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JUHA NURMI

CHUNKING AND CHIPPING WITH CONESCREW CHIPPER

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Metsäntutkimuslaitos on maa- ja metsätalousministeriön alainen vuonna 1917 perustettu valtion tutkimuslaitos. Sen päätehtävänä on Suomen metsätaloutta sekä metsävarojen ja metsien tarkoituksenmukaista käyttöä edistävä tutkimus. Metsäntutkimustyötä tehdään lähes 800 hengen voimin yhdeksällä tutkimusosastolla ja kymmenellä tutkimus- ja koeasemalla. Tutkimus- ja koetoimintaa varten laitoksella on hallinnassaan valtionmetsiä yhteensä n. 150 000 hehtaaria, jotka on jaettu 17 tutkimusalueeseen ja joihin sisältyy kaksi kansallis- ja viisi luonnonpuistoa. Kenttäkokeita on käynnissä maan kaikissa osissa.

The Finnish Forest Research Institute, established in 1917, is a state research institution subordinated to the Ministry of Agriculture and Forestry. Its main task is to carry out research work to support the development of forestry and the expedient use of forest resources and forests. The work is carried out by means of 800 persons in nine research departments and ten research stations. The institute administers state-owned forests of over 150 000 hectares for research purposes, including two national parks and five strict nature reserves. Field experiments are in progress in all parts of the country.

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Palahakkeen ja hakkeen valmistus kartioruuvihakkurilla

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Sasmo HP-30 is a medium-sized chunkwood chipper capable of producing both chips and chunks. Chunks have a lenght of 50—250 mm in fiber direction. Sasmo HP-30 has four conescrew knives available for chipping and two for chunking, each producing particles of a specific size.

The study consisted of four stages: output of chunking and chipping; power requirement and energy consumption of comminution; drying of chunks and chips; and charcoaling of chunkwood.

When comminuting pulpwood and whole-trees, the output of chunking was 40—46 and output of chipping 25—40 loose m^3 per hour. The chunking and chipping of slash and sawn surfaces were much slower.

The power requirement of chipping was higher than that of chunking. Power requirement increased with increasing stem diameter. Chipping consumed more energy (2.5—4.0 kWh/m^3) than chunking (1.0—2.5 kWh/m^3). Stem diameter had no effect on energy consumption.

Chunks dried in 3.4 m^3 bins considerably faster than chips during the first two months. This is contributed to the better air circulation inside the bin. After four months the moisture content of chunks (15 %) and chips (15—20 %) was almost the same.

Charcoal yields from 1-meter-long firewood (26.9 %) and chunkwood (25.9 %) were comparable. Chunkwood had a longer burning time but a higher percentage of fixed carbon (90.6 %) than firewood (85.1 %).

Sasmo HP-30 on kartioruuviperiaatteella toimiva hakkuri, jolla pystytään tuottamaan sekä haketta että palahaketta. Palahake on tavanomaista hienohaketta huomattavasti karkeampaa, pituudeltaan 50—250 mm. Sasmo HP-30-hakkurin terävalikoimaan kuuluu neljä terää haketusta ja kaksi palahaketusta varten. Jokainen terä tuottaa tiettyä palakokoa.

Tutkimuksessa selvitettiin haketuksen tuotosta, tehon tarvetta ja energian kulutusta, hakkeen ja palahakkeen kuivumista sekä palahakkeen hiiltoa.

Palahaketuksen käyttötuntituotos oli kuitupuulla ja koivukokopuulla 40—46 i—m^3. Haketuksen tuotos oli vastaavasti 25—40 i—m^3. Erityisesti sahapintojen ja hakkuutähteiden palahaketus, mutta myös haketus oli hidasta. Syynä tähän olivat syöttöaukon pienuus ja syöttölaitteen puuttuminen.

Haketuksen tehontarve oli palahaketusta suurempi. Tehon tarve kasvoi rungon läpimitan kasvaessa. Haketuksen energiankulutus (2,5—4,0 kWh/m^3) oli palahaketusta korkeampi (1,0—2,5 kWh/m^3). Rungon läpimitalla ei ollut vaikutusta energiankulutukseen.

Hakkeen ja palahakkeen erot kuivatuskokeessa olivat huomattavat. Ensimmäisen kahden kuukauden aikana palahake kuivui 3,4 m^3:n kontissa huomattavasti nopeammin. Neljän kuukauden kuluttua palahakkeiden (15 %) ja hakkeiden (15—20 %) kosteudet olivat kuitenkin lähes samat.

Palahakehiilen saanto (25,9 %) on vertailukelpoinen halkohiilen (26,9 %) kanssa. Palahakkeen hiilto kesti halkoja kauemmin, mutta palahakehiilen hiilipitoisuus (90,6 %) oli halkohiiltä (85,1 %) korkeampi.

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1. INTRODUCTION

At present almost all of the field comminution of wood in Finland is done with disc and drum chippers. There are several modifications of these two principles in use. The aim of these machines is to produce standard pulp chip size particles when the chips are used as fuel.

Over the past decade interest has been paid to the production and use of large-sized wood particles known as chunkwood. The United States, Finland, Norway and Sweden have been particularly active in this field. In 1985 an international co-operation project was started within the International Energy Agency (IEA/FE/PGC) to study chunking machinery, handling, drying and storing as well as the utilization of chunkwood in different fields of industry.

As part of Finland's contribution to the program the Finnish Forest Research Institute has completed a study in co-operation with Saastamoinen Iron Works on the Sasmo HP-30 chipper/chunker. The study is also part of the PERA (Wood as an Energy Source) project of the Finnish Forest Research Institute.

Sasmo HP-30 uses a conescrew knife as cutting principle. This principle was first tested as a wood comminution method in the United States by the North Central Forest Experiment Station in Michigan in the 1970's (Erickson 1976). In spite of the fact that the results were encouraging they never led to the construction of a commercial machine. Later the development was concentrated on the involuted disc slicer principle.

In 1978, independent from the work done by the North Central Forest Experiment Station, a Finnish agricultural technician, Pasi Kylmänen, built a prototype of a conescrew chunker for small-scale use. KOPO-Konepohja Oy, a company in Oulu, Finland, further developed the chunker and serial production was started in 1979. A total of 1500 light KOPO PH-10 and PH-15 chunkers were manufactured in 1979—1982. These were mostly for domestic use.

In May 1983 the production of KOPO chunkers was sold to Saastamoinen Iron Works in Kuopio, Finland and given a new name: Sasmo. In 1985 the iron works became an independent company and now carries the name Savomet Oy. Several changes in design have taken place during the last few years. The most important of these are the selection of interchangeable knives, each one capable of making particles of a specific nominal size, and massive flywheels. In addition to the small Sasmo HP-15 model, larger size classes HP-25 and HP-30 were brought onto the market. HP-25 is meant for use on strip roads as well as in the stands. HP-30 is used on landings.

Two studies have been done earlier on the KOPO PH-10 chunker at the Finnish Forest Research Institute. The first one by Hakkila and Kalaja (1981) described the whole KOPO chunkwood system including comminution, material analysis, handling and combustion of chunks. The second one by Heikka and Piirainen (1981) concerned the power consumption of small chippers including the KOPO PH-10 chunker. The following conclusions were made on the KOPO chunker when compared with disc and drum chippers:

— peak torque of comminution for PH-10 was high
— the torque on power take-off shaft fluctuated more and with a wider range
— energy consumption per unit volume of wood (kWh/m^3) was low
— peak torque decreased with increasing revolving speed
— output was high

Based on the experience gained in these previous studies, an experiment was set up to study the Sasmo HP-30 (Fig. 1). The special feature of the machine was the selection of six available knives, each producing particles with a different nominal length. The study was divided into four stages.

— In the first stage the output of Sasmo HP-30 was tested on 3 m Scots pine and birch pulpwood, birch whole-trees, Scots pine slash and sawn surfaces. Fuel consumption and bulk densities were also recorded.

Fig. 1. Sasmo HP-30 chunkwood chipper.
Kuva 1. Sasmo HP-30 palahakkuri.

Fig. 2. Mounting an L-size knife.
Kuva 2. L-terän kiinnitys käynnissä.

— In the second stage power consumption and requirement as well as torque were measured when comminuting trees in different diameter classes.
— In the third stage a drying study took place over the summer 1985. This was done by drying chips and chunks in 3,4 m^3 bins with ambient air. The emphasis was put on the effect of particle size on the rate of drying.
— In the fourth stage a pilot-scale experiment on charcoaling chunkwood and 1 meter long firewood took place.

2. TECHNICAL DATA ON SASMO HP-30

Sasmo HP-30 is a landing chipper/chunker. It is mounted on its own rolling chassis. As an alternative it can also be mounted on a truck. It is available both in rear and side-fed models. Power is provided from a farm tractor's power take-off shaft or from the truck engine.

The center of the HP-30 is a conescrew knife (Fig. 2). There are six different interchangeable knives available. Each produces particles of its own nominal size (Fig. 3). The factors controlling the particle size are (1) the pitch of the thread and (2) the number of threads on the knife. The maximum particle lengths in fiber direction, number of threads and the length of pitch are listed below for each knife.

