BOREAL ENVIRONMENT RESEARCH 11: 283–293 ISSN 1239-6095
Helsinki 30 August 2006

Fine particle emissions from milled peat production

Jarkko M. Tissari[1)], Tarja Yli-Tuomi[2)], Taisto M. Raunemaa[1)], Petri T. Tiitta[3)], Janne P. Nuutinen[1)], Pentti K. Willman[1)], Kari E. J. Lehtinen[3)4)] and Jorma K. Jokiniemi[1)5)]

[1)] *University of Kuopio, Department of Environmental Sciences, Fine Particle and Aerosol Technology Laboratory, P.O. Box 1627, FI-70211 Kuopio, Finland*
[2)] *KTL, National Public Health Institute, P.O. Box 95, FI-70701 Kuopio, Finland*
[3)] *University of Kuopio, Department of Applied Physics, P.O. Box 1627, FI-70211 Kuopio, Finland*
[4)] *Finnish Meteorological Institute, P.O. Box 1627, FI-70211 Kuopio, Finland*
[5)] *VTT, Technical Research Centre of Finland, Fine Particles, P.O. Box 1000, 02044 VTT, Espoo, Finland*

Received 10 Jan. 2006, accepted 12 May 2006 (Editor in charge of this article: Veli-Matti Kerminen)

Tissari, J. M., Yli-Tuomi, T., Raunemaa, T. M., Tiitta, P. T., Nuutinen, J. P., Willman, P. K., Lehtinen, K. E. J. & Jokiniemi, J. K. 2006: Fine particle emissions from milled peat production. *Boreal Env. Res.* 11: 283–293.

Peat dust emissions and particle concentrations at different distances from a milled peat production field were studied for two different harvesting methods. The dust emissions were found to be sporadic. The momentary $PM_{2.5}$ concentrations, which varied up to 5 mg m^{-3} near the operation area, depended on the operation and weather conditions as well as peat composition. By using the Fugitive Dust Model, $PM_{2.5}$ emission rates were estimated to range from 0.3 to 43 g s^{-1}. Wind erosion increased the $PM_{2.5}$ concentrations remarkably at wind speeds over 4 m s^{-1}. Using time activity data of the different operational phases the lowest fine particle emissions were observed from the milling phase and the highest in the harvesting phases, respectively. As compared with the present EU daily limit value, the concentrations further from the peat production field were estimated to be low. However, short term negative influences on living conditions in the neighbourhood of peat production areas may be possible under certain environmental conditions.

Introduction

In Finland, peat is used as fuel and a horticultural material. Several operations in the production of milled peat generate dust emissions. Information on the emission rates and the extent of the dust dispersion are required to enable the estimation of the health risk and habitability in nearby surroundings. The knowledge of these effects is also needed for the environmental permission procedure and the environmental impact assessment. Epidemiological studies have shown a distinct correlation between adverse health effects and the concentration of fine particles in urban environments. Associations between particulate air pollution, respiratory illness and increased cardiovascular diseases have been reported in studies of e.g. Dockery *et al.* (1993), Künzli *et al.* (2000) and Mukae *et al.* (2001). However, the most responsible particle types or sources are yet uncertain.

The chemical composition and particle size distribution of peat dust deviates from urban aerosols. Thus their health effects may differ. How-

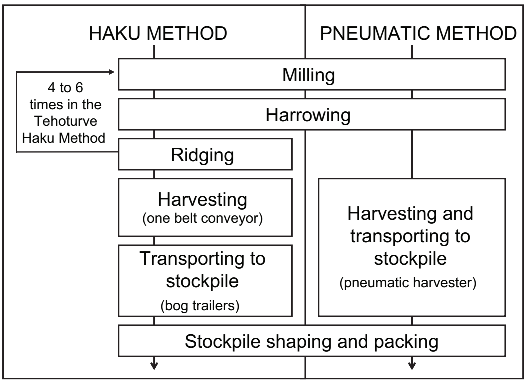

Fig. 1. Diagram from the milled peat production for HAKU and pneumatic-harvester methods.

ever, there are only a few occupational health studies on peat dust exposure. Sandstrom *et al.* (1991) reported a significant correlation between the respirable fraction of peat dust recorded in the breathing zone of the workers and a decrease in forced expiratory volume in one second (FEV1). The effect on lung function in non-asthmatic peat workers was, however, small. There are no long-term epidemiological studies on the peat dust exposure.

Globally there exists about 400 million hectares of peatland, from which annually around 100 million m^3 of peat is extracted. Only 0.05% of peatland resources in the world and 0.7% in Finland have been put in use (Selin 1999). The Finnish peatlands and production volumes are some of most important in Europe and globally. In Finland the production area was about 52 000 hectares in 1999 producing around 25 million m^3 of extracted peat. Two thirds of the extracted peat in the world and over 80% in Finland are used as fuel.

Peat production for fuel use requires several operational activities: milling, harrowing, ridging, collection, stockpiling, harvesting and transporting phases (Fig. 1). In the process a thin layer (circa 20 mm) of peat is first milled from the surface of the bog using a 6.5–9 m wide miller. The peat extracted in one milling is called harvest. The extracted layer is left on the bog surface and harrowed one to three times to accelerate the drying using a harrow with plastic spoons. The harrow operates over a width of 19 metres (Alakangas and Hölttä 1997). The drying of the milled peat to approximately 30%–60% moisture content takes around two days.

