PRELIMINARY INVESTIGATION INTO THE USE OF A DEHUMIDIFYING KILN FOR DRYING WILD HERBAL TEAS IN SOUTHEAST ALASKA

A Senior Thesis

by Daniel Joseph Slakey

Presented to the faculty of the School of Natural Resources and Agricultural Sciences, University of Alaska Fairbanks
and the Senior Thesis Committee: P.S. Holloway, Chair, V.A. Barber, and R.R. Dinstel
in partial fulfillment of the requirements for the degree of bachelor of science
in natural resource management, plant, animal, and soil sciences option
Fairbanks, Alaska, 16 December 2005

Senior Thesis Series ST 2006-03

The dehumidifying kiln used in the herb-drying experiments. The kiln was purchased with a grant from the Sitka Forest Products Program.

— PHOTO BY DANIEL SLAKEY

Abstract

This project investigates the use of a dehumidifying dry kiln (traditionally used for drying lumber) for drying wild herbal teas in Southeast Alaska. Its major considerations are kiln design, moisture content data (for use in drying schedules), and preliminary drying schedules. Project conclusions result from literature review and experimentation. Regarding kiln design for uniformity and efficiency, the researcher found the following principles of utmost importance: 1) proper direction of airflow (achieved by incorporating measures that will direct the airflow, such as baffling and air deflectors); 2) maximizing space by fitting the maximum number of drying racks into the kiln and using a small spacing (9cm) between drying trays; and 3) minimizing electric costs by installing a heat source other than electric auxiliary heat, as well as operating the kiln continuously until materials are dry. Regarding moisture content (MC), the researcher found that herbal teas should be dried to 5–10 percent MC (green basis), and that the moisture contents of most green materials collected in Haines were too variable to use for creating drying schedules. Regarding drying schedules, the researcher found that pre-drying plant materials in ambient air for about a day improves quality and efficiency of the kiln drying process. Material depth was also examined, and no upper limit on depth was found for most materials. Pre-drying increased the maximum depth for some materials, including dandelion and fireweed leaf. The main problem identified was the variation in drying rates between different leaf parts (leaf blades dried out much faster than midveins and became brittle). This problem could be avoided in the future by using water sorption isotherm data to ensure that no part of any material will dry out below a given MC. It is still unclear whether a dehumidifying kiln is an economically viable option for drying wild herbs.

Introduction

This project is designed to coincide with the economic goals of a small herbal tea company, Alaska SuperNatural Teas, located outside of Haines, Alaska, as well as the broader Alaska nontimber forest products (NTFP) industry. The tea company harvests wild herbs from the Haines area and markets them as Alaska herbal teas. Several similar companies exist throughout Alaska, including Alaska Botanicals, based in Homer, and Alaska Wild Teas, based in Anchorage. The potential for a strong non-timber forest products industry in Alaska can be seen in a market research report conducted by Mater (2000). In this report, an unmet market demand is documented for several of the species looked at in this project, including rosehips, blueberry leaf, and devil's club inner bark. There are a number of difficulties that need to be overcome, however, even with an unmet market demand. For example, according to Walsh and Fongemie (2003), the large-scale commercial cultivation of rosehips makes it very difficult for wild harvesting to be economically efficient. This difficulty is apparent in the business plan of Alaska Wild Teas, which imports rosehips rather than wild harvesting them (rosehips are the main ingredient in all of their teas).

Mater (2000) also describes some of the other species studied in this project, without specifically commenting on their market demand. These include yarrow, labrador tea, nettle, and kinnickinnick. For some of these plants, buyer prices are quoted that may be difficult for a foraging operation to compete with ($18 per lb. for yarrow, $12 per lb. for nettle, and $2 to $2.50 per lb. for rosehips). One fault of the Mater study, however, is that it is written without any mention of product differentiation. By establishing a market for a value-added product, Alaska SuperNatural Teas may be able to sell its products at a higher price than would otherwise be possible. The fact that the teas are wild-harvested by hand and are from Alaska may increase the demand for them. In a similar way, the USDA's Alaska Grown program has led Alaskans to place a higher value on produce grown in-state as opposed to produce shipped from more distant locations (Alaska SuperNatural Teas is a member of the Alaska Grown program) (FSMIP 2003). It is possible that only some of the species in this study are economically viable as ingredients in herbal teas. The main components of this viability are the ability to command a high price and the efficiency with which harvesting, processing, and drying can be done. Harvesting efficiency is highly correlated with the density of the plant stand in question (Miller 1998). Thus, any wild tea company in Alaska should focus its efforts on plants that sell at for a decent price and can be harvested relatively efficiently in the company's geographic area.

The owner of Alaska SuperNatural Teas, Erika Merklin, has received a dehumidifying kiln through a research grant with the UAF-Sitka Forest Products Program. To make use of the kiln, a research project was initiated with the main goal of producing drying schedules for it. The reasons for developing drying schedules are summarized in Potter (1973): "to balance dehydration conditions to produce maximum drying rate with minimum product damage at the most economical cost." Maximum drying rate is important because it decreases costs and generally tends to increase product quality (Desrosier and Desrosier 1977). Following drying schedules can greatly reduce labor costs because this eliminates the need for constant monitoring of the material. Furthermore, product quality can be extremely dependent on the drying process. For example, Desrosier (1977) shows that drying method has a significant effect on vitamin retention in peaches. Likewise, Kirsi et al. (1989) show that drying methods can significantly affect the flavor of raspberry leaf herbal tea. Thus, an organized method of drying is an important aspect of producing a high-quality product. Drying schedules can involve any number of variables, including time, temperature, relative humidity, turning frequency, and material thickness. Being very pertinent to drying schedules, moisture content will be examined extensively in this project.

High-quality product is very important to a business, but equally important to the business is the economic efficiency of processing the product. This study does not attempt to provide an economic analysis of the use of a dehumidification kiln for drying herbs (although such a study would be very worthwhile). It does, however, look into ways to improve the efficiency of the dryer and the drying process.

This thesis is based upon work supported by the University of Alaska and the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, under Agreement No. 2003-34158-14063. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

Literature Review

Kiln Design

Dehumidying kilns have traditionally been used for drying lumber, so the use of one for drying herbs can be considered a very experimental procedure. The essential component of a dehumidification kiln is a dehumidifier, consisting of refrigeration coils on which water condenses from the moist air. The water then leaves the system, and dry air is recirculated through the kiln, becoming moist as it passes over the wet product. The process of powering the refrigeration coils produces waste heat, which is utilized to heat the air in the kiln. In a conventional dryer, the moist air would be exhausted to the outdoors after having passed over the product, causing a great deal of heat loss (Nyle Corporation). A typical practice for a conventional dryer of the design used in this experiment would be to recycle some of the air that has already been passed over the product (Barbosa-Cánovas et al. 1996).

The basic design of the kiln is that of a cabinet or tray dryer, in which the food is placed on a large number of trays, and air is forced over or through the trays. One major problem with this type of dryer is that it can be very difficult to achieve uniform drying (Barbosa-Cánovas et al. 1996). There are several methods to alleviate this problem. According to the Nyle Corporation (the maker of the dehumidification kiln), a baffling system that forces air over the product being dried is instrumental in producing fast and even drying. Nyle also suggests that a number of air deflectors be put in place to direct airflow. Barbosa-Cánovas et al. (1996), while not mentioning the use of an air deflector, include one in the illustration of a tray dryer, and also suggest that this type of dryer use an airflow of 2-5m/sec.

Aside from having difficulties with drying evenness, cabinet or tray dryers are also very labor intensive, as trays must be manually loaded and emptied (Baker 1997). Such a dryer is used as a batch dryer, meaning that it is filled completely full at one point in time, and completely emptied at a later time. A similar dryer, called a tunnel dryer, operates in a continuous mode and is less labor intensive. However, the cabinet or tray dryer is generally the most practical design for use in small-scale operations (Barbosa-Cánovas et al. 1996). For this reason, it would likely be a good option for a small-scale herbal tea foraging operation.

Miller (1998) also recommends a design for a simple shed made specifically for drying herbs, using an oil or gas heater. His recommended drying shed has a volume of 79.2m3 (2280 cu. ft). According to Miller, a drying shed of this size, if designed efficiently, can produce 227kg (500 lbs.) of dry leaf in three continuous days of operation.

It is questionable, however, whether such a large kiln should be used for drying in a foraging operation. Miller's design is intended for use with small- to midscale cultivated crops. Walsh and Fongemie (2003) also offer a design for a kiln, but on a much smaller scale (this kiln can be constructed for less than $100). The smaller drying facility can be more easily filled with a uniform crop than a large drying facility can, at least in the case of a foraging operation. Walsh and Fongemie (2003) also suggest that several small kilns may be built in order to dry small batches of different herbs simultaneously. A dehumidifying kiln, however, does not lend itself to such a setup (even the smallest kiln unit sold by Nyle, the L50, would be able to service a large drying room, such as Merklin's). The advantage of filling a kiln uniformly is that drying schedules can be customized to individual materials, allowing for a high-quality product and increased efficiency of the drying process.

Another important aspect of kiln design is the placement of the material inside the kiln. Miller (1998) offers a design for drying racks and trays. In this paper, trays are defined as the actual container on which the herbs lie, while racks are the structures onto which the trays are stacked. One of the main principles behind his rack design is that the trays are angled at a 10-degree incline from the source of heat. He claims that this allows for the air flow to be broken up and distributed in a relatively uniform fashion. All other sources examined in this study showed trays that were lying flat. Miller (1985) also recommends a certain amount of space between trays, specifically 41cm (16 in.). This large amount of space allows for 20.3 to 25.4cm (8 to 10 in.) of wet produce to lie on each tray. Industrial racks for tray dryers typically have much smaller spacing. Walsh and Fongemie (2003) suggest that wet produce not be piled any higher than 7.6cm (3 in.). Dan Parrent (2005), a wood utilization specialist for the Juneau Economic Development Council, suggested a spacing between trays of only 2.5-5cm (1-2in).

The material used in the construction of the drying racks and trays is also an important concern. Wood has the advantage of being cheaper than any metal alternatives. However, according to John Bannister (2005), wooden racks will tend to warp over time as a result of frequent drying and re-absorbing of moisture. Thus, wooden racks may have a lower initial cost than metal ones, but may need to be replaced more frequently. The large majority of drying racks for industrial tray dryers found by the researcher were made of metal.

Careful monitoring is a very important part of the drying process (Rufus 1972). Several pieces of equipment can aid in this process. A hygrometer, consisting of a wet bulb and dry bulb thermometer, is essential to measuring the relative humidity in the dryer. The hygrometer should be placed in a rapidly moving stream of air, at a place in the dryer where the air has not yet passed over any plant material (Barbosa-Cánovas et al. 1996). Any temperature-sensing device should also be placed 15.2-30.5cm (6-12in) away from a wall (Nyle Corporation).

One of the major challenges associated with using a dehumidifying kiln is the cost of electricity. Naturally, sources of energy vary in cost from place to place. In Haines, the price of electricity for businesses was $0.36 per kWh at the time of this project, making the efficiency of the kiln extremely important. A dehumidifying kiln does have the advantage, however, that it does not produce any exhaust heat (as long as it is well sealed). An additional concern with efficiency is the removal rate of water from the kiln. According to the Nyle Corportation, the L200 kiln can remove up to 4.33L of water per hour of operation.

