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A Comparison of Hop Drying with Unheated, Dehumidified Air Versus Traditional Drying with Heated Air

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ABSTRACT

The traditional hop drying method in the United States is to pile them 24–32 inches deep in a large box and force 120–150°F heated air through the bed. The result is uneven drying, even under the best circumstances, with the bottom hops at about 5% moisture and the hops at the top at 15–20% moisture. The process is hard to control and can result in quality problems, including fire danger. Overheating the hops often results in the formation of an undesirable onion/garlic aroma, which can be avoided by not heating the hops. Drying a 24–30 inch deep bed of hops with unheated, dehumidified air results in a less than 1% moisture difference between the top and bottom of the bed, and the process is easy to control. Traditional hop drying is extremely energy intensive, and it was hoped that drying with unheated, dehumidified air would reduce energy use. The system studied uses an almost identical amount of energy per pound of hops, but the system could probably be optimized to reduce this. The disadvantage of drying with dehumidified air is that it requires 24–48 h versus 5–13 h for traditional drying.

Purpose of Drying Hops

Freshly harvested hops are typically 75–80% moisture. They will quickly spoil if they are not dried down to about 10% moisture. If the dried hops are too moist, they will tend to compost in the bale and spoil—or, in more extreme cases, are subject to spontaneous combustion and have been known to burn down entire hop warehouses. If the hops are overdried, they lose much of their aroma, are broken up badly when baled, store poorly, and are also subject to spontaneous combustion. Overdried hops have even been known to catch fire in the hop drier and burn down the facility. A farmer can spend the growing season producing a perfect crop and then render the hops completely useless to the brewer in a few hours by improper drying. Drying is *the* most critical process on a hop farm.

Traditional American Drying

A typical American hop drier is a 35 × 35 ft box where the hops are piled 24–32 inches deep (or more), and heated air directly from a natural gas, propane, or diesel fuel burner is forced through the bed. The goal is to reduce the moisture from around 80% to about 10% over a period of 5–13 h. The drying time is dependent on the drying air temperature (120–150°F), depth of the bed, air speed through the bed, hop variety, weather, and a number of other factors.

The data in Table 1 provide a summary of results of a hop drying study done on commercial American hop drying equipment that was presented at the Master Brewers national meeting in 2013 (3). The conclusions of the study were that this process results in a great deal of moisture variation between the top and bottom of the hop bed, and it is difficult to determine when to stop the process, which often results in overdrying of the hops. The study indicated that reducing the air temperature, reducing the depth of the bed of hops, and increasing air speed through the bed all resulted in less moisture variation and greater control of the process. Other reported observations were that all the samples recovered from the bottom layer of the bed for both varieties and at both temperatures had a strong onion/garlic aroma, and this aroma was largely absent from samples from the middle and top of the beds. It was also suggested that this aroma was a bit more intense in the hops dried at the higher temperature (150°F).

The large moisture variability of the American system typically requires the dried hops be "conditioned" before baling. This is traditionally done by allowing the hops to sit in a large pile for 24-48 h not only to allow moisture to be transferred from the wetter hops to the drier hops but also to allow individual cones time to wick some of the moisture from the overwet center strig to the overdried outside bracts and bracteoles, making them more supple and less prone to breaking during baling. Some progressive farms even have customized "conditioning" facilities to optimize this process.

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Traditional German Hop Drying (Three-Tier Wolf® Drier)

In Germany and in some other parts of Europe, a different system of heated air drying is used. There are two main differences from the American system: First, the exhaust gases from the combustion of fuel do not go directly through the hop bed. Instead, intake air for the bed is heated by the exhaust gases in a heat exchanger before passing through the hops. This does lower the relative energy efficiency of the system. Second, instead of having one large bed of hops, this system has three layers, and the layers can be dropped to the next level by activating louvers as drying progresses. Undried hops are typically piled to a depth of 30 cm (12 inches) in the top tier, partially dried, and then dropped to the second tier as a new load of hops is loaded into the top tier. Again, after partial drying the middle tier is dropped to the lowest tier, the top tier to the middle, and the top once again reloaded. When the bottom tier is finished drying, the entire tier is pulled out of the tower like a drawer on rails, and the hops are dropped onto the floor for cooling, or into a conditioning chamber. The energy use of this system is said to be 44 L (energy equivalent including fan power) of heating oil per 100 kg of dried hops (1). This compares with 28.6 L per 100 kg (heat only, calculated from data of Table 1) for the American system plus 0.8 L per 100 kg energy use for the fan, for a total of 29.4 L per 100 kg. The German system is said to use a third of the energy for the fan and the rest for fuel consumption for the burner. The heat exchanger is said to be typically around 50% efficient, but this can vary anywhere from 10 to 90% in practice, depending on how much the exhaust air stream is used to preheat the intake air. For a detailed description of this German system, see reference 2.