The extracted layer is harvested (collected) onto a stockpile using different harvesting methods. In Finland, about 80% of the milled peat is harvested with the HAKU method. In HAKU, the extracted peat is gathered onto the middle of the strip by a tractor-towed ridger. The length of a strip depends on the peat bog dimensions, and can vary from 100 m up to 1 km. Underneath the 9-m wide ridger flexible brush elements ensure effective lifting of the dry peat. The ridge is typically around 40 cm high and 80 cm wide. After the ridging, the peat is loaded from the ridge with a one-belt conveyor and transported to the stockpile by four tractor-driven bog-trailers. In the conventional HAKU method, peat is transferred onto the stockpile immediately after ridging. In the Tehoturve HAKU method, four to six harvests are piled together on the ridge before transport, which increases operational efficiency.

In Finland, about 10% of the milled peat is collected using the pneumatic-harvester method. The harvester collects the extracted peat like a vacuum cleaner directly into the 40 m^3 harvester silos and the harvester also transports the peat onto the stockpile. The new pneumatic-harvesters are equipped with a multicyclone that reduces emissions as compared with those of the old one. No ridging operation is required. The peat is also more homogeneous when collected with the pneumatic method. The operation is, however, rather vulnerable to weather conditions. In Finland, the milled peat is also collected using the mechanical harvester method as well as using the peco method, but these methods were not investigated in this study.

Once the peat has been collected on the stockpile location, the pile is shaped and packed by a bulldozer. One pile may contain several tens of thousands of cubic meters of peat. After a storage period, piles are loaded with a bucket loader onto a lorry and transported during the heating season to the peat power plant silos. Some of the piles are loaded also in summer, but to a lesser extent (Alakangas and Hölttä 1997).

Peat dust is emitted during the field operations from several types of sources, some being point sources (pneumatic-harvester cyclone outlet) and some fugitive sources (machine tyres, miller, harrow, etc.). Most of the sources are

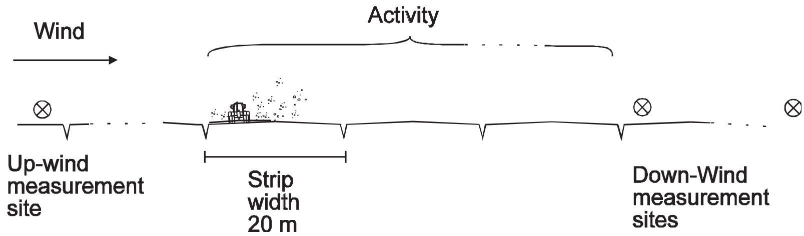

Fig. 2. Diagram of the layout of the sampling site. The circles with "x" within depict the particle sampler sites.

moving. In peat bog, the wind-risen dust is also an important dust source although not directly connected to the operational activities.

The aim of the present study was to experimentally determine the peat dust emission rates and particle concentrations on the field during different operation phases of the two main harvesting methods employed in Finland. In addition, a new pneumatic-harvester system could be compared with the old one. The role of wind in peat dust emission and the extent of dust dispersion at the production site were also important objectives of the study. As emissions vary considerably even within each operational phase, the emission levels, rather than the exact values, were of primary interest. The HAKU method and the emissions in loading were measured in the Konnunsuo peat bog in summer 2000. The results for the pneumatic-harvester method were obtained in the measurements at the Kaikonsuo peat bog in summer 1999 (Yli-Tuomi *et al.* 1999a, 1999b). The peat bogs are situated in central Finland.

Methods

Sampling methods and equipment

The particle concentrations at one upwind and two downwind locations from the peat production field were measured using six EPA-WINS samplers (BGI Inc., Waltham, MA). In each location a sampler with a PM_{10} inlet and another sampler with a TSP inlet were positioned side by side. A typical setup is presented in Fig. 2. The sampling time varied from 15 minutes to two hours depending on the operational phase and the dust concentration. Peat samples for moisture determination were taken after measurement for each operation (excluding few measurements).

The EPA-WINS sampler consisted of an EPA-WINS $PM_{2.5}$ impactor (BGI), a 47-mm filter holder (BGI), and a PQ100 pump (BGI). In addition, either a Graseby-Andersen PM_{10} inlet or a TSP inlet was employed. The sampler inlets were located at the height of 1.9 m above ground for the PM_{10} and at 1.2 m height for the TSP measurements. A flow rate of 16.7 l min^{-1} was used. Particles larger than 2.5 μm (50% cutsize) were collected on a Whatman or Gelman Sciences Glass Fiber Filter and particles smaller than 2.5 μm on Gelman Sciences Teflo™ 2 μm pore size filter. Normally, a small amount of oil is applied to the impactor filter in order to prevent any bounce of impacted particles from the impaction plate. However, particulate mass deposition cannot be determined from oiled filters. In this study, an estimation of the size distribution was needed and thus no oil was used. This might have led to a slight overestimation of the $PM_{2.5}$ mass. According to a rough estimation based on Hinds (1982), 15%–20% of particles larger than 2.5 μm in aerodynamic diameter may be bounced to lower collection stage. The PQ100 pump was equipped with a microprocessor-controlled timing and mass flow adjustment system. The airflow was normalised to the air pressure of 101.3 kPa and temperature of 20 °C. The samplers were calibrated in the laboratory with a bubble flow meter (Buck M-30) before and after the sampling.