Moisture Content

The moisture content of a dried food product is most important in that it is responsible for the integrity of that food. At a moisture content (MC) of 30 percent (green basis) or higher, bacteria and yeast can grow on the substrate. Molds can typically grow on a material with an MC of 12 percent, and sometimes even down to 5 percent (Desrosier and Desrosier 1977). While it is known that the MC of dried herbs is important in keeping them from being degraded by microorganisms, it is not clear whether the MC has a significant effect on their flavor. A great deal of literature exists on the drying process and its effect on tea and herb flavor, but there is rarely a mention of the effect of final MC on flavor. There are, however, recommendations from several sources on the ideal MCs of dried herbs and teas. Temple et al. (2001) suggest that black tea be dried to an MC of 3 percent. This is much lower than most recommendations found for herbal teas, however. Miller (1998) suggests a final MC of 8 to 10 percent for dried herbs. Walsh and Fongemie (2003), on the other hand, give the guideline of 5 to 8 percent for dried herbs.

There is some information regarding the moisture content of green leaves available in the literature. Ribe (1973) gives green and dry weights for the leaves of a number of timber species [paper birch (*Betula papyrifera* Marsh.), sugar maple (*Acer saccharum* Marsh.), American beech (*Fagus grandifolia* Ehrh.), and others, as well as some noncommercial species, such as pin cherry (*Prunus pensylvanica* L.), choke cherry (*Prunus virginiana* L.), alder (*Alnus* sp.), and willow (*Salix* sp.). Moisture contents in this study ranged from 49 to 70 percent (green basis).

There will likely be a significant amount of variability among different specimens of a single species, due to factors such as microclimate, stage of growth, and collection date. Ribe (1973), for example, found that a particular paper birch tree with a 1cm diameter at breast height (DBH) had foliage with an MC of 68.48 percent (green basis). A tree of the same species with a 16cm DBH had foliage with an MC of 59.15 percent (green basis). Similarly, reindeer lichen (*Cladina rangiferina* L.) Nyl.) can vary in MC from near bone dry to 80 percent (green basis) in Canadian forests. Pech (1989) even formulated a model to predict the MC of reindeer lichen, which takes into account air temperature, wind speed, relative humidity, and rainfall, among other things. A similar model might be useful in determining the MCs of the plants in this study under a given set of conditions. Such a model, however, is beyond the scope of this project.

According to Barbosa-Cánovas et al. (1996), the process of determining moisture content should be done by drying the food in a vacuum oven or by using gas chromatography. These methods are more accurate than drying with a traditional convection oven, because they prevent the loss of volatile oils from affecting the results of such experiments. Such methods become very important when dealing with materials high in volatile oils, such as culinary herbs and spices. A convection oven, however, should suffice when dealing with foods not so high in volatile oils, such as most of the herbs being studied in this project (McClements 2001).

Drying Schedules

A number of sources offer guidelines for the process of drying herbs and food products in general. However, no source could be found that listed highly detailed drying schedules; it is likely that such information is specific to a particular kiln design and the product being dried in it.

Regarding quality, several drying phenomena can be avoided by using good drying schedules. When materials are dried for too long or at too high a temperature, they may be degraded and turn brown, a phenomenon known as browning. Another possible defect in the drying process is called case hardening. When this occurs, moisture in the inner part of the material becomes trapped by an impenetrable case, and requires a long time to dry out. This situation can be avoided by drying rapidly in the early stages of the drying process, which produces internal cracks, speeding up the later stages of drying (Van Arsdel et al. 1973).

The drying process can be divided up into at least three different segments. In the first period, called the constant rate period, water loss remains constant. During this time the water is supplied to the surface of the material as fast as it evaporates. At a certain point, however, the internal flow of water becomes the limiting factor in the drying process, and the rate of water loss begins to decrease. At a second point, the food surface becomes completely dry, and the area of evaporation moves inward. The drying rate becomes even slower in this period (Barbosa-Cánovas et al. 1996).

Miller (1998) and Walsh and Fongemie (2003) make a number of recommendations for the drying process. The suggestions, however, are made with the assumption that a traditional cabinet or tray dryer will be used, rather than a dehumidification system. Regarding time, both sources recommend that the drying process take place over a three-day

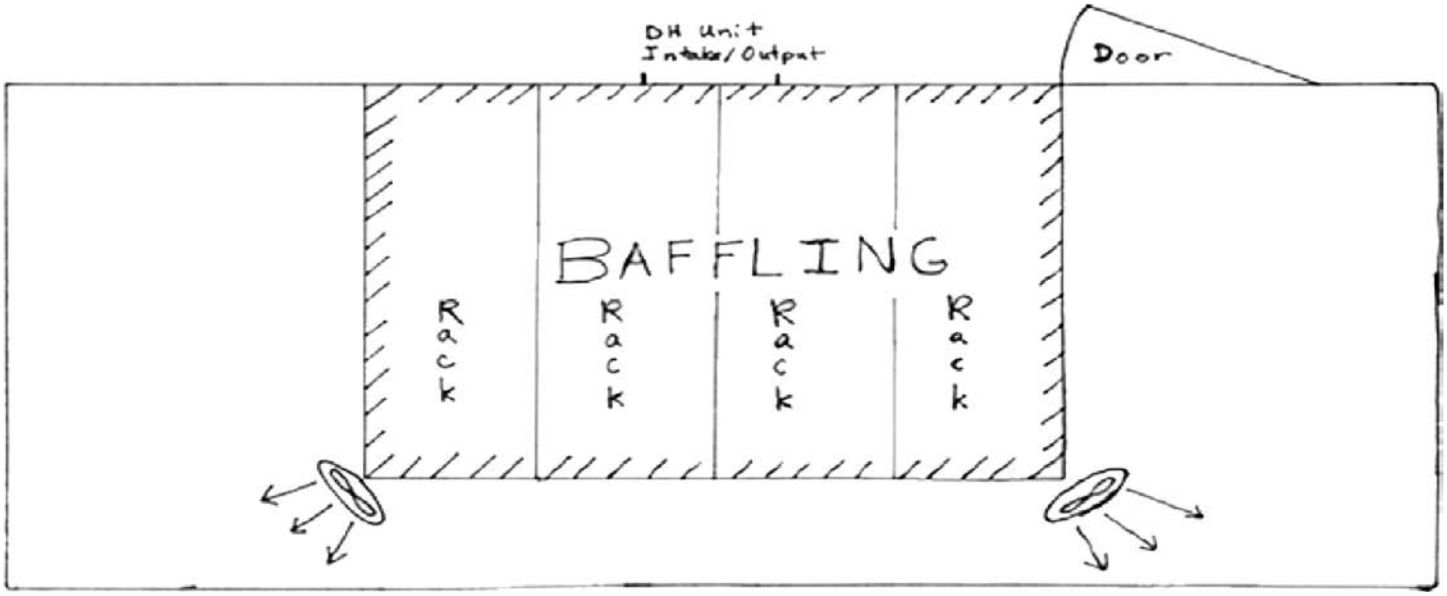


Figure 1. Top view of initial kiln design. The kiln is 5.49 m long, 2.24 m wide, and 2.20 m high.

period of continuous operation. With respect to temperature, both sources recommend that the temperature increase over the three-day period, with a low starting temperature on the first day, an intermediate temperature on day two, and a high temperature on day three. This division of the drying process by temperature may coincide with Barbosa-Cánovas et al.'s (1996) description of the three drying stages. It is in direct contrast, however, to Van Ardsel's method of drying to avoid case hardening, described above. Miller (1998) actually goes into much greater detail, recommending temperature ranges for a large number of herbs, including many used in this study. For the most part, flowers should be dried at 29.4°C (85°F) to 43.3°C (110°F); most leaves and herbs should be dried from 32°C (90°F) to 46.11°C (115°F); barks should start at a low of 32°C (90°F) and progress to at least 48.9°C (120°F).

Regarding material depth, Miller (1998) states that up to 25.4 cm (10 in.) of wet produce can be placed on an individual drying tray. Walsh (2003), however, discourages the piling of material any deeper than 7.6 cm (3 in.).

Looking at turning frequency, Miller (1989) states that the material should be turned once every four hours on the first day of drying, once on the second day, and once again on the third day. Turning consists of mixing the material so that the plants in the interior do not mold or compost.

A pre-dry process may be beneficial to both the quality of the product and efficiency of the drying process. The withering of plant materials has been shown to have a positive effect on the aroma profiles of certain materials. The method of withering raspberry leaf (*Rubus idaeus*) used by Kirsi et al. (1990) consisted of the plants sitting at room temperature (22-24°C) for three hours. Walsh and Fongemie (2003) suggest that plants be withered outdoors in the shade for 24 to 36 hours prior to being placed in a dryer, but without regard to the effect of this process on flavor. Rather, the significance of the process, in their view, is that the plant material will have decreased in volume and MC before entering the dryer, thus allowing more material to be placed on each tray and decreasing the drying time.

A potential benefit of the use of a dehumidification kiln is that one has the ability to control the relative humidity of the air in the drying room (Bannister 2005). At a given temperature and relative humidity, a given food will have a certain equilibrium MC, above which it will gain moisture, and below which it will lose moisture. When these values are experimentally determined, one can plot them as water sorption isotherms. Each food product has a unique water sorption isotherm; when a new product comes to market, testing is usually required to determine the isotherm (Potter 1973). Wolf et al. (1985) has written a comprehensive bibliography of sorption isotherm data for foods, but none of the products being examined in this project are included (black tea, however, is). Labuza (1984) has written detailed methods for experimentally determining sorption isotherms.

The period immediately following the drying process is also critical to product quality. According to Miller (1998) the product should be allowed to remain for several days in the open in order to absorb some moisture from the atmosphere. This allows for the product to become less brittle, so that less of it will turn to powder and be lost.

