Heat Pump Pollen Drying

Kellogg Rural Leadership Programme

Course 44 2021

Nicholas Woolsey

Disclaimer

I wish to thank the Kellogg Programme Investing Partners for their continued support. With additional special thanks to Agmardt.

Strategic Partners

Programme Partners

Service Partners

Acknowledgements

I would like to thank the following groups for their support, motivation, and inspiration over the course of my Kellogg Rural Leaders programme:

Cohort 44

The New Zealand Rural Leadership Trust

The board of Eastpack Ltd

Andrew and Sue Ross

Cape Fruit Company Ltd

My wife and family.

Executive Summary

The project described in this report formed part of the Kellogg Rural Leadership Programme. It investigated the use of a heat pump in kiwifruit pollen drying in order to reduce energy use. The author worked with a pollen producer to establish limitations in the existing conventional system, before researching and developing a concept that utilised heat pump technology. Initial findings suggested such a system presents significant financial and environmental advantages that may be exploited by individual producers and industry bodies alike. The recommendations were to:

1. Build a prototype pollen dryer using a Temperzone packaged water-cooled unit coupled with a reheat coil as per concept design.
2. Use the above prototype phase to gather more data, particularly around water volume requirements and heat transfer.
3. Investigate other potential sources of supplementary heat to provide further efficiencies.

Table of Contents

1. Introduction

The use of supplementary pollen in pollination processes is a key driver of the success enjoyed by New Zealand's kiwifruit industry. In recent years the demand for male kiwifruit pollen has increased significantly and a kilogram of pollen is currently worth approximately $5,500, up from around $2500 5 years ago. Recognising the potential growth opportunity, a number of kiwifruit growers are branching out into pollen production alongside traditional fruit production.

Additionally, the New Zealand kiwifruit industry is responding to growing global awareness of sustainability issues and is looking for ways to reduce carbon emissions. This research brings together these two market trends by investigating an innovation in the pollen drying process that requires far less energy than traditional technologies.

The research project centres on an orchard situated between Whakatane and Edgecumbe in the Bay of Plenty. The proprietors had already begun drying pollen using the conventional fan/heater method and were interested in improving performance. Having gained a bachelors degree in mechanical engineering and working in the HVAC industry for 7 years, the author was able to collaborate with the owners of Haas Orchard by developing a proposed alternative system. Throughout the development process, the following considerations shaped the design of the system:

1. Operating efficiency
2. Ease of installation
3. Ability to scale up

The report is structured as follows. First, background context is provided both at the macro level, and as an introduction to the research site. A description of the current system is then followed by an overview of initial concept development. The proposed design and installation are then outlined, including considerations around scaling up and additional opportunities. Finally, some recommendations and implications are suggested.

2. Methodology and Research Design

This research follows an objectivist methodology and investigates the development of a concept plan that may provide alternatives to traditional pollen drying technologies. A literature review revealed very little prior research in the specific area of study. A technology review, however, was helpful in isolating the possible contributions the new concept might make. It also supported the selection of a single case study method, in which initial prototyping would be possible. Unstructured interviews and a single focus group were carried out with nine participants, all of whom were connected to the research site, and recorded in field notes. The data generated in these interactions was supplemented by secondary data and observation.

3. Background

3.1 The New Zealand Kiwifruit Industry

New Zealand kiwifruit exports have grown from $931m in 2014 (Fresh Facts, 2014) to over $2.5B in 2020 (HEA, 2021) with Zespri looking to further double returns over the next 10 years. This growth has (and will) come from three main areas:

1. An increase in planted area.
2. Growth of market demand and returns.
3. An increase in orchard productivity.

The first is related to the second and the second derives from Zespri's blind determination to sell a 'furry brown egg'[1] coupled with the success of their gold variety SunGold. Increased orchard productivity has come about through decades of industry research, technological breakthroughs, improved plant nutrition and refined pest and disease management, all of which incrementally lift production.

[1] Commonly used industry euphemism to describe kiwifruit.

One significant factor that has driven an increase in orchard productivity is improved pollination. While better bee management has helped, it is believed that increases in orchard returns of over 25% may be due to the use of supplementary pollen (Torr, 2021).

