Report R2126(S)

Visit to India to Evaluate the Use of Hydrocyclones for Water Conservation and Effluent Reduction in the Cassava Starch and Sago Industry.

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Acronyms

BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CTCRI	Central Tuber Crops Research Institute
NRED	Natural Resources and Environment Department
NRI	Natural Resources Institute
ODA	Overseas Development Administration
TNPCB	Tamil Nadu Pollution Control Board

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TERMS OF REFERENCE

1. The terms of reference for the visit were:

In collaboration with the Central Tuber Crops Research Institute (CTCRI):

(a) install and commission a hydrocyclone at a selected factory in Salem and assess its performance against laboratory data;

(b) based on the results of (a) operate the hydrocyclone at the sago factory with the objective of reducing water consumption in starch extraction whilst maintaining product quality;

(c) install and operate the hydrocyclone at a starch factory and assess its performance as in (b);

(d) with co-operartion from SAGOSERVE, demonstrate the hydrocyclone to other starch and sago producers;

(e) produce a report on the visit within one month of receipt of analytical data.

SUMMARY

2. As a follow up to laboratory work completed under the project A0305 (Process Improvements to Starch Products from Root and Tuber Crops) and a process audit of starch and sago production (Trim and Curran, 1993) a visit was undertaken to carry out a preliminary field test of a hydrocyclone unit and evaluate its potential for application in the sago and starch industry.

3. The commissioning trials showed that the unit performed marginally better than predicted during laboratory tests. Solid recoveries from the unit were in the range 91-95% compared to 88-92% with similar underflow volume splits of around 45%. Integrated factory trials demonstrated the possibility of re-cycling up to 60% of the water required for root crushing and sieving of the starch milk with equivalent reduction in the volume of waste water produced.

4. Composition of factory waste waters when the hydrocyclone unit was used was little different from that of the waste waters produced under normal operation. However, the reduction in pollution load possible from using hydrocyclones to re-cycle process water may be more than 50%

5. There appeared to be a positive effect on the quality of the starch, in terms of the colour and level

of impurities, produced when using the hydrocyclone. This offers the possibility of eliminating subsequent washing of the starch. A slight improvement in the whiteness of the polished sago was recorded which may be reflected in higher prices.

6. Based on these highly successful results and the positive reaction showed by producers and local authorities, proposals are made for full-scale trials of a hydrocyclone unit over a full processing season, and to assess the implications at the macro level, both in economic and environmental terms, of introducing the technology. It is also recommended that collaboration be made with a hydrocyclone manufacturer in order to facilitate uptake of the technology by producers, and to collaborate with SAGOSERVE on the development of strategies for introduction of the technology and its wider dissemination across the industrial sector.

INTRODUCTION

Background

7. As a component of the Root and Tuber Crops Problem Area of the Horticultural and Tree Crops Programme funded by the Natural Resources and Environment Department (NRED) of the Overseas Development Administration (ODA) the Natural Resources Institute (NRI) is conducting research on the processing of starch from root and tuber crops. The objectives of Project A0305 **Process Improvements to Starch Products from Root and Tuber Crops** are to:

(a) investigate and develop the processing operations employed in small - medium-scale starch factories to improve the quality and yield of starch;

(b) reduce the adverse effects on the environment attributable to process effluents by reducing their volume and the overall level of pollutants.

8. A process audit of a sago factory at Salem in India was carried out in January and February 1993 by NRI and CTCRI (Trim & Curran 1993). From this study it was recommended that research should be conducted to reduce the volume of fresh water used in the processing operations. Reduction of water consumption would also decrease the volume of effluent produced. Previous laboratory research by NRI on the use of a hydrocyclone to concentrate starch suspensions had provided extremely promising results. The objective of this visit was to evaluate a hydrocyclone under factory conditions; the terms of reference were as above (Para.1).

Starch and Sago Production in India

9. As previously reported by Trim (1989), the majority of cassava starch and sago production in India is centred around Salem in Tamil Nadu. In addition to being an area of traditional cultivation of roots, the development of the starch industry in Salem is facilitated by the local climate, long dry seasons with high temperatures and low humidities, enabling rapid drying in the sun of the starch and sago. Starch is also produced in northern Kerala and there are a number of sago factories in Andhra Pradesh. With the exception of 3-4 large scale factories that employ modern processing technology (none of which are in Salem) all cassava starch is produced in small - medium-scale factories, typically processing 10-50 tonnes/day of roots. All sago production is by small - medium-scale factories with many producing both starch and sago as finished products.

10. There are no comprehensive data on the number of starch and sago factories operating in and around Salem although it is estimated that there may be as many as 850-1000 (Trim & Curran 1993). Similarly there are no accurate data on the combined production of starch and sago in the area but this is estimated as in the order of 280,000-300,000 tonnes/year.

