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Thermal Analysis of Foods: A Review

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ABSTRACT

Out of a wide variety of techniques of thermal analysis, only few are significant for food analysis.The technique in which a physical property of a substance is measured as function of temperature whereas and the material is under controlled temperature program is called Thermal Analysis. The main thermal techniques for food analysis are- thermal mechanical analysis (TMA), thermogravimetry (TG),dynamic mechanical analysis (DMA), differential scanning calorimetry (DSC) and differential thermal analysis (DTA). Protein, mainpart of large variety of foods and, apart from its nutritional values, contributes to the functional properties of various foods. Protein processing and conformation with DSC study is helpful in explaining protein aggregation, gelatin and denaturation mechanism also gives a path to get maximum utility of proteins.

Keywords: Thermal, Techniques, Analysis, Food, Function, Temperature.

INTRODUCTION

Most of foods are subjected to variations in their temperature during production, transport, storage, preparation, and consumption, for example, pasteurization, sterilization, evaporation, cooking, freezing, and chilling, etc.

Temperature changes, cause alterations in the physical and chemical properties of the food components, which influence the overall properties of the final product, for example, taste, appearance, texture, and stability. To understand the influence of temperature on the properties of food, certain analytical techniques to monitor the changes that occur in foods when temperature changes is known as thermal analysis of foods.

Foods with low-moisture content and frozen foods i.e. concentrated foods are rarely in equilibrium as they these form non-crystalline, amorphous structures. Various glass transitions in these types of foods affect their shelf life and stability, e.g., recrystallisation of gelatinised starch, crispness of snack foods, caking and stickiness of powders, gelatinised starch crystallization, enzymatic reactions, rates of non-enzymatic browning and recrystallization and ice formation in frozen foods.

Thermal analysis includes numerous techniques by which chemical or physical changes of a substance, either alone or in the presence of other substances are measured as a sample is subjected to a control temperature program versus time.

Calorimetry: The ultimate chemical change that can be in a food system by thermal analysis is the total combustion of a product to determine its mineral and caloric content. Usually, determined by bomb calorie meter and is achieved by uncontrolled heating of materials in the presence of oxygen.

Thermal Analysis of chemical reactions depends on following.

- Transition temperature that is when one physicist changes into another.
- Heat capacity change.
- Weight loss or gain.
- Energies of transition or enthalpy, change ΔH
- Viscoelastic property changes during phase change or chemical reaction.
- Changes in electrical polarization
- Evolved gases.

A broad transition is indicative of transitions that relate to dehydration, temperature, dependent phase behavior or polymer melts. Exothermic transitions, relate to reactions without decomposition can be caused by a decrease in enthalpy of a phase or chemical system.

Narrow exotherms are obtained for crystallization of a metastable system, whether under cooled organic, inorganic, amorous, polymer, or liquid, or annealing of stored energy, resulting from mechanical stress.

Broad exotherms are obtained for solid, solid phase transitions, chemical reactions, polymerization.
Exothermic transitions that relate to decomposition can be narrow or broad, depending on their kinetic behavior.

Principle of calorimetry: measurement the chemical changes in food are coupled with energy transformations.

- Oxidation- heat released, temperature increases and are exothermic reactions.
- Hydrolysis- Little or no heat evolution and are known as isothermic reactions.
- Reduction- Heat is absorbed and temperature rises known as endothermic reactions. Net amount of heat absorbed or released by a sample can be measured quantitatively in a calorie meter. Units of thermal energy are-

1 calorie per gram = 1.8 Btu/b = .001 Kcal/g = 4.184 J/g

Out of a wide variety of techniquesof thermal analysis, only few are significant for food analysis.The technique in which a physical property of a substance is measured as function of temperature whereas and the material is under controlled temperature program is called Thermal Analysis.Heat transformations are observed in almost all the foods these may occur during processing, preparation, manufacturing,distributing, and harvesting.During these treatments the physico-chemical and functional properties of thefood gets altered thereby affecting the acceptability and qualityof the foods. The main thermal techniques for food analysis are), thermal mechanical analysis (TMA), thermogravimetry (TG),dynamic mechanical analysis (DMA),differential scanning calorimetry (DSC) and differential thermal analysis (DTA). Protein, mainpart of large variety of foods and, apart from its nutritional values, contributes to the functional properties of various foods.Protein processing and conformation with DSC study is helpful in explaining protein aggregation, gelatin and denaturation mechanism also gives a path to get maximum utility of proteins.

