MAXIMIZING TERPENE RETENTION

CANNABIS DRYING WITH RADIANT ENERGY VACUUM (REV™) TECHNOLOGY

INTRODUCTION

THE DAWN OF A NEW AGE: LEGAL CANNABIS

On October 17, 2018, the Federal Cannabis Act came into effect making Canada the first G7 country to legalize the cultivation, possession, acquisition and consumption of cannabis. The passing of this milestone legislation by Canadian Parliament paved the way for new economic activity around recreational cannabis as a legal, yet controlled substance.

The subsequent economic frenzy led a number of opportunistic entrepreneurs across Canada to acquire Health Canada cultivation licenses with the intent of rapidly building out infrastructure to legally grow and harvest cannabis. In the early stages of this cannabis boom, investment dollars poured into the industry to fund infrastructure projects both privately and through the public capital markets. Canada, second only to Uruguay, became a pioneer in legalizing the recreational use of cannabis and businesses found themselves without any formal blueprint to properly build out indoor or greenhouse facilities.

Much of the knowledge and methodology behind the build-out of legal cultivation facilities was influenced by the cultivation methods previously employed by the grey and black market. Illicit operations were previously unable to legitimize their businesses and therefore unable to purchase fit-for-purpose equipment built by established international manufacturers. Cultivation technologies employed in similar agriculturally focused industries were not sufficiently adopted in the legal cannabis realm.

ILLICIT MARKET METHODS FOR DRYING

Grey and black-market grown cannabis has typically been dried without the use of fit-for-purpose technology. In simple terms, cannabis plants were harvested and hang-dried in a walled empty room, at times equipped with a limited number of household dehumidifiers or fans.

The unsophisticated nature of drying rooms allows for mold to spread due to uncontrolled airflow and inconsistent humidity controls. Resultingly, the “hang dry” method requires a significant amount of time for cannabis plants to dry from 75% to 80% initial moisture down to 3% to 15% final residual moisture.

Amongst craft growers, it is thought that the hang dry method is the only way to properly dehydrate plant material, largely in ode to “that’s the way it has always been done” lingering from the illicit market. The issue with moist cannabis plants being left to hang dry is their elongated exposure to mold and bacterial pathogens originating from the growing phase and in unfiltered air in the drying room then propagate on the flower itself. High mold counts are not an issue when selling product illegally as there are no product standards imposed by a governing body.

However, when selling legally grown product under strict license requirements, the hang dry method requires product be sent off-site for ionizing irradiation post-drying to lower the bioburden below Health Canada imposed limits.

A slightly more modern approach to drying cannabis in Health Canada approved facilities has been the introduction of rack drying in humidity-controlled rooms utilizing high-end HVAC systems. Typically, harvested flowers are shucked and trimmed prior to being placed on stacked trays, then rolled into drying rooms. Dehydration from fresh material at 75% to 80% initial moisture down to final residual moisture of 3% to 15% takes approximately 7 to 14 days. These drying rooms utilize expensive HVAC systems that control temperature, airflow and air contaminants but each room requires a large amount of dedicated space within a Licensed Producer’s facility footprint.

A typical drying room is approximately 3,000 sq ft and it is commonplace for producers to have multiple drying rooms built for drying sequestered harvests. While these drying rooms do a more effective job of controlling air contamination than hang drying, the prolonged dry time still exposes the moist plant material to air for 7 to 14 days creating a breeding ground for mold and pathogens to grow.

Resultingly, the rack dry method often requires dried cannabis product to be transported off-site for ionizing irradiation to bring product below Health Canada imposed microbiological quality parameters. This comes at a financial cost, logistical inconvenience and impact to product quality from the ionizing form of beta or gamma radiation utilized to lower microbial counts.

THE INTRODUCTION OF SCALABLE DRYING TECH FOR A GROWING INDUSTRY

Drying bottlenecks caused by insufficient drying room space on-site can be eliminated. The introduction of more stringent quality regulations by Health Canada and other international governing bodies are to ensure the safety of recreational cannabis users is causing Licensed Producers to evaluate their processes.

EnWave Corporation’s Radiant Energy Vacuum (“REV™”) vacuum-microwave technology is proven to facilitate bioburden reduction without the use of irradiating product off-site – a type of ionizing radiation that can damage plant material at the molecular level. Different governing bodies around the world are imposing varying regulations on cannabis supply chains and product standards of cannabis material entering their respective market.

REV™ has the ability to comply with the manufacturing requirements of both GACP or EU-GMP compliant supply chains, along with drying plant material to quality standards set out by international governing bodies. A Licensed Producer looking to automate processing can increase speed-to-market by taking a 7 to 14 day traditional drying process and lowering it to under 2 hours.

A Licensed Producer focused on retaining the broadest spectrum of the cannabinoid and terpene profile in their strains can maximize yield with REV™.

A Licensed Producer tight on space can adopt REV™ technology and convert unneeded drying rooms into value-add, usable real estate.

The intent of this white paper is to provide factual evidence behind EnWave's new Terpene Max™ drying protocol that can increase both the efficiency and efficacy of a Licensed Producer drying operations.