11. The production of starch in Salem is seasonal and dependent on the availability of fresh roots. Production is concentrated in the period from late September until March. For the first 6-10 weeks of the season, roots are transported to the factories by truck from northern Kerala. These roots are cultivated in rain-fed plots producing yields of 15-20 tonne/hectare for traditional varieties and 25-30 tonnes/hectare for improved varieties (Gupta 1989). Local supplies of roots are utilized from November to March of which 70% is the improved cultivar, H226, grown on irrigated land and yielding 30-40 tonnes/hectare. Local varieties, such as Burma, grown on rain-fed land provide yields of 15-20 tonnes/hectare.

12. Sago produced from extracted starch is manufactured over a longer period, from September until May/June. The length of the season is dependent on the capacity of factories to store wet starch for subsequent processing after starch extraction has ceased. The monsoon in early June restricts sun drying and curtails the season. The period from June to September is used for plant maintenance and repairs.

Starch Production Technology

13. A flowsheet of the processing operations generally employed in factories for the production of starch as the marketable product is shown as Figure 1. A more detailed account of processing operations for both starch and sago production has been given by Trim & Curran (1993).

14. Roots are received at the factory in truck loads in the late afternoon or evening having been harvested earlier in the day. They are washed before crushing the following day to remove adhering dirt, either in a tank of water or in a continuous spray washer.
15. The roots are fed to the crusher either manually from wash tanks or by conveyor from the spray washer. Water is continuously fed to the crusher and the resultant slurry of disintegrated roots falls into a sump tank. Additional water is added to the tank from which the diluted slurry is pumped to a series of reciprocating screens.

16. The starch milk is separated from the fibrous pulp residue (*thippi*) as the slurry passes over the screens. The number of screens employed and the path of the slurry from screen to screen varies from factory to factory. The more sieving passes employed the higher the purity (starch concentration) of the product.

17. Often pulp from the initial sieving is returned to a secondary crusher for further extraction of starch. More water is added to the slurry from the crusher and this is pumped to a second reciprocating screen.

18. Starch milk from the first two screens is pumped through a third and at some factories a fourth screen of diminishing mesh sizes. The screened milk then flows either to settling tanks or settling tables and the waste fibrous pulp from the third (and fourth screens) is channelled to a storage pit.

19. Settling tanks are operated batch-wise. Starch milk is directed into a tank, and when it is filled directed into a second, and so on. Tanks are filled during the day and the starch is allowed to settle overnight.

20. Settling tables are operated semi-continuously. Milk enters at one end of a long and shallow tank and is discharged at the other end over a weir extending the full width of the table. Compaction of the starch at the bottom of the table is facilitated by labourers walking up and down the table.

21. After settling, the remaining supernatent liquor is drained off via discharge ports in the tables and tanks. In most cases, the liquor is discharged direct to nearby watercourses or to tanks for use for irrigation of nearby land. The uppermost layers of the settled bed of starch, containing relatively high concentrations of protein, ash and fibre concentrations, are scooped and hosed off the bed and pumped to tanks for subsequent recovery of the starch as a secondary product of inferior quality which is sold for animal feed.

22. Depending on the purity required the starch remaining in the settling tanks may be washed by re-suspending in water. The starch is re-settled and the

supernatent liquor drained away. The starch cake is then swept of surface liquor and dug out of the tables and taken to large concrete drying floors in baskets.

23. The drying starch is agitated at intervals using rakes. When dry the starch is gathered into heaps and taken in baskets to the packaging shed. The starch is ground to a powder and then bagged for sale.

24. The sieved pulp remains in the storage pit until dug out for drying in the sun usually at the end of the season. The storage pit is generally constructed of stone walls with a base of loose bricks covered by a screen of bamboo slats. Free water from the waste pulp thereby leaches into the soil underneath the pit.

Sago Production Technology

25. A flow sheet of the operations used for sago production is shown as Figure 2.

26. Upon arrival at factories, batches of roots destined for sago production are manually sorted with small and damaged roots separated for subsequent use for starch production. The roots selected for sago production are manually peeled and the roots are then loaded into soaking tanks to keep them moist.

27. The peeled roots are scooped out of the water tank in baskets and loaded on a conveyor, from which they pass through an overhead spray washer and into the primary rasper. The washing, crushing and sieving operations are very similar to those employed for starch production described previously, except that in most factories a fifth screen is used for final sieving of the starch milk.

28. Either settling tanks or settling tables are used to de-water the starch milk as described above. Generally the settled starch is washed at least once before final settling and compaction of the starch cake.

29. The cake is removed from the washing tank and taken to the sago preparation shed. The lumps of cake are first broken up in a spike mill to produce a fine powder free of agglomerated lumps. The starch powder is then fed into a globulator, a device in which the starch is agglomerated into spherical beads.

30. The agglomerated beads are scooped out of the globulator in baskets and fed to a grader for the removal of both under-sized and over-sized fractions. The former are returned to the globulator and the latter to the spike mill. The beads are then roasted on heated flat metal plates and stored overnight.