In the present work, the authors measured the drying performance of one of these German systems at Hop Head Farms in Michigan. The system was a Wolf model HL-12 built in 2016, with drier bed dimensions of 7 × 7 m (23 × 23 ft). The undried hops were loaded into the upper tier to a depth of 30 cm (12 inches). The drying air temperature was 135°F. When the lowest tier was drawn out at the end of the process, samples from the bottom 3 inches and top 3 inches were taken from three different locations in the dry hop bed. Because the hop bed is only about 8 inches deep, sampling from the middle as in Table 1 seemed impractical. Samples were taken from eight batches of Cascade hops and three batches of Nugget hops. A summary of the data collected is presented in Tables 2 and 3. As with the data in Table 1, the moisture data were determined by drying approximately 10 g of hops in an oven at 110°C (230°F) for 1 h. The weight lost indicated the percent moisture.

With this system, one might expect there to be some mixing of the hop bed as it is dropped to each lower level. Perhaps the heavier, wetter hops at the top of the bed would fall faster than the lighter, drier hops of the bottom of the bed. From the data, it appears this is the case. The averages of all 24 top samples and 24 bottom samples of Table 2 were 10.94 and 11.14%, respectively, which are almost identical. There was considerable batch-to-batch variation, and a bit of variation in the position where samples were taken, but not much top versus bottom difference. In Table 2, position B was the center of the drawer, A was halfway from the center to a corner, and C was halfway

Table 1. Summary of data on conventional American hop-drying equipment

Hop variety	Cascade		Citra®	
Bed depth	27–30″ deeper in back		26 inches	
Drying air temperature	130°F	150°F	130°F	150°F
# runs (9 samples/run)	6	6	3	3
Average moisture bottom 3″	5–8%	3–5%	4–9%	3–9%
Average moisture middle 3″	8–15%	8–12%	6–15%	3–14%
Average moisture top 3″	13–22%	15–22%	16–26%	12–28%
Average hop storage index	0.215	0.230	0.270	0.280
Average drying time	7.5 h	5.0 h	13.5 h	10.9 h
Average gallons diesel fuel used			217 (821 L)	206 (780 L)
Drier fan power			25 hp	25 hp
Dry weight hops dried/batch			6,000 lb (2,727 kg)	

Table 2. Moisture content of Cascade hops dried at 135°F in a three-tiered hop drier

Batch #	Position A, top	Position A, bottom	Position B, top	Position B, bottom	Position C, top	Position C, bottom
1	14.12%	9.44%	9.13%	11.81%	8.30%	9.41%
2	11.88%	10.89%	8.57%	6.65%	8.76%	8.50%
3	14.77%	14.03%	10.66%	11.38%	17.95%	17.68%
4	7.74%	8.97%	10.28%	10.58%	12.83%	9.10%
5	11.06%	9.06%	9.24%	10.94%	9.55%	9.64%
6	13.56%	12.75%	8.89%	9.27%	10.28%	14.01%
7	12.54%	11.93%	9.09%	12.61%	11.98%	13.26%
8	11.05%	11.57%	9.68%	9.85%	10.73%	14.14%
Average	12.09%	11.08%	9.44%	10.39%	11.30%	11.97%

Table 3. Moisture content of Nugget hops dried at 135°F in a three-tiered hop drier

Batch #	Position A, top	Position A, bottom	Position B, top	Position B, bottom	Position C, top	Position C, bottom
1	13.51%	8.31%	9.55%	9.14%	11.55%	14.56%
2	18.30%	11.19%	11.62%	12.36%	16.35%	12.75%
3	13.70%	9.72%	10.11%	9.41%	16.89%	17.48%
Average	15.17%	9.74%	10.43%	10.30%	14.93%	14.93%

from the center to the opposite corner. Similar location differences were seen in the study summarized in Table 1.

