# Studies on Centrifugal Clarification of Sugarcane Juice - Possibilities and Limitations

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## ABSTRACT

A centrifugal clarifier based on the principles of a hydrocyclone with an impeller was developed for centrifugal clarification of sugarcane juice, for improvement in the quality of jaggery and khandsari. The developed clarifier and an existing standard sedimentation disc centrifuge were tested in regards of effect of operational parameters, namely, settling, boiling, clarificant addition and sampling time/ juice volume on their performance. For both equipments separation efficiencies improved significantly (1% level of significance) by the four independent parameters. Gravitational sedimentation by allowing the juice solids to settle during a settling period of 45 minutes could separate 15.23% solids, boiling the cane juice at 105°C could separate 34.41% solids while clarification of sugarcane juice through vegetative/chemical clarificant could separate additional 9.1% solids from the juice. However, the overall separation efficiency ranged from 41.52% to 70.23% for centrifugal clarifier and from 44.48% to 69.11% for disc centrifuge

**Keywords**: Clarifier, centrifugal, clarification. G-factor, hydrocyclone, settling, disc centrifuge, India

## 1. INTRODUCTION

In India, jaggery and khandsari are among the most important cottage industries because about 30% of the sugarcane produced is processed in such industries, yielding 10-12 million tonnes of these products (Indian Sugars, 2002). However, the quality of sweeteners produced by these industries is inferior to sugar because in these industries vegetative and/or chemical clarificants are used to remove the foreign materials present in sugarcane juice. These clarificants are unable to efficiently remove the bagacillo, mud and other colloidal materials, resulting in lowered quality of jaggery. The suspended particles are carried over in the next subsequent processing and eventually get embedded in the product resulting in inferior quality of jaggery. It was envisaged that a mechanical device (centrifugal clarifier) causing accelerated sedimentation, using the concept of centrifugal separation could separate such impurities at desired stage of juice processing and would be helpful in improving the quality of jaggery.

Among the various types of solid liquid separators, structural and functional concept of hydrocyclone was taken into consideration to design the clarifier. This was done because hydrocyclones have no moving parts, are simple devices in structure and operation, and have found a wide application in various fields of technology, such as cleaning atomizing classification, solid-liquid separation etc (Lagutkin and Barannov, 1998; Li and Lin, 2004).

Hydrocyclones are also being used in food industry for the separation of starch and protein, in the separation of sand from sugarcane juice, in apple juice clarification, sugarcane juice clarification and in the cleaning of wash waters in potato processing (Murray, 1973; Azad, 1996; Cilliers and Harrison, 1997; Ortega et al., 1997). Studies of particle size indicated that clarifying ability of the hydrocyclone was good and it was better than that of a centrifuge for removal of fine particles and was suggested that hydrocyclone could be used prior to filtration to improve the clarification process, and that their use might be a simple and inexpensive option in treatment of foods and biological materials (Svarovsky, 1974; Klima and Kim, 1998; Hsich, 1999).

Various researchers have reported that the hydrocyclone when used for small-scale industries like the dairy industry poses an application problem (Williams, 1983). It was found that for a hydrocyclone of any size, the capacity of the hydrocyclone should not be less than 3300 l/h for an optimal residence time, for a satisfactory and efficient separation (Svarovsky, 1974; Rovinsky, 1991; Sanjeev, 2001.). Such a feed rate is not possible in practical operation in a small scale industry.

Sanjeev (2001) working on use of 12.5 cm hydrocyclone to separate starch from impurities and to concentrate starch milk obtained from different crops, concluded that the maximum pressure obtained was only 4kg/cm$^2$, which was too low for effective starch separation. Hence a high pressure pump (30hp) was required to develop 15kg/cm$^2$.

