EXTRACTION OF PHARMACOLOGICALLY ACTIVE THYMOQUINONE IN NIGELLA SATIVA L.

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Abstract

Black Seed Oil or Nigella Sativa L. is said to be the universal remedy. It has an amazing healing power and its greatness has been recorded in the Hadith stating that it could cure any diseases except death. Today black seed oil has been commercialized; research is carried out from time to time to improve its quality. This research purposely is to determine the best solvent to be used in extracting black seed oil, in terms of time and most importantly its yield. Rotary Evaporator employed with Ultra Sonic Bath is used in extraction process. Time and heat is chosen as the parameter to manipulate and several trials is carried out. Optimum condition will be recognized. After the extraction, oil is obtained then HPLC analysis is carried out to determine the existence of Thymoquinone which is the main compound in Black Seed Oil. Quantitatively, more Thymoquinone means better quality of Black Seed Oil.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Black seed is considered to be one of the greatest healing herbs of all times. This herb has been used for millenniums to strengthen the immune system, cleanse the body, purify the blood, protect against irritants and support healthy longevity. Black Seed is also known as Black Cumin, Black Caraway Seed, Habba Sawda (the Black Seed) Habbatul Baraka (the Blessed Seed), and by its botanical name "Nigella Sativa.

Historically, the first essential oil encountered was the oil of rose. It was discovered by the Chinese prior to the Christian era. A layer of this oil was found on a pool that was filled with rose water. Essential oils contain DNA of the plant of herbs they are extracted from. Essential oils or sometimes called volatile oils are believed to be that small portion of the plant material, which imparts the characteristics odors and flavor most closely associated with the vegetative matter which they are obtained [1]. Most of the essential oils are used at about a level of 0.01-0.1 percent in the finished product. They are often slightly colored and have a specific gravity of about 1.

The advantages of essential oils are their flavor concentrations and their similarity to their corresponding sources. The majority of them are fairly stable and contain a few natural antioxidants. Although most are soluble in high strength alcohol (more than 90 percent), they have poor water solubility and most contain terpenes that contribute to their poor water solubility [8]. Some essential oil are adaptogenic. This implies that the essential oil increase resistance and resilience to stress, enabling the body to avoid reaching collapse. Adaptogenic essential oils aid the body in maintaining homeostasis throughout stressful periods.

While the Black Seed is highly effective by itself, ongoing studies with the combination of other herbs have produced remarkable results. Amazingly Black Seed's chemical composition is very rich and diverse. Aside from its primary ingredient, crystalline nigellone, Black Seed contains 15 amino acids, proteins, carbohydrates, both fixed oils (84% fatty acids, including linolenic, and oleic), and volatile oils, alkaloids, saponin, and crude fiber, as well as minerals such as calcium, iron, sodium and potassium. There are still many components in Black Seed that haven't been identified. But research is going on around the world

In general, there are many way to extract Black Seed (*Nigella Sativae*) to produce Black Seed oil. Black Seed oil is the value added product obtains from the dry seed using extraction method such as Supercritical Fluid, Supercritical CO_2, Solvent Extraction or Steam Distillation.

In this research, Rotary Evaporator is used to obtain Black Seed oil. To obtain a series of high quality extracts from black seed, the effect of heat is need to be study

1.2 Objectives

i. To extract the essential oils of Black Seed Oil (Nigella Sativa) using Rotary Evaporator.
ii. To study the existence of Thymoquinone in Black Seed Oil
iii. To compare commercial sample of Black Seed Oil with the one extracted using via solvent extractions.

1.3 Scope of Study

To accomplish the objectives, scopes have been decided in this research. The scopes of this research are to investigate the fastest solvent that need to use for solvent extraction, to investigate the heat effect at rotary evaporator. The experimental work for black seed oil is based on the fastest solvent that obtains from the lab scale experiment by using a rotary evaporator.

