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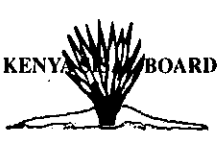
COMMON FUND FOR COMMODITIES
Project CFC/FIGHF/07

Product and market development of sisal and henequen

Production of Sisal Fibre and Pulp for Market Trials

Project completion report/Addendum C.2

Kenya and Tanzania, January 1997–June 2004



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Project completion report, Addendum C.2

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna, 2006

Project Completion Report preparation: National and international experts and consultants involved with the project, with contributions and support from the national teams.
General guidance and consolidation: Ms. Mayra. Sanchez Osuna, Project Manager. The opinions, figures and estimates reflected in the Report and its Addenda are the responsibility of the authors and should not be necessarily be considered as reflecting the views or carrying the endorsement of the CFC or UNIDO.
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Project Completion Report

Sub-component C.2
"Production of Sisal Fibre and Pulp for Market Trials"

CONTENT

Abbreviations and acronyms

AD	Air Dried
AQ	Anthraquinone
CEH	Chlorine (C), Alkaline Extraction (E), Hypochlorite (H)
CFC	Common Fund for Commodities
DIN	Deutsche Industrie Norm (German Industrial Norm)
ECF	Elemental Chlorine Free
ISO	International Standards Organization
m^3	Cubic metre(s)
MT	Metric tonne(s)
PCC	Project Coordinating Committee
TATC	Tanzania Automotive Technology Center
TCF	Totally Chlorine Free
TOR	Terms of Reference
UNIDO	United Nations Industrial Development Organization

I. Project Sub-component Summary

1. Title: Production of Sisal Fibre and Pulp for Market trials

2. Location: Kenya: Vipingo Estate; Tanzania: Kwaraguru Estate, Hale Estate

3. Starting Date: January 1997

4. Completion Date: June 2004

5. Financing

Total subcomponent cost:	U$ 91,309
Of which:	
CFC Financing:	U$ 54,772
UNIDO:	U$ 36,537

II. Background and context in which the sub-component was conceived

II.1 Background and context

Sub-component C.2 was conceived as the link between sub-component C.1 and D.1. In sub-component C.1 the possible fibre extraction technologies were evaluated and the quality of fibre and pulp extracted from the agricultural trials assessed. The aim of the C.2 activities was to produce enough fibre and pulp on the bases of the results achieved and the recommendations made in C.1. The fibre and the pulp were then to be used to provide samples to be sent to commercial mills to perform the market trials foreseen as part of sub-component D.1.

The hammer mill proved to extract sisal fibre efficiently and in order to obtain feedback from the pulp and paper market, samples of sisal fibre and pulp were produced and then dispatched to interested mills. The market study conducted indicated that a total of 45 mills in specialty business would be interested in receiving samples of sisal fiber and pulp between 1 kg and 25 kg totaling 120 kg. A total of 29 mills in reinforcement pulp indicated interest in samples but did not indicate the quantities required. Further contacts will be made to establish their requirements and to reconfirm the amounts requested, but it can be estimated that about 300 kg of fiber and 120 kg of pulp will be sent to the mills.

In order to have a significant example of the quality of the fiber extracted by the hammer mill and therefore allow for a full load test of the fiber extraction equipment about 3.3 metric tonnes (MT) of dry fibre were produced. The source of raw material for pilot pulp production was the CEPS-II plantation at Hale (about 1750 plants from CEPS-II a) and about 1750 plants from CEPS-II b). Pulping was done in the industrial digester of Kibo Match pulp mill (Moshi).

In addition, part of the pulp produced was bleached, on a laboratory scale, in order to make available relevant information on the quality achievable and on the bleaching sequence most suitable for sisal pulp. The results of the bleaching tests were also made available to interested mills as part of the market trials. The original idea was to run a paper machine and produce paper samples. This was not possible with the available resources, and no commercial mill showed interest in pulping and producing paper from the project sisal fibre at its facilities. It was concluded that laboratory trials would have provided a clear indication of the pulp quality that could be obtained from sisal.

In order to allow the production of the planned quantity of fibre, additional field works and modifications to the hammer mill had to be completed:

- Construction of a chip pad, of a fibre receiving-end, and of a drying area;
- Sisal chips feeding system;
- Washing system, including the required civil works.

II.2 Objectives, outputs and targeted beneficiaries

The main objectives of this sub-component were:

- to produce cost-effectively quantities of sisal fiber and of pulp to be used as samples in the market trials;
- to perform laboratory bleaching trials.

The expected output included:

- a report on the activities performed and fibre and pulp available for market and laboratory trials.

The targeted beneficiaries were the various stakeholders involved in sisal and in particular:

- estates involved in sisal growing and processing leaves into fibre, including smallholders;
- pulp and paper mills using sisal fibre.

III. Implementation and results achieved

III.1 Preliminary activities

As mentioned, a few preliminary activities were implemented to pave the way for the extraction and pulping of sisal fibre on an industrial scale. These activities are described in the sections below.

III.1.1 Sisal chips feeding system

Feeding the hammer mill conveyor was initially to be done manually from chip stacks stored near the hammer mill. After the load tests were undertaken on the hammer mill it was realized that manual feeding was cumbersome, labor intensive and reduced mill efficiency to 20% capacity.

Resulting from this, a new design for the feed system had to be developed. The new design envisaged chipping at the mill site with leaves transported from the field to the mill site on modified estate trailers. The leaf would then be fed into the chippers at the mill site and the chippers would feed a modified 3-tonnes silage trailer imported from Brazil. This trailer had a chute for discharging and could be used to feed the hammer mill feed conveyor; its capacity in terms of weight is two tonnes.

The trailer was equipped with a motor and the possible discharge rate was of 25.6 tonnes/hour, this was then adjusted to the maximum capacity of the hammer mill (12 tonnes/hour). The trailer chute was improved and the feeding height optimized.

The major limitation in terms of feeding the hammer mill continuously were the two chippers, as the highest workable feeding rate of each of them was found to be 2.4 tonnes/hour. The trailer effective volume is 3.6 m^3, it can hold 1.6 tonnes of fresh chips (considering a sisal chip density of 0.45 tonnes/m^3). The trailer was filled for 20 minutes by the two chippers and then discharged in 10 minutes at 10 tonnes/hour, if the chippers were stopped, and in 15 minutes if the chippers were kept in operation.

III.1.2 Washing system

The need for a fibre washing system resulted from the requirement to improve the quality of sisal fibre produced by the hammer mill by reducing the levels of parenchyma to acceptable values. The process of mechanically removing trapped parenchyma from sisal fibre produced by the mill was tried following different approaches (these are described in the Addendum C.1, section III.7 Selection of Fibre Extraction Technology). Nevertheless, washing was found necessary. Initially it was handled manually in big washing tanks, but that proved unfeasible and ineffective for washing the quantities of fibre required for the purposes of the sub-component C.2. As a result, a washing system was designed for washing and cleaning of processed fibre extracted by the hammer mill. The concept of sisal fibre washing by using the water trough system has been developed by imitation of the manual washing system used at Hale Estate.

The design, manufacture and testing of the washing system, as well as training activities were contracted to the Tanzania Automotive Technology Centre (TATC) in November 2003.

The installed hammer mill production capacity is 12 tonnes of sisal chips per hour. The operational capacity has however, been limited to about 10 tonnes per hour. The fibre extraction process through the hammer mill produces about 45% (approximately 4.3 tonnes per hour) of wet fibre by weight of fresh charged sisal chips. Separation of sisal fibre and parenchyma from the mill was achieved by one pass through the hammer mill with a result of about 33% parenchyma content by weight. Further cleaning is possible by a second milling process, but the remaining parenchyma attached to the fibre has to be removed by washing. Both parenchyma and sisal fibre are insoluble in water, but parenchyma is denser than water and this makes separation possible by using a water bath system that allows parenchyma to settle at the base of a sedimentation tank. Operation through the hammer mill may also leave some parenchyma still weakly bonded to the fibre. This calls for forced removal by the use of high-pressure water jets to dislodge the sticky parenchyma.

The washed fibre collects a lot of water, which drips while sending the fibre to the drying yard. To avoid this situation two water-dripping benches were manufactured for drainage of water prior to drying. The benches overall dimensions measure; 4060 mm in length, 565 mm in width and 1000 mm in height. The two units have an overall weight of 170 Kg.

The system comprises a high pressure water jet system for dislodging trapped parenchyma from the fibre matrix and a deep water bath system for conveyance of fibre to the dripping benches. Dislodged parenchyma is allowed to settle at the bottom of the sedimentation tanks for disposal. Fibre is removed at the end of the washing trough in the water-dripping benches and then moved to the air-drying yard.

The water jet system was divided into two sub systems:

1. Motor-pump system: to supply water to the fibre-washing unit and in particular to:
   1.1. Supply water under high pressure to the water jet system which hits the incoming fibre from the hammer mill for the purpose of dislodging trapped parenchyma in the sisal fibre web;
   1.2. Supply water to the conveyor basin for deep-water bath washing. The process is arranged to be immediately after the high pressure water jet system;
   1.3. Supply water to the hammer mill to facilitate ease of movement of sisal fibre through the mill chutes during the second pass sisal fibre processing;
   1.4. Supply water to the plant systems for cleaning purposes.

