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Temperature Changes in an Initially Frozen Wood Chip Pile

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Abstract

White spruce trees and tops were chipped and placed in a pile near Fairbanks, Alaska, in February 1983. The pile was 6 meters in diameter and 6 meters high in a cylindrical shape. Thermocouples were placed at 25 locations within the pile so that temperatures could be tracked over time. Gypsum blocks were placed at 10 locations to determine changes in moisture content.

The first evidence that the pile was generating heat appeared at the end of May 1983. This heat accelerated the warming and thawing of the pile. By early August, all thermocouple points were above freezing. The highest temperature recorded was 61 °C near the core of the pile. The chip pile did not freeze at all points the second winter, and all points in the pile were above freezing by early July 1984. The highest temperature recorded inside the pile during the second summer was 41 °C.

Keywords: Chip fuels, energy, white spruce, Alaska (interior), interior Alaska.

Potential for Wood Chips for Energy in Interior Alaska

Since 1978, the State of Alaska has sold 63 932 hectares of uncleared, forested agricultural land (Drew 1984). Large-scale clearing of land for farming will likely occur in the next decade in interior Alaska as it did in Delta I, Delta II, and the Point MacKenzie projects. In the past, most of the biomass from clearing activity was burned after it was chained down and pushed into berm rows. Much of the burning has been done in the winter to prevent escape of fire, and as a result, the berm rows do not completely burn. Repiling with repetitive burning is necessary, making the process expensive. Using the woody part of the biomass for fuel would undoubtedly require storing it as chips in piles for up to a year. Storing the residue in its natural form (tree length or long length) is impractical because of stacking, piling, and handling problems. The most practical and economical method for harvesting residual biomass is the whole tree chipper (McKnight 1983).

Some remote villages are interested in using wood as a substitute for expensive oil for generating electricity. Also, farmers could use wood as a fuel for drying grain. For both uses, the users would benefit if the wood could be stored for long periods. Chippers and chipping crews could be shared more easily among several users if a 2-year or more supply of chips could be produced at one time.

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If chipping is done during the late spring or summer in interior Alaska, biological activity will probably proceed at a rate similar to that in warmer climates with self-heating and significant temperature increases (Allen 1968, Bergman and Nilsson 1979, Springer and Hajney 1970). Information is not available on temperature changes and subsequent deterioration that may occur in chips that are produced and placed in piles while temperatures are below freezing. One possibility we wished to explore was whether the core of a large pile of wood chips would remain frozen throughout the year in a climate such as that of Fairbanks, Alaska. If they would remain frozen, wood chips could be stored for years without significant deterioration.

Purpose of Study

The purpose of this pilot study was to determine changes in temperature, moisture content, and energy that occur during a 2-year period in a large pile of wood chips in a subarctic climate such as Fairbanks, if chipping is done in the winter.

Methods

The wood chips for this study included whole-tree white spruce (*Picea glauca* (Moench) Voss) thinnings from the University of Alaska aboretum near Fairbanks (about 10 percent of the total volume) and white spruce tops from a commercial timber sale along the Tanana River west of Fairbanks. The trees and tops were chipped with a portable chipper on the site where they were to be stored. The chips were blown into a circular pile 6 meters in diameter and 6 meters high. Most chipping was done while the temperature was -12 to -18 °C. The chip pile was maintained in a circular shape by use of a snow fence anchored by four poles (fig. 1).