RADIANT ENERGY VACUUM (REV™)

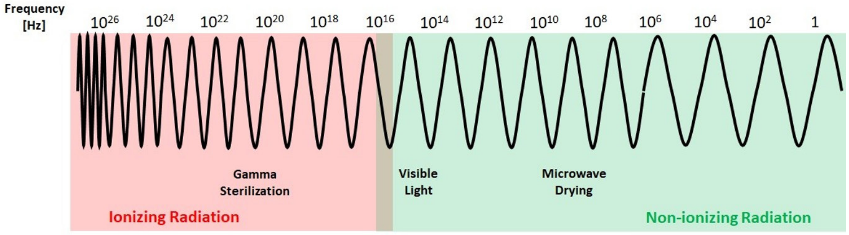
REV™ drying is a novel drying technology which utilizes a combination of microwave and low pressure. It's a rapid drying method which can help to produce products with unique characteristics while retaining their biological functions and properties.

The application of vacuum has dual functionality of increased rate of moisture removal with a lowered boiling point of water to control the drying temperature. By controlling the pressure and microwave levels, one can effectively control both the temperature-time treatment (for microbiological safety) and the final moisture of the product (for texture and shelf stability).

Microwaves are a type of non-ionizing radiation (Figure 1), widely accepted as safe for processing different types of food products, including organic certified materials. The World Health Organization considers microwave drying a safe form of food processing[1].

When used according to manufacturer's instructions, microwave ovens are safe and convenient for heating and cooking a variety of foods. Nowadays, over 90% of American households regularly use a microwave oven for cooking[2].

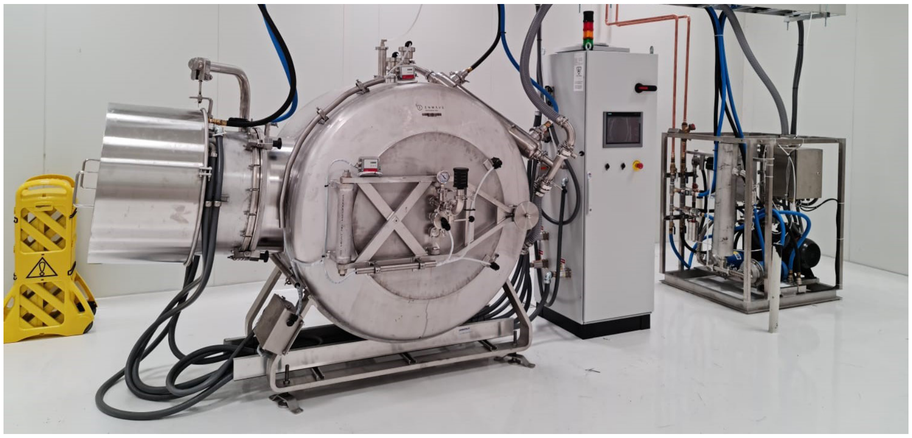
Figure 1. Frequencies of ionizing and non-ionizing radiation



The use of electromagnetic fields in the microwave region to temper, blanch, cook, sterilize, pasteurize, and particularly dry organic materials such as food, pharmaceutical and therapeutical products is well established and a proven technology.

Drying under vacuum lowers the boiling point of water, allowing for the moisture in the organic materials to be removed at relatively low temperatures minimizing damage and degradation to the material; furthermore, in the absence of ambient oxygen concentrations, the detrimental effect of oxidation is mitigated.

On the other hand, the virtuous addition of microwave energy to the drying process allows for an efficient energy transfer process where the energy is absorbed by the material volumetrically, promoting a uniform dehydration process compared to conduction or convection driven methods where the energy is captured at the surface of the solid material and then conducted to its core.



Early evidence of successful vacuum microwave dehydration applications can be found in research done in the middle of the past century. However, limitations such as ineffective delivery of microwave radiation, lack of efficient microwave delivery mechanisms, automation and scalability issues due to arcing resulted in the inability to grow this technology to become attractive for large industrial applications.

It wasn't until about ten years ago when EnWave Corporation resolved five key issues that opened the possibility to scale vacuum microwave dehydration technology to serve commercial and industrial applications reliably.

These solutions include:

- Development of an efficient mechanism of delivering microwave energy;
- Optimization of the shape and size of the drying chamber to promote scalability without compromising performance;
- Improved design of the transport mechanism for the organic material;
- The development of a sophisticated process science program to optimize the drying protocols of a multitude of organic materials; and,
- Complete control of the microwave supply to allow precise and repeatable thermal control.

The synergy of vacuum and microwaves acting together in the drying process promote conservation of the organic material structure; microwaves vaporize the water molecules in the organic material creating a vapor pressure differential with the vacuum environment, this promotes the transfer of water vapor molecules to the surface of the organic material and the maintenance of an open structure in the organic material that help preserve or enhance its original structure, including the conservation of the structural details of the cannabis flower, such as the trichomes.

EnWave's industrial REV™ driers are reliable and follow the highest international standards for design, safety and operation. The REV™ drying process includes the organic product loading into containers (e.g. baskets or trays) compatible with the REV™ dryer.

The containers are loaded in the drying chamber via an airlock that brings the container from ambient pressure to vacuum conditions. The container is transferred to the drying chamber, which is already under vacuum. The containers are conveyed through microwave sections in which stable and controllable electric fields are maintained.

Depending on the type of product, the microwave's uniformity relies either on the product's rotation while conveyed across spatially uniform microwave fields contained in resonant cavities, or the conveyance of products across single-pass travelling waves coupled with energy-absorbing traps (e.g. water loads) to avoid interference of stray energy. Moisture removed from the product is then collected in liquid form at the condenser. This liquified water and other volatile compounds can be recovered, and if practical, it can be used for post-processing (e.g. recovery of terpenes).