2. Plumbing system.

The deep-water bath system is a concrete tank equipped with a comb drive unit and with a screen assembly.

The comb drive unit consists of a 4-inch galvanized steel pipe and Ø16mm SAE 1030 steel rods welded to the pipe to form the comb-like unit. Each comb drive pipe is

welded with nine or ten steel rods and the system is supported at each end by Y-bearings. The system is composed of nine comb drive units, which perform the following main functions: (i) scramble the intertwined fibre for the purpose of removing trapped parenchyma which eventually settles down the water bath and is forced through the screen holes to the drainage system and (ii) move sisal fibre through the water bath from the mill discharge chute to the dripping benches prior to transportation to the drying yard.

The screen assembly consists of three, 2-mm thick stainless steel plates cut to size and anchored to the water bath concrete trough by stainless steel bolts. The screen is perforated by Ø 8 mm holes to form a sieve through which particles of parenchyma are forced for collection at the bottom of the sludge chambers.

There is also a drive system that consists of the 3-phase, 5-Hp electric motor, set of pulleys with power transmission V-belts, speed reducer gearbox and coupling which transmits power from the speed reducer gearbox to the galvanized steel pipe assembly.

All materials and parts for manufacture of the washing systems were sourced and purchased locally. All the parts were produced and assembled at the TATC workshops.

The concrete part of the washing system (foundation, concrete structure plus plumbing) was constructed by M.P. Investment Ltd.

III.1.2.1 Performance tests and optimization

The results of the manual sisal fibre washing approach were the production of relatively clean fibre with as low as 10% parenchyma contamination by weight. The remaining parenchyma adhered to the fibre matrix and could therefore not be separated by further washing. This result was considered to be adequate based on the adopted process; especially considering that the hammer-mill produced sisal fibre had high residue parenchyma content of about 33% before washing, with moisture content of about 70%.

It has also been concluded through these preliminary test results that commercial fibre with as low as 3% parenchyma contamination by weight cannot be extracted from the hammer mill by only one pass of production process and washing. The sticking parenchyma (10%) has to be reduced to an acceptable level by mechanical means.

Reprocessing fibre from the first pass through the hammer mill without water produces clean fibre with about 5% residual parenchyma, but the fibre appears greenish due to chlorophyll. Washing the fibre after the second pass turns the fibre white and reduces the parenchyma contamination to about 4.1%. Washing the fibre after first stage extraction, reprocessing and washing again after the second pass process produces the commercial grade fibre with residual parenchyma content as low as 3%.

Process optimization of the system after the preliminary tests aimed at minimizing the following critical shortfalls, which occurred during the concept design testing, and those obtained during manual washing:

- Intertwining of the fibre matrix, which caused the comb drive system to jam during the operation.
- Poor sedimentation of parenchyma for disposal, which made effective separation and cleaning of the fibre difficult.
- Lack of effective conveyance of fibre due to carrying over effect of the fibre by the comb drive fingers and high speed of operation.

After design optimization the system was tested for verification of function and performance. Tests were conducted after one pass of production and in two stages as follows; fibre production at the specified capacity in terms of reference of two tonnes per hour and at full plant production capacity of 4.3 tonnes per hour. Results of the tests were as follows:

a. Two tonnes of wet fibre per hour: fibre was easily conveyed from the mill discharge chute to the dripping benches without any problem. Fibre washing was adequately effective and Katani are currently working on the test results for data processing.

b. Full plant production capacity: washing of sisal fibre at 4.3 tonnes of wet fibre per hour was not very effective, as parenchyma was still bonded to the fibre matrix as they reached the dripping benches. The following problems occurred during the process:

(i) Accumulation of fibre at the end of the trough. This was a clear indication that the system was overloaded.

(ii) The hammering effect of the fibre/parenchyma mixture produced a lot of foam, which completely covered the trough making it difficult to proceed with the tests.

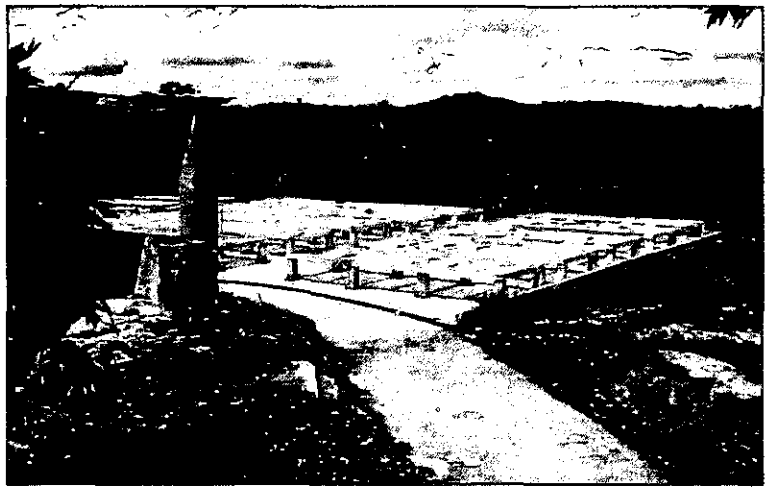
The following recommendations can be proposed:

- The required capacity of the washing system is suggested to be over five tonnes of wet fibre per hour, rather than the two tonnes. This capacity is adequate to handle the current system production capacity with one hammer mill estimated at 4.3 tonnes of wet fibre per hour. It is therefore recommended that the whole system from the trough to the driving systems be modified to meet the actual production capacity.
- The installed system is only useful as a means for function and performance verification of the unit. It is therefore recommended that thorough testing of the unit be conducted in order to arrive at conclusive recommendations on the specification requirements for the full capacity production washing system.

III.1.3 Drying yard

Sisal fibre contains some chlorophyll, which bleaches on fast drying and decolorizes when drying is delayed. It is therefore important that the fibre be dried as quickly as possible; drying should also be facilitated by circulation of air through the fibre. While there were no problems drying the relatively small quantities of fibre produced for the technology selection or for the pulping trials, drying larger quantities of fibre

and at the same time preserving its quality was a problem. To address that, a drying yard was built.



Drying yard and walkway by m. P. Investment ltd and dripping benches by katani ltd

The drying yard floor is 30 m long and 20 m wide (see Annex 1). All 15 benches are 2 m wide, but 10 of them are 6 m long and five are 12 m long. The dripping troughs are placed 0.65 m above the concrete floor, and supported by concrete columns. One main driveway 4.3 m wide and two feeder driveways 3 m wide have been provided for the fibre trailer. Fifteen walkways 1 m wide have been provided for the drying yard attendants to walk comfortably around all the troughs during drying and lifting of the fibre. The floor is provided with drainage outlets and the concrete floor has been provided with rubber strips to take care of concrete expansion.

The benches have trough frames made of hard wood of size 50 mm wide by 75 mm high. These were bolted on the concrete columns using anchor bolts and coffee wire fixed on the frame using wire nails. The frame was painted with black oil paint to resist degradation by water.

Effective drying area is 240 m^2, and has capacity to dry up to 250 kg fibre in 10 hrs depending on spreading density and weather. During the rainy season the fibre can take up to three days to dry. In case of full production operations of a complete fibre extraction plant it is recommended to dry fibre using a drier.

III.1.4 Civil construction activities

Despite the fact that the base of the hammer mill was newly prepared as part of C.1 activities, the surroundings were rugged and would not allow for continuous, major operations. Therefore the following was built:

- chip pad (side wall and sloping floor);
- fibre receiving-end (stair, slab, side wall plastering, retaining wall, cement layers);
- bridges on existing flume channels (outflow of the decorticator) to the drying area;
- concrete pads for the drying area and 150 concrete columns to hold the dripping benches;

- general building repair.

The contract was awarded to M.P. Investment Ltd., the company that submitted the lowest offer.

III.2 Production of fibre and pulp for market trials

The laboratory scale tests and trials conducted under sub-component C.1 indicated that commercial grade pulpable fibre can be produced using the hammer mill after chipping, chip feeding, making two passes in the hammer mill, fibre washing, drying and baling. In order to evaluate the quality of sisal fibre and pulp in relation to the world market, it was necessary to test the quality of the fibre and pulp produced by sending samples to interested mills and conducting bleaching trials on a laboratory scale.

The first market study undertaken by Sevenhuijsen Associates in 1999 identified a number of specialty mills and reinforcement mills interested in the fibre and pulp samples. Samples of fibre and pulp were sent to these mills (report of sub-component D.1).

III.2.1 Leaf chipping and feeding to the hammer mill

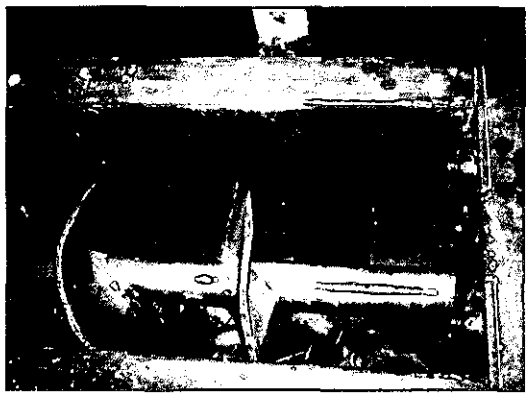
A total of 171.83 meters of sisal leaves were harvested manually from CEPS IIA (Hybrid 11648) bundled and transported to the hammer mill site (about 5 km away) using estate sisal trailers. The leaves were unloaded manually from the trailers to the leaf yard. The leaf bundles were offloaded in a way that the butt ends were in one direction to facilitate feeding to the chippers. The leaves were carried manually from the leaf yard to the chipping yard and piled with tip ends pointing in the direction of the chippers feeding.

