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**THE EFFECTS OF TEMPERATURE AND AIR HUMIDITY ON
DRYING OF WATERBORNE PAINT PRODUCTS**

Case Centria Puulaboratorio

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ABSTRACT

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<p>This thesis is made for Centria Puulaboratorio, a wood laboratory located in Ylivieska. The goal of this thesis is to research how air humidity and temperature effect on drying of waterborne paint products. Because there are four seasons in Finland that cause challenges to dry waterborne paints. The practical part in the thesis verifies how much temperature, humidity and flash-off time adjusted to achieve the most drying percentages. It is also known that different colors have an influence on drying.</p> <p>The theory part gives some introduction about wood coatings (finishes), application methods and drying methods. In practical part, an indoor waterborne paint and an outdoor waterborne paint were chosen. They were sprayed on two different types of materials under specific parameters and circumstances.</p> <p>The data was collected, calculated and analyzed by Design of Experiments. The tables and graphs were created during the experiments. Some graphs and picture were provided by Centria Puulaboratorio.</p>		

<p>Key words Evaporation, drying percentage, flash-off time, paint, relative humidity, temperature drying, waterborne.</p>

CONCEPT DEFINITIONS

DOE - Design of Experiments, Designed Experiments, Experimental Design

HVLP- High air volume and low-pressure

IR- Infrared

MDF - Medium-density fiberboard

RH- Relative humidity

S/N - Signal-to-noise ratio

ABSTRACT
CONCEPT DEFINITIONS
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1 INTRODUCTION

The purpose of this thesis is to research how temperature and air humidity affect on drying of waterborne paint products. The thesis includes two parts: theory and practice. The theory introduce some basic information related to waterborne paint products such as various type of wood finishing products, application methods for spraying and coating finishes, drying or curing methods and film formation process.

The second is practical part which explains step by step how to test, how to apply Design of Experiments (DOE) and how its work. The first experiment indicates to glass-based material with selected circumstances and parameters in order to find out which parameters have strongest influence to drying of the paint.

Subsequently, based on those figures, experiments have been set up with two chosen paints spaying on two chosen different wood-based material. Lastly, get the results and make the comparisons among two paints and two materials to figure out which paint has the most evaporation rate on which kind of wood-based material.

2 BASIC INFORMATION ABOUT WOOD COATINGS (FINISHES)

Finish is described as a mixture of materials and in liquid form, which is easily spread out on a substrate of any shape and leaves very thin film on the surface. A wood finish aims to protect, preserve, enhance or color the wood substrate. (Dresdner 1997, 4.)

This theory will closely approach and introduce some information related to classification types of wood coatings, components of wood coatings, spraying/coating applications, what is waterborne product and end-uses of wood coatings.

2.1 Coating technologies

The coating technologies are classified into categories: solvent-borne, high solids, water-borne, powder coating and radiation curing (or Radcure).

- Solvent-borne is a coating where the volatile component is predominantly a non-aqueous solvent, for example, traditional paints and lacquers.
- High solids technology is basically a solvent-borne coating but it contains higher solids to adapt solvents legislation. (Bulian & Graystone 2009, 8 - 11.)
- Water-borne is described as a paint where the pigment and binder are dissolved or dispersed in a continuous phase that contains essentially water. Waterborne coatings do not mean they contain solvent-free, instead they can have some organic solvent to serve for other usages, in some cases up to 10%, to build up film formation. (Bulian & Graystone 2009, 54.)
- Powder coating is a coating material in dry powder form and contains solvent-free. After fusing by heat, it may experience curing to form a continuous film.

- Radiation curing or Radcure is seen as liquid coating material with 100% solids content, which will be transferred into a solid by UV or EB radiation method; and solvent content can be up to 25%.

In Europe, water-borne coating is the most used but mostly for decorative wood coating. However, water-borne technology is less use than other technology in industrial usage. For the solvent-borne technology, it is going to decline due to the solvent emissions on the environment. (Bulian & Graystone 2009, 8 - 11.)

2.2 Generic type of wood coatings

There are few different ways to classify wood coating categories. This generic type is one of those methods. There are three types in generic group that have some things in common, hence they are grouped together.