Male kiwifruit pollen is typically harvested by picking unopened male flowers, milling them, drying the anthers and then separating the pollen from the dry anthers. The pollen is then stored in a freezer for future use or applied on the orchard. Pollen is applied by spraying it on the female flowers mixed in a solution (referred to as wet pollination) or blown on neat (referred to as dry pollination).

According to Campbell Hunt of Eastpack Ltd (2021), the price of pollen has doubled in the last five years to over $5000/kg. These increased prices have pushed the returns for male only blocks as high as SunGold, with reduced operating costs and no associated license requirement.

Alongside the objective of doubling returns within 10 years, Zespri has set a number of ambitious sustainability goals including for the industry “to be carbon positive by 2025” (Zespri, 2021). While this goal will inevitably be achieved by an amount of carbon offsetting, initiatives are being sought to reduce industry carbon emissions to minimise the amount of offsetting required. These will include the reduction of fuel and electricity consumed on orchard and in ancillary services.

3.1 Research Site - Haas Orchard

Situated near Whakatane in the Bay of Plenty, Haas Orchard is a six-canopy hectare kiwifruit orchard owned and operated by Andrew and Sue Ross. The orchard is comprised of two hectares of Zespri Sungold, one and a half hectares of Hayward (green) and two and a half hectares of male varieties in a single block. The male block was planted on previously unused land to capitalize on the high price of kiwifruit pollen. To maximise this investment a second-hand processing plant was purchased and set up in a shed on the property. After a season of operating the plant, it was established that the capacity of the mill outstripped that of the four dryers. To match capacity of the mill, pollen drying capability would need to be doubled. Investigations exposed a limit to the power supply to the property, meaning the transformer and lines to the shed would have to be upgraded in order to add more conventional dryers. The power upgrades alone were estimated at over $150,000. Instead, efforts to reduce the power requirements of the system began to be investigated.

4. Current Technology

Typical pollen dryers consist of a simple timber cabinet with access in the front to a number of trays that hold the male flower anthers during drying. The trays are staggered to increase the air pathway and ensure air passes evenly over all surfaces. Timber has been used historically for its low cost and ease of use but also as an alternative to metals which can have a detrimental effect on the pollen (Sawidis T., 1995). Air is driven through the cabinet by a Ø250mm axial plate fan at a volumetric flow rate of approximately $0.17m^3s^{-1}$, giving an approximate velocity across the drying surfaces of $0.2ms^{-1}$. This velocity is purposefully low to minimise the risk of pollen grains being carried into the airstream.

The air is heated by a 2kW electric element fitted to the back of the fan and is controlled by a simple on/off thermostat. The warm air passes over the trays and is vented to the outside through the top of the unit. Warming the air lowers its relative humidity thus increasing its drying potential and speeding up evaporation from the flower stamens.

These traditional pollen dryers are suitably agricultural, born out of back sheds and number 8 wire mentality, but they are very inefficient and may even fail to comply with current safety regulations meaning they are a potential fire hazard.

For the reasons outlined above, the proprietors of Haas Orchard were interested in exploring alternative drying technologies.

5. Concepts and Preliminary Development

Initial discussions with the Ross were around a very rudimentary idea of an insulated shipping container ("Reefer" or refrigerated container) fitted with one or many, wall mounted, split, reverse cycle air conditioning units, commonly referred to as "heat pumps". Heat pumps were originally proposed based on the following traits:

1. Low cost
2. Easy to install
3. Stock/standard items

This concept looked to replace the fan and heater assembly with the indoor component of a heat pump with the assumed energy savings inherent in this technology. Two main flaws in this idea quickly became evident: First, heat pumps are not designed to operate at 'full fresh air'. They warm a room up incrementally rather than taking in outside air warming and it up to the desired temperature. Second, the fan inside them is not capable of pushing the air through any obstructions (ie drying racks) as it is only designed to meet the static pressure requirements of the filter, coil and outlet grille/louvres. The second can be easily solved by the addition of a stand-alone fan or by using a ducted indoor unit which has a more powerful fan.

