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# Design, Development and Testing of a Neem Seed Steam Roaster

B.A. Orhevba[1]*; O. Chukwu[2], Z.D. Osunde[3], V. Oguagwu[4] and A. Gbagbo[5]
[1,2&3]Department of Agricultural and Bioresources Engineering, Federal University of Technology, PMB 65, Minna, Niger State, Nigeria
[4]Department of Mechanical Engineering, Federal University of Technology, PMB 65, Minna, Niger State, Nigeria
[4] National Cereals Research Institute (NCRI), PMB 8, Badeggi, Bida, Minna, Niger State, Nigeria
* E-mail of the corresponding author: borhevba@yahoo.com

**Abstract**
A neem seed roaster which makes use of steam as source of heat energy was designed and fabricated to be used in heating neem seeds prior to expelling oil from them. It helps to check the disadvantage of using seed scorchers which produces burnt or unevenly heated seeds which results in black oil formation. The equipment consists of an insulated heating unit, roaster, seed inlet unit, seed discharge outlet, power transmission unit and the frame work. A gear motor of 0.25kW was selected to supply power to the shaft whose end was welded to the stirrer. The roasting unit consists of three compartments: roasting chamber, steam chamber and insulator chamber. The insulated heating unit has two pipes: water inlet pipe and steam delivery pipe. Also, two electric heating elements of 2.75kW each were installed in the heating unit to help boil the water for steam to form; this steam will then be transported by the steam delivery pipe to the steam chamber which in turn heats up the outer surface of the roasting chamber and thus the seeds inside are roasted through the heat being supplied. The machine was fabricated with about 90% local materials. Test results of the seed roaster using neem seeds indicate successful heating/roasting, the seeds were not scorched or burnt, rather they were looking dry but fresh, this indicates that the design of the machine suits its purpose for heating neem seeds prior to oil expelling . The machine being a simple one will be easy to maintain by the local artisans.
**Keywords:** Heating, steam, neem seed, roaster, design

## 1. Introduction

### 1.0 Introduction

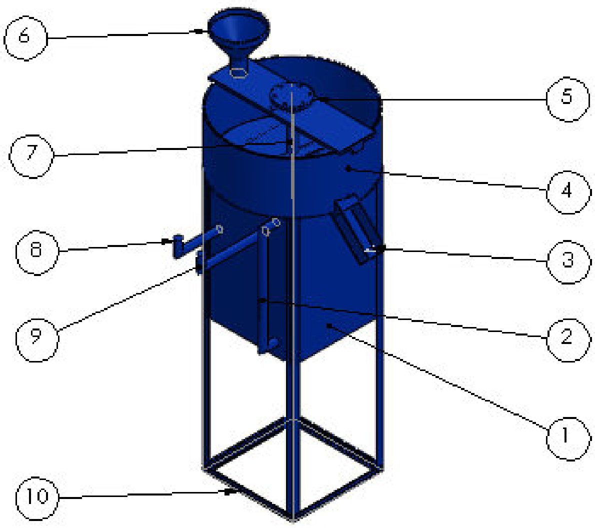
Heating of oil seeds prior to expelling is an essential unit operation as it helps in breaking the oil bearing cells in the seeds thereby releasing the oil stored up in the seed from its solid (fat) state to a liquid (oily) state. Heating of oilseeds provides several advantages like moisture conditioning of the seeds, oil viscousity reduction, increasing plasticity of seed and deactivation of thermo sensitive enzymes.
Cooking or scorching of oil seed is needed for three reasons; to facilitate oil extraction, to lower or increase the moisture of seed, and to reduce the wear in the screw press. The best temperature and moisture content depend on the extraction system. For some seeds, the temperatures attained during cooking should not exceed 120 °C as otherwise the protein quality may be adversely affected. In general, the required cooking temperature is a function of the cooking time, the type of oil extraction technology, the moisture content of the raw material and the type of seed. All these variables should be considered simultaneously when estimating the cooking temperature and arriving at a suitable heating equipment (www.fapc.biz.)
Heat is energy transferred from one system to another by thermal interaction (Kittel and Kroemer, 1980). In contrast to work, heat is always accompanied by a transfer of entropy. Heat flow from a high to a low temperature body occurs spontaneously. Heat transfer occurs in a variety of ways: conduction, convection, radiation, net mass transfer, friction or viscosity and chemical dissipation (Lebon *et al*., 2008). When energy in the form of heat is added to a system, it is stored as kinetic and potential energy of the atoms and molecules in the system (Smith *et al*., 2005).
Steaming is a method of cooking using steam. Steaming works by boiling water continuously, causing it to vaporize into steam. The steam then carries heat to the nearby food thus cooking the food. Phenophilic compounds with antioxidant properties have been found to retain significantly better through steaming than through boiling, roasting or microwaving (Vallejo *et al*., 2003).
Heating breaks the oil bearing cells; allowing for easy flow of the oil. Olaomi (2008) reported that when groundnut seeds were not heated prior to expelling, only groundnut paste was observed coming out of the cake outlet of the expeller, no oil. Thus, heating helps in breaking of oil bearing cells in the seed. Gerald (2009) suggested that incorporating a heating chamber along the expeller barrel of an oil expeller helps in improving its extraction efficiency.
The most common method of heating seeds prior to expelling is by roasting. Roasting is a method of cooking which uses dry heat, whether an open flame, oven, or other heat source. Steaming on the other hand heats the seeds without burning them. The heating of seeds should be carried out with care in order to avoid deteriorating

