Effect of operating parameters on mechanical expression of solvent-soaked soybean-grits

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Abstract Oil from soybean is obtained mostly by solvent extraction of soybean flakes. Legislation banning the use of hexane as solvent for extracting edible vegetable oil has forced a search for an alternative solvent and for developing a suitable oil recovery process. Expellers are being used for obtaining vegetable oil by mechanical means (expression) from oil seeds having oil content higher than 20 %. It was felt, in view of the stiffness of the soybean matrix, a combination of solvent treatment and expression could be a cheaper alternative; thus an attempt has been made here to develop a two stage process constituting soaking of soybean grits in solvent followed by mechanical compression (hydraulic press) of solvent-soaked grits to recover oil. The present work aimed at studying the effect of various process parameters on oil yield from solvent soaked soybean-grits during soaking as well as pressing stages using the solvents: hexane, ethanol (alternative solvent). The process parameters were identified through holistic approach. The dependant variable was oil recovery (expressed as fraction of initial oil content of soybean) whereas the independent parameters were particle size, solvent-bean mass ratio, soaking time, soaking temperature, applied pressure and pressing time. The effect of each of the above parameters on fractional oil recovery (FOR) was studied. The results of the present study indicate that the above

parameters have a significant effect on the fractional oil recovery with particle size, soaking temperature, soaking time and pressing time being the most significant factors. The present study also indicates that ethanol can be used as an alternate solvent to hexane by optimizing the factors as discussed in this paper.

Keywords Expression · Extraction · Fractional oil recovery (FOR) · Residual oil · Soybean grits

Introduction

Commercially oil from soybean was being recovered through mechanical expression till 1920; solvent extraction followed thereafter (Langhurst 1950). The Indian Edible Oil Industry comprises of 15,000 oil mills, 600 solvent extraction plants, 250 vanaspati units and about 400 refining units (NIIR Project Consultancy Services 2013). The oil content in soybean ranges between 16.5 and 21 % (whole mass basis) (Hammond 2005); oil globules in soybean are trapped in tiny cells; rupturing of these cells is a prerequisite in mechanical expression as well as in solvent extraction for recovery of soy oil. An empirical relationship between pressing time and volumetric oil yield from conophor nut using a laboratory press was proposed by researchers (Fasina and Ajibola 1989). Reduction of particle size and application of high pressing temperature is necessary for recovery of oil by mechanical expression. Researchers reported that moisture content, pressure, pressing time, temperature were important factors that influence oil yield during expression process while a hydraulic press was used (Khan and Hanna 1983; Smith and Kraybill 1993; Tikkoo et al. 1996).

Researchers presented a review on the state of art technology of extraction systems particularly with reference to feed preparation to enable an energy efficient method of oil

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extraction (Hammond 2005; Lusas et al. 1990). The solvent extraction industry had long been searching for “perfect” solvent which will be plentiful in supply, low in toxicity, non-flammable, inexpensive, and having rapid penetration rate, high solvency power, ease of separation, low specific heat, low latent heat of vaporization and high stability (Lusas et al. 1990). Literature revealed that workers in a solvent extraction plant when exposed to n-hexane suffered from nervous disorder (Conkerton et al. 1995; Hron and Koltun 1984; Lusas et al. 1991; Wan et al. 1995). US clean Air Amendment of 1990 (Public Law No. 101–549 Nov., 15, 1990) listed n-hexane among 189 hazardous air pollutants affecting both health and environment. Ethanol has long been considered an attractive alternative solvent in lieu of hexane. Since natural resources for alcohol production are much greater than that for production of petroleum solvents, ethanol was expected to be popular as solvent if an economical process for its use could be developed.

In the present work, an attempt was made to develop a process to enhance recovery of oil from soybean-grits by integrating two unit operations, namely: soaking soybean-grits in ethanol followed by pressing the soaked soybean-grits using a hydraulic press. Parameters pertaining to the processes of oil recovery were studied.

Experimental procedures

Soybean-grit sample preparation

Soybean seeds of Punjab-1 variety were procured from Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora, Uttarakhand (India). Cleaned and whole soybean seeds were crushed in a Burr mill (Scientific Traders, Post Box No. 256, Kolkata – 700001). Soybean-grits thus obtained were aspirated for removal of hulls and finer particles. Soy grits were separated into desired particle sizes in a vibratory mechanical sieve shaker. Soygrit samples in all cases had an initial moisture content of 9.89 % dry basis (db) and an initial oil content of 17 % (whole mass basis).