2.2.1 Paints

Paints and varnishes are mentioned in European Standard EN 971-1(1996) and defined as a product in liquid, paste or powder form. When applying them to a substrate, a film is established for protective, decoration or other usages. (Bulian & Graystone 2009, 54.)

The advantages of paints are ease of usage due to suitability for applying on various substrate types; and suits to wood substrate if paints provide it positive properties such as flexibility, adhesion and permeability. Paints can be used as wood primer or undercoat, as topcoat or finish. (Bulian & Graystone 2009, 140.)

2.2.2 Clear and semi-transparent coating (varnishes and lacquers)

Some special wood substrates have unique and attractive features, so there is a need for clear coating (or transparent coating, or glaze coat) to build up the wood appearance. Even though the agents

(pigments, dyes, stains) are limited in clear coating than in paint, the transparency does not prevent from color; therefore, the color of substrate will affect the final outlook of the wood features.

Varnishes and lacquers are defined as transparent materials for wood coatings. When applying varnishes, it should cure solely by oxidation, while lacquers need to dry exclusively by evaporation of solvents. (Bulian & Graystone 2009, 140.)

2.2.3 Stains and lasures

Stains comprise dyes or some chemicals activating with wood such as oxalic acid, bleaches and caustic alkalis. In contrast, lasures involve to pigments, for example, biocidal agents are used in order to hinder blue stain as service desires.

Stains are described as materials to color a wood substrate without hiding its structure, which raise the appearance of wood before coating it with a transparent finish. There are few kinds of stains including water stains, oil stains and spirit stains. (Bulian & Graystone 2009, 140 - 141.)

Today, water-based stains are popular and developed rather than solvent-based stains due to its properties, for example, making the structure of the substrate more consistent and offering environmental advantages.

Stains work productively in various finishing application methods such as spraying, roller staining and flow coating; or manual applied by dipping, brushing and sponging. Making a stain experiment before starting production is essential in order to examine and decide the right color and characteristic appearance of the stained product. (Becker Acroma 2007, 20.)

2.2.4 Oils, polishes, waxes and patinas

The characteristics of oil are strong and absorption effect on wood depending on the structure of the substrate. A dried and smoothly sanded surface is required before applying the next layer of oil. To have functions as a stain and surface protection, oil might be lightly tinted.

All oiled surfaces experience periodic after-treatment, so that they can be able to maintain their protective properties. (Becker Acroma 2007, 20.)

The major use of oils and waxes on wood is to improve the natural wood grain and appearance. Waxes are made use for interior products. Wax can be described as creams, pastes or liquid dispersion due to their consistency, which can be semi-solid or liquid according to the quantity of solvent used - usually hydrocarbon mixture.

Waxes can be tinted with iron oxide (red, brown and yellow shades) pigments, and applied on bare wood or after priming coating application. Because of non-establishing a real solid film, the protective surface need to be maintained frequently, especially for intense deterioration purposes (floorings).

The repeated layers of wax associated with light and in-use elements make up gradually a characteristically colored layer on wood, which is seen as patina. As same as waxes, polishes use in interior environment and they can be colored as well. (Bulian & Graystone 2009, 142.)

2.3 Raw materials for wood coating

Formulation is a process including many steps to combine all components (other raw materials) to carry a product to full production. There are four major components creating the formulation: binders, volatile materials (solvent, water, etc), pigments and additives.

Depend on the purpose of end-users, there will select which categories going to apply. Firstly, binder technology involves chemistry of binders (acrylic, urethane, etc) with an appropriate technology of delivery (water-borne, solvent-borne, radcure or powder).

Second step is choosing pigments, except for transparent coating, depending on the desire for color, opacity, transparency and protective purposes. Lastly, adding specific additives to match the selected technology in order to enhance additional properties and make the formulation to become possibility. (Bulian & Graystone 2009, 143 - 144.)

2.3.1 Binders

Binders can be dissolved as well as altered and controlled the properties including wetting, film formation and penetration. Using binders in coating will provide good adhesion, flexibility, durability, body and wide range of advantage characteristics. Nitrocellulose, alkyd resins, amino resins, acrylates and polyester resin are typical binders. (Becker Acroma 2007, 18.)