the kernels. Over-heating or charring reduces the oil extraction rate and yields low quality oil. Also, normal (common) roasting has the disadvantage of producing burnt seeds which in turn leads to black oil formation and loss of vital and essential nutrients; Numan *et al;* (2012) reported that dry heating exposes oil palm fruits to potential burning. As such, there was a need to fabricate equipment which would heat the seeds using steam so as to check the disadvantage of obtaining burnt seeds. Also, "steam roasting" helps in conserving nutrients while still making the seeds look dry and fresh.

This paper highlights the design, features and test results of a neem seed roaster that makes use of steam which would help check the limitations of the available seed roasters/scorchers. As such, the fabricated machine will be very useful in the oil expelling industry; also, small rural processors may not afford heating equipment with automatic control of temperature thus the need for an equipment as this.

**2.0 Machine Components**

The seed roaster is made up of the following components as shown in Figures 1-3: Seed inlet unit, seed discharge outlet, steam generating unit, roaster and power transmission unit.




| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | insulated heating unit | 1 |
| 2 | Water Level Indicator | 1 |
| 3 | roasted seed discharge outlet | 1 |
| 4 | roasting compartment | 1 |
| 5 | motor_plate | 1 |
| 6 | hopper | 1 |
| 7 | stirrer | 1 |
| 8 | steam delivery pipe | 1 |
| 9 | water inlet pipe | 1 |
| 10 | frame | 1 |