	Chips				Chunks	
Knife code	3S	2S	S	M	L	XL
Max. particle length, mm	20	25	30	50	80	130
No. of threads	3	2	2	1	1	1
Pitch, mm	104	80	104	80	104	208

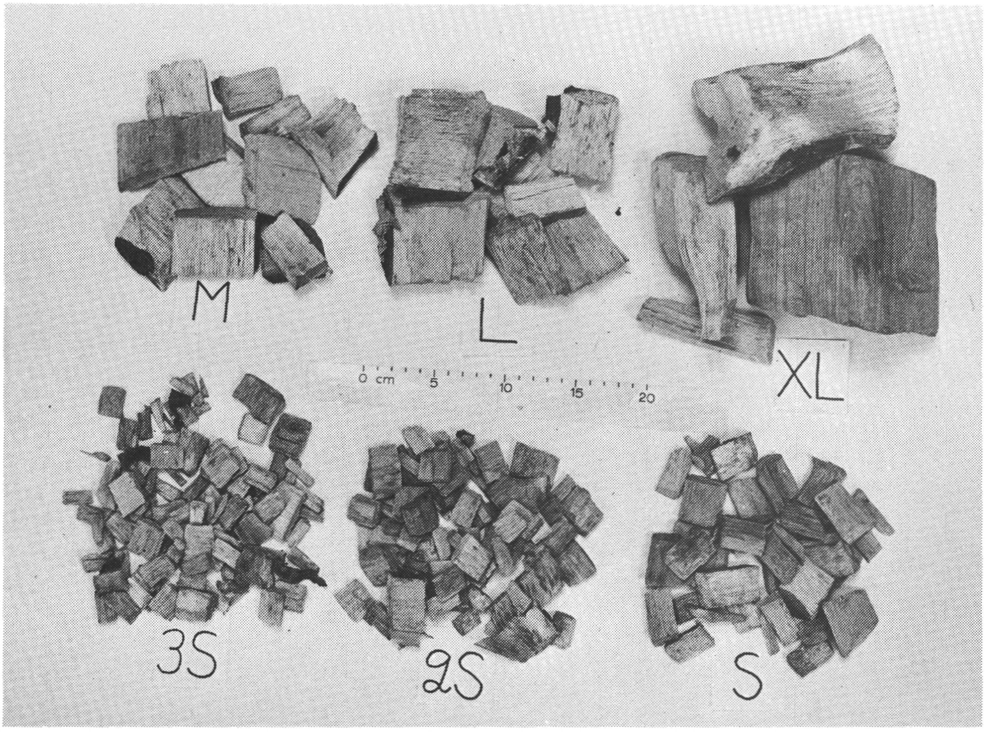

Fig. 3. Particle sizes produced with Sasmo HP-30.
Kuva 3. Sasmo HP-30:llä tuotettavat palakoot.

The knife is fastened to a 1500 kg flywheel with six bolts. The knife weighs 230—300 kg, depending on the size, and has a diameter of 600 mm at the base of the cone. Knife change is required if particles of a different size category are desired. The change will take 20—30 minutes.

The knife is most convenient to sharpen when in place. It is done with an electric or hydraulic grinder. The latter is specifically manufactured by Savomet Oy for the sharpening of conescrew knives. It can be taken to the field as it is powered by the hydraulic pump of the tractor. The most important technical specifications given by the manufacturer are as follows:

Model	Sasmo HP-30
Weight	3000 kg
Flywheel, weight	1500 kg
diameter	1200 mm
Knife	Choice of 6 different knives
Infeed opening	270 × 315 or 400 × 500 mm
Power requirement	60—110 kW
Power take-off speed	540—1000 rpm
Output	20—40 m^3 loose/h
Manufacturer	Savomet Oy, P.O. Box 156, 70101 Kuopio, Finland
Price	FIM 100 000 in April 1986 with one knife

3. MATERIAL AND METHODS

31. Time studies

The experiment was carried out on Saastamoinen Oy mill grounds in Kuopio, Finland during May 1985. Five assortments of wood were piled on the yard for the study on the output of comminution. These were 3-meter pine and birch pulpwood, birch whole-trees, pine slash and sawn surfaces from a sawmill. Each assortment was comminuted with each of the six knives.

A 80 kW Fiat farm tractor was used as the power source. A Patu 2710 grapple loader mounted on the tractor was used for infeeding.

A total of 701 loose m^3 of chips and chunks were made. The amount of each assortment and the number of knives used are given below.

	Pine pulpwood	Birch pulpwood	Birch whole-trees	Pine slash	Sawn surfaces
Volume, m^3 loose	152	176	150	91	134
No. of knives used	6	6	6	4	6

Because of the large number of knives vs. assortment combinations, only some 25 loose m^3 of material were produced in each category.

Time consumption of comminution was recorded for each knife and assortment combination. After comminution each load was scaled and then weighed with a Haenni WL 100 vehicle scale and moisture samples were taken. Fuel consumption of the tractor was measured with a graduated glass.

32. Power measurements

The second stage of the study dealt with torque, revolving speed and power consumption of comminution. For this purpose the following components were used:

— torque and speed transducer HBM T30FN
— measuring amplifier set MBM.N.Mz.D8
— peak detector built at the Forest Research Institute
— FM tape recorder TEAC R-61

The transducer was placed between the power take-off axle and the drive shaft, then connected to the amplifier set, the peak detector and the tape recorder.

Birch was used as test tree species. Trees were delimbed and sorted into three diameter classes (2—5, 5—10 and over 10 cm). Measurements were made at the butt and not at the breast height. This was done because the butt is also where the greatest torque is created. This is why the results of this study are given as a function of butt area. See Table 1 for data on test stems. Power take-off speed of 1000 revolutions per minute was used.

The test stems were manually fed one by one into the HP-30 with no time lapse in between the stems. Particles were blown into a graduated container so that the volume and weight could be recorded.

During comminution the torque and speed as well as power comsumption, calculated from the two factors above, were simultaneously recorded on tape. Peak torque readings for each stem were manually recorded from the display during chipping. Energy comsumption and mean power requirements for each knife and diameter class were calculated from the recordings with an ABC 80 micro computer.

To approach the circumstances of a practical operation as much as possible, test trees were also comminuted in bunches and fed in with a grapple loader. There were 6—7 bunches per knife, each containing 5—7 stems (Table 2). Otherwise the procedure was the same as with single stems.

33. Drying and storing experiment

To study the effects of particle size on drying and storing characteristics of chips and chunks, six 3,4 m^3 bins were built of raw lumber and 20 mm wire screen. There was one for each knife, i.e. particle size.

Table 1. Data on single test stems according to the knife and butt diameter class.
Taulukko 1. Tietoja yksittäisistä koerangoista terän ja tyviläpimittaluokan mukaan.

Variable *Muuttuja*	Knife — *Terä* 3S	2S	S	M	L	XL
	Diameter class 2—5 cm — *Läpimittaluokka 2—5 cm*					
Mean diameter, cm *Tyven keskiläpimitta, cm*	4.6	4.5	4.5	4.4	4.5	4.4
Number of stems *Rankojen lukumäärä*	23	36	35	35	35	30
Mean stem volume, dm^3 *Rangan keskitilavuus, dm^3*	4.2	3.8	4.0	3.7	4.1	3.9
Total volume, dm^3 *Kokonaistilavuus, dm^3*	96.6	136.8	140.0	129.5	143.5	117.0
	Diameter class 5—10 cm — *Läpimittaluokka 5—10 cm*					
Mean diameter, cm *Tyven keskiläpimitta, cm*	7.0	7.0	7.1	7.1	7.0	7.3
Number of stems *Rankojen lukumäärä*	34	35	35	35	35	30
Mean stem volume, dm^3 *Rangan keskitilavuus, dm^3*	10.0	9.6	9.8	9.7	9.4	10.7
Total volume, dm^3 *Kokonaistilavuus, dm^3*	340.0	336.0	343.0	339.5	329.0	321.0
	Diameter class >10 cm — *Läpimittaluokka >10 cm*					
Mean diameter, cm *Tyven keskiläpimitta, cm*	12.1	12.3	12.6	12.4	11.7	12.6
Number of stems *Rankojen lukumäärä*	16	20	20	20	20	20
Mean stem volume, dm^3 *Rangan keskitilavuus, dm^3*	31.0	29.3	30.1	29.7	22.8	32.4
Total volume, dm^3 *Kokonaistilavuus, dm^3*	496.0	586.0	602.0	594.0	456.0	648.0

Table 2. Data on bunched test stems according to the knife.
Taulukko 2. Tietoja kourakasoissa olleista koepuista.

Variable *Muuttuja*	Knife — *Terä* 3S	2S	S	M	L	XL
Mean butt diameter, cm *Tyven keskiläpimitta, cm*	7.0	6.8	7.0	7.5	7.6	6.7
Number of bunches *Kasojen määrä*	6	6	7	6	6	6
Mean bunch volume, dm^3 *Kasan keskitilavuus, dm^3*	60.7	53.6	52.7	61.6	63.0	52.0
Total volume, dm^3 *Kokonaistilavuus, dm^3*	364.2	321.6	368.9	369.6	378.0	312.0

Birch pulpwood was used as raw material. This was done to have as uniform material as possible and to reduce the number of factors affecting drying to a minimum.

The bins were located on an open mill yard about 100 meters from a lake. They were filled with freshly comminuted wood on the 22nd of May and emptied on the 17th of September, 1985.