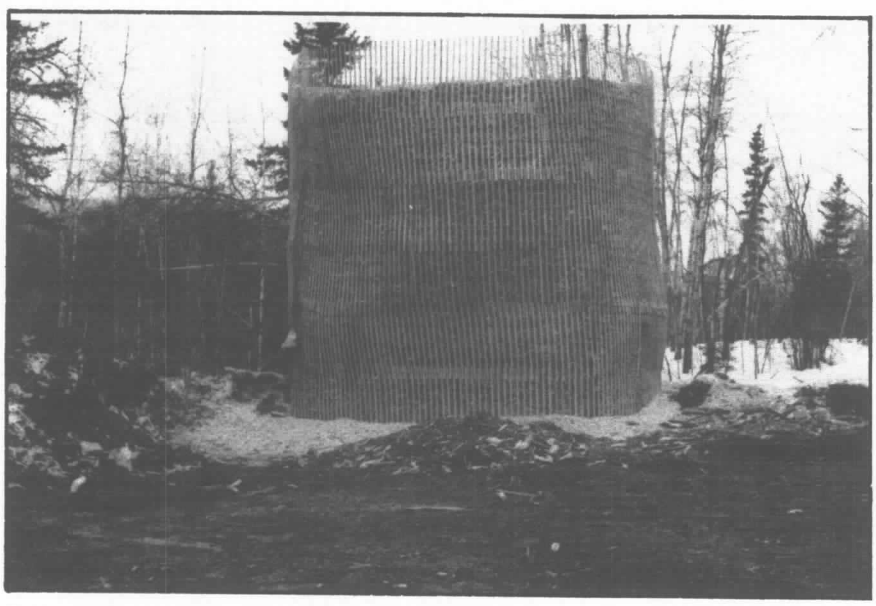

Figure 1—Snow fence keeps chip pile circular.

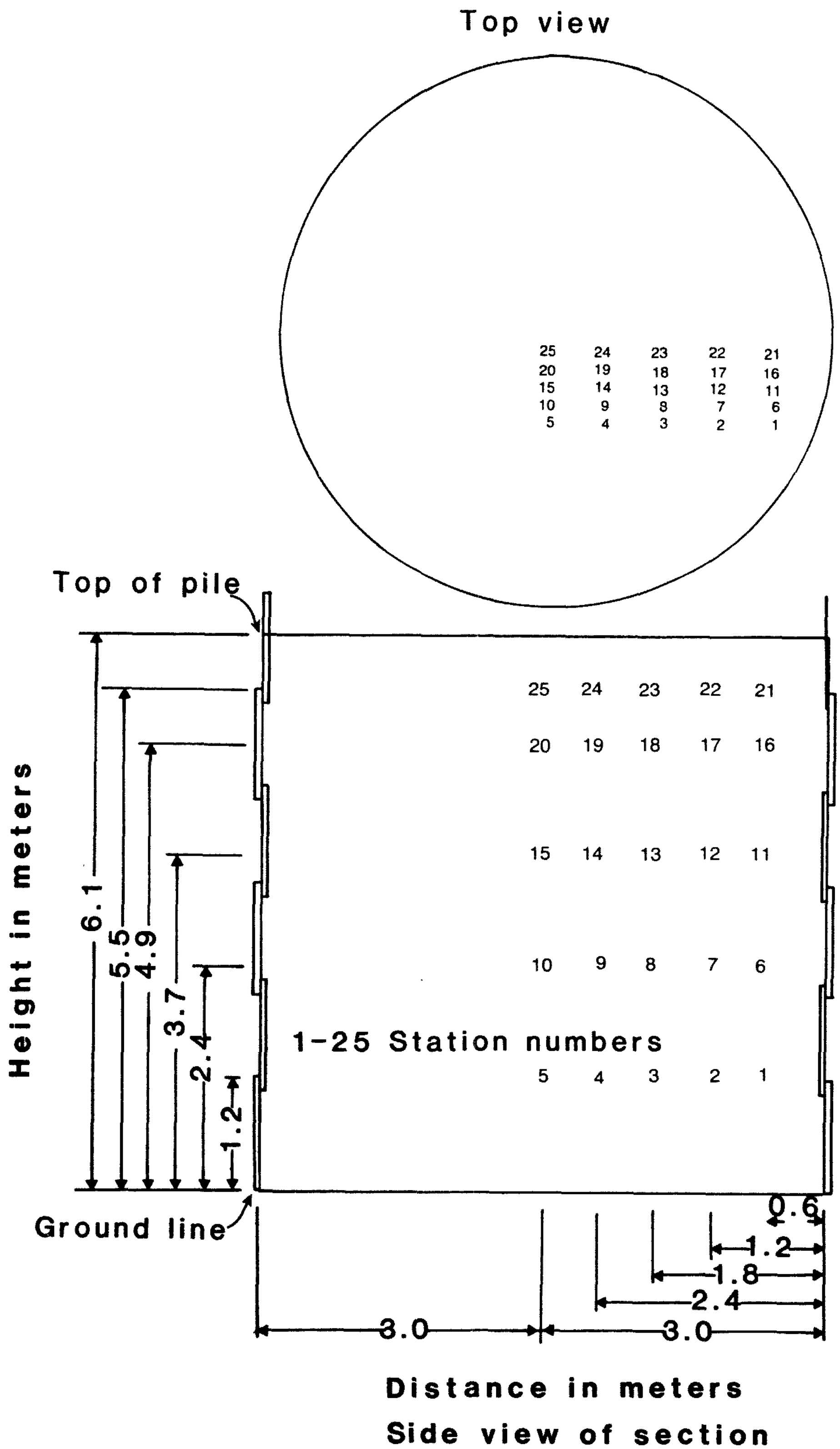

Figure 2—Location of stations, thermocouples, mesh bags, and gypsum-block moisture probes within the study pile.