Methods

Kiln Design

The initial design for the kiln can be seen in Figure 1. The kiln is 5.49 m long, 2.24 m wide, and 2.20 m high. Several different techniques were employed to test kiln and rack design for uniformity and efficiency. To study drying uniformity, in experiment 1, the researcher filled the kiln with a uniform crop of fireweed leaf, adding the same weight to each tray (fireweed leaf was used because it can be harvested the fastest among all

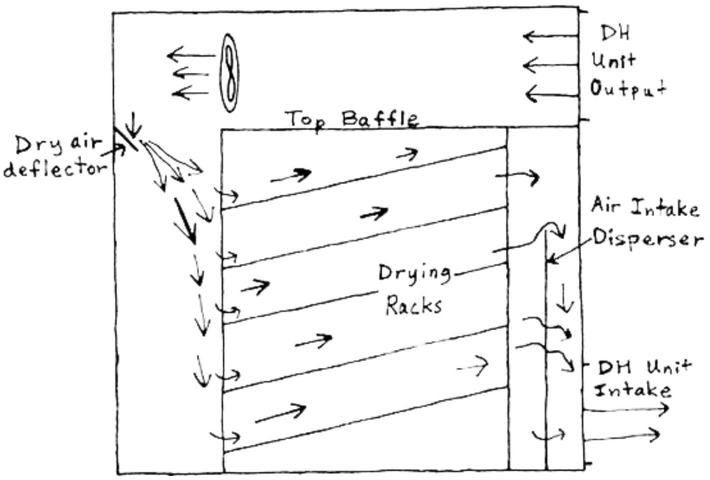


Figure 2. General airflow pattern of kiln. Air enters the kiln from the dehumidification (DH) Unit output, then is accelerated by the fan. It is then deflected downward and travels up through the drying racks. Finally, it is forced to go around the air intake disperser before being taken up by the DH Unit.

the plants used by Alaska SuperNatural Teas). After a certain amount of time in the kiln, all of the trays were measured with the partially dried leaf on them. The percent weight loss was calculated for each tray of material. These values were charted on grid by color-coding to visually represent which areas of the kiln dried out fastest and which dried out the slowest. The areas in which drying was slow were assumed to have poor airflow, and high airflow was associated with the areas that dried out faster. The kiln was modified to produce more even or faster drying after each test took place. The initial experiment on kiln design examined both uniformity and efficiency, using a relatively small amount of fireweed leaf, 0.45 kg (1 lb), per tray.

Experiments 2 and 3 were conducted using the above described methods to test the effectiveness of side baffling, a dry air deflector and an air intake disperser in producing drying uniformity both vertically (from the top to bottom of individual drying racks) and horizontally (side to side and front to back). The air deflector should ideally distribute the air more evenly across the trays; the air intake disperser spreads out the area over which air is taken in by the dehumidification unit, so that the trays in the immediate vicinity of the air intake do not undergo drying at a much faster rate than all of the other trays. Both of these experiments incorporated side baffling. Experiment 2 served as the control, while Experiment 3 incorporated these two new components. A simple illustration of the dryer with these components and its general airflow pattern can be seen in Figure 2.

In both of these experiments, 0.86 kg (1.9 lb) of fireweed leaf was used for each tray that was measured (some racks were not filled completely in both experiments because the researcher ran out of fireweed leaf, so these trays were filled with dandelion leaf and were not measured). In Experiment 2 the drying process lasted seven hours, while in Experiment 3 it took place for eight hours. Data from these experiments were analyzed for uniformity using the above-described color-coded grid method. The data from these experiments were also used to infer information about kiln operating efficiency.

A number of other techniques were also applied in evaluating the operating efficiency of the kiln. The water removed by the refrigeration coils can easily be collected and measured, as it runs in a small tube to the outside of the kiln. This water was collected for most experiments. The closer a kiln design came to approaching 4.33 L per hour, the more efficient it was assumed to be. Naturally, not all of the water lost by the plants is collected by the refrigeration coils. Rather, some water is lost each time the kiln door is opened, some moisture remains in the air at the end of the drying process, and the kiln may not be completely airtight. For these reason, the results of these measurements were reconciled with some of the results in the airflow experiments, comparing the actual weight of water lost by the plants to the amount of water collected by the refrigeration coils.

The results of these experiments were used to modify the kiln to bring it up to or nearer to its capacity. Various designs for racks were tested, which included 5 rows of trays, with a drying surface area of 16.88 m2, 7 rows, with a surface area of 23.64 m2, and 10 rows, with a surface area of 33.77 m2. There were two trays in each row for all of the rack designs. In the 5-row racks, spacing between rows was 19.1 cm (7.5 in). In the 7- and 10-row racks, it was 15.2 cm (6 in) and 12.2cm (4.8 in), respectively. The trays were 6.35 cm (2.5 in) deep, so the actual amount of empty space between trays is much less than the numbers given above. Due to limited time, these various rack designs were mostly evaluated subjectively, based on drying uniformity and amount of product that could fit into the kiln each time. Tests on these racks were done using fireweed and rose leaf.

Aside from the kiln's ability to remove water, its efficiency was also evaluated based on the amount of electricity used by different aspects of the kiln. The following components of the kiln all consume energy: refrigeration coils, supplementary heater, internal blower motor, and external fans. These different aspects of the kiln were evaluated by counting the number of spins in the electric meter in a two-minute period with and without each individual part running. This method leaves some room for error, but it provides a general idea of what parts of the kiln are the most expensive to operate, and, therefore, can be used to reduce the kiln's electricity costs.

Moisture Content

Tests were performed in two general areas of moisture content. First, commercial herbal teas from throughout Alaska, as well as one company outside Alaska, were dried to bone dry in order to determine their moisture contents. The teas were removed from the packaging, put into a pre-weighed bowl of aluminum foil, and weighed. Samples were put into a laboratory convection oven to dry at approximately 39.4°C (103°F), enough heat to drive off all the water (Haygreen and Bowyer 1982). It was not always possible for this temperature to be maintained exactly, due to the cumbersome method for setting oven temperature. Samples were weighed every 30 minutes to an hour, until the weight of the sample did not change by more than 0.02g between measurements. Samples ranged from approximately 10g to 50g. The packaging of each tea was noted, since herbs will equilibrate with the moisture content in the air (Desrosier and Desrosier 1977). Thus, any teas packaged in containers that were not airtight were likely dried to a different moisture content than that which was measured. Only one sample was used for each type of commercial tea.

The second area of moisture content involved plants of potential economic importance in the Haines area, most of which are commercially harvested by Merklin. These herbs underwent the same measurement and drying process conducted on the dried teas, except that most herbs were dried on wire mesh screen. The samples were taken from material that had been harvested for the tea company, so there is a delay of several hours between the time of harvest and the initial weight measurement. Therefore, the MCs acquired will be slightly lower than that of plant material immediately after harvest. Most samples for this portion of the project ranged from 50g to 100g. At least four samples were collected for each material when possible.

For both experiments, moisture content was evaluated on a green weight basis, as this is the method most commonly used by food scientists. The equation for this calculation is given by McClements (2001):

percent MC(green basis) = (green weight – oven dry weight) / green weight) x 100

Although only green basis MCs will be given in this project, one can calculate the dry basis MCs by using the following equation:

percent MC(dry basis) = percent MC(green basis) / (1- percent MC(green basis))

Drying Schedules

The majority of information regarding drying schedules was achieved through subjective evaluation and informal experiments. Informal experiments were conducted on most of the plant materials used by Merklin (dandelion leaf, fireweed leaf and flower, rose leaf, nettle leaf, strawberry leaf, and yarrow flower) to determine the ideal depth of material from the perspective of product quality. In these experiments, material depth ranged from 3.1 to 9.5cm (1.25-3.75in.). Product quality was based on drying evenness within a given tray, incidence of plant materials shattering (breakage into small pieces or powder), and incidence of browning.

The pre-dry process was evaluated in a similar fashion. Plant materials (dandelion and rose leaf) were allowed to wither for 24 to 36 hours indoors with fans blowing over them, and were then put into the drying room. Although Walsh (2003) recommends that the pre-dry process take place outside in the shade, it was more practical to perform the process indoors, due to both the setup of Alaska SuperNatural Teas and the unpredictability of the weather. Evaluation was based on product quality, the amount of material in the tray at the end of drying process, and drying time (all in comparison to non-pre-dried materials).

One formal experiment involving spruce tips evaluated material depth from the standpoint of economic efficiency. eight trays of spruce tips were divided into four different experimental groups. In group A, 0.91 kg (2 lbs) of spruce tips were placed in each tray, which did not cover the entire tray surface. In group B, 1.36 kg (3 lbs) of tips were placed in each tray, so that the material was one tip, or about 1-1.5 cm (0.4-0.6in) thick. Group C trays weighed 1.82 kg (4 lbs) each, and the material was about 2-2.5 cm (0.8-1 in) thick. Group D trays contained 2.27 kg (5 lbs) of tips, which were 3-3.5cm (1.18-1.4 in) thick. Trays were dried at 32.2° to 37.8°C (90°-100°F). The trays were reweighed at 5, 16, and 19 hours. From the subsequent weights, the percent weight loss and total weight loss were calculated for each group. The trays were placed so that one tray from each group would be in a faster-drying location and one would be in a slower-drying location.

In addition to the actual drying process, herbs were also examined during the period of time immediately thereafter. Herbs were allowed to remain in the open for one to two days after completion of the drying process, as per Miller (1998). They were evaluated subjectively for changes in texture and incidence of shattering.

Figure 3. Experiment 1: Percent total weight loss of trays with initial kiln design. Darker cells represent trays that had a percent weight loss greater than the mean of 51.03 percent. Row 1 was the top row, Row 5 was the bottom row. The standard deviation of percent weight loss per hour was 0.45. Drying took place over eight hours.

Front Row

Rack #	1	2	3	4
Row 1	52	46	50	54
Row 2	47	48	48	53
Row 3	49	44	46	52
Row 4	54	51	50	56
Row 5	52	58	52	53

Back Row

Rack #	1	2	3	4
Row 1	50	46	48	56
Row 2	55	48	53	56
Row 3	53	47	44	54
Row 4	54	48	52	53
Row 5	50	50	51	58

Results

Kiln Design

The first experiment regarding kiln design looked at both drying uniformity and efficiency. On the basis of measuring the weight of trays before and after drying, about 1.16 L of water was removed per hour (the amount actually removed by the refrigeration coils was certainly less, but this was not measured). The average percent weight loss from trays per hour was 6.38 percent, with a standard deviation of 0.45 (Figure 3).

The first change was to implement a baffling system that would force the air to flow through the drying racks (Experiment 2). The baffling also necessitated the repositioning of the fans to a more central location. From the results of the experiments in this project, it is impossible to ascertain whether or not baffling increased drying rate, since all subsequent experiments took place with significantly more fireweed leaf in the trays (0.91 kg (2 lb) for experiments 2 and 3. Water loss did increase in Experiment 2, but how much of that increase is due to the baffling and how much is due to the increased leaf mass per tray is uncertain. Drying uniformity, on the other hand, decreased with the addition of the baffling. Because of this problem, the researcher developed two small additions to the kiln, namely a dry air deflector and an air intake disperser (Experiment 3).

The upper trays in Experiment 2 tended to dry much more slowly than the lower trays. However, they dried rather uniformly from front to back as well as from left to right (Figure 4).

Trays in Experiment 3 dried rather uniformly from top to bottom, but showed a high degree of variation between the front and back as well as a moderate degree of variation from left to right (Figure 5).

While the additions in Experiment 3 may have improved the drying uniformity of the kiln vertically, they also resulted in a slower drying rate. In Experiment 2, plants in the kiln lost 2.62 L per hour, while those in Experiment 3 lost 2.02 L per hour. Since the amount of leaf was the same in each experiment, this would appear to be a valid representation of the effects of the additions (Figure 6).