The power, vacuum and temperature of the product are monitored and controlled during the entire drying process. After drying, the containers are moved through an unloading airlock that transits the container from vacuum to ambient pressure conditions. EnWave offers integrated mechanisms to handle the containers and organic material after the REV™ drying process.

EnWave's REV™ technology is protected by a portfolio of 17 patents.

CANNABINOIDS, TERPENES, AND CONVENTIONAL CANNABIS DRYING

Cannabinoids

Cannabinoids are naturally occurring chemical compounds found in the cannabis plant that act on receptors within the human body. There are more than 100 cannabinoids isolated and identified in cannabis[3] along with the primary psychoactive component, Δ9-tetrahydrocannabinol (Δ9-THC). In addition to Δ9-THC, there are other components of cannabis that have been shown to be medically beneficial.

Terpenes

Terpenes are naturally occurring, volatile organic compounds found in many plants. People familiar with essential oils know that their beneficial properties are derived from terpenes.

Terpenes coexist in varying amounts in various cannabis strains. Specific cannabis strains have specific terpene profile expressions attractive to consumers. Limonene dominant strains express an uplifting lemon and lime profile, while linalool dominant strains express a calming floral and lavender profile. No two strains are the same and this is what's known as the "entourage effect".

The entourage effect refers to the complex profile of terpenes, their medicinal properties, aroma, and flavor. This is why proper drying of cannabis is so important to preserving terpenes, which begin to evaporate at just above room temperature. Terpenes are responsible for the odor and flavor of the different cannabis strains.

Terpenes are classified in diverse families according to the number of repeating units of 5-carbon building blocks (isoprene units, such as monoterpenes with 10 carbons, sesquiterpenes with 15 carbons, and triterpenes derived from a 30-carbon skeleton[4].

Mono-terpenes and sesqui-terpenes have been detected in flowers, roots, and leaves of Cannabis, with the secretory glandular hairs as main production site. Monoterpenes dominate generally the volatile terpene profile (from 3.1 to 28.3 mg/g of flower dry weight, and include mainly D-limonene, β-myrcene, α- and β-pinene, terpinolene and linalool. Sesquiterpenes, β-caryophyllene and α- humulene in particular, occur also to a large extent in Cannabis extracts from 0.5 to 10.1 mg/g of flower dry weight[5].

Cannabis drying is still considered more of an art than science. The most common method used to dry cannabis is a slow drying process which is generally referred to as “Hang drying” or “Rack drying”. In these methods, cannabis branches are hung up or placed on racks. In some cases the branches are hung upside-down to make sure water travels from larger stems to smaller branches. In other cases, the trimmed flowers are placed in the trays in single layer and then onto racks in a drying room. In general, traditional drying can range from 5 to15 days, depending on the size of the branches, buds and the surrounding environment.

The Ideal cannabis drying temperature and relative humidity ranges are 16 to 20°C, at 50 to 62% relative humidity (RH), with a dew point of 5.5°C to 12.2°C and minimal light exposure. It is also important to have a continuous airflow. Inadequate control of these conditions will often contribute to the potential evaporation of terpenes, degradation of THC into CBN, and growth of mold and bacteria.[6]

CHALLENGES WITH TRADITIONAL DRYING METHODS

Lengthy Cannabis drying durations, results in the loss of lighter, more delicate essential oils (terpenes). Monoterpenes are more volatile as they have the lowest evaporation points and dissipate first during drying, even before water.

Another common problem with commercial growers is the drying of plants harvested on one day alongside the harvested plants from another day. This practice may span to drying room having plants harvested on different days of week. This results in uneven and longer drying times as the moisture from freshly harvested plants is absorbed by the partially dried plants and the cycle continues.

Rehydration of over dried buds is a common practice in the cannabis industry which results in uneven moisture distribution and may lead to mold growth.

Inadequate airflow and mixing of freshly cut product with almost dry product in the same environment will result in degradation and production of ammonia.[7]

Other challenges associated with conventional drying are the larger space needed for drying rooms, time consuming and labor-intensive process and unpleasant odors.

ROOM DRYING AND BIOBURDEN CHALLENGES

If the cannabis buds are infected with powdery mildew or other mold and fungi, they are unfit for consumption (smoking) and extracts[8].

If the drying environment is too humid or the buds are not dried properly to a safe moisture level, mold will start growing in the buds. Once mold has consumed all the available oxygen in a sealed container, anaerobic bacteria will become active, which will result in brown and crumbly buds. If the buds are dried properly, the chances of mold growth are very minimal.

Fresh cannabis contains around 80% water. If the dried bud's moisture is over 15% (water activity over 0.65), there is a strong possibility of mold growth. To avoid these potential issues, it's important to dry quickly, and use of a very controlled drying process to avoid potential loss of terpenes.[9]

REV™ DRYING OF CANNABIS

REV™ drying uses a combination of microwave energy and low pressure. Vacuum lowers the boiling point of water and microwaves provide energy to evaporate the moisture rapidly from the flowers at a lower temperature.

It's a volumetric heating process which results in fast and relatively uniform drying. This combined effect will result in desirable moisture distribution, visual quality, and cannabinoid/terpene retention in the product.

Terpenes are the volatile compounds that quickly begin to dissipate after harvest. REV™ drying allows for a rapid drying at a low temperature where terpenes are retained. Also, the absence of oxygen helps to avoid oxidative loss of cannabinoids.