The leaves bundles were lifted manually and placed on the chipper-receiving hopper, where they were fed to the chipper rollers. The feeding was such that the leaves overlap each other to have a continuous chipping. Two chippers were used with three operators each, two collecting leaf from the leaf trailers to the chipping yard and handing the leaves to the chipper operator who fed the leaves into the chipper hopper and feed rollers at the chipper.

It was possible to feed three to four leaves at a time in the chipper feeding rollers. The two chippers were operated at a chipping rate of 2.4 tonnes per hour per chipper, or 4.8 tonnes per two chippers. The chippers were discharging sisal chips to the feeding trailer of capacity 1.8 tonnes. It took about 22 minutes to fill the feeding trailer. The hammer mill, feeding trailer and two chippers were operated continuously for periods of about 15 minutes due to the limitation of the chipping rate in relation to the hammer mill rate, and the size of the feeding trailer. 131.3 meters of sisal leaf were chipped and fed to the hammer mill.

III.2.2 Hammer mill operation

Sisal chips were fed to the hammer mill at a pre-determined rate of about 10 tonnes per hour. The material flowed continuously through the feeding conveyor, the helicoidal conveyor ∅ 420, the dozing feeder, the helicoidal conveyor ∅280, and finally to the hammer mill. No overflow was observed at the overflow return chute.



Helicoidal conveyor ∅280

The fibre from the first pass was received at the bottom of the hammer mill, and no water was supplied during the process. The fibre with about 33% parenchyma was collected using plastic buckets and carried back manually to the helicoidal conveyor ∅280 for the second pass to remove the remaining parenchyma. Fibre from the first pass was fed by hand to the conveyor at a slow rate, which was established to produce acceptable fibre quality. Water was supplied at a rate of about 3 m^3 per hour to the helicoidal conveyor ∅ 280 to clean and reduce the bulkiness of fibre to be accommodated in the hammer mill chute.

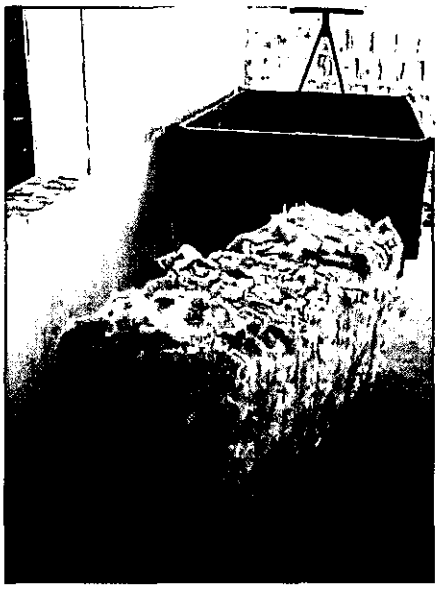
The fibre was received at the hammer mill exit chute and collected for drying using the wet fibre trolley fabricated by TATC.

III.2.3 Fibre drying and baling

The fibre was spread on the drying benches in the drying yard and allowed to dry naturally. It took one day to dry when the weather was sunny and up to three days when it was raining. The drying benches accommodated about 250 kg dry fibre per batch.

The fibre was lifted manually by four laborers and packed in plastic bags, which were able to hold up to 10 kg of air-dry (AD) fibre per bag. The fibre was carried manually to the baling press where the fibre was filled in the pressing box and pressed. Due to the bulkiness of the fibre, two-stage pressing was required to accommodate 200 kg of fibre per bale instead of one stage of 250 kg per bale as in the traditional baling of fibre from the conventional decorticator.

At the first stage three tonnes of AD fibre was produced, baled and transported to Kibo Pulp and Paper Mill in Moshi for pulping. Another batch of 2.6 tonnes of AD fibre was later processed the same way and transported for pulping in Moshi.



III.2.4 Preliminary commercial pulping

The first 3 tonnes of sisal fibre were pulped in the industrial rotary digester at Kibo Pulp and Paper Board Mill in Moshi under the following pulping conditions:

Active alkali	13.5% as NaOH (13.5kg NaOH/100kg OD fibre)
Anthraquinone	0.1%, (1kg AQ/ton of dry fibre)
Heating time to Maximum Temperature	90 minutes
Time at Maximum Temperature	90 minutes
Maximum Temperature	173°C
Bath ratio	1:4

The pulp was passed through the beater for washing to remove black liquor. No refining was carried out at this stage, but the fibre was squeezed to reduce the moisture content. Freeness of the pulp was about 670 CSF and kappa number as measured at Moshi Laboratory was around 9. Samples were sent to Mgololo Paper Mill in Iringa for testing. The pulp properties tested were strength properties, and bleachability.

It was observed that the fibre produced from two passes in the hammer mill was slightly softer than the fibre produced in the selection of extraction technology. It was also observed that the fibre had a low pulp yield of around 50% and low strength properties, and therefore could not be used as samples for the mills or for bleaching trials and it was considered necessary to optimize pulping conditions.

Table 1: Preliminary commercial pulp – strength properties

Sample	Yield	CSF	Basis Weight	Tensile		Elasticity	Tear		Tear		Burst		Kappa Number
	%	Ml	G/m^2	Strength kN/m	Index Knm/kg	%	Strength KJ/m^2	Index KJ/g	Strength mN	Index Nm2/g	Strength KPa	Index KPam2/g	
1		303	59.5	1.8	29.4	5.6	73.5	1.2	940	15.8	131	2.2	14.8
2		293	60.7	1.8	29.7	7.0	83.2	1.4	1040	17.1	142	2.3	14.8
Average	*50*	*298*	*60.1*	*1.8*	*29.6*	*6.3*	*78.4*	*1.3*	*990*	*16.5*	*137*	*2.3*	*14*

III.2.5 Optimization of pulping conditions at laboratory scale

Nine scenarios with different combinations of cooking conditions were proposed with active alkali charge ranging from 12 to 14.5%, cooking time ranging from 60 to 90 minutes and maximum temperature ranging from 165^0C to 173^0C. Other parameters such as time to maximum temperature of 90 minutes, Anthraquinone 0.1% and bath ratio of 1:4 remained unchanged. During cooking it was found necessary to add one more scenario with active alkali 12%, time at maximum temperature of 120 minutes and maximum temperature 180^0C.

Table 2: Pulping scenarios

Parameter	Scenario									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Active alkali %	12.5	13.5	14.5	13.5	13.5	13.5	12.5	12.5	12.5	12.0
Time at Maximum Temperature (min)	90	90	90	90	75	60	90	75	60	120
Maximum Temperature ($^{\circ}$C)	173	173	173	165	165	165	165	165	165	180

Two cooks per sisal fibre sample were first carried out under the above conditions (a and b in Table 4 below), and the resulting pulp was washed and dried in the sun. No refining was carried out after pulping. The pulps were weighed and pulp yield determined.

Pulp testing was carried out at Mgololo Paper Mill (MPM) laboratory in Iringa from 7 to 12 July 2004 and strength properties and bleachability determined. The optimum scenario selected was Scenario 5 (Table 4). The selection was based on two observations:

1. Workability – appearance of the pulp and whether it could be easily pumped from the digester to the beater (Table 3);
2. Average general strength properties (Table 4).

The results achieved are presented below.

Table 3. Pulp appearance after washing

Parameter	Scenario									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Color	BP	PB	PB	BB	BP	PB	PB	BB	PB	B
Shives	NN	NN	NN	NN	NN	YY	YY	YY	YY	N
Soft cook	NN	NY	NY	NN	NN	NN	NN	NN	NN	Y
Can be pumped	YY	YY	YY	YY	YY	NN	NN	NN	NN	Y
Rejects	NN	NN	NN	NN	NN	NL	LL	LL	LL	N

Color	B = Brown	P = Pink
Shives	Y = Yes	N = No
Soft cook	Y = Yes	N = No
Can be pumped	Y = Yes	N = No
Rejects	N = Nil	L = Low