Solvents

The solvents used were hexane and 99.9 % ethanol (absolute) of analytical grade and obtained from E-Merck (Mumbai, India); each of these solvents was used as soaking medium for grits. In each experiment fresh ethanol/hexane was used.

Oil recovery from solvent-soaked soy grits under uniaxial compression

Oil recovery was undertaken in two stages on a sample of 20 g soy grits: soaking stage and pressing stage. Independent

variables and their range of values used during experiments are given in Table 1. Effect of independent variables, namely, particle (grit) size (0.85–1.72 mm), solvent (hexane/ethanol) to bean ratio (1.5:1–2.5:1), soaking time (1–4 h), applied pressure (9,800–49,000 kPa), duration of applied pressure (10–30 min) and soaking temperature (30–60 °C) on oil yield from soybean-grits were studied.

Oil recovery from soy grits during soaking stage

Experiments were performed according to Chien et al. (1990) with slight modification. 20 g of soy grits of desired particle size were dipped into solvent taken in an Erlenmeyer/conical flask. Solvent to bean (grits) ratio was predetermined. The conical flask was placed in a water bath shaker and the soaking process was undertaken at a selected temperature for a predetermined time period upon the lapse of which samples were filtered and the mass of filtrate as well as filtered marc (leached solids) were recorded. Oil content in the filtrate was determined by conducting mass balance.

Oil recovery from soy grits during pressing stage

A compression cell similar to the one used by Singh et al. (1984) was used for studying the expression characteristics of solvent-soaked soybean-grits. The filtered marc obtained from the soaking stage was put into the cylinder locked to the bottom plate and the plunger was pushed inside the cylinder. Desired pressure was applied to the sample; after the lapse of desired duration, pressure was released. The pressed cake was taken out and oil recovered during pressing was measured using mass balance. The process flow chart and mass balance for a typical experiment is shown in Fig. 1.

Statistical analysis

Each experiment was carried out in triplicates and ANOVA was performed using stepwise linear regression model procedure in SPSS Version 20. The significance level was set at 0.05.

Table 1 Values of independent variables for oil recovery from solvent-soaked soy grits under uniaxial compression

Independent variable	Values
Particle (grit) size (mm)	0.85, 1, 1.2, 1.4, 1.72
Solvent-to-bean ratio (g/g)	1.5:1, 1.75:1, 2.0:1, 2.25:1, 2.5:1
Soaking time (h)	1.0, 2.0, 2.5, 3.0, 4.0
Applied pressure (kPa)	9800, 19600, 29400, 39200, 49000
Duration of applied pressure (min)	10, 15, 20, 25, 30
Soaking temperature (°C)	30, 35, 40, 45, 50, 60
Type of solvent	Hexane/Ethanol

Fig. 1 Typical Process Flowchart for recovery of oil from solvent soaked soy grits showing mass balance at soaking and pressing stage

Results and discussion

Effect of independent variables, namely, particle (grit) size, solvent (hexane/ethanol)-to-bean ratio, soaking time, applied pressure, duration of applied pressure and soaking temperature on the dependant variable, namely, oil recovery from soybean-grits are presented below. The oil recovery has been expressed as fraction of initial oil content of soybean-grits. Table 2 shows the ANOVA results where the effect of the independent variables were found to be significant ($p < 0.05$).

Effect of particle size

The effect of particle size has been studied separately in terms of fractional oil recovery (FOR) during soaking stage, pressing stage and for the total process using ethanol as the solvent.

Table 2 Analysis of Variance (ANOVA) for the effect of independent variables on fractional oil recovery using ethanol for the total process (soaking and pressing)

ANOVA ^a					
Model	Sum of squares	df	Mean square	F	Significance $p=0.05$
Regression	0.078	6	0.013	3.346	.016 ^b
Residual	0.089	23	0.004		
Total	0.166	29			

a. Dependent variable: fractional oil recovery

b. Predictors: (Constant), Pressing time, Applied pressure, Particle size, Soaking time, Solvent-to-bean ratio, Temperature

