processing characteristics. Their melt processability along with other exceptional properties enables the polymer to stand apart from its counterparts [11].

These properties make PVDF highly adaptable for applications in a wide range of industries, spanning aerospace, automotive, civil engineering, bio-medical and healthcare. They are extensively used in structural health monitoring systems, vibration and noise control, distance ranging and navigation, and security systems. In all these systems, PVDF predominantly plays the role of sensor and/or actuator. Apart from these, PVDF also plays a role as the electrolyte in polymer fuel cells, insulation of the electrical harness, micromanipulators and high-energy storage devices. The five most frequently described areas of application of PVDF are: as actuators, for vibration control, in medical ultrasound, as single-element pyroelectric infrared sensors, and in strain and acceleration measurement devices [11].

II. Purpose of this Project:

The suggested method depends on the measurement of a collective IR radiation absorption signal of food matrix in conjunction with photopyroelectric film (PVDF). IR radiation from a wideband pulsed IR source is allowed to fall on an aqueous food sample placed on top of a

photopyroelectric film and the resulting signal from absorption is measured. The attained signal is then employed as a characterization of food nutrient whose absorption of IR radiation follows the food component structure. The Radiation absorbed by sample on top of PVDF initiates a Pyroelectric (PE) signal related to the Pyroelectric effect (PEE). The signal is measured as a potential difference across the PVDF and is expected to follow any variations composition of food content structure, hence allowing differentiation between different samples under study. This makes the technique practical to study food composition detection and pathogen purposes by an inexpensive, easy, rapid to handle method.

III. Analysis Materials:

Food Nutrients material:

Materials used in this investigation were pure food nutrients and real food matrix (milk, oil, butter, and egg).

However, the following materials were involved in the investigation:

- Carbohydrates:
  1. Sucrose was used as a solution prepared in different concentrations (0.1%, 0.5%, 1%, 1.5%, 3%, 5%, 10%) obtained from a local supermarket.
- Protein:
  1. Pure albumin crystals as a solution prepared in different concentrations (0.1%, 0.5%, 1%, 3%, 5%,7%, 10%) obtained from a biology lab in al Quds University.
  2. Threonine powder (98%) prepared in 0.5 g/ 10 ml distilled water, obtained from Chechen farmer
  3. Lysine prepared in 0.5 g/ 10 ml distilled water, obtained from Chechen farmer
  4. Methionine prepared solution of 0.5 g/ 10 ml distilled water, obtained from Chechen farmer
  5. Tryptophan prepared solution of 0.5 g/ 10 ml distilled water, obtained from Chechen farmer
- Vitamin:
  1. Vitamin $B_{6,}$ prepared solution of 5% obtained from Bet Jala Company for drug and supplement.
  2. Vitamin $B_{1,}$ prepared solution of 5% obtained from Bet Jala Company for drug and supplement.
  3. Vitamin $B_{9,}$ prepared solution of 5% obtained from Bet Jala Company for drug and supplement.
- Fat:
  1. Sunflower oil, prepared solution of 2% and 10% in chloroform, obtained from local supermarket.
  2. Cow butter, prepared solution of 2% and 10% in chloroform, obtained from a local supermarket.
- minerals:
  1. Table salt (NaCl) was used as s solution prepared in different concentrations (0.1%, 0.5%, 1%, 1.5%, 3%, 5%, 10%)
  2. $Cacl_2$ was used as a solution prepared in different concentrations (0.1%, 0.5%, 1%, 1.5%, 3%, 5%, 10%)
  3. Ferrous powder, prepared solution of 5% obtained from Bet Jala Company for drug and supplement.
  4. Sodium chloride powder, prepared solution of 5% obtained from Bet Jala Company for drug and supplement.
- Real food sample:

Milk: Fresh milk, Pasteurized milk, UHT milk, was purchased from a local supermarket.

Eggs: purchased from a local supermarket.

