Analytical study and development in conventional grinding to cryogenic grinding system

(*Retention of flavor and medicinal property of some important spices*)

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***Abstract*-- This project aims to the design of traditional grinding to cryogenic grinding system. In grinding process high grinding zone temperature may lead to thermal damage to work surfaces, induces micro-cracks which deteriorates surface quality. So grinding fluids are applied in different forms to control such high temperature. Due to this temperature rise, spices lose of their volatile oil and flavoring components. So, cryogenic grinding system was designed and developed to cool the spices before feeding to the grinder and also maintain the low temperature in grinding zone. The test conducted on grinding of cumin seed revealed that it could be successfully ground below the temperature of -70°c.**

The loss of volatile content can be significantly reduced by cryogenic grinding technique using liquid nitrogen or liquid carbon dioxide that provides the refrigeration needed to pre-cool the spices and maintain the desired low temperature by absorbing the heat generated during the grinding operation. The extremely low temperature during grinder condenses the volatile matter and retains their presence in spices. The application of cryogenic technology for grinding of spices has been scientifically proved to be a suitable technique with negligible loss of volatile content and improved colour of oil and grinding operation of seeds.

***Index Terms*—Seeds spices,volatile contain,cryogenic grinding.** *(key words)*

I. INTRODUCTION *(HEADING 1)*

CRYOGENIC grinding is a proven technology that is extremely effective in various industry sectors. Grinding of spices is an age-old technique like grinding of other food materials. The main aim of spice grinding is to obtain smaller particle size with good product quality in terms of flavor and color. In the normal grinding process, heat is generated when energy is used to fracture a particle into a smaller size. This generated heat usually is detrimental to the product and results in some loss of flavor and quality. The fat in spices generally poses extra problems and is an important consideration in grinding. During grinding, the temperature of the product rises to a level in the range of 42±95°C (Pruthi & Misra, 1963), which varies with the oil and moisture content of the spices, but spices lose a significant fraction of their volatile oil or flavoring components due to this temperature rise. The losses of volatile oil for different spices have been reported to be in the tune of 37% for nutmeg, 14% for mace, 17% for cinnamon and 17% for oregano (Andres, 1976). The loss of volatile oil during grinding of caraway seed has been reported to be 32% with an increase in grinding temperature from 17°C to 45.

The extremely low temperature in the grinder solidifies oils so that the spices become embrittled ; they crumble easily permitting grinding to a finer and consistent size. Thus considerably smaller particle size can be obtained under cryogenic conditions. The finely ground spices spread their flavor uniformly throughout the product body in which they are used, thereby reducing the problem of large specks appearing in the food products. With cryogenic grinding, the temperature

e of the products can be as low asÿ195.6°C. But such a low temperature is not required for all spices. In practice, it is regulated anywhere from ÿ195.6°C to few degrees below ambient temperatures (Russo, 1976). The temperature to be used is determined by parameters, viz., the final product size, colour required etc. of the product. For removing the required heat from a particle prior to its feeding into the grinder, cryogenic precoolers are used. The cryogenic precoolers can be combined with impact, attrition, or air swept mills. It is ensured that the particle during grinding is at or below its brittle point. Provisions are made to control the precooler temperature and feed rate to the mill. From the aforesaid statements, there seems enough justification for cryogenic grinding of spices in order to obtain high quality products. Therefore, a cryogenic grinding system was designed, developed and tested for cumin seed.

Cryogenic grinding was shown to significantly affect active constituent levels in herbs. Test results showed an average increase of 15.6% in constituents tested in four medicinal herbs when they were ground cryogenically. The range was 10.7% to 21.8%, indicating that some herbs are affected more than others by the temperatures at which they're ground. Cryogenic grinding provides higher production rate, lower energy consumption, finer particle size, more uniform particle distribution, lower grinding cost, .no heat generation which is good while grinding spices and provides an inert atmosphere thus eliminating the possibility of oxidation.