p =level of significance

The study for all the cases was conducted at a solvent-bean ratio of 1.5:1 (minimum ratio required to completely submerge the soy grits) and soaking time of 2 h. Figure 2 shows the effect of particle size at 3 different soaking temperatures (30°, 40° and 50 °C) when ethanol was used as the solvent. Referring to Table 3 the coefficient of particle size is negative which indicates the decrease in fractional oil recovery with increase in particle size. Reduction in particle size increased fractional oil recovery during soaking stage. This is because reduced particle size meant rupture of cell walls to a higher degree and also higher surface area available for mass transfer. It was further observed that the degree of oil recovery was higher below a particle size of 1.2 mm. This was substantiated by the fact that the rupture of cell wall was achieved to a higher degree for lower particle sizes. Similar results about the effect of particle size were also reported for soybeans by researchers (Snyder et al. 1984). Also an increase in temperature increased fractional oil recovery. Figure 3 depicts the effect of particle size during pressing stage at 3 different soaking temperatures (30°, 40° and 50 °C) with ethanol. The filtered marc was subjected to an applied pressure of 29,400 kPa for duration of 10 min. Fractional oil recovered during the pressing operation exhibited a peak at a particle size of 1.2 mm. A possible explanation for such behaviour could be that on application of pressure on the filtered marc, a reduction in porosity or higher degree of compactness was achieved. Once the soaked grits were moved into the vacant interparticle spaces, they were likely to rupture accompanied by facilitated transport of oil in presence of solvent. The soaked marc contained the solvent and oil as miscella (oil-solvent solution) in the void space between the particles and it was primarily this intercells which oozed out on application of pressure. Mechanism of oil outflow during mechanical extraction was investigated by researcher to study oil-point (Faborode and Favier 1996). They suggested that at low pressure level the seed particles will deform and more compactly fill up the empty voids. With increase in pressure the voids were reduced and the seed particles begin to resist the applied pressure through contact points between particles.

Fig. 2 Effect of particle size on fractional oil recovery (FOR) during soaking stage from soy grits soaked in ethanol at three different temperatures (30 °C, 40 °C and 50 °C)

Table 3 Coefficient of regression, *t*-test values and significance of each independent variable on fractional oil recovery using ethanol as solvent for the total process

Coefficients ^a					
Model	Unstandardized coefficients		Standardized coefficients Beta	t	Significance <i>p</i> =0.05
	B	Std. Error			
Constant	-0.143	0.192		-0.747	0.463
Particle size (mm)	-0.031	0.090	-0.053	-0.346	0.732
Temperature (°C)	0.006	0.002	0.378	2.424	0.024
Solvent-to-bean (g/g)	0.010	0.049	0.032	0.208	0.837
Soaking time (h)	0.078	0.022	0.533	3.453	0.002
Applied pressure (kPa)	2.347E-006	0.000	0.178	1.170	0.254
Pressing time (min)	0.005	0.002	0.315	2.018	0.055

a. Dependent variable: Fractional oil recovery

p=level of significance

Further increase in pressure will force the oil to start flowing out of the particles. A lesser portion of oil through cell wall rupture was removed from smaller particles. A higher pressure was necessary to rupture the cell walls for smaller size particles. It was observed that the differential increase $\{\delta(\text{FOR})/\delta p\}$ in oil recovery for larger particles (particles greater than 1.2 mm) was more for pressing stage than for soaking stage. This was substantiated by the fact that the fractional oil recovery during the pressing stage for larger particles did involve some degree of rupture of cell walls thereby releasing oil. Figure 4 depicts the effect of particle size on fractional oil recovery for the total process (soaking + pressing) at 3 different temperatures. It was observed from the figure that at 30 °C fractional oil recovery increased as the particle size was reduced from 1.72 to 1.2 mm and then reduced to 0.85 mm. At 40 °C fractional oil recovery increased linearly from particle size 1.72 to 1.2 mm but then increased marginally from 1.2 to 0.85 mm. At 50 °C fractional oil recovery did not increase from 1.2 to 0.85 mm. Hence, for all successive experiments, 1.2 mm particle size was chosen.

Fig. 3 Effect of particle size on fractional oil recovery (FOR) during pressing stage for soy grits soaked in ethanol at three different temperatures (30 °C, 40 °C and 50 °C)

Effect of solvent-to-bean ratio

The effect of solvent-to-bean was studied with a particle size of 1.2 mm at 30 °C, soaked for a period of 2 h and at 29,400 kPa applied pressure for duration of 10 min using ethanol as solvent (Fig. 5). Fig. 5 depicts the effect of solvent-to-bean ratio on fractional oil recovery (FOR). It may be noted from the figure that as solvent-to-bean ratio increased the fractional oil recovery (FOR) for the process of soaking increased. The amount of oil recovered from soaked marc after pressing decreased as the solvent-bean ratio increased. This could be because a major portion of the total oil recoverable was removed during the soaking period itself. The total oil recovery increased with increase in solvent-bean ratio. Hexane also exhibited similar trend when used as solvent (data not shown). Kwiatkowski and Cheryan (2002) also reported an increase in oil recovery with increase in solvent-to-bean ratio during solvent extraction of ground corn using ethanol.