To follow the moisture changes in the material, a portable strain gauge system of tree cells was used ro weigh the bins. Weighing was done after the bins were filled and from there on every morning on weekdays for the following two months. From August on, weighing was done less frequently. Wood moisture samples were taken before and after drying.

34. Charcoaling experiment

The charcoal yield from XL-size chunkwood was compared with the yield from ordinary 1-meter-long firewood. This was done by charcoaling the material in a 4,1 m^3 portable metal kiln. The instructions for the construction of a similar, so-called Mark V, portable kiln are given in a guide by Tropical Products Institute (Whitehead 1980). The kilns operate with the reverse draught principle.

This stage was only a pilot study and consisted of only one charge of chunkwood and one of firewood. A mixture of birch and grey alder was used as raw material in both kilns. The experiment was carried out in Kiihtelysvaara, Eastern Finland in mid-December.

Chunks and firewood were weighed before charcoaling. The yield was weighed, screened and weighed again. Moisture samples were taken from the wood and charcoal. The fixed carbon content of screened charcoal was determined according to the LECO Coke and Coal standard.

4. RESULTS

41. Output of comminution

It can be seen from Table 3 that the output is affected by both the knife and the wood assortment. Pulpwood in general gives the highest output. This is because of the uniformity of the material, high solid wood content, and ease of handling. Birch whole-trees were long, which reduced the idling time considerably compared to other materials. As a result the output per operating hour was as high as with pulpwoods.

Comminution of pine slash and sawn surfaces was difficult as the infeed opening was too small for these materials. Even though most of the slash was tree tops, handling and

Table 3. Output (m^3, loose) per operating hour and the share of idling time (%) according to the knife size.
Taulukko 3. Käyttötuntituotos (i—m^3) ja tyhjänäpyörimisajan osuus (%) puutavaralajin mukaan.

Timber assortment *Puutavaralaji*	Knife — *Terä* 3S	2S	S	M	L	XL
	Output, m^3 loose/h — *Tuotos, i—m^3/h*					
Pine pulpwood — *Mäntykuitu*	30	25	35	32	40	44
Birch pulpwood — *Koivukuitu*	24	24	35	37	39	46
Birch whole-trees — *Koivu kokopuu*	32	29	40	37	40	46
Pine slash — *Hakkuutähde*	—	—	39	33	13	17
Sawn surfaces — *Sahapinta*	9	29	22	13	18	14
	Idling time, % — *Tyhjänäpyörimisaika, %*					
Pine pulpwood — *Mäntykuitu*	53	53	45	47	56	57
Birch pulpwood — *Koivukuitu*	48	57	54	45	45	55
Birch whole-trees — *Koivu kokopuu*	35	25	35	33	42	42
Pine slash — *Hakkuutähde*	—	—	36	58	70	56
Sawn surfaces — *Sahapinta*	50	30	47	51	48	52

Table 4. Fuel consumption per solid cubic meter of wood (dm^3/m^3) and in per cents of the energy content of wood at 40 % moisture content (%).
Taulukko 4. Polttoaineen kulutus kiintokuutiometriä kohti (dm^3/m^3) sekä prosentteina puun energiasisällöstä 40 %:n kosteudessa.

Timber assortment *Puutavaralaji*	Unit *Yksikkö*	Knife — *Terä* 3S	2S	S	M	L	XL
Pine pulpwood	dm^3/m^3	1.47	2.00	1.33	1.38	0.98	0.84
Mäntykuitu	%	0.75	1.03	0.68	0.71	0.50	0.43
Birch pulpwood	dm^3/m^3	1.89	1.69	1.20	1.23	1.00	0.63
Koivukuitu	%	0.76	0.68	0.48	0.50	0.40	0.25
Birch whole-trees	dm^3/m^3	1.76	2.00	1.37	1.44	1.41	1.06
Koivu kokopuu	%	0.75	0.85	0.58	0.60	0.60	0.45
Pine slash	dm^3/m^3	—	—	1.61	1.72	1.55	0.97
Hakkuutähde	%	—	—	0.82	0.88	0.79	0.50
Sawn surfaces	dm^3/m^3	2.23	1.67	2.02	1.77	1.27	1.49
Sahapinta	%	1.16	0.87	1.05	0.92	0.66	0.78

infeeding with the grapple loader was time consuming. The sawn surfaces were thin and they broke easily when handled. Their ends would spread out making it very difficult to aim the material into the opening. These complications had obvious effects on the output. Comminution of pine slash was slightly more productive than sawn surfaces (Table 3).

The varying properties of different wood assortments have similar effects on most of the medium-sized chippers. This is why the most interesting feature in this particular study is the comparison of the knives, i.e. particle sizes.

The effect of the knife on output is most clear when pulpwood or whole-trees are comminuted. As a general rule it can be concluded that the larger the particles, the higher the production. On an average the output of chunking with XL-knife was 30—50 % higher than chipping with these three assortments. The shorter pitch of 2S- and M-knives could be expected to reduce the output as they have a slower rate of infeed. This, however, is not clearly indicated by the results.

The effect of the knife on the comminution of pine slash and sawn surfaces, the two less uniform assortments, is not similar to the conclusions made above. It was found that comminution to chunk size particles with L- and XL-knives was difficult. Apparently a knife with only one thread and a long pitch is incapable of handling these materials without more sophisticated feeding devices. On the other hand, production of proper chunkwood from these assortments may not even be possible because of their non-uniform structure.

The fuel consumption of chipping was 0,63—2,23 dm^3 per solid cubic meter of chipped wood. This means that the energy content of consumed fuel equals to 0,25—1,16 % of the energy content of comminuted wood at 40 % moisture content (Table 4).

The results indicate that fuel consumption is very dependent on the degree of comminution. Chunking with XL-knife especially required much less fuel than did chipping. Depending on the assortment and knife, chipping required 0,50—1,00 dm^3/m^3 more fuel than chunking with XL-knife. This means minimum fuel savings of about 30—50 %, which is important from the contractor's point of view.

Despite the considerable differences in fuel consumption between chipping and chunking, it should be remembered that the energy consumption of comminution accounts only for a small percentage of the total energy consumption of fuelwood harvesting. This means that the differences between chipping and chunking may become negligible when the total fuel cost of harvesting is considered — including chain saw, forwarding, on-road transportation of the chipper and long-distance transportation of chips.

The bulk densities of fresh whole-tree chips and chunks were lower than for any other material because of the great percentage of branchwood and lower moisture content. However, the dry matter contents of whole-tree chips and chunks were compared with all the other assortments not including material from birch pulpwood (Table 5) because of the higher specific gravity of birch wood over Scots pine.

The high bulk densities of pine slash and sawn surfaces are explained by the high moisture content (50—60 %) of the material. The dry weights of sawn surfaces were close to those of pine pulpwood. This is logical as the surfaces were composed entirely of pine and spruce. The dry weights of pine slash were the lowest of all the materials (Table 5).

Bulk densities have been reported to be higher for chunkwood than for ordinary chips (Arola et al. 1982). This seems to hold true in this study with the material comminuted from pine and birch pulpwood, as the difference between chips and chunks was in the order of 10 %. The results from other materials do not seem to support this statement. These results, however, are based on small quantities of material and are no absolute by any means.

42. Power measurements

421. Torque

The torque that is exerted on the drive system can be expressed as a function of time. Figures 4—7 give a good visual comparison between the knives. There are no distinct differences among the knives in the shape of the graphs in a given diameter class. Sharp fluctuations found by Heikka and Piirainen (1981) with lighter KOPO PH-10 revolving at a speed of 630 revolutions per minute are completely lacking with Sasmo HP-30. For comparison a graph representing PH-10 is placed at the bottom of Figure 5. The contrast is noticeable and the effects of heavy flywheel and higher revolving speed are evident.

The greatest fluctuation in this experiment was found to occur when comminuting stems in bunches (Fig. 7). This is caused by the random shifting of stems in the bunch. This fluctuation, however, is not excessively high and is not likely to cause damage.

The torque increases with increasing diameter. The magnitude of torque, however, is about the same for large individual stems (>10 cm) and bunched trees. This is true inspite of the fact that the total cross-sectional area of bunched stems is greater. This is understandable because the stem area is already broken into smaller units, decreasing the torque.

The relationship between the butt area and torque is presented for each knife separately in Figure 8 where the average peak torques are plotted against the butt area. It can be seen that the peak torque is also dependent on the knife. As a general rule a greater degree of comminution causes more torque in all given diameter classes. The increase in

Table 5. Fresh and dry mass of chips and chunks according to the timber assortment.
Taulukko 5. Hakeirtokuution tuore- ja kuivamassa puutavaralajin mukaan.