Table 4. Pulp main physical properties

Sample	Yield	CSF	Basis Weight	Tensile		Elasticity	Tear		Tear		Burst		Kappa Number
	%	Ml	g/m^2	Strength kN/m	Index KNm/kg	%	Strength KJ/m^2	Index KJ/g	Strength mN	Index Nm^2/g	Strength KPa	Index $KPam^2/g$	
1a	63	307	64.8	2.8	43.2	4.4	85.0	1.3	1174	18.1	210	3.2	21.2
2a	62	309	66.0	2.7	40.8	3.9	72.4	1.1	1240	18.6	205	3.1	20,6
3a	61	290	66.4	2.7	40.9	6.2	104	1.6	1520	23.0	237	3.6	19.0
4a	68	320	67.8	2.7	39.4	3.8	62.2	0.9	1450	21.8	220	3.3	20.7
5a	**65**	**304**	**67.5**	**3.1**	**45.9**	**4.9**	**88.0**	**1.3**	**1173**	**17.4**	**244**	**3.6**	**19.5**
6a	66	284	64.0	3.1	48.4	5.3	104.0	1.7	1160	19.3	248	4.1	20.1
7a	67	318	65.0	2.9	44.6	4.4	90.5	1.4	1380	21.2	262	4.0	21.1
8a	68	280	67.5	3.4	49.9	4.0	93.4	1.4	1600	23.7	273	4.1	17.8
9a	66	302	62.8	3.1	49.4	5.6	111.5	1.8	1210	19.3	292	4.6	25.9
1b	60	305	63.2	2.3	36.2	4.7	71.7	1.1	120	17.7	187	3.0	18.5
2b	60	312	63.6	2.4	37.6	4.5	70.6	1.1	1460	22.9	198	3.1	18.4
3b	60	290	66.8	2.5	38.2	3.8	64.6	1.0	1110	166	189	2.8	16.1
4b	69	306	63.5	2.6	40.9	4.0	68.7	1.1	1280	20.2	212	3.3	19.5
5b	**65**	**291**	**61.5**	**3.2**	**52.0**	**4.7**	**103.1**	**1.7**	**1080**	**17.7**	**250**	**4.1**	**20.4**
6b	65	321	61.2	3.1	50.6	3.9	82.2	1.3	1140	18.6	258	4.2	21.5
7b	66	313	65.0	2.9	44.6	4.3	90.5	1.4	1380	21.2	262	4.0	26.1
8b													
9b	67	288	64.0	3.3	51.6	6.4	135.4	2.1	1120	17.5	290	4.5	27.1
10	58	313	51.0	1.91	37.4	4.1	51.2	1.0	920	18.0	162	3.2	28.5

Note: a, b refer to the first and second cook under the same conditions (same scenario). Sample number 8b was discarded. The temperature could not be controlled properly thus resulting in hard cook. Due to time constraint only one sample was pulped under scenario 10.

Scenario 5 was selected because of its generally high strength and high workability. Higher pulping conditions (e.g., scenario 2, 3, and 10) produced soft cooks, which have higher workability but generally low strength properties. On the other hand medium pulping conditions (e.g. scenario 1, 4 and 5) produced normal cooks. Low pulping conditions (e.g. scenario 6, 7, 8 and 9) produced hard cooks, though some had higher strength properties but all had low workability.

III.2.6 Pulping at commercial scale under optimum conditions

Commercial scale pulping of 2.6 tonnes of fibre (the second batch) was carried out using the industrial rotary digester in Kibo Pulp and paper Mill under the selected optimum scenario with the following modifications:

Active alkali	13.5% as NaOH (13.5kg NaOH/100kg AD fibre)
Anthraquinone	0.1%, (1kg /ton of dry fibre)
Heating time to Maximum Temperature	90 min
Time at Maximum Temperature	75 min
Maximum Temperature	165°C
Initial Bath ratio	1:4

The digester was direct heated by steam from the boilers. Temperature was controlled by a thermometer and pressure by a pressure gauge fixed to the rotary digester. Degassing was done after 30 minutes when temperature was about 100°C. The pulp was beaten to freeness of around 700 CSF, washed and squeezed to reduce moisture.

The pulp was brown in color; pulp yield was about 60%, and freeness about 700 CSF. Physical appearance of the pulp produced at laboratory and commercial scale under optimum scenario conditions was different. Under commercial digester the pulp appears as if it is slightly over-cooked than one from laboratory at the same conditions, probably due to proper chemical mixing in the commercial digester caused by baffles, and internal heating by steam. Pulp samples were not sent to Mgololo Paper Mill for pulp testing due to time constraints. Nevertheless the samples were analyzed in the laboratory where the bleaching trials were performed.

III.2.7 Pulp transportation, packing and shipping to laboratories

The pulp samples could not be dried at the mill due to the maintenance schedule of the mill. About 250 kg of pulp were taken to Tanga and dried on the floor in a hall at Katani premises. The hall had forced air circulation, and all measures were taken to avoid contamination. The samples sent to the mills had a moisture content of about 11%.

III.3 Bleaching trials at laboratory scale

A contractor to perform bleaching trials with sisal pulp was selected through competitive bidding. The contract (US$ 19,000) was awarded in July 2004 to the Pulp and Paper Institute, Ljubljana (Slovenia). The target brightness to be achieved was about 87-89 ISO.

A total of 20 Kg of sisal fibre and 10 kg of sisal pulp were sent to the laboratory and used to perform the following activities:

- To pulp samples of sisal fibre, on a laboratory scale, under the same conditions of the industrial digester in Moshi and evaluate the main characteristics of the pulps,
- to conduct sisal pulp bleaching trials at laboratory scale using ECF (Elemental Chlorine Free) sequences and TCF (Totally Chlorine Free) sequences,
- to evaluate the main characteristics of the bleached pulps and to select the best bleaching ECF and TCF sequences to achieve a pulp brightness level of about 87-89 ISO,
- to produce 40 samples of 60 g/m2 basic weight of the bleached pulps produced with the best ECF and TCF sequences.

The list of methods and analysis conducted is included in Annex 3.

III.3.1 Pulping trials

Two preliminary cooks were done: one (PK1) under the same conditions as in the industrial digester in Moshi (Section III.2.6), the other one (PK2) using a lower quantity of Anthraquinone. The conditions used and the results achieved are included in Table 5 below. Pulping was done in a 10-l rotating digester with electric heating; 700 g of oven dried sisal material was fed into the digester for each trial. The concentration of NaOH solution was 200 g/L

The digester and the sisal material were preheated before each trial to approx. 80 - 90°C. The Wennberg laboratory strainer was used for pulp screening and cleaning after cooking. The yield was measured and sample sheets were prepared to perform the analyses.

Table 5. Pulping trials at laboratory scale

Trial	PK1	PK2
Cooking chemicals:		
NaOH, %	13.5	13.5
Antroquinone, %	**0.1**	**0.01**
Material/liquor ratio	1:4	1:4
Diagram:		
Heating up time, min	90	90
Temperature $_{max}$, °C	165	165
Time on temperature $_{max}$, min	75	75
Results:		
Kappa number	12.0	15.7
Total yield, %	72.7	72.9
Shives, %	0.12	1.66
Pulp yield, %	72.6	71.3
Active alkali in black liquor, g/L	1.04 1.04	2.24 2.24
Alkali consumed, %	97.0	94.4
Brightness, %	32.8	32.2
Limiting viscosity No, mL/g	970	1015

The basic characteristics of the pulp produced in Moshi were as follows:

Dry matter content, %	89.81
Kappa number	9.22
ISO brightness, %	38.69
Limiting viscosity No, mL/g	572

The differences in the main characteristics of the pulp obtained using the same parameters in the laboratory and in Moshi are quite important. These are probably due to the pulping conditions, which were evidently different. That is, the plant pulping conditions could not be replicated in the laboratory. Another reason could be that the pulp delivered from Tanzania was practically oven-dried while the laboratory pulp was de-watered only to ca. 30% water content. The constant water content obviously has a great influence on fibre quality as it allows hydrogen bonds to loosen more easily after the re-wetting of the fibres. Therefore, the never-dried fibres always have higher mechanical properties than dried ones. This also depends on the conditions used in the drying process.

III.3.2 Bleaching trials

The bleaching experiments were conducted with the unbleached pulp provided from the field. Initially an extended oxygen delignification stage was performed using the same 10-l rotating digester used for pulping. 500 g of oven dried sisal pulp was fed into the digester for each trial. Before the process, the digester and the pulp were preheated to ca. 80 - 90°C. The procedure is presented in Table 6 and the results obtained are included.

Table 6. Oxygen stage procedures and results

Conditions:	
NaOH, %	1.5
$MgSO_4$, %	0.5
Oxygen pressure, bar	6
pH begin/end	12.3/10.9
Consistency, %	10
Reaction time, min	60
Temperature, ^0C	95
Results:	
Active alkali in spent liquor, g/L	15.2
Yield, %	94.9
Brightness, %	55.2
Micro kappa Number	5.3

After preliminary oxygen delignification, small scale bleaching experiments for all stages were conducted in plastic bags (30 g oven dried pulp, each), immersed in water baths of specific temperature. Plastic bags with pulp suspensions were taken out of the water bath and periodically hand-mixed. At the end of the stage, pulp suspension was dewatered; the rest of the chemicals were analyzed in spent liquors. Fibres were washed and sample sheets were made for measuring the brightness level achieved after each stage; brightness stability and limiting viscosity number were measured only for final bleached fibres.

ECF (Elemental Chlorine Free) trials included the following sequences:

1. DED without oxygen stage
2. DED with oxygen stage (ODED)
3. DEpD

where:

O Oxygen
D Chlorine dioxide
E, Ep Extraction stage, reinforced by peroxide

The results are presented in Annex 4.

TCF bleaching sequences were divided into three groups:

1. with ozone stage (with oxygen at the beginning);
2. with ozone stage (without oxygen at the beginning);
3. without ozone stage and with oxygen at the beginning.

Three bleaching agents were proposed: oxygen, ozone and peroxide. The oxygen stage is already described in Table 6; the small-scale peroxide stage was conducted in plastic bags in water bath, the same as with ECF sequences. The ozone stage was carried out in a laboratory digester in a stainless steel-covered vessel with a gas input and output installed on the roof of the vessel. For the production of ozone gas a

laboratory ozone generator, produced by Erwin Sander Company, Germany, was available. The procedure was carried out according to the 19627 DIN standard.