II. EXPERIMENTAL PROCEDURE

Two varieties of Coriander namely RCr-436, and Sudha were obtained from seed store of NRCSS, Ajmer. The seeds were cleaned and used for grinding. Cryogenic grinding of seeds was done using cryogenic grinder (Hoso-Kava Alpine, Germany) model Fine Impact Mill 100UPZ at Central Institute for Post Harvest Engineering and Technology, Ludhiana. Feed rate of material was set at 1 kg/hr with screw speed 3 rpm. The speed of pin mill was set at 10,000 rpm. Inlet temperature was adjusted to below -50 ºC and outlet temperature was -5 to 15ºC. Product particle size was set on 50 microns. In the process of cryogenic grinding the material is feed into a feeder hopper and dropped into a conveyor where the material to be processed enters the pre-chilled conveyor. Liquid nitrogen is then sprayed and blended directly onto the material. The material is conveyed via a stainless steel special design auger. The auger not only transports the grinding media, but also mixes it with liquid nitrogen for greater cooling efficiencies. Liquid nitrogen is added until the temperature of the material is reduced to a predetermined set point. This set point is the glass transition temperature of the material. The extremely low temperature in the grinder solidifies oils so that the spices become brittle.

they crumble easily permitting grinding to a finer and more consistent size. Finally the brittle material enters an impact (pin) mill where it is ground to a desired particle size. Computer controls the entire process. The Cryogenic ground powder was quickly packed in aluminum foil packets using sealing machine and opened at the time of analysis. For obtaining seed powder through conventional grinding dried seeds (30 gm) was ground separately by domestic mixer grinder (Sujata, model Dynamix, 810 W) and packed in sealed polythene bags

III. TECHNICAL DETAILS

A laboratory model cryogenic grinding system was developed and some basic studies on the grinding characteristics of cumin and clove under cryogenic and ambient conditions have also been conducted and reported (Singh and Goswami, 1999a; Singh and Goswami, 1999b; Singh and Goswami, 2000, Goswami and Singh, 2003). The grinding temperatures for cumin and clove were reported as -70°C and -50ºC,

respectively. The cryogenically ground cumin and clove powders retained about 30% more volatiles than that ambiently ground. Sridhar and Manohar (2004) reported effect of some operational and machine parameters on volumetric efficiency of cryo-feeder in grinding of black pepper. Further, Murthy and Bhattacharya (2008) reported a study on cryogenic grinding of black pepper at different temperatures and feed rates. The comparison was made between ambient grinding and cryogenic grinding. It was concluded that in cryogenic grinding of black pepper, 50% more volatiles were retained in comparison to the ambient grinding. The study conducted on cryogenic grinding of spices is significant contribution for characterization of grinding parameters vis-à-vis quality of the product. However, the earlier developed laboratory scale cryogenic grinding system can not be directly scaled up for higher capacity because the phenomena of gas circulation, heat and mass transfer, control systems for gas flow, type of grinder would be quite different in the large grinding systems.

IV. BASELINE ANALYSIS

The earlier work on use of liquid nitrogen or liquid carbon dioxide for cryogenic grinding of spices mainly highlights the benefits of cryogenic grinding over the conventional grinding in ambient condition (Wiestrieich and Schafer, 1962; Andres, 1976; Russo, 1976; Rice, 1984; Pesek et al., 1985; Landwehr and Pahl, 1986; Wolf and Pahl, 1990; Li et al, 1991). In the above studies, attempts were made to prove that cryogenic grinding of spices was better than conventional grinding in terms of higher retention of volatiles and flavoring components, color, particle size distribution of ground powder, free and continuous operation of the grinder without any choking, less energy requirement in grinding, etc. Howeve none of the above literatures report design aspects of cryogenic grinding system, grinding characteristics of the agricultural materials, optimization of grinding parameters, and modeling of heat and mass transfer in the grinding operation. Few firms in Germany and Japan manufacture cryogenic grinders for application in rubber and plastic grinding which are basically hammer mills or pin mills with pre-cooling and liquid nitrogen or liquid carbon dioxide injection systems. These mills may also be used for grinding of spices. But the design of such grinders is not readily available for direct adoption in the Indian context for grinding of spices and other high value agricultural materials

Engineering considerations *-The main engineering considerations (Wagner, 1972) which can be adopted in the design and development of a cryogenic precooler are:*

1.Retention time of the seed in the liquid nitrogen and gaseous zone should be accurately proportioned so that the available refrigeration could be utilised at its optimum level.

2. Appropriate insulation should be used such that loss- es to the ambient could be minimised.

3. Various components of the precooler should be ar- ranged in such a manner that dismantling and clean- ing could be easier.