Timber assortment *Puutavaralaji*	Variable *Muuttuja*	Knife — *Terä* 3S	2S	S	M	L	XL
				kf/m³			
Pine pulpwood	Fresh — *Tuore*	340	310	360	350	340	330
Mäntykuitu	Dry — *Kuiva*	154	136	156	155	171	165
Birch pulpwood	Fresh — *Tuore*	310	340	360	350	370	380
Koivukuitu	Dry — *Kuiva*	182	193	203	192	213	215
Birch whole-trees	Fresh — *Tuore*	280	270	290	310	270	270
Koivu kokopuu	Dry — *Kuiva*	160	153	168	175	160	179
Pine slash	Fresh — *Tuore*	—	—	330	320	310	300
Hakkuutähde	Dry — *Kuiva*	—	—	140	138	145	139
Sawn surfaces	Fresh — *Tuore*	375	360	370	380	370	380
Sahapinta	Dry — *Kuiva*	170	162	155	166	156	150

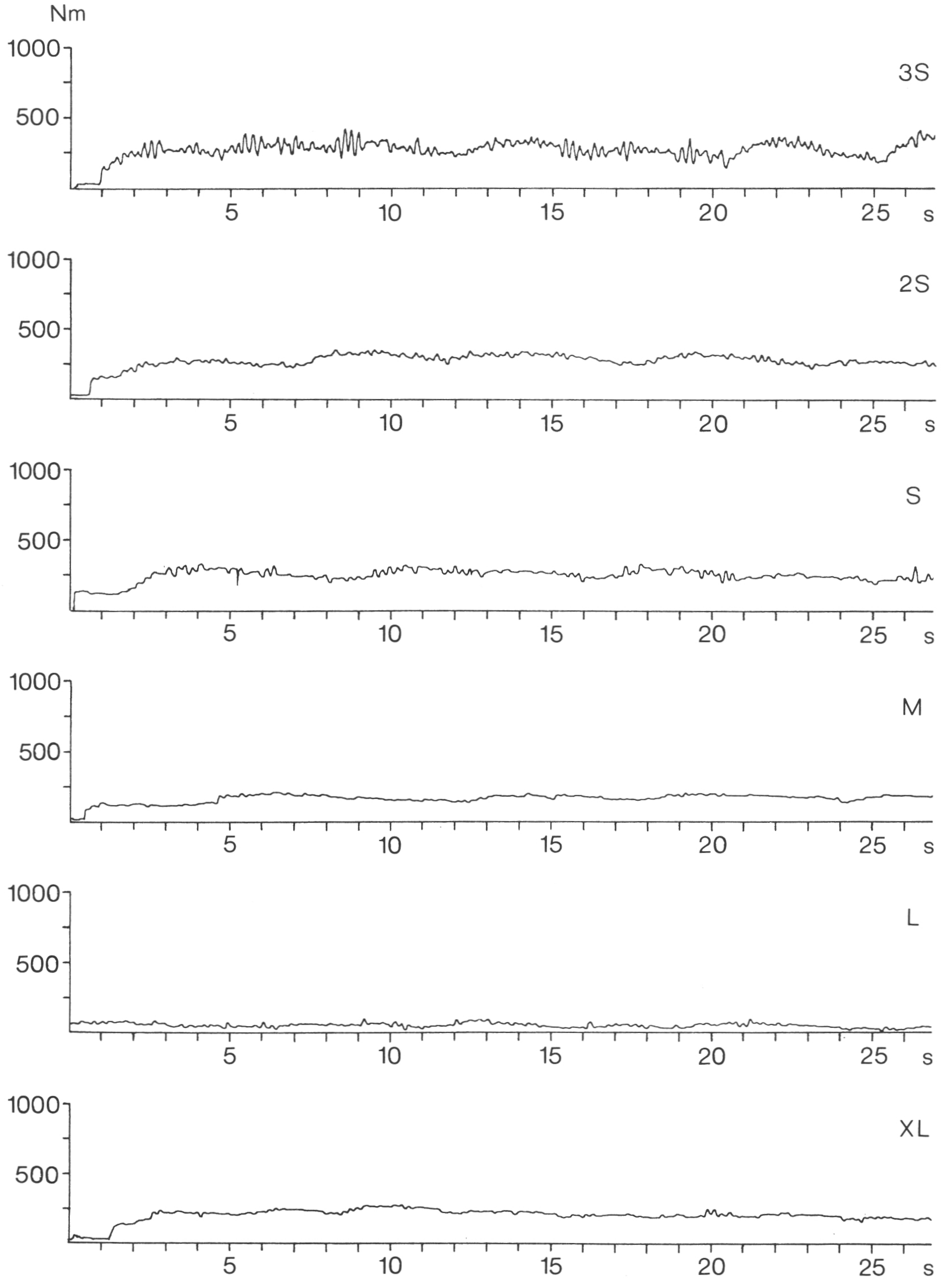

Fig. 4. Torque (Nm) as a function of time when comminuting trees in the 2—5 cm diameter class.
Kuva 4. Vääntömomentti (Nm) ajan funktiona 2—5 cm läpimittaluokan puita haketettaessa.

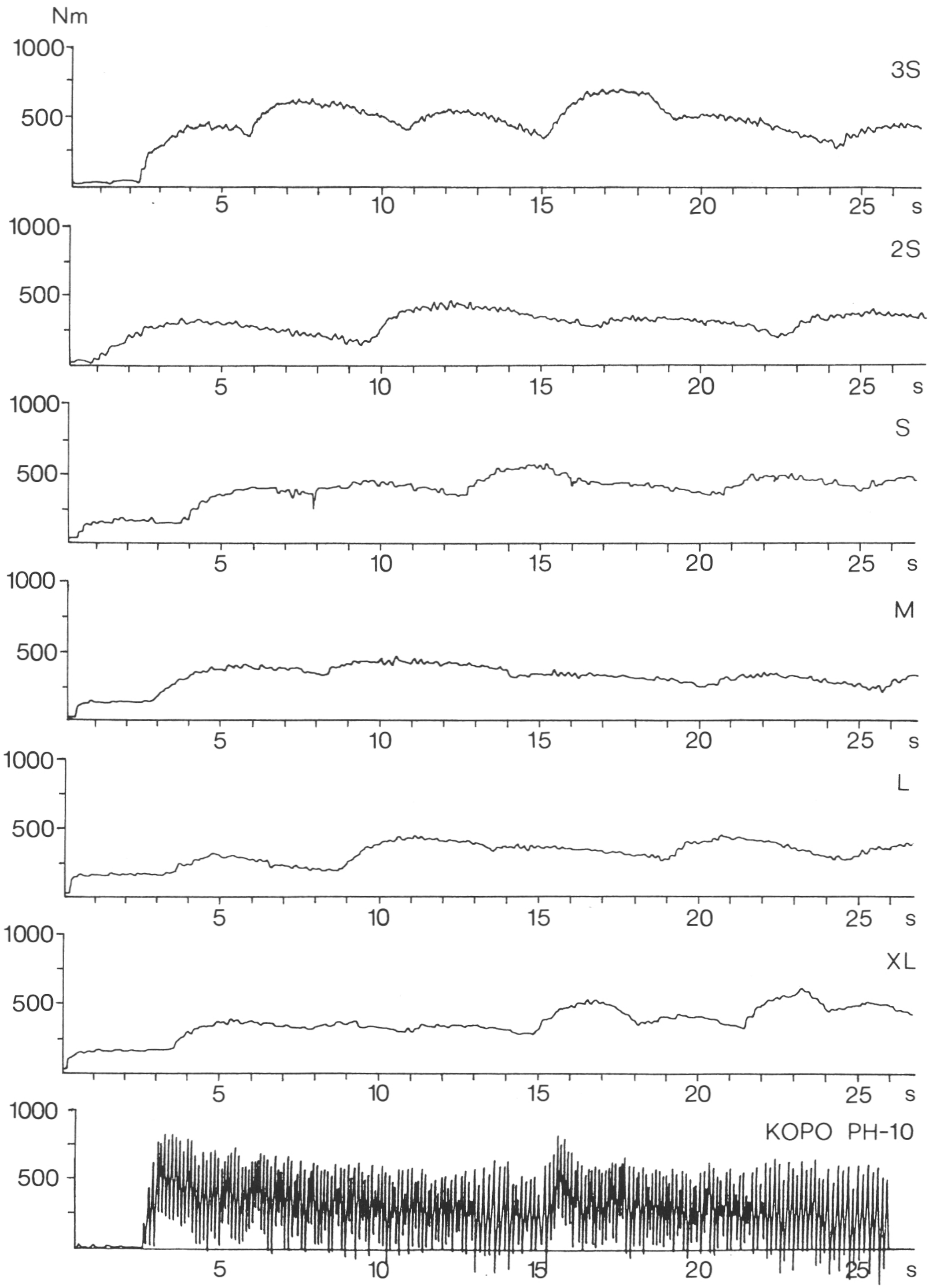

Fig. 5. Torque (Nm) as a function of time when comminuting trees in the 5—10 cm diameter class. KOPO PH-10 is according to Heikka and Piirainen (1981).
Kuva 5. Vääntömomentti (Nm) ajan funktiona 5—10 cm läpimittaluokan puita haketettaessa. KOPO PH-10 Heikan ja Piiraisen (1981) mukaan.