31. Early the next morning the sago is taken to large concrete sun drying yards. The dried sago is swept up

and loaded into baskets and taken to the polishing and packaging shed. It is fed into a rotary polisher which produces singular polished beads. These are graded over a reciprocating sifter and bagged for sale.

32. At periods during the peak season most factories are unable to process all the starch extracted into sago due to insufficient sago preparation or drying capacity. Surplus wet starch is kept in storage tanks covered with water. The surplus starch remains in the tanks until sago preparation and drying capacity is available at the end of the season when it is then dug out, washed with water, re-settled and processed as for fresh starch.

Hydrocyclones

33. A hydrocyclone consists of a cone shaped body, usually made of plastic, into which the feed slurry or suspension is fed tangentially to the top of the cone under pressure around a central opening called the vortex finder. The motion of the liquid fed into the cyclone develops high centrifugal forces creating a primary vortex adjacent to the cone wall into which the suspended particles migrate and are forced downwards to the discharge point via a spigot. A secondary upward moving vortex is developed along the central axis of the hydrocyclone in which fine material discharges with the majority of water.

34. Hydrocyclones divide a fluid stream into two output streams, the underflow containing the majority of the solid particles and the overflow of comparatively low solids concentration. Larger particles are concentrated into the underflow as a result of centrifugal action.

35. In cassava starch extraction as described above, it was considered that the volume of water required for crushing and sieving could be considerably reduced if the starch milk flowing from the sieving system were passed through a hydrocyclone. The underflow containing the bulk of the starch particles would be ducted to the settling tanks and the overflow of relatively low starch concentration re-cycled to the crushing and sieving plant replacing fresh water.

36. Water conservation by re-cycling the supernatent liquor from the settling tanks has been attempted previously (Trim & Curran 1993) but the souring of the liquor caused by microbiological activity over the 12-18 hour settling period adversely affected the colour and odour of the sago. Re-cycling of the overflow from the hydrocyclone would not incur this problem since the contact time between starch and the associated water would not be lengthened.

37. The use of hydrocyclones in the starch industry is not new, particularly in the corn starch industry and, to some extent, the potato starch industry, however they are

generally only utilized for the final refining and washing stages (Verberne 1977: Van Esch 1991).

WORK PROGRAMME

38. The work programme was conducted and arranged in collaboration with the Central Tuber Crops Research Institute (CTCRI), Thiruvananthapuran (formally Trivandrum) in Kerala and SAGOSERVE, Salem. The itinerary for the visit is shown in Appendix 1. Time spent at Salem was unavoidably foreshortened due to an industrial dispute at Bombay airport delaying the delivery of the hydrocyclone unit; this together with the starch production season ending earlier than usual due to unusual weather meant that evaluation of the unit at a starch factory (Para.1) was not possible.

39. The hydrocylone unit was evaluated at the sago factory where the process audit had been conducted in 1993. The unit, consisting of a pre-assembled cluster of eight 50 mm diameter hydrocyclones (purchased from a leading manufacturer, Richard Mozley Ltd.), pump and associated pipework and valves was designed to process a major proportion of the starch milk produced under normal operation. A range of vortex finders and spigots (upper and lower discharge ports for the hydrocyclone) were also purchased enabling selection of different performance characteristics in terms of total volumetric throughput, volume splits and solid recoveries[1]. There was also provision to blank some of the hydrocyclones to enable the unit to be run at a reduced volumetric throughput.

40. The unit was positioned adjacent to the sieving plant receiving feed from the starch milk flowing from the screens to the settling tanks. The pipework was installed to direct the underflow into isolated settling tanks and for the overflow to be re-cycled to the primary and secondary crushers. A centrifugal pump was purchased in Salem to power the unit. The unit was generally operated according to the manufacturers recommendations, although it was found in practice that the the unit was best operated at a slightly reduced operating pressure than that recommended (50 psi).

41. Following completion of the installation, commissioning trials were conducted at a reduced capacity to determine the performance using selected vortex finders and spigots in order to compare results with those obtained in the laboratory. During these trials the overflow and underflow from the unit were allowed to flow directly to the settling tanks. Samples of these

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1. Volume split is the term used to denote the volumetric proportion of the feed stream in the overflow and underflow respectively, and solids recovery is the ratio of the solids present in the feed stream recovered in the underflow.

streams were collected to determine the performance characteristics for the selected configurations.

42. Based on the results of the initial trials and experience in operation of the unit further trials were completed with the unit set up as an integral part of the production process. In these latter trials, each lasting several hours, the overflow was re-cycled to replace the fresh water supplied to the two crushers in normal operation. The underflow was directed into an empty settling tank. Surplus starch milk was allowed to bypass the unit and was directed into a second settling tank.