1 and 2, TCF sequences with ozone: these sequences were made by combining all chlorine free bleaching chemicals: oxygen, ozone and peroxide. The oxygen treatment of pulp was the same as with previous trials. At acidification stage, the pulp has to be treated with hot diluted sulfuric acid and without in-between washing before the ozone stage. If further high consistency ozone is proposed, the pulp is dewatered after the acidification stage until the target consistency is reached. A high consistency ozone stage was selected for the first series of trials. Only time varied. At the end of the ozone stage, the pulp was washed and the final peroxide stage was carried out in all the ozone "time-variant" samples.

The conditions and results for the OAZ_hP sequences, for the AZ_hP and for the OAZ_lP sequences are included in Annex 5. Where:

O Oxygen
A Acidification stage
Z Ozone stage: Z_h – high consistency, Z_l – low consistency

3, TCF sequence without ozone: by means of the sequence O(Q)P(Q)P (without the ozone stage) only the oxygen pretreated pulp was selected for testing. Where:

O Oxygen
Q Chelation stage
P Peroxide stage

The procedure and the characteristics of the end-bleached fibres of the sequence are included in Annex 6.

III.3.3 Selection of best ECF and TCF bleaching sequences

The results of brightness and limiting viscosity number show that the oxygen stage is obviously very favorable to both ECF and TCF bleaching sequences. It does not cause any strong deterioration of the cellulose molecule (viscosity) and, at the same time, chlorine chemicals can be reduced to a lower level.

It is possible to reach the target brightness with **ECF** sequences: with oxygen, ODED (total active Cl= 3,5 %) or without oxygen, **DEpD** (total active Cl= 3.5 % and 0.5 % of peroxide for extraction stage).

In the case of TCF sequences, it is easier to achieve target brightness by using oxygen and ozone in the sequence. Thus, better viscosity values are reached as well.

The important parameter is consistency of the ozone stage. The fear of losing too much strength with a high-consistency ozone stage was not confirmed. It seems that the high consistency (close to 40%) offers enough thick water surface layer to protect the fibres from destruction. On the other hand, the reaction time during high consistency is short enough and keeps the inside of the fibres more or less intact.

The proposed **TCF** sequence is **OAZ_hP** (with high consistency ozone stage and with peroxide 3%, and eventually with a decreased amount, due to it's high residue).

The amount of ozone needed for bleaching was measured during the large-scale experiments (described in the next section).

III.3.4 Bleaching of larger quantities of pulp

Larger quantities of the sisal pulp produced at Kibo Pulp and Paper Mill in Tanzania were bleached according to the selected ECF and TCF bleaching sequences in order to have enough pulp for testing and preparing the required amount of standard pulp sheets of 60 g/m^2 (ISO 5269-1).

The trials were conducted in a stainless steel vessel rotating in the electrical heated comora. The capacity of the vessel was 1 kg of oven-dried pulp.

The detailed bleaching conditions for ECF sequence (DEpD) and for TCF sequence (OAZP) are presented in Annex 7.

At the end of each sequence the pulp was washed with SO_2-water to 4.5 pH, at 3 % consistency, and for 15 min. Sample sheets were made of both bleached pulp grades according to the standard method for testing and presentation.

Physical properties of both, ECF and TCF bleached grades are shown in Annex 8.

The pulp obtained in the laboratory from sisal fibre was also delignified using the two selected sequences; the results of which are in Annex 8.

It was concluded by the laboratory that both pulp obtained in Tanzania and pulp obtained at the laboratory from sisal fibre can reach the target brightness level of 88 % ISO with both ECF and TCF bleaching sequences. It was also concluded that "sisal pulp generally has excellent properties".

The results obtained are summarized in Annex 9. In the same Annex 9 a tentative estimation of the bleaching costs is included.

IV. Lessons learned

IV.1 Development lessons

The objectives identified in the Appraisal Report were broadly met. Even though the large quantities of pulp originally foreseen were not produced the planned semi-commercial production of pulp was carried out. Enough quantities of pulp were generated for the market trials, as foreseen, and confirmatory laboratory tests were also performed.

Commercial mills and research institutions were contacted by UNIDO in August 2003 to bleach a large quantity (five tonnes) of pulp, but only a few responses were received and the proposed costs were too high. It was therefore decided to perform laboratory trials only.

Ideally it would have been interesting to produce paper from bleached sisal pulp, but the costs of such trials would not have had a technical benefit as each commercial mill uses its own blends and procedures. The quality of sisal fibre and pulp can be assessed by the mills against their own needs with the samples provided.

The Project Coordinating Committee (PCC) decided not to prepare a feasibility study for a pulp mill based on sisal, as the main interest of the industry is to produce and sell fibre, and not pulp.

IV.2 Operational lessons

The implementation of sub-component C.2 suffered from the delays accrued in the development of the other sub-components. Thanks to the project extension granted by CFC, the activities were conducted in 2004. Unfortunately further delays were caused by the necessity of additional equipment for the hammer mill and by the poor quality of the first pulping at Kibo Pulp and Paper Mill. This affected the preparation of the fibre and pulp samples (sub-component D.1) and delayed the activities of the institute that conducted the bleaching trials.

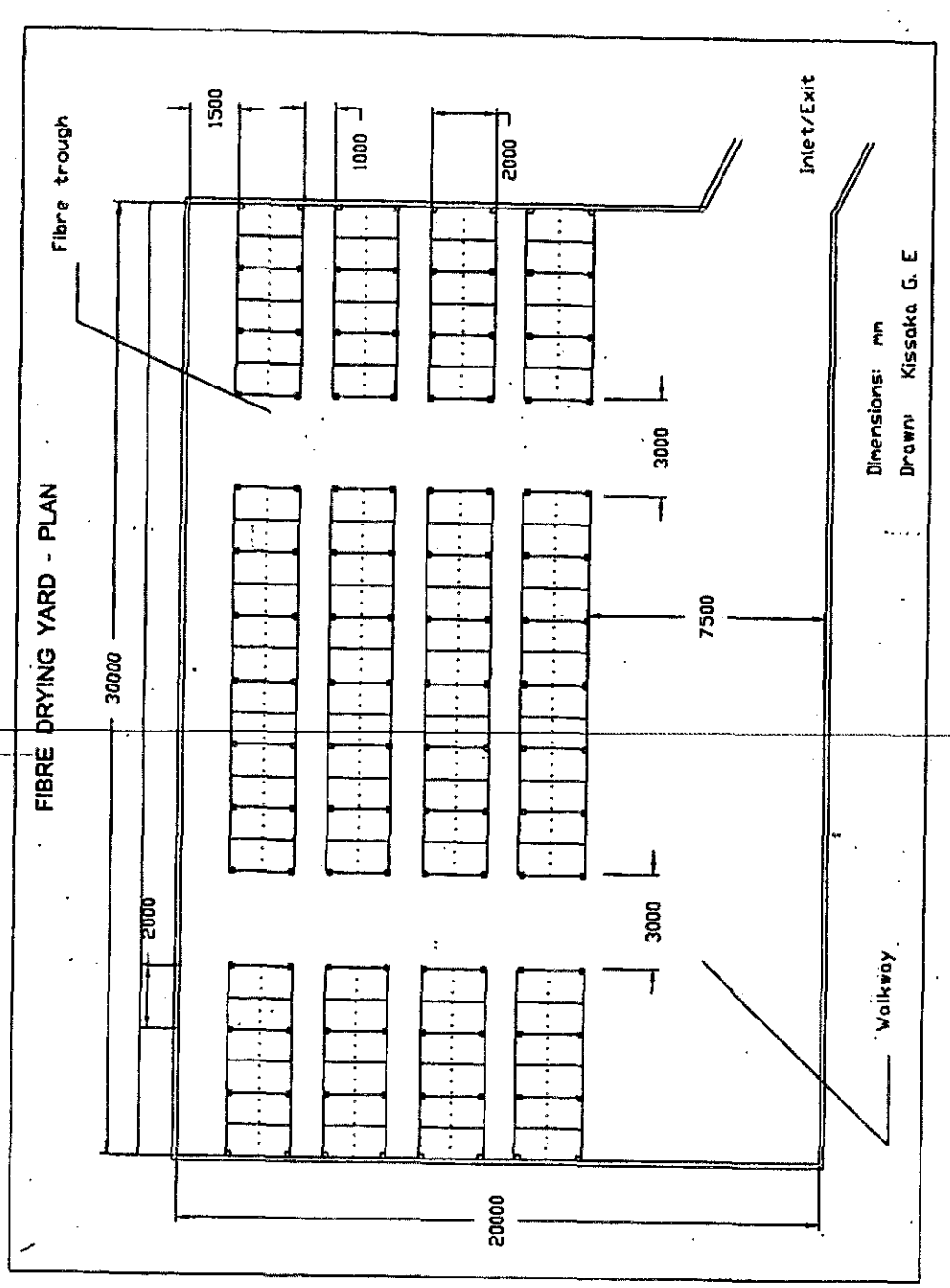
The Ljubljana Pulp and Paper Institute proved to be professional and reliable.