Liang-Yin Chu *et al.*( 2000) designed a hydrocyclone with a series of modifications based on the conventional hydrocyclone, the structural modifications with central insertions named winged core, solid core and inner diffuser could increase all the reduced separation efficiency, separation sharpness, cut size, capacity and flow split, and decrease the energy loss coefficient. The structural modification of 20° cone with spiral has the same function. For increasing separation efficiency and reducing energy loss coefficient only, straight vortex finder with siphon and straight underflow pipe with cone are efficient structure designs.

## 2. MATERIALS AND METHODS

Under gravitational force, solid particles settle in a fluid at a fixed maximum sedimentation rate. To increase the settling rate the force of gravity may be replaced by a stronger centrifugal force. The basic separation principle employed in a centrifugal separator is centrifugal sedimentation i.e. the suspended particles are subjected to centrifugal acceleration which separates them from the liquid (Svarovsky, 1974). Centrifugal separators have replaced gravity separators in production operation to a considerable extent because of their greater effectiveness with fine drops and particles and their smaller size for a given capacity (Hugot, 1986; Wang *et al.*, 2006; Kraipech *et.al.*, 2005).

A particle, at any point within the flow in a centrifugal separator is basically subjected to two forces; the external and internal field of acceleration termed as gravity and centrifugal forces respectively and the drag force exerted on the particles by the flow (Fig. 1). The gravity effect is usually neglected in the separators so that only centrifugal force ($C_f$) and drag force are taken into account. If the centrifugal force acting on the particles exceeds the drag, the particle moves radially outward and if drag force is greater, the particle is carried inwards (Hsich, 1999; Neesse *et al*., 2004; Rovinsky,1995).

When a spherical ball of mass ‘m’ and radius ‘r’ is rotating inside a circular path of radius ‘R’, the effective radius of rotation of the ball is ‘R-r’. If the drum is rotating at ‘N’ rpm then

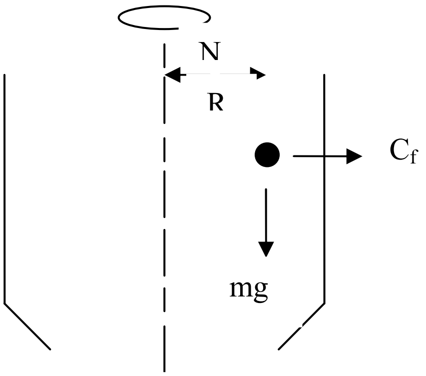

Figure 1. Concepts of centrifugal sedimentation

Centrifugal Force acting on a particle,

$$C_f = \frac{mv^2}{R-r}$$

$$= \frac{m[4\pi^2(R-r)^2N^2]}{(R-r)}$$

$$= 4\pi^2 \, m \, N^2 \, (R-r) \qquad (1)$$

Since R >> r, neglecting r, the above equations for $C_f$ may be written as:

$$C_f = 4\pi \, m \, N^2 \, R \qquad (2)$$

Also weight of particles acting downwards,

$$W = mg \qquad (3)$$

Considering the separation factor, G.

$$= C_f / W$$

$$= \frac{4\pi^2 N^2 R}{g} \qquad (4)$$

The settling time of the particles is limited by residence time of the liquid in the bowl. At the end of this residence time let the particle be at a distance $r_B$ from axis of rotation.

Residence time ($t_T$) is equal to the volume of the liquid in the bowl (V’) divided by the volumetric flow rate Q.

$$\text{Thus, } t_T = \frac{V^1}{Q} \qquad (5)$$

## 2.1 Design of the Clarifier

Preliminary experiments were conducted on standard solid retaining sedimentation disc centrifuge (Fig 2) to examine the possibilities of development of low cost equipment for clarifying the cane juice. Based on the results of these preliminary experiments, a clarifier was designed and fabricated. Structural and functional concepts of hydrocyclone were also taken into consideration for designing this clarifier. The design proposed by Columbus (1993) for a 12.5 cm diameter hydrocyclone was tried. However, hydrocyclone as a clarifier for cane juice clarification was found to be unsuitable for practical operation due to high feed rate requirement or due to fabrication constraints. Therefore, an agitator was used to provide the required centrifugal force. With addition of an agitator, the concept of hydrocyclone, which have no moving part had to be discarded (Cilliers and Harrison, 1997). Adhering to the optimum relative dimensions of cyclones proposed by Columbus (1993) for a 12.5 cm diameter hydrocyclone, structural design of the clarifier was made (Fig3).

