TECHNICAL FEASIBILITY STUDY

CASE DRYING CENTER

Lapela Technology Oy

Contents

1. Abstract

This is the feasibility study report for Case Drying Center. The study was conducted by the research team at Lapela Technology Oy and commissioned by Prizztech Oy.

Research covered the technical feasibility of drying equipment or machine for a client company. Prior to this study, little was known about the root cause of emerging issues, and even less on how the issues could be tackled.

The study was conducted as an applied constructive study and the report, in conjunction with other related studies and data, will be used as a reference in the designing of the drying equipment.

The catalyst to the entire R&D process was the concerning amount of customer complaints regarding apparent moisture related damages to goods upon delivery. The case company's production and products underwent a comprehensive analysis relating to said moisture issues (damaged packaging etc.), and this analysis kickstarted the feasibility study.

Following the analysis, the research team conducted a number of tests to determine the optimal drying method. The drying methods are evaluated and chosen based on their operational functionality, including energy and cost-efficiency, with respect to the shape, size and materials of the products to be dried.

Once the optimal drying method is successfully tested, the research team moves onward to the challenges said method proposes to the drying equipment. The findings create an outline for the actual machine design.

The feasibility study is one part of a collection of studies conducted by the research team for the case company. Due to its' public nature, the

study is reported as a stand-alone study with applications beyond the case company's production, and with no identifying information of the case company.

As the study dives into the technical feasibility of drying equipment, a suggestion is presented as to what the basic form of the equipment should be according to the study findings. Final form of the machine is to be decided on with the case company, with respect for their privacy and competitive advantage, but the study conclusively finds that the ideal method for the drying is a combination of a centrifuge and targeted air jets.

In the case of this specific drying operation, the centrifugal force from the necessary velocity reaches great heights, leaving the hardware exposed to a semi-constant high strain. This level of strain requires special measures to combat it. These high forces and automated functions place a level of responsibility on all involved parties; the manufacturer, the client and the end user. These responsibilities are defined through a risk analysis.

2. Research Agenda

This is a report on the technical and operational **feasibility study** conducted by the research team at Lapela Technology. Research is conducted during 2019 as a part of larger research and development (R&D) project conducted for the case company.

Starting point

The starting point of this feasibility study follows previous evaluations conducted internally by the case company. Following issues have been acknowledged and evaluated prior to this study:

- Poor production lead time
- Costs accumulating from long lead times due to the necessity for large storage units (for drying) between production stages
- Quality issues (client complaints)

The causal relationship between the lack of proper drying equipment and issues is undisputable. The case company currently has no drying protocol besides letting products air dry for three days. This method is inconsistent and inefficient.

Objective

The objective of the larger R&D project is to design, test and manufacture a drying machine. This feasibility study is a part of said project.

As is with most feasibility studies, the objective of this feasibility study is to **gather, evaluate and analyze** information regarding the technical and operational feasibility of a drying machine. The report is to be used as a reference in the designing of said machine.

Research questions

The necessity for this feasibility study stems from **efficiency and quality management issues** of case company's a production facility. These issues are approached through a **case study**, to ensure the understanding of source data, research methods and drawn conclusions, yet **preserving the anonymity of case company** and their operations.

Research questions are defined as follows:

1. What amount of water is trapped in the objects and why?
2. What are the methods with which the objects could be dried?
3. What risks need to be considered with the drying methods, and what are the necessary preventative actions?

Ethical matters

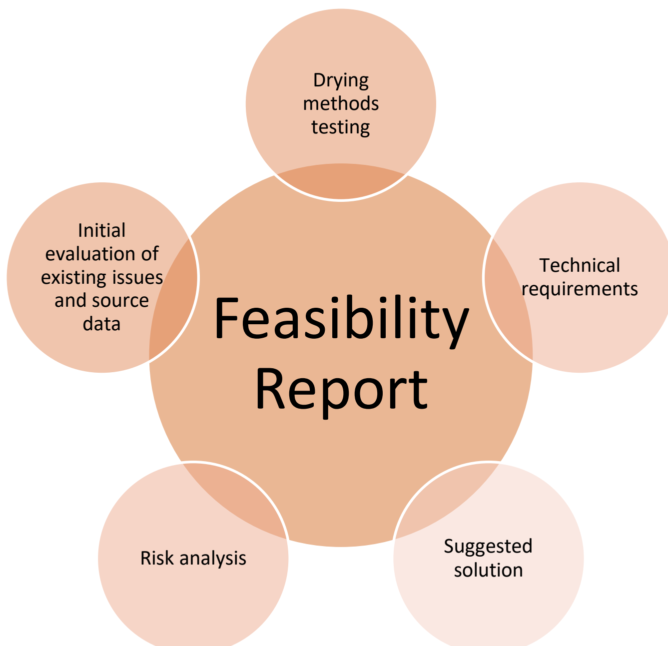
Per the request from case company, all information regarding their operations, production, products, staff, strategy, financial status or any other aspects of their business that they have expressed is classified, has naturally been left out of this report. To preserve the anonymity of case company, all identifying information has also been left out of this report. Products are identified with P1 to P5 identification number. Parts of the appendices have been concealed or altered to prevent any recognizability of case company.

To protect intellectual property of Lapela Technology, technical specifications, drawings etc. are to remain concealed from the public.

Methodology

This feasibility study will analyze the **technical feasibility** of drying equipment.

The study is conducted as an applied constructive study in which the conceptual framework is constructed as follows (Figure 1.)



1. *Figure: Conceptual Framework*

3. Initial Evaluation

Initial evaluation consisted of observations made by the case company, as well as by the research team that paid a visit to the production facility of the case company. Products in question are mostly cylindric in shape, with power cords and other protruding parts. Materials include hard plastic, light metals, and rubber.

Determined by both the case company and the research team, a clear set of issues exist between two production stages; pressure testing and electrical testing. These issues are directly linked to the customer dissatisfaction experienced by the case company. Related complaints all express similar issues of either visible water on the products or moisture damage to paper manuals and cardboard packaging caused by water trapped inside the products.

Water enters the products during pressure testing, which takes place in large pressure chambers filled with impure water. The water used in said pressure testing is unheated. Discovered through initial testing conducted by the research team, there is no sealing to prevent the water from leaking into different parts of the products (Appendix 1).

The products are left to air dry leaving them more exposed to superficial damages. The drying time is longer than preferred, leading to longer than preferred lead time. As apparent from the client feedback, some of the moisture remains trapped within the products regardless of drying.

After the efforts to air dry the products, they are packaged. Packaging includes plastic elements to protect the products from superficial damages during transport, as well as a cardboard box that holds the product, related documents and other packaging materials. Depending on the duration and conditions of the transportation to the client, in most cases all visible water will have evaporated from the product, but not before causing damage to paper documents and cardboard packaging. These damages are a clear-cut quality issue and create distrust between the manufacturer, the client and the end-user.