REV™ drying facilitates higher throughputs, is less energy and labor intensive compared to room/rack drying. Also, it doesn't need large space or infrastructure.

Experimental data has proven that REV™ could be used in drying of sensitive plant materials such as rosemary to get a good sensory profile and retain the volatile compounds in the dried product[10].

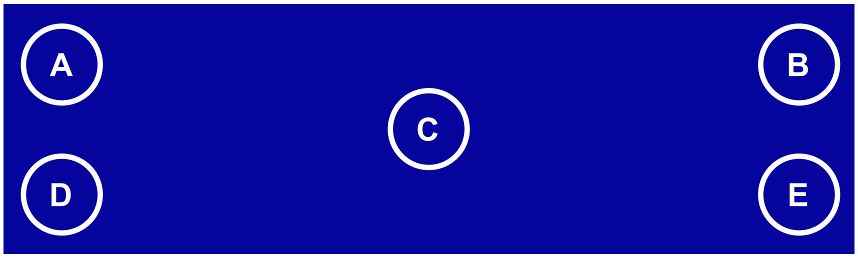
REV™ DRYING OF CANNABIS FLOWERS

STANDARD REV™ DRYING PROGRAM WITH A 10 KW NUTRAREV® AND QUANTAREV® DRYER

A total of 4 to 12 kg of untrimmed or trimmed fresh flowers with an initial moisture content around 80% (w/w), were evenly loaded to the 8 polyethylene trays. The chamber was evacuated with a vacuum pump to reach 20 to 25 Torr (2.7 to 3.3 kPa) of absolute pressure.

The flowers were exposed to power levels between 2000 to 8000 W. The drying duration was 30-55 minutes. The final moisture content of the flower was around 14% (w/w) and with a water activity (aW) value between 0.60 to 0.65.

Moisture content uniformity (Figure 2)

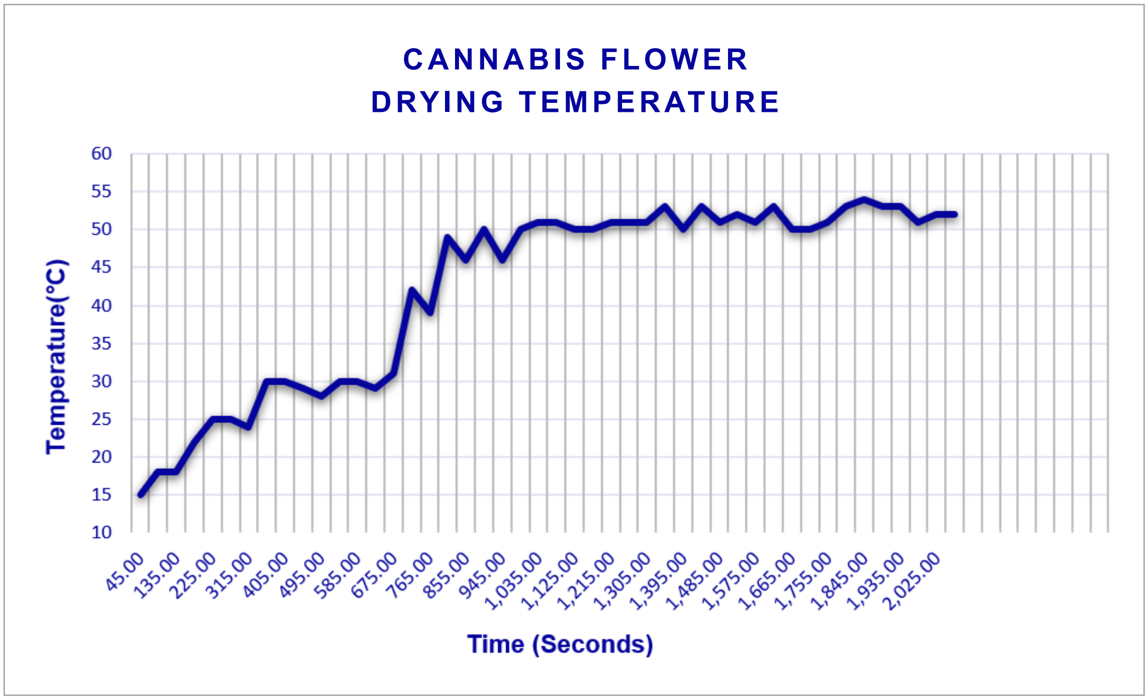


Five grams of dried samples were collected from the four corners and the center (5 spots in total, Figure 2) of the 10 kW drying trays and the residual moisture contents were measured by the infrared (IR) moisture analyzer. The moisture content variation across the drying tray is within ±1.2%. The moisture distribution of room dried flowers is very sensitive to the flower size variations.

Often when smaller sized flowers are dried, the larger sized buds are still wet, especially towards the center of the flower cone. This opens up opportunities for microbial and fungal attack.

Due to the volumetric heating pattern of the REV™ process, the moisture distribution in the same flower, and across the drying trays are relatively more even than other drying methods, and the drying rate is very similar across different particle sizes. This is also well demonstrated in the REV™ drying of various food materials.

Product temperature during 10 kW standard drying (Figure 3)



The flower surface temperature was monitored using the chamber top-mounted IR thermometer during the entire drying process. As shown in Figure 3, the flower temperature stayed at below 30°C for the first 10 min, even as the product was exposed to a high microwave power level.

The temperature was then gradually increased to 50°C for the next 5 minutes and stayed at between 50 and 55°C for the remainder of the drying process.