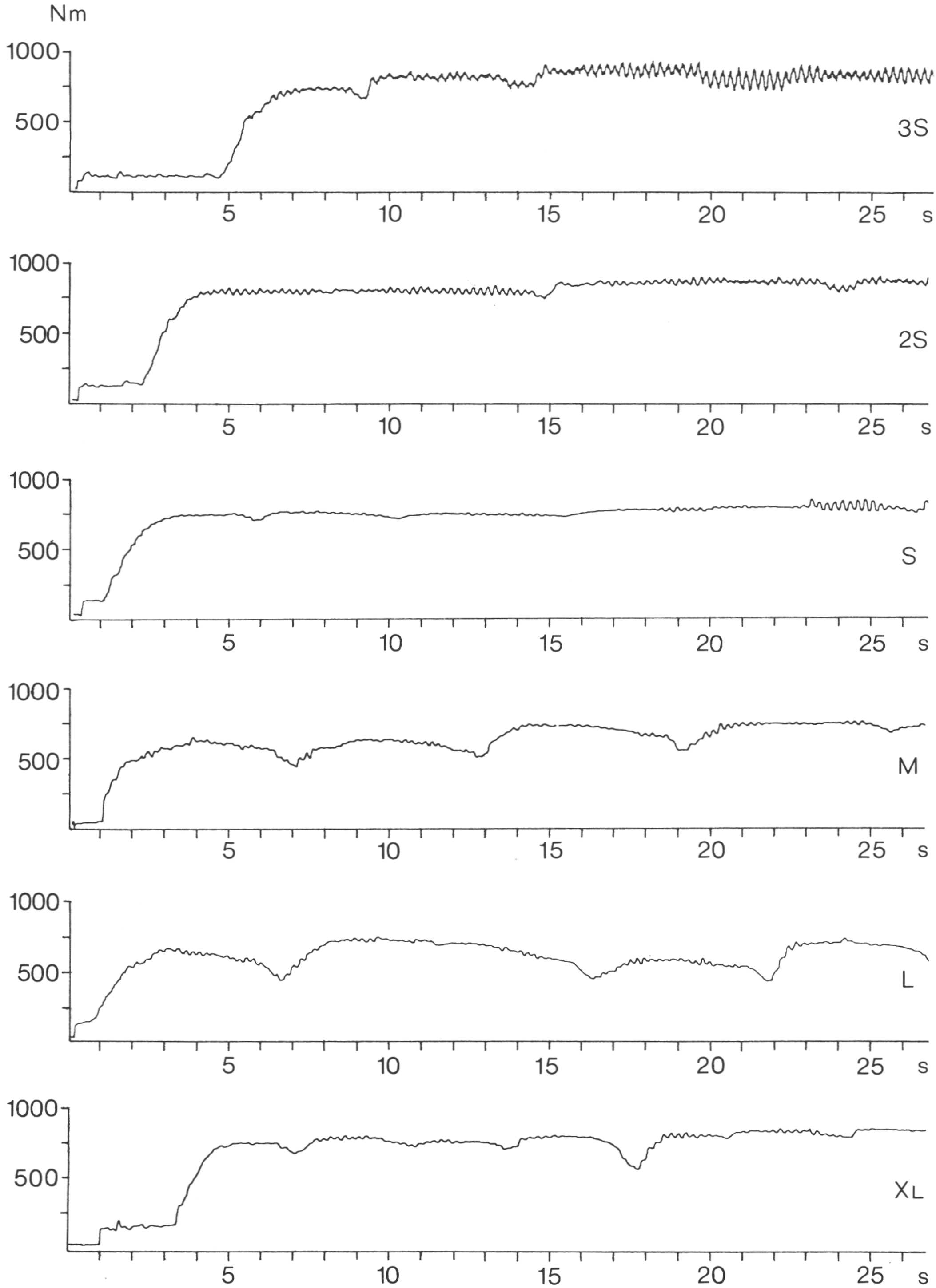

Fig. 6. Torque (Nm) as a function of time when comminuting trees in the >10 cm diameter class.
Kuva 6. Vääntömomentti (Nm) ajan funktiona>10 cm läpimittaluokan puita haketettaessa.

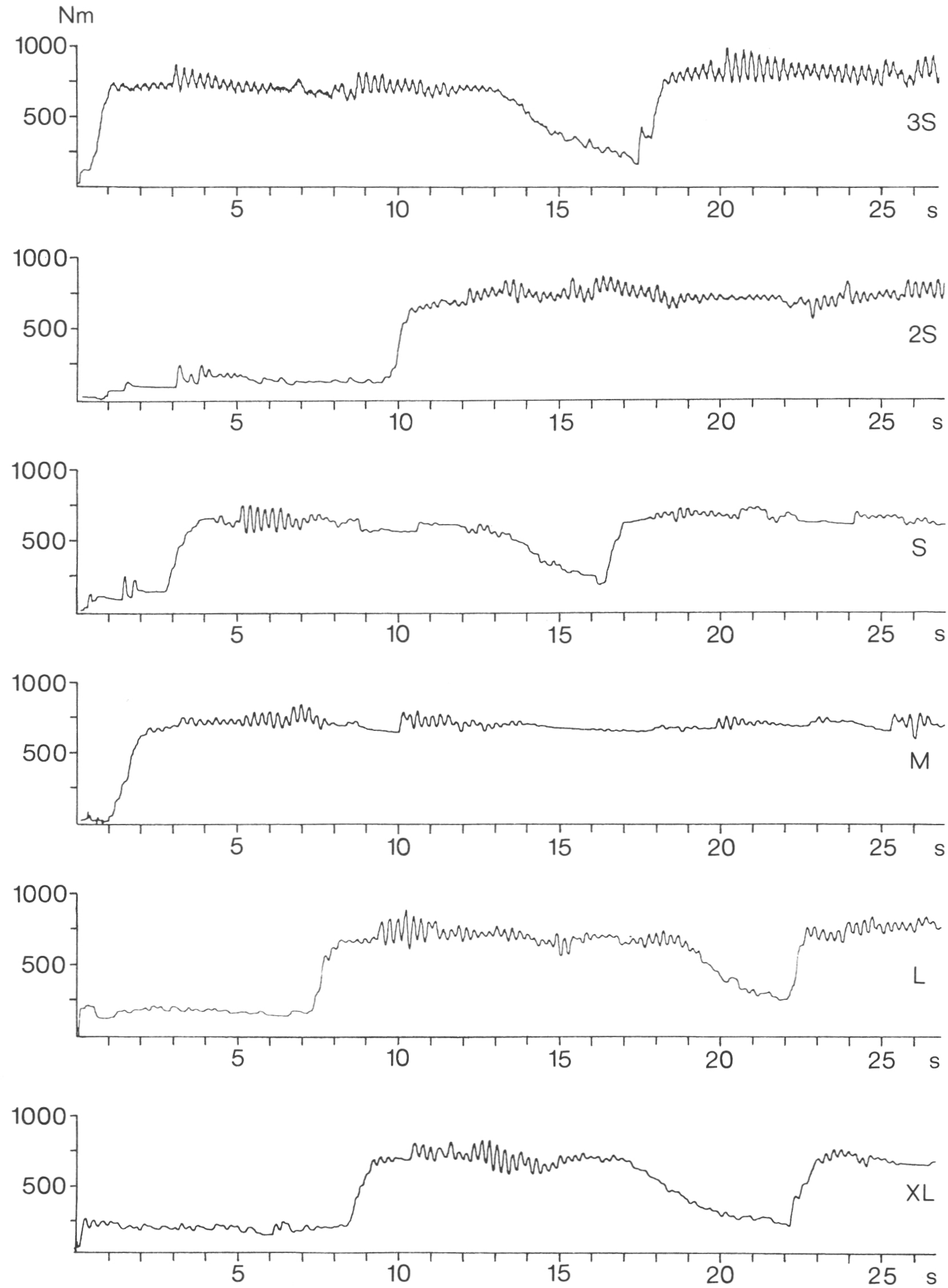

Fig. 7. Torque (Nm) as a function of time when comminuting bunched trees.
Kuva 7. Vääntömomentti (Nm) ajan funktiona kourakasoja haketettaessa.

butt area, however, had almost the same effect on the torque of all the knives. This causes the lines to be parallel but on different levels.

The highest torques were recorded for the largest stems. This is in accordance with earlier studies (Heikka and Piirainen 1981, Arola et al. 1982). The maximum readings for individual stems ranged 600—1000 Nm, which is well below the 1300 Nm setting of the slip clutch (Table 6).

When the knife cuts into a stem of a given diameter the friction between the wood and the knife is the greater the denser the threading, i.e. the cutting area is larger. Hence the torque-lines are in order according to the particle size. The XL-knife, however, is an exception.

The reason for the displacement of the XL-line is most likely found in the long pitch of the knife. When the stem is fed into the machine the knife will advance it a certain distance during each revolution. This distance is dependent on the pitch of the knife but is independent of the stem diameter. This means that XL-knife with its 208 mm pitch will advance a stem of any given diameter during one revolution twice as much as the knives with 104 mm pitch. As the knife cuts into the wood it causes a force in the downward direction. A high friction is formed between the stem and the surface of the infeed opening. The longer the distance the stem advances during each revolution the greater the resisting force and torque, and the more power is required to overcome the friction.

422. Power requirement

To quarantee the proper functioning of a chipper the manufacturer indicates a power requirement which is specific to the make. This requirement is usually the power of the

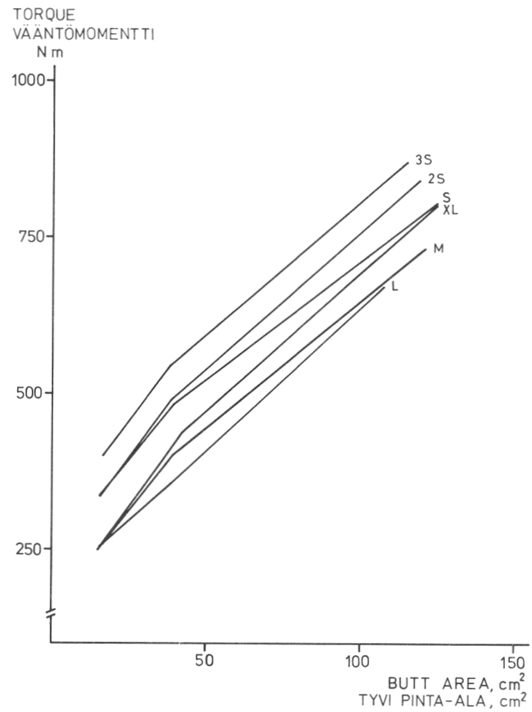

Fig. 8. Peak torque (Nm) as a function of butt area (cm^2).
Kuva 8. Huippuvääntömomentti tyven poikkipinta-alan (cm^2) funktiona.