4. Cooldown losses should be reduced by keeping the machine size and structural components to a minimum. In addition to the above design considerations, other major factors which influence the design of a cryogenic precooler have been described below.

Cooling load.- The temperature of the cumin seed at the outlet of the precooler was assumed as ÿ120oC, and the temperature required to be maintained in the grinder was from ÿ100°C to ÿ90oC. This temperature was selected as it was below the freezing point of cumin oil, i.e. ÿ43oC and the brittle point of the seed, i.e. ÿ70°C. It was considered that a part of the temperature rise in the grinder would be neutralised by the lower temperature of the cumin seed entering the grinder and the remainder would be neutralised through heat re- moval from the grinder by liquid, if any, as well as gaseous nitrogen passing out from the precooler.

$$q = C_1(T_1 - T_f) + L_f + C_2(T_f - T_2)$$

Where, q= heat transferred from the seed, J/kg.
C_1= specific heat of the seed above freezing point, J/kg °C
C2= specific heat of the seed below freezing point J/kg °C
Lf= latent heat of fusion of the seed, J/kg
T1= the initial temperature of the seed, °C
T2= final temperature of the seed, °C

The values of the following parameters were taken from Singh (1997): Speci®c heat of the cumin seed above freezing point (C1)ˆ2600 J/kg. Speci®c heat of the cumin seed below freezing point (C2)ˆ2000 J/kg. Freezing point of the cumin oil (Tf)ˆÿ43°C. Latent heat of fusion (Lf) of moisture and oil present in the seed is calculated assuming 10% m.c.w.b. and 14% oil content. Lf ˆlatent heat of fusion of water ´ m.c.w.b + latent heat of fusion of cumin oil ´ oil contentˆ35000 J/kg. Initial temperature of the seedˆ30°C. Final temperature of the seedˆÿ120°C. Using Eq. (1), the cooling load is calculated as, qˆ379000 J/kg. Assuming the insulation, leakage and other losses of the system as 20%, the total cooling load (q) is 455000 J/ kg. The cooling load can be assumed to be distributed in the ratio of 70 : 30 in the liquid and gaseous zone, thus: Cooling load in the liquid zone (ql)ˆ318500 J/kg. Cooling load in the gaseous zone (qg)ˆ136500 J/kg.

Freezing or retention time-The time required for freezing with liquid nitrogen depends on several thermo physical and geometrical parameters of the cumin seed, initial and final temperatures of the seed, heat transfer coefficients between the cooling medium and the surface of the seed, etc. The time required for freezing with liquid nitrogen has been cited by Barron (1972) based on modification of Plank's basic formula for calculating freezing time of moisture and oil present in the seed-

$$t_f = \left[1 + \frac{5C_1(T_1 - T_f)}{8L_f}\right] \frac{\rho_s q d}{T_f - T_g} = \left(\frac{1}{h_c} + \frac{Bd}{k}\right)$$

where Tg = refrigerant temperature, °C,
qs = true density of the seed, kg/m3,
d = radius of the seed, m,
hc= the convectional heat transfer coeffcient of the seed, W/ m2 °C,
k =the thermal conductivity of the seed, W/m °C and
B = constant that depends on the geometry of the seed. The freezing or retention time (tf) is calculated by using Eq. The freezing or retention time (tf) is calculated by using Eq. (2). While calculating the retention time it was assumed that the cumin seeds are of cylindrical shape. The values of following parameters are taken from Singh and Goswami (1996); Singh (1997). True density of the seed (qs)ˆ1070 kg/m3. Radius of the seed considering cylindrical shape (d)ˆ1.1´10ÿ3 m. Thermal conductivity of the seed (k)ˆ0.15 W/m °C. Heat transfer coefficient in liquid zoneˆ170 W/m2 °C (Wagner, 1972). Heat transfer coefficient in gaseous zoneˆ70 W/m2 °C (Wagner, 1972). Constant B for cylindrical shaped productˆ1/16 (Wagner, 1972). The freezing or retention time in liquid zone was calculated by substituting the above mentioned values in Eq. (2) as: tf …liquid†ˆ68 s. tf… gaseous†ˆ134 s. Total retention time of the seed in the precooler: (tf)liquid+(tf)gaseousˆ68+134ˆ202 s.