Some major changes needed to be made in order to bring the kiln closer to its capacity of removing 4.33 L of water per hour. The highest recorded amount of water removed by the refrigeration coils was 1.54 L per hour with the previously described kiln design (in this most efficient experiment 0.66 kg, or 1.5 lb, of fireweed leaf was used per tray). Because of this inefficiency, new racks were built with seven and ten rows, respectively, as opposed to the original five. While time constraints only allowed for a brief subjective evaluation of these trays, this proved to be enough in determining their fitness for use in the drying process. The racks

Figure 4. Experiment 2: Percent weight loss of trays with the inclusion of side baffling. Graphical representation of percent weight loss of trays in Experiment 2. Empty cells were not measured. White cells with numbers represent the slowest third of the range in drying rates, 39 to 46.9 percent. Light pink cells had a percent weight loss of between 46.9 and 54.7 percent. Dark pink cells, representing the fastest third of the range of drying rates, had a percent weight loss of between 54.7 and 62.6 percent. Drying took place over seven hours.

Front Row

Rack #	1	2	3	4
Row 1	48.9	44.2	43.7	50.5
Row 2	49.5		49.0	53.7
Row 3	53.2		52.6	55.8
Row 4	58.4		41.6	60.0
Row 5	62.6		62.1	59.5

Back Row

Rack #	1	2	3	4
Row 1	40.5	40.0	39.0	47.9
Row 2	42.6	40.5	40.0	46.8
Row 3	45.3	45.3	43.2	51.6
Row 4	51.1	55.3	53.7	52.1
Row 5	55.8	62.6	60.5	50.5

Figure 5. Experiment 3: Percent weight loss of trays with the inclusion of side baffling, air deflector, and air intake disperser. The slow-drying rate (white) is from 33.7 to 44.9 percent weight loss. The intermediate drying rate (light pink) is from 44.9 to 56.2 percent weight loss. The fast drying rate (dark pink) is from 56.2 to 67.4 percent weight loss. Drying took place over eight hours.

Front Row

Rack #	1	2	3	4
Row 1	51.6	53.7		50.5
Row 2	67.4	58.4		49.5
Row 3	65.3	60.0		46.3
Row 4	62.1	59.5		49.5
Row 5	53.7	59.5		51.1

Back Row

Rack #	1	2	3	4
Row 1	45.8	40.5	39.0	50.5
Row 2	45.3	37.4	36.8	42.1
Row 3	43.7	40.0	35.3	33.7
Row 4	44.2	41.6	36.8	37.4
Row 5	43.7	47.4		44.7

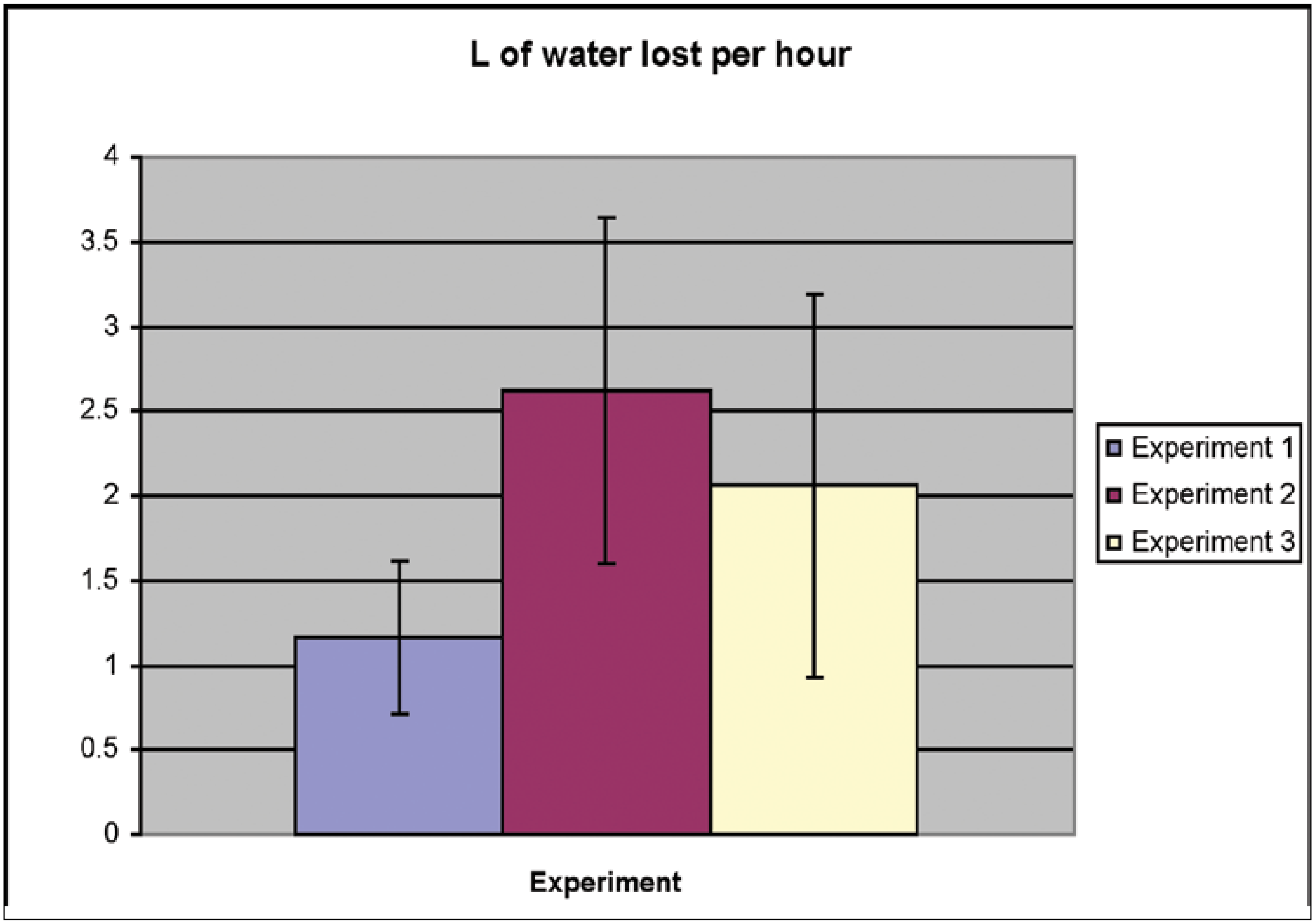


Figure 6. Experiment 2 exhibited a faster drying rate per hour (2.62 L per hour) and an intermediate standard deviation of drying rate per tray (1.02). Experiment 1 had the slowest drying rate, (1.16 L per hour) but also the lowest standard deviation (0.45). Experiment 3 had an intermediate drying rate (2.06 L per hour) and the highest standard deviation (1.13). Experiments 2 and 3 had the same amount of material per tray.

with ten rows had some serious problems with drying uniformity. The top two rows of trays always dried much faster than any of the other rows. In the other rows, drying was extremely slow. The design was still efficient, however, because there was so much material that more water was being taken out per hour than in the previous rack design (up to 1.88 L per hour). This rack design, however, proved very difficult to work with. One of the important aspects of drying herbs is the turning of the product during the drying process, which was nearly impossible with the limited space between rows.

The seven-row trays can be seen as a compromise between the five- and ten-row trays. There was not enough time to do a great deal of testing on this final rack design. One rack was filled with a uniform batch of rose leaf (0.41 kg or 0.9 lb per tray), and was weighed after being dried. Drying was rather uniform; only one tray (row 3, front) had leaf that dried out much more quickly than the others (Table 1). No difficulties with turning the product were experienced.

Although no measurements of water outtake by the refrigeration coils were taken with this rack design, it would not likely bring the kiln up to its capacity. Simply based on the 40 percent surface area increase over the original rack design, one could estimate a maximum water outtake of 2.16 L per hour (140 percent of 1.54 L, or 2.16 L per hour). Since this is still well below the kiln's capacity, some other changes are needed.

Table 1. Percent weight loss per individual drying tray in a 7 row drying rack. Row 1 is the top row, Row 7 is at the bottom of the rack.

Front	% Weight Loss	Back	% Weight Loss
Row 1	37.78	Row 1	38.89
Row 2	33.33	Row 2	30.00
Row 3	48.89	Row 3	35.56
Row 4	38.89	Row 4	38.89
Row 5	36.67	Row 5	37.78
Row 6	35.56	Row 6	40.00
Row 7	37.78	Row 7	36.67

The logical step was to increase the number of racks in the drying room, because there was a great deal of empty space. Physically, seven racks could fit in the room, but only four were being used up to this point. Due to the placement of the door in the kiln, however, it was only feasible to put six racks in the kiln. For this reason, two extra racks were constructed. This arrangement of the kiln, however, was very off-center, due to the placement of the door in a less-than-ideal location. A side fan was used in an attempt to increase drying uniformity across the kiln. Unfortunately, by the time such modifications were made to the kiln, time constraints prevented extensive testing of this design. Based on the drying rates in previous designs, however, one can calculate a maximum water removal rate of about 3.23 L per hour with six racks and 3.77 L per hour with seven racks.

One aspect of kiln design that needs attention is proper sealing. Based on tray weights from before and after experiments 2 and 3, an average of 2.06 L and 2.62 L were removed per hour from the plant materials in the kiln, respectively. However, averages of only 1.22 L and 1.29 L per hour were collected by the refrigeration coils in the same experiments, respectively, suggesting the exit of water from the drying room by some means other than the refrigeration coils.

The amount of electricity consumed by different parts of the kiln system was also looked at in this project. By counting the number of spins during a two-minute period, the researcher was able to determine which aspects of powering the kiln were most costly. The auxiliary heater was the most energy intensive, causing the meter to spin about 18 times. The refrigeration coils only produced about five spins, while the internal blower motor and external fans produced only about ½ to 1 spin.

Moisture Content

The moisture contents of the commercial teas evaluated in this project are given in Table 2.

The teas range in MC from a low of 5.48 percent to a high of 10.17 percent, excluding one blend that contained raisins. Because the raisins required several days in the drying oven to reach bone dry, the rest of the tea probably lost a significant amount of volatile oils, thus giving an inaccurately high MC value. For this reason, this tea will be excluded from the remainder of the discussion of results. The average MC of the teas was 7.54 percent. Those teas packaged in an airtight container dried out to an average of 8.90 percent, ranging from 7.91 to 10.17 percent. Those packaged in containers that were not airtight dried out to 6.76 percent on average, with a range of 5.48 to 8.78 percent. One cannot infer from these results, however, that, by packaging a tea in an airtight container, one conserves more moisture. The teas were made by four separate companies, which may use very different drying practices. Therefore, differences in moisture content may reflect packaging, storage, and/or drying methods.

The moisture contents for the selected plants in the Haines area (except labrador tea and kinnikinnick, which were also collected in the Fairbanks area) are given in Table 3.

Although it was not initially intended to be a part of this project, a look at the variability in MC throughout the harvest season and across microclimates is provided by moisture content data from several different plant materials. In fireweed leaf, for example, there appears to be a general trend of decreasing moisture content as the season progresses (Figure 7). Similarly, the MC of dandelion leaf varies depending on its harvest

Table 2. Moisture content analysis of selected commercial teas

Ingredients	Packaging	Airtight?	MC (green basis)
Black currants, red currants, raisins	loose	yes	14.93
Wild berries, natural herbs, spices, range zest	tea bags	no	6.33
Elderflower, rose, peppermint, fireweed, other select botanicals	tea bags	no	5.90
Black tea, goldenrod, wild rose, other select botanicals	tea bags	no	6.34
Rosehips, rose leaves, rose petals, natural flavor	loose	no	5.48
Rosehips, blueberries, blueberry leaves, chamomile, natural blueberry flavor	loose	no	7.73
Rosehips, cranberries, yarrow flowers, natural cranberry flavor	loose	no	8.78
Peppermint leaves	tea bags	yes	10.17
Chamomile flowers	tea bags	yes	8.61
Chamomile flowers	loose	yes	7.91

location. All but one of the ten samples of dandelion leaf were collected in open areas, such as lawns and driving ranges. The MCs of these samples ranged form 82.37 to 84.52 percent, with an average of 83.52±0.67 percent. One sample, however, was collected alongside a shaded logging road, and had an MC of 86.35 percent. By including this one sample the standard deviation increases dramatically, to 1.09.