**Figure 1: Orthogonal Drawing of the Roaster**

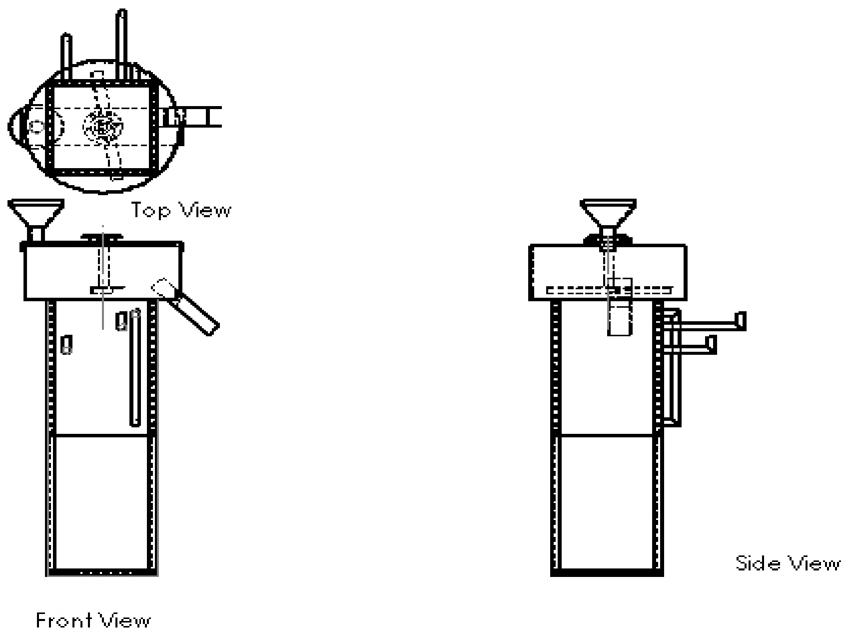



**Figure 2: Top, side and front view of the roaster**

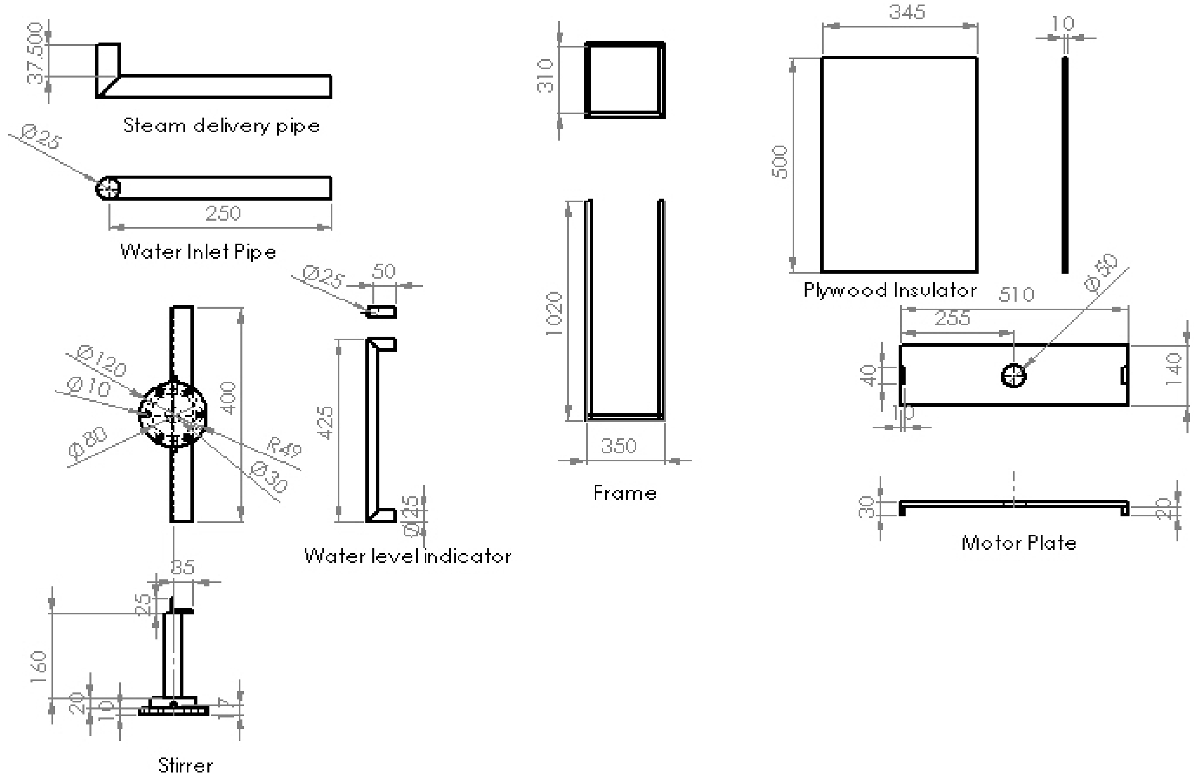



**Figure 3: Part view of the roaster**

**2.1 Seed Inlet Unit**

The seed inlet unit is primarily the hopper which guides the seeds into the toasting chamber. The hopper is conical in shape, having a cylindrical protruded base. The hopper is made from thick gauge 16 mild steel plate.

**2.2 Roasted Seed Discharge Outlet**

The roasted seed discharge outlet is a rectangular shaped trough located at the base of the toaster and it is inclined at an angle of $45^0$ from the horizontal plane in order to allow the free flow of the roasted seeds into the hopper of the oil expeller. It also has a stopper which is kept closed during roasting. Once roasting is completed, the stopper is opened for the seeds to come out.

**2.3 Steam Generating Unit**

This unit is plywood insulated rectangular shaped tank made with 2.5mm thick mild steel plate. Water is filled to half of its height so that the empty space remaining can aid steam formation. The heating unit has two pipes: water inlet pipe which serves as an inlet for water into the tank and a steam pipe which helps in transferring steam formed at the upper part of the tank, into the steam chamber of the roaster. The flow of steam through this pipe is regulated by gate valves. The water inlet and steam outlet pipes are located almost at the top of the tank. Two electric heating elements of 2.75kW each were installed in the heating unit to boil the water for steam generation. The steam is used in roasting the neem seeds.