1.4 ` Problem Statement

Local Black Seed oil is on the verge of its establishment, hence it is crucial to ensure the quality is as good as the commercial Black Seed oil. It is vital to identify which is the most appropriate condition to extract Black Seed oil as the suitable parameter could lead to more yield of oil. Up till today the best way to extract black seed oil is still under research. Conventionally, black seed oil is extracted using cold pressed, however solvent extraction could be used as an alternative.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Nigella sativa is an annual flowering plant, native to southwest Asia. It grows to 20-30 cm tall, with finely divided, linear (but not thread-like) leaves. The flowers are delicate, and usually coloured pale blue and white, with 5-10 petals. The fruit is a large and inflated capsule composed of 3-7 united follicles, each containing numerous seeds. The seed is used as a spice.

Nigella sativa seed is known variously as kalonji. In English it is called fennel flower, black caraway, nutmeg flower or Roman coriander [2]. Other names used, sometimes misleadingly, are onion seed and black sesame (both of which are similar-looking but unrelated). Frequently the seeds are referred to as black cumin, this is, however, also used for a different spice, Bunium persicum. It is also sometimes just referred to as nigella or black seed. An old English name gith is now used for the corncockle.

This potpourri of vernacular names for this plant reflects that its widespread use as a spice is relatively new in the English speaking world, and largely associated with immigrants from areas where it is well known. Increasing use is likely to result in one of the names winning out, hopefully one which is unambiguous.

Nigella sativa has a pungent bitter taste and a faint smell of strawberries. It is used primarily in candies and liquors. The variety of naan bread called Peshawari naan is as a rule topped with kalonji seeds. In herbal medicine, Nigella sativa has hypertensive, carminative, and anthelminthic properties.

2.2 History of The Black Seed

For over two thousand years the black seed, a plant from the Ranunculaceae (buttercup) family, has been traditionally used by various cultures throughout the world as a natural remedy for several diseases and ailments and to improve health in general.

The ancient Egyptians knew and used the black seed and described it as a panacea (cure for problems and diseases). Tutankamun even had a bottle of the oil in his tomb.

The Romans also knew this seed and called it Greek Coriander and used it as a dietary supplement. In the first century, the Greek physician Dioscoredes recorded that the black seed were taken to treat headaches, nasal congestion, toothache and intestinal worms [4].

The black seed is also mentioned in the Bible in Isiah 28:25-27 as the 'fitches'. Ibn Senna, known in the West as Avicenna, who wrote the great medical treatise 'The Canon of Medicine', referred to the black seed as the seed 'that stimulates the body's energy and helps recovery from fatigue'.

2.3 Black Seed

Figure 2.1: Black Seed Flower (Kalonji)

An annual herbaceous plant, black cumin seed (botanical name is nigella sativa , or black seed for short, is believed to be indigenous to the Mediterranean region but has been cultivated into other parts of the world including the Arabian peninsula, northern Africa and parts of Asia [15].

The plant has no relation to the common kitchen herb, cumin. Tiny and hairy, being no more than 3mm in length, black seed originates from the common fennel flower plant (nigella sativa) of the buttercup (Ranunculaceae) family. Nigella sativa is sometimes mistakenly confused with the fennel herb plant (Foeniculum vulgare). The plant has finely divided foliage and pale bluish purple or white flowers. The flowers grow terminally on its branches while the leaves grow opposite each other in pairs, on either side of the stem. Its lower leaves are small and petioled, and the upper leaves are long (6-10cm). the stalk of the plant reaches a height of twelve to eighteen inches as its fruit, the black seed, matures. Nigella sativa is bisexual and forms a fruit capsule which consists of many white triagonal seeds. Once the fruit capsule has matured, it opens up and the seeds contained within are exposed to the air, becoming black in color (black seeds). Nigella sativa and its black seed are known by other names, varying between places. some call it black caraway, habbat al barakah , and habbat sawda , others call it black cumin (kalounji), onion seeds or even coriander seeds. in English, the nigella sativa plant is commonly referred to as black cumin . Nevertheless, this is nigella sativa, which has been known and used from ancient times and is also known in Persian as Shonaiz.