The first flaw could be solved by not introducing fresh air. This solution creates a third problem in that; drying would occur at a decreasing rate as the air approached saturation and then stop. To dehumidify the air, a second unit could be added and operated in cooling mode. Water vapour would condense on the cold coil to be drained away. This second unit would add a second fan to the system improving air distribution potential. During the next phase of concept development an opportunity to use the outdoor unit in the place of the second unit was identified. When a heat pump is operating in a home in heating mode the indoor unit has a coil warmer than room temperature thus increasing the room air temperature as it passes over it. The outdoor unit has a coil cooler than the outdoor air, effectively cooling the outside air and dehumidifying it as water vapour condenses on the relatively cold coil and drains away. If the outdoor unit of the first heat pump were to be moved inside it could remove the requirement for the second heat pump described above. In this configuration the heat (typically considered 'lost') from the compressor and the outdoor fan motor would be added to the system, improving efficiency.

6. Proof of Concept

Further research suggested that placing the indoor and outdoor sides of a heat pump in the same space was a viable concept. Similar configurations are used in heat pump clothes dryers and heat pump food dehydrators.

Compared to conventional clothes dryers, heat pump clothes dryers offer power savings of around 50% (Energy Rating, 2020). This suggests adopting a heat pump system could double pollen drying capacity with no additional energy requirements.

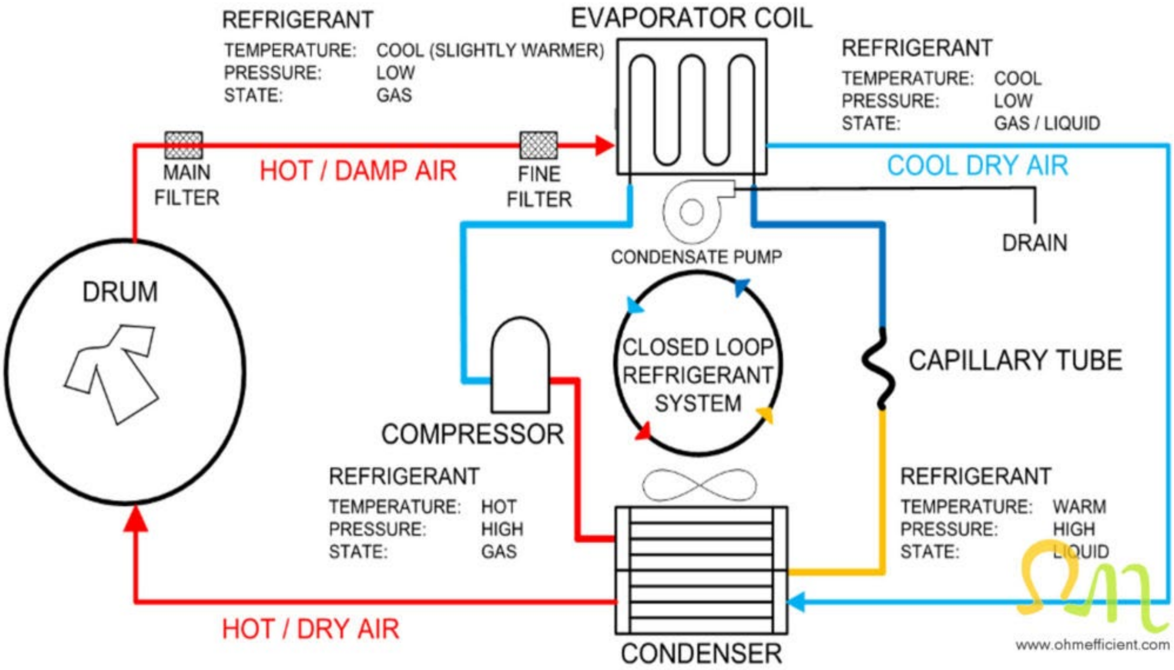

Figure 1: Heat pump Clothes Dryer Schematic. Image Courtesy of OHMefficient 2021

At first glance heat pump food dehydrators appear to provide a suitable method for drying kiwifruit pollen. They typically operate at higher air velocity than what would be acceptable for a pollen dryer, but the fan speed could easily be controlled down to suit. With lower air volumes passing across the coils, less energy is able to be passed from the refrigerant to the air and vice versa, meaning the refrigeration side of the system would be oversized relative to the pollen drying volume. To resolve this issue; either a custom system would have to be designed, or a standard unit could be modified. The easiest modification would be to increase the volume of the pollen drying space. As these units are predominantly manufactured overseas, it may be more cost effective to import the refrigeration and control systems only to allow for the custom build of the drying volume and remove the requirement to ship this empty volume.