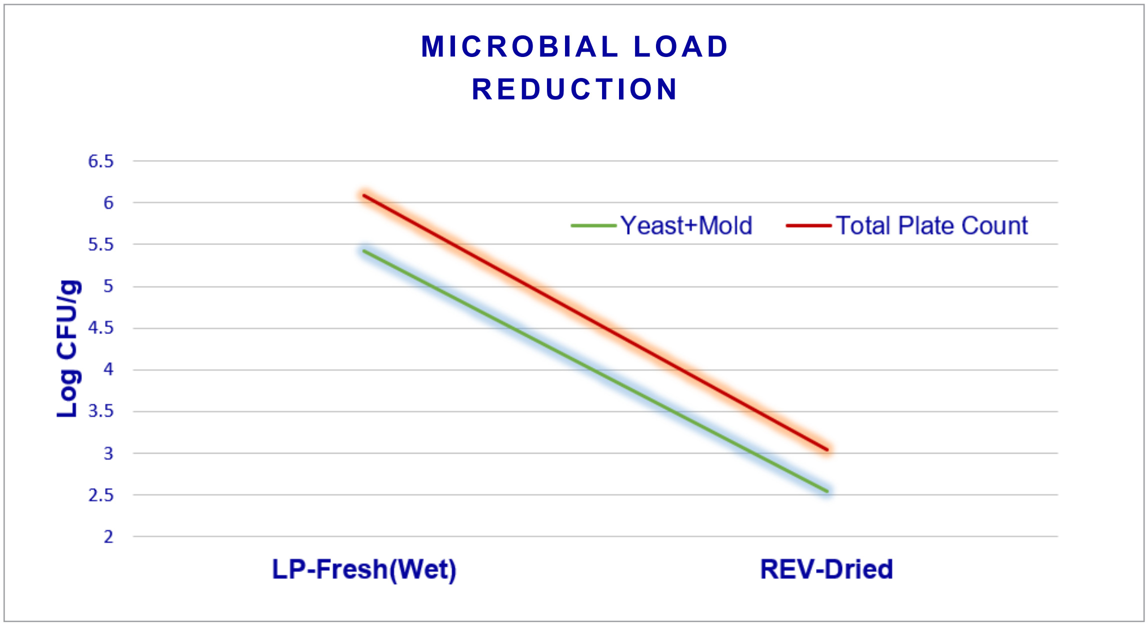
The exposure to temperatures over 50°C for longer than 25 minutes in such a process provided an opportunity for the destruction of mold and other unwanted microorganisms present in the fresh material.

Bioburden reduction (Table 1 and Figure 4)

Table 1. Numbers of total aerobic count and yeast and mold count in fresh and REV™-dried cannabis flowers

	Total Aerobic Count (CFU/g of solids)	Yeast and Mold Count (CFU/g of solids)
Fresh Flowers	> 250,000	> 50,000
REV™ Dried Flowers	< 1,000	375

Figure 4. Yeast and mold, and the total aerobic count of cannabis flowers before and after the REV™ process.



Eight kilograms of fresh, untrimmed Green Kush flowers were processed with the standard REV™ program. The total aerobic count (TAC), and yeast & mold (YM) count were enumerated both before and after REV™ drying, using Health Canada approved microbiological test methods.

The microbial count results are listed in Table 1. The numbers were converted to CFU/g of solids (dry matter) to facilitate direct comparison. As shown in Figure 4, both the viable YM and TAC were reduced 3 logs (99.9% reduction) by REV™ drying. This confirmed the impact of higher than 50°C of flower temperatures during the latter half of the process on the bioburden reduction of the fresh flowers.

Compared to traditional room dry, REV™ provides a much faster drying option. Instead of allowing mold to freely proliferate in contaminated flowers in the drying rooms, the REV™ process not only can stabilize the microbial quality by rapidly reaching undesirable level of dryness for microbial propagation, but can also inflict a kill step in selected processes.

This feature will set the microbial quality of REV™-dried flowers far apart from the conventional dried and cured cannabis. Also, the considerably more even residual moisture distribution of the REV™-dried buds will enhance of microbial shelf stability, avoiding occasional mold outgrowth from the center area of the room dried larger buds.

CANNABINOID RETENTION

Figure 5. Average total cannabinoid content in three strains of dried cannabis flowers