The initial evaluation leads to an obvious conclusion. A solution to the issue is necessary. If the case company wishes to upscale their production, they have to be able to optimize their use of space. The case company operates in a red ocean market meaning that there is a high emphasis on productivity, shorter lead-times, as well as quality.

Examples of problematic products were delivered to the research team in May 2019, marking the beginning of the evaluation phase. Products were numbered (ID nr.), weighed, visually evaluated and disassembled. See the original evaluation and testing log sheet in the appendices (Appendix 1).

The evaluation phase consists of three stages;

1. Stage 1: Evaluation, straight out of the package
2. Stage 2: Evaluation after drying the products completely. 8hrs of drying in an oven at 40 °C
3. Stage 3: Evaluation after submerging, products submerged for 1h in an upright position, visible moisture shaken off manually

Stage 1: Remarks

- Staining on all of the products
- No visible or otherwise detected water on the products
- Some crinkling on paper manuals

Date	ID Nr	Rank. in mass	Mass (g)
29-May-19	1	1	9737.8
29-May-19	2	4	3386.2
29-May-19	3	5	3325
29-May-19	4	3	3736
29-May-19	5	2	4032.6

1. Table: Stage 1, Remarks

Stage 2: Remarks

- No change in weight in comparison to Stage 1 data
  - Conclusion: Products were completely dry upon arrival

Date	ID Nr	Rank. in mass	Mass (g)
29-May-19	1	1	9737.8
29-May-19	2	4	3386.2
29-May-19	3	5	3325
29-May-19	4	3	3736
29-May-19	5	2	4032.6

2. Table: Stage 2, Remarks

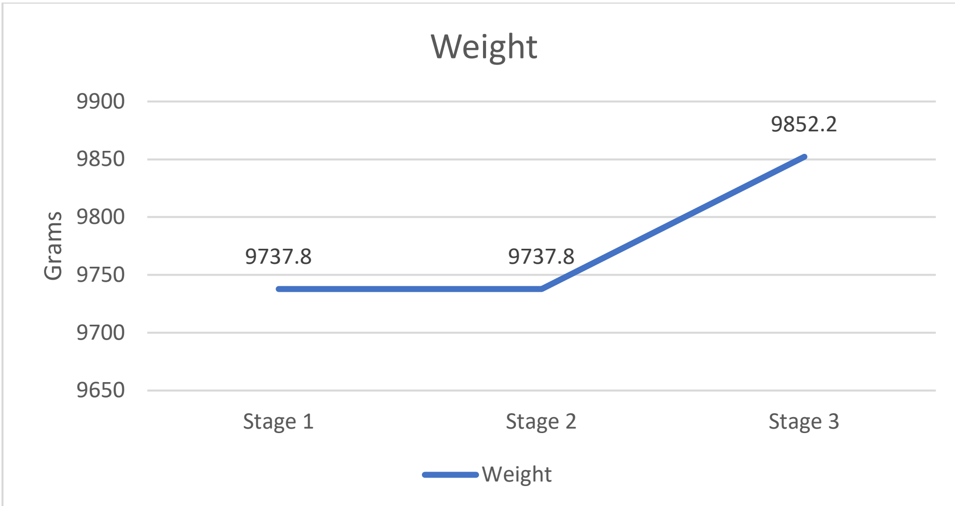
Stage 3: Remarks

- Significant amounts of water trapped inside the products

Date	ID Nr	Rank. in mass	Mass (g)	Remarks
3-Jun-19	1	1	9852.2	=114.4g, 1.16% of water
3-Jun-19	2	4	3408.4	=22.2g, 0.65% of water
3-Jun-19	3	5	3365.8	=40.8g, 1,21% of water
3-Jun-19	4	3	3759	=23g. 0.61% of water
3-Jun-19	5	2	4096.8	=64.2g, 1.57% of water