The weather data were registered at the peat bog site. The weather station (Davis Instrument, GroWeatherLink) registers the air temperature, barometric pressure, relative humidity, wind speed and direction, dew point, rainfall and solar radiation at a height of 2 m every minute.

Gravimetric analysis

A microbalance (Mettler Toledo MT5, accuracy

1 μg) was used for the gravimetric analysis of filters, which were allowed to standardise to the temperature and relative humidity in the weighing room (40% ± 5% relative humidity, 20 ± 1 °C) for 24 hours before weighing. Each filter was decharged on both sides with a Po-210 alpha radiation source (Staticmaster Po-210 Ionizing unit). Two weightings within 1 μg were required before the mass value was accepted. The effect of air buoyancy was corrected in the weighing.

Fugitive dust model

Once the emission factors are known, a dispersion model can be used to estimate the environmental concentrations. Consistently, if the particle concentrations, weather conditions, and other factors affecting the concentrations and dispersion are known, a dispersion model can be used iteratively to estimate the emission rates. In this work, the EPA Fugitive Dust Model (FDM) (Winges & Wilson 1990) was employed.

The FDM is generally based on the well-known Gaussian Plume formulation, but an improved gradient transfer deposition algorithm has been incorporated. The line-source and area-source algorithms are based on algorithms in the CALINE3 Model (Winges and Wilson 1990). The model is well-suited for flat and exposed areas, similar to peat bog fields.

The FDM requires data for wind speed and direction, atmospheric stability, temperature and mixing height. Wind speed is used directly to determine the dust concentration. Atmospheric stability is used to determine the standard deviations of the horizontal and vertical plume dimensions. The Pasquill stability classes are defined by the values of sun radiation and wind speed. In peat dust dispersion the model is rather insensitive to the mixing height, since fugitive dust emissions are released at the ground level (Winges and Wilson 1990). In this study, a typical mixing height of 1000 m was used.

Other input parameters are the surface roughness height, particle density, anemometer height, emission rates and source and receptor co-ordinates. For roughness the value of 5 cm was used, which equates to the roughness of farmland. The peat dust density varies somewhat from less than 1 g cm^{-3} to over 2 g cm^{-3}. In this work the value of 1.5 g cm^{-3} was adapted (Puustijärvi 1973). The influence of dust density is rather small for fine particle dispersion because the deposition velocity is significantly different from the gravitational settling velocity for these particles (Winges and Wilson 1990).

In the FDM analysis, a moving source was modelled as a line source. The emission rate in units of g s^{-1} was converted to g s^{-1} m^{-1} based on the information on the number of times the tractor passed by the receptor site, on how many strips the tractor was working on, the dimensions of the strips, and the speed of the vehicle.

In the iteration, a value for the emission rate was guessed and the FDM was applied to calculate the concentration at the measurement site (receptor point) using the actual meteorological data (10-minute averages). The result was then compared with the gravimetrically determined mass concentration (upwind concentration subtracted). The starting value of the emission rate was adjusted until the modelled and measured peat dust concentration additions were equal. Each measurement for different operations was modelled separately.

Using typical emission rates for different operations, concentrations in the vicinity of a peat bog were modelled for typical meteorological conditions. The exhaust emissions of tractors were not considered in the modelling but may introduce some uncertainty in the concentration values. However, the tractor exhaust emissions are low as compared with the peat dust emissions. According to LIPASTO, a typical exhaust PM emission is 1.9 g kWh^{-1}, which corresponds approximately to an emission rate of 0.07 g s^{-1} (Mäkelä *et al*. 1999).

Results and discussion

Particle concentration on the milled peat production areas

The airborne particle concentration downwind of the peat production area depends on the up-wind concentration, the dust emissions from the activity on the field as well as on the distance from the activity and the factors affecting the dispersion.

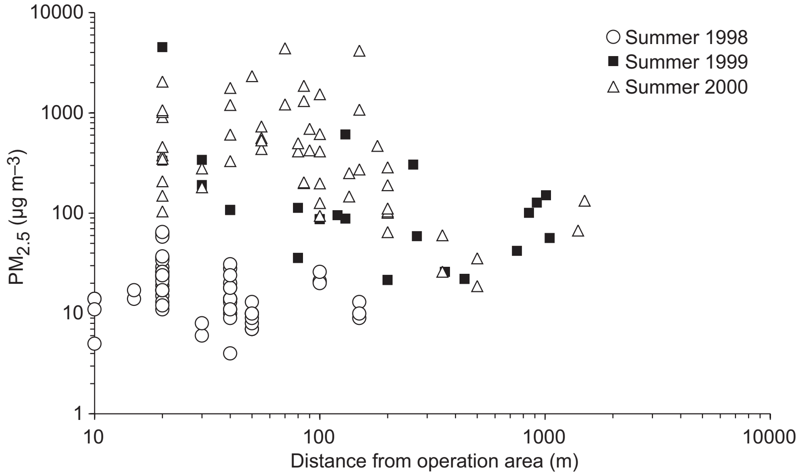

Fig. 3. $PM_{2.5}$ concentrations downwind of all operations except for stockpile shaping.