Table 6. Maximum and mean torques (Nm) according to knife and butt diameter class.
Taulukko 6. Terien huippu- ja keskiarvovääntömomentti (Nm) rangan tyviläpimittaluokan mukaan.

Butt diameter, cm *Tyviläpimitta, cm*	Torque, Nm Vääntö-*momentti, Nm*	Knife — *Terä* 3S	2S	S	M	L	XL
2—5	Peak — *Huippu*	403	336	337	250	256	253
	Mean — *Kesk.*	184	197	204	144	139	158
5—10	Peak — *Huippu*	548	493	487	405	359	439
	Mean — *Kesk.*	359	328	329	260	231	296
>10	Peak — *Huippu*	874	843	809	735	675	803
	Mean — *Kesk.*	653	678	678	590	516	653
Bunches *Kourakasat* x = 7,0 cm	Peak — *Huippu*	910	857	749	803	845	729
	Mean — *Kesk.*	522	563	394	535	403	322

engine or the power at the power take-off shaft. The power requirement of a chipper or a chunker is difficult to determine because comminution is very uneven work. Tractor power, on the other hand, is determined with an even loading. To overcome the problem in this study the power consumption of each lot of test stems was divided by the time consumed in comminution, which gives the mean power (kW). The butt ends, however, cause power peaks which are considerably higher than the mean power.

In Figure 9 the mean power requirements for each knife are given as a function of butt area. The power requirement of idling (8—10 kW) has been deducted from the mean power to give the net power of comminution.

The net power requirement increases with increasing butt area. More power was needed to comminute wood to smaller particles than to large ones. An exception to this rule is the XL-knife which demands more power than M- and L-knives. As power is a product of torque and revolving speed the behaviour of the XL-knife can be explained with the same argument as with the torque in chapter 421.

Figure 9 shows the power requirements of the knives to be most dispersed in the 5—10 cm diameter class (40 cm²). To test the dispersion of mean power requirements in different diameter classes the coefficients of variation were calculated. The variation actually decreased with increasing butt area. The coefficients were 39,9% (2—5 cm), 25,2 % (5—10 cm) and 6,3 % (over 10 cm). Hence, the relative differences in net power

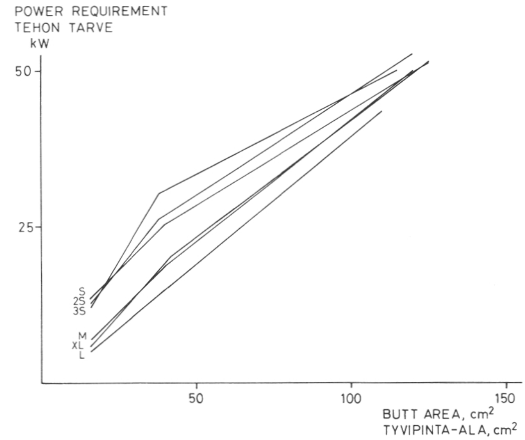

Fig. 9. The net power requirement (kW) of comminution as a function of butt area (cm²).
Kuva 9. Haketuksen tarvitsema nettoteho (kW) tyven poikkipinta-alan (cm²) funktiona.

requirement between knives decrease as the butt area increases.

In practice, infeeding of small stems is done in bunches with a grapple loader. This is why it is important to look into the results from the comminution of bunched stems. This is done best by comparing the power requirement of bunched and large individual stems.

Table 7 gives the power and the cross-sectional data for both assortments according to the knife. Roughly speaking the butt area of bunches was twice as large as the area of large individual stems. Despite this the power

Table 7. The power required by the comminution of bunched and individual stems.
Taulukko 7. Kourakasojen ja yksittäisten rankojen tehontarve.

Variable *Muuttuja*	Knife — *Terä* S3	2S	S	M	L	XL
	Power requirement, kW — *Tehontarve, kW*					
Bunched *Kourakasat*	37.6	39.9	29.2	38.0	28.2	21.5
Stems *Rangat*	50.1	52.5	51.1	49.7	43.6	50.9
	Cross-sectional area, cm² — *Poikkileikkauspinta-ala, cm²*					
Bunched *Kourakasat*	224.5	199.7	197.9	235.7	272.2	199.8
Stems *Rangat*	115.0	118.8	124.7	120.8	107.5	124.7

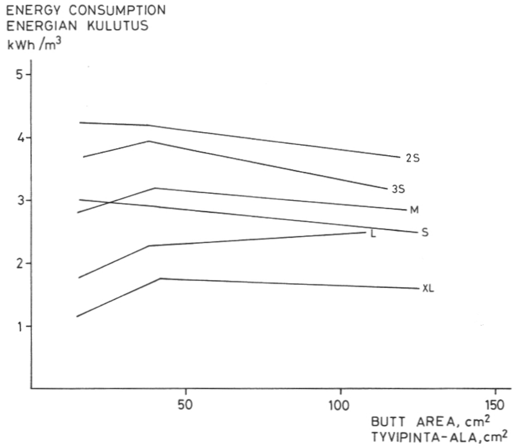

Fig. 10. The net energy consumption (kW/m^3) as a function of butt area (cm^2).
Kuva 10. Haketuksen nettoenergian kulutus (kW/m^3) tyven poikkipinta-alan (cm^2) funktiona.

required by comminution of large stems was considerably higher. A bunch that is composed of small units requires considerably less power to be comminuted than large individual stems. In this respect conditions are favourable for smaller machines in Scandinavia where most of the trees available for comminution for energy purposes are small in size.

423. Energy consumption

In chapter 41 the fuel consumption of the tractor was discovered to be greater in the production of small particles than in large ones. Similar evidence has also been reported previously by Heikka and Piirainen (1981) and by Arola (1983). These findings are also supported by the data collected in the power measurements of this study.

In Figure 10 the energy consumption (kWh/m^3), measured from the power take-off axle, is given as a function of butt area. The amount of energy required to idle the chipper/chunker has been subtracted leaving the energy consumption of comminution itself. Energy consumption was found to be independent of the area but differences between knives seem to be considerable.

If the assumption that a greater degree of comminution requires more energy was to hold with HP-30, the lines on Figure 10 should be in order according to the particle size. This was not, however, self-evident with HP-30. Comminution with 2S-knife required more energy than with 3S-knife. Also M-knife required more energy than S-knife. Both of these observations are contrary to the assumption.

When the lines are studied keeping the pitch of each knife in mind, the situation becomes clear. The S3-, S- and L-knives, all with a 104 mm pitch, are in the right order. Similarly 2S- and M-knives are in order of particle size. On these bases it can be concluded that with HP-30 both particle size and pitch affect the energy consumption. The 2S- and M-knives do not fall into the ''right'' place because knives with a shorter pitch require more energy per unit volume than those with a longer pitch.

Even though XL-knife has considerably higher torque and power requirements it consumed the least amount of energy of all the knives. This is caused by the least amount of comminution. The conventional chips required two to three times more energy per unit volume of wood than the XL-chunks did. This is in accordance with the results achieved by Radcliffe (1982) with the US Forest Service disc slicer (Table 8).

43. Drying and storing of chips and chunks

The initial moisture content of chips and chunks on the 22nd of May was 42,4 % (s = 1,8) on green weight basis. The dry matter content of wood in covered bins according to the particle size was 626 (3S), 624 (2S), 655 (S), 671 (M), 681 (L) and 727 kg (XL). Particle size distribution is seen in Figure 11.

Table 8. Energy consumption of chunking and chipping in a North-American experiment (Radcliffe 1982).
Taulukko 8. Haketuksen ja palahaketuksen energian kulutus eräässä Pohjois-Amerikkalaisessa kokeessa (Radcliffe 1982).