V. Conclusions and recommendations

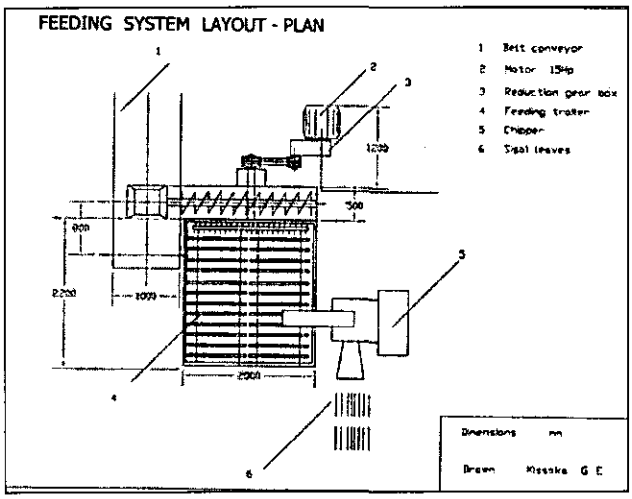
From the activities performed it can be concluded that the hammer mill provides suitable technology for fibre extraction and that sisal pulp has competitive properties.

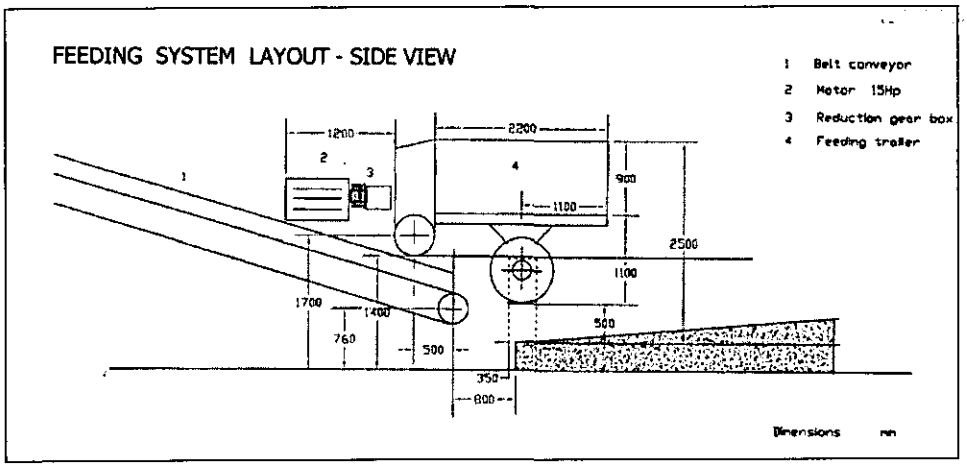
The differences in the quality of the pulp produced at Kibo Pulp and Paper Mill in Tanzania and the pulp produced at the Ljubljana Pulp and Paper Institute in Slovenia confirmed that adjustments in the pulping conditions are always required depending on the equipment used. Nevertheless, the fibre and pulp samples and the bleached pulp sheets sent to commercial mills provide the necessary information for the companies to assess the quality of the final product achievable at their facilities.

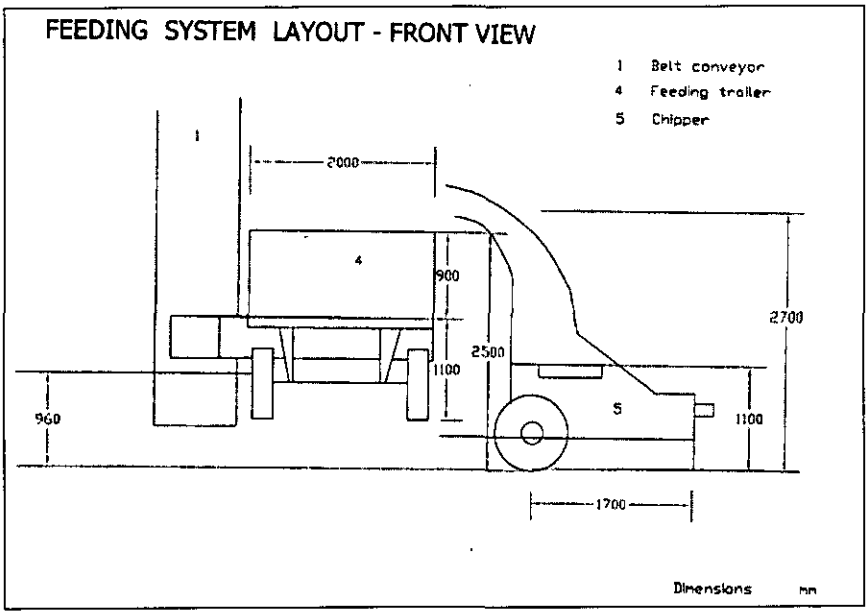
Annex 1. Plan of the fibre drying yard



Annex 2. Sisal Chips Feeding System







Annex 3. Bleaching at laboratory scale: methods and analyses used

Dry matter content	ISO 638 - 1978
Kappa number	ISO 302 - 1981
Brightness	ISO 3688 – 1977
Brightness stability	ISO 5630/1 – 1982
Limiting viscosity number	SCAN-CM 15:88
Residual alkali	SCAN-N 33:94
Ozone consumption	DIN 19627 - 1993
Preparation of laboratory sheets for physical testing- Conventional sheet-former method	ISO 5269-1 - 1998
Determination of physical properties	ISO 5270 - 1998
Average fibre length and coarseness (Kajaani FS)	Tappi 271 pm-91
Average fibre width	*Handbuch Der Mikroskopie in der Technik*, Band V, Teil 2, 1951
Dirt in pulp	T 213 om-89
Determination of pH of aqueous extract	ISO 6588 - 1995

Annex 4. Small scale ECF bleaching trials and basic results

Trials	DED	ODED	DEpD
D_1-stage:			
ClO_2, as activeCl added, %	2.0	1.5	2.0
pH, begin/end	6.0/6.4	6.3/6.7	2.2/3.3
Consistency, %	10	10	10
Temperature, °C	50	50	50
Reaction time, min	60	60	60
Rest of Cl, %	0.008	0.19	0.02
Brightness, % ISO	74.2	82.2	
E, Ep*-stage:			
NaOH, %	1.0	1.0	1.0
H_2O_2, %			0.5
Rest of H_2O_2, %			0.1
pH, begin/end	11.9/11.1	11.9/10.9	11.3/11.1
Consistency, %	10	10	10
Temperature, °C	50	50	50
Reaction time, min	90	90	90
Brightness, % ISO			82.5
D_2-stage:			
ClO_2, as activeCl added, %	1.5	1.5	1.5
pH, begin/end	4.6/4.9	4.6/4.9	4.6/4.9
Consistency, %	10	10	10
Temperature, °C	60	60	60
Time, min	180	180	180
Rest of Cl, %	0.05	0.05	0.05
End characteristics:			
Brightness, %	87.6	88.9	88.5
Brightness loss, %		2.0	
Lim. viscosity number, mL/g	507	479	522

* to the extraction stage, reinforced with peroxide, $MgSO_4$ (0.2 %) and DTPA (0.2 %) were added.

Annex 5. Small scale TCF (with Ozone) bleaching trials

Table 1. TCF sequence including ozone stage (high consistency) - OAZ_hP

Oxygen stage: Described in Table 6 (in the text).				
Acidification stage:				
Consistency, %		10		
Temperature, ^0C		60		
Time, min		60		
Acidification with H_2SO_4 to pH		2		
Actual pH, final		2		
Z-stages:	Z1	Z2	Z3	Z4
Consistency, %	40	40	40	40
Temperature, ^0C	40	40	40	40
Time, min	1.5	3.0	4.5	6.0
Brightness, %	68.9	74.9	77.1	78.9
P-stage (equal for all Z-variants):				
H_2O_2, %		3.0		
NaOH, %		1.5		
$MgSO_4$, %		0.2		
DTPA, %		0.2		
Consistency, %		10		
Temperature, ^0C		70		
Time, min		180		
pH, begin/end		10.6/10.7		
Rest of peroxide, %		1.1		
Results:	OAZ_1P	OAZ_2P	OAZ_3P	OAZ_4P
End brightness, %	88.4	90.4	90.6	91.4
Brightness loss, %	1.56	1.50	1.07	1.55
Lim.viscosity No, mL/g	476	445	423	412

Table 2. TCF sequence including ozone stage (high consistency) without oxygen - AZhP

Acidification stage:				
Consistency, %		10		
Temperature, ^{0}C		60		
Time, min		60		
Acidification with H_2SO_4 to pH		2		
Actual pH, begin/end		2		
Z-stages:	Z1	Z2	Z3	Z4
Consistency, %	40	40	40	40
Temperature, ^{0}C	40	40	40	40
Time, min	1.5	3.0	4.5	6.0
Brightness, %	58.4	61.4	63.6	66.6
P-stages(equal for all Z-variants):				
H_2O_2, %		3.0		
NaOH, %		1.5		
$MgSO_4$, %		0.2		
DTPA, %		0.2		
Consistency, %		10		
Temperature, ^{0}C		70		
Time, min		180		
pH, begin/end		10.6/10.7		
Rest of peroxide, %		Round 1.1 (increases with time used in the Z stage)		
Results:	AZ_1P	AZ_2P	AZ_3P	AZ_4P
End brightness, %	86.3	87.0	88.9	89.1
Brightness loss, %	1.46	1.46	1.69	1.61
Lim.viscosity No, mL/g	445	439	422	437