2.4 Chemical Analysis of Black Seed Oil

Black Seed Oil contains several ingredients (in significant amounts) with potential value. The following chart reflects the composition of Black Seed Oil in terms of its active, nutrient components, and any other significant ingredients.

Essential Oil Composition (1.4%)	**Black Seed Oil**
Carvone	21.1%
Alfa-Pinene	7.4%
Sabinene	5.5%
Beta-Pinene	7.7%
P-cymene	46.8%
Others	11.5%

Fatty Acids	**Black Seed Oil.**
Myristic Acid (C14:0)	0.5%

Palmitic Acid (C16:0)	13.7%
Palmitoleic Acid (C16:1)	0.1%
Stearic Acid (C18:0)	2.6%
Oleic Acid (C18:1)	23.7%
Linoleic Acid (C18:2)(Omega-6)	57.9%
Linolenic Acid (18:3n-3) (Omega-3)	0.2%
Arachidic Acid (C20:0)	1.3%
Saturated & Unsaturated Fatty Acids	**Black Seed Oil**
Saturated Acid	18.1%
Monounsaturated Acids	23.8%
Polyunsaturated Acids	58.1%
Nutritional Value	**Black Seed Oil**
Protein	208 ug/g
Thiamin	15ug/g
Riboflavin	1 ug/g
Pyridoxine	5ug/g
Niacin	57 ug/g
Folacin	610 IU/g
Calcium	1.859 mg/g
Iron	105 ug/g
Copper	18 ug/g
Zinc	60 ug/g
Phosphorus	5.265 mg/g
Nutritional Composition	**Black Cumin Seed**
protein	21%
carbohydrates	35%
fats	35-38%

Table 2.1: Chemical Compositions in Black Seed Oil

Black Cumin (Nigella sativa) Seed is rich in nutritional values. Monosaccharides (single molecule sugars) in the form of glucose, rhamnose, xylose, and arabinose are found in the black seed. The Black Cumin (Nigella sativa) Seed contains a non-starch polysaccharide component which is a useful source of dietary fiber.

It is rich in fatty acids, particularly the unsaturated and essential fatty acids (Linoleic and Linolenic acid). The EFAs, consisting of alpha-Linolenic acid (omega-3) and Linoleic acid (omega-6), are substances that cannot be manufactured in the body, and thus must be taken in as supplements or through high-EFA foods in order to sustain health.

Fifteen amino acids make up the protein content of the Black Cumin (Nigella sativa) Seed, including eight of the nine essential amino acids. Essential amino acids cannot be synthesized within our body in sufficient quantities and are thus required from our diet. Black seed contains Arginine which is essential for infant growth. Chemical analysis has further revealed that the Black Cumin (Nigella sativa) Seed contains carotene, which is converted by the liver into vitamin A.

The Black Cumin (Nigella sativa) Seed is also a source of calcium, iron, sodium, and potassium. Required only in small amounts by the body, these elements' main function is to act as essential cofactors in various enzyme functions.

2.5 Uses of Black Seed Oil

The common name "love in the mist" aptly describes the poetry of this exquisite plant. In the garden, one easily imagines etheric spirits flitting about amongst its evanescent bluish-white blossoms. Even the seedpods, which are so often used in dried flower arrangements, suggest an otherworldly sense of exotic enchantment. Is it possible that such a delicately beautiful herb, with such potent medicinal properties would be so hardy as to easily reseed itself in our gardens year after year?

With an exalted position of use throughout the Middle East and to a somewhat lesser extent in India and other Eastern lands, the information about Nigella I owe to herbalist, plant-scientist extraordinaire, Jim Duke as presented in his book Medicinal Plants of the Bible. In it he describes Black Cumin as a Muslim Miracle Herb which, according to an Arab Proverb it is said that, 'in the black seed is the medicine for every disease except death.'