Modern Thermal Analysis:

1. Differential scanning calorimetry (DSC).
2. Differential thermal analysis (DTA).
3. Thermal gravimetric analysis(TGA).
4. Dynamic mechanical analysis (DMA).
5. Thermal mechanical analysis (TMA).

First two methods are most used methods. These measure different temperatures or heat flow to or from a sample versus a reference material, and this is displayed as a function of temperature or time. These techniques differentiate between endothermic and exothermic reactions. whereas, thermometric analysis, measures change in weight of a sample as a function of temperature, both losses as well as gains can be measured.

Endothermic curves are related to physical changes not to chemical changes. A sharp endotherm is obtained in case of crystalline transition rearrangement, fusion, or solid-state transition for pure materials.

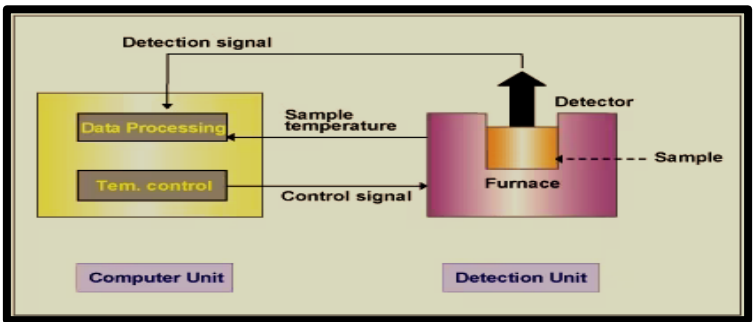


Figure: configuration of Thermal Analysis instrument

Main components of thermal analysis instruments are:

1. Data Recording unit-Records the signals of sensor and sample temperature and analyse them.
2. Detection unit- Includes furnace, sample, the reference holder and sensor, heats and cools the sample in the furnace, and detects the sample temperature and the required properties.
3. Temperature Control Unit- which controls the furnace temperature.

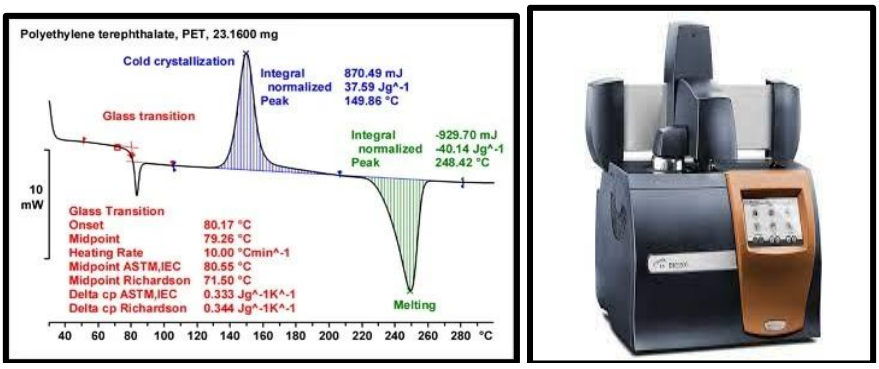
All the above are computer controlled. Sensor and Furnace combination give means todifferent types of measuring techniques. This device can be connected to many instruments, which are used for measuring other properties , thus measurement and analysis can go side by side.

Differential Scanning Calorimetry (DSC): calorimetry isused for analyzingthe physical properties of water in different variety of food stuffs. Differential Scanning Calorimetry is used for the characterization of polymorphic mixtures of fats and to determine the hydrogenation and to inculcate changes to get desired polymorphic changes.

Table:1 Food samples with their application by DSC

S.No.	Type of Sample	Information received
1	Vegetablepowders.	Glass transitionTg
2	Flour and rice starch.	Retrogradation/gelatinization/Glass transition Tg.
3	Oils, fats and spreads.	Onset temperature of melt/Crystallization/Polymorphic behaviour/Oxidation stability
4	Protein.	Denaturation /aggregation
5	Paste and gels containing polysaccharides or gums.	Specific heat, C_p , onsettemperature of melt, and crystallization.