**2.4 Roaster**

The roaster is a cylindrical shaped vessel with three compartments: roasting chamber, steam chamber and insulator chamber.

The roasting chamber accommodates the neem seeds and has a stirrer attached to a shaft and to the gear motor. The stirrer helps to stir the seeds as steam is applied to the walls of the toasting chamber. As such, with constant stirring and heat (steam) application, uniform roasting of the seeds is achieved.

The steam chamber is a vacuum chamber situated between the roasting chamber and the insulator chamber. This chamber receives steam via the steam pipe and heats up the outer wall surface of the roasting chamber thereby enabling roasting to take place.

The insulator chamber is the third compartment of the roaster. It is filled with an insulator (foam). This insulator helps in reducing heat loss by conduction through the surface of the walls of the roaster, as such conserving the heat in the system.

**2.5 Power Transmission Unit**

This unit comprises of a 0.25kW gear motor. The gear motor is connected to the stirrer via a shaft linked together by two flanges. The gear motor receives power from an electric source.

**3.0 Design Calculations**

**3.1 Power Required to Drive the Stirrer**

The power required to drive the stirrer can be calculated as:

$$P_s = T_s \omega_s \qquad 3.1$$

Where;

$P_s$ = Power to drive the stirrer (kW)

$T_s$ = Torque of the stirrer (Nm)

$\omega_s$ = Angular speed of the stirrer (rad/sec)

Where,

$$\omega_s = \frac{2 \times \pi \times N}{60} \qquad 3.2$$

N = Speed of rotation (rpm)

**3.2 Determination of the Shaft Minimum Diameter**

Shaft design is necessary for the determination of the minimum diameter that will guarantee a satisfactory strength and rigidity of the shaft under operation. In order to determine the minimum shaft diameter that will withstand the roasting strength of the seeds, the following equations were employed:

$$\sigma = \frac{16T_s}{\pi \times d^3} \qquad \text{(Khurmi and Gupta, 2005)} \qquad 3.3$$

$$d = \sqrt[3]{\frac{16T_s}{\sigma\pi}} \qquad 3.4$$

Where,

$T_s$ = Torque of the shaft/stirrer (Nm)

σ = Maximum permissible working stress ($MN/m^2$)

d = Minimum shaft diameter (m)

**3.3 Determination of the volume of the Roaster**

The roasting chamber is cylindrical in shape, as such; the formular for calculating the volume of a cylinder was applied. This was done with respect to the quantity of seeds it can toast per time.

$$V = \pi r^2 h \qquad 3.5$$

Where,

V = Volume of roasting chamber ($m^3$)

r = Internal radius of roasting chamber (m)

h = Height of the roaster (m)

**3.4 Determination of the Volume of the Heating Tank**

The heating tank is cuboidal in shape; as such the formular for calculating the volume of a cuboid was applied.

$$V = L \times B \times H \qquad 3.6$$

Where,

V = Volume of heating tank ($m^3$)

L = Length of heating tank (m)

B = Breadth of heating tank (m)

H= Height of heating tank (m)

**3.5 Heat Loss Through the Walls of the Roaster**

Heat loss through the inner wall, second wall, insulator and outer wall of the roaster was expected hence, it was put into consideration in the design. Due to symmetry, any cylindrical surface concentric to the axis of the tube is an isothermal surface and the direction of heat flow is normal to the surface (Rayner, 1987). Considering the roaster as a cylinder made of different materials, Fourier's law of heat conduction was applied;

The surface area of the cylinder is:

$$A_r = 2\pi r l \qquad 3.7$$

When Fourier's equation is applied:

$$q = -KA_r \frac{dT}{dr} \qquad 3.8$$

Substituting equation 3.7 into 3.8 gives

$$q = -2K\pi_r l \frac{dT}{dr} \qquad 3.9$$

After rearranging and applying limits we obtain

$$\int_{r_1}^{r_2} \frac{1}{r} \partial r = -2\pi KL \int_{T_1}^{T_2} dT \qquad 3.10$$

The heat loss (q) = $\frac{2K\pi L(T_1 - T_2}{ln(^{r_2}/_{r_1})}$ 3.11

For a three concentric cylinder having an insulator,

$$q = \frac{2\pi L(T_1 - T_5)}{\frac{\ln({}^{r_2}/_{r_1})}{K_A} + \frac{\ln({}^{r_3}/_{r_2})}{K_B} + \frac{\ln({}^{r_4}/_{r_3})}{K_C} + \frac{\ln({}^{r_5}/_{r_4}}{K_D}} \qquad 3.12$$