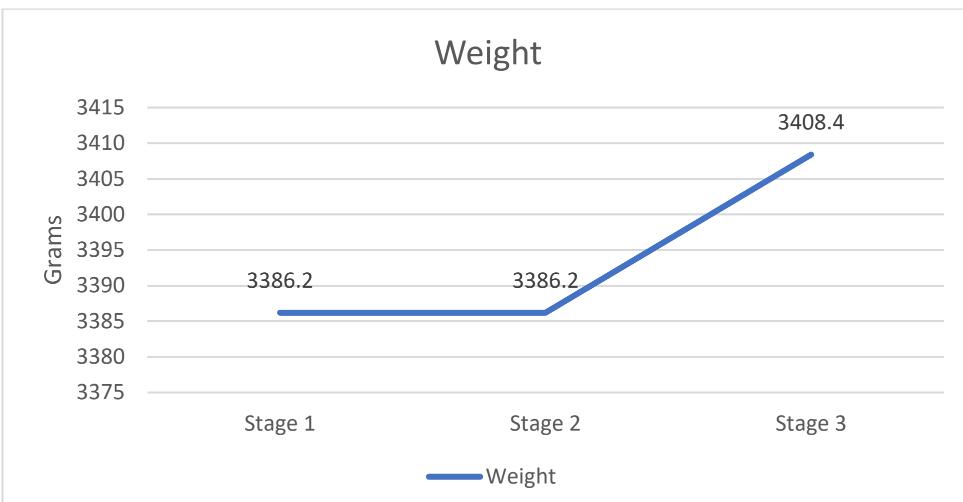
3. Table: Stage 3, Remarks

P1



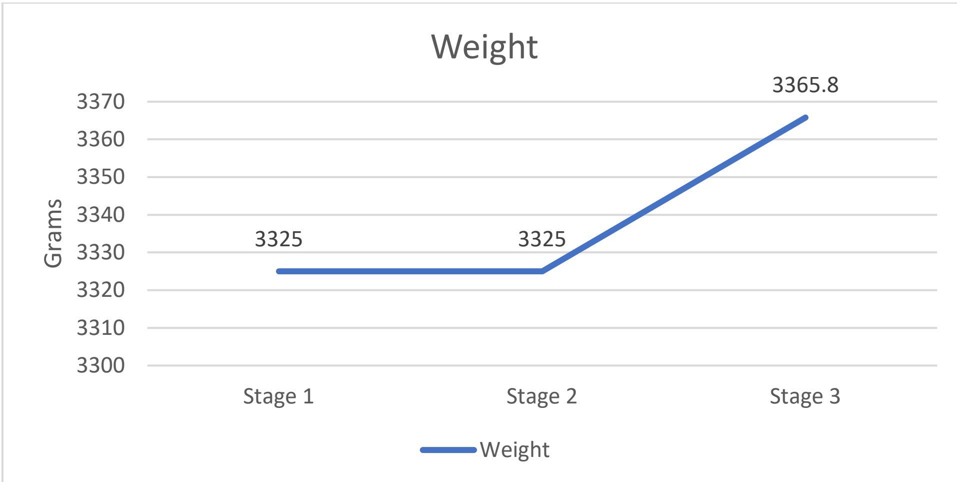
1. Graph: P1, Stages 1-3

P2



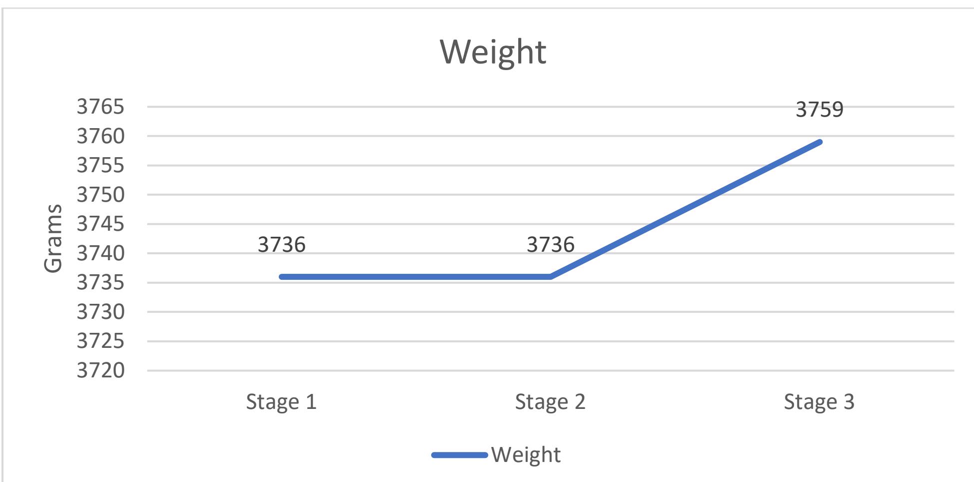
2. Graph: P2, Stages 1-3

P3



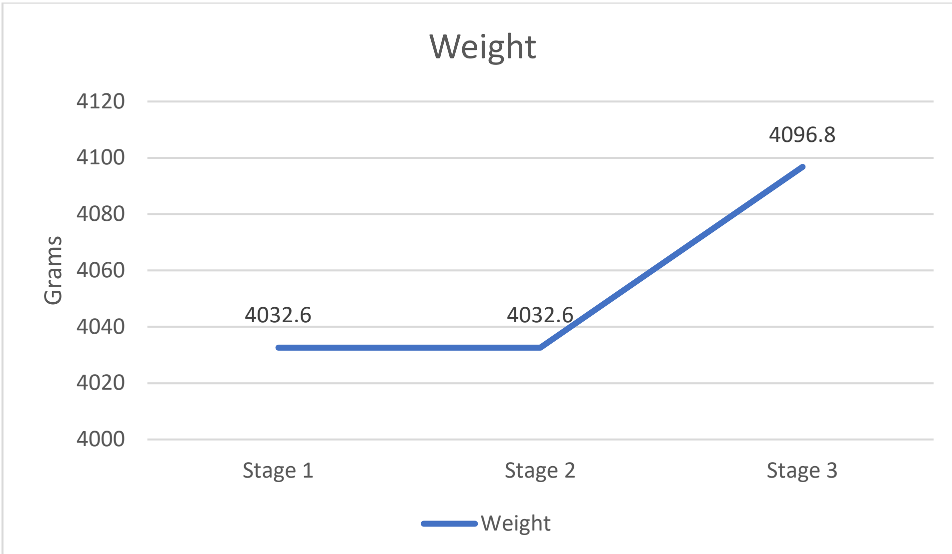
3. Graph: P3, Stages 1-3

P4



4. Graph: P4, Stages 1-3

P5



5. Graph: P5, Stages 1-3

Conclusion

The amount of water trapped in each product after Stage 3 was relative to the size of the product. The most problematic model was **P5**, with **1,57%** of the measured weight being water. Second place went to **P3** with **1,21%** of water, third place to **P1** with **1,16%** water, fourth place to **P2** with **0,65%** of water and finally **P4** with **0,61%** of water.

The amount of water detected in all of the models led to the conclusion that most of the water was trapped somewhere inside the product. The amounts were significant with respect to the dry weight of the products.

4. Disassembly

All of the models were disassembled. The main objective of the disassembly was to get an idea on what the areas within the products are that are exposed to water.

Before the disassembly, all of the models were submerged for 1 hour in an upright position. Once lifted from the water, the products were shaken manually to remove dripping water.

Disassembly was conducted immediately after the submerging. Some water droplets were inside the larger hollow areas within the product. Most of the water was found to be trapped in the supporting framework of the plastic casing covering most of the surface area of the products. None of the models had any sealing to prevent water from entering the "pockets" within the frame.

5. Drying methods testing

The shape, size, structure and materials of the products proposed restrictions as to which drying methods are safely applicable. Due to these factors, the two drying methods that the research team determined to be the most effective were **centrifuging** and **targeted air jets**. The "pockets" in which most of the water is trapped in are not reachable with other methods.

Other submissions, besides centrifuging and targeted air jets, included placing the products in a heated room, but this submission was deemed unfit for the purpose due to inefficiency in time and energy consumption. Also, this method would need to consider a significant number of variables such as water purity and relative humidity of air. These variables leave the method to be relatively unpredictable and unrepeatable in unstable conditions.

The two drying methods were tested by comparing results to Evaluation Stage 3 data. Methods were tested in a testing site with relatively uniform conditions, to ensure a level of accuracy and consistency. The room temperature in the testing facility was 20°, with minor (<1 °) fluctuation due to weather conditions. Testing was conducted during June 2019 (Appendix 2), with relative air humidity at 50-70% (fluctuation due to weather conditions). Neither the centrifuging nor the targeted air jets method is significantly affected by temperature or relative air humidity.

Stage 4: Remarks, Air jets

Date	ID Nr	Rank. in mass	Mass (g)	Remarks
10-Jun-19	1	1	9815.8	78g of water remains, 68.18% (comparison point data Stage 3)
10-Jun-19	2	4	3401.4	15.2g of water remains, 68,47% (comparison point data Stage 3)
10-Jun-19	3	5	3358.4	33.4g of water remains, 81.86% (comparison point data Stage 3)
10-Jun-19	4	3	3744.4	8.4g of water remains, 36.52% (comparison point data Stage 3)
10-Jun-19	5	2	4091	58.4g of water remains, 90.97% (comparison point data Stage 3)

4. Table: Stage 4, Remarks, Air jets

The models were submerged for 1 hour in an upright position. After submerging the products were dried by blowing with targeted air jets.