Wood coating field uses a wide range of resin and polymer such as nitrocellulose, alkyd, acrylic, amino, and polyester, polyurethane, etc. (Bulian & Graystone 2009, 8.)

2.3.2 Solvents and diluents

Depending on the type and the amount of solvent used in binders will affect the consistency, ease of application, wetting properties and film drying time of chosen coating. A specific mixture of solvent is found in lacquer and aids to achieve its optimum properties. The quantity of solvent is modified to increase flow, adhesion, evaporation rate, combat blistering and etc.

Water-based coatings are different from solvent-based systems due to their outcome properties reacting on different surfaces like wetting, surface tension characteristics, film formation, and so on. (Becker Acroma 2007, 18.)

Solvent is defined as a single liquid or blend of liquids and volatile under specified drying circumstances, and completely soluble when combining in binder.

Diluents are a slightly different from solvents because it does not dissolve anything but it has impacts on fluidity, rate of evaporation and other characteristics. The film former can be precipitation and cloudiness due to too much diluents carried. (Bulian & Graystone 2009, 96.)

Water is a very special type of volatile liquids and has environment gains like non-toxic and non-flammable as well as cheap and readily available. Furthermore, it is also known as a carrier for coatings. (Bulian & Graystone, 2009, 102.) The mixtures of solvents are described as thinner and adjusted to suit with a wide range of materials and application methods. (Becker Acroma 2007, 9.)

2.3.3 Additives

According to EN 171, additives refer to any substance added in small quantities, usually <1%, to coating material in order to enhance or adjust one or more properties (Bulian & Graystone 2009, 105). Therefore, it is applied to modify certain finish properties like gloss, consistency, wetting, flow, blister prevention and sandability (Becker Acroma 2007, 18).

2.3.4 Colorants (pigments and dyes)

Pigments are aids to give finishes to get hiding property as well as a specific color. It can be used in glaze to perform the right color. Dyes and dispersed pigments are utilized for stains. (Becker Acroma 2007, 18.)

Dyes are substances that will penetrate in a wood substrate to make the soluble areas become insoluble in process, while pigments carry insoluble going through coloration process, and these insoluble will be dispersed during coating process.

Pigments are substances added to a coating in order to change the optical properties of the film. They not only interact with visible light and color, but also promote the phenomenon of color through the light absorption or scattering.

As a result, pigments protect coatings and coated substrates from UV degradation. Especially in some special pigments, they can able to reflect infrared (IR) heat. Other advantages of pigments are fire retardance and prevention from corrosion. (Bulian & Graystone 2009, 125 - 126.)

2.4 Waterborne coatings

Nowadays, moving from solvent-born to water-borne brings along many benefits for environments as well as safety. Besides, it also produces disadvantages of using water in the wood-based material due to increasing grain-raising and other problems occurring from the high latent of water during industrial process. (Bulian & Graystone 2009, 87.)

By spreading out a thin non-grain-raising sealer coat before applying waterborne finishes, after a sealer dried, scuff-sand the surface, this method not only eliminates grain-raising but also enhances significantly the surface appearance. Another alternative is tinting with non-grain-raising stains. (More Finishes and Finishing Techniques: The Best of Fine Wood Working 1997, 36.)

According to Flow, Leveling and Viscosity Control in Water-Based Coatings article published on Prospector website in 2014, there are two major groups of waterborne coating: water-reducible and latex.

- Resins are made in solvent and reduced in water in order to generate a dispersion of resin in water, which called water reducible resin and is suitable for baked coatings.
- The term latex is used for resins that are prepared by emulsion polymerization in water, which used most in architectural coatings.
- Besides, resin chemistry, surfactants, wetting agents and flow agents are added to complete the formulation of waterborne finish.

Waterborne coatings consist of various resin types including acrylic, alkyd, urethane, polyester, epoxy and fluoropolymer. (Lewarchik 2015.)