Thermal resistance, $R_C$;

$$R_C = \frac{\frac{\ln({}^{r_2}/_{r_1})}{K_A} + \frac{\ln({}^{r_3}/_{r_2})}{K_B} + \frac{ln({}^{r_4}/_{r_3})}{K_C} + \frac{ln^{r_5}/_{r_4}}{K_D}}{2\pi L} \qquad 3.13$$

Where,
L = Depth of the roaster
$T_1$ = Temperature inside the roaster
$T_5$ = Temperature of the surrounding
$r_1$ = Internal radius of the inner cylinder (toasting chamber)
$r_2$ = Internal radius of the second cylinder (steam chamber)
$r_3$ = External radius of the second cylinder (steam chamber)
$r_4$ = Internal radius of the outer cylinder (insulator chamber)
$r_5$ = External radius of the outer cylinder (insulator chamber)
$K_A$ = Thermal conductivity of the inner cylinder ($W/m^0c$)
$K_B$ = Thermal conductivity of the second cylinder ($W/m^0c$)
$K_C$ = Thermal conductivity of the insulator (foam)
$K_D$ = Thermal conductivity of the outer cylinder ($W/m^0c$)

**3.6 Heat Loss through the Walls of the Heating Tank**

For a homogenous material of 1-D geometry between two end points at constant temperature, heat loss is given by:

$$q = -k\,A\,\frac{\Delta T}{\Delta x} \qquad 3.14$$

Where,
A = cross sectional surface area
$\Delta T$ = Temperature difference between the ends

$$U = \frac{K}{\Delta x} \qquad 3.15$$

Where,
U = Conductance ($W/m^2K$)

Therefore$q = U\,A(-\Delta T)$ 3.16

The reciprocal of conductance is resistance, R, given by:

$$R = \frac{1}{U} = \frac{\Delta x}{K} = \frac{A(-\Delta T)}{q} \qquad 3.17$$

Considering the heating tank as a heterogeneous material having two layers of metal sheets and a layer of an insulator (plywood);

$$q = \frac{A(\Delta T)}{\frac{\Delta x_1}{K_1} + \frac{\Delta x_2}{K_2}} \qquad 3.18$$

Where,
q = Heat loss (kJ)
A = Cross sectional surface area ($m^2$)
$\Delta T$ = Temperature difference between the inner surface and the environment ($^0C$)
$\Delta x$ = Thickness of the individual material (m)
$K_1$ = Thermal conductivity of the metal sheet ($W/m^0C$)
$K_2$ = Thermal conductivity of insulator ($W/m^0C$)

**4.0 Testing and Performance Evaluation of the Seed Roaster**

The roaster was tested to assess its throughput capacity and efficiency. The machine was switched on and the seeds poured into the roasting chamber through the hopper. The heat (steam) circulated round the walls of the roasting chamber and with the stirrer stirring the seeds with respect to a particular time limit, roasting was achieved. The capacity of the seed roaster was calculated by summing the total number of batches in kilograms divided by the total time required for the roasting:

Capacity of machine, $(C_m) = \frac{W_g}{t}$ 3.19

Where,
$C_m$ = Machine capacity (Kg/day)
Wg = Weight of seeds roasted (g)
t = Time taken to roast the seeds.

## 5.0 Materials Selection and Fabrication of Machine Components

Fig. 2 shows an orthographic view of the roaster. The hopper was fabricated from a standard length of 1.5 mm thick mild steel sheet. The insulator chamber was made with plywood and foam. The steam generating compartment was made with the steel plate and the two heating elements were then installed inside; this unit was encased with an external casing made from plywood to prevent heat loss. The main frame was made from 2" angle iron which was cut to the required dimensions and welded together. Fabrication process included: marking out, machining, cutting, joining, drilling and fitting. The workshop tools and machines used included: scriber, steel rule, compass, centre punch, treadle-operated guillotine for cutting and welding machine for joining. The specification of construction materials is shown in Table 1.