43. Samples from the feed stream, underflow and overflow of the hydrocyclone were collected simultaneously and the flowrates of the three streams recorded. The samples were weighed and them allowed to settle overnight, after which the supernatent liquid was decanted and the wet starch dried in an oven at 50°C until a constant weight was recorded.

44. Samples of settled starch, washed starch and sago produced (a) under normal operating conditions and (b) with the hydrocyclone installation in place, were collected for laboratory analysis and comparison of starch content and colour.

45. Similarly, effluent samples produced were collected and forwarded to the Tamil Nadu Pollution Control Board (TNPCB) for determination and comparison of their pollution potential. The samples were anlysed for: biological oxygen demand (BOD); chemical oxygen demand (COD); suspended solids (SS); dissolved solids (DS) and pH.

RESULTS AND DISCUSSION

Hydrodynamic Perfomance of Hydrocyclone

46. The performance of the hydrocyclone can be measured in many ways depending on the functional requirements of the process. For this application, it is required primarily to optimise the maximal starch recovery in the underflow with minimal volume split in the underflow.

47. The results in Table 1 show the performance characteristics in terms of the volume split of the feed stream and solids recovery in the underflow for selected hydrocyclone configurations obtained from the commissioning trials at the factory compared to laboratory results. These indicate that the starch recoveries were greater in the factory trials (91-93%) than in the laboratory (84-85%) for similar underflow volume splits of 46% at the advised operating pressure of 50 psi and with feed concentrations 4-6%(db) solids. These results perhaps indicate that the particle size of starch extracted at the factory was in a slightly larger

range. This could be validated by analysis of particle size distribution of the feed starch used in laboratory trials and the extracted starch samples from the factory.

48. Table 2 shows the performance characteristics for the selected configuration (8mm diameter vortex finder and 6.4mm diameter spigot) at slightly lower operating pressures. The results show that the starch recoveries were of a similar order (91-95%), but the underflow volume split increased with reduced operating pressure, for example 38% at 40 psi. In operating terms, this implies that whilst the starch recovery can be maintained above 90%, there is scope to reduce the operating pressure of the unit to decrease the underflow volume split. The lower the underflow volume split the greater the overflow volume split and the greater the volume of overflow available for re-cycling. Reduced operating pressure would also permit the use of a pump with a lower motor rating and hence reduced power costs.

49. Table 3 shows data relating to flowrates and solids concentrations of the feed, underflow and overflow streams during the subsequent integrated trials. The selected hydrocyclone configuration operated with a mean volumetric throughput of 4.3 l/s of starch milk (Table 3); approximately 62% of the total starch milk flowrate (6.7-7.1 l/s) from the washing and screening stages recorded under normal operation. The data show that the hydrocyclone effectively concentrated the (feed) starch milk by a factor of more than two; from 4.1-5.8% solids in the feed to 9.0-13.5% solids in the underflow. The solids concentration in the overflow was less than 1% (0.4-0.8%).

50. From the data in Tables 2 and 3, it can be seen that the overflow was 60% of the feed stream which was re-cycled to the crushers with an equivalent reduction in fresh water. This was achieved in the integrated trials at a throughput of approximately 4.25 l/s (62% of the total flow of starch milk) using 8 mm diameter vortex finders and 6.4 diameter spigots. However, laboratory trials had showed that a 50% greater throughput could be achieved with an 11 mm diameter vortex finder and a 9.4 mm diameter spigot with comparable underflow volume split and solids recovery. The eight hydrocyclone cluster configuration with larger vortex finders and spigots would therefore be able to handle virtually all the starch milk produced under normal conditions with a reduction in water consumption of 55-60%.

51. Data obtained in the 1993 process audit show that the water used in crushing and sieving (including starch extraction from small and damaged roots) accounts for 75% of total water consumption in sago manufacture. The installation of a hydrocyclone unit capable of handling all the starch milk would reduce total water consumption in sago production by 40-45%.

Waste Water Characteristics

52. The results obtained from analysis of the waste waters are presented in Table 4. It was expected that use of hydrocyclones would have little effect on the pollution load (kg/BOD) and therefore the concentration of pollutants in the reduced volume of waste waters discharged from the (primary) settling tanks would be considerably higher than those in the waste waters produced under normal operation. However, this was not found: analysis of the waste waters showed little significant difference in the characteristics of the waste waters produced both under normal operation and when the hydrocyclone unit was operated. The BOD of the waste waters when the unit was used were around 7,200 mg/l compared with approximately 8,400 mg/l for normal factory operation. The COD figures were around 11,500 mg/l and 12,800 mg/l, dissolved solids 6,500 mg/l and 5,700 mg/l, and suspended solids 5,100 mg/l and 7,000 mg/l respectively. These results imply that with use of the hydrocyclone unit, the materials which contribute to the pollution load (mainly dissolved solids and small particles remaining in suspension) are abstracted elsewhere, possibly associated with the waste pulp or with the settled starch. However, as discussed below the composition and quality of the starch and resultant sago were not adversely affected when the unit was employed.