Temperatures within the pile were monitored over time by 25 thermocouples placed in the pile. These 25 locations or stations are shown on figure 2. Ten gypsum blocks were placed in the pile so that changes in moisture content could be determined. Nylon mesh bags, each containing about 14 liters of chips, were placed in 15 locations. These bags will be removed at the time the pile is broken up, and the extent of chip deterioration will be determined for each location by comparison with chips removed from these same locations while the pile was being built. Solubility of wood samples in sodium hydroxide solution will be used as an indication of decay. Higher heating value will be determined through use of an adiabatic calorimeter.

Chip samples were taken at the mesh-bag locations when the pile was constructed to determine initial moisture content and chip size. Moisture content was determined by drying each sample in an oven at 103 °C until weighings at intervals of several hours revealed no further weight loss. Moisture content was calculated on an ovendry basis.

In the analysis, a set of four sieves with square openings of 38.1, 19.0, 9.5, and 4.0 millimeters was used; each sample was shaken about 3 minutes. Particles passing through the 4.0 millimeter sieve were caught in a pan. The percentage of chips retained on each sieve and in the pan and the mean size of the chips were calculated as follows:

$$\bar{X} = \frac{\Sigma W_i x_i}{100};$$

where:

$\bar{X}$ = mean size of chips or particles in millimeters,
W_i = weight of chips or particles collected on the ith sieve as a percentage of the total sample weight, and
x_i = size of opening in ith sieve in millimeters.

The losses and gains in the energy of the core of the chip pile resulting from conductance were estimated. These estimates helped us determine the overall energy loss resulting from storage. Heat losses and gains were estimated from the average ambient temperature between readings and the temperature readings at stations 1, 6, 11, 16, 21, 22, 23, 24, and 25. Temperatures at these nine stations were extrapolated to similar locations around the core surface above ground. The outer and upper 61-centimeter shell of the pile was treated as if it were inert insulation material. The resistivity factor used was based on data for sawdust or wood shavings reported in "Wood Handbook" (U.S. Forest Products Laboratory 1974).

Estimates of energy loss or gain for the chip pile were calculated as follows:

$$L_{im} = C(S_{im} - O_m)Tm\ A_i;$$

where:

L_{im} = energy loss or gain for the part of the pile represented by station i during time period m;
C = the constant 0.033593, which represents heat loss or gain for a layer of wood chips 61 centimeters thick in kilojoules per square meter per hour for each degree (Celsius) difference in temperature on the two sides of the chip layer;
S_{im} = average temperature (°C) of the ith station during time period m;
O_m = average outside temperature (°C) during time period m;
T_m = hours in time period m; and
A_i = surface area (m^2) represented by station i.

Calorific value per unit of dry weight of chips will be determined at the time the pile is broken up for comparison with calorific values for fresh white spruce chips. Time of pile breakup is planned to coincide with a study at a local powerplant in 1986 on the feasibility of burning wood chips mixed with coal.

Results

Late in the summer of 1985, chip samples were taken from the half of the pile cylinder without instruments. Samples were taken from positions analogous to stations 1, 3, 4, 11, 13, 14, 21, 23, and 24. The chips were analyzed for moisture content. Sampling was done with an auger designed to allow sampling at specific locations within a chip pile (White and others 1980).

Temperature changes in the pile over time are indicated by figure 3. Self-heating accelerated if rate of heat diffusion was less than rate of heating; however, no thermocouple station was ever higher than 61 °C.

Plots of temperatures for stations 1, 15, and 21 are shown in figure 4. For each date that chip pile temperatures are reported, a plot of the average ambient temperature for the preceding 5 days is also provided.