The weather and peat composition (moisture, decomposing) were found to primarily regulate the emission rate and dispersion of the peat dust. The $PM_{2.5}$ up-wind concentration varied from 4 to 460 μg m^{-3}. Concentrations up to 5 mg m^{-3} were measured at distances of 20–200 m from the field operations, while the maximum $PM_{2.5}$ concentration further away (200–1500 m) was about 300 μg m^{-3} (Fig. 3). Exceptionally high concentrations, up to 60 mg m^{-3}, were measured in the vicinity of stockpile shaping. The weather conditions and peat bog properties clearly affect the concentrations.

The peat moisture content is higher during all the operational activities in a rainy summer and the emission rates are accordingly lower. Yli-Tuomi *et al*. (1999b) observed in the rainy summer 1998 at Kortesuo the highest particle concentrations of only 65 μg m^{-3} (Fig. 3). In the warm and dry summer 1999 at the Kaikonsuo peat bog, the highest concentration was 5 mg m^{-3} (Fig. 3). The peat properties at the Kaikonsuo and Kortesuo peat bogs were rather similar. The peat at Konnunsuo was, on the other hand, very well decomposed as compared with peat at the Kaikonsuo and the Kortesuo fields. Well-decomposed peat, when milled and piled, is more easily dispersed than less-decomposed peat (Fig. 3). As also the weather conditions were mainly favourable for the peat production in summer 2000, the high dust concentrations were recognized at the Konnunsuo.

During favourable dry weather conditions, the peat is operated also at night. Stable atmosphere and inversion at ground level air, and consequently low wind speed and poor mixing during the night can result then in very high concentrations on the field.

Emissions

The $PM_{2.5}$ fugitive emissions ranged from 0.3 to 43 g s^{-1} with an average of 6.5 g s^{-1} (Table 1). The highest fugitive emissions were measured for the old pneumatic-harvester method (JIK 35), whereas with the new method (JIK 40) the emissions were the lowest. When evaluating the particle emission rates, wind erosion was not taken into account. Thus the values may also include wind-raised dust, not directly connected to the production method. Due to the sporadic nature of wind-raised dust (*see* next section), its true effect is difficult to estimate. In theory, wind-raised dust would lead to higher emission estimates from more distant receptors. This was observed in about half of our measurements, but not always at high wind speeds.

Yli-Tuomi *et al*. (1999a) determined the cyclone TSP emission of the new and old pneumatic-harvester with values ranging from 0.2 to 4.2 g s^{-1} and from 210 to 1050 g s^{-1}, respectively, depending on the degree of humification and the humidity of the peat. The $PM_{2.5}$ fraction was on average 40% of the TSP emission for the new and about 1% for the old pneumatic-harvester. The $PM_{2.5}$ fugitive dust emissions (Table 1) and the cyclone outlet emissions are thus of the same order of magnitude for the pneumatic harvesters.

The dustiest operations in the milled peat production were unloading onto the stockpile and stockpile shaping with a bulldozer (with average values of 17 g s^{-1} and 18 g s^{-1}) (Table 2). Loading onto a lorry was much less dusty with an average $PM_{2.5}$ emission of 1.3 g s^{-1}. The corresponding PM_{10} emission was 2.6 g s^{-1} and TSP emission of 8.1 g s^{-1}. Since the lorry loading operation occurs rather seldom, it is, however, insignificant as compared with the other operations.

During daytime, different sources have a variable contribution to the average concentration. The vehicle speed, the number of vehicles and the milled area of peatland vary from day to day, and operations are not carried out in equal sequence during every day. With the pneumatic-harvester method one strip must be driven even five times for each harvest (Table 3).

Fine particle emissions per extracted peat harvest were estimated using the time activity data from Kaikonsuo and Konnunsuo and average emission rates from Table 1. The lowest emissions were observed from the milling phase (1 kg per hectare per one harvest) in both the HAKU and new pneumatic-harvester methods (Table 4). The emission levels from the other phases were higher and varied between 2.1 and 15.1 kg per hectare during one harvest. The total emissions per harvest were 6.0 and 15.9 kg per hectare in the new pneumatic-harvester method and the HAKU method, respectively. The total emission was the highest for the pneumatic-harvester method with an old harvester, 18.9 kg per hectare. Since the produced peat volume per harvest in the HAKU method is higher than in the new pneumatic-harvester method, total $PM_{2.5}$ emissions per produced peat volume can be estimated to be of the same order of magnitude. Similarly in the pneumatic method the collection

Table 1. Details of the measurements and $PM_{2.5}$ fugitive emission rates (g s^{-1}) at Konnunsuo peat bog in summer 2000 (HAKU method) and at Kaikonsuo peat bog in summer 1999 (pneumatic-harvester method).