Drying Schedules

Regarding material depth, the researcher found that quality was diminished in unwithered dandelion leaf and fireweed leaf when material depth was 6.3cm (2.5in) or greater. Diminished quality most commonly took the form of uneven drying within a tray, with leaves that dried out too much tending to brown. Fireweed flowers required an extremely long drying time at depths of 6.4cm (2.5in) or greater, so much that some of the material was lost to molding. The remainder of the plant materials examined (rose leaf, strawberry leaf, nettle leaf, and yarrow flower) could safely be piled to 9.5cm (3.75 in.) without sacrificing quality. These materials, however, were never piled higher than this, due to the restraint of tray depth.

Lower material depths, as low as 3.2cm (1.25 in) resulted in no signs of diminished quality in dandelion and fireweed leaf, but appeared to be very economically inefficient. As the drying progressed, the material shrank to such an extent that the trays' wire mesh screens were not even completely covered by a layer

Table 3. Moisture content data for selected species in the Haines area, organized by which part of the plant was used. N = number of samples.

Species Name (Latin)	Sp. Name (common)	Material	MC (green basis)	N	Collection Dates
Achillea borealis Bong.	Common Yarrow	Flower	69.8 ± 0.38	3	07/11-08/08
Chamerion angustifolium (L.) Holub	Fireweed	Flower	79.15 ± 0.95	5	7/11-7/25
Rosa nutkana Presl	Rose	Petals	83.32	1	06/19
Trifolium pretense L.	Red Clover	Flower	78.75 ± 0.59	4	06/16-07/20
Arctostaphylos uva-ursi (L.) Spreng.	Kinnikinnick; Bearberry	Leaf	51.49 ± 1.5	10	08/06-09/14
Chamerion angustifolium (L.) Holub	Fireweed	Leaf	74.99 ± 3.51	7	06/03-07/20
Fragaria chiloensis (L.) Duchesne subsp. *pacifica* Staudt	Beach Strawberry	Leaf	64.01 ± 3.53	3	6/18-6/30
Ledum palustre L. subsp. *groenlandicum* (Oeder) Hult.	Labrador Tea	Leaf	53.09 ± 1.91	12	07/20-09/02
Matricaria matricarioides (Less.) Porter	Pineapple Weed	Herb	82.86 ± 1.53	4	07/20-08/08
Picea sitchensis (Bong.) Carr.	Sitka Spruce	New Spring Foliage	83.03	1	05/27
Rosa nutkana Presl	Rose	Leaf	61.47 ± 2.19	7	06/29-08/08
Rubus idaeus L. subsp. *melanolasius* (Dieck) Focke	Raspberry	Leaf	70.17 ± 3.48	6	07/15-07/20
Solidago decumbens Greene	Goldenrod	Leaf and Flower	69.78 ± 2.48	6	07/11-07/25
Taraxacum officinale Weber	Dandelion	Leaf	83.80 ± 1.09	10	05/24-06/01; 07/11-08/08
Urtica lyallii S. Wats.	Nettle	Leaf	82.50 ± 1.32	4	05/26; 07/01-07/13
Oploplanax horridus Miq.	Devil's Club	Inner Bark	63.79 ± 0.16	2	07/16
Viburnum edule (Michx.) Raf.	High Bush Cranberry	Bark	55.28 ± 1.33	4	07/15-07/26

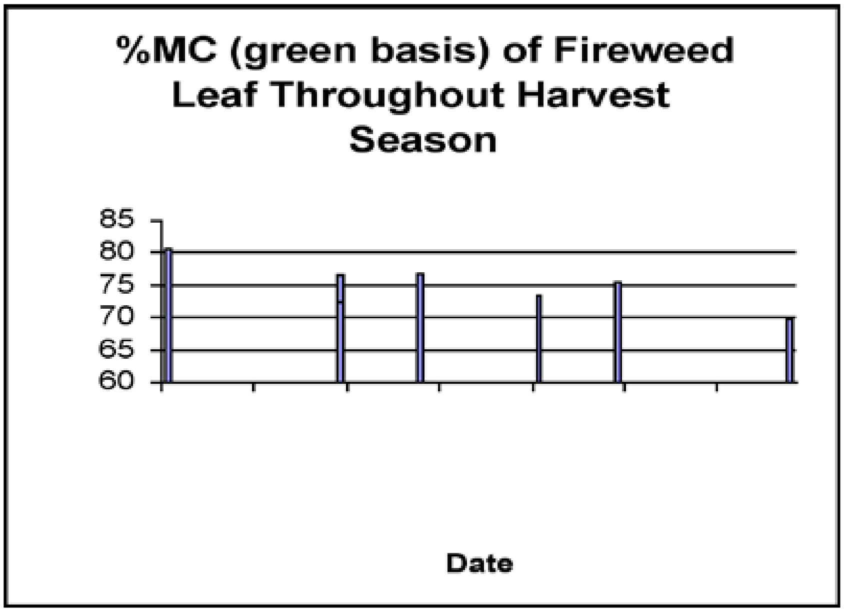
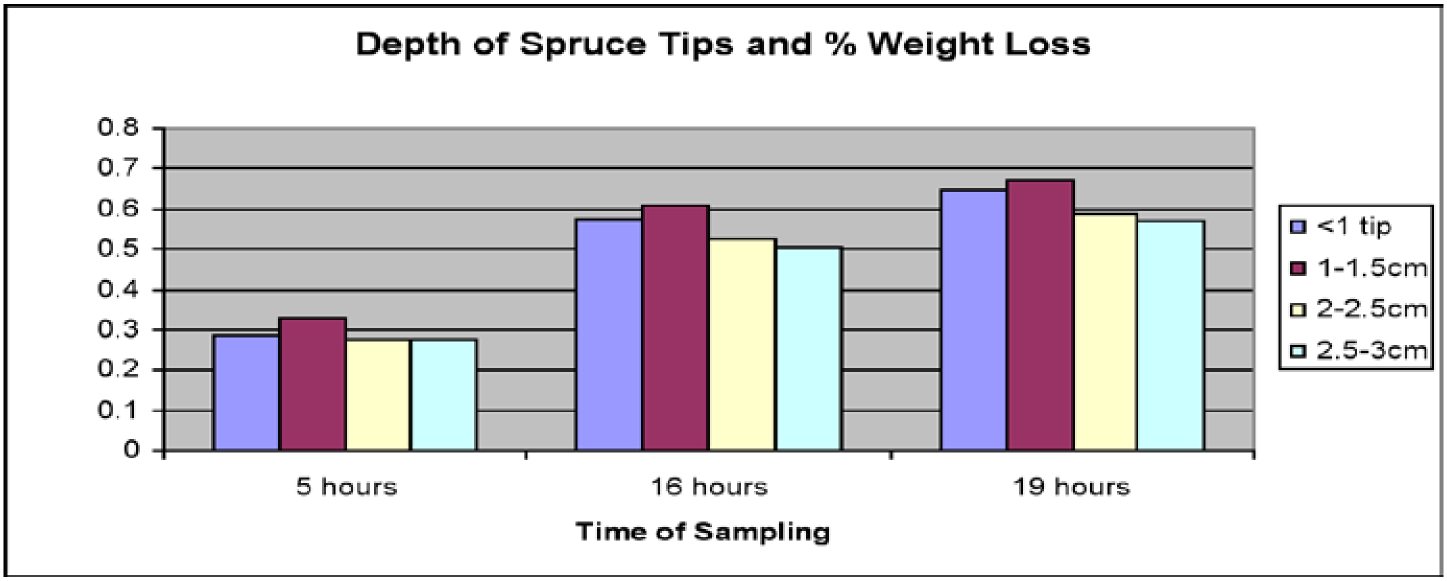


Figure 7. Moisture content of fireweed leaf throughout the harvest season. Notice the trend of decreasing MC as the season progresses.

Figure 8. Spruce tips placed 1-1.5cm consistently exhibited the fastest drying rate.



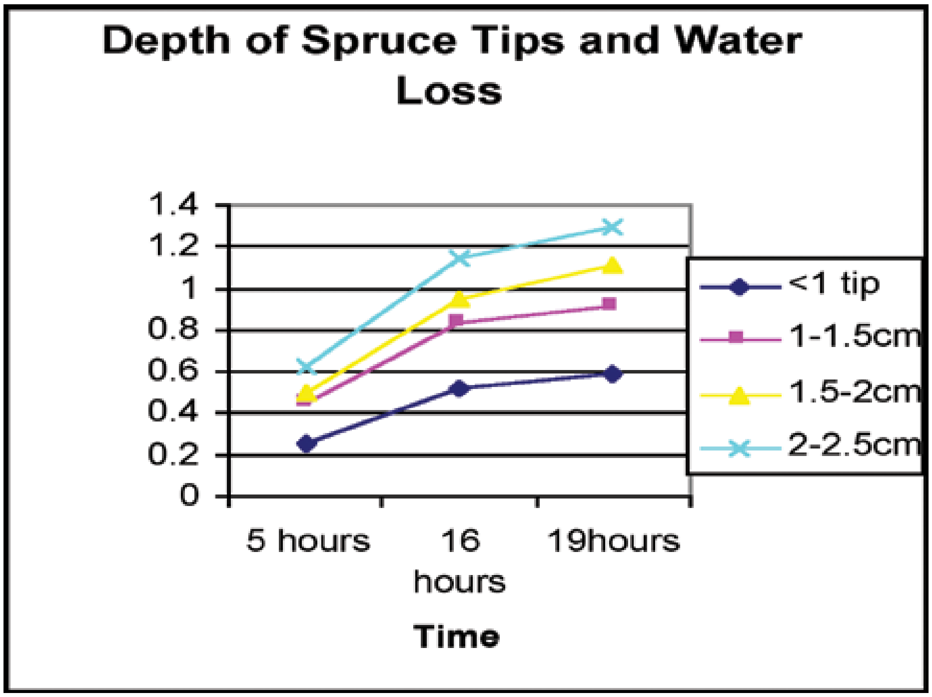


Figure 9. In this experiment, the amount of water lost per tray increased with the amount of material in each tray.

of plant material. This was problematic because of the limited space available in the drying room. One method of coping with this problem was to combine the contents of several trays into one. As trays were emptied in this way, they were refilled with fresh material. This process necessitated that the kiln operate as a continuous, rather than a batch, dryer, and was very complex and labor intensive.