Processing Methods: Photopyroelectric Cell Design:

The photopyroelectric cell used in investigation consists of a square piece of biaxially PVDF foil metallized on both sides with aluminium foil to provide for reflecting surfaces and electrode connections. The foil dimensions are 1cm x 1cm x 25 μm thickness. The aluminium foil is important to make sure that only heat resulting from radiation absorption and propagating through the sample is

detected and not that generated by direct interaction between radiation and detector. The foil was glued to a block of Perspex glass, which acts as a holder and support for the PVDF. The sample is placed on top of the foil using a micropipette. Perspex block and foil on top constitute the detection cell; it was enclosed in an aluminium box to minimize the ambient electromagnetic interference with the foil, prevent evaporation of the liquid sample during measurements, and reduce air turbulence. The infrared radiation was allowed in through a small opening 1cm diameter bored in the aluminium box side. Two electrodes were connected to the top and bottom of the foil with silver paint constituting terminals for the PEE output signal. This cell design was first used by [12] to study essential oils and olive oil adulteration. The detection cell shown in Figure 2 is connected to the electronic monitoring system for signal processing as shown in Figure 3.

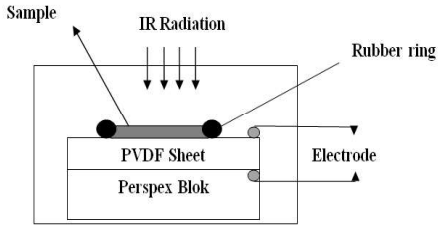


Fig. 2 Schematic showing the photopyroelectric cell used to study food samples

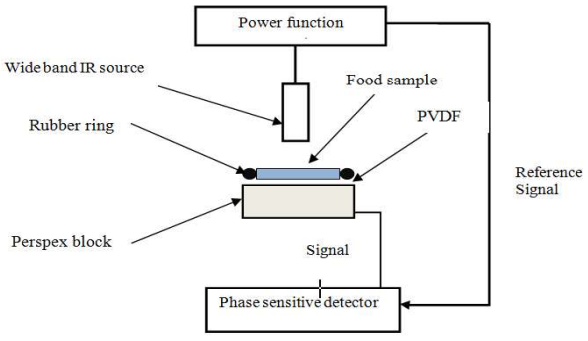


Fig. 3 Schematic illustration of the complete photopyroelectric detection scheme used to study food samples.

Wide band infrared (IR) source:

The source is a broadband infrared light source which has pulsed operation at large temperature modulations and an active area of 32.7 m^2, whose rated temperature is 850 C°, and minimum and maximum resistances are 2.8 ohms and 4.5 ohms respectively. The source looks dull red at 300 mA, and red at 320 mA, its rated drive power ~ 0.460 watts. It is an electrically pulsed source and radiates with low thermal-mass filament tailored for high emissivity in the specified range. This high-efficiency device minimizes drive power and greatly reduces parasitic heating of detectors and optics; it also eliminates the mechanical choppers, permitting a sealed optical path. The high emissivity enables the source to efficiently and rapidly cool via thermal radiation. The hot filament nearly cools to background temperature before the next pulse, thus providing several hundred degrees of temperature modulation. In this study results were obtained at source driving current of 300 mA and modulation frequency of 12.0 Hz.

Operational Methods:

The investigated sample of food nutrients were poured into the PVD film by dropper in isolated form. Each sample was individually studied and analysed to obtain accurate results

Real food sample:

Milk:

Under aseptic conditions, a drop of 100 µL of three different types of milk were studied: raw milk, pasteurized milk, and UHT milk. Each type of milk was studied in two different conditions, under ambient temperature and under refrigeration. All samples were studied through different storage periods of time (after 1 day, 2 days, 3days, 7 days, and 10 days) as seen in figure 4.

Egg:

A drop (100µL) of egg yolk, egg white and whole egg were studied using PVDF film separately under aseptic conditions as shown in figure 5.

Detection Method:

Different samples of food nutrients were investigated to study its reaction with ability of PVDF film to react with the studied nutrients.