Differential Scanning Technique, is a thermal analysis used for measuringthe heat flows and temperature related with phase transitions in substances as a function of temperature and time. These type of measurements provide both qualitative and quantitative information relating physical and chemical changes which are endothermic (Heat absorbing) and exothermic (Heat evolving) processes, or changes in heat capacity. DSC is best suited for food analysis systems as they are often subjected to cooling or heating during their processing. The calorimetric datareceived from DSC can be directly used to predict thermal transitions that the food systems may undergo during storage or processing. As no special sample preparation is required for DSC, it is very easy to operate.Both liquid and solid food samples can be studied with DSC , as a wide range of DSC sample pans are available. These tests can be used for R&D and quality control purposes.



Dynamic thermal analyzers (DTA): The test sample is inserted internally. It is used as difference material in this case.Test and materials are heated at the same time under identical conditions.Temperature of sample, either more or less than the reference material, depending on whether the reaction is exothermic or endothermic. If there is no pressure difference, then it is known as isothermal.in nearly isothermal state exists, a small temperature differential between test sample and a reference may.

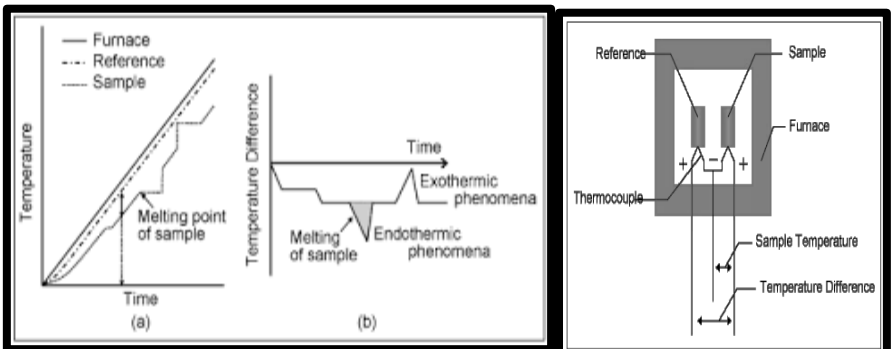
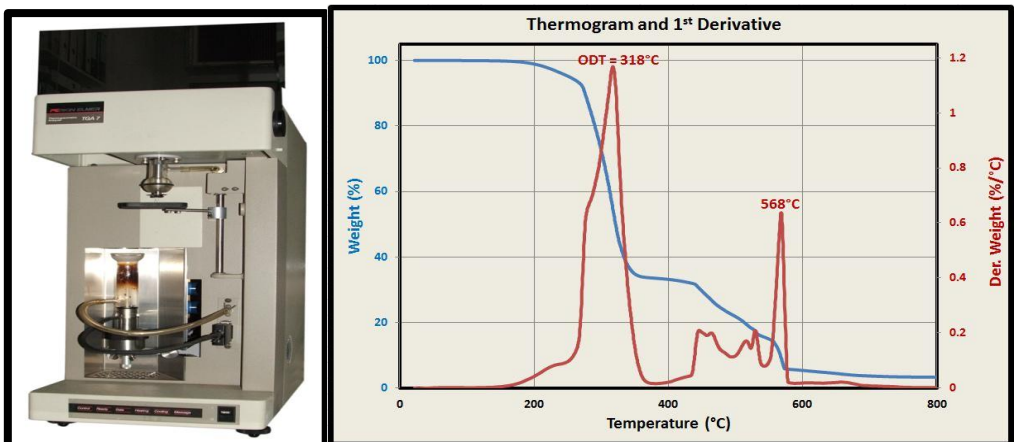


Figure: DTA

Thermogravimetric Analysis (TGA): Thermogravimetric Analysis is a technique in which the mass of a substance is monitored as a function of time or temperature as the sample is analysed under a controlled temperature program in a controlled conditions.



Thermal Mechanical Analysis (TMA):
A technique in which sample deformity under non oscillating stress is observed against temperature / time of the sample, in particular conditions. The stress can be torsion, compression or tension.