Species *Puulaji*	Chunks *Palahake*	Chips *Hake*	Ratio *Suhde*
Aspen *Haapa*	1.4	3.8	1/2.7
Red maple *Vaahtera*	2.1	5.5	1/2.6
Sugar maple *Vaahtera*	2.5	7.6	1/3.0

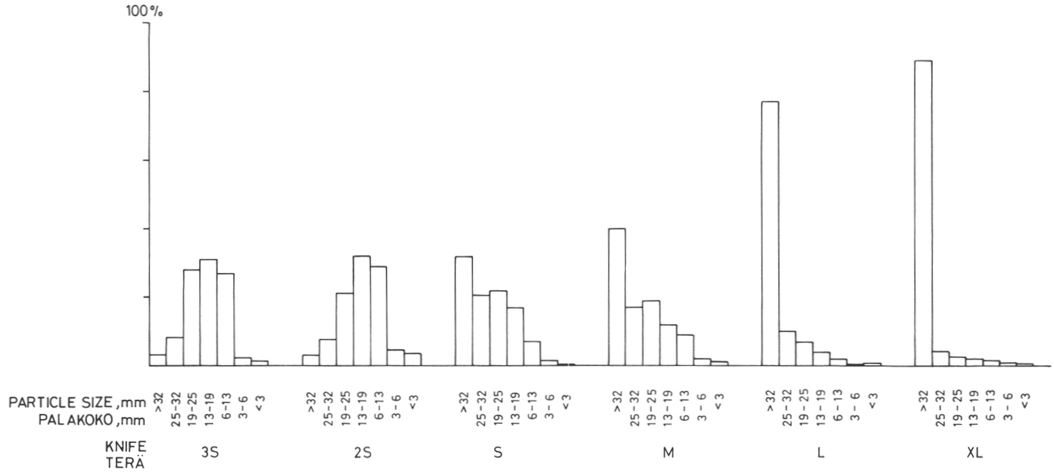

Fig. 11. Particle length distribution of birch pulpwood chips and chunks.
Kuva 11. Koivukuituspuusta valmistettujen hakkeiden ja palahakkeiden palakokojakaumat pituuden mukaan.

During the first days of drying the weather was poor. The average temperature ranged between −1,3 and +3,2 °C. Snow fell quite heavily from time to time. The mean monthly temperature, relative humidity and wind velocities are given below for the length of the experiment.

	June	July	August	September
Temperature, °C	13.7	16.1	15.7	9.4
Humidity, %	64	67	83	86
Wind, m/s	2.8	2.9	2.8	3.5

The changes in moisture content, based on the daily weighings, are shown in Figure 12 as a function of time. Only the weekly averages, however, are shown here. The differences between particle sizes are already evident in the first week. Chunks did not only dry faster but also reached a lower moisture content during the first two months of the experiment. This is contrary to the Swedish study where drying of chips and chunks from logging residue were tested (Fredrikson and Rutegård 1985). It should be noted that it took three of the smallest chip sizes (3S, 2S and S) twice as long as the chunks to reach any given moisture content above 20 %.

The differences in drying rate between chips and chunks are due to the air movement within the bin. Larger gaps of space are left between large particles than between small particles, which facilitate a freer air movement and moisture transfer to the sur-

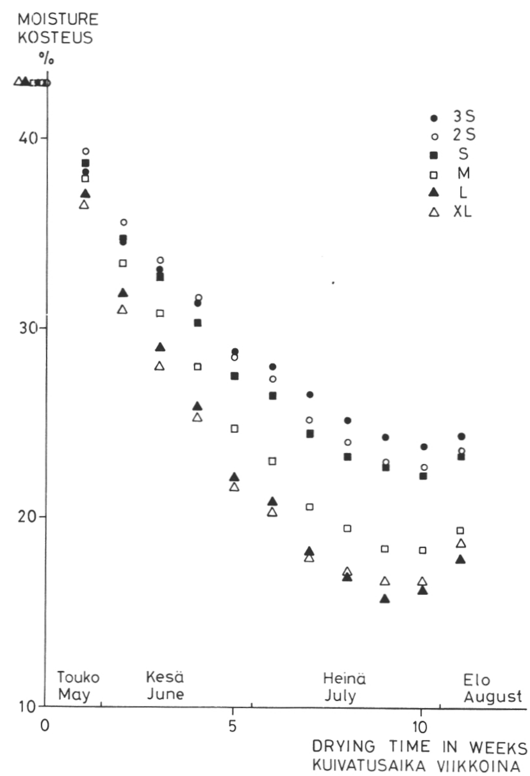

Fig. 12. Moisture content of chips and chunks (%) as a function of time.
Kuva 12. Hakkeen ja palahakkeen kosteus (%) ajan funktiona.

rounding air through, the chunk-bin than the chip-bin (Gislerud 1983, Sturos 1984a).

The drying of L- and XL-chunks was almost identical. This means that the combined rate of moisture movement out of the individual particles and out of the bin were equally fast for both chunk sizes in this given situation. If the bins had been larger, however, the rates of drying might have been different.

All the smallest particle sizes dried at a similar rate and were clearly different from the larger particles. Nonetheless, the effect of particle size is seen even here. S-size particles dried fastest followed by 2S- and 3S-particles. The drying of M-particles falls between the small chips and the chunks, but their drying followed chunks more closely than chips.

The bins were emptied on the 17th of September after 17 weeks of drying and storing. The final moisture content of wood in each bin can be seen in Table 9. The figures are based on samples taken at the end of the experiment.

It is seen here that all the particle sizes will eventually come to the same moisture content as they approach an equilibrium state with the ambient air (Sturos 1984b). It should be remembered that these figures represent the situation at the end of the study and are not necessarily the lowest values over the whole study period.

The changes in dry matter content during seasoning are based on the moisture samples taken at the beginning and at the end of the experiment as seen in Table 10. Because of the errors included in the sampling system, the results actually indicate an increase in dry matter contents. This, of course, is not possible. Although the standard deviations are small both at the beginning and the end, it is obvious that an error is involved. Either the moisture content was determined too high at the beginning or too low at the end. The latter is a more likely reason because drying leads to the formation of regions with varying moisture contents. This makes sampling difficult. As a result the possibility of the mean moisture content having a wrong weighing is very great. In this case all of the chips and chunks show an increase in dry matter which indicates a consistent error in all of the samples.

This assumption is supported by the results received from the daily weighings of the bins on the basis of the earlier knowledge that moisture change determinations by weighing over long periods give optimistic drying rates. This results from the fact that dry matter losses are shown as moisture losses giving

Table 9. The effect of particle size on drying of fuel chips.
Taulukko 9. Palakoon vaikutus polttohakkeen kuivumiseen.

Variable *Muuttuja*	Knife — *Terä* 3S	2S	S	M	L	XL
Initial MC, % *Alkukosteus, %*	42.4	42.4	42.4	42.4	42.4	42.4
Final MC (weighed), % *Loppukosteus (punnittu), %*	20.5	20.0	20.6	17.5	16.8	18.2
Final MC (sampled), % *Loppukosteus (näytteet), %*	20.4	18.8	19.0	15.2	15.5	15.1
Initial dry matter, kg *Kuivamassa alussa, kg*	626	624	655	671	681	727
Final dry matter (sampled), kg *Kuivamassa lopussa (näytteet), kg*	626	633	668	690	691	754
Change, % *Muutos, %*	0.0	+ 1.4	+ 2.0	+ 2.8	+ 1.5	+ 3.9
T-value *T-arvo*	0.0	0.94	1.21	1.99	1.02	2.62

Table 10. Charcoal yield from chunkwood and 1-meter firewood.
Taulukko 10. Puuhiilen saanto palahakkeesta ja halois-ta.

	Chunks *Palahake*	Firewood *Halot*	Earl, 1974
Green wood, kg *Tuorepaino, kg*	1137	1123	
Moisture content, % *Puun kosteus, %*	56.9	54.0	
Dry weight, kg *Kuivapaino, kg*	490	517	
Charcoal, kg *Puuhiiltä, kg*	125	139	
Total yield, % *Kokonaissaanto, %*	25.6	26.9	20—25
Charcoal, >20 mm, kg *Puuhiili, >20 mm, kg*	103	115	
Screened yield, % *Seulottu saanto, %*	21.0	22.2	
Share of over 20 mm particles, % *Yli 20 mm:n palojen osuus, %*	82.4	82.7	75—90
Fixed carbon[1)], % *Hiilipitoisuus[1)], %*	90.6	85.1	80—90
Charcoal moisture, % *Puuhiilen kosteus, %*	2.2	1.4	1—5
Non-carbonized wood, kg *Hiiltymätön puu, kg*	3.2	27.2	
Total time of burning and cooling, h *Palamiseen ja jäähtymiseen kulunut aika, h*	23	18	

[1)] Leco coke and coal standard 501—698
Leco koksi ja hiili standardi 501—698

too low a moisture content. Thus the true moisture content, which should be approached by sampling, will actually be higher. Now, however, the values based on sampling are consistently lower than those determined by weighing, leaving only the choice of consistent error.

The t-tests were run to test the significance of these differences in dry matter contents between the initial and the final values. As a result it was found that only the dry matter of XL-particles were found to be significantly different at the 95 % confidence level (see Table 9).

44. Charcoaling of chunks and firewood

Chunkwood and firewood kilns both contained an almost equal quantity of wood when fully loaded (Table 10). Chunkwood had to be screened with a 80 mm screen prior to use as 46 % of the particles it contained were too small to be classified as chunkwood. This high percentage of rejects was caused by the chunking of frozen wood with a truck mounted HP-30 chunker that had too high a revolving speed. As a result a lot of the chunks were splintered.

Even though, the experiment was done in mid-December, the results were satisfactory for both charges. For comparison a few figures from Earl's (1974) list of general features of wood charcoal are listed in Table 10. The yields of over 25 % are good considering the cold winter conditions. The longer carbonization time of chunkwood yielded more ash and a slightly lower yield. On the other hand, as a result of slower but more complete carbonization, the percentage of fixed carbon was higher in the charcoal from the chunkwood kiln (90,6 %) than from the firewood kiln (85,1 %). The faster process in the firewood kiln resulted also in a higher content of non-carbonized wood.