The 24- to 36-hour pre-dry process served as a more practical method to alleviate the problem of material shrinkage. Withered dandelion leaves could be added to a tray at a depth of 6.3cm (2.5in) with no apparent loss of quality. Withered leaves also underwent less shrinkage than unwithered leaves, and drying time was reduced by the pre-dry process as well. The pre-dry process was not implemented until after the seasons for collecting fireweed leaf and flower were over, so its effectiveness in improving their quality is unknown. Withered rose leaves were also successfully dried in the kiln in only two days. Fresh rose leaves, on the other hand, dried for an additional day after the withered leaves were done drying.

In the experiment involving the depth of spruce tips in drying trays, it was found that the tips that were placed 2.5 to 3cm deep lost the lowest percentage of their weight, while those with spruce tips 1-1.5cm deep (1 tip thick) lost the highest percentage of their weight at all three times of measurement (Figure 8). However, the total amount of water lost was greatest in the tips that were 2.5 to 3cm deep and lowest in the tips that were less than one tip deep (Figure 9). Not enough replicates were made to statistically analyze these data.

Drying time was essential to maintaining product quality. The most common difficulty faced with drying was consistency in drying among the various parts of the individual material. In dandelion, fireweed, and nettle leaf, for example, the leaf midvein consistently dried much more slowly than the leaf blade. In fact, the leaf blade would become very crispy and frail before the midvein showed signs of drying. This problem was dealt with by allowing the kiln to run for only 6 to 12 hours (depending on material depth, species used, etc.) on the first day, 4 to 8 hours on the second day, and 2 to 6 hours on the third day. By spreading the drying process out in this manner, the different parts of the plant materials had a chance to equilibrate, so that no part became too dry and frail.

In addition to the drying process, a post-dry process was also briefly examined. After one to two days of remaining in the open, herbs generally lost their brittleness. However, if the ambient air had a high relative humidity, as was the case on rainy days, the herbs would re-absorb so much moisture that they needed to be put back in the kiln.

Discussion & Conclusions

Kiln Design

Based on both a review of literature and extensive experimentation with kiln design, a number of principles of kiln design can be extrapolated. They include maximizing space and accessibility, proper direction of airflow, and good insulation and sealing. These principles will be extrapolated at the end of this section to come up with a recommended design for the drying room used by Alaska SuperNatural Teas.

Maximization of Space and Accessibility

The main purpose of maximizing space is to be making use of all the air that is being heated. Heating air to fill an empty space within the kiln is wasteful and should be avoided as much as possible. The initial kiln design incorporated only four racks, although up to seven such racks could fit into the drying room. It only makes sense to use this space. Likewise, the number of rows of trays per rack was increased from five to seven. Since no adverse effects were observed with this increased number of trays, this also seemed to be an effective method of maximizing space for plants. However, there comes a point when workers can no longer easily enter, which is especially important in drying herbs, since the plant material must be turned. For this reason, the door on such a kiln should be located so that workers can enter at a spot where they can easily access all of the drying trays. In the case of Alaska SuperNatural teas, only six racks could be included, due to poor door placement.

Proper Direction of Airflow

Properly directing the airflow in a kiln is essential to both speed and evenness of drying. The speed of airflow was not looked at in the various experiments conducted on the kiln, so Barbosa-Canovas et al.'s (1996) recommendation of 2-5m/sec will be accepted in this situation. If the airflow setup used in this study was somehow different than this recommended value, the air deflector may require adjustment to account for any future changes made to the airflow.

The addition of the air deflector and intake disperser produced mixed results. Individual racks dried more uniformly from top to bottom with the addition of these components. However, there was much more horizontal variation in drying rates. This may have been partially due to the frequent opening and closing of the kiln door, which was located on one side of the drying racks. Ideally, opening of the door should be minimized, and the kiln should be symmetrical from left to right. By adhering to these two rules of thumb, it is likely that any problems with drying uniformity from left to right could be alleviated. The addition of the two components also produced a greater difference between the front and back trays, necessitating that the trays switch places sometime in the drying process. This can be easily accomplished by flipping the racks midway through the drying cycle.

That being said, the problems with uniformity associated with the air deflector and intake disperser can be easily alleviated, while the problems with uniformity in their absence (uneven drying from the top to the bottom of a tray) cannot be as easily avoided. The air deflector used in this project extended only a short distance from the wall (about 16 cm). However, one extending the entire length of the wall, as illustrated by

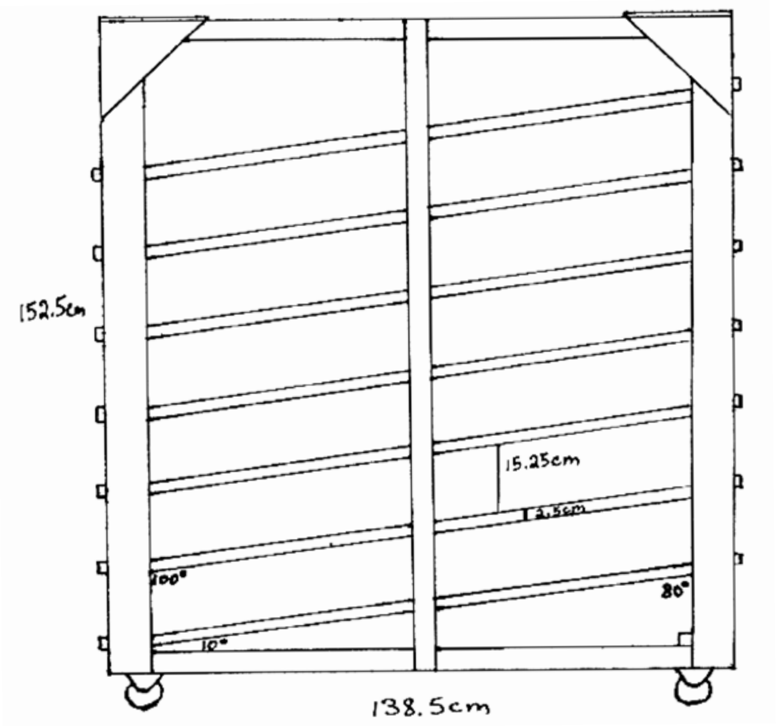
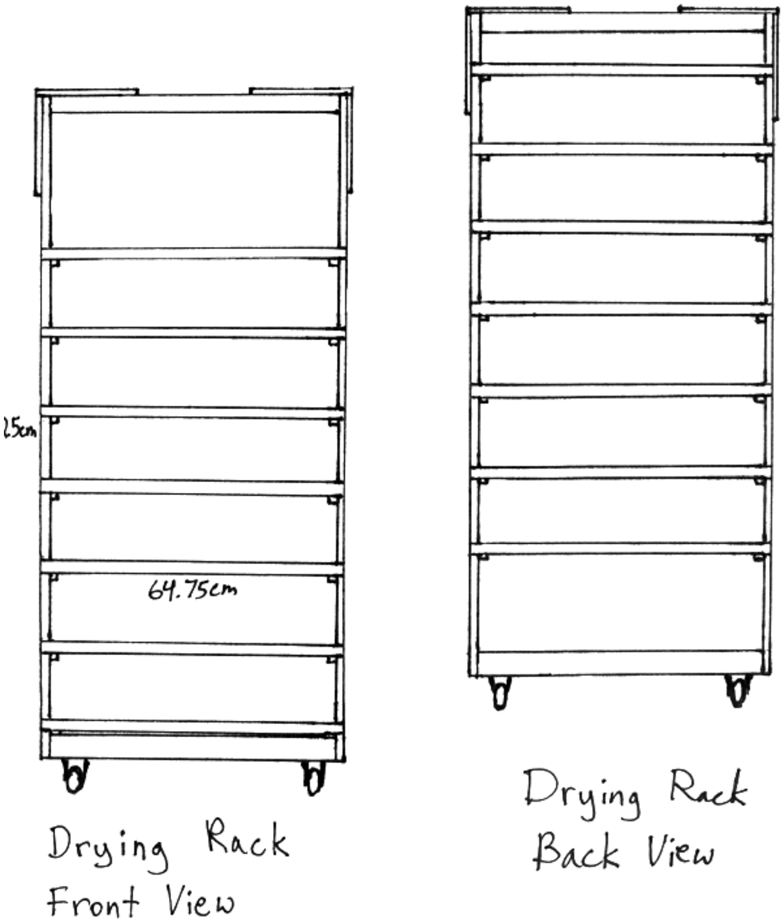


Figure 10. Side view of recommended drying rack.

Barbosa- Cánovas et al. (1996) may be worth including if the space is available. The air intake disperser also proved to be important in achieving even drying among a few of the lower racks. No mention of such a kiln component was found in any literature. The disperser may have been beneficial because of the relative proximity of it to the nearest drying trays: 17.8cm (7in). Despite improved drying evenness among these few trays associated with the air intake disperser, it may be wise to eliminate it, because it may serve as an impediment to air intake. The disperser may be responsible for the decreased drying rate observed in Experiment 3 as compared to Experiment 2. Other options exist to control this problem, such as a larger intake site or multiple air intake sites, or increased space between drying racks and the air intake. The air intake disperser is not included in recommendations for Alaska SuperNatural Teas to implement in its kiln design.

While the impact of a baffling system was not directly studied, the Nyle Corporation states that it essential to a good kiln design. One important component of the baffling system that was not included in the kiln experiments is that of a gap block beneath the drying racks. A few centimeters of empty space exist below each drying rack, through which dry air can freely pass. This air is cycled through the kiln without ever passing over plants, so it does not contribute to the drying process. By blocking these gaps, one can likely increase drying rate by a small amount.

It was seen in this study that rack design is actually an important component of airflow, since a small space between trays will interfere with the airflow between them. Naturally, this ideal amount of space varies among plant materials, as some



Drying Rack
Front View

Drying Rack
Back View

Figure 11. Front and back views of recommended drying rack.

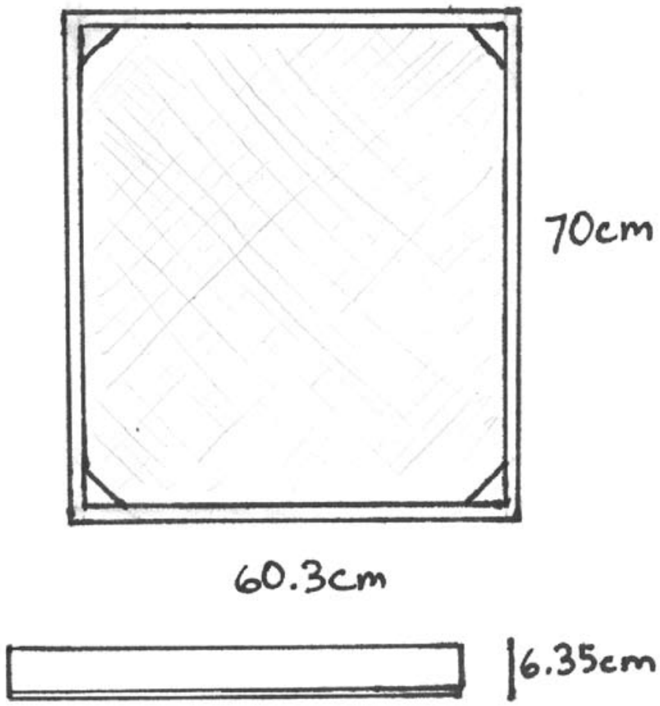


Figure 12. Drying trays and their dimensions.

can be piled higher than others. The amount of empty space between racks in the recommended design was 8.9 cm. The distance between each of the side rails was 15.25 cm, but the trays took up an additional 6.35cm. The design for drying racks that was most successful (produced even drying and allowed a large amount of product), as well as the drying trays which were placed on them, can be seen in figures 10 through 12.