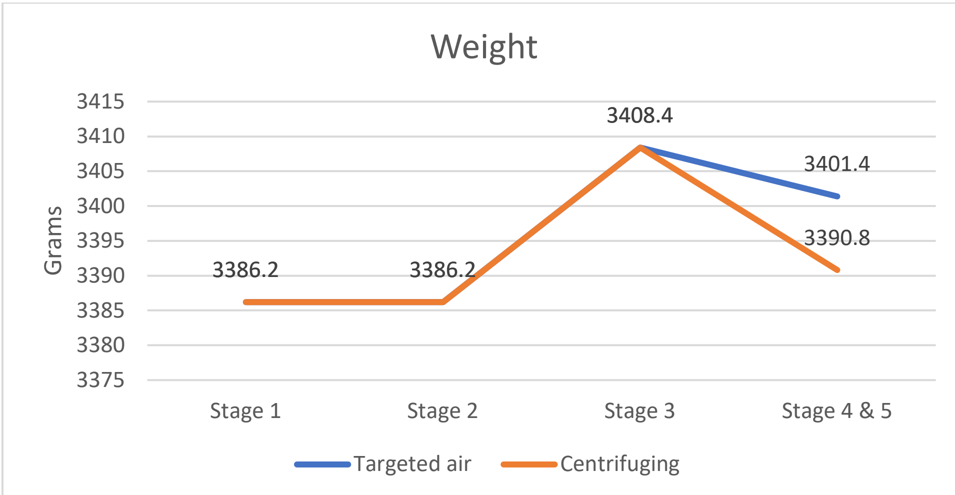
Stage 5: Remarks, Centrifuging

Date	ID Nr	Rank. in mass	Mass (g)	Remarks
12-Jun-19	1	1	-	-
12-Jun-19	2	4	3390.8	4.6g of water remains, 20.72% (comparison point data Stage 3)
12-Jun-19	3	5	3329.2	4.2g of water remains, 10.29% (comparison point data Stage 3)
12-Jun-19	4	3	3747.4	11.4g of water remains, 49,57% (comparison point data Stage 3)
12-Jun-19	5	2	4040.4	7.8g of water remains, 12.15% (comparison point data Stage 3)

5. Table: Stage 5, Remarks, Centrifuging

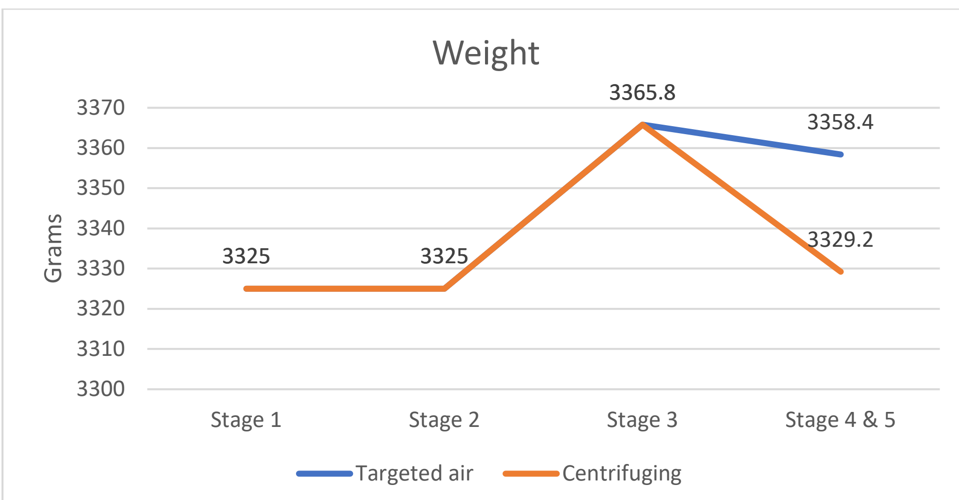
The models were submerged for 1 hour in an upright position. After submerging, the products were centrifuged for total of 30 seconds each at 600rpm. The data for centrifuging testing for P1 is concealed but does not affect the conclusions drawn in this report.