53. The implication of these results is that not only does the use of a hydrocylone reduce the quantity of water required for crushing and sieving, and therefore the volume of waste waters produced, but there is also a considerable reduction in the overall pollution load. This would have a major effect on the capacity and cost of effluent treatment plants now being considered for implementation by factories and local authorities such as the TNPCB.

Starch Purity and Colour

54. Table 5 shows the starch content of settled starch cakes (after overnight settling) and washed starch cakes produced when the hydrocyclone unit was operated and also under normal operating conditions. The data indicate that the settled cake was of slightly higher starch concentration when the unit was used, but there was no significant difference in composition in the washed cakes. It was noticeable that there was very little discoloured sludge which contain a relatively high level of impurities on top of the settled starch when using the hydrocyclone. This might be anticipated since the the smaller particles that would normally accumulate in the sludge would tend to be separated into the overflow stream from the hydrocyclone. However the smaller particles would then be re-cycled and would accumulate within the system; this was not observed from samples taken of the overflow. A possible explanation might be that the small particles become associated in some way

with the fibrous pulp; if so this may explain in part the low level of pollutants in the waste waters (Para.44). Although the starch concentrations of the waste pulp (Table 5) were slightly higher than those recorded during the process audit carried out in 1993 (Trim & Curran 1993), rinsing the pulp did not releses any free starch in the rinse waters.

55. Colour measurements on starch samples are presented in Table 6. These show that there is little difference in the whiteness values (L^*) of the samples of settled and washed starch produced when using the hydrocyclone unit. These were in the range 98.59-98.63 for dry settled starch (93.44-93.51 when wet) and 98.61-98.78 for dry washed starch (93.80-93.89 when wet). There was a slight but noticeable difference in the whiteness of samples obtained under normal operating conditions, particularly when wet; measured in the ranges 97.47-97.60 for dry settled starch (89.74-89.94 when wet) and 98.26-98.38 for dry washed starch (93.32-93.54 when wet). This would strengthen the hypotheses mooted above (Para. 46) of a higher level of impurities in the settled starch obtained under normal operating conditions.

56. The factory owner was of the opinion that the settled starch cake produced when using the hydrocyclone unit was much "brighter" and "cleaner" and considered that it may be possible to produce sago directly from the settled starch without further washing which is the normal practice. Emanating from someone with a lifetimes experience of starch and sago manufacture, this viewpoint is of great significance. Eliminating the washing operation would lead to appreciable reduction in processing time, further decrease in water consumption, and waste water production, and a saving in labour.

Sago Quality

57. The quality and hence market price of sago is primarily determined by its colour and appearance, especially its "whiteness". The result of colour analysis of the both unpolished and polished sago manufactured from starch produced using the hydrocyclone unit and also of sago produced from starch made under normal conditions are given in Table 7.

50. The data indicate that there is a slight improvement in the overall colour in terms of its whiteness values (L^*) for sago produced from the extracted starch when the hydrocyclone unit was in use. These were measured in the range 86.38 - 86.71 for polished sago produced when the hydrocyclone was operated compared to the values in the range 84.18-84.30 for polished sago produced under normal operation.

58. These results would tend to confirm the indications of improved colour of the starch due to operation of the hydrocyclone unit (Para.44). The implications of

improved whiteness of the polished sago are that it could command a higher price. This would need to be evaluated in the starch and sago auctions at SAGOSERVE.

Local Reaction

59. Starch and sago producers are very aware of the problems associated with cassava starch extraction in terms of the environmental impact of disposing of heavily polluted waste waters (Trim & Curran 1993). The supply and quality of water is also a major problem to producers in the region. The owner of the factory where the trials were conducted was impressed with the ease of operation of the hydrocyclone and the indicated benefits and was making enquiries about purchase. Considerable interest was also expressed by other producers and the subject is a major discussion point within the industry

60. During the visit talks were held with Mr S Mukerjee of Tega Industries Ltd., in Calcutta, who are the appointed agent for Richard Mozley Ltd. the manufacturers of the hydrocylone. He reported that there has been several enquiries from starch producers about the use of hydrocyclones in their industry, but as their performance and use is unknown in India producers have been unable to take the matter further. A carefully designed dissemination programme would address this situation.

FUTURE ACTION

61. The trials have shown emphatically that incorporation of a hydrocyclone unit in a sago factory could:

(a) reduce the fresh water required for root crushing and starch milk sieving by up to 60%;

(b) reduce the volume of waste water and the pollution load from the factory by approximately 50%;

(c) possibly improve the quality and value of the sago produced and reduce the need for further washing of the starch.