Fig. 4 Effect of particle size on fractional oil recovery (FOR) during total process for soy grits soaked in ethanol at three different temperatures (30 °C, 40 °C and 50 °C)

Fig. 5 Effect of solvent-to-bean ratio on fractional oil recovery (FOR) during soaking & pressing stages and total process for soy grits soaked in ethanol

Effect of soaking time

Figure 6 presents the effect of soaking time on FOR for ethanol and hexane during soaking. The study was conducted at a solvent-bean ratio of 1.5:1, particle size of 1.2 mm and soaking temperature of 30 °C. It is observed from Fig. 6 that with increase in soaking time beyond 3.5 h, the increase in oil recovery from hexane soaked sample becomes insignificant while that from ethanol soaked sample still increases. Also the amount of oil which was recovered from the grit after soaking with hexane was more than that of ethanol. Hexane exhibited superior oil extraction characteristics because of its high diffusion coefficient which can be determined from the following equations. Diffusion coefficient can be estimated using Vignes relation (O'Connell et al. 2001) based on the absolute rate theory which is given by the following equation:

$$D_{AB}\mu = [(D_{AB}^0\mu_A)^{x_B}(D_{BA}^0\mu_B)^{x_A}]\alpha \quad (1)$$

Where α = Thermodynamic factor and D_{AB}^0 and D_{BA}^0 = diffusion coefficient at infinite dilution, m^2/s , μ_A and μ_B are the viscosity, $\text{kg}/\text{m} \cdot \text{s}$ of solute (A) and solvent (B) and x_A and x_B are the mole fraction of A and B respectively. And the diffusion coefficients at infinite dilutions D^∞ as per Wilke–Chang equation (Treybal 1981) is given by

$$D^\infty_{AB} = \left\{ 117.3 \cdot 10^{-8} (\phi M_B)^{1/2} T \right\} / \mu V_A^{0.6} \quad (2)$$

Fig. 6 Effect of soaking time on fractional oil recovery (FOR) during soaking stage from soy grits soaked in ethanol and hexane

Where D^∞_{AB} = diffusivity of A in very dilute solution in solvent B, m^2/s

M_B = molecular weight of solvent, kg/kmol

T = temperature, Kelvin

μ = solution viscosity, $\text{kg}/\text{m} \cdot \text{s}$

V_A = molal volume of the solute at normal boiling point, m^3/kmol

Φ = association factor and has a value as 1.5 for ethanol and 1.0 for hexane (Treybal 1981).

Thus viscosity and diffusion coefficient played a major role in the process of mass transfer. In order to compensate for the lower diffusion coefficient of ethanol system a higher soaking time was required. Increase in soaking time is beneficial when ethanol is used as a solvent while the beneficial effects were insignificant when hexane was used as a solvent.

Figure 7 depicts the effect of soaking time on fractional oil recovered after pressing the soaked samples as a function of soaking time. It may be observed from the figure that the fraction of oil extracted at this stage remained more or less constant with respect to soaking time when hexane was used as solvent, while that with ethanol it showed an increasing trend. This fact is further established by the analysis shown in Table 3 where the soaking time was found to be a significant parameter on the overall fractional oil recovery for ethanol ($p < 0.05$). Possible explanation for this behaviour could be that the diffusivity of the oil in ethanol being low, a longer time was required for the oil to flow into the solvent or bulk fluid and it was primarily this miscella which was entrapped in the inter particle void space that was being recovered and similar trend was observed for the total process. Figure 8 depict the effect of soaking time on fractional oil recovered from the combined process of soaking and subsequent pressing for both hexane and ethanol. As the amount of oil extracted on soaking with hexane was much higher, the combined effect (of soaking and pressing) also exhibited hexane to be a better solvent compared to ethanol. So increase of soaking time is recommended while ethanol is used as a solvent.