Production method	Phase[1]	Summer	Wind speed (m s^{-1})	Peat moisture content (%)	$PM_{2.5}$ emission (g s^{-1})
Pneumatic harvester	Milling	1999	4.5	40–45	1.7
Pneumatic harvester	Milling	1999	4.7	40–45	3.1
HAKU	Milling	2000	1.3	–	5.0
Pneumatic harvester	Harrowing	1999	3.8	53	5.8
Pneumatic harvester	Harrowing	1999	3.8	53	4.0
Pneumatic harvester	Harrowing	1999	3.8	53	7.5
HAKU	Harrowing	2000	4.5	–	9.4
HAKU	Ridging + miling	2000	2.4	34	2.7
HAKU	Ridging + miling	2000	2.4	34	6.4
HAKU	Harvesting	2000	2.0	37	3.9
HAKU	Harvesting	2000	2.0	37	12
HAKU	Harvesting	2000	1.7	43	9.5
HAKU	Harvesting	2000	1.7	43	5.9
Pneumatic harvester	Harvesting, JIK 40	1999	7.4	59	1.4
Pneumatic harvester	Harvesting, JIK 40	1999	4.0	36	0.6
Pneumatic harvester	Harvesting, JIK 40	1999	4.0	36	0.9
Pneumatic harvester	Harvesting, JIK 40	1999	4.0	36	5.8
Pneumatic harvester	Harvesting, JIK 40	1999	3.3	50	0.4
Pneumatic harvester	Harvesting, JIK 40	1999	3.3	50	0.3
Pneumatic harvester	Harvesting, JIK 35	1999	7.3	< 58	6.7
Pneumatic harvester	Harvesting, JIK 35	1999	7.2	< 58	11
Pneumatic harvester	Harvesting, JIK 35	1999	7.2	< 58	5.3
Pneumatic harvester	Harvesting, JIK 35	1999	2.9	29	1.6
Pneumatic harvester	Harvesting, JIK 35	1999	2.9	29	8.2
Pneumatic harvester	Harvesting, JIK 35	1999	2.9	29	43

[1]JIK 40 = new pneumatic-harvester, cyclone emissions 0.3 g s^{-1}, JIK 35 = old pneumatic-harvester with no secondary cyclones, cyclone emission 0.6 g s^{-1}. – = not measured.

Table 2. Details of the measurements and $PM_{2.5}$ emission rates (g s^{-1}) for unloading, loading and shaping of the stockpile at Konnunsuo peat bog in summer 2000 and at Kaikonsuo peat bog in summer 1999.

Production phase[1]	Summer	Wind speed (m s^{-1})	Peat moisture content (%)	$PM_{2.5}$ emission (g s^{-1})
Unloading	1999	1.8	36	9.6
Unloading	1999	1.8	36	8.9
Unloading	1999	1.6	43	45
Unloading	1999	1.6	43	11
Unloading	1999	1.6	43	14
Unloading	1999	1.8	43	17
Unloading	1999	1.5	43	15
Bulldozer	1999	4.0	–	20
Bulldozer	1999	4.0	–	3.9
Bulldozer	1999	4.0	–	3.7
Bulldozer	2000	5.8	33	46
Loading to lorry	2000	2.0	44	0.2
Loading to lorry	2000	2.0	44	0.5
Loading to lorry	2000	4.7	44	7.2
Loading to lorry	2000	4.7	44	1.4
Loading to lorry	2000	2.7	43	0.3
Loading to lorry	2000	2.7	43	0.2
Loading to lorry	2000	3.1	42	0.4
Loading to lorry	2000	3.1	42	0.1

[1]Unloading = Unloading into the stockpile with JIK 40. – = not measured.

Table 3. Time activity data and average $PM_{2.5}$ emission rates (in g s^{-1} from Table 1) used in calculating total emission per harvest (Table 4).

Production phase[1]	Velocity (km h^{-1})	Runs per strip	Runs per harvest, HAKU	Runs per harvest, pneumatic	$PM_{2.5}$ emission rate (g s^{-1})
Milling	12	2	1	1	3.3
Harrowing	9	1	5	2	6.7
Ridging-milling	12	2	3	0	4.3
Harvesting, HAKU	3.5	1	1	0	7.8
Harvesting, JIK 35	8	5	0	1	13.2
Harvesting, JIK 40	8	5	0	1	1.9

[1]JIK 40 = new pneumatic-harvester, cyclone emissions 0.3 g s^{-1}, JIK 35 = old pneumatic-harvester with no secondary cyclones, cyclone emission 0.6 g s^{-1}.

Table 4. Total emission per harvest (kg ha^{-1}) in the different production methods.

Production phase[1]	HAKU (kg ha^{-1})	Old pneumatic (kg ha^{-1})	New pneumatic (kg ha^{-1})
Milling	1.0	1.0	1.0
Harrowing	7.1	2.8	2.8
Ridging-milling	3.8	–	–
Harvesting, HAKU	4.0	–	–
Harvesting, JIK 35	–	15.1	–
Harvesting, JIK 40	–	–	2.1

[1]JIK 40 = new pneumatic-harvester, cyclone emissions 0.3 g s^{-1}, JIK 35 = old pneumatic-harvester with no secondary cyclones, cyclone emission 0.6 g s^{-1}.

cycle is faster (one to three days) as compared with that in the HAKU method (five to seven days), and therefore similar total emissions were produced during the same period of time (two pneumatic cycles corresponds approximately to one HAKU cycle).