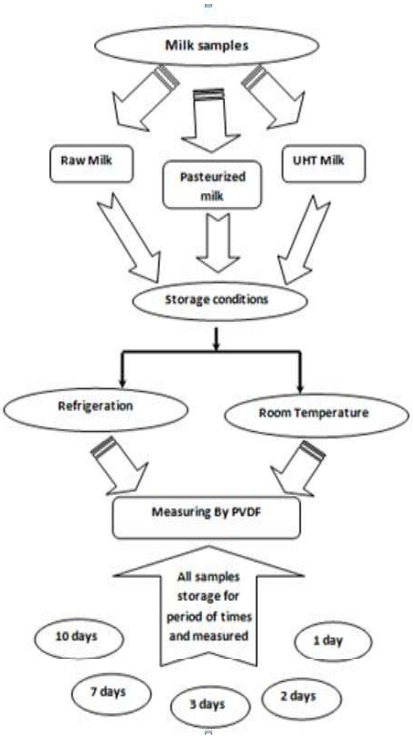


Fig. 4 Flowchart of Milk samples preparation for study.

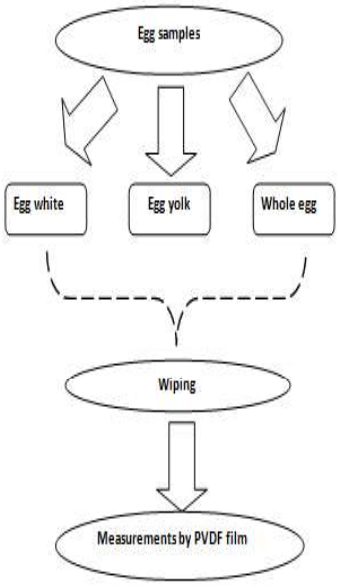


Fig.5 Flowchart showed the Egg sample preparation for measurement by PVDF film.

In each run a single drop of 10 µL by micro pipette was placed on the surface of PVD film in the region of ring rubber. The radiation of IR was driven from the power function generator and made to fall directly on the sample, where each sample's reaction with absorbed radiation depends on its structure and functional group, and its resulting absorption of IR radiation by food or microbe sample generates a signal that is picked up by the detection system and recorded as shown in figure 6.

Each sample examined was examined three times to reduce the analytical mistakes. The process was performed under aseptic conditions during sample tested as shown before.

Cleaning the Cell: After each run used, the PVDF film was cleaned carefully with swab and distilled water, and after microbial testing of each microbe the PVDF film was carefully cleaned with 97% alcohol and distilled water to ensure that all microbes are killed.

IR Filters: IR filters in different wave lengths (720nm, 760nm, 850nm, 950nm, 1000nm) were invested to examine the experimental samples to define the specific food matrix and microbes. In this study five filters were used to investigate the ability of this technique to detect each food component and differentiate it from other components or materials. All samples were studied with each filter separately, these filters were placed over the PVDF film and directly under the IR source, to allow a specific wavelength to pass through.

Quality Assurance Test:

This investigation is based on the fact that each food element of constituents should have one specific wavelength to be measured by. To verify this assumption one measure quality assurance test was conducted.

The test is based on the basis that each filter will be specified for each food element. Thus as the results showed, five major nutrients and food elements were linked with a specific wavelength through IR-

filters. One of these five food nutrients was chosen to be measured with its specific IR-filter and to compare its results with measuring it again by using two filters at the same time.

IV. Methodology:

The goal of this study is to introduce a new technique for food analysis. Analysis of food is continuously requesting the development of more robust, efficient, sensitive, and cost-effective analytical methodologies to guarantee the safety, quality, and traceability of foods in compliance with legislation and consumers' demands.

All samples that are prepared in different concentrations were placed under the IR source and each sample showed a remarkable signal that picked up by the detector will go through further experimentation using IR filters.

The sample which generates signals will be compared with other samples to catch if there are any two different nutrients that release the same reading with the same filter.