Insulation and Sealing

The fact that more water was being lost by the plant materials than was actually being collected by the refrigeration coils highlights the need for proper sealing. One cause of this problem, however, is that the kiln door was frequently opened and closed, letting hot, moist air escape. This happened so frequently during the course of this project because of frequent monitoring of the drying process. When more complete drying schedules are available for the plant materials, monitoring can be done on a more limited scale. It is nonetheless possible that some of the water that was not accounted for escaped through leaks in the drying room. In order to avoid such inefficiencies, it

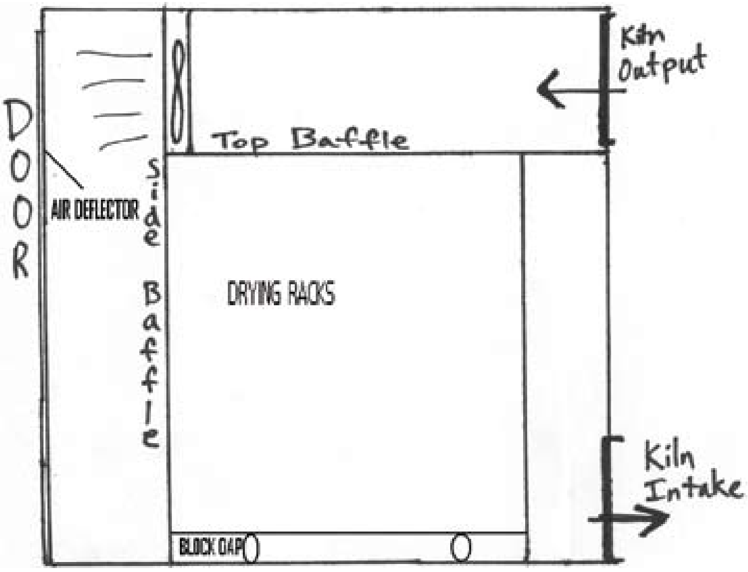


Figure 13. Front view of recommended kiln design.

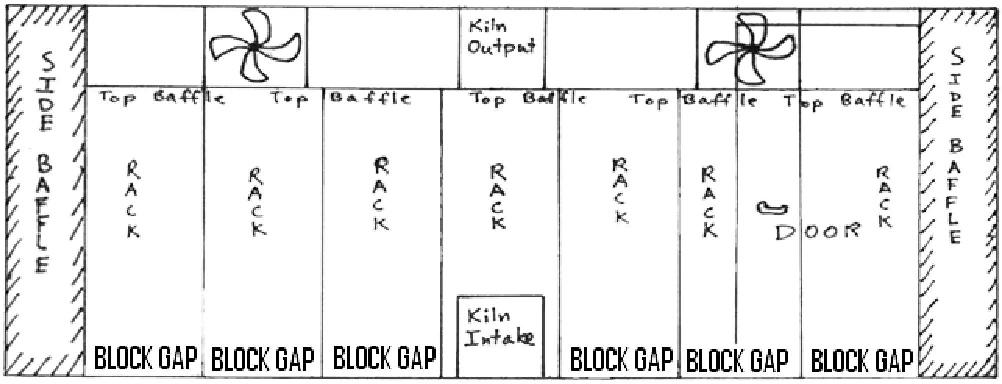


Figure 14. Side view of recommended kiln design.

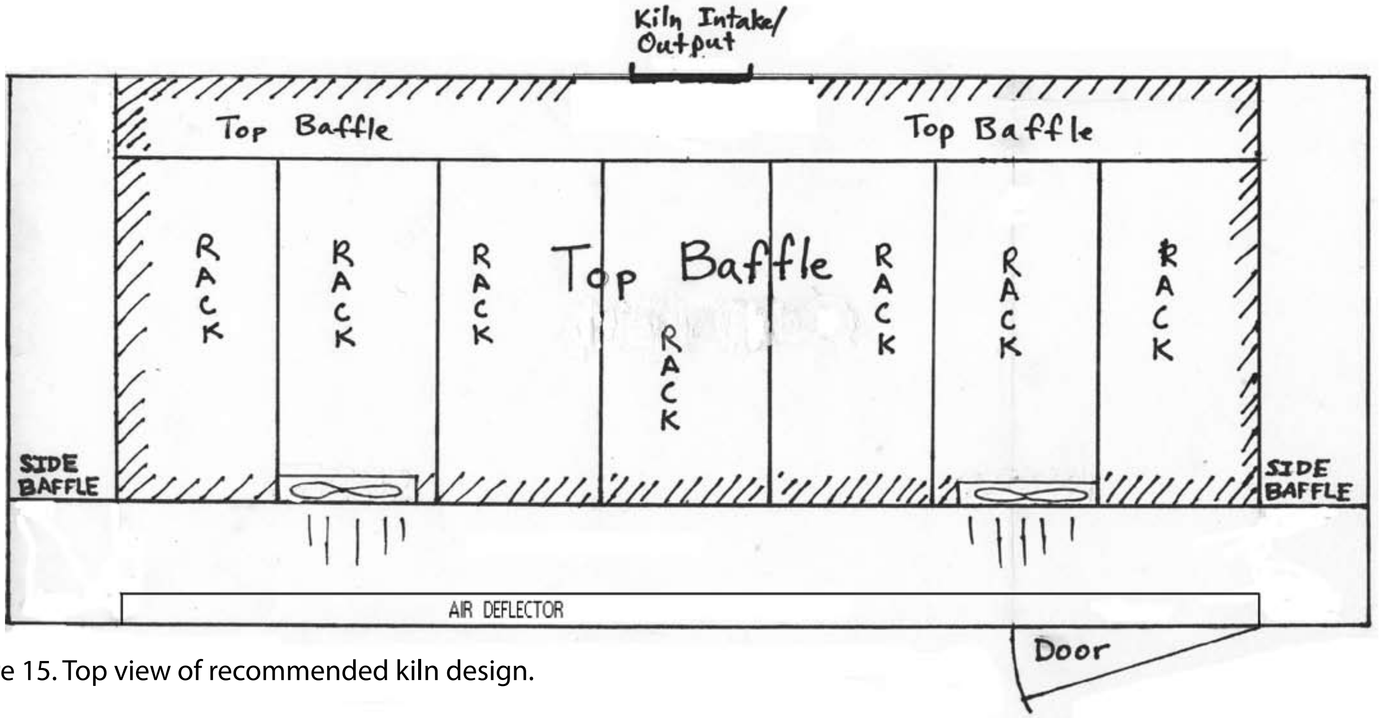


Figure 15. Top view of recommended kiln design.

is important to make sure that the kiln is well sealed. Likewise, good insulation is important in avoiding the loss of heat by convection.

Reducing Electric Costs

Auxiliary heat was by far the most energy-intensive component of the kiln's electric cost. This reinforces the importance of good insulation and sealing. It also suggests other possible methods of reducing the cost of running the kiln. For the majority of the drying process the refrigeration coils produce enough heat to eliminate the need for auxiliary electric heat. However, the initial process of heating the kiln to a desirable temperature makes use only of the auxiliary heat. This process can easily take over an hour if the difference between the ambient temperature and the desired drying temperature is over 16°C (30°F). Adding to the problem is the fact that most herbs require a two- to three-day drying process using the methods applied in this project. Since the kiln was turned off overnight to allow the herbs to equilibrate, the pre-heat process had to be performed two to three times for each batch in the kiln. One possible method of dealing with the costly auxiliary heat is to employ the use of another auxiliary heat source, such as that used in a conventional kiln. Direct heat (the exhaust gases of combustion) is the most efficient method, and is sometimes used in cabinet dryers, but it may damage some products. (Barbosa-Cánovas et al. 1996). Furthermore, it would likely be unhealthy for workers to enter a room with such gases. Therefore, an indirect heat furnace would be more suitable for this application. Another option for decreasing the electric cost associated with preheating the dryer is to develop a drying method that did not involve any down-time. This will be dealt with in the "Drying Schedules" section of the discussion. That way, each batch would only need to be pre-heated once.

A design for a drying room for Alaska SuperNatural Teas that is based on the above-mentioned principles in given in figures 13-15. Since the drying room has such a large capacity with the new design, it is also recommended that the company focus mainly on herbs which can easily be harvested in large quantities. For the Haines area, these would likely include fireweed leaf, dandelion leaf, rose leaf, and yarrow flower.

Moisture Content

The experiment involving the moisture content of commercially marketed teas provides valuable information for the drying process. The most valuable is that dealing with teas packaged in airtight containers. It is so important because one can assume that the MC measured in the experiment is a fairly accurate reflection of the MC of the tea at the completion of the drying process (this assumption is dependent on the teas being stored in relatively airtight containers after drying). Using only data from this portion of the experiment, one can estimate an ideal dry MC (green basis) to fall between 7.9 and 10.2 percent. By including the other teas, one extends the lower end of the range down to 5.5 percent. These results coincide very well with the two sources offering ideal MCs for dried herbs: Miller (1998) suggests 8-10 percent, and Walsh (2003) suggests 5-8 percent. Based on these suggestions as well as the results of this experiment, the researcher would recommend a final MC of 5-10 percent for herbs to be used in teas. To acquire any more detailed information on this issue in the future, one may need to conduct some formal taste testing of plants dried to different MCs.

In examining the green MCs of plants of potential economic importance in the Haines area, it is important to look at the standard deviations associated with the results. As an example, fireweed leaf was shown to have a MC of 74.99 ± 3.51 percent. At least 75% of the values will fall within two standard deviations of the mean (Bluman 2001). This means that the leaf could easily range anywhere from 67.97 to 82.01 percent. This figure is not nearly accurate enough to use in drying herbs to the narrow range of 5 to 10 percent MC. However, since fireweed leaf showed a trend of decreasing MC throughout the season, it may be possible to predict the MC of the leaf at various harvest dates. Even if one did acquire detailed information about MC content of a given plant material throughout the season, one would also likely need to relate the information back to the stage of plant growth (i.e., vegetative, flowering, producing fruit, etc.) because these stages often vary somewhat from year to year.

Microclimate also is a factor that may need to be considered in predicting moisture contents. As an example, the one sample of dandelion leaf that was collected from a shaded dirt road had a much higher MC value than any collected from sunnier locations. Thus, if plant materials are to be collected from a number of different microclimates, this factor should be considered in estimating MC. It may be necessary to incorporate any of a number of other variables into a model that predicts moisture content, as Pech (1989) used to predict the MC of reindeer lichen.

Regardless of whether or not moisture content data may someday be used in drying schedules, the data acquired in this project is valuable in determining the economic viability of the various herbs. By knowing approximately how much weight a given plant material will shrink as it goes through the drying process, one can figure out how much dry tea will be obtained from a harvested amount of green material.