Nugget is a denser hop than Cascade with a more tightly packed cone. It is harder to dry and takes longer. In positions B and C, again, little variation was seen in the top versus bottom average moisture. In position A, however, a large unexplained difference between top and bottom was observed. Overall, moisture uniformity seemed better with this system than with the American system, but the problem with controlling the final moisture (determining when to stop drying) was not improved. Hops were still prone to heat abuse and the formation of onion/garlic aroma. The fuel efficiency was poorer, but it could be improved by removing the heat exchanger.

Drying Hops with Unheated, Dehumidified Air

The data for this part of the study were collected at Arendt's Hop Haven in Nekoosa, WI. Up to now, this technology seems unique to Wisconsin. There are several other operations in the state with similar systems. The system used had a 12 × 24 ft bed. Undried hops were loaded 24–30 inches deep in the chamber. The top of the chamber had sliding doors that enabled loading and unloading of the drier bed but that could be sealed off so that air pressure could be maintained to blow the dried air from the top of the bed to the bottom. This handy reverse flow of air eliminated the problem of blow-outs. As the bed of hops dries in a conventional drying system, the hops become lighter and tend to form blow-holes where some of the hops blow out of the bed, and all the airflow then goes through the hole rather than through the remaining hops. If the airflow is reversed, this cannot happen. With this new system, the moist air removed from the bottom of the bed was recirculated through a dehumidifier, and the dried air was then forced through the top of the bed once again. Typically, at the start of drying, ambient air is blown through the bed for 24 h without dehumidification before the dehumidification unit is activated. In this phase, the hops are dried from the original 75–80% moisture to about 35%. The air tends to heat up by about 20°F from ambient temperature by compression in the top chamber. For the next 24 h, air is recirculated through the dehumidification unit, and the relative humidity of the air exiting the bottom of the bed of hops is monitored. Unfortunately, the relative humidity gauge used bottoms out at 30% and could not be used to determine the endpoint. Perhaps with better instrumentation this would be possible. However, because the rate of drying at the end is so slow, it is possible to physically remove samples for moisture analysis from the bed and get results back soon enough to turn off the unit before overdrying occurs. This is not possible with conventional systems. At the end of drying, samples of Cascade hops were taken from three different drier loads for moisture analysis. The bed depth was approximately 30 inches, corresponding to 1,100 lb of dried hops. Six samples were taken from each drier load studied: in the center of the bed, top and bottom, and about 1 ft from the edge of each end (West and East) at the top and bottom. Moisture data are presented in Tables 4 and 5.

Moisture values were far more consistent with this system than with the other systems. All values were reasonably close to the desired 10%. With the two conventional systems, many samples were uncomfortably far from the desired moisture level, the American system being far worse than the German. In addition, because the drying rate is slower in the dehumidification system, it is less likely to overdry the hops. There appears to be almost no moisture gradient between the top and bottom of the bed of hops. One would expect the bottom to be wetter than the top (reverse air flow), but the data showed this difference is small. Uniformity with regard to position in the bed also was greatly improved.

We were curious if this system would result in less oxidation of the hops during drying, so hop storage index (HSI) analyses were performed on the top center samples of each bed load. The results are presented in Table 6. The HSI of freshly dried hops is usually close to 0.25. If the value is lower, it indicates the hops were harvested early, or little oxidation occurred. If the value is higher, this indicates a late harvest or excessive oxidation during processing. These were Cascade hops harvested late in the season (September 12–14), so one would expect them to have a high HSI, but they were unusually low. Unfortunately, it was not possible to dry other hops from the same lot with a conventional system for comparison, so the data must be considered standalone. The aroma of the hops was typical of well-processed but late-harvested Cascade—and with no garlic/onion aroma.

Each 12 × 24 ft drier bed is serviced by a 6.9 amp, 220 V dehumidifying unit and is equipped with two 25 hp fans that run at 80% power. So the air speed must be considerably faster through the bed of hops with this system than the American system with only one 25 hp fan servicing a 35 × 35 ft bed. High air speed through the bed from bottom to top is problematic because the hops will blow out of the bed. The reverse airflow of the dehumidification system makes using high air speed possible. The dehumidification system uses far more fan power relative to bed area (40 hp/288 sq ft) than the American system (25 hp/1,225 sq ft). This extra power consumption must also be considered when making energy comparisons.