V. Results:

Measurements at Full Beam IR Source:

As seen in Tables 1 and 2, all used samples absorbed the broad band infrared light radiation, while it is on the top of the PVDF film. As shown, a noticeable different reading with the PVDF film depends on types of components, e.g. the signals that are obtained from Sucrose at different concentrations completely differed from that obtained from albumin, which could be defined due to the differences in food components and their functional groups(C-H, COOH, N-H, C=O) and its reaction with the photopyroelectric film (PVDF). The signals obtained from samples differed due to the difference in their chemical structures. When IR radiations hit the molecules, the radiation induces a vibrational excitation of the covalent bonds and groups—this excitation causes the bond to stretch or bend.

The chemical bonds have a specific frequency and it vibrates due to exposure to IR radiations. This frequency is related to the strength of bond or the mass of the atoms on the end of the molecules or its functional group. The amount of the absorbed radiation is related to the strength of chemical bond, the different kinds of chemical bonds in food materials like: (carbonyl group C=O, carboxyl group COOH, hydroxyl group OH, amine N-H, methyl group, double and triple bond C=C) induces different vibrations.

Table 1. Values of different samples at different concentrations measured by full beam of wideband infrared source.

Type of samples:	Different concentrations (%)						
	0.1%	0.5%	1%	3%	5%	7%	10%
Sucrose	0.5	0.7	0.9	1.3	1.3	5.6	5.4
Albumins	6	6.1	7.2	6.2	6.9	9.7	5.3
NaCl	0.5	2.7	0.9	1.1	6.3	8.3	7.8
$CaCl_2$	4.5	3.6	3.7	2.5	3.7	4.0	4.1

As noticed in Table 1 signal readings of same sample were different, as different concentrations were investigated. The concentrations were started from 0.1% and increasing to 10% for each material tested. For example, the sucrose generates signals increased from 0.5 to 5.4 with increasing the concentrations.

Same findings noticed in the signals that generates from table salt and range from 0.5 to 7.8, however the signals that obtained from calcium chloride slightly more than sucrose and table salt at 0.1% concentration was 4.5 while it's 0.5 in both sucrose and salt.

On the other hand, signals obtained from protein (Albumin) have more reactivity with the PVDF at concentration 0.1% and decreased with increasing concentrations. It's obvious that at concentrations 3% all signals at all samples had other pathways which all exhibit a decrease in signals measurement and retained to increase again for higher concentrations. The possible explanation for such a case could be due to the reaction of PVDF with the variation in the sample structure and properties like the presence of the hydroxyl group in sucrose(OH), amine group in protein (NH), and ionic properties of both NaCl, $CaCl_2$ react with PVDF in differently.

As seen in Table 2, all samples react with PVDF in different manners. Unlike the result of reacting PVDF with previous samples (sucrose, protein, NaCl, $CaCl_2$), the albumin had the highest reading. But as seen in Table 2, all samples at 5% concentration of vitamins, fat, and minerals like ferrous have high signal reading while the amino acid had shown a lower signal output in an exception for tryptophan which had a higher reading like other samples. Most samples generate signals around 5 (a.u) while vitamin B_6 generated around 8. This result could be explained due to samples' chemical structure and their different functional groups and behavior at water and its ability for IR absorption.

Table 2. Values of different samples at 5% concentrations measured by full beam of wideband infrared source

Type of samples	Signals values at concentrations (5%)
amino acids	
Tryptophan	5.5
Threonine	0.58
Methionine	0.64
Lysine	0.74
Fat	
sunflower oil	5.53
Butter	5.3
Vitamins	
B_1	6.72
B_6	8.02
B_9	5.92
Minerals:	
Ferrous	6.65
Ultra Pure Sodium chloride	5.82

Measurement of NaCl:

As shown in Table 3, NaCl solutions with different concentrations showed reasonable readings with full beam spectrum of IR. Using the five available filters showed non reacted activity between NaCl samples and filters with certain wavelengths, namely: 1000, 950, 850, and 760. At the same time the NaCl solutions expressed a noticeable measuring in the absorbance figures measured under the use of 720nm and through IR-filter.