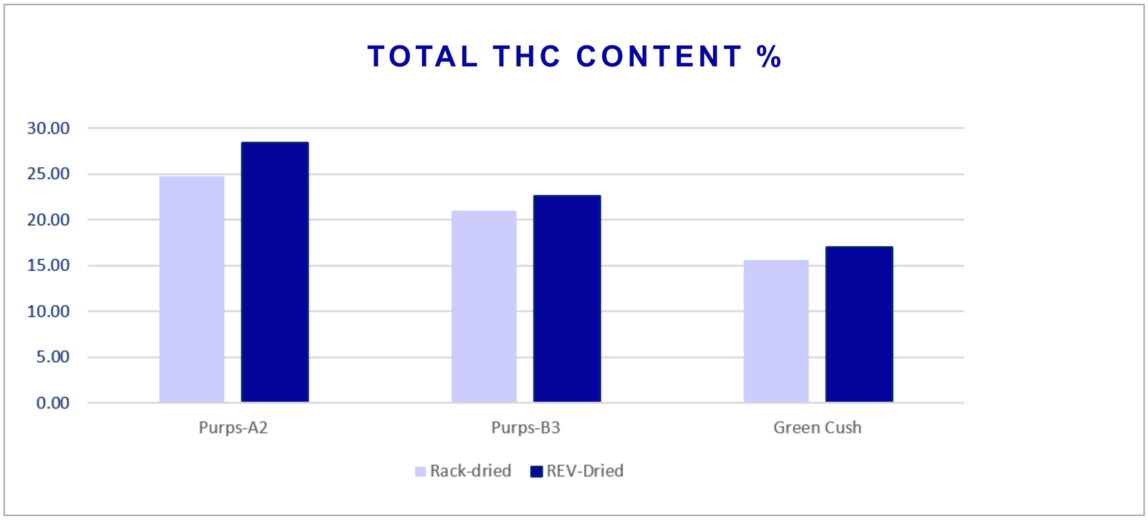


Figure 6. Average total cannabinoid and flavonoid content in dried cannabis strain CSCB.

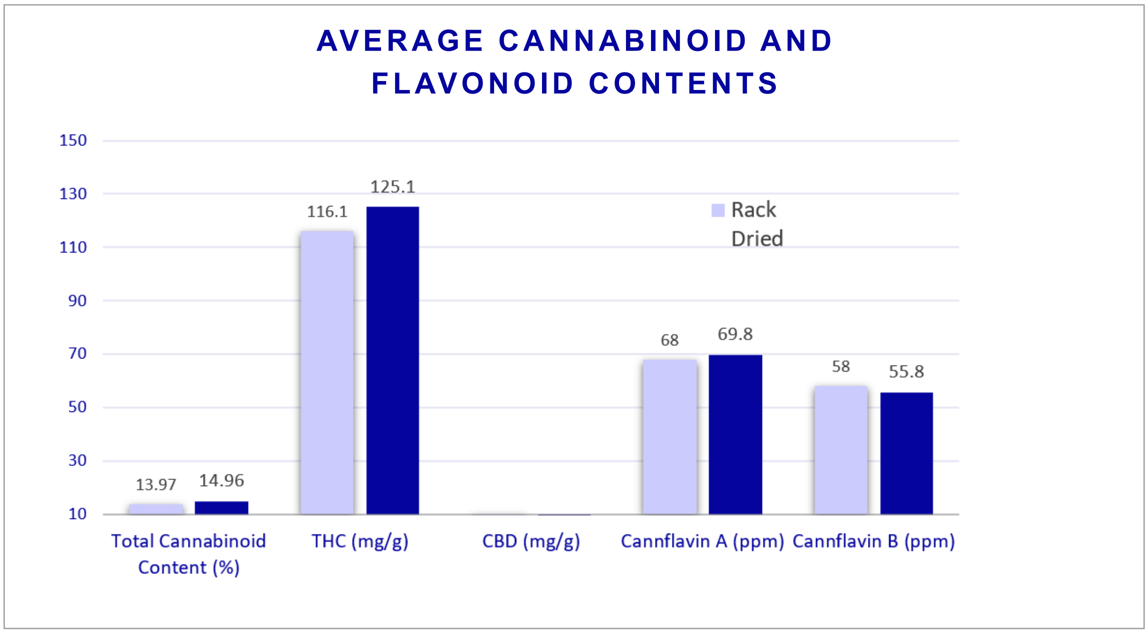
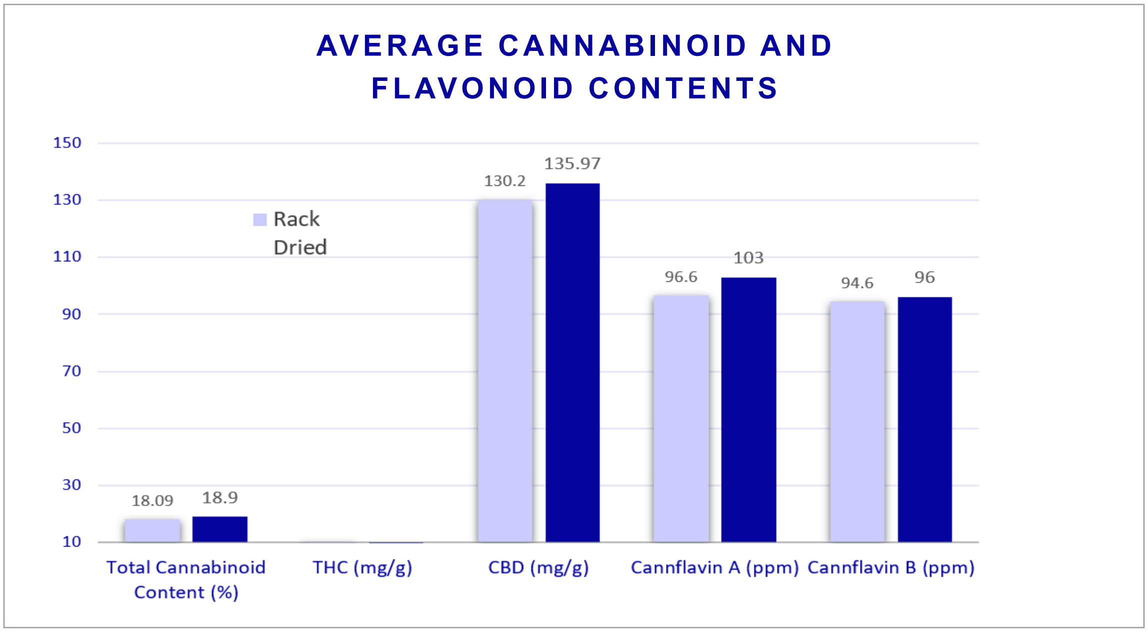


Figure 7. Average total cannabinoid and flavonoid content in dried hemp strain CSCJ.