Table 3. TCF sequence including ozone stage (low consistency) – with oxygen OAZ_1P

Acidification stage:			
Consistency, %		10	
Temperature, ^0C		60	
Time, min		60	
Acidification with H_2SO_4 to pH		2	
Actual pH, begin/end		2	
Z-stages:	Z1	Z2	Z3
Consistency, %	10	10	10
Temperature, ^0C	40	40	40
Time, min	3.5	5.0	8.0
Brightness, %	61.1	62.7	63.6
P-stage(equal for all Z-variants):			
H_2O_2, %		3.0	
NaOH, %		1.5	
$MgSO_4$, %		0.2	
DTPA, %		0.2	
Consistency, %		10	
Temperature, ^0C		70	
Time, min		180	
pH, begin/end		10.9/11.4	
Rest of peroxide, %		round 0.25	
Results:	OAZ_1P	OAZ_2P	OAZ_3P
End brightness, %	85.5	85.1	86.4
Brightness loss, %	2.86	2.27	2.70
Lim.viscosity No, mL/g	493	487	467

Annex 6. Small scale TCF (without Ozone) bleaching trials

Sequence O(Q)P(Q)P

Oxygen stage:	
Described in Table 6 (in the text)	
Q-chelation stages:	
Consistency, %	10
Temperature, ^{0}C	60
Time, min	60
Acidification with H_2SO_4 to pH	5-5.5
DTPA, %	0.2
Actual pH, begin/end	5.1/6.7
P_1-stage:	
H_2O_2, %	2.0
NaOH, %	1.5
$MgSO_4$, %	0.2
DTPA, %	0.2
Consistency, %	10
Temperature, ^{0}C	70
Time, min	180
pH, begin/end	10.9/10.9
Rest of peroxide, %	0.65
Brightness, %	79.1
P_2-stage:	
H_2O_2, %	1.0
NaOH, %	1.5
$MgSO_4$, %	0.2
DTPA, %	0.2
Consistency, %	10
Temperature, ^{0}C	70
Time, min	180
pH, begin/end	11.2/11.0
Rest of peroxide, %	0.6
Results:	
End brightness, %	84.3
Brightness loss, %	3.38
Limiting viscosity No, mL/g	486

Annex 7. Conditions for large scale ECF and TCF bleaching trials

DEpD Trial

D_1-stage:	
ClO_2, as act.Cl added, %	2.0
pH, begin/end	2.2/3.3
Consistency, %	10
Reaction time, min	60
Temperature, °C	50
Rest of Cl, %	0.05
Ep*-stage:	
NaOH, %	1.0
H_2O_2, %	0.5
Rest of H_2O_2, %	0.1
pH, begin/end	11.3/11.1
Consistency, %	10
Temperature, °C	50
Reaction time, min	90
D_2-stage:	
ClO_2, as act.Cl added, %	1.5
pH, begin/end	3.6/3.8
Consistency, %	10
Temperature, °C	60
Time, min	180
Rest of Cl, %	0.05

OAZhP trial

Oxygen stage:
Described in Table 6 in the text.

Acidification stage:	
Consistency, %	10
Temperature, ^{0}C	60
Time, min	60
Acidification with H_2SO_4 to pH	2
Actual pH, final	2
Z-stage:	
Consistency, %	40
Temperature, ^{0}C	40
Ozone - charged, % (calculated on o.d. pulp)	1.96
Ozone - consumed, %	1.10
P-stage:	
H_2O_2, %	2.0
NaOH, %	1.5
$MgSO_4$, %	0.2
DTPA, %	0.2
Consistency, %	10
Temperature, ^{0}C	70
Time, min	180
pH, begin/end	10.6/10.7
Rest of peroxide, %	0.77

Annex 8. Characterization of unbleached and bleached pulps

Table 1. Raw material (i.e. unbleached pulp) prepared in Tanzania, bleaching performed using selected ECF and TCF sequences.

Property	Unbleached				DEpD				OAZP			
Kappa No.	9.2											
Brightness ISO	38.7				88.8				90.0			
Viscosity SCAN	572				458				432			
Final pH	9.5				7.7				7.9			
Dirt counting (mm^2/m^2)	35.8				30.8				35.8			
Fibre length w.w.av. (mm)	2.06				1.87				1.97			
Fibre width (m)	ca. 25				ca. 25				ca. 25			
Coarseness (mg/m)	0.125				0.186				0.182			
Opacity (%)	96.0				73.8				71.8			
PFI beating:												
No. of revolutions*	Ø	3000	4000	5000	Ø	3000	4000	5000	Ø	2000	3000	4000
Beating degree (SR)	13	22	32	56	14	21	35	52	14	19	32	48
Freeness (CSF)	770	550	400	175	770	560	360	210	770	600	400	225
Basis weight (g/m^2)	62.2	63.9	63.4	65.2	66.1	60.3	63.3	62.7	60.1	64.9	64.3	64.3
Density (kg/m^3)	300	540	570	630	290	520	590	630	290	530	570	620
Tensile index (N.m/g)	6.0	38.5	42.5	48.0	5.5	35.0	42.0	45.5	5.5	31.5	37.0	39.0
Breaking length (km)	0.61	3.93	4.35	4.93	0.56	3,55	4.30	4.63	0.59	3.20	3.78	3.95
Tear index ($mN.m^2/g$)	2.19	8.26	7,.24	6.21	2.27	8.05	6.86	5.79	2.51	7.44	6.26	5.04
Burst index ($kPa.m^2/g$)	0.56	3.12	7.92	4.15	0.59	3.17	3.58	3.66	0.63	2.51	3.01	3.18
Porosity (m/Pa.s)	**	190	78	12	**	195	52	16	**	250	93	24

* Number of revolutions at PFI beater

** Too high porosity of being measured

Table 2. Raw material (i.e. unbleached pulp) prepared at the laboratory

Property	**Unbleached**				**DEpD**				**OAZP**			
Kappa No.	12.1											
Brightness ISO	34.7				89.0				91.6			
Viscosity SCAN	969				878				676			
Final pH	8.7				7.5				8.1			
Dirt counting (mm^2/m^2)	139				26.2				25.0			
Fibre length w.w.av. (mm)	2.29				2.23				2.06			
Fibre width (m)	ca. 25				ca. 25				ca. 25			
Coarseness (mg/m)	0.144				0.124				0.125			
Opacity (%)	97.6				73.4				72.8			
PFI beating: Number of revolutions*	Ø	4000	5000	6000	Ø	4000	6000	8000	Ø	4000	5000	6000
Beating degree (SR)	11	25	38	47	12	22	34	50	13	25	34	47
Freeness (CSF)	>800	480	320	280	>800	550	370	210	800	480	370	250
Basis weight (g/m^2)	62.4	62.6	65.0	64.5	63.5	64.7	64.4	64.3	64.6	64.4	65.0	64.0
Density (kg/m^3)	330	600	630	670	320	610	660	710	350	610	670	680
Tensile index (N.m/g)	14.5	86.0	91.5	94.0	12.5	72.5	87.0	93.5	14.0	73.5	80.0	77.0
Breaking length (km)	1.50	8.76	9.35	9.57	1.29	7.39	8.84	9.54	1.44	7.51	8.13	7.85
Tear index ($mN.m^2/g$)	5.96	16.4	14.5	13.2	6.01	18.2	15.3	13.1	6.07	14.6	13.2	13.0
Burst index ($kPa.m^2/g$)	0.85	7.70	8.71	8.88	0.86	6.88	8.28	8.84	0.93	6.48	6.99	7.78
Porosity (m/Pa.s)	**	44	12	4.4	**	92	8.9	1.6	**	45	10	3.6

* Number of revolutions at PFI beater

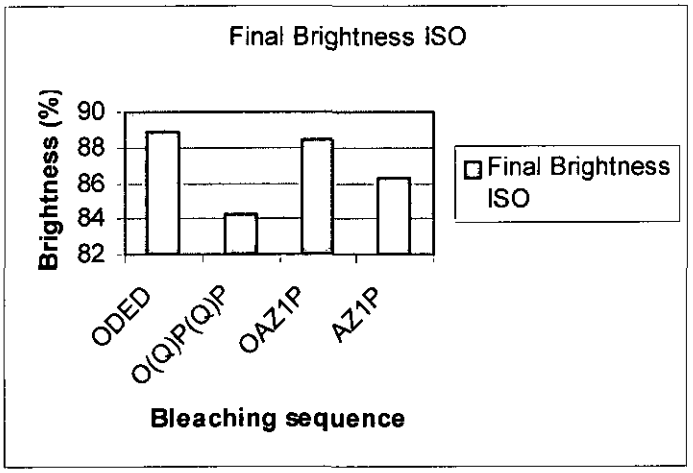
** Too high porosity of being measured

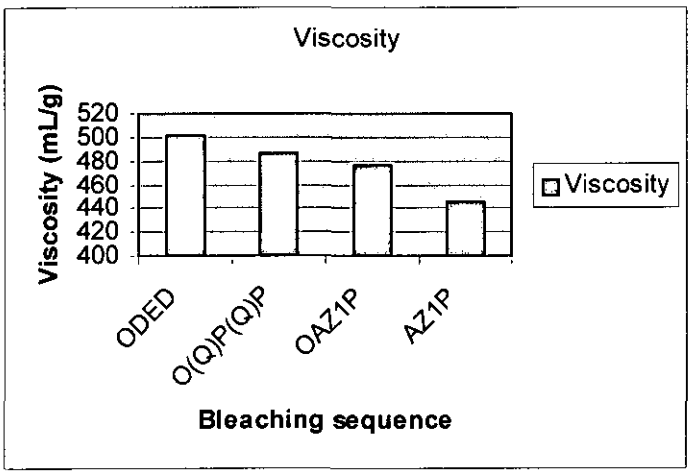
Annex 9. Summary of results achieved and preliminary cost estimation