Influence of peat moisture and air temperature on wind erosion

Wind erosion depends on peat quality, weather conditions and operational phase. Wind dust emissions are sporadic and spatially heterogeneous and cause difficulties for a precise assessment of their impacts (Fecan *et al.* 1999). The wind erosion occurs when a threshold value of the wind velocity is reached. The threshold value depends on peat surface features such as its water content and the decomposing level of peat.

The ability of wind to cause erosion is strongly and nonlinearly dependent on wind energy (Merrill *et al.* 1999). On the other hand, at high wind speeds the dilution is more efficient and particles are dispersed over long distances and concentrations in the neighbourhood of the source may be lower than at low wind speeds.

The thickness of the milled peat layer, the water content of peat and air temperature influences the amount of wind-raised dust. A thick layer of loose peat increases the probability of the wind erosion. Clausnitzer and Singer (2000) observed that for cultivation operations under widely different environmental conditions, the PM_4 (particles smaller than 4 μm in aerodynamic diameter) dust concentrations decreased as a power function of the soil water content and increased linearly with the air temperature. The influence of the moisture content has been attributed to the cohesion and adhesion forces of water and soil and to the effect on the weight of the soil particles (Fecan *et al.* 1999, Clausnitzer and Singer 2000). The peat dries from milling to harvesting and thus the probability of wind erosion is highest on strips just before harvesting.

In agricultural areas a threshold value of wind speed erosion was 4 m s^{-1} (Clausnitzer and Singer 2000). The threshold value on the peat field is somewhat lower, probably due to difference in the dust density. The emission of $PM_{2.5}$ particles increased with over 4 m s^{-1} wind speeds (Table 5). At 4 m s^{-1}, the $PM_{2.5}$ emission due to wind erosion was about 5 μg m^{-2} s^{-1}. When the peat bog surface did not have a layer of milled peat, the amount of wind-raised dust was substantially lower. When the layer was thick (e.g. after harrowing), the wind erosion was very high. Consistently the highest emissions occurred during combination of high wind speed and dry layer of milled peat on the field. However, the number of data was limited and more information is needed.

Particle mass fractions

The major particle mass emission was attributed to particle sizes larger than 10 μm (Table 6). The

Table 5. Details of the measurements and $PM_{2.5}$ emission rates (μg m^{-2} s^{-1}) for wind-raised dust at Konnunsuo peat bog in summer 2000 (HAKU method) and at Kaikonsuo peat bog in summer 1999 (Pneumatic harvester method).

State of the field	Summer	Wind speed (m s^{-1})	Peat moisture content (%)	$PM_{2.5}$ emission (μg $m^{-2}s^{-1}$)
After harrowing	1999	4.2	40	10.4
After harrowing	1999	4.2	40	4.7
No milled layer of the field	1999	2.6	30–43	0.7
No milled layer of the field	1999	2.6	30–43	0.4
After ridging	2000	2.4	55	3.2
After ridging	2000	2.4	55	0.0
After harrowing	2000	3.4	28	0.0
After harrowing	2000	6.0	28	7.1
After harrowing	2000	4.6	–	7.3
After harrowing	2000	4.6	–	5.2

– = not measured.

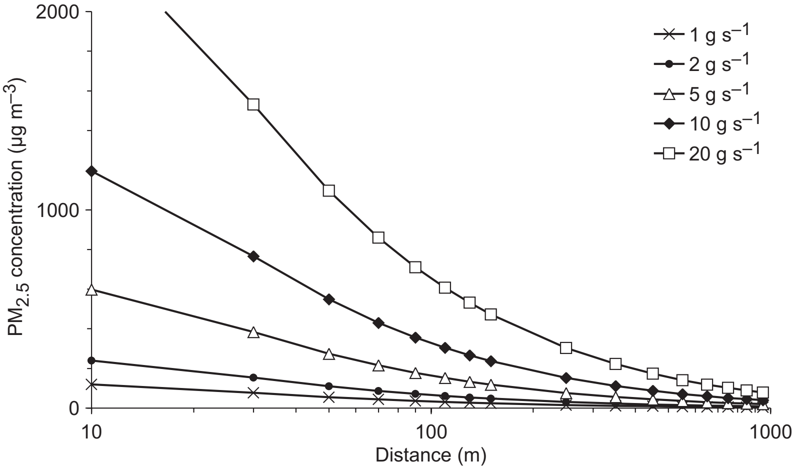

Fig. 4. $PM_{2.5}$ concentration *versus* downwind distance from peat production for different emission rates defined by the FDM model. Assumptions: sun radiation is moderate, temperature 20 °C, wind speed 3 m s^{-1}, stability class B, emission source width 20 m, emission height 0 m, number of milled strips 3, length of strips 1 km.

average PM_{10} mass fraction for all operations was 47% and the $PM_{2.5}$ mass fraction 33% of the TSP mass. The $PM_{2.5}$ fraction was, however, very high in the wind-raised dust and during the pile shaping. The higher settling velocity of coarse particles may affect the size distribution of wind-raised dust in wide peat production areas. There is only one measurement of the size distribution of the pile shaping and the reason for the high portion of $PM_{2.5}$ particles is unknown.