Fig. 7 Effect of soaking time on fractional oil recovery (FOR) during pressing stage from soy grits soaked in ethanol and hexane

Fig. 8 Effect of soaking time on fractional oil recovery (FOR) during total process from soy grits soaked in ethanol and hexane

Effect of soaking temperature

The diffusion coefficients at infinite dilutions D^∞ is given by Wilke–Chang equation (Equation 2).

The viscosities for ethanol and n-hexane at temperatures in the vicinity of 30°C have been correlated by Orrick–Erbar equation as (O’Connell et al. 2001) as

$$\ln \frac{\mu_L}{M_{\rho_L}} = A + \frac{B}{T} \quad (3)$$

Where, μ_L is viscosity in cp, A and B are constants obtained from group contribution methods and ρ_L is density in gm/cm³ at 20°C, M is the molecular weight and T is temperature in Kelvin.

From the findings on the study of soaking time and from the above two equations (1, 2 and 3) it could be established that viscosity and diffusion coefficient of solvent played a major role in the process of mass transfer. A major parametric manipulation by which viscosity could be lowered and diffusion coefficient could be increased was by increasing the soaking temperature as may be observed from the above equations. Figure 9 depicts the effect of soaking temperature on fractional oil recovery for ethanol. It shows that as soaking temperature increased, the amount of oil recovered on soaking increased. The amount of oil recovered on pressing the filtered

Fig. 9 Effect of soaking temperature on fractional oil recovery (FOR) during soaking & pressing stages and total process from soy grits soaked in ethanol

marc also increased. Though fractional oil recovery during pressing stage at any soaking temperature was lower than that during the soaking stage, the change in fractional oil recovery per unit change in temperature was more during pressing than during soaking. This may be because elevated temperatures also causes rupturing of cell walls thus resulting in improved oil extraction characteristics. The statistical analysis shown in Table 3 also signifies the importance of soaking temperature on fractional oil recovery ($p < 0.05$).

Figure 10 depicts the effect of temperature on the fractional oil recovery for particle size of 0.85 mm while keeping other conditions as before (Fig. 9). It may be observed from the figure that fractional recovery of oil during soaking stage increased up to 50 °C and then fell marginally at 60 °C. The fractional oil recovery during the pressing stage increased sharply between 50 and 60 °C. The increase in fractional recovery of oil during soaking stage could be explained in line similar to the preceding paragraph, but the marginal fall in the oil recovery during soaking at 60 °C as compared to 50 °C and the abrupt increase in oil recovery during pressing at 60 °C as compared to 50 °C probably because

(a) The experiment was conducted by taking grit and solvent in an Erlenmeyer/conical flask, sealing the opening of the conical flask and raising the temperature to 60 °C in a water bath and maintaining it for 2 h (soaking time). During this operation the pressure of the system increased and the beneficial effect of the temperature on diffusion and oil viscosity were lost because of the higher system pressure caused by the vapour pressure as per Antoine equation (O’Connell et al. 2001)

$$\ln P_{vp} = A + \frac{B}{T - C} \quad (4)$$

where P_{vp} = vapour pressure, A, B, C are constants and T = temperature in Kelvin.

Using hexane as solvent under the same conditions as above it was observed that more oil could be extracted during the soaking stage (0.588) as was the trend observed with

Fig. 10 Effect of soaking temperature on fractional oil recovery (FOR) during soaking & pressing stages and total process from soy grits of 0.85 mm particle size soaked in ethanol

ethanol but a lower amount of oil could be extracted during the pressing stage (0.081). The oil recovery in the pressing stage with hexane was lower than that with ethanol under similar conditions. The drop in oil recovery during pressing stage with hexane may be because of loss of hexane due to vaporisation which resulted in loss of carrier/continuous phase (hexane) for transport of miscella out of marc. The total oil recovery with hexane was 0.67 as against 0.434 for ethanol. It could be concluded that there exists maximum value of soaking temperature up to which it results in improved oil recovery for solvent and this temperature is dependent on its vapour pressure characteristics.