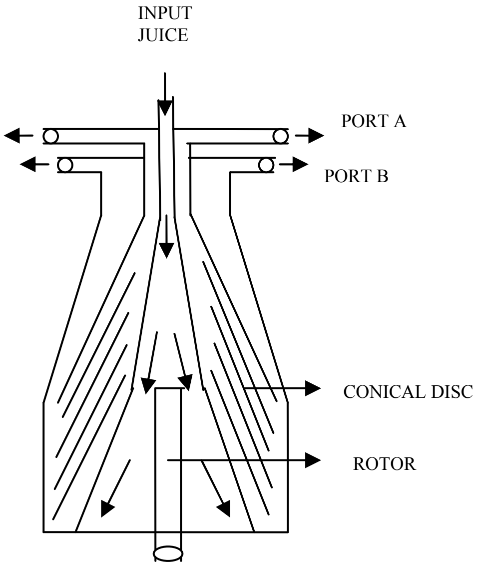

Figure 2. Schematic diagram showing the principles of centrifugal separation in a Disc

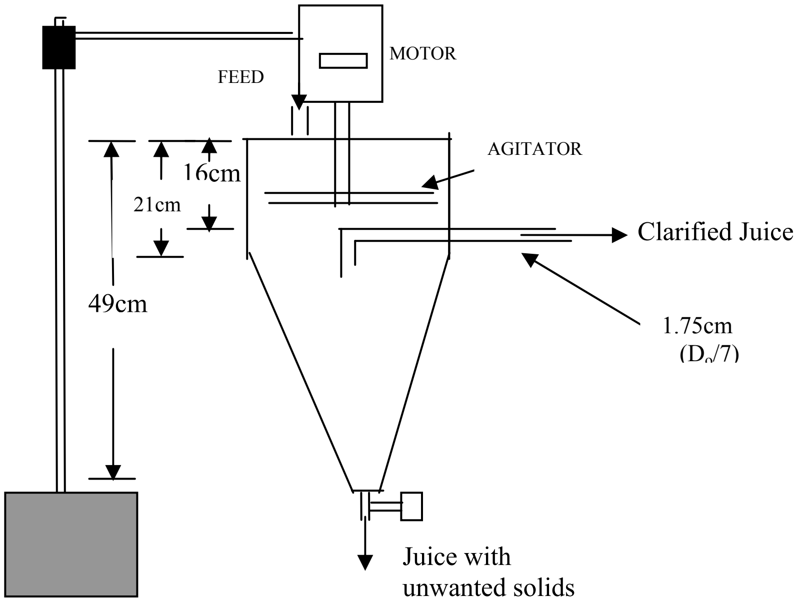

Figure 3. Experimental setup of the Centrifugal Clarifier

## 2.2 Experimental Design

Four independent parameters, namely, settling, boiling, clarificant addition and sampling time/volume were selected for performance evaluation. As an alternative, the juice was also processed in a standard solid retaining sedimentation disc centrifuge (Fig 2) for its mechanical clarification using centrifugal force. For the first three parameters, two levels (zero and optimum) were used while for the centrifugal clarifier five levels of sampling time (5, 7, 9, 11 and 13 minutes) and for the disc centrifuge; six levels of juice volume (1, 2, 3, 4, 5and 6 litre) were used. However, use of clarificant was recommended only for boiled juice and hence experimental combinations involving juice plus clarificant were not executed. Three runs of each experimental combination were done in order to minimize experimental errors. Factorial experimental design was employed to determine the number of experiments. Performance of the developed clarifier and the standard sedimentation disc centrifuge available in the laboratory was estimated under various operating conditions on the basis of separation efficiency (ή), defined as