2.5 End-use sectors for coated wood

Wood has variety of uses that may require coating for protective and decoration purposes. Depending on the types of coating required, there are two different distinctions to describe their purposes of using coated wood. First is the distinction between interior and exterior applications, if the demand of end-users for exterior environment, the coating should be able to resist to moisture and solar radiation. Other distinction is between decorative/architecture and industrial applications (joinery, flooring and furniture).

Coatings for decoration are usually applied by hand and air-drying, while in industrial coatings, it uses different kind of application techniques and products, which may need stoving or radiation curing. (Bulian & Graystone 2009, 4.)

2.6 Application methods

In order to succeed in wood coating, one of the crucial stages is the preparation of surfaces made up by the application and drying of coatings.

Application is a kind of process that coating material is converted from the bulk state in plastic or stainless containers to a smooth film on a prepared substrate. Then it goes through drying and curing stages with optional finishing operations - sanding between coats.

Choosing which application to utilize is based speed, suitability, materials, cost, etc. Robotics applications match for industrial sector while hand applications go with house decorative and small-scale operations. Application system in liquid coatings divided into two categories: contact methods and atomizing methods. (Bulian & Graystone 2009, 259 - 260.)

2.6.1 Contact methods

Contact methods are defines as the continuous contact among application system, coating materials and substrate.

2.6.1.1 Brushing

It is one of simplest application methods due to its benefits including low cost, high-transfer efficiency and low capital cost. However, it mostly use in architectural painting; for industry, brushing incurs low efficiency and low quality.

It also uses for touch-up after sanding processes where imparted color of wood was removed by tinting and impregnating products. (Bulian & Graystone 2009, 263.)

2.6.1.2 Padding

Padding is a simple manual coating technique. Craftsmen spread semi-solid coating products (waxes or shellac) on the surface by special plugs made of fibers or textiles. They will repeat this operation to increase a deep penetration of the coating into wood pores and to get homogeneous result. (Bulian & Graystone 2009, 263.)

2.6.1.3 Dipping

Dipping is a manual, economic, fast and productive coating method for wide range of products, especially having complex shapes with difficult accessible sides. Dip coating is divided into two basic ideas.

The first is an aid to achieve as thick film as possible when slowly dipping products in a dipping bath containing high-viscosity lacquer. This is suitable for implements industry such as spade handles, baseball bat, etc. The second is dipping in thin solutions and mostly used for staining, priming and even sealer (topcoat) of machined components.

This manual dipping technique is best suit to water-based coatings rather than solvent-based coatings due to solvent emissions and risk of evaporation from open tanks of solvent-based coatings. The liquid vessel should be kept in stainless steel or plastic. (Becker Acroma 2007, 31.)

2.6.1.4 Autoclave vacuum and pressure application

Autoclave and other closed vessel applications are applied for outdoor wooden products. The advantages of this method aim to achieve deeper absorption of wood, while simple dipping cannot accomplish. When combined with precise preservatives, it generates the better resistance against biological deterioration the more efficient impregnation. (Bulian & Graystone 2009, 263.)

2.6.1.5 Roller coating

Roller coating is fast growing application system with quick, simple and cost efficient for coating flat products. This technique allows to transfer coating from the rollers to the surface of object, as well as adding more the amount of coating applied to achieve a premium quality topcoat. (Becker Acroma 2007, 28.)

Consequence, it is useful for high viscosities and solid content coatings like radiation curing products, to enhance the film thickness and even surface. Furthermore, roller coating is also popular for the application of stains such as water or solvent based and one-component coatings- primers, priming coats and topcoats. (Bulian & Graystone 2009, 264.)

Single-roller machine with synchronized application roller The finishing material flows in between the doctor and the application rollers. The amount of the coating issued from 10 to 40 g/m² and leave corrugated trace patterns on applied surface. Application rollers are coated with rubber; hence, the hardness of roller rubber varies from 25 to 50 Shore. If installing with soft roller, the Shore number is around 25 - 30 and the substrate should be totally equalized. (Becker Acroma 2007, 28.)

Relative process roller application In contrast with single-roller machine, the doctor roller or steel roller in this technique plays as a counter-rotating roller. The major benefits of using relative process roller are to increase the amount of coating applied and to decrease the corrugated trace patterns.