Measurements at Certain Wavelengths:

Measurements of prepared samples were taking place by using five different IR-filters that allow only one wavelength to react with the food sample and PVDF film. Since the investigated food nutrients, real food samples, showed high interaction with the full beam wavelength of infra-red and the

PVDF, certain nutrients were reacted with specific wavelengths and the rest needed another wavelength to be linked with.

Table3. The values of different concentrations of NaCl solution measured by different IR wavelengths.

Concentration (%)	Absorbance under Full beam wavelength	Absorbance With filter At specific wavelength				
		1000	950	850	760	720
0.5%	2.74	2.743	2.69	2.69	2.5	2.6
1%	0.9	0.8175	0.8025	1.08	2.184	0.592
3%	1.12	0.936	0.718	0.522	0.648	0.883
5%	6.29	0.14	1.366	1.303	1.06	1.19
7%	8.28	1.61	1.136	0.81	0.855	1.23
10%	7.8	1.154	1.346	0.7366	0.684	2.228

At the same time, measurements of NaCl concentrations under the 720 nm IR filter showed a certain trend; as the concentration of NaCl increased, the absorbance value increased, as appeared in Figure 7. However, the results trend appeared to be in linear mode with R^2 =0.91.

This result is due to the reaction between PVDF film and NaCl which is found to react positively. The possible explanation for such reaction is the ability of PVDF porosity to react more with the presence of more NaCl molecules.

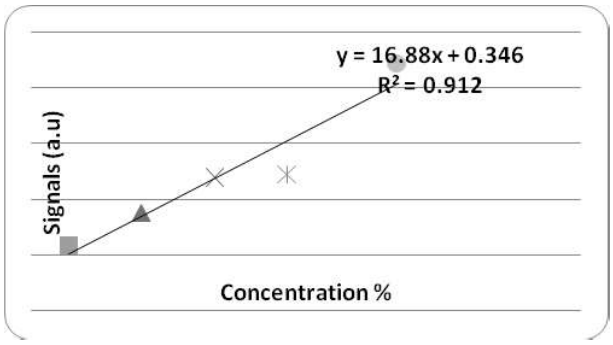


Fig. 7 The trend of different NaCl concentrations measured under 720 nm IR wavelength.

Measurement of $CaCl_2$:

In addition, as shown in Table 4, a reasonable reading with full beam spectrum of IR was obtained from $CaCl_2$ solutions with different concentrations. Using the five available filters showed non reacted activity between $CaCl_2$ samples and filters with certain wavelengths, namely: 1000, 950, 850, and 760 nm. At the same time $CaCl_2$ solutions expressed a noticeable measuring in the absorbance figures measured under the use of 850nm IR-filter.

Table 4. Values of different concentrations of $CaCl_2$ solution measured by different IR wavelengths

Concentration (%)	Full beam	With filter (nm)				
		1000	950	850	760	720
0.5%	4.5	0.17	0.17	1.233	0.283	0.123
1%	3.6	0.11	0.477	1.443	0.46	0.417
3%	3.7	0.443	0.443	1.47	0.453	0.443
5%	2.5	0.25	0.187	1. 567	0.15	0.233
7%	3.7	0.48	0.383	1.57	0.367	0.27
10%	4.0	0.507	0.127	1.49	0.553	0.623

As well as, measurements of the $CaCl_2$ concentrations under the 850nm IR filter displayed certain trend, as the concentration of $CaCl_2$ increased the absorbance value increased, as appeared in Figure 8. However, the results trend appeared to be in linear mode were R^2 was equal to 0.89.

This result due to the reaction between PVDF film and $CaCl_2$ found to be a positive reaction. The possible explanation for such reaction is the ability of PVDF porosity to react more with more $CaCl_2$ molecules presents.