Dispersion

With FDM the concentrations at the peat bog area and its surroundings can be studied for different emission rates and weather conditions. If other conditions are kept constant, the concentrations observed at receptor sites are proportional to the source emission rate (Fig. 4). Naturally, also the wind direction in relation to the strip orientation affects the concentrations with essentially higher concentrations when the wind is parallel to the strips.

The most common Pasquil stability classes during the most active phase of peat production in summer in Finland are B and C (Yli-Tuomi *et al.* 1999b) (Fig. 5). Annually, the stability is classified as B for 2.7% and as C for 5.7% of the hours. During summer, the prevalence of B is 8% and C is 15% (Kukkonen and Savolainen 1988).

Table 6. Mass fraction of the Total Suspended Particulate (TSP) mass at Konnunsuo peat bog in summer 2000 for different peat production operations.

Production phase	< 2.5 µm (%)	2.5–10 µm (%)	> 10 µm (%)
Milling	10	15	75
Ridging	38	23	38
Harvesting, HAKU	23	15	62
Pile shaping	75	5	19
Loading to lorry	20	12	68
Wind erosion	74	6	20

Conclusions

Fugitive emissions and wind erosion are important dust sources in the milled peat production. The emission rates depend on peat quality and peat production method as well as prevailing weather conditions. Based on the measurements made at the Konnunsuo peat bog, the lowest calculated fine particle emissions per extracted peat harvest were observed from the milling phase (1 kg per hectare per one harvest) in both the HAKU and the new pneumatic-harvester methods. The emission levels from the other operational phases were higher and varied from 2.1 to 15.1 kg per hectare for one harvest.

The total emissions per harvest amounted to 6.0 and 15.9 kg per hectare in the new pneumatic-harvester method and the HAKU method, respectively. Since the produced peat volume in the HAKU method is higher (larger volume per harvest) than in the new pneumatic-harvester method, it can be estimated that the total $PM_{2.5}$

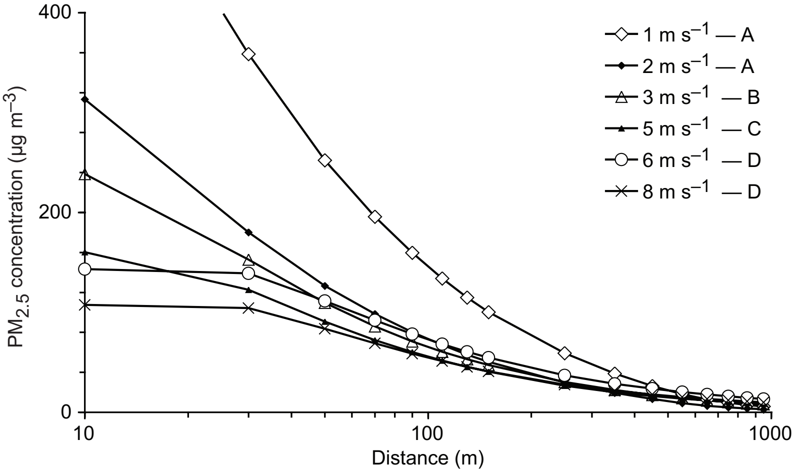

Fig. 5. $PM_{2.5}$ concentration *versus* downwind distance from peat production for different wind and stability values defined by the FDM model. Assumptions: emission rate is 2 g s^{-1}, temperature is 20 °C, emission source width is 20 m, emission height is 0 m, the number of milled strips is three and the length of the strips is 1 km. The combinations 2 m s^{-1} + A, 5 m s^{-1} + C, 6 m s^{-1} + D and 8 m s^{-1} + D do not appear when the solar radiation is in the medium level (Yli-Tuomi *et al.* 1999b).

emissions are of the same order of magnitude.

Momentarily during the peat harvesting and in the stockpile shaping operation, the fugitive emissions may rise high and result in dust dispersion over longer distances. The highest concentrations were in a range up to 200 meters from the operations. Kartastenpää *et al.* (1998) measured PM_{10} concentrations outside peat production areas. As compared with the present EU daily limit value 50 μg m^{-3} (EUR-Lex 1999), the observed concentrations were lower, 11 to 49 μg m^{-3}. However, short-term harmful influences on living conditions in the neighbourhood of peat production areas could be observed under certain environmental conditions.

With technological improvement the emissions from the pneumatic-harvester method have been reduced approximately by 90%. Generally, the emission reduction is difficult because low peat humidity content is preferred and the emissions are mainly from fugitive sources.

In 1991, about 6500 persons lived in the vicinity of the 335 peat production areas in Finland (Vartiainen *et al.* 1998). In order to decrease the costs of the peat transport, there is an increasing pressure to utilize also the bogs located close to large population sites. The emission rates estimated in this study can be used for the environmental impact assessment and in air quality studies in areas where peat production might be a significant particulate pollution source.