$$\acute{\eta} = \frac{S_r - S_c}{S_r} \times 100 \qquad (5)$$

For the centrifugal clarifier, the juice was fed to the clarifier to the depth 6.6 cm below the top lid and its rpm was adjusted to 3400. The motor was switched on to provide the necessary centrifugal force in accordance to the requirement of residence time for the juice. The juice was processed for 5 minutes as a batch type to provide sufficient residence time for solid removal and after that it was made continuous. Siphon mechanism was used to feed the clarifier at a rate of 25 l/h. The feed rate of 25l/h provided sufficient residence time for the incoming juice for their clarification before coming out from the clarifier.

Samples were collected at 2 minute interval at 5, 7, 9, 11 and 13 minute. Optical density and separation efficiency were recorded for each sample drawn.

For the case of the disc centrifuge, six litre of juice were used in form of six lots of one litre each for each run. The first lot of juice was fed to the open pan of the disc centrifuge. Volume of juice coming from each port of the disc centrifuge was measured. Also, the processing time of the lot was recorded with a help of a stopwatch. From each port samples were drawn and its optical density and separation efficiency measured (Hugot, 1986). Same steps were repeated for the subsequent five lots. Flow chart for the experiments is shown in Fig. 4.

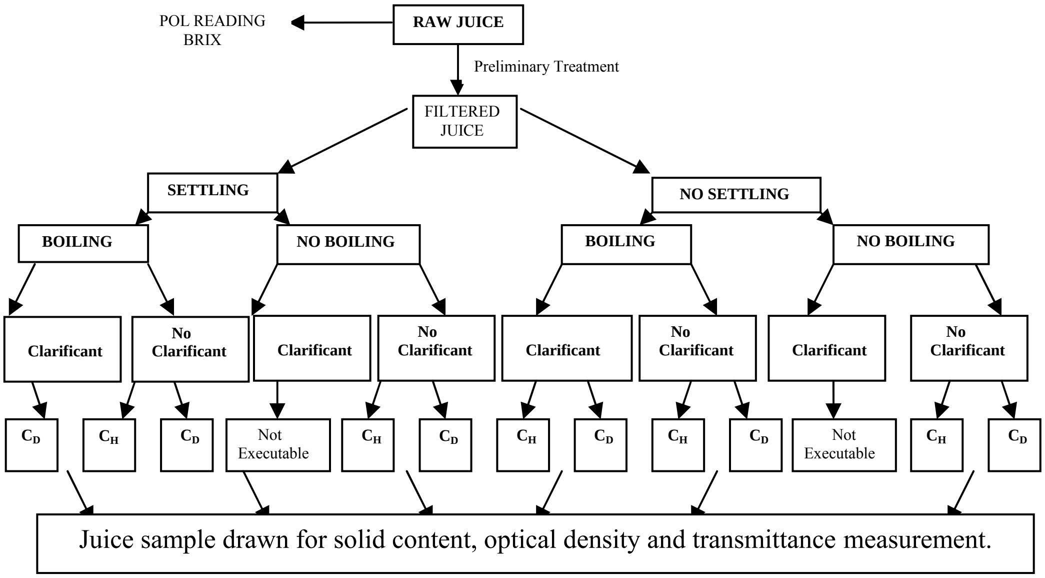

Figure 4. Flow chart showing the experiment design

## 3. RESULTS AND DISCUSSION

The exclusive effects of boiling, clarificants, settling and run on separation efficiency are given in Table 1. The table indicates that separation efficiency of solids due to settling is 15.23% and that due to boiling is 34.41%. When both settling and boiling treatments are given, the values increase by 1.81% to become 36.22%. Thus, it can be inferred that out of the 15.23% solids separated by the process of settling, 13.42% solids are such that boiling can as well separate them. Furthermore, increase in solid separation due to addition of clarificants is 9.62% with settling and 8.58% without settling i.e. an average increase of 9.10% due to addition of clarificants.