The amount of lacquer applied can be adjusted by changing the speed of doctor roller, the higher speed the lower lacquer consumption. The coating applied is from 2 to 30 g/m². At least three thin layers of basecoat is a need if applying pigmented surfaces with UV coatings.

The speeds of the conveyor belt, doctor roller and application roller have to be modified separately. Plastic doctor-blades will cause problems in future, and steel doctor-blades can cause visible lines in the lacquered finish surface due to its sharp razor. (Becker Acroma 2007, 29.)

Roller coating by applying filler with a glazing roller (or filling roller coater) It is a single-roller machine with synchronized application roller with an adjacent steel glazing roller. The counter-rotating (chromium-plated steel glazing roller) rotates opposite direction with conveyor belt. It aims to

remove any surplus of coating applied and coat the filler into every pore and cavities of the substrate in order to generate a filled and smooth surface.

The amount of filler or priming coats varies from 30 – 40 g/m² for porous substrates (processing chipboard or similar materials), and approximate 20 g/m² for more compact surfaces (MDF board and veneers). (Bulian & Graystone 2009, 268 - 269.)

Opti-roller coating This is a common method using for UV curing coating clear lacquers. The principle of this technique is the surface of the application roller threaded with small grooves, and those grooves will rupture surface tension in the coating to achieve extremely smooth film.

On the surface of opti-roller, very fine thread cuts rupture the surface tension that allow the coating to lie flatter against the substrate of object. Opti-roller technique can apply for pigmented UV products with the same outcome properties comparing with spray coating or curtain coating. This also performs efficiently with clear lacquer, primers and sealers. (Becker Acroma 2007, 30.)

Printing roller coating The method is similar to roller coating, but the desired pattern to be produced will engrave into the steel roller, then transfer it to the application roller and finally to the substrate. The printing roller coater consists of three printing heads or applications.

If using water-based inks, it needs to dry physically, while UV inks will dry with UV radiation. The UV curing products usually use basecoats and topcoats. The main benefits of full UV systems are reducing the inter-coat adhesion and gaining scratch resistance.

Printing systems can operate from very cheap board systems to unique tabletop and flooring systems with various product prices. Therefore, at present, printing associated with UV coatings performs fast processing line for industrial coatings. (Becker Acroma 2007, 30.)

Staining roller coating Staining roller coaters can apply for flat wood surfaces of stains or primers. If using stains, roller coaters are provided with one or two brushing (or wiping) rollers, so that they will clean the substrates before operating. The doctor roller made of chromium-plated steel and the application roller, establish the head.

A soft rubber coats on the surface of the head if using solvent-based stains. The hardness of this coated head is approximately 30 Shore. In the contrary, a sponge material will replace a soft rubber in case of water-borne stains. The application rate is from 10 to 50 g/m².

The advantages of this technique are good penetration of the stain into the pores, especially large pores such as in oak, surplus removed and high capacity performing. (Bulian & Graystone 2009, 266 - 267.)

2.6.1.6 Curtain coating

Curtain coating was the most popular technique using in wood finish industry with extremely fast systems up to 100 meters a minute (m/min), normally approximate 45 to 70 m/min. Flat surfaces or slightly contoured in one direction such as sheets and strips (fillets, moldings) are applied by curtain coating machine.

The products are placed on the conveyer belt and then coated a uniform thin liquid layer flowing from the curtain (or a narrow slot or over a blade). The amount of applied coating is between 70 to 300 g/m².

Some elements can be adjusted in curtain coating machine such as the viscosity of the coating, the speed of conveyer belt (20-150 meters a minute), the installation of the slot opening in the curtain head and the amount of coating materials added in the curtain head.

Curtain coater concerns to recirculation, the ease of evaporation of volatile components and viscosity adjustment. As the result, the application systems approach for either water-borne, solvent-borne polyester or acrylate coatings or coatings that are sensitive to blistering. (Becker Acroma 2007, 27.)