I have spoken with a Turkish colleague who reports that it the seeds are widely cultivated and traded in ton lots within his country throughout the Middle East, Northern Africa and India. The seeds are used both as a condiment in bread and cakes and various confections and like pepper or combined with pepper such as cayenne in sauces. The Ethiopians add along with other spices to flavor local alcoholic beverages. Still another use is to sprinkle them with woolen garments as a moth repellant.

The major uses I have employed it for are upper respiratory conditions, allergies, coughs, colds, bronchitis, fevers, flu, asthma and emphysema for which it is effective. Simply collect the abundance of seeds from the pods and grind them to a paste and mix with melted honey to a 'hahlava' (a Middle Eastern confection usually made with toasted sesame seeds and honey). Jim Duke confirms its folk use for these and a wide variety of other diseases and conditions including bilious ailments, calluses, cancer, colic, corns, eruptions, headache, jaundice, myrmecia, orchitis, puerperal fever, sclerosis, skin, snakebite, stomachache, swellings, tumors of the abdomen and eyes, and warts. In Algeria, the roasted seeds are combined with butter for cough and honey and taken for colic.

For upper respiratory conditions, at least a few of its constituents have shown an antihistamine-like action, which explains is positive effects for upper respiratory diseases including asthma, bronchitis, and cough. The oils of the seed increase milk flow which explains its folk use as a galactagogue. In large quantities, however, the seeds have also been used to abortion.

It is unusual for a hot spicy herb to have a positive effect on liver diseases as it is used by the Lebanese. Of course, one of its most obvious uses is for diarrhea and dysentery, combined with astringents. Externally the seeds can be ground to a powder, mixed with a little flour as a binder and applied directly to abscesses, on the forehead for headache, nasal ulcers, orchitis, and rheumatism. The seeds also are a rich source of sterols, especially beta-sitosterol, which is known to have anticarcinogenic activity. This substantiates its folk use for indurations and/or tumors of the abdomen, eyes and liver.

In India, Nigella seeds are combined with various purgatives to allay gripping and colic and also help kill and expel parasites. Middle Eastern Unani medicine affirms its abortifacient properties and also use it as a diuretic to relieve ascites, for coughs, eye-sores, hydrophobia, jaundice, paralysis, piles and tertian fever

2.6 Overview of Separation Process

Separations are extremely important in Chemical manufacture. Separation processes are any set of operation that separate solutions of two or more components into two or more product that differ in composition. These may either removed a single components from a mixture or separate a solution into its almost pure components. This can be done by exploiting chemical and physical property differences between the substances through the used of a separating agent. Separation process is used for three primary functions which are purifications, concentration and fractionation.

In purification, the principal is to remove undesired components in a feed mixture from the desired species. For example is the purification of acid gases such as sulfur dioxide must be removed from power plant combustion gas effluents before discharge into atmosphere.

In concentration, the principal is to obtain higher proportion of desired components that are initially dilute in a feed steam. For example is concentration of metals present in an electroplating process by removal water. This separation allows one to recycle the metals back to the electroplating process rather than discharge to environment.

In fractionation, a feed stream of two or more components is segregated into product streams of different components, typically relatively pure streams of each component.

Separation also divided into two classes which is equilibrium based and rate-based processes. These classes are designated using thermodynamic equilibrium relationships between phases and the rate of transfer of a species from one phase to another respectively.

Equilibrium processes are those in which cascades of individual units called stages are operated with two system typically flowing countercurrents to each other. Examples of equilibrium based processes are including extraction and solid extraction or leaching. Extraction is the removal of species from a liquid in which it dissolved by means to another liquid for which it has a higher affinity. Leaching is the removal of a species from a solid phase by means of liquid for which it has stronger affinity.

Rate-based processes are limited by the rate of mass transfer of individual components from one phase to another under influence of physical stimuli. One mass transfer based process is gas absorption a process by which a vapor is removed from its mixture with an inert gas by means of a liquid in which the vapor is soluble.

2.7 Essential Oil Extraction Processes

There are a few conventional and modern methods of extracting essential oils. It can be extracted by steam distillation, water distillation, hydrodistillation, supercritical fluid extraction, vapo-cracking, turbo-extractor and microwave extraction.