Drying Solutions in Tauranga indicated they would be able to custom build a solution to meet the requirements for pollen drying. Their approach would be to keep their standard drying volume and optimise the refrigeration and control side. While this solution would likely produce a very effective system their relatively small drying volume would mean multiple units would be required and their indicated price point would mean a prohibitively low return on investment.
Auckland based Temperzone, a manufacturer and distributor of commercial and domestic air conditioning products suggested they could offer a custom refrigeration and controls solution using one (or a combination of) their standard products and/or competitively priced custom components. The decision was made, therefore to work with Temperzone in the next stage of development.

7. Detailed Design

Head of research and development at Temperzone, Adrian Kerr, provided a preliminary system specification based on the limited data held and a number of assumptions. His recommendation was a Temperzone model CWP90 with a reheat coil.

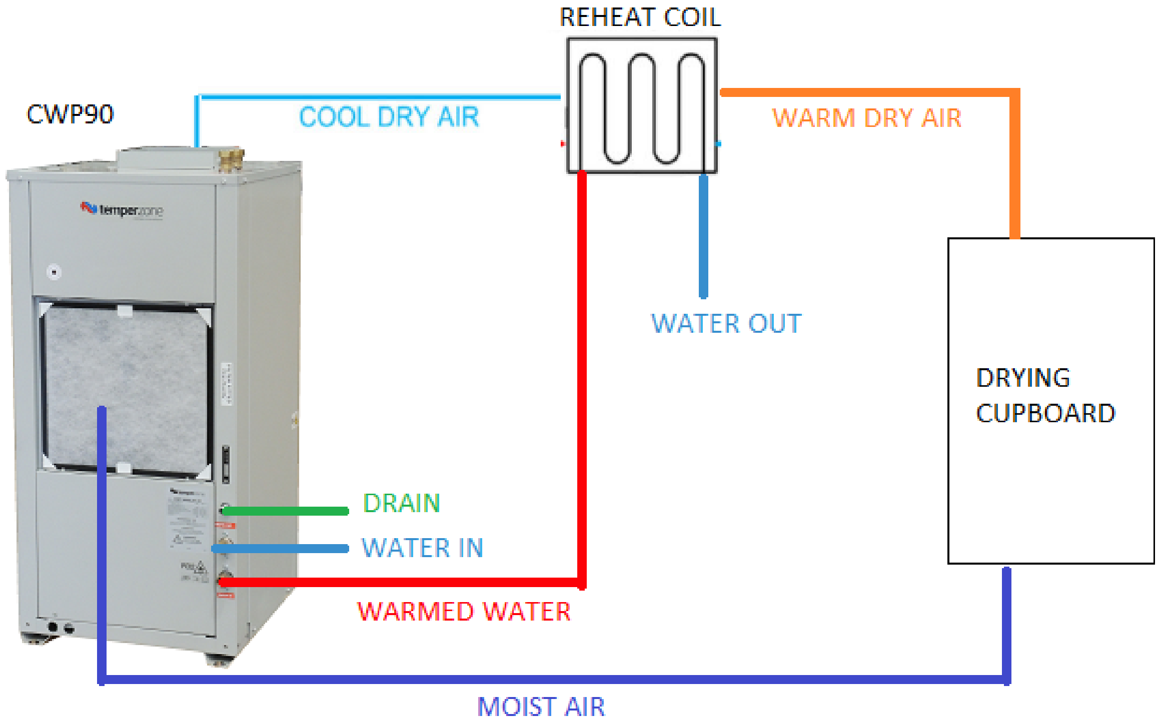

Figure 2: Proposed system schematic showing CWP90 and reheat coil

The proposed system has a number of differences to the aforementioned wall mounted and ducted splits. The main two differences are the packaging of the indoor and outdoor units and the replacement of air with water as the outdoor working fluid. These two combined greatly increase the practicality of the system as connections on site are with water pipes rather than refrigerant lines allowing for easy installation, commissioning and decommissioning across seasons. The additional requirement of a water source does add a few challenges with the main one being the potential requirement for a reservoir or buffer volume, but at this stage the magnitude of this volume is hard to quantify until more empirical data has been gathered.