62. Based on these results and on the considerable interest generated within the industry and associated authorities, it is recommended that action should be taken to install a full-sized hydrocyclone unit at a factory in Salem and monitor its performance over a full processing season. In order to do this, the active collaboration of a hydrocyclone manufacturer would be extremely beneficial and steps should be taken to identify and secure this cooperation. The continued assistance and support of SAGOSERVE and the TNPCB would also be required.

63. It is also recommended that the implications for introducing the technology into the industrial sector are assessed at the macro level, both in terms of the wider economic nad environmental aspects. Further, NRI should collaborate with the TNPCB on the development of stategies for introduction of the hydrocyclone technology and its wuder dissemination across the industrial sector, assuming favourable results are achieevd from the later trials. The continued assistance and support of SAGOSERVE and the TNPCB would be necessary.

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TABLE 1: HYDROCYCLONE PERFORMANCE IN LABORATORY AND COMMISSIONING TRIALS

Vortex finder diameter mm	Spigot diameter mm	Under-flow split %	Solid recovery %
Laboratory Trial			
8.0	6.4	47	85
11.0	9.4	46	84
Factory Commissioning Trials			
8.0	6.4	46	91
11.0	9.4	46	93

Operating pressure 50 psi

TABLE 2: HYDROCYCLONE PERFORMANCE IN FACTORY INTEGRATED TRIALS

Trial	Operating pressure psi	Under-volume split %	Solid recovery %
FT1	47	42	95
FT2	44	40	93
FT3	40	38	91

Vortex finder diameter 8.0 mm
Spigot diameter 6.4 mm

TABLE 3: HYDROCYCLONE FLOWRATES AND SOLIDS CONCENTRATIONS IN FACTORY INTEGRATED TRIALS

Trial	Flowrate l/s			Solids Conc % (w/w)		
	Feed	OF	UF	Feed	OF	UF
FT1	4.33	2.55	1.78	5.2	0.5	12.3
FT2	4.23	2.53	1.69	5.8	0.8	13.5
FT3	4.27	2.63	1.64	4.1	0.4	9.0

UF = Underflow
OF = Overflow

TABLE 4: COMPOSITION OF WASTE WATERS FROM PRIMARY SETTLING TANKS

Sample	pH	BOD mg/l	COD mg/l	DS mg/l	SS mg/l
Hydrocyclone in use					
FT1	3.92	8,085	12,624	6,800	5,542
FT2	3.93	6,180	10,349	6,135	4,599
Normal operation					
C1	3.91	8,650	12,074	5,044	6,143
C2	3.90	8,250	13,798	6,430	7,897

BOD Biological oxygen demand
COD Chemical oxygen demand
DS Dissolved solids
SS Suspended solids

TABLE 5: STARCH CONTENT OF SETTLED AND WASHED STARCH CAKES AND PULP

Sample	Total Starch Content %(db)		
	Settled Cake	Washed Cake	Waste Pulp
Hydrocyclone in use			
FT1	96.80	96.90	78.93
FT2	96.34	96.53	77.78
FT3	95.72	95.47	76.42
Normal Operation			
C1	95.60	96.49	75.56
C2	94.95	95.46	73.93

TABLE 6: COLOUR MEASUREMENTS OF STARCHS

Sample	L^*		a^*		b^*	
	Dry	Wet	Dry	Wet	Dry	Wet
Settled Starch						
Hydro-cyclone in use	98.59	93.44	-0.15	-0.76	+1.35	+5.38
	98.61	93.51	-0.17	-0.82	+1.35	+5.29
	98.63	93.44	-0.16	-0.83	+1.36	+5.27
Normal operation	97.60	89.74	-0.09	-0.30	+1.55	+4.49
	97.47	89.76	-0.10	-0.35	+1.65	+4.61
	97.59	89.94	-0.12	-0.40	+1.59	+4.76
Washed Starch						
Hydro-cyclone in use	98.78	93.89	-0.04	-0.40	+0.95	+0.92
	98.73	93.83	-0.07	-0.42	+1.02	+0.15
	98.61	93.80	-0.07	-0.40	+0.99	+0.98
Normal operation	98.26	93.32	-0.10	-0.40	+0.91	-0.30
	98.38	93.52	-0.11	-0.38	+0.89	-0.35
	98.45	93.54	-0.09	-0.38	+0.88	-0.40

Measurements were made using a Minolta Chroma Meter CR310 (Minolta Camera Co. Ltd., Osaka, Japan). Results are given in the $L^*a^*b^*$ colour space system (Commision International l'Eclairage, CIE, 1976).