Self-heating began near the outer top of the pile because this part of the pile has greatest exposure to solar radiation, and it therefore thawed first. Until self-heating began, the pile was in a general state of net heat gain; however, after self-heating began, the pile was in a state of net heat loss through the summer and fall until midwinter. Warming of the upper part of the pile the second spring was probably retarded by the snow layer on top of the pile, which was allowed to melt in place.

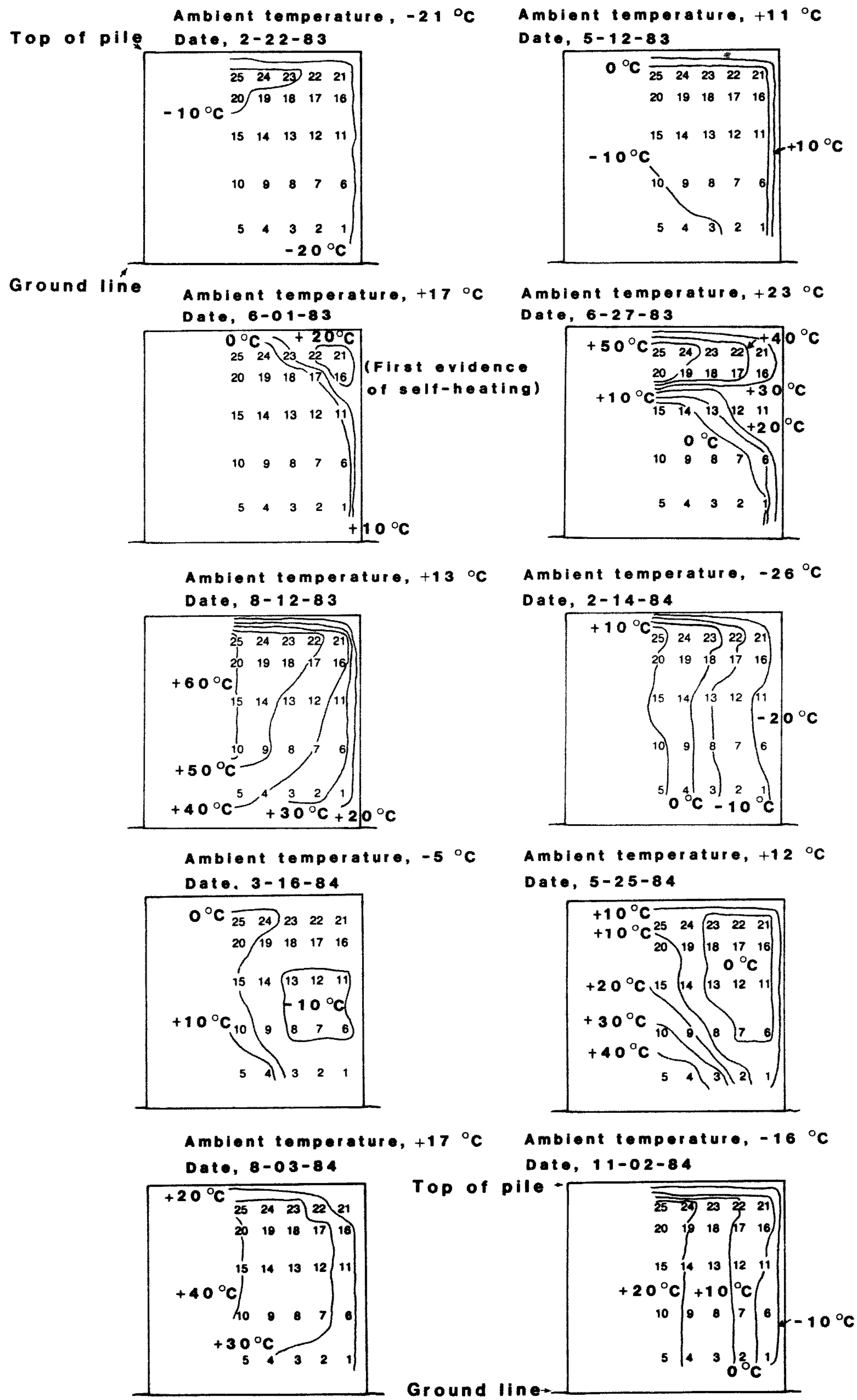

Figure 3—Isotherms on 10 dates during the storage period and average ambient temperature for the preceding 5 days.