Drying Schedules

Probably the most important finding with respect to drying schedules in this project was the importance of the pre-dry process. By withering the plant materials before they are put in the kiln, one can both increase product quality and the energy efficiency of the drying process. If the process is done outside in the shade, no additional energy input is needed for this part of the drying process.

Based on the results of informal experiments involving material depth, it appeared that there are several factors that influence the ability of a material to dry successfully at a high depth, including porosity and shrinkage during drying. Strawberry leaf, for example, essentially maintained its original shape throughout the drying process. The original shape of the strawberry leaf leads to a high porosity when the leaves are placed in a tray, so air can easily pass between the leaves throughout the whole process. Yarrow flowers are another example of a very porous material. The flowers are picked and dried in large inflorescences (group of flowers on a single stem), which contain a large amount of empty space. Like the strawberry leaf, the yarrow inflorescence maintains its original shape throughout the drying process, and air can easily move throughout the drying tray. When dandelion and fireweed leaves are dried, however, they tend to lose their shape. As they wither, they form a large mass, with wet material on the inside and dry material on the outside. Even with frequent turning of these materials, it is difficult to achieve a high-quality product. If dandelion leaves are first withered outside of the kiln, however, they do not tend to form a single impenetrable mass, and they can be piled high without worry. Fireweed flowers, on the other hand, have a high bulk density and low surface area compared to most of the other plants in this study. This may have been the cause behind the difficulties in drying the flowers in thick layers. It seems unlikely that a pre-dry process could alleviate this problem, so it may be a good idea to use relatively thin layers of fireweed flower on the trays.

The experiment involving the varying depths of spruce tips showed that the percent water loss of the material was maximized at a relatively low thickness, 1-1.5cm. At the same time, however, more water was lost from trays that had more material, simply because there was more water to be removed. This illustrates the principle that kiln efficiency can be increased in two ways: by increasing the number of trays or by increasing the amount of material per tray. If the number of trays has already been maximized and the kiln is still not at its capacity of 4.33 L/hr, the depth of spruce tips should continue to be increased, as long as no quality differences are observed

Spruce tips, like fireweed flowers, have a relatively high bulk density. For this reason, these materials should never be piled too thick onto a drying tray. Most materials, however, dry rather well at higher thicknesses. By including a pre-dry as part of the drying process, an operator should be able to pile even dandelion and fireweed leaves higher than Walsh's (2003) recommended maximum depth of 7.6cm (3in) without an associated loss in quality. Unfortunately, no maximum height for these plants could be established, due to the spilling over of material from the trays. With larger trays, thicker piles of material would likely become possible. Miller (1998), who recommends that herbs be piled to 25.4 cm (10 in), also includes a tray design that is twice as wide as the trays used in this project. As seen in the spruce tip experiment, however, the most efficient drying tends to happen when a large number of thin layers are used, as opposed to a few thick layers. The thicker layers, however, have the advantage of decreased labor cost, as it takes less time to pile one large tray high with leaf and load it onto a rack than it does to pile four small trays with a smaller amount of leaf and load each of them onto a rack. Thus, it may be worthwhile to calculate an efficient balance between drying time and labor cost.

Regarding drying time, the main problem was that the drying process had to be frequently halted in order for the various parts of the plant materials to equilibrate. In most materials the leaf midvein was the limiting factor. With respect to fireweed flower, the unopened flowers dried much more slowly than those that had already opened. Spruce tips were the only material studied that did not have some part drying out more slowly than the rest. Rather, these compact tips dried out much like foods described by food scientists, in which the main consideration is the rate of water moving from the interior of the material to its exterior. It is very possible that no break between drying days was necessary for spruce tips, but the kiln could never be kept full with them, because their harvest was so labor intensive.

Most materials studied in this project, however, did require some off-time when dried in a dehumidifying kiln. Turning the kiln off and on every day for two to three days in a row is very economically inefficient, since it has to be pre-heated each time. Fortunately, one can set the temperature and relative humidity of a dehumidifying kiln so that no material will fall below its equilibrium MC. In that way, leaf blades will never fall below a critical MC, such as 5 percent, even though the midveins of the leaves may still be drying out for a long period. Unfortunately, a control box that allows one to set relative humidity was not acquired until after this project was completed. Furthermore, experimentally generated water sorption isotherms would still be needed to determine the equilibrium moisture content of materials at a given relative humidity and temperature. Whether or not most materials could be fully dried within 24 hours using this method is uncertain, although it appears to be a promising way to improve drying efficiency and ensure high quality.

The post-dry process of leaving herbs in the open to re-absorb some moisture worked well in making the herbs easier to handle. However, such a process should always be avoided if the moisture content of the ambient air is particularly high, as the herbs may re-absorb too much moisture. If the MC of the final product can be accurately controlled with the use of a new control box and water sorption isotherms, this process may be unnecessary.

In conclusion, this preliminary study does not attempt to create an automated system of drying tea. Rather, alert monitoring is likely to always be an important factor in successful tea drying (Rufus 1972). A dehumidifying kiln may have the potential to be economically viable in a small-scale Alaska herbal tea operation if it is designed and used efficiently. By using the information from this project as well as any future projects on related topics, one may be able to successfully expand the use of such kilns beyond lumber.

Literature Cited

Baker, C.G.J. 1997. *The industrial drying of foods.* 1st. ed. Chapman & Hall. New York.

Bannister, J. 20 June, 2005. Personal communication. Research manager for Kenai Wood Technologies Center.

Barbosa-Cánovas, G.V., H. Vega-Mercado. *Dehydration of foods.* 1996. Chapman & Hall. New York.

Bluman. 2001. *Elementary statistics: a step by step approach.* 4th. ed. McGraw-Hill. San Francisco.

Desrosier, N.W., J.N. Desrosier. 1977. *The technology of food preservation.* Avi Publishing Company, Inc. Westport, Connecticut.

Federal State Marketing Improvement Program. 2003. Building a strategy for marketing Alaska Grown products. FSMIP Report to the Division of Agriculture. [On line] Available at www.ams.usda.gov/tmd/FSMIP/FY2001/AK0329.pdf. 2 October 2005.

Haygreen, J.G. and J.L. Bowyer. 1982. *Forest products and wood science.* 1st. ed. Iowa State University Press. Ames, Iowa.

Kirsi, M., R. Julkunen-Tiitto, and T. Rimpiläinen. 1990. The effects of drying-methods on the aroma of the herbal tea plant (*Rubus idaues*). *Developments in Food Science* 24:205-211.

Labuza, T.P. 1984. *Moisture Sorption: Practical Aspects of Isotherm Management and Use.* AACC. St. Paul, Minnesota.

Mater, C. 2000. Alaskan special forest products market research report. In: *Proceedings: Linking healthy forests and communities through Alaska value-added forest products.* Conference held in Sitka, Alaska, Sept. 27, 28, 1999. USDA Forest Service. [On line] Available at http://fs.fed.us/pnw/pubs/gtr500/. 6 March 2005.

McClements, D.J. 2001. Food Science 581: Analysis of Food Products. Univ. Mass. Amherst, Massachusetts. [On line] Available at www-unix.oit.umass.edu/~mcclemen/581Toppage.html. 18 March 2005.

Miller, R.A. 1998. *The potential of herbs as a cash crop.* 2nd. ed. Acres USA. Metairie, Louisiana.

Nyle Corporation. L50 – L200 Manual. Bangor, Maine.

Parrent, D. 14 June 2005. Personal communication. Wood utilization specialist for Juneau Economic Development Council.

Pech, G. 1989. A model to predict the moisture content of reindeer lichen. *Forest Science* 35:1014-1028.

Potter, N.N. 1973. *Food Science.* 2nd. ed. Avi Publishing Company, Inc. Westport, Connecticut.

Kiln unit.

—PHOTO BY DANIEL SLAKEY

Ribe, J.H. 1973. Puckerbush weight tables. University of Maine at Orono Life Sciences and Agriculture Experiment Station. Misc. Rpt. 152. Orono, Maine.

Rufus, I.A. 1972. Faults in the drying of tea leaves. *The Assam Review and Tea News* 60 (11):549-559.

Temple, S.J., C.M. Temple, A.J.B. van Boxtel, and M. N. Clifford. 2001. The effect of drying on black tea quality. *Journal of the Science of Food and Agriculture* 81:764-772.

Van Ardsel, W.B., M.J. Copley, and A.I. Morgan. 1973. *Food dehydration volume I: drying methods and phenomena.* Avi Publishing Company, Inc. Westport, Connecticut.

Walsh, C. and S. Fongemie. 2003. *Foraging and wildcrafting in Alaska for fun and profit.* Plant Press. Anchorage, Alaska.

Wolf, W., W.E.L. Spiess, and G. Jung. 1985. *Sorption Isotherms and Water Activity of Food Materials.* Elsevier Science Publishing Company. New York, New York.

Fireweed growing in the Haines area, ready for harvesting.

—PHOTO BY DANIEL SLAKEY

Agricultural and Forestry Experiment Station

University of Alaska Fairbanks
AFES Publications Office
P.O. Box 757200
Fairbanks, AK 99775-7200
fynrpub@uaf.edu • www.uaf.edu/snras
907.474.6923 or 907.474.5042
fax: 907.474.6184

Note: The Senior Thesis Series presents papers prepared for the course NRM 405-6, Senior Thesis in Natural Resources Management. Only those theses that are of exceptional quality are reprinted in this special publication series. Students are required to submit a project proposal for approval before proceeding to the thesis. The original theses are edited for posting on the SNRAS publications website. To view other papers in the series, go to www.uaf.edu/snras/afes/pubs/SeniorTheses/index.html.

UAF UNIVERSITY OF ALASKA FAIRBANKS

About the Agricultural and Forestry Experiment Station

The federal Hatch Act of 1887 authorized establishment of agricultural experiment stations in the U.S. and its territories to provide sicence-based research information to farmers. There are agricultural experiment stations in each of the 50 states, Puerto Rico, and Guam. All but one are part of the land-grant college system. The Morrill Act established the land-grant colleges in 1862. While the experiment stations perform agricultural research, the land-grant colleges provide education in the science and economics of agriculture.

The Alaska Agricultural Experiment Station was established in Sitka in 1898, also the site of the first experiment farm in Alaska. Subsequent stations were opened at Kodiak, Kenai, Rampart, Copper Center, Fairbanks, and Matanuska. The latter two remain. The Alaska station was not originally part of the Alaska land-grant college system. The Alaska Agricultural College and School of Mines was established by the Morrill Act in 1922. It became the University of Alaska in 1935. The Fairbanks and Matanuska farms are now part of the Agricultural and Forestry Experiment Station of the University of Alaska Fairbanks, which also includes the Palmer Research Center.

Early experiment station researchers developed adapted cultivars of grains, grasses, potatoes, and berries, and introduced many vegetable cultivars appropriate to Alaska. Animal and poultry management was also important. This work continues, as does research in soils and revegetation, forest ecology and management, and rural and economic development. Change has been constant as the Agricultural and Forestry Experiment Station continues to bring state-of-the-art research information to its clientele.