2.8 Rotary Evaporator

Rotary evaporators commonly found in organic laboratories. They are used to remove solvents from reaction mixtures and can accommodate large volumes of liquid. It is usually utilized to separate solvents such as n-hexane, acetone and ethanol from the essential oils produced in solvent extraction. Figure 2.3 below shows the technical specifications of rotary evaporator.

Rotary Evaporator	Water Bath
Speed range:20-190 rpm	Temperature range: ambient to 95°C
Vacuum: <1 mmHg	Capacity: 3.5 Liters
Lift distance: 150 mm	Heater power: 1300W
Dimension: (w x d x h) – 385 x 335 x 470 - 610mm, excluding glassware	Dimension: (w x d x h) – 260 x 280 x 200mm

Table 2.2: Technical specifications of a rotary evaporator

Rotary evaporator has several parts. The main parts of a rotary evaporator include a water bath, a speed motor, a condenser and a vacuum supply. A typical rotary evaporator has a water bath that can be heated in either a metal container or crystallization dish to keep the solvent from freezing during the evaporation process. Water or silicon oil is used as the heating medium. Besides that, the evaporator normally uses a variable speed sparkles induction motor that spins at 0- 220 rpm and provides high constant torque (R. Toreki, 2005).This enables the flask containing solution to rotate continuously according to the speed set as well as enhances the evaporation of solvent. Vacuum is used to evaporate the solvent while the condenser condenses the vapor trapped to liquid that is later collected for easy reuse or disposal. Rotary evaporator cannot be used for air and water-sensitive materials unless special precautions are taken.

A vacuum is usually applied to the setup and this shows that the boiling points of the solvents are going to be significantly lower than at ambient pressure. Since the flask is rotated during the evaporation process, the surface area is larger which increases the evaporation rate. These two factors combined make it a very useful tool in synthetic chemistry to remove solvents. Apart from that, the need for lower temperatures also avoids overheating of the target compounds (R. Toreki, 2005). Figure 2.4 and 2.5 below shows the whole part of rotary evaporator.