Screw conveyor A horizontal screw conveyor was designed to meet the requirement of feeding to the grinder and metering. The throughput capacity of a screw conveyor mainly depends on the screw diameter, pitch of the screw, and rotational speed. The capacity of the screw conveyor can be calculated by using Eq. (3) (Spivakovsky & Dyach- kov, 1985).

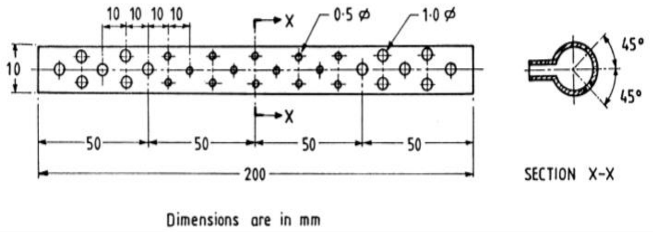
$$Q = 47 \times (D^2 - d^2) \times p \times n \times \psi \times \rho_b \times C$$

where, Q = capacity of a screw conveyor, kg/h,
D=the screw diameter, m,
d =the screw shaft diameter, m,
p=the pitch of the screw, m,
n= the rotational speed of the screw conveyor,
qb=the bulk density of the seed, kg/m3, w the coefficient of friction of screw cross section and
C=total length and diameter of shaft.

Measurements-

A single phase wattmeter (range 0±750 W, least count 5 W) was connected with the machine to measure the power consumed and ultimately to measure the energy required in grinding. The following formula is used to calculate the speci®c energy consumed in grinding:

Specific energy consumption ˆ Power consumed…W†□ 3:6 Feed rate…kg=h† The particle size analysis was carried out by laser scat- tering using Malvern Particle Sizer (Malvern 3601, Malvern Instruments, UK). The volatile oil content of cumin powder ground at di€erent cryogenic temperatures was estimated by dis- tillation method using Clevenger apparatus (Pearson, 1973).



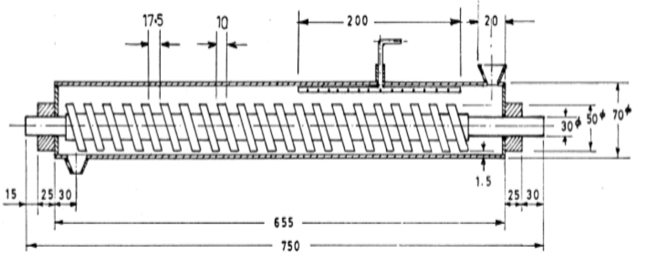


Fig. 1. Sectional view of coolong zone showing position of screw conveyor and distributor.

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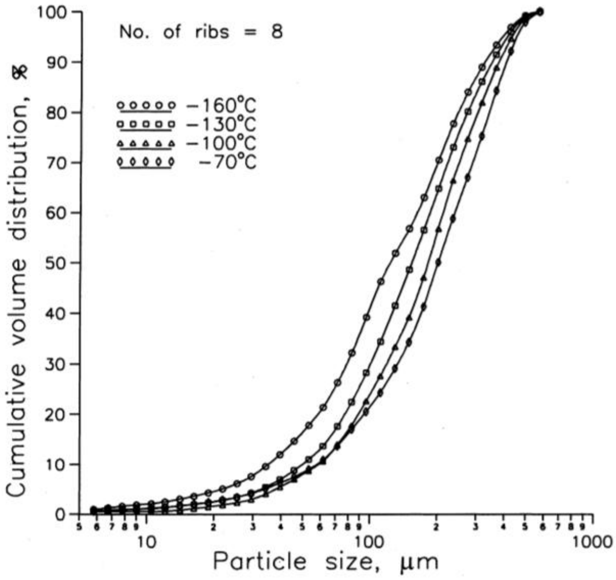

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Table 1
Effect of grinding temperature on volume mean diameter, specific energy consumption and volatile oil

Grinding temperature (°C)	Volume mean diameter (μm)	Specific energy consumption (kJ/kg)	Volatile oil (ml/100 g)
−160	153.2	55	3.30
−130	169.5	65	3.28
−100	193.1	79	3.28
−70	215.0	98	3.26
F-value	365[a]	164[a]	3[b]

[a] Significant at 1% level.
[b] Non-significant.