TABLE 7: COLOUR MEASUREMENTS OF SAGO

Sample	L^*	a^*	b^*
Unpolished sago			
Hydro-cyclone in use	80.94 82.00 83.22	+0.29 +0.27 +0.30	+5.89 +5.96 +5.76
Normal operation	80.86 80.93 79.94	+0.14 +0.19 +0.01	+6.38 +6.74 +6.64
Polished sago			
Hydro-cyclone in use	86.71 86.41 86.38	+0.02 -0.09 -0.10	+5.96 +6.25 +5.84
Normal operation	84.20 84.34 84.18	+0.04 +0.06 +0.06	+6.80 +6.73 +7.11

Measurements were made using a Minolta Chroma Meter CR310 (Minolta Camera Co. Ltd., Osaka, Japan). Results are given in the $L^*a^*b^*$ colour space system (Commision International l'Eclairage, CIE, 1976).

FIGURE 1: SCHEMATIC OF STARCH MANUFACTURE

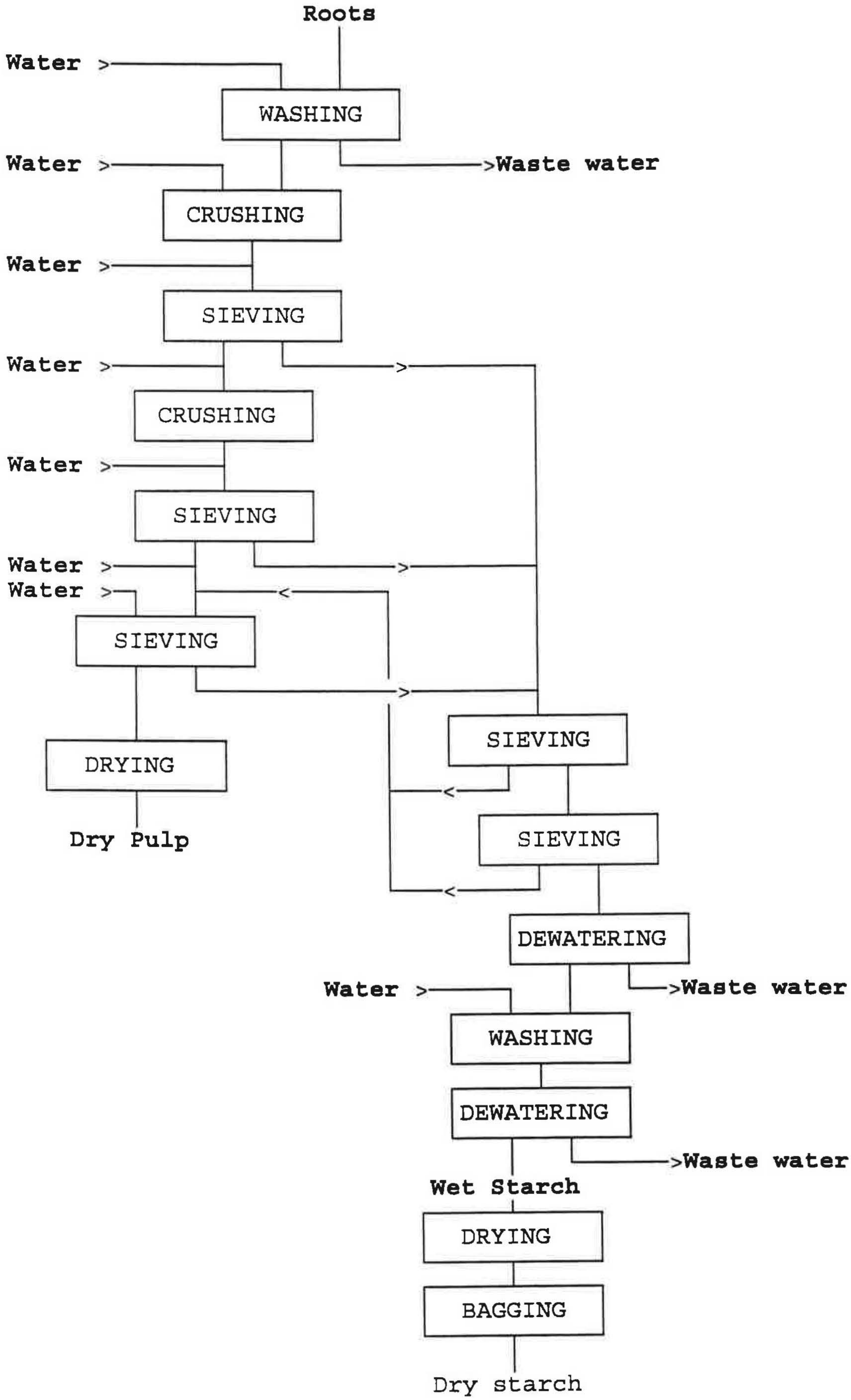
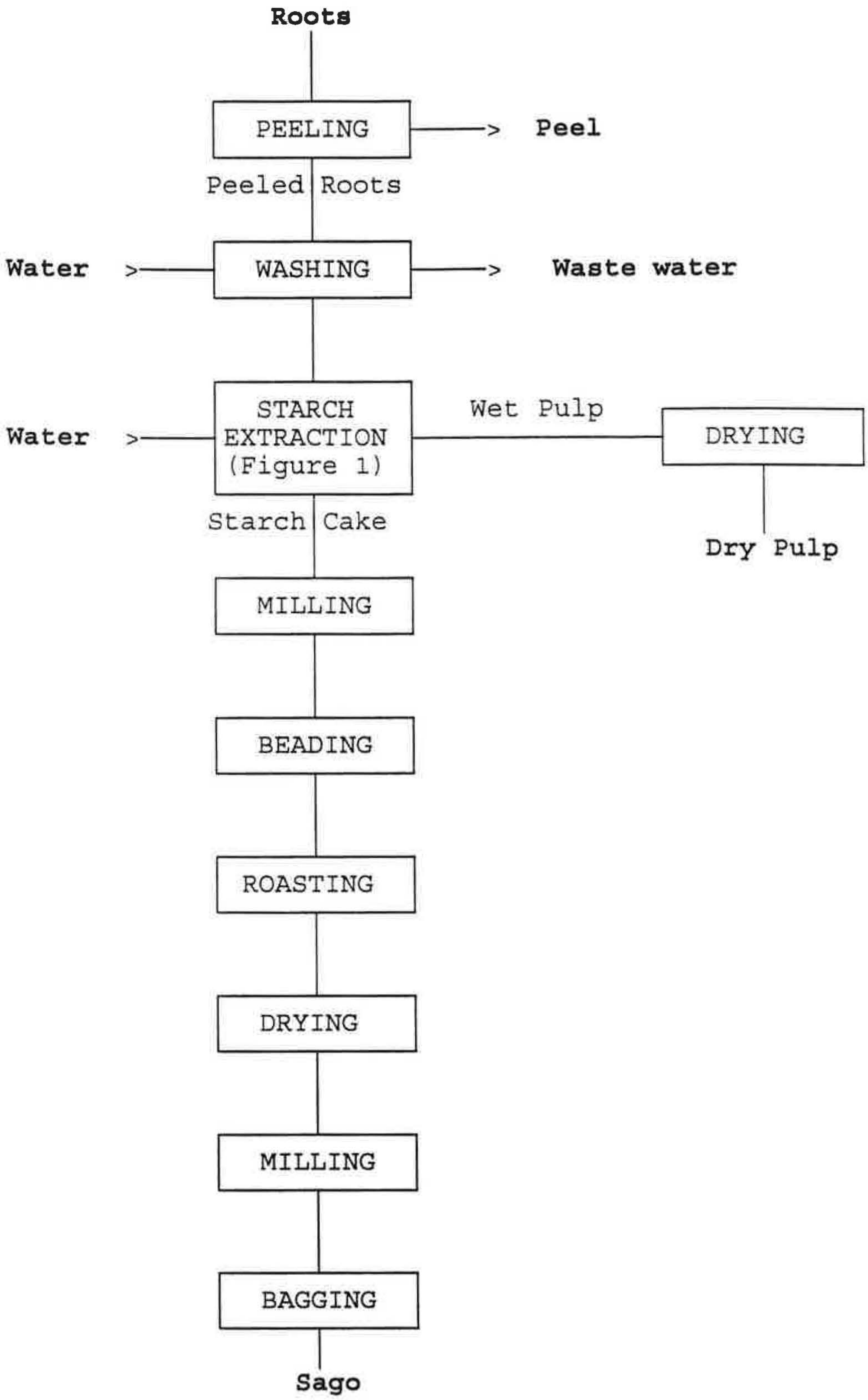