The downside of curtain coating are the need for well-maintained, the risk of curtain breaking down due to simple air draughts and the suitability for horizontal plane surfaces. In order to avoiding the downtime while changing the finish or breakdown machine, the demand for two or more curtain coating machines is essential. (Bulian & Graystone 2009, 270.)

2.6.1.7 Flow coating

Flow coating is an alternative to simple dip coating with high productivity. The coating materials are sprayed at low pressure from coarse nozzles located above and below the conveyor, to work pieces that are hanging by conveyor. All the surfaces of components are flooded by coating materials in a single pass through the machine.

The excess materials from the spraying process will be removed by an air jet on emerging from the tunnel, and then flows to the bottom of the application chamber for reuse. (Becker Acroma 2007, 31 - 32.)

This method is desirable for low viscosity coatings like stains, impregnating stains and intermediate coatings. For instance, components, and already fully assembled window frames and chairs can be coated by flow coating. One again, this system is not suitable for solvent-based stains due to toxic emissions and solvent evaporation, therefore, water-based stains is the best for flow coating. (Bulian & Graystone 2009, 271.)

2.6.1.8 Vacuum coating

Vacuum coating is a very fast technique for applying paint and lacquer to the components. The whole work-piece is flooded in coating material before moving to a partial vacuum, so that the paint or lacquer can absorb to the substrate and leave the film thickness as desired. The advantages of vacuum coating are high efficiency as well as fast line speed.

Nevertheless, the drawbacks are the difference in the film thickness applied to the front and rear of the product, and vacuum pump needs to be maintained and requires high energy while operating. This method designs for coating trip, filets or moldings by meter in combination with water-based, oil-based and UV curing products. (Becker Acroma 2007, 30 - 31.)

2.6.2 Atomizing methods

By applying these atomizing methods, the liquid coating will be transferred to the droplets status and launched towards the intended surface.

2.6.2.1 Conventional air-atomized systems - Pneumatic atomization or Conventional Spraying (“low pressure”)

The principle of this method is to transport the coating material and disperse it with compressed air by means of spray gun. The advantages of conventional spraying are the ease of use with different coating types and form a smooth film, especially for complex shape objects. (Bulian & Graystone 2009, 273.)

The drawbacks of this method are slow productivity, overspray problems leading to high coating consumption and high environmental risk. (Becker Acroma 2007, 22.)

2.6.2.2 Pneumatic atomization with high air volume and low pressure (HVLP)

The principal is similar to conventional spraying; however, the spray gun and nozzle have been redesigned to atomize the coating by using high air volumes at low pressure (HVLP) technique, which decrease emissions issues. The method suits for application of 100% solid UV products at low application rate with less than 30 g/m². (Becker Acroma 2007, 22.)

2.6.2.3 Hydraulic atomization (Airless spraying, High-pressure spraying)

Airless spraying is more common than conventional spraying and a quick way to minimize overspray. In airless spraying systems, the high pressure (up to 200 bars) is applied to subject the paint or lacquer toward to the spray nozzle, and then atomize the finishing material when it goes through the spray gun nozzle. The pressure is derived from a piston pump.

Spray width and the amount of paint or lacquer can be controlled by adjusting the spray gun nozzle. Airless spraying is most used for water-based finishes with automated spray coating systems. (Becker Acroma, 22.) It is suitable for the interior large closed containers or to where a large amount of finishing material requirements (Bulian & Graystone 2009, 275).

2.6.2.4 Hydraulic air-assisted atomization (Airmix spraying)

Airmix spraying method is the most popular in the wood finishing industry due to its fine atomization and a minimum of overspray. Solvent-based systems require different spray gun nozzles from water-based systems.

The technology involves the high pressure pump (from 15 to 45 bar) sucks the coating from an open container; a spray gun combined with high pressure nozzle and an air nozzle for both atomization and spray-width adjustment, which shape the mist of coating to be more gentle and softer fan pattern. The air pressure using for atomization is low and varies from 0.5 to 2 bars with air consumption about 40 liters a minute. (Becker Acroma 2007, 22.)

At last, airmix spraying matches for various coating material, for example, stains, priming coats, base coat and top coats. (Bulian & Graystone 2009, 276.)