The CWP90 has an electronically commutated (EC), forward curve, scroll fan. This fan has good static pressure characteristics and effectively has a built-in speed controller to vary the airflow. This unit is powered by an inverter compressor allowing for control down to 40% of its rated capacity. The control offered by this combination of fan and compressor means the system could be ducted into existing drying cabinets and only one run at a time, thus retaining the flexibility of the original systems. The reheat coil could be a custom sized and custom-made coil but a standard coil out of an existing unit is likely to be more cost effective and more readily available. Furthermore, it is likely that a small amount of electric heat would be required to account for heat losses in the system. Electric heat is available as an option on the CWP90 but as it would be before the reheat coil in the system, it will reduce its efficiency greatly. Instead, a standard Temperzone fan coil unit (IMD range) could be used. This range offers electric heat as an option, but it is likely to be too much for this application, for example: the IMD 135-4E (a likely sized candidate for this application) has 6kW of electric heat as its standard option. A standard unit with 6kW of electric heat has three 2kW elements, one for each phase for three phase power. Wiring only one element up to single phase power complete with a solid-state relay, however, would be a practical and cost-effective solution for this application. IMDs have an integral forward curve scroll fan available with a standard AC motor or a more expensive but easily controllable EC motor. The CWP fan and IMD fan are likely to be required to operate in series to overcome the static pressure losses of the two coils, filters, ducting and drying racks. Care must be taken, therefore, to ensure the fans are balanced and one does not cause the other to overrun and burn out the motor.

The CWP 90 comes complete with a UC8 (unit controller) which can be controlled by a TZT-100 controller and a remote thermostat to be located after the electric heat. While research indicates pollen can be heated to 55°C (Everett et al., 2012) without significant pollen degradation, most pollen dryers operate up to 30°C to maximise viable pollen production.

8. Installation

While custom drying cupboards designed to suit the scale and configuration of the system would be the ultimate solution, the proposed system could be ducted into the existing system to aid in testing and development. In this case the IMD would be mounted on top of the CWP and a plenum attached to the discharge of the IMD complete with duct dampers in each spigot to facilitate isolation of individual cupboards. Insulated flexible ducting could be used from each spigot to the outlet side of the existing cupboards and a similar arrangement would be used from the inlet side of the cupboards to the return side of the CWP. Insulating the outside of the cupboards would greatly reduce the heat lost from the system and ensure maximum efficiency.

9. Scaling Up

It is imagined that if the proposed system is successful, there will be additional demand for similar solutions. One of the considerations for entities interested in drying pollen on a larger scale would be the configuration of units. The current and proposed systems for Haas Orchard are restricted by its access to single phase power only and utilise only a single small unit. Other sites may have access to three phase power and, therefore could use configurations of larger capacity units instead of multiples of the CWP90/IMD135. Temperzone’s larger units typically have fixed speed compressors so if multiple dryers were supplied by one system, individual dryers would not be able to be turned off as there would be no close control capacity reduction available. Temperzone’s onshore design and manufacturing capabilities do lend themselves to producing custom systems, specifically designed to the application and site parameters. This could include variable capacity compressors, custom sized coils and high static fans. Any system should be carefully designed to suit the conditions of the site and production requirements.

10. Secondary Heat Sources

In the course of developing the proposed pollen drying system a further potential efficiency was identified. The use of water as a working fluid in the proposed system allows for the easy adaptation to include other sources of heat, further increasing efficiencies and reducing operating costs. For example, Haas Orchard is located approximately four kilometres from Awakeri Hot Springs, a natural geothermal heated pool. Irrigation bores near to both Awakeri Hot Springs and Haas Orchard produce water at over 30°C and the energy content of this water may be enough to mitigate the requirement of the proposed electric heat.