A standard REV™ process was applied to dry 8 kg of Purps A2, Purps B3, Green Kush, CSCB, and CSCJ (hemp). The remainder of same batch of harvest was also simultaneously dried in the commercial drying rooms where flowers were dried in a single layer on stainless steel racks, with relative humidity controlled at around 60% for a total of 8 days of drying).

The dried samples were cryogenically ground, extracted and subjected to ultra-high pressure liquid chromatography (UHPLC) analysis with an ultraviolet (UV) detector. Duplicates were run on each extracted sample. The measurements are presented in Figure 5-7 and Table 2.

Table 2. Comparison of cannabinoid concentration on dry basis by REV™ and room/rack drying

Strain	Concentration % By REV	Concentration % By Rack Drying	% REV™ Retention Improvement
Purps A2	28.38	24.76	14.6
Green Kush	17.06	15.58	9.5
Purps B3	22.60	21.00	7.6
CSCB	14.96	13.97	7.1
CSCJ (Hemp Strain)	18.90	18.08	4.5

As shown in in Figure 5 to 7, REV™-dried flowers consistently retained more cannabinoids and flavonoids than the room/rack dried controls for all the five strains tested.

The amount of cannabinoids found in the REV™-dried product ranges from 4.5% to 14.6% higher than the room dried controls (Table 2). This material increase is most probably due to the absence of oxygen and light and the much shorter drying time (under 1 hour). Minimizing cannabinoid damage during the drying process is certainly desirable in the industry which ensures maximum potency preservation for the fresh harvests.

TERPENE RETENTION

TERPENE MAX™ (REV-TMAX) PROCESS ON THE 60 KW DRYER

Freshly trimmed cannabis flowers (LA Confidential strain) were loaded in multilayers in standard polyethylene quantaREV® drying trays, with a loading depth of 2.5 inches. The total product weight for each tray was 5.0 kg. The fresh trimmed flower trays were fed automatically on a conveyor belt to the entrance vacuum lock of the 60 kW quantaREV® dryer. The pressure of the drying chamber was 20 Torr. The flower trays travelled horizontally on a conveyor belt inside the chamber, passing 6 drying sections/zones.

The microwave power for each section were set at alternating high, medium and low values for specific zones to achieve low drying temperatures. The total power applied was 30 kW and the total travel time for each tray is about 70 min (drying time).

As shown in Figure 8, the maximum surface temperature of flowers was approximately 39°C. Every 8 minutes or so, one tray with fresh flowers entered into the dryer at the loading side and at the same time, one tray with dried flowers exited from the unloading side. The hourly throughput of this particular process was around 37 kg fresh flowers.

Figure 8. Surface temperature of cannabis flowers during the 60 kW Terpene Max™ drying process.

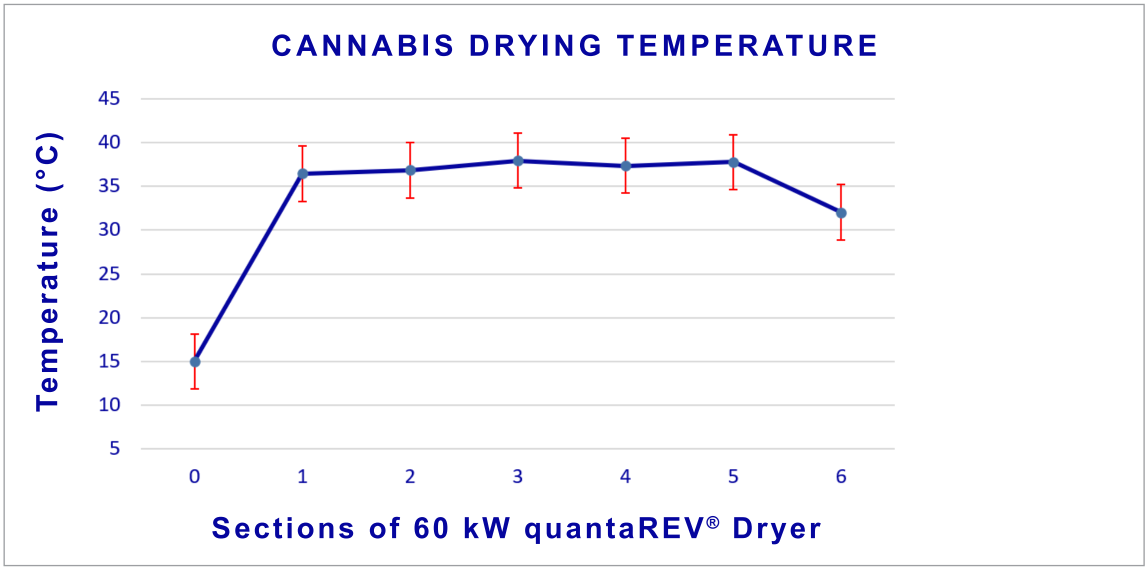


Figure 9. Total terpene retention rate of Terpene Max™ and room dried LA Confidential flowers.