Table 1. Separation efficiency ( ή ), of sugarcane juice due to boiling, clarificant addition, settling and experimental run

| Treatment | | Run1 | | Run2 | | Run3 | | Average | |
|---|---|---|---|---|---|---|---|---|---|
| Boiling | Clarificant addition | Settling | No settling | Settling | No settling | Settling | No settling | Settling | No settling |
| No | No | 14.54 | 0.00 | 15.64 | 0.00 | 15.53 | 0.00 | 15.23 | 0.00 |
| Yes | No | 33.98 | 33.12 | 38.57 | 36.24 | 36.12 | 33.88 | 36.22 | 34.41 |

At the end of centrifugation of juice in the clarifiers, the samples drawn were analyzed for their separation efficiency (ή).The separation efficiency ranged from 49.04% to 66.03% for centrifugal clarifier (Fig 5) and from 53.08% to 66.97% for the disc centrifuge (Fig 6). The statistical analysis of data showed that for both the equipments separation efficiencies improved significantly (1% level of significance) by boiling, settling and addition of clarificants.

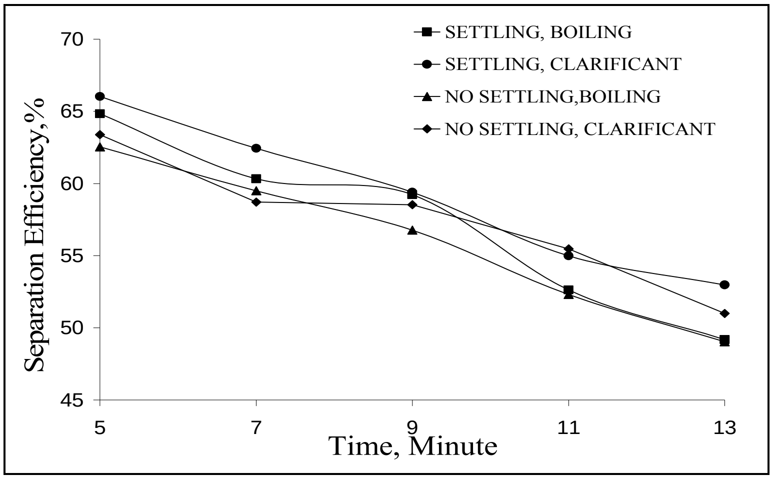

Figure 5. Effect of clarificant, settling and time elapsed on separation efficiency for mechanical clarification of cane juice in clarifier

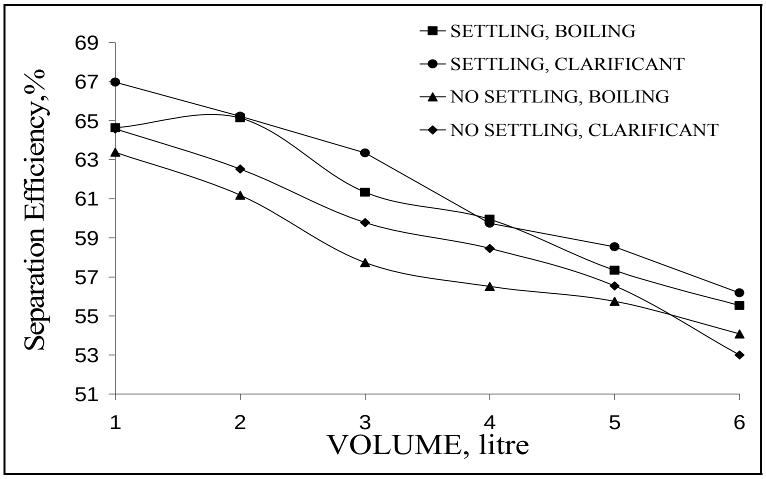

Figure 6. Effect of clarificant, settling and volume on separation efficiency for mechanical clarification of cane juice in a disc centrifuge