Effect of applied pressure

Figure 11 depicts the effect of applied pressure on fractional oil recovery (FOR) for ethanol and hexane. The above study was conducted keeping the following parameters fixed at soaking time of 1 h, solvent-bean ratio of 1.5:1, particle size of 1.2 mm, soaking temperature of 30 °C and duration of applied pressure of 10 min. With increase in applied pressure, oil recovery during the pressing stage also increased. Hexane extracted more oil as compared to that by ethanol. This might be because viscosity of ethanol was more than that of hexane and consequently diffusion coefficient of hexane-oil system was higher than ethanol-oil system. It may further be observed from the graph that on increasing the pressure ethanol soaked soy grits showed an increasing trend while that from hexane soaked soy grits became asymptotic to the line $y(\text{fractional oil recovery}) = 0.02$. In analytical geometry, asymptote of a curve is a straight line such that the distance between the curve and the straight line approaches zero as they tend to infinity. The possible explanation for this observation could be that the access of oil to ethanol during soaking was restricted because of high viscosity and further slowed down because of low diffusion coefficient. Increase in pressure was responsible for forcing oil out of the ruptured cell walls. The rupture of cell walls contributing to additional oil flow was more when hexane was used because hexane migrated through the

Fig. 11 Effect of applied pressure on fractional oil recovery (FOR) during pressing stage and total process from soy grits soaked in ethanol

membrane (cell wall) by virtue of its low viscosity and enabled release of oil. Researchers reported that oil yield (wt %) is directly proportional to the square root of the pressure Khan and Hanna (1983).

Effect of pressing time

Figure 12 depicts the effect of pressing time on fractional oil recovery for both hexane and ethanol. The study was conducted keeping other parameters fixed at solvent-bean ratio of 1.5:1, applied pressure of 29,400 kPa, soaking time of 1 h, particle size of 1.2 mm and soaking temperature of 30 °C. It may be observed from the figure that as the pressing time increased the marginal fractional recovery of oil when ethanol used as solvent was higher than the case with hexane. Data presented in Table 3 is also in accordance with this observation of increase in fractional oil recovery for the total process with increase in pressing time. This observation appeared logical from the findings in previous subsection (refer to Fig. 6) because the amount of oil which was extracted during soaking for a fixed solvent-bean ratio and soaking temperature for a particular soaking period was higher for hexane than that for ethanol. This signifies that more of oil was retained within the soaked bean when ethanol was used as the solvent. After soaking in/extraction with ethanol the amount of oil resident in the bean was more. During subsequent operation of pressing, the amount of oil recovered against a fixed applied pressure showed an increasing trend with ethanol compared to the case with hexane. Researchers reported that square of oil yield (wt %) was proportional to the cube root of pressing time (Khan and Hanna 1983). From Fig. 12 it was observed that after 20 min, oil recovery from hexane soaked soy grits was not significant. The recovery of oil with increase in pressing time for both the solvents increased because of release of miscella due to concentration and due to gradual rupture of cell walls under sustained or prolonged loading. The extraction during soaking of the grits while hexane was used as a solvent being more than that with ethanol, the degree of compaction also was probably different as was observed

Fig. 12 Effect of pressing time on fractional oil recovery (FOR) during pressing stage and total process from soy grits soaked in ethanol and hexane

from the pressed button/pellet size. The viscosity of the oil being very high and also the viscosity of ethanol being higher than that of hexane the net solution viscosity is higher for ethanol-oil miscella than the hexane oil miscella. The diffusion coefficient of hexane-oil system was more than the ethanol-oil system (explained in Section 3.3). In other words, for the same concentration gradient as per Fick's law the flux N_A (amount transferred/unit time $\times$ unit area) was more through $N_A = -D \frac{\partial c}{\partial x}$ for hexane. So despite the fact that the oil resident in the soaked bean was higher in the case of ethanol, the amount of oil extracted was not higher but showed an increase in fractional oil recovery probably because of the high viscosity of the ethanol-oil miscella. A higher pressing time is recommended when ethanol is used as solvent, while similar benefits could not be obtained while using hexane.

Conclusions

The oil recovery from solvent soaked soy grits was more than non-soaked soy grits. Following conclusions could be drawn from the study:

1. At elevated temperatures (40 °C, 50 °C) a particle size of 1.2 mm was found to be optimum during pressing stage.
2. Beyond 50 °C there was a fall in oil recovery during soaking stage possibly due to vapour pressure effect. This effect was more pronounced in case of hexane as soaking medium than in case of ethanol.
3. With the increase of pressing time oil recovery during pressing stage from ethanol soaked soy grits increased more or less linearly while that for hexane soaked soy grits the increase was not significant as compared to ethanol after 20 min of pressing time.
4. Soaking time duration of 3 to 4 h is recommended when ethanol is used as a soaking medium; a soaking time duration of 1 to 2 h when hexane is used as soaking medium.
5. For maximum oil recovery a pressure beyond 49,000 kPa, and a pressing time of 30 min or more are recommended for soy grits soaked in ethanol.

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