Table 4. Moisture data for Wisconsin dehumidified air system

Bed load/position	Top	Bottom
1, West	7.68%	9.97%
1, Center	8.46%	9.66%
1, East	8.64%	10.66%
2, West	11.44%	10.05%
2, Center	11.20%	10.07%
2, East	10.39%	9.48%
3, West	7.44%	8.44%
3, Center	8.92%	8.52%
3, East	7.98%	7.46%
Average	9.13%	9.37%

Table 5. Batch-to-batch uniformity for dehumidified air system

Position	Bed load 1	Bed load 2	Bed load 3
West, top	7.68%	11.44%	7.44%
West, bottom	9.97%	10.05%	8.44%
Center, top	8.46%	11.20%	8.92%
Center, bottom	9.66%	10.07%	8.52%
East, top	8.64%	10.39%	7.98%
East, bottom	10.66%	9.48%	7.46%
Average	9.18%	10.44%	8.13%

Table 6. Hop storage index (HSI) of Cascade hops dried with dehumidified air

Sample ID	HSI
Bed load 1, top center	0.20
Bed load 2, top center	0.19
Bed load 3, top center	0.19

Comparison of Energy Consumption of the Three Systems

The German system, with a heat exchanger between the combustion gases and the air passing through the bed of hops, requires 44 L of fuel (equivalent) per 100 kg of dried hops. The American system requires only 29.4 L per 100 kg of hops because there is no heat exchanger. The German system can be engineered to be more fuel efficient by using the exiting warm air to preheat the intake air.

The American system requires 206 gallons of diesel fuel and a 25 hp fan running 11.9 h to dry 6,000 lb dry weight of hops. The average drying time is 10.9 h, but the common practice is to leave the fan on for an hour after the heat is turned off to cool the hops down. Converting 25 hp to kilowatts 25 hp × 0.746 kW/hp = 18.65 kW. Running the fan 11.9 h is 222 kWh. For the diesel, 206 gallons × 37.95 kWh/gallon = 7,818 kWh. Total energy use per batch is 7,818 + 222 = 8,040 kWh. Each batch is 6,000 lb, so this means each pound of dried hops requires 1.34 kWh to dry.

The dehumidification process requires running two 25 hp fans at 80% capacity for 48 h and one dehumidification unit (6.9 amps and 220 V) running 24 h to dry 1,100 lb dry weight of hops. The hops are never heated up, so no "cooling down" is necessary. The fans total 50 hp (running at 80%), which is equivalent to 29.8 kW. Fan power use is 29.8 kW × 48 h = 1,430 kWh. The dehumidification units require 220 V × 6.9 amps × 24 h = 36,400 Wh or 36.4 kWh. Total power use per batch is 1,430 + 36 = 1,466 kWh. Each batch is 1,100 lb, so this means each pound of dried hops requires 1.33 kWh to dry—almost identical to the American system. These dehumidification systems have only been around for a few years, and better energy efficiency could likely be possible with optimization of bed depth and air speed. Perhaps less powerful fans would do the job just as well.

Conclusions

The big advantages of the American system are greater throughput and a relatively low capital investment. The disadvantages are poor control of the process and greater variation in the final moisture of the hops, resulting in both safety concerns (fires) and quality problems. The German system is a great improvement in terms of moisture uniformity, but it also suffers from the problem of not knowing when to stop the drying. The onion/garlic aroma problem is present with both heated systems. The German system is more energy intensive, but if converted to direct fire instead of running the intake air through a heat exchanger it would likely be as good as or better than the American system. The big advantage of the dehumidification system is much better moisture uniformity in the hop bed, and the process control is excellent, making it unlikely the hops will be overdried or underdried. Another advantage is that at the end of the process, the hops require no cooling or conditioning before baling. Energy consumption is about the same as for the American system but could possibly be reduced. The main disadvantage is the longer batch processing time, reducing throughput compared with the American system, although that is somewhat mitigated by elimination of the conditioning step prior to baling.

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