Although this pilot experiment consisted of only one charge of chunkwood and firewood, the yield results look promising for the chunkwood. The real advantage of chunkwood in charcoaling is that manual bucking of firewood and kiln loading could be replaced by chunking and mechanical loading. It is estimated that the use of chunks would reduce the preparation and loading costs by 25—35 %. The prerequisite for this, however, is that the chunkwood material is composed of at least 80—90 % of acceptable sized particles.

A drawback of chunkwood could be the long burning time. This, however, may be contributed to the inexperience with chunkwood charcoaling and may be sped up as experience is gained. On the other hand, the high percentage of fixed carbon in the chunkwood charcoal is contributed to the longer burning time.

5. SUMMARY

Sasmo HP-30 is a medium-sized chunkwood chipper capable of producing both chips and chunks. There is a choice of six different conescrew knives available — each producing particles of different nominal length. Four knives are available for chipping and two for chunking.

The study on Sasmo HP-30 chipper/chunker was divided into four stages. These were (1) output of comminution, (2) power measurements, (3) drying and storing of chips and chunks, and (4) charcoaling of chunkwood. The first three focused on the differences between chips and chunks. The fourth one dealt with charcoaling as a possible method of chunkwood utilization.

Output of the six alternative conescrew knives was tested on birch and pine pulpwood, birch whole-trees, pine slash and sawn surfaces. Output of chunking was found to be 30—50 % higher than chipping with pulpwood and whole-trees. Comminution of slash and sawn surfaces was difficult with all the knives, especially so with L- and XL-knives. Slash and sawn surfaces were found to be unsuitable as raw material for chunkwood.

Power measurements consisted of torque, power requirement and energy consumption. All measurements were done simultaneously. For this purpose test trees were divided into three classes according to butt diameter (2—5, 5—10 and >10 cm) and to an extra class of bunched stems. Torque and power requirement increased with an increasing butt area. In general, the greater degree of comminution increased both torque and power requirement.

Energy consumption, however, was found to be only dependent on the degree of comminution. Stem diameter had no effect on consumption. The short pitch of the conescrew increased power requirement.

The seasoning of chips and chunks was done in 3.4 m^3 bins over the period of four months. Chunks had a considerably faster drying rate than the chips during the first two months. Both chunk-sizes had an equal rate and the rate of M-size chips was closer to the rate of chunks than chips. The effect of particle size was also visible among the 3S-, 2S- and S-size particles, the largest having the highest rate. At the end of the four-month period the moisture contents were approaching a stage of equilibrium. The XL-chunks were at 15.1 % and the S3-chips 20.4 % moisture content. All the other particle sizes fall in between.

The charcoaling of chunkwood and firewood were compared in a pilot scale study. This was done in 4.1 m^3 portable metal kilns. The yield of chunkwood charcoal (25.6 %) was found to be comparable with the yield of firewood charcoal (26.9 %). The burning time of chunkwood was longer. This might be contributed to the inexperience with the material. The percentage of fixed carbon, however, was found to be higher in chunkwood charcoal (90.6 %) than in firewood charcoal (85.1 %).

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SELOSTE

Palahakkeen ja hakkeen valmistus kartioruuvihakkurilla

Palahakejärjestelmän kehittely alkoi 1970-luvulla lähes samoihin aikoihin sekä Yhdysvalloissa että Suomessa. Yhdysvalloissa kartioruuviperiaatteella toimivaa palahakkuria kehitteli North Central Forest Experiment Station Michiganissa. Rohkaisevista tuloksista huolimatta kaupallista hakkuria ei rakennettu. Myöhemmin samassa tutkimuslaitoksessa siirryttiin toisen palahaketusperiaatteen (involuted disc slicer) tutkimiseen, josta on olemassa kaksi prototyyppiä Yhdysvalloissa ja yksi Ruotsissa.

Täysin Yhdysvaltalaisesta tutkimustyöstä riippumatta maanviljelysteknikko Pasi Kylmänen rakensi vuonna 1979 vastaavalla periaatteella käytännön työhön soveltuvan laitteen. Vuosina 1979—1982 tätä isännänlinjan KOPO-palahakkuria valmistettiin noin 1500 kappaletta. Vuonna 1983 tuotanto siirtyi Saastamoinen Oy:n konepajalle, joka vuonna 1985 itsenäistyi Savonet Oy:ksi. Täällä tuotekehittelyn tuloksena syntyi kaksi urakoitsijaluokan keskisuurta hakkuria Sasmo HP-25 ja HP-30.

Tärkeimmät ulkoiset muutokset hakkureissa olivat massiivisen teräpyörän käyttöön otto sekä kartioruuviterien valikoima. Näillä uudistuksilla päästiin tasaiseen voimansiirtojärjestelmän ja nivelakselin rasitukseen sekä mahdollistettiin eri kokoluokan palojen valmistus eri terävaihtoehtoja käyttäen.

Kahdesta aikaisemmasta KOPO-palahakkuria koskevasta tutkimuksesta (Hakkila ja Kalaja 1981, Heikka ja Piirainen 1981) saatuihin kokemuksiin nojautuen Metsäntutkimuslaitoksen metsäteknologian tutkimusosasto suoritti toukokuussa 1985 Sasmo HP-30 koskevan tutkimuksen, joka liittyy toisaalta PERA-projektiin sekä toisaalta IEA:n kansainväliseen metsäenergiaprojektiin (FE/PGC).

Tutkimuksessa käsiteltiin hakkurin tuotosta, voimankäyttöä, hakkeen kuivumista sekä palahakkeen hiiltoa. Kolmessa ensimmäisessä vaiheessa selvitettiin lähinnä hakkeen ja palahakkeen eroja. Neljännessä vertailtiin palahakkeen ja halon hiiltoa.

Tutkimuksessa oli mukana kuusi kartioruuviterää. Niiden tunnukset ja tuotetun palan pituudet olivat seuraavat: 3S (20 mm), 2S (25 mm), S (30 mm), M (50 mm), L (80 mm) ja XL (130 mm). Tuotostutkimuksessa materiaaleina käytettiin mänty- ja koivukuitupuuta, koivukokopuuta, hakkuutähdettä ja sahapintoja. Palahaketuksen tuotos (L- ja XL-terät) oli 30—50 % haketuksen (3S-, 2S-, S- ja M-terät) tuotosta suurempi kuitupuulla ja koivukokopuulla. Hakkuutähteen ja pintojen haketus oli vaikeata kaikilla terillä, erityisesti L- ja XL-terillä. Hakkuutähde ja sahauspinnat osoittautuivat sopimattomiksi palahakkeen raaka-aineiksi.

Voimankäytön tutkiminen sisälsi vääntömomentin, tehon tarpeen sekä energian kulutuksen. Tutkimus kohdistui koivurankoihin, jotka jaettiin kolmeen tyviläpimittaluokkaan (2—5, 5—10 ja >10 cm). Lisäksi muodostettiin kourakasoja käytännön haketustilanteen jäljittelemiseksi. Kaikilla terillä haketettiin kaikissa läpimittaluokissa sekä kourakasoissa olleita puita (taulukot 1 ja 2). Vääntömomentti ja tehon tarve lisääntyvät tyvipinta-alan kasvaessa sekä palakoon pienentyessä. Energian kulutukseen ei rangan koolla ollut merkitystä. Palahaketuksen energian kulutus kiintokuutiometriä kohti laskettuna oli haketusta pienempi.

Hakkeen ja palahakkeen kuivumiskoe suoritettiin kesän 1985 aikana. Tätä tarkoitusta varten rakennettiin kuusi 3,4 m^3:n katettua hakehäkkiä — yksi kutakin palakokoa varten. Kosteuden muutoksia seurattiin päivittäin häkkien punnituksilla. Kahden ensimmäisen kuukauden aikana palahakkeet kuivuivat hakkeita huomattavasti nopeammin. Molempien palahakekokojen kuivuminen tapahtui samalla nopeudella. Kuitenkin on luultavaa, että suuremmissa muodostelmissa palahakkeet saattaisivat kuivua eri tahdissa. Palakoon vaikutus on myös havaittavissa pienimpienkin hakkeiden kohdalla, missä kuivuminen tapahtui järjestyksessä 3S-, 2S- ja S-hake. Neljän kuukauden kuivatuksen jälkeen eri palakokojen kosteudet olivat lähes samat. XL-palojen kosteus oli 15,1 % ja 3S-hakkeen 20,4 %. Muiden palakokojen kosteudet olivat tältä väliltä.

XL-palahakkeen hiiltoa kokeiltiin 4,1 m^3:n metallipöntöissä joulukuussa 1985 Kiihtelysvaarassa yhteistyössä Poppamiehet Oy:n kanssa. Vertailukohteena oli yleisesti hiillon raaka-aineena käytetty halko. Sekä hake että halot koostuivat koivu- ja leppäpuusta. Kyseessä oli pienimittainen esikoe, jossa palahaketta ja halkoja hiillettiin kumpaakin vain yksi erä. Vaikka koe suoritettiinkin talviolosuhteissa olivat saannot tyydyttävät. Palahakehiilen saanto (25,6 %) oli vertailukelpoinen halkohiilen saantoon (26,9 %). Palahakkeen palamisaika oli pitempi. Tämä saattaa kuitenkin johtua kokemattomuudesta palahakkeen hiillossa. Pitkästä palamisajasta johtuen saatiin palahakehiilen hiilipitoisuudeksi 90,6 %, kun se halkohiilellä oli 85,1 %.

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