P2



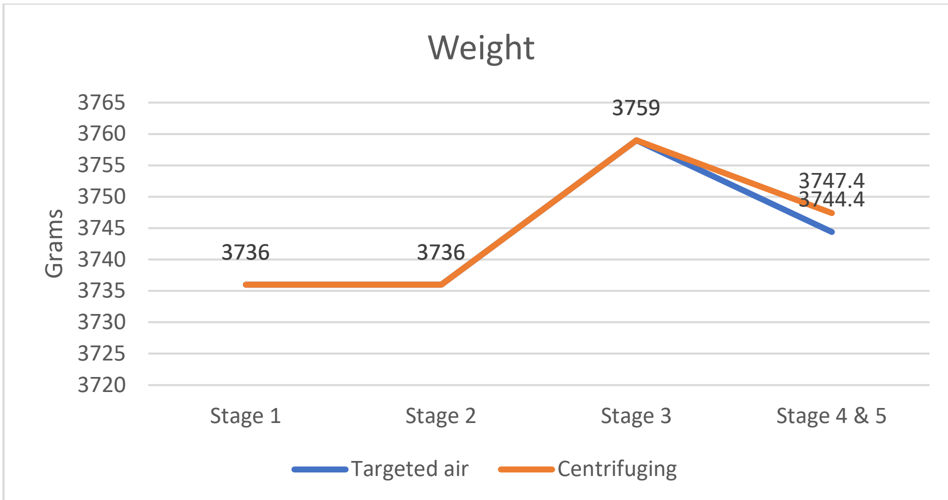
6. Graph: P2, Stages 1-5

P3



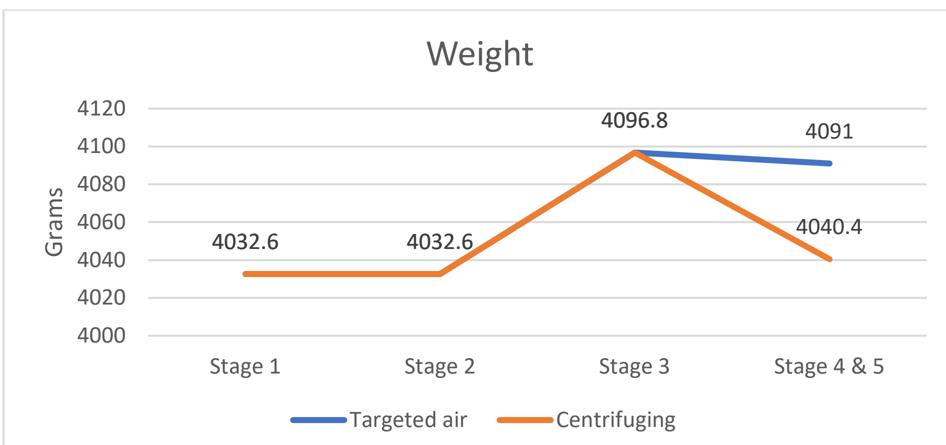
7. Graph: P3, Stages 1-5

P4



8. Graph: P4, Stages 1-5

P5



9. Graph: P5, Stages 1-5

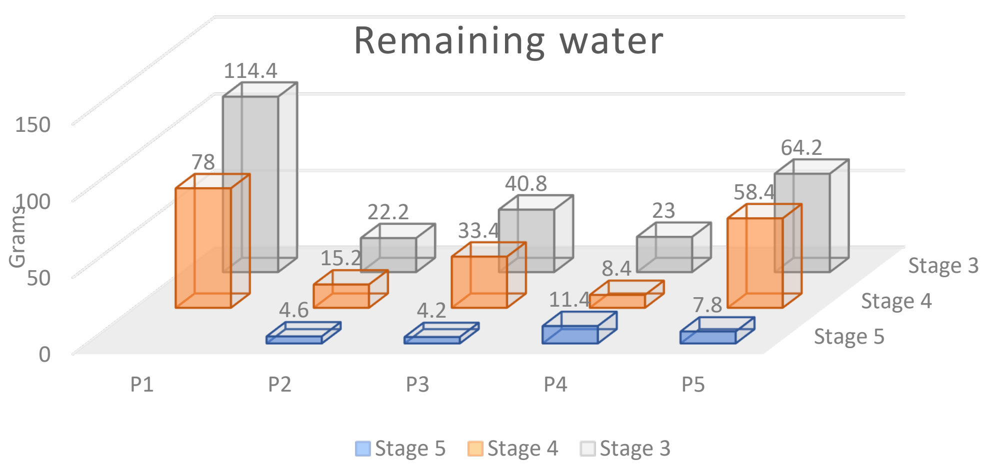
Conclusion

Based on the drying methods testing, the research team concluded that the most thorough drying is achieved with centrifuging, as the method proved to be more effective on 3 out of the 4 models that it was tested on (Graph 10.) *

Although proven less effective with most models, the targeted air had an effect none the less. On one of the models (P4) the targeted air option was more effective (Graph 10.) *

Results for targeted air can be enhanced with the application of heated air, as well as determining the optimal pressure. Same goes for the centrifuging, as the cycle time and applied force can be optimized for better results. Also, with the centrifuging an even better outcome can be achieved with small design changes to the products to allow the water to escape the pockets even faster and more efficiently.

**These results are relative to the prevailing conditions.*



10. Graph: Remaining water

6. Technical requirements: Centrifuge

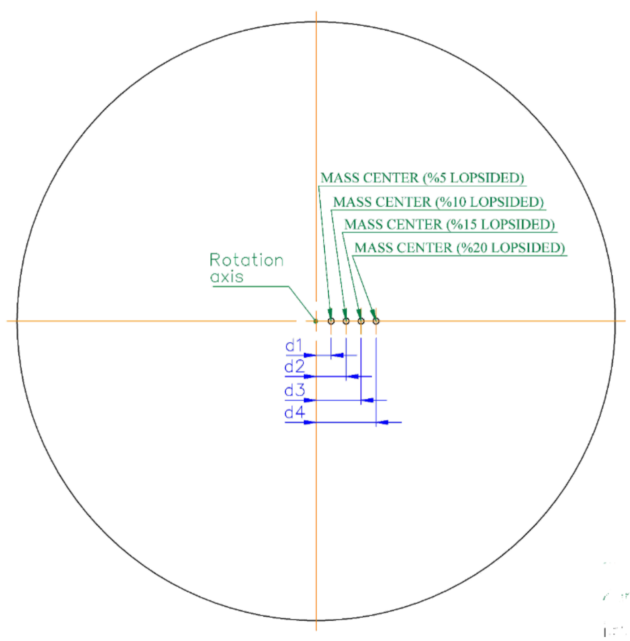
A centrifuge is a piece of equipment that puts an object in rotation around a fixed rotational axis (spins it in a circle), applying a force perpendicular to the axis of spin (outward) that can be very strong. The centrifugal acceleration causes denser substances and particles to move outward in the radial direction. At the same time, objects that are less dense are displaced and move to the center. In the case of a drying centrifuge, the water that is trapped inside the products moves outward and is replaced with a lighter substance gas, in this case heated air.

The research teams strongly advises that the centrifuging is done with **a custom and sturdy centrifuge**. The following chapters describe the reasoning as to why the research team has come this conclusion, and what exactly is the force in the centrifuge. The force plays an incremental role in deciding what safety measures and other structural and component level requirements there are.

Distribution of mass within the centrifuge

In order to get the best results, the products are to be centrifuged around their vertical center axis. Products are mostly perfectly cylindric but have some protruding parts such as exit ways and a power cord. These elements make it physically impossible to have the mass of the product perfectly evenly distributed in the centrifuge.

This unbalance creates significant forces in the centrifuge. The research team estimates that there is at least a 10% (of product's total mass) lopsidedness. This lopsidedness will create a "whisking" motion that will put a significant strain on the centrifuge. With 10% lopsidedness, 20% of total mass will be at the mass center point at the perimeter, as the remaining 80% is located around the rotating axis, with 40% on each side, each side cancels each other out (Figure 2.)



2. Figure: Mass center point

The centrifugal force will grow exponentially with even a percentage more in lopsidedness. Therefore, it will be absolutely crucial to have the drying center built with a consideration of the potential increase in forces.

The drying center needs to be built with a consideration of the safety of the products that are dried, the drying center itself, surrounding areas, an most of all the user and other persons. Therefore, the research team strongly advises that the entire centrifuging process happens within a closed-off machine (Chapter 7: Suggested solution: Drying Center) to prevent any parts from potentially flying from the centrifuge, as well as preventing any further damage to surrounding area, people and other devices in case of a centrifuge malfunction or breakdown.

Source data

The calculated force (N), effective mass (kg) and centrifugal acceleration (m/s^2) are based on source data and the data on velocity. The total mass presented in the table below is the wet weight of each product (Table 6.)

	Total mass (kg)	Ø (m)	r (m)
P1	9.8522	0.15	0.075
P2	3.4084	0.15	0.075
P3	3.3658	0.16	0.08
P4	3.759	0.14	0.07
P5	4.0968	0.16	0.08

6. Table: Source data

Other source data includes the estimated of 10% lopsidedness, which is a rough estimate.

Velocity

The products are centrifuged at 600rpm speed. This converts to an angular velocity of **62.831853 rad/s** (as 1 rad/s is 9.549296596 rpm).

With the radius of each product and the angular velocity in rad/s, the research team was able to calculate the tangential velocity (m/s) for each product when centrifuged at 600rpm.

Tangential velocity was calculated with the following formula

$V_t = \omega r$

(ω=angular velocity, r=radius of the product, V_t=tangential velocity)

Centrifugal force

With source data and the calculated tangential velocity, the research team was able to calculate the mass at the perimeter and the force it results in during centrifuging at 600rpm. Calculations are based on the estimated 10% lopsidedness, with 20% of total mass at the mass center point (Table 7.)