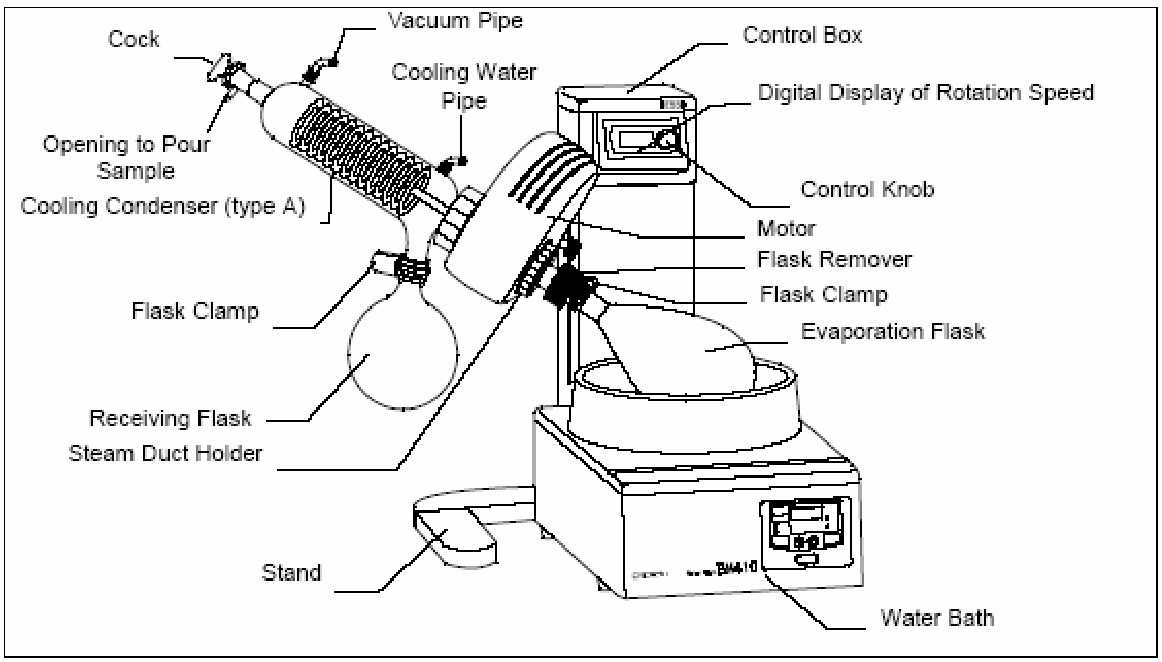

Figure 2.2: Rotary evaporator components

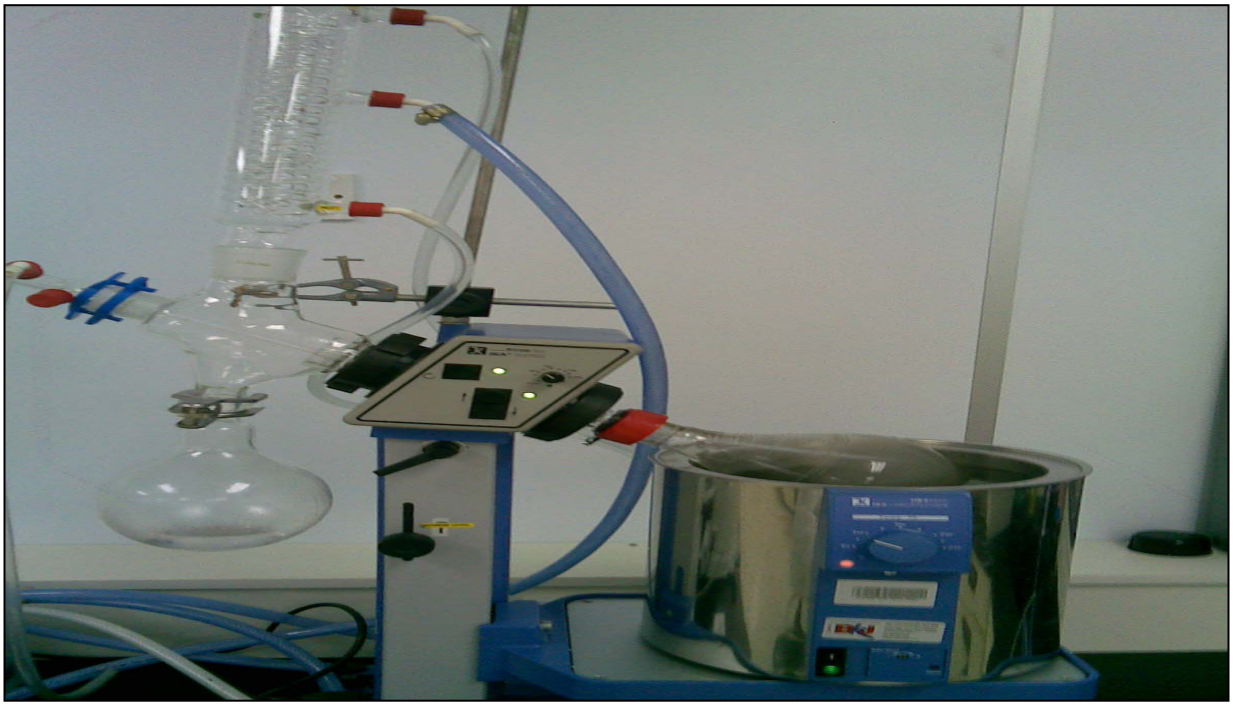

Figure 2.3: Rotary evaporator

2.9 Solvent Extraction

In 1997, Kreuter, M.H. [10], *et.al* invented and patented a process for the preparation of a stable, homogeneous extract of plants. They used a 400 kg dried herbs sample mixed with 1600 kg ethanol and extraction was done at a temperature between 60-70^{0}C. solvent removal of the patented process was done under evaporation, reduced pressure and elevated temperature.