Acknowledgements: The authors thank Jari Marja-aho and Pirkko Selin of the Vapo Ltd for technical and scientific support of this work. The financial support from the National Technology Agency of Finland and Vapo Ltd is gratefully acknowledged.

References

Alakangas E. & Hölttä P. 1997. *Energiaturpeen tuotantotekniikka*. Project report ENE39/T0081/97. VTT Energy, Jyväskylä.

Clausnitzer H. & Singer M.J. 2000. Environmental influences on respirable dust production from agricultural operations in California. *Atmos. Environ.* 34: 1739–1745.

Dockery D.W., Pope C.A., Xu W., Spengler J.D., Ware J.H., Fay M.E., Ferris B.G.Jr. & Speizer F.E. 1993. An association between air pollution and mortality in six US cities. *New Eng. J. Med.* 329: 1753–1759.

EUR-Lex 1999. Council Directive 1999/30/EC of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air. *Official Journal* L163: 41–60.

Fecan F., Marticorena B. & Bergametti G. 1999. Parametrization of the increase of the aeolian erosion threshold wind friction velocity due to soil moisture for arid and semi-arid areas. *Ann. Geophysicae* 17: 149–157.

Hinds W. 1982. *Aerosol technology: properties, behaviour and measurement of airborne particles*. John Wiley & Sons, New York.

Kartastenpää R., Varjoranta R., Rantakrans E., Saari H., Marja-aho J., Selin P. & Haarala S. 1998. *Turvetuotannon pölypäästöt ja ympäristö. Pölypäästöt ja niiden leviäminen imukokoojavaunutuotannossa. Loppuraportti*. Finnish Meteorological Institute.

Kukkonen J. & Savolainen A.L. 1988. *Vaarallisten aineiden leviämisen arviointi onnettomuustilanteissa*. Air Protection Publications 4, Finnish Meteorological Institute, Helsinki.

Künzli N., Kaiser R., Medina S., Studnicka M., Chanel O., Filliger P., Herry M., Horak F.Jr., Puybonnieux-Texier V., Quénel P., Schneider J., Seethaler R., Vergnaud J.C. & Sommer H. 2000. Public-health impact of outdoor and traffic-related air pollution: a European assessment. *The Lancet* 356: 795–801.

Mäkelä K., Tuominen A. & Rusila K. 1999. *TYKO 1999. Työkoneiden päästömalli*. Technical Research Centre of Finland, Communities and Infrastructure. Contractor report 546/2000.

Merrill S.D., Black A.L., Fryrear D.W., Saleh A., Zopeck T.M., Halvorson A.D. & Tanaka D.L. 1999. Soil wind erosion hazard of spring wheat-fallow as affected by long-term climate and tillage. *Soil Sci. Society Am. J.* 63: 1768–1777.

Mukae H., Vincent R., Quinlan K., English D., Hards J., Hogg J.C. & van Eeden S.F. 2001. The effect of repeated exposure to particulate air pollution (PM10) on the bone marrow. *Am. J. Resp. Cri. Care Med.* 163: 201–209.

Puustijärvi V. 1973. *Kasvuturve ja sen käyttö*. Turveteollisuusliitto ry, Liikekirjapaino, Helsinki.

Sandstrom T., Kolmodin-Hedman B., Ledin M.C., Bjermer L., Hornqvist-Bylund S. & Stjernberg N. 1991. Exposure to peat dust: acute effects on lung function and content of bronchoalveolar lavage fluid. *Br. J. Ind. Med.* 48: 771–775.

Selin P. 1999. *Turvevarojen teollinen käyttö ja suopohjien hyödyntäminen Suomessa*. Ph.D. thesis, University of Jyväskylä, Finland.

Vartiainen M., Jantunen M., Willman P., Yli-Tuomi T., Raunemaa T., Marja-aho J. & Selin P. 1998. *Turvetuotannon pölypäästöjen ympäristöterveysriski. Loppuraportti*. Publications of the National Public Health Institute B11.

Winges K.D. & Wilson R.B. 1990. *User's guide for the Fugitive Dust Model (FDM) (revised), EPA-910/9-88-202R*. U.S. EPA, Seattle, Washington.

Yli-Tuomi T., Tiitta P., Willman P., Nuutinen J., Raunemaa T., Marja-aho J. & Selin P. 1999a. *Pienhiukkasten aiheuttama pölyhaitta jyrsinturvetuotannossa. Imukokoojavaunujen PM2.5- ja kokonaispölypäästöt sekä imukokoojavaunumenetelmän työvaiheiden PM2.5-hajapäästöt*. Report Series of Department of Environmental Sciences 35, University of Kuopio.

Yli-Tuomi T., Raunemaa T., Tiitta Willman P., Vartiainen M., Jantunen M., Marja-aho J. & Selin P. 1999b. *Turvetuotannon PM2.5-päästöt: Pöypäästölähteiden osuudet. Mittaukset kesällä 1998 Vieremän Kortesuolla*. Report Series of Department of Environmental Sciences 1, University of Kuopio.