	Tangentical Velocity (Vt, m/s)	Mass (kg)	**Force (N)**
P1	4.712388975	1.97044	**583.423897549155**
P2	4.712388975	0.68168	**201.837357382771**
P3	5.02654824	0.67316	**212.602332270526**
P4	4.39822971	0.7518	**207.759120009892**
P5	5.02654824	0.81936	**258.776289395060**
Average	4.775220828	0.979288	**292.879799321481**
Highest	5.02654824	1.97044	**583.4238975**
Lowest	4.39822971	0.67316	**201.8373574**

7. Table: Centrifugal force

Force (in Newtons) was calculated with the following formula

$F = m * V_t ^2 / r$

(*F=force, m=mass,* V_t *=velocity, r=radius of the product)*

Other related data

Based on the presented calculations, the research team also calculated to effective mass (kg) and centrifugal acceleration (m/s²) (Table 8.)

	Force (N)	Effective mass (kg)	Centrifugal acceleration (m/s²).
P1	**583.423897549155**	61,46	296,1
P2	**201.837357382771**	21,263	296,1
P3	**212.602332270526**	22,353	315,8
P4	**207.759120009892**	21,937	276,35
P5	**258.776289395060**	27,207	315,8
Average	**292.879799321481**	30,844	300,03
Highest	**583.4238975**	61,46	315,8
Lowest	**201.8373574**	21,263	276,35

8. Table: Other related data

Conclusion

The research team strongly advises that when determining the final form of the drying center, the design is based on the worst case scenario. This is crucial to making the machine meet safety standards.

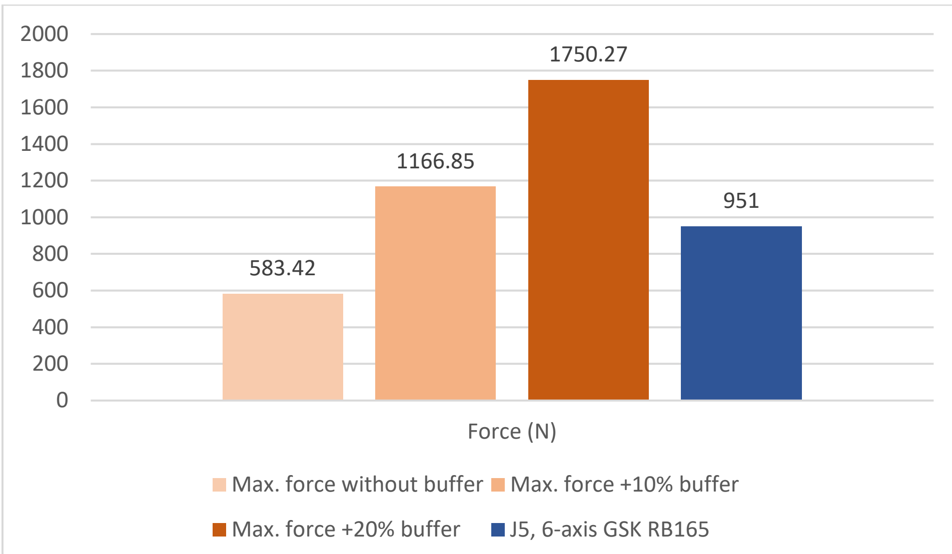
This means that from the data presented in previous chapters, the **highest values** are considered the threshold and a buffer is calculated overtop of the threshold to minimize the risk of any damage to the machine, user or the surroundings.

The largest examined product was P1 with a **dry weight of 9737.8 g** and **wet weight of 9852.2g**, which presented the highest forces of 583.4238975 N.

The buffer should be calculated with **a minimum of 10% increase or an ideal increase of 20% to the existing 10% lopsidedness** of the distribution of product's mass in the centrifuge. When the research team increased the lopsidedness from 10% to 20%, the forces from P1 jumped to 1166.847795 N. When the lopsidedness was raised to 30% the forces jumped to 1750.271693 N (Graph 12.)

For comparison and conceptualizing purposes the calculated forces (Chapter 6: Centrifugal force) are reflected on a typical 6-axis industrial robot. 6-axis industrial robots that could withstand the centrifugal forces from the drying operations are very large in size and are not financially reasonable options. Some 4-axis packing robots can theoretically withstand these forces, but it is not recommended as the "whisking" motion will transfer to each axis of the robot and puts a strain on them. It's is not recommended to continually apply maximum forces on the robot since it will greatly increase the damages to the robot as well as the necessity for maintenance.

A comparison of the forces from the centrifuging and maximum torque for example model of industrial robot from GSK CNC Equipment Co., Ltd. is presented below. The maximum torque for the robot presented in the graph applies for static torque and does not consider the accelerations, decelerations and stops during the spinning motion, which will cause momentary spikes in force that the robot is not equipped to handle.



11. Graph: Force increase

In the hypothetical case in which the centrifuging is conducted with an industrial robot, the highest forces including the 20% buffer can be cut down in half (1750.271693 N-> 875.1358463N) by fastening the bottom of the frame in where the product is fastened to during centrifuging, to a bearing system. This would reduce the “whisking” motion, but it would not remove it entirely.

Other supporting arguments as to why the centrifuging is not recommended to be done with an industrial robot include the lack benefits it presents. The tilting of the product during the centrifuging (tilting the robot around the TCP, only possible with a 6-axis robot) does not change the orientation of the rotating axis of the centrifuge with respect to the center axis of the product and therefore has no effect on the efficiency of the centrifuging process. If the frame to which the product is fastened into would have a mechanism that tilted the product's center axis around the rotating axis of the centrifuge (increasing the radius), the forces would grow exponentially to a level that is impossible to handle with an industrial robot.

The centrifuge works using a sedimentation principle, where the centrifugal acceleration causes denser substances and particles to move outward in the radial direction. At the same time, objects that are less dense are displaced and move to the center. The core idea of the drying centrifuge is to use the centrifuge as means to replace the water within the products with hot gas (air). This and the centrifuging itself is best done with a sturdy revolver style machine (Chapter 7: Suggested solution: Drying Center.)

Other benefits of the revolver style drying center, beyond basic functionality and safety, is lower amount of necessary maintenance (lower costs) as well as versatility, as the machine can be equipped with different types of tools for various applications. The drying center could also be used for the centrifuging of different shape and size objects with relatively minor changes to the fastening system for the products and programming of the machine.

On the contrary, using an industrial robot instead of a revolver style centrifuge for the centrifuging, poses many issues. Even if a model with theoretically high enough torque is found, the robot will continuously be exposed to high forces that will drive the robot to protective stops constantly. These protective stops can constantly halt the production creating a production bottleneck. A seemingly small difference in for example the position of the product or i.e. its' power cord in the frame will result in a big difference in the centrifugal force. And even if the products are perfectly placed every time, the “whisking”-motion can bend the rotating axis resulting in even higher forces. The “whisking”-motion also creates a vibration through the robot that damages different measuring systems within the robot.

Whatever the final design of the machine is, the product and all the moving parts have to be fastened securely and to absolute positions. This will require sensor systems and sturdy clamping systems within the frame to which the products is fastened to.

7. Suggested solution: Drying Center

This chapter describes the suggested solution by the research team. Based on the conducted research and the conclusions drawn from said research, the research team suggests that a drying center is introduced into the production process.