FIGURE 2: SCHEMATIC OF SAGO MANUFACTURE



APPENDIX 1: VISIT ITINERARY

8 December - 9 December	London - Bombay - Thiruvananthapuran
10 December - 20 December	Meetings with CTCRI Construction of equipment
20 December- 2 January	Christmas leave
3 January	Thiruvananthapuran - Salem
4 January - 8 January	Installation of equipment
9 January - 15 January	Commissioning trials
16 January - 26 January	Integrated trials
27 January	Meetings with SAGOSERVE and producers
30 January	Salem - Thiruvananthapuran
1 February - 3 February	Meetings with CTCRI
3 February - 4 February	Thiruvananthapuran - Bombay - London

APPENDIX 2: PERSONS MET

Dr G T Kurup	Central Tuber Crops Research Institute
Dr C Balagopalan	Sreekariyam
Dr S N Moorthy	Thiruvananthapuran 695017
Dr S K Nanda	Kerala
Dr V Shegaonkar	Sagoserve Omalur Main Rd Salem 636302 Tamil Nadu
Dr G S Thangaraj	Tamil Nadu Pollution Control Board Siva Tower 1/276 Meyyanur Main Road Salem 636004 Tamil Nadu
Mr S Palaniswamy	Velmurugan Traders Nethimedu Salem 636002 Tamil Nadu