**Table 1: Materials Used for the neem seed roaster**

| S/NO | Materials | Quantity |
|---|---|---|
| 1 | Gauge 16 plate | $1\frac{1}{2}$ |
| 2 | 2" angle iron | Standard length, 2 |
| 3 | Φ2.5 cm rod | 40cm |
| 4 | 1" Galvanized pipe | Half length |
| 5 | 1" gate valve | 1 no |
| 6 | ¾" gate valve | 1 no |
| 7 | 1" union | 1 no |
| 8 | 1" nipple | 2 nos |
| 9 | 3/3 socket | 1 no |
| 10 | ¾ nipple | 1 no |
| 11 | 1 Hp gear motor | 1 |
| 12 | Stirring rubber | 60 cm length |
| 13 | Connecting pipe | 2 nos |
| 14 | 3x2 square pipe | I length |
| 15 | Plywood | 1 sheet |
| 16 | Connecting flanges | 2 nos |
| 17 | 13 bolts and nuts | 30 nos |
| 18 | ¾" horse | 50cm length |
| 19 | Welding Electrode | 1 packet |

## 6.0 Materials and Methods used for Testing

The machine was tested to assess its throughput capacity and efficiency in roasting. The machine was switched on, the water in the steam generating unit boiled and the steam generated was transported to the steam chamber via the steam delivery pipe. Over time, as this steam continued to heat the roasting chamber, heat began to circulate within it. As soon as the required temperature was reached, seeds were poured into the roasting chamber through the hopper. The attached control valves were used to regulate the delivery of the steam. The insulator chamber helped to reduce heat loss by conduction through the walls of the roasting chamber. As the heat continued to circulate within the roasting compartment and the stirrer incorporated within it continues to stir the seeds, roasting was achieved. As soon as the required duration of heating was reached, the seeds were released through the discharge outlet. The capacity of the seed roaster was calculated by summing the total number of batches in kilograms divided by the total time required for the roasting: Capacity of machine,

$$(C_m) = \frac{W_g}{t} \qquad \textbf{3.19}$$

Where,
$C_m$ = Machine capacity (Kg/day)
Wg = Weight of seeds roasted (g)
t = Time taken to roast the seeds.

## 7.0 Results and Discussion of Testing

The results obtained showed that roasting of the neem seeds with the fabricated machine was successful and efficient because the seeds obtained from it after the testing were heated well, looking dry yet without looking burnt (Plate 1). The machine will thus serve as a right partner and complementary equipment to oil expellers. It can therefore serve as a part of oil expelling production process. The machine is simple, easy to operate and maintain.

## References

Gerald, L. (2009). The Application of Fluid Mixers in Edible Oil Processing. http:www.emimixers.com.

Retrieved 22/06/2012.

Khurmi, R.S. and Gupta, J.K. (2005). *Machine Design*, 14th Edition. S. Chand and Company Ltd., Ram Nagar, New Delhi- 110055. Pp 434-960.

Kittel, C. and Kroemer, H. (1980). *Thermal Physics*. 2nd Edition; Freeman, W.H. San Francisco. ISBN 0-7167-1088-9. Pp 227.

Lebon, G.; Jou, D. and Casas-vasquez, J. (2008). *Understanding Non-equilibrum Thermodynamics Foundations*, *Applications.* Frontiers, Springer. ISBN 978-3-540-74252- 4. Pp 120.

Nu'man, A. H.; Ng, M.H.; Choo, Y. M. and Ma, A. N. (2012). Dry Heating of Palm Fruits: Effect on Selected Parameters. *American Journal of Engineering and Applied Sciences;* 5(2), 128-131. ISSN: 1941-7020

Olaomi, J. (2008). Design and Construction of a Motorised Groundnut Oil Expelling Machine. Unpublished B.Eng Thesis, Department of Mechanical Engineering, University of Ilorin, Nigeria.

Rayner, J. (1989). Conduction through a Flat Plate or Wall in: Basic Engineering Thermodynamics. Longman Singapore Publishers (Pte) Ltd., Singapore.

Smith, R.M. (1999). Supercritical Fluids in Separation Science: The Dreams, the reality and the future. *Journal of Chromatography A;* 856: 83 – 115.

Vallejo, F.; Tomas-Barberon, F.A. and Garcia-Viguera, C. (2003). "Phenophilic Compound Contents in Edible Parts of Broccoli Inflorescences after Domestic Cooking". *Journal of the Science of Food and Agriculture;* 83(14):1511-1516.

www.fapc.biz. Oil and Oilseed Processing I. Food Technology Fact Sheet. Robert M. Kerr Food and Agriculture Products Centre. FAPC-158. Accessed on 22nd December 2012.