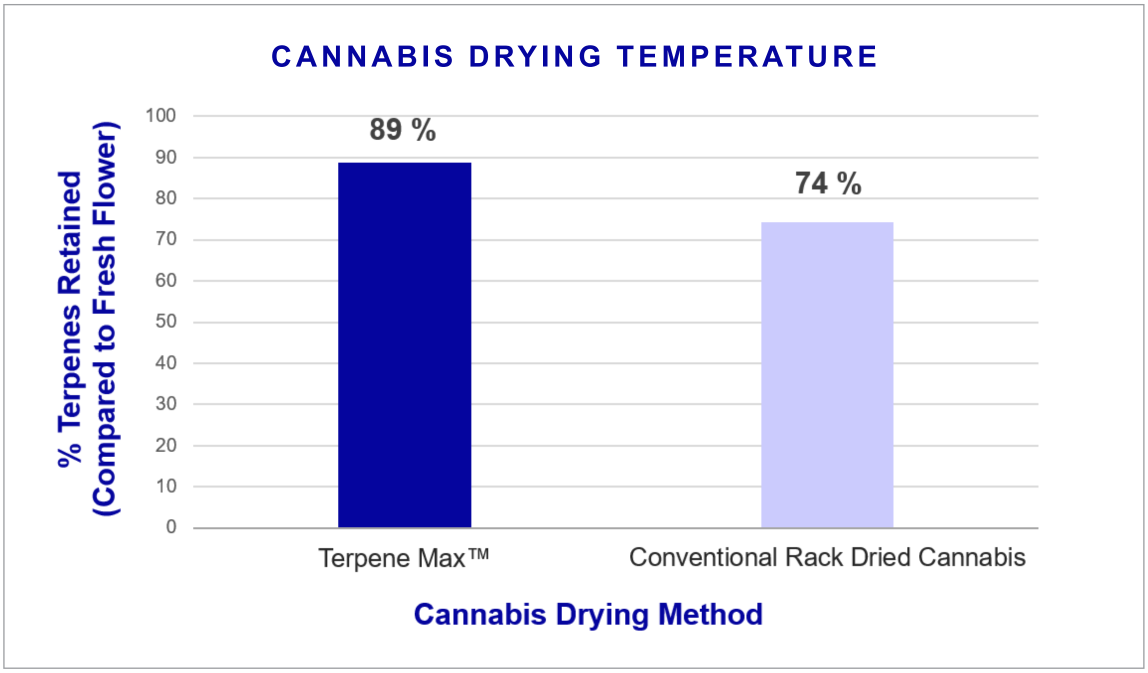


Table 3. Comparison of total terpene concentration on dry basis by REV-TM and room/rack drying

Strain	Concentration % By REV-TM	Concentration % By Rack Drying	% REV™ Retention Improvement
LA Confidential	1.742	1.457	19.56
Think Fast	2.233	1.509	47.98

For the total terpene measurements, fresh, REV-TMAX and RD flowers were cryogenically ground, extracted and subjected to gas chromatography-mass spectrometry.

Triplicates were run on each extracted sample. The measurements are presented in Figure 9 and Table 3.

The low drying temperature during the Terpene Max process resulted in substantially greater retention in the dried LA Confidential flowers.

Compared to the room/rack dried control flowers from the same harvest, the REV-TMAX dried flowers contained 19.56% more terpenes. In another separate trial, the REV-TMAX dried “Think Fast” strain flowers retained 47.98% more terpenes than the room dried control sample.

High terpene retention in the combustible product is an important quality feature. Terpene retention level in the range of 70-80% in traditionally room dried product is the current gold standard for premium quality cannabis. Higher retention rates achieved by REV™ drying will certainly be desirable. More trials will be conducted by EnWave researchers to confirm the findings by screening more strains of cannabis crops.

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REFERENCES:

1. https://www.who.int/news-room/q-a-detail/radiation-microwave-ovens

2. Source, Cox and Alm, (1997), "Time Well Spent: The Declining Real Cost of Living in America," Federal Reserve Bank of Dallas—1997 Annual Report, Exhibit 8(p22)

3. ElSholy, M.A., Gul, W. Handbook of Cannabis. Oxford University Press: Oxford, 2014.

4. Andre, C. M., Hausman, J. F., & Guerriero, G., 2016. Cannabis sativa: The Plant of the Thousand and One Molecules. Frontiers in plant science, 7, 19. https://doi.org/10.3389/fpls.2016.00019

5. Fischedick, J. T., Hazekamp, A., Erkelens, T., Choi Y. H., Verpoorte, R., 2010. Metabolic fingerprinting of Cannabis sativa L., cannabinoids and terpenoids for chemotaxonomic and drug standardization purposes. Phytochemistry 71 2058–2073. 10.1016/j.phytochem.2010.10.001

6. Rosenthal, E. & Downs, D. (2017) Marijuana Harvest 'Maximizing Quality & Yield in Your Cannabis Garden'. 'Drying' (p.g.146)

7. https://www.cannabisbusinesstimes.com/article/master-the-art-of-drying-curing-cannabis/.

8. Rosenthal, Ed. Marijuana Harvest (p. 60). Quick Trading Company. Kindle Edition).

9. Rosenthal, Ed. Marijuana Harvest (pp. 63-64). Quick Trading Company. Kindle Edition.

10. Ángel, C. S., Antoni, S., Adam, F., Klaudiusz, J., Maciej, A., Ángel A. Carbonell, B., 2011 Effects of vacuum level and microwave power on rosemary volatile composition during vacuum–microwave drying, Journal of Food Engineering,103 (2), 219-227.