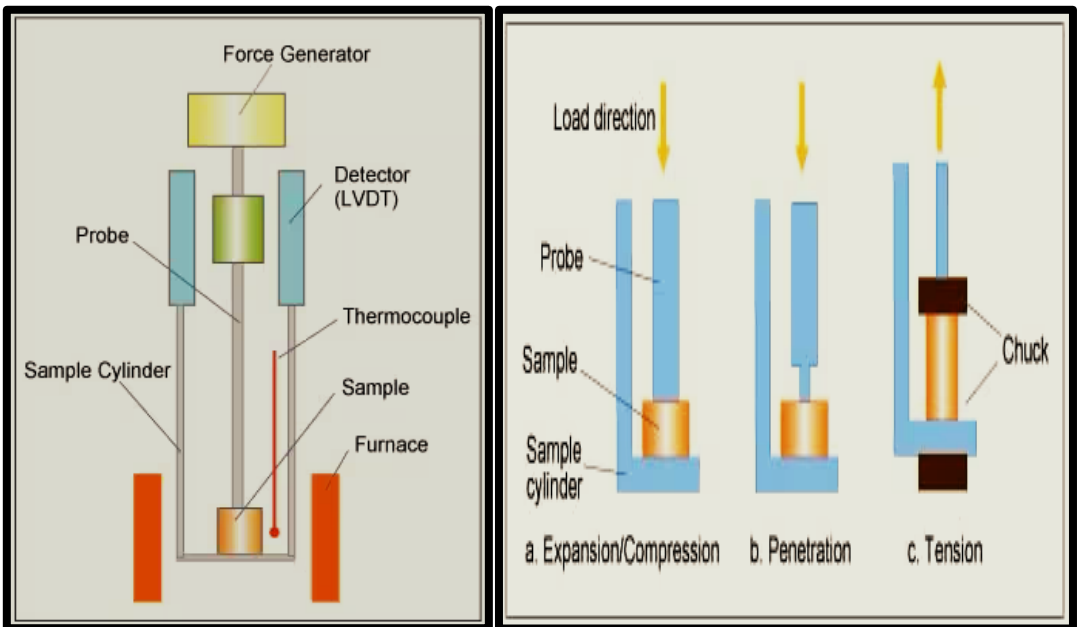


Fig: Block diagram of TMAFig: Different Probes of TMA

i) Tension Probe: This can be used for the measurement of thermal expansion and the thermal shrinkage of the sample like film and fibre. Materials used in probe are quartz, glass, metals and alumina. These can be chosen depending upon the temperature range and the purpose for measurement.
ii) Expansion/compression probe: This probe can be used for measuring deformation by transition of the sample and thermal expansion where the compressed force is applied.
iii) Penetration Probe: This probe can be used for measurement of the softening temperature.

Dynamic Mechanical Analysis (DMA): A technique which is applied to a sample for analyzing its kinetic properties using variation of stress, strain with time.