		Unbleached Pulp	O	DED	DE_PD	ODED
Kappa	number	9.22				
Micro kappa	number		5.3			
Final brightness ISO	%	38.7	55.2	87.6	88.5	88.9
Viscosity	mL/g	572	na	na	na	502
Chemicals cost (excluding O_3 and H_2SO_4)	US$/ton pulp		15.1	20.3	30.2	33.5

	O(Q)P(Q)P	OAZ_1P	OAZ_2P	OAZ_3P	OAZ_4P	AZ_1P	AZ_2P	AZ_3P	AZ_4P	OAZ_1P	OAZ_2P	OAZ_3P
Kappa		*All sequences using 40% consistency in Ozone stage*								*10 % consistency ozone stage*		
Micro kappa												
Final brightness ISO	84.3	88.4	90.4	90.6	91.4	86.3	87	88.9	89.1	85.5	85.1	86.4
Viscosity	486	476	445	423	412	445	439	422	437	493	487	467
Chemicals cost (excluding O_3 and H_2SO_4)	67.4	49.8	49.8	49.8	49.8	35.4	35.4	35.4	35.4	50.5	50.5	50.5

	ODED	O(Q)P(Q)P	OAZ_1P	AZ_1P
Final brightness ISO	88.9	84.3	88.4	86.3
	ODED	**O(Q)P(Q)P**	**OAZ_1P**	**AZ_1P**
Viscosity	502	486	476	445





Estimated cost of bleaching chemicals for ECF sequences								
Bleaching Chemicals	**Unit**	**DED**	**DE_PD**	**ODED**	**Price**	**DED**	**DE_PD**	**ODED**
					US$/Kg	**US$/ton pulp**	**US$/ton pulp**	**US$/ton pulp**
Oxygen	**Kg/ton pulp**			**30**	0.12	0	0	3.6
ClO2 as reagent	**Kg/ton pulp**	**13.31**	**13.31**	**11.41**	**1.00**	13.31	13.31	11.41
Hydrogen Peroxide	**Kg/ton pulp**		**10**		0.75	0	7.5	0
Total NAOH	**Kg/ton pulp**	**10**	**10**	**25**	**0.7**	7	7	17.5
MgSO4-total	**Kg/ton pulp**		**2**	**5**	0.2	0	0.4	1
DTPA- EP stage	**Kg/ton pulp**		**2**		1	0	2	0
Total cost	**US$/ton pulp**					**20.31**	**30.21**	**33.51**
Estimated AOX	**Kg/ton pulp**	4.9	4.9	4.2				
AOX (kg/ton pulp)= 0.7(Cl_2/1 + NaClO/2 + ClO_2/5) all chlorine compounds as Kg/ton pulp active chlorine								

Estimated consumption and cost of chemicals- TCF sequences (O_3 -40% consistency)					
Estimated consumption of chemicals- TCF sequences					
Chemical	**Unit**	**AZ_1P**	**AZ_2P**	**AZ_3P**	**AZ_4P**
H_2O_2 applied in P stages	%	3	3	3	3
NaOH- P stages	%	1.5	1.5	1.5	1.5
$MgSO_4$ - P stage	%	0.2	0.2	0.2	0.2
DTPA- P stage	%	**0.2**	**0.2**	**0.2**	**0.2**
H_2SO_4 to reduce pH	?	?	?	?	?
Ozone	Nm^3/kg pulp		?	?	?
Estimated Cost of Bleaching Chemicals for TCF sequences					
Chemical	**Price**				
	US$/kg	**AZ_1P**	**AZ_2P**	**AZ_3P**	**AZ_4P**
H_2O_2 applied in P stages	0.75	22.5	22.5	22.5	22.5
NaOH- P stages	0.7	10.5	10.5	10.5	10.5
$MgSO_4$ - P stage	0.2	0.4	0.4	0.4	0.4
DTPA- P stage	1	**2**	**2**	**2**	**2**
H_2SO_4 to reduce pH	?	?	?	?	?
Ozone	US$ 1/Nm^3		?	?	?
US$ Total excluding H_2SO_4 and O_3 per ton pulp		**35.4**	**35.4**	**35.4**	**35.4**

Estimated consumption and cost of bleaching chemicals- TCF sequences (O_3 -40% consistency)						
Esimated consumption of bleaching chemicals- TCF sequences						
Chemical	**Unit**					
		O(Q)P(Q)P	**OAZ_1P**	**OAZ_2P**	**OAZ_3P**	**OAZ_4P**
Oxigen	%(weight)	**3**	**3**	**3**	**3**	**3**
H_2O_2 applied in P stages	%	3	3	3	3	3
NaOH- oxygen stage	%	1.5	1.5	1.5	1.5	1.5
NaOH- P stages	%	3	1.5	1.5	1.5	1.5
NaOH- total	%	**4.5**	**3**	**3**	**3**	**3**
$MgSO_4$ -oxygen stage	%	0.5	0.5	0.5	0.5	0.5
$MgSO_4$ - P stages	%	0.4	0.2	0.2	0.2	0.2
MgSO4- total	%	**0.9**	**0.7**	**0.7**	**0.7**	**0.7**
DTPA- P&Q stages	%	**0.8**	**0.2**	**0.2**	**0.2**	**0.2**
H_2SO_4 to reduce pH	%	?	?	?	?	?
Ozone	Nm^3/kg pulp		?	?	?	?
Estimated cost of bleaching chemicals for TCF sequences						
Chemical	**Price**					
		O(Q)P(Q)P	**OAZ_1P**	**OAZ_2P**	**OAZ_3P**	**OAZ_4P**
	US$/Kg	**US$/ton pulp**	**US$/ton pulp**	**US$/ton pulp**	**US$/ton pulp**	**US$/ton pulp**
Oxygen	0.12	**3.6**	**3.6**	**3.6**	**3.6**	**3.6**
H_2O_2	0.75	**22.5**	**22.5**	**22.5**	**22.5**	**22.5**
NaOH- total	0.7	**31.5**	**21**	**21**	**21**	**21**
MgSO4- total	0.2	**1.8**	**0.7**	**0.7**	**0.7**	**0.7**
DTPA- P&Q stages	1	**8**	**2**	**2**	**2**	**2**
H_2SO_4 to reduce pH	?	?	?	?	?	?
Ozone	US$ 1/Nm^3		?	?	?	?
US$Total excluding H_2SO_4 and O_3/ton pulp		**67.4**	**49.8**	**49.8**	**49.8**	**49.8**

Estimated consumption and cost of bleaching chemicals TCF sequences (O_3- 10% consistency)				
Estimated consumption of bleaching chemicals TCF sequences				
Chemical	**Unit**			
		OAZ_1P	**OAZ_2P**	**OAZ_3P**
Oxygen	%	3	3	3
H_2O_2	%	**3**	**3**	**3**
NaOH- total	%	**3**	**3**	**3**
$MgSO_4$ - *total*		**0.7**	**0.7**	**0.7**
DTPA- P stage	%	**0.2**	**0.2**	**0.2**
H_2SO_4 to reduce pH	%	?	?	?
Ozone	Nm^3/kg pulp	?	?	?
Estimated cost of bleaching chemicals TCF sequences				
Chemical	**Unit**			
	US$/kg	**OAZ_1P**	**OAZ_2P**	**OAZ_3P**
Oxygen	0.12	3.6	3.6	3.6
H_2O_2	0.75	22.5	22.5	22.5
NaOH- total	0.7	21	21	21
$MgSO_4$ - total	0.2	1.4	1.4	1.4
DTPA- P stage	1	2	2	2
H_2SO_4 to reduce pH	?	?	?	?
Ozone	US$ 1/Nm^3	?	?	?
US$ Total excluding H_2SO_4 and O_3/ton pulp	US$/ton pulp	*50.5*	*50.5*	*50.5*

Estimated cost of chemicals-Oxygen stage		
Oxygen	%	3
	kg/ton pulp	30
	US$/ton pulp	**3.6**
NaOH	%	1.5
	kg/ton pulp	15
	US$/ton pulp	**10.5**
$MgSO_4$	%	0.5
	kg/ton pulp	5
	US$/ton pulp	**1**
Total cost	US$/ton pulp	**15.1**

Annex 10. Summary of costs for equipment construction

Description	Contract No.	Cost (USD)	Funds Type
Civil works (M.P. Investment Ltd.)	6/2003	18,650	FC
Drying yard (Katani Ltd.)	11/2003	3,500	XA
Sisal chips feeding system (Katani Ltd.)	10/2003	8,380	XA
Washing system (TATC)	8/2003	19,800	XA
Civil works for washing system (M.P. Investment Ltd.)	9/2003	4,842	XA

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