Objective

The main objective of the drying center is dry the products efficiently and safely, but the intended design has a consideration for potential integration of other production procedures as well. These procedures may include inspection, marking etc.

The drying center is designed to withstand the necessary forces and remain scalable to fit products of different size and amounts. The product intake, as well as amount of integrated procedures is determined by the case company.

The introduction of this drying center would allow for higher level of control of the products during the drying procedure, as well as during other integrated procedures. Current partially manual transportation of the products from production stage to another leads to the products exposed to superficial damages, as well as an unpredictable flow of products.

The higher controllability also allows for further automation and integration leading to even shorter lead time and potentially lower production costs.

Principles

The principle of the drying center is relatively simple; The products are placed into the machine and fastened securely to a frame with clamps. Once the products are placed securely into the machine, they are then ready to undergo any integrated procedure. Each procedure is completed on a station. The amount of stations is to be defined according to the amount of desired product intake and integrated procedures.

Each station within the drying center will be equipped with the securing frame and clamps, as well as a servo motors for centrifuging and positioning during the procedures.

The frames to which the products are placed into are custom designed to fit the product and to hold the product sturdily. Considering the speed and force from the centrifuge, the whole system (clamps, fastening, frame, sensors, bearings etc.) is designed and built to with stand constant high forces. Each frame holds one product at a time. Each frame is installed overtop of a motor with the center axis of the frame perfectly aligned with the rotational axis. The motor spins the frame for as long and as fast that is determined necessary.

The entire drying process and other integrated processes are completed automatically and out of the users reach, protecting the user from potential hazards caused by the procedures. Each product will have its' own custom program with custom parameter settings to allow for optimal outcome. The unloading station is designed in a way that allows for automated integration of the drying center to the production line. One user is necessary to control certain functions through the user interface, as well as placing the products into the drying center.

The final design of the machine will follow the requirements presented by the client company, local officials and legislation, as well as the

European Union Directive 2006/42/EY on Machines as well as applicable standards.

8. Risk analysis

The risks related to the Drying Center are evaluated by the severity of the discovered risks (Table 9.) Depending on the severity of the risk, more action may be needed (Tables 10 and 11.) This risk analysis applies to the current design related risks of the machine. It also applies to risks caused by reasonably foreseeable user errors. All the detected risks, as well as any emerging risks, are to be considered in the designing of the machine and user training.

Risk severity	Consequences		
Likelyhood	Minor	Hazardous	Extremely hazardous
Unlikely	2. Insignificant risk	3. Minor risk	4. Moderate risk
Possible	3. Minor risk	4. Moderate risk	5. Significant risk
Likely	4. Moderate risk	5. Significant risk	6. Intolerable risk

9. Table: Risk analysis, Risk severity

Level	Classification	Action
2	Insignificant risk	No action necessary
3	Minor risk	Risk needs to be monitored and re-evaluated later. User-experiences and safety issues need to be actively monitored.
4	Moderate risk	Risk needs to be minimized further.
5	Significant risk	Risk needs to be minimized further.
6	Intolerable risk	Risk needs to be minimized further.

10. Table: Risk analysis, Action

Detected risks

Design

1. **Loud noise during running (Level 4: Possible and Hazardous)**
    - Discomfort for the user and other people around
    - Possible permanent hearing damage from elongated exposure without earmuffs

2. **Crushing of parts of the human body (Level 5: Possible and Extremely hazardous)**
    - Potentially permanent damage to health or death
3. **Machine component fatiguing (Level 3, Unlikely and Hazardous)**
    - Irreparable damage to products or the machine
    - Losses of goods
    - Production halts
4. **Overheating (Level 3, Possible and Minor)**
    - Protective stops, shutdowns
    - Production halts
    - Machine component damage
5. **Mechanical vibration (Level 3, Possible and Minor)**
    - User discomfort
    - Strain on components
6. **Splashing water (Level 4, Likely and Minor)**
    - Component corrosion
    - Friction
7. **Mechanical damages (Level 3, Possible and Minor)**

Reasonably foreseeable user errors and other user related risks

8. **High emphasis on user responsibility, potential faulty placement of products into the machine (Level 4, Possible and Hazardous)**
    - Product loss
    - Damages to the machine
    - Production haults
9. **Unexpected seizures or other sudden bouts of illness (Level 4, Unlikely and Extremely hazardous)**
    - Potentially permanent damage to health or death
    - Product loss
    - Damages to the machine
    - Production haults

10. Dangly accessories or clothing items etc. that could potentially get caught up in the machine (Level 5, Possible and Extremely hazardous)
   - Potentially permanent damage to health or death
   - Product loss
   - Damages to the machine
   - Production haults

11. Ergonomic challenges (Level 3, Possible and Minor)
   - User discomfort

12. Fast working pace (Level 3, Possible and Minor)
   - User discomfort
   - Stress

Actions

Risk nr.	Level	Action
Design		
1.	4	The manufacturer requires that the client assigns a team to responsibly enforce all directions in the user manual of the machine, to ensure user's personal safety and safety of those around. Working with and around the machine strictly requires all persons to wear protective earmuffs to prevent potentially permanent hearing damage from elongated exposure to the potentially loud noises coming from the machine. Loud noises coming from the machine need to be diminished by the manufacturer to the lowest possible level, with acoustic designing. The machine needs to be equipped with adequate standardized signs to inform the people around of the necessity of protective earmuffs.
2.	5	To prevent crushing of parts of the human body, the manufacturer is required to equip the machine with protective sensors and accessible emergency stops.

		Protective sensors will prevent the machine from running if humans or objects are in its' workspace. If any points remain where there exists a chance of crushing of the human body, these points need to be equipped with clear and standardized warning signs to alert the user of potential danger.
3.	3	To prevent component fatiguing, the manufacturer is required to completely remove the risk of fatiguing or diminish it to the lowest possible level by designing and manufacturing the machine with consideration of potential sudden spikes of forces, as well as steady continuous forces. Necessary forces to withstand need to include safety buffers to prevent fatiguing due to unexpected force anomalies. The manufacturer requires that the client assigns a team to responsibly enforce all directions in the user manual of the machine, including requiring the end user to observe the machine and its' functions, and report and log all signs of fatiguing such as cracks. In case of any signs od fatiguing, the client is required to abstain from using the machine and to contact the manufacturer immediately.
4.	3	To prevent the machine from overheating, the manufacturer is required to design and manufacture the machine with components that withstand the heat created from the operations of the machine, and a cooling system to control the heat. The manufacturer is required to define the highest allowed operating temperature and to inform the client about it.
5.	3	The manufacturer is required to design and manufacture the machine in a way that diminishes the chance of mechanical vibration. The user interface needs to be designed with a consideration for mechanical vibration and the potential discomfort for the user from elongated exposure. The components and structure need to withstand the strain from mechanical vibration.