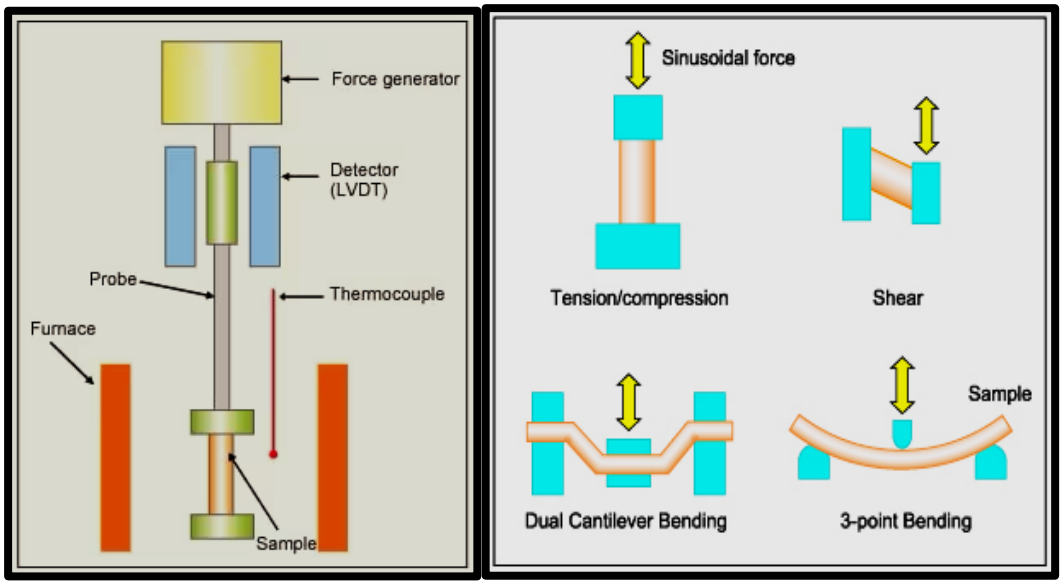


Fig: Block diagram of DMAFig: DMA deformation modes

The measurement head of the DMA instrument contains sample. The sinusoidal force is applied to the sample through the probe during measurement.During this, the deformation gets detected by the sinusoidal forces and the relation betweenapplied force and the deformation is also measured. The other properties like viscosity

and elasticity can be determined from the applied stress and strain, which are plotted as a function of temperature or time.

Main importance of DMA is for the measurement of different polymer materials having different deformation modes.There can be compression dual cantilever bending, tension, 3- point bending., sheer modes, and the most suitable type can be selected depending on the sample shape, modulus, and measurement purpose.Various viscoelastic properties which can be measured by DMA are- Storage modulus, loss modulus and loss tangent. Their dependence on temperature and frequency can also be analysed with DMA.Glass temperature dependence and glass. Transition temperature analysis can be measured by the temperature dispersion measurement. If temperature dispersion and frequency dispersion relaxation phenomena are measured side by side, glass transition, side chain relaxation and local mode relaxation can also be determined. This will be helpful in obtaining information about molecular motion and molecular structure of polymers.

Dynamic thermal analyzers (DTA): The test sample is inserted internally. It is used as difference material in this case.Test and materials are heated at the same time under identical conditions.Temperature of sample, either more or less than the reference material, depending on whether the reaction is exothermic or endothermic. If there is no pressure difference, then it is known as isothermal.in nearly isothermal state exists, a small temperature differential between test sample and a reference may.

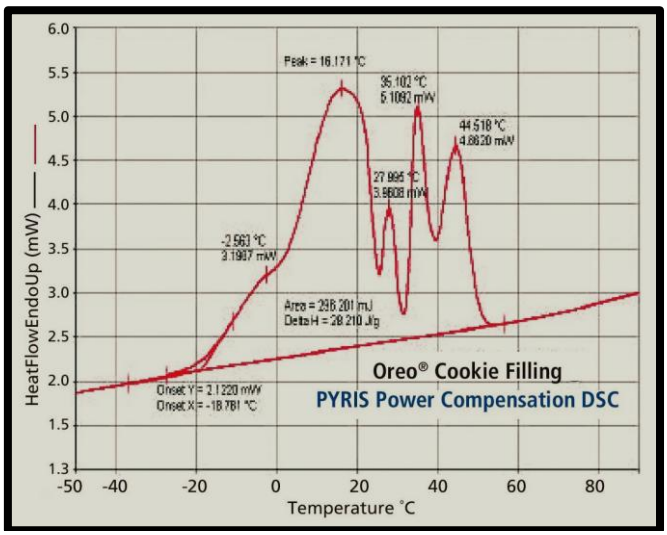


Table: 2 Property measured with all the thermal analysis techniques

Thermal Analysis Techniques	Abbrev.	Property	Unit
Differential Thermal Analysis	DTA	Temperature difference	°C / μV
Differential Scanning Calorimetry	DSC	Enthalpy (Heat of Reaction)	W= J/sec
Thermogravimetric Analysis	TGA	Mass	gram
Thermomechanical Analysis	TMA	Deformation	meter
Dynamic Mechanical Analysis	DMA	Elasticity	$Pa=N/m^2$

CONCLUSION

Differential Scanning Calorimetry can contribute to the development of new food products, for systems with a clearly established phase-composition-functionality relation.DSC is an essential technique to reveal the underlying phase- compositional principles of food systems.DTA and DSC techniques are used regularly in the food industry to determine phase transitions in foods, e.g. melting, crystallizations, conformational changes and glass transitions. These are used to give information about the transitions temperature.Understanding the influence of temperature on the food properties, food manufacturers can optimize processing conditions for improved quality product. All of these techniques come under one heading i.e. thermal analysis. Nowadays, the term thermal analysis is usually given to techniques that measure changes in the physical properties of foods with temperature and time, e.g., density, mass, rheology and heat capacity.

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