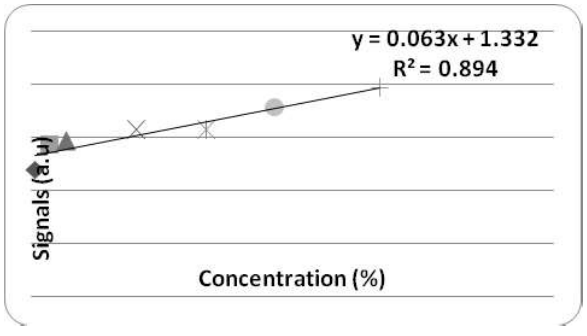


Fig. 8 Trend of different $CaCl_2$ concentration measured under 850 nm IR wavelength.

Measurement of Sucrose:

In the same manner, as shown in Table 5, Sucrose solutions with different concentrations presented a reasonable reading with full beam spectrum of IR. Using the five available filters showed non reacted activity between sucrose samples and filters with certain wavelengths, namely; 1000, 950, 850, and 760 nm. At the same time the sucrose solutions expressed a noticeable measuring in the absorbance figures measured under the use of 1000 nm IR-filter.

Moreover, measurements of the sucrose concentrations under the 1000nm IR-filter showed certain trend, as the concentration of sucrose increased the absorbance value increased, as appeared in Figure 9. However, the results trend appeared to be in logarithmic mode with

R^2=0 .978.

This result due to the reaction between PVDF film and sucrose found to be positive reaction. The

possible explanation for such reaction is the ability of PVDF porosity to react more with more sucrose molecules presents.

Table 5. The values of different concentration of sucrose solution measured by different IR wavelengths

Concentration (%)	Full beam	With filter (nm)				
		1000	950	850	760	720
0.5%	0.48	3.308	0.254	0.483	0.3	0.205
1%	0.66	3.355	0.426	0.873	1.048	0.845
3%	8.5	3.39	1.07	1.034	0.672	1.023
5%	1.25	3.332	1.24	1.478	1.178	1.134
7%	1.3	3.323	1.055	1.536	1.482	1.465
10%	5.56	3.49	1.415	1.592	1.566	1.702

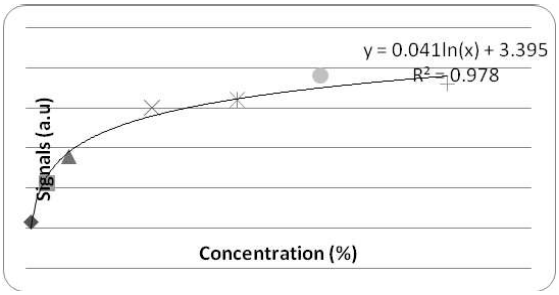


Fig. 9 Trend of different sucrose concentration measured under 1000nm IR wavelength.

Measurement of Tryptophan:

Furthermore, as shown in Table 6, tryptophan solutions at 5% concentration presented a reasonable reading with full beam spectrum of IR. Using the five available filters showed non reacted activity between tryptophan samples and filters with certain wavelength, namely; 1000, 950, 850, and 760. At the same time the tryptophan solutions expressed a noticeable measuring in the absorbance figures measured under the use of 760 nm IR-filter.

Table 6. The values of tryptophan at 5% concentration solution measured by different IR wavelengths.

Concentration (%)	Full beam	With filter (nm)				
		1000	950	850	760	720
5%	5.541	1.1	1.3	2.4	5.5	2.4

Unfortunately, due to the lack of tryptophan sample, no further investigations in terms of a seires of different concentrations took place.

Measurement of Candida:

As seen in Table 7, a reasonable reading with full beam spectrum of IR were obtained for Candida dilution. Using the five available filters showed non reacted activity between Candida samples and

filters with certain wavelengths, namely; 1000, 950, 850, and 760. At the same time the Candida dilution showed a noticeable measured reading in the absorbance figures measured under the use of 950 nm IR-filter.

Table 7. The values of Candida stock concentration measured by different IR wavelength.