Purseglove, J.W. *et.al*, stated that the solvents most widely used commercially for obtaining ginger oleoresin from dried ginger are acetone, ethanol and chlorinated hydrocarbons. Their statement was further confirmed by Govindarajan in 1982 [15]. The yield and quality of the oleoresin can be variable depent on the source material, solvent and preparative methods used. a study was conducted on Malaysian ginger oleoresin extraction using petroleum ether as solvent and the yield was comparatively low, which was 2.8% [16]. With acetone, yields from Australian grown ginger have been found to vary between 5 and 11% on a dried weight basis. On the same ginger, oleoresin yields of up to 20% have been obtain using ethanol as extractant [10].

Extraction may be improved by using dried material. But when drying is used some decomposition can occur, and aromatic materials from natural sources differ widely in their physical and chemical properties, particularly in their volatility and solubility, so the choice of the solvent may determine the success of the extraction [10]. The solvent is removed from the solution by fractional distillation. The residue is termed the "concrete" and consists of volatile matter and oleoresins as well. Industrial practice is to treat the concrete with alcohol to obtain a selective removal of the volatile constituents.

Oleoresins are extracted by a process of solvent extraction, followed by removal of the solvent to extremely low levels typically less than 25-30 parts per million. In 1998, Balladin, *et.al* [17] used pilot plant extraction to extract oleoresin from ginger. The solvent used followed its designated route to the vertically oriented water cooled 20 liters leaching vessel. The process continued for 10 hours until the majority of the oleoresin was extracted, determined by the transparent appearance of the extracting solvent.

The quality of an oleoresin is typically evaluated on the basis of presence of the active ingredients in desired levels which is the "bite" giving resin portion containing a combination of alkaloids, gums, pigments, etc. The aroma giving volatile/essential oil component is also considered to be the most important part in oleoresin quality indication. In 1998, Spiro, M. *et.al* [18] conducted a kinetic study using solvent mixtures stirred at 450 r.m.p. with a glass paddle stirrer so as not to damage the particles. The extraction of oleoresin from the comminuted dry ginger using solvent extraction is influenced by factors below [16] :

I. Particle size

To increase the rate of solvent extraction, it is desirable that the range of particle size to be small. This is due to the greater interfacial areas between the solid and liquid and therefore the higher is the rate of transfer of material.

II. Choice of solvent

The liquid chosen should be good selective solvent , less hazardous for mass production, low viscosity and economical. The organic solvents more frequently used are :

- Aliphatic hydrocarbons: propane, butane, hexane
- Alcohols: methanol, ethanol, 2-propanol
- Hydrocarbons with a carbonyl group: acetone, methyl acetate
- Halogen derivation: dichloro methane, dichloroethane, freons

III. The fluid agitation

Agitation of the solvent is important because it is increase the eddy diffusion and therefore increase the transfer of material from the surface of the particles to the bulk of the solution

IV. The temperature

The solubility of the material which is being extracted will increase with temperature to give a higher rate of extraction.

2.10 Heat Effect

Heat effect is important because it is relative to the simple chemical-manufacturing process. It also associates with the reactions. Sensible heat effect are characterize by temperature changes, the heat effect of chemical reaction, phase transition and the formation and separation of solutions are determined from experimental measurement made at constant temperature.

2.11.1 Standard Heat of Reaction

Heat effect is not only for physical processes, but in chemical reaction it accompanied either by the transfer of heat or by temperature changes during the course of reaction. These effects are manifestation of the differences in molecular structure, in energy of the product and reactants. Each reaction carried out in a particular way accompanied by a particular heat effect.

Tabulation of heat effect for all possible reaction can be calculate with the heat effect for reaction carried out in diverse ways from data for reactions carried out in a standard ways. The heat is associate with a specific chemical reaction depends on the temperature of both reactant and product.