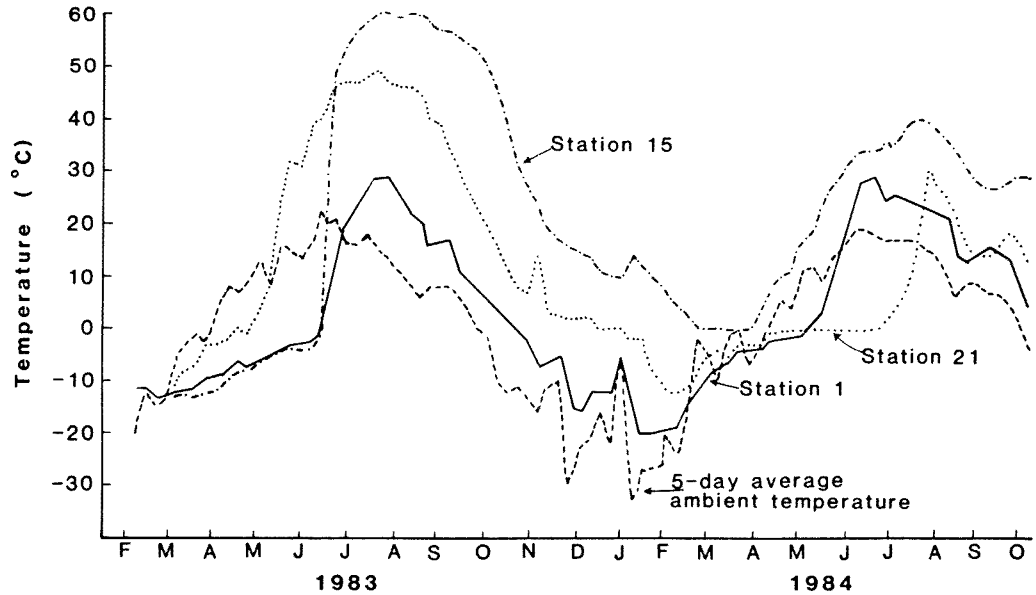

Figure 4—Temperatures for stations 1, 15, and 21 during the storage period and corresponding average ambient temperature for the preceding 5 days.

Mean moisture content of the wood chips at the time of pile construction was 89 percent. Range of individual samples was 64 to 103 percent. The gypsum blocks buried within the pile at 10 locations used in conjunction with an electronic moisture detector are not capable of detecting moisture content changes except at low ranges. Concurrent laboratory experiments showed that moisture content of wood chips may drop as low as 30 percent before moisture detector readings for gypsum blocks buried within the wood chips drop below the maximum. Readings are affected by below freezing temperatures for either the moisture detector or the gypsum blocks. Therefore, the gypsum blocks indicate changes in relative moisture content only when the wood chips are below 30 percent. The only clear indication of moisture content decreasing is for station 6 located 2.4 meters high and 0.6 meter from the outside of the pile. Moisture content for auger samples taken in mid-September 1985 are shown by table 1.

Table 1—Moisture content of samples from selected stations in the back half of the chip pile, mid-September 1985

Station number	Moisture content (dry weight basis)
	Percent
1	26
3	28
4	27
11	121
13	195
14	74
21	197
23	228
24	233

Table 2—Chips retained by each sieve and the mean size of the chips

Sieve opening	Proportion of chips retained
Millimeters	*Percent*
38.1	0.7
19.0	17.5
9.5	57.1
4.0	22.1
Pan	2.6
	Millimeters
Mean size of chips	9.9

The proportion of chips retained on the various sieves and the mean size of the chips are shown in table 2.

The estimated energy losses and gains of the core of the chip pile resulting from conductance are shown in figure 5. Some daily heat loss resulted from the pile absorbing heat when ambient temperature was higher than the temperatures in the chip pile, then releasing heat when the ambient temperature dropped below the internal temperatures of the chip pile. Over the course of a year, energy gains in the chip pile should offset such losses. The daily rate of heat loss was considerably less the second summer than the first summer.