6.	4	The manufacturer is required to design and manufacture the machine from materials and with methods that consider the likely splashing of water. This means that areas where splashing occurs need to be sealed, ventilated and equipped with draining system. The user workspace needs to be organized in a way that diminishes risks from water from the products, including slip-proof mats.
7.	3	The manufacturer is required to minimize any risks of mechanical damage with vigorous testing and optimization of methods, materials and compositions. It is required that the machine is equipped with proper sensors and other tools to monitor the health and state of the machine and alerts the user if mechanical damages occur. In case of mechanical damage, the client is required to abstain from using the machine immediately.
Reasonably forseeable user errors and other user related risks		
8.	4	The manufacturer is required to provide the client and user with adequate information and training to safely utilize the machine in its' intended purpose. This includes defining the necessary skill-level and experience to use the machine. It is required to equip the machine with protective measures and functions that stop it from running unless products are placed into the machine correctly (sensor systems).
9.	4	The manufacturer is required to design and manufacture the machine with a consideration of user's unexpected seizures or other sudden bouts of illness. This means that turning the machine on needs to only be possible in a way that requires focus and can't happen by accident. The shape of the machine, user interface and user workspace needs to be designed with a consideration of diminishing the risk for damage to people in case of a seizure or other bouts of illness. This means that there

		needs to be no sharp, pointy or otherwise hazardous parts unless absolutely necessary for operation, and if any remain, the user needs to be informed of these with proper warning signs and training.
10.	5	The manufacturer requires that the client assigns a team to responsibly enforce all directions in the user manual of the machine, to ensure user's personal safety and safety of those around. Working with and around the machine strictly requires all persons to abstain from wearing ay dangly accessories or clothing. This includes all earrings, necklaces, bracelets, scarfs, bags, purses, keychains, loose clothing etc.
11.	3	The manufacturer is required to design and manufacture the machine with consideration for user ergonomics. This means that the user interface and loading station are installed at heights and locations that the user can clearly see and reach with minimal effort.
12.	3	The manufacturer is required to design and manufacture the machine in a way that allows the user to easily and safely stop the running if necessary.

11. Table: Risk Analysis, Actions

9. Final Conclusion

The research team concludes that the technical feasibility of the drying center depends on some factors. It is absolutely necessary to move forward with the acquisition with great respect for the findings of this study. The feasibility exists but it requires devotion from all involved parties. As the machine will be a custom piece to an extent, it is crucial to thoroughly evaluate the circumstances and to establish a relationship between the manufacturer and the case company that produces a constant flow of documented data, that can be and is utilized in the optimization of the machine.

It was found that the most efficient method for drying is a combination of implementation of centrifugal force and targeted air jets. This method is already widely used for some drying operations and can, according to this study, be applied to the case company’s production as well. These two drying methods, along with other client defined procedures, are to be combined into a drying center.

As with any other evaluation of technical feasibility of machinery and equipment, safety creates an outline for all other aspects of the technical design. Other aspects include efficiency in time, energy- and costs, and all can be achieved with sturdy industrial centrifuge.

The research team finds that the with vigorous designing, all of the detected potential risks of the drying center can be combated. As the machine design will most likely include custom components, the research team puts a high emphasis on collaboration with the client company to ensure the applicability of these components.

In closing, the research team finds that feasibility study to be a success as all of the research questions were answered.

APPENDICES

Appendix 1

Lapela Technology Oy				Drying Center	[redacted]
All [redacted] are evaluated as is, powerchords included. ID Nr. will be referred to in test related documentation.					
Stage 1: Initial evaluation, straight out of the package					
Date	Model	ID Nr	Rank. in mas	Mass (g)	Remarks
29-May-19	[redacted]	1	1	9737.8	no visible or otherwise detetctable water, no documented data of previous submerging
29-May-19		2	4	3386.2	no visible or otherwise detetctable water, no documented data of previous submerging
29-May-19		3	5	3325	no visible or otherwise detetctable water, no documented data of previous submerging
29-May-19		4	3	3736	no visible or otherwise detetctable water, no documented data of previous submerging
29-May-19		5	2	4032.6	no visible or otherwise detetctable water, no documented data of previous submerging
Stage 2: Evaluation after drying the [redacted] completely. **8hrs of drying in an oven at 40 °C.**					
Date	Model	ID Nr	Rank. in mas	Mass (g)	Remarks
30-May-19	[redacted]	1	1	9737.8	no significant difference to initial weight, comparison point data Stage 1
30-May-19		2	4	3386.2	no significant difference to initial weight, comparison point data Stage 1
30-May-19		3	5	3325	no significant difference to initial weight, comparison point data Stage 1
30-May-19		4	3	3736	no significant difference to initial weight, comparison point data Stage 1
30-May-19		5	2	4032.6	no significant difference to initial weight, comparison point data Stage 1
Stage 3: Evaluation after submerging [redacted] submerged for 1h in an upright position, visible water shooked off manually					
Date	Model	ID Nr	Rank. in mas	Mass (g)	Remarks
3-Jun-19	[redacted]	1	1	9852.2	=114.4g, 1.16% of water
3-Jun-19		2	4	3408.4	=22.2g, 0.65% of water
3-Jun-19		3	5	3365.8	=40.8g, 1,21% of water
3-Jun-19		4	3	3759	=23g. 0.61% of water
3-Jun-19		5	2	4096.8	=64.2g, 1.57% of water

Appendix 2

Disasembly of all models. No visible water in the chambers of the [redacted]. A significant amount of water found trapped within "pockets" located in supporting framework of plastic parts of the [redacted]					
Stage 4: Evaluation after [redacted] are submerged again, for 1h, then dried with targeted air jets					
Date	Model	ID Nr	Rank. in mas	Mass (g)	Remarks
10-Jun-19	[redacted]	1	1	9815.8	78g of water remains, 68.18% (comparison point data Stage 3)
10-Jun-19		2	4	3401.4	15.2g of water remains, 68,47% (comparison point data Stage 3)
10-Jun-19		3	5	3358.4	33.4g of water remains, 81.86% (comparison point data Stage 3)
10-Jun-19		4	3	3744.4	8.4g of water remains, 36.52% (comparison point data Stage 3)
10-Jun-19		5	2	4091	58.4g of water remains, 90.97% (comparison point data Stage 3)
Stage 5: Evaluation after [redacted] are submerged again, for 1h, then dried with implementing centrifugal force (30sec, 600r/min)					
Date	Model	ID Nr	Rank. in mas	Mass (g)	Remarks
[redacted]					
12-Jun-19		2	4	3390.8	4.6g of water remains, 20.72% (comparison point data Stage 3)
12-Jun-19		3	5	3329.2	4.2g of water remains, 10.29% (comparison point data Stage 3)
12-Jun-19		4	3	3747.4	11.4g of water remains, 49,57% (comparison point data Stage 3)
12-Jun-19		5	2	4040.4	7.8g of water remains, 12.15% (comparison point data Stage 3)