The respective reasons of these improvements were i) boiling coagulates nitrogenous impurities present in the juice, which starts floating in the form of scum at the surface and are removed, ii) settling for 45 minutes removes some amount of the coarsely dispersed materials, and iii) addition of clarificants agglomerates the waxes, pectin, and colouring matters which are otherwise not removed by boiling. These unwanted agglomerated materials (in the form of scum and mud) are removed using a strainer. However, the clarificants added get embedded in the juice which gives it a hazy appearance. Operating the juice in clarifier and disc centrifuge separates these materials thus improving the separation efficiency.

In all the experiments, it was observed that separation efficiency was maximum (66.03% for the centrifugal clarifier and 66.97% for the disc centrifuge) at the start of the experiment but decreased significantly, with operating time/juice volume. In case of the centrifugal clarifier, this was due to the partial mixing of the incoming and outgoing streams of juice, which resulted in transfer of solids from the raw juice to the lower portion of the clarifier and replacement of the solids from lower portion to the outgoing stream in order to reach an equilibrium with no concentration gradient of the solids. For the case of the disc centrifuge, the solids, which continue to get accumulated inside the bowl, mix with the incoming juice and keep on decreasing the separation efficiency with the increasing volume of juice processed.

Statistically, it was observed that the run also had a significant effect on the separation efficiency which may be due to difference in composition of the juice due to variation in variety, age of the crop, agronomical practices, crushing methods etc. Since such variations cannot be avoided in commercial juice, ‘run’ as an independent parameter remains beyond.

Also, mass balancing of the solids in the case of centrifugal clarifier was done but it was found that in most of the cases the solids accumulation, in the residual juice, due to accelerated sedimentation, exceeded the amount separated from the incoming juice. The reason being that the samples being drawn intermittently from the middle outlet differ in their solid concentration due to continuous change of solid concentration gradient, and also the sample drawn from the lowest point is not a true representative of the juice in the conical portion of the clarifier holding the separated solids.

## 4. CONCLUSIONS

On the basis of the study following conclusions had been drawn:

- Physical operations such as gravitational/centrifugal sedimentation and boiling could be used effectively for clarification of sugarcane juice.

- Gravitational sedimentation through allowing the juice solids to settle during a settling period of 45 minutes could separate 15.23% solids.

- Boiling the cane juice at 110°C could separate 34.41% solids. However, out of these, 13.42% solids are those, which could also be separated through gravitational settling. Thus, in case of boiling, the added advantage of settling gets reduced to 1.81% only.

- Clarification of sugarcane juice through vegetative/chemical clarificants could separate additional 9.1% solids from the juice.
- All the independent parameters considered for the study i.e. boiling, clarificants addition, settling, experimental run and time of processing/volume of juice processed, affect the separation efficiency significantly (1% level of significance), for the developed Clarifier and existing Disc Centrifuge equipments. However, experimental run remains uncontrolled parameter for actual field conditions.

- For both the equipments, the separation of solids decreases with time of equipment operation/volume of juice processed. The amount of additional solids separated through centrifugal sedimentation ranges from 20.72% at 5 minute operation (zero litre juice volume) to 7.12% at 13 minute operation (3.33 litre juice volume) for the developed Clarifier and from 21.13% at one litre juice volume ( 23 second operation) to 10.35% at sixth litre juice volume (193 second operation) for Disc Centrifuge.

- In addition to the decline in separation efficiency with time of equipment operation/volume of juice processed for the two equipments, for Disc Centrifuge the capacity also decrease from 156 litre per hour for the first litre (initial) of juice processed to 111.9 litre per hour for the sixth litre of juice processed (final). Therefore, further studies would be required for incorporating appropriate modification in these equipments in order to maintain a constant level of separation efficiency and equipment capacity.