A consistent basis for treatment of reaction heat effect result when the product of reaction and the reactants are all at same temperature. Heat effect can be calculated using equation;

$$Q = \Delta H$$

Where, Q = heat absorbed

ΔH = enthalpy change of reaction

2.11.2 Standard Heat of Formation

Standard heat of formation is a reaction which forms a single compound from its constituent elements. Formation reaction is understood to result in the formation of 1 mole of the compound and therefore heat of formation is based on 1 mole of the compound formed.

The standard heat of formation of compound at standard temperature is representing by the symbol ΔH^{o}_{f298}. The f value shows that it is a heat of formation and 298 is the approximate absolute temperature in Kelvin (^{o}K). Formation equation and standard heat of formation may always be combined to produce any desired equation and its accompanying standard heat of reaction.

2.11.3 Latent Heat of Pure Substances

Latent heat occurs when a pure substance is liquefied from the solid state or vaporized from the liquid at constant pressure there is no change in temperature. The process required the transfer of a finite amount of heat to the substance. The latent heat processes coexistence of two phases. According to the phase rule, a two phase system consisting of a single species in invariant and intensive state is determined by the specification of just one intensive property

Latent heat is phase change is a function of temperature only and related to other system properties by an exact thermodynamic equation;

$$\Delta H = T \Delta V (dP_{sat} / dT)$$

Where (dP_{sat} / dT) is the slope of vapor pressure versus temperature curve. ΔV is the difference between molar volumes of saturated vapor and saturated liquid. ΔH is the latent heat of vaporization. ΔH also can be calculated from vapor-pressure and volumetric data. Approximate methods are used for estimates of the heat effect accompanying a phase change.

2.11 Heat Transferred

2.11.4 Introduction

Heat is defined as the form of energy that is transferred between two systems (or a system and its surroundings) by virtue of a temperature differences. In daily life, heat frequently refers to the sensible and latent forms of internal energy as thermal energy and it is different from heat transfer. Heat flow, heat addition, heat rejection, heat absorption, heat removal, heat gain, heat loss, heat storage, resistant heating, heat of reaction, specific heat, process heat and heat source are not consistent with the strict thermodynamic meaning of the term heat. So in thermodynamics, the term of heat simply means heat transfer.

Heat transfer Q during the process between two state is denoted by Q_{12} or just Q and for per unit mass;

$$q = Q/m \text{ (kJ / kg)}$$

When Q varies with time, the amount of heat transfer during a process is determined by integrating Q over the time interval of the process which is;

$$Q = \int Q \, dt \text{ (kJ) from } t_1 \text{ to } t_2$$

Heat is transferred by three mechanisms which are conduction, convection and radiation. Heat of conduction is the transfer of energy from the more energetic particle of a substance to these adjacent less energetic ones as a result of interaction between particles. Heat of radiation is the transferred of energy due to the emission of electromagnetic waves. Heat of convection is the transferred energy between a solid surface and the adjacent fluid that is in motion and it involves the combined effect of conduction and fluid motion.

In the vernacular of the time, heat transferred is indeed a relevant subject not to mention an inherently fascinating part of the engineering sciences. Heat transferred phenomena play an important role in many industrial and environmental problems. Heat transferred processes effect the performance of propulsion system such as the internal combustion.

2.11.5 Heat of Conduction

At mention of word "conduction" it conjure up concepts of atomic and molecular activity for it is processes at these levels that sustain this mode of heat transfer. Conduction is most easily understood by considering heat flow in homogeneous isotropic solids in these and there is no convection and the effect of radiation is negligible unless the solid is translucent to electromagnetic waves.

Conduction may be viewed as the transfer of energy from the more energetic to less energetic particles of substance due to interactions between particles. According to

Fourier Law, the heat flux is proportional to the temperature gradient and opposite to it sign. Fourier law equation;

$$q_x / A = -k \, (dT / dx)$$

Heat conduction Q/ Time = (Thermal conductivity) x (Area) x (Thot - Tcold)/

Where q is the rate of heat flow (W), A is a surface area (m^2), T is temperature in Kelvin (K), k is the thermal conductivity (W / m.K) and x is the distant (m).

At steady state heat transfer;