Concentration (%)	Full beam	With filter (nm)				
		1000	950	850	760	720
5%	4	1.2	3.1	1.7	1.6	1.34

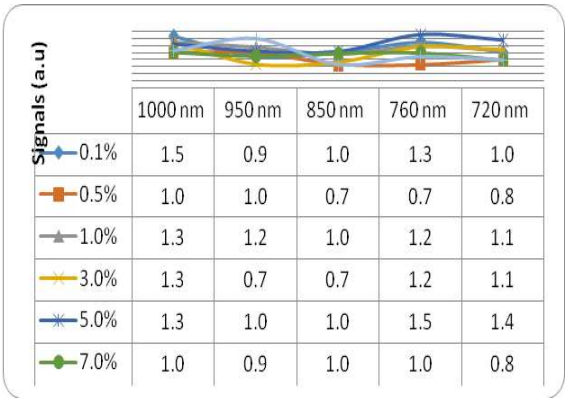
This result was confirmed when a series of different dilutions were prepared for candida and the signal measurement took place by using 950nm IR wavelength, as shown in Table 8.

The measurements obtained showed a gradual decrease in absorbance measurement value as the dilution increased. This is due to the fact that the PVDF film was able to react with higher number of candida cells more than with lower number of candida cells, thus more cells produce higher reading values.

Table 8. The values of candida different dilution measured by 950nm IR wavelength.

No.	Candida dilution	signal measurement (a.u)
1	1	4.8
2	0.1	4
3	0.01	3.7
4	0.001	3.4
5	0.0001	3.1
6	0.00001	2.1
7	0.000001	2.2

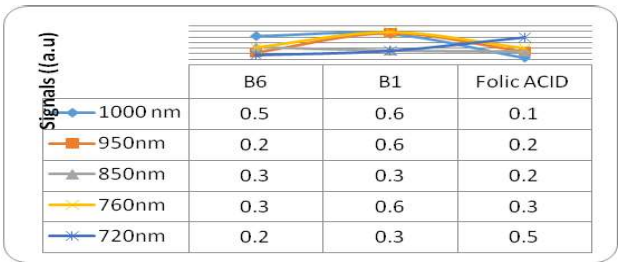
Measurements at Unavailable Specific IR Wavelength: In contrast to previous results, in this section all samples showed only a noticeable reaction with full beam of IR but no obvious reaction with certain IR-filters, the possible assumption for such results is that the sample could react with other filters with certain wavelength rather than the available one in this study, since the budgets of this study couldn't provide all filters set that cover infrared radiation. As examined in Figure 10, all albumin samples showed no reaction with the available filters with certain wavelength, namely; 1000, 950, 850,760 and 720 nm.



	1000 nm	950 nm	850 nm	760 nm	720 nm
0.1%	1.5	0.9	1.0	1.3	1.0
0.5%	1.0	1.0	0.7	0.7	0.8
1.0%	1.3	1.2	1.0	1.2	1.1
3.0%	1.3	0.7	0.7	1.2	1.1
5.0%	1.3	1.0	1.0	1.5	1.4
7.0%	1.0	0.9	1.0	1.0	0.8

Fig. 10 Values of IR-filters with different albumin concentrations.

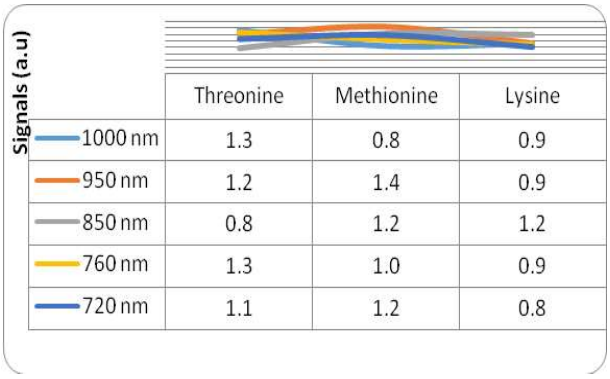
Furthermore, same obstacles were found in measuring vitamins by available IR filters. The investigated vitamins were subjected to full beam of infra-red showed a reasonable measurement. At the same time the available IR-filters were unsuitable for specific wavelength readings, as appeared in Figure 11. Although amino acids involved in this investigation, namely; Threonine, Methionine, and Lysine showed a measurable value under the effect of full beam infra-red source.