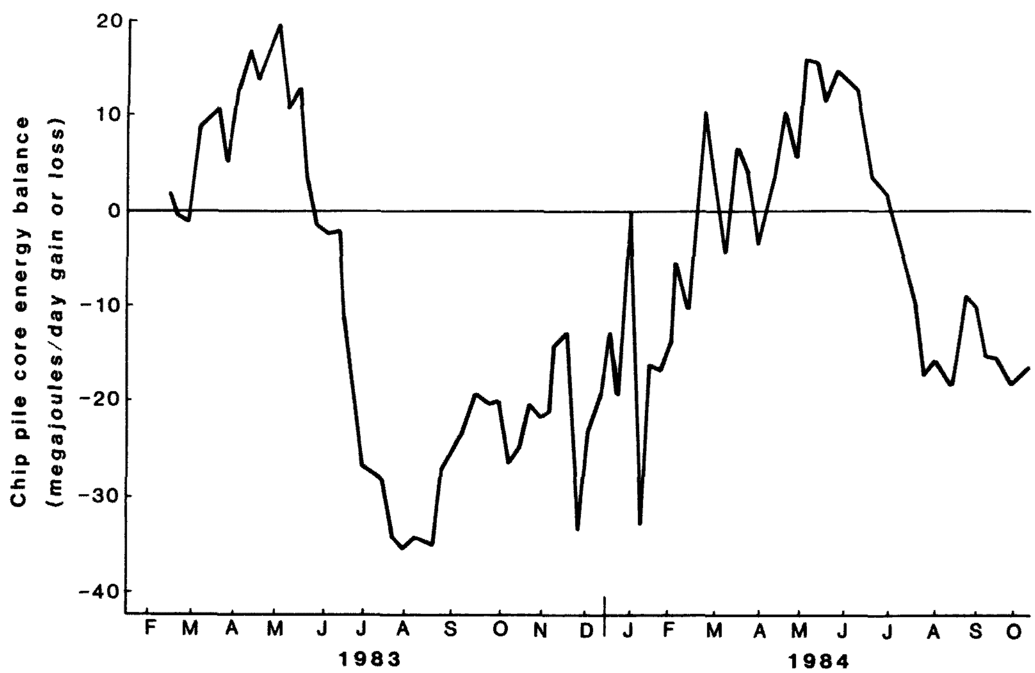

Figure 5—Chip pile energy balance based on outer pile temperatures, average ambient temperatures, and conductance.

Discussion

There was no lasting insulation effect from the outer layers of chips in the frozen chip pile. As the outer layers of chips warmed to about 5 °C, thermogenesis (the chip pile generating heat) began, and temperatures in these outer areas rose far above ambient temperatures, accelerating thawing and the subsequent thermogenesis of the core of the pile. The lower center of the pile remained frozen until early August of the first summer. The pile did not completely refreeze the second winter, and no part of it remained frozen after early July of the second summer, although it began to refreeze again by early November.

The maximum temperatures reached within the pile probably result from the interaction of the rates of thermogenesis and heat diffusion. The major buildup of heat results from the metabolism of the mixed saprophytic, microbial flora that develops in green chips. As the temperature rises, the thermophiles can multiply rapidly and increase the temperature to 70 °C or slightly higher (Unligil 1982). The upper limit for growth of fungi is about 60 °C (Cooney and Emerson 1964). Subsequent heating results from autocatalytic processes which can begin to operate at this temperature. In studies of large (6000 m^3) pulpwood chip piles of Scotch pine (*Pinus silvestris* L.) and spruce (*Picea abies* (L.) Karst.), the highest temperatures remained below 70 °C (Bergman and Nilsson 1971). The Fairbanks chip pile contains about 178 m^3, but the cylindrical shape may cause it to react differently from conical piles.

The energy losses and gains suggested by figure 5 are only an approximation of changes resulting from conductance for ambient temperature and temperatures within the chip pile. At temperatures above 50 °C, heat lost through diffusing vapor may approach heat lost through conduction (Kubler 1984). Significant heat may also be lost by convection of hot air at high temperatures. Loss of potential energy from the entire pile will be estimated after the pile is broken up.

Plans

The chip pile will be broken up late in 1986. If the chips are still suitable as fuel, they will be mixed with coal and burned at a local powerplant in conjunction with an experiment on the technical and economic feasibility of harvesting wood chips and burning them as fuel supplement for coal at a large powerplants.

Conversion Factors

centimeter = 393.7008 mils or 0.3937 inch
meter = 3.2808 feet
hectare = 0.4047 acre
cubic meter = 35.31 cubic feet or 0.2759 cord
liter = 0.353 cubic foot
kilojoule = 0.9479 British thermal unit
megajoule = 947.9 British thermal units
degrees Celsius (°C) = 0.5556 (°F-32)

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