As another possibility, solar water heating could easily be integrated into the system. While it may be hard to control the system with solar integrated directly, it could be used to heat the buffer volume.

Some sites may have process heat available such as that expelled from the outdoor unit of a chiller on a coolstore. This heat could be captured via a coil and used to heat the reservoir, but as it is likely to be more consistent over a 24hr period than the likes of solar, the warmed water could be inputted directly into the system.

11. Recommendations and Implications

Based on this research, Haas Orchard should:

1. Build a prototype pollen dryer using a CWP/IMD combination ducted on to the existing cabinets.

This prototype would provide a side-by-side comparison of the conventional dryers and the proposed heatpump dryer configuration. As opposed to building a full-scale dryer, prototyping would minimise capital outlay in the next stage.

2. Use the above prototype phase to gather more data.

The system configuration and control is based on a number of assumptions that should be validated before a full system is implemented, with the main one being the mass of water removed during drying.

Measuring the amount of heat recovered through the reheat coil and lost through the entire system would give a better understanding of the system energy balance. It may also allow for further optimisation and improved sizing of the water buffer volume.

3. Investigate other sources of heat.

'Free' heat from geothermal, solar or industry could significantly reduce operating costs and, if incorporated into the initial design, may also reduce capital costs.

The implications of this research for the industry are potentially significant. If it can be successfully established that this technology is as energy efficient as it appears to be, major reductions in operating costs and carbon emissions may be attainable.

12. Risks and Limitations of the Study

Due to the method of single case study selected for this research, one of the limitations is around generalisability. Although it is anticipated that the proposed technology could be applied widely in other similar contexts the research findings are based on only one particular site. A possible risk associated with this limitation is that the technology will not deliver if applied in an inappropriate way, for example in cooler climates. In order to mitigate this risk, it is suggested any parties interested in applying the recommendations of this report contact the author for further information.

Another limitation of the study is that, without having fully tested the technology under a range of conditions it is not possible to determine the full range of possible health and safety hazards. There is, therefore, a risk that if such a system were to be installed incorrectly injury could occur.

To mitigate this risk, expertise should be sought and safety procedures established and followed.

13. Conclusion

The purpose of this project was to investigate an opportunity to dry pollen using heat pump technology as opposed to conventional methods. The results were presented in the form of a concept design and recommendations of how this might be applied both at Haas Orchard and other sites. There appears to be a significant energy saving in adopting the proposed system. Such a saving offers environmental and financial benefits to pollen producers. This research thus presents an exciting new trajectory for the New Zealand kiwifruit industry.

14. Appendix 1 - Glossary

Anthers - The part of the flower stamen that contains pollen

CWP - A range of ducted, water cooled package units manufactured by Temperzone ltd

EC Fan - A fan with an integral brushless DC motor and controller allowing for airflow control

HEA - Horticulture Export Authority NZ

HVAC - Acronym for Heating, Ventilation and Air Conditioning

IMD - A range of ducted fancoil units manufactured by Temperzone ltd

Inverter compressor - A variable speed refrigeration compressor allowing for capacity control

SunGold - The name for Zespri's gold kiwifruit variety

15. References

Energy Rating (2020), Australian, State and Territory and New Zealand Governments
https://www.energyrating.gov.au/dryers

Everett, K.R., Cohen, D., Pushparajah, I.P.S., Vergara, M.J., Larsen, N.J., Curtis, C.L. (2012). Cleaning Infected Pollen. A report prepared for ZESPRI Group Limited
http://www.kvh.org.nz/vdb/document/962

Fresh Facts (2014), Horticulture New Zealand and Plant and Food Research
https://www.freshfacts.co.nz/files/fresh-facts-2014.pdf

HEA (2021), Horticulture Export Authority,
http://www.hea.co.nz/2012-05-11-03-05-28/kiwifruit-trade

Sawidis, T., Reiss, H.-D. (1995), Effects of heavy metals on pollen tube growth and ultrastructure, Protoplasma

Torr, T. (2021), Kiwifruit Consulting Ltd, Personal Interview

Zespri (2021)
https://www.zespri.com/en-US/zespri-sustainability