## 5. ACKNOWLEDGEMENTS

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## 6. REFERENCES

Azad, I. A. 1996. Efficient and economic way to remove cush-cush and grit from mixed juice using battery of hydrocyclones.In: *Proc of the 59th Annual Convention of the Sugar Technologists Association of India, 14-17August, 39 - 51*. Goa, India

Cilliers, J. J. and S. T. L Harrison. 1997. The application of mini hydrocyclone in the concentration of yeast suspensions. *The Chemical Engineering Journal and the Biochemical Engineering Journal.* 65(15):22-22.

Columbus. 1993. A theoretical study of the hydraulic cyclone, *International Chemical Manufacturer*.34: 473-489

Hsich, W. D. 1999. Desanding of mixed juice by hydrocylones and screw conveyor. *23rd ISSCT Congress, New Delhi, India.*

Hugot, E. 1986. Handbook of cane sugar engineering., Elsevier Publication Company, Amsterdam

Klima, M. S. and B. H. Kim. 1998. Dense medium separation of heavy metal particles from soil using a wide angle hydrocyclone. *Journal of Environmental Science and Health* 33(7): 1340.

Lagutkin, M.G., and D.A. Barannov. 1998. Selection of optimal and regime parameters for the operation of hydrocyclones. *Chemical and Petroleum Engineering* 34(1):79-82.

Liang-Yin Chu, Wen-Mei Chen and Xiao-Zhong Lee.2000. Effect of structural modification on hydrocyclone performance. *Separation and Purification* Technology21(1-2):71-86

Li-yang Wang, Zhi-chu Zheng, Jun Guo, Jun Zhang and Chi Tang.2006. Investigation on separation efficiency of liquid/solid hydrocyclone. *Journal of Hydrodynamics*18(3):400-404

Murray. 1973. Solid-liquid separation. *Journal of environmental Science and Health.* 31(3): 105 - 112.

Neesse, J., Dueck and L. Minkov.2004. Separation of finest particles in hydrocyclones. *Minerals Engineering* 17(5):689-696

Ortega, E.; F Velasquez and V. R Olivas. 1997. Reduction of solids by liquid cyclones as an aid to clarification in apple juice processing. *Food Science and Technology International* 3(5):325 – 331.

Rovinsky, L. A. 1991. Hydrocyclone for processing food liquids. *Journal of food Engineering.* 14(1):129.

Rovinsky,L.A 1995. Application of separation theory to hydrocyclone design. *Journal of Food Engineering* 26(2):131-146

S. Li and Y. Lin.2004. Modeling a Single-stage Hydrocyclone for Potato Starch Separation. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Manuscript FP 03 003. Vol. VI

Sanjeev, R.2001. *Final Report*. AIRCP on processing handling and storage of Jaggery and Khandsari, Trivandrum, India

Statistics, *Indian Sugars*, December 2002. 52 (9): 134 - 135.

Svarovsky, L. 1974. Solid-liquid separation. TMH Publication, New York

W. Kraipech, A. Nowakowski, T. Dyakowski and A. Suksangpanomrung.2005. An investigation of the effect of the particle–fluid and particle–particle interactions on the flow within a hydrocyclone. *Chemical Engineering Journal* 111(2-3):189-197.

Williams, R.D. 1983. The use of hydrocyclones for small particle separation. *SeparationScience and Technology* 18:1395-1416.

## NOMENCLATURE

| | | |
|---|---|---|
| $C_f$ | : | centrifugal force |
| $D_c$ | : | diameter of cyclone |
| $D_i$ | : | diameter of inlet |
| $D_o$ | : | diameter of outlet |
| G | | separation factor |
| O.D. | : | optical density |
| Q | : | volumetric flow/feed rate |
| g | : | mass of the spherical ball |
| RPM | : | revolution per minute |
| R | : | radius |
| Sc | : | Insoluble solids in clarified juice |
| Sr | : | Insoluble solids in raw juice |
| V’ | : | volume of liquid in bowl |
| V | : | linear velocity |
| ή | : | Separation efficiency |