	B6	B1	Folic ACID
1000 nm	0.5	0.6	0.1
950nm	0.2	0.6	0.2
850nm	0.3	0.3	0.2
760nm	0.3	0.6	0.3
720nm	0.2	0.3	0.5

Fig. 11 Values of IR-filters with vitamins samples.

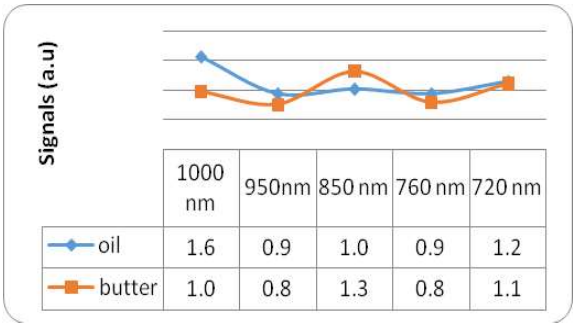
At the same time non of the available IR-filters showed constant reading for the amino acid's samples tested (Figure 12).



	Threonine	Methionine	Lysine
1000 nm	1.3	0.8	0.9
950 nm	1.2	1.4	0.9
850 nm	0.8	1.2	1.2
760 nm	1.3	1.0	0.9
720 nm	1.1	1.2	0.8

Figure 12. Values of IR-filters with amino acids.

The last sample investigated was the lipid sample. Samples of oil and butter were tested under the full beam wavelength of IR source. While these samples showed an interaction with the PVDF and exhibited a valuable reading, the available specific IR wavelength showed no reading.



	1000 nm	950nm	850 nm	760 nm	720 nm
oil	1.6	0.9	1.0	0.9	1.2
butter	1.0	0.8	1.3	0.8	1.1

Fig. 13 Values of IR-filters of lipid materials.

Results obtained in this section are shown in Figure 13. The investigation emphasized on the ability of the PVDF to interact with those materials and managed to provide certain measurement of considerable values when the full beam of the IR wavelength was used. This means that those materials need a specific wavelength rather than the available ones as none of the available five IR-filters was suitable for those materials.

Quality Assuring Test:

As this investigation is based on the fact that each food element of constituents should have one specific wavelength to be measured with, and to verify this assumption one quality assurance test was conducted to validate this assumption.

As shown in Figure 14, measurements of $CaCl_2$ with specific IR-filter (850nm wavelength) showed a remarkable measurement with certain reasonable trend. At the same time when this measurement was carried out with merging the 850nm IR-filter with 720 IR-filter or merging the 850nm IR-filter with 1000nm IR-filter no readings were observed.

This tremendous result revealed the idea and the fact that the food component could have only one specific IR wavelength to be measured with.

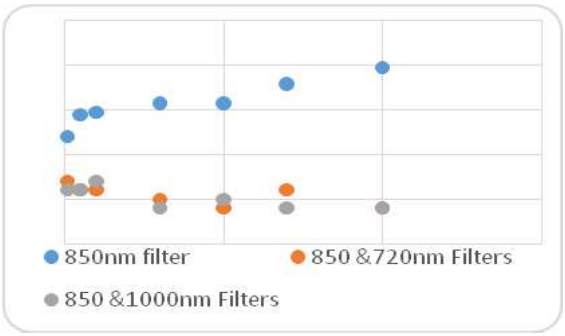


Fig. 14 $CaCl_2$ sample tested by combined IR-filters in comparison with its specific IR-filter.

VI. Conclusions:

The following conclusions were highlighted from the major findings of this study.

•The PVDF film was found to react with organic materials and not limited to certain physical materials.

•IR source was able to create a measurable interaction between food components and PVDF.

•Major food components found to be interacting with specific wavelengths.

•The specific wavelength linked with specific food item found to be determined.

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