2.6.2.5 Hot spraying

The hot spraying method can modify the viscosity while applying 100% solid UV materials to conquer good leveling. However, the material must be constantly circulated to prevent from polymerization. This technology allows to minimize the use of thinner in solvent-based systems as well as solvent emissions. (Becker Acroma 2007, 23.)

2.6.2.6 Operational aspects of spray application

Spray application can be manual or with the aid from automation and robotics. Depends on purchase price and legislation impact, or at the shop floor, the ease of use, skills and maintenance will affect the choice of spray application. (Bulian & Graystone 2009, 277.)

Manual application (spray booths) Manual spraying is suitable for objects with complex shapes or small lots. The skills and experiences of workers will influence the quality of the application.

The operator will work inside spray booths or spray room associated with an adequate air circulation. By using water curtains or dry filters, it helps to remove solvent and other overspray in the working place. Application systems should be in the same direction as air suction flow. (Bulian & Graystone 2009, 277.)

Newly painted products will be put in drying trolleys, and then move to drying room or curing oven. Before curing or drying, those products are easy to be dust and draughts. A suction hood is a need to against solvent and chemical emissions from newly painted products, which escaping into ambient air. (Becker Acroma 2007, 22.)

Robotic application (Painting robots) It is a type of spray application with spray guns mounted on robotic arms. Robots are programmed with complex movement axes as closely as possible to the movements of operators in order to replace human workers in efficiency. (Bulian & Graystone 2009, 277.)

Industrial robots are an alternative for heavy and monotonous works; nevertheless, if painting the large amount of items having various shapes and sizes, robots cannot perform effectively. This robot uses for finishing edges (like window frames), milled grooves as well as at jobs where has high risks from spray mist or strong UV radiation.(Becker Acroma 2007, 27.)

Automatic applications (automatic spraying)There are many different kind of automatic spraying equipments and the selection based on the shape and size of objects to be atomized, or even the type of finishing material. (Becker Acroma 2007, 25.)

- **Automatic molding sprayer** The goods with high capacity spray coating requirement such as moldings, fillets, wood edges suit to these automatic spraying systems. The products are moved along at high speed under fixed spray guns.

Today, automatic molding sprayer is combined with high efficient UV curing ovens. Sealed automatic molding sprayers are installed with high efficient cleaning filters. Therefore, no UV lacquer spray mist can release into working area. These spraying systems can apply for clear lacquer and pigmented coating. (Becker Acroma 2007, 25.)

- **Automatic reciprocating spray machines** In this kind of machine, two or more spray guns move along a horizontal conveyor. The quantities of spray guns rely on the width of the items, the speed of the conveyor and different coatings to be sprayed. The automatic reciprocating spray is connected with sensors to detect surface of items to be coated.

The spray pattern derived from spray guns is decided by turning on or off the guns when the front, rear and sides of each good pass over the sensors. Nowadays, most automatic spray units comprise airmix spray guns or airless and conventional spray guns, which depend on the selection of finishing type and product characteristics. (Becker Acroma 2007, 25 - 26.)

- **Automatic reciprocators (vertical spray units)** A suspension conveyor moves the product in a vertical reciprocating movement inside the automatic reciprocating machine. Thanks to this principle, overspray from spraying items can be recycled and reused. This technique is an idea for water-based products due to decreasing the spray loss from spraying small items. When vertical spray unit equips with electrostatic spraying, spray loss is extremely minimized. (Becker Acroma 2007, 26.)

Electrostatic application (Electrostatic spraying) Electrostatic spraying becomes more and more popular and can be an alternative application for conventional spraying. Chairs, bed, window frames or other large– scales units can apply this method by using water-based paints or lacquers.

Electrostatic spraying uses electromagnetic field occurred from two bodies that have different electrical charges (negative-charged spray gun and positive-charged object to be sprayed). The paint or lacquer particles from the spray gun will follow the electromagnetic field lines and coat the object.

Moreover, the electromagnetic field generates a wrap-around effect, which will spray even in the hidden spots of the item. (Becker Acroma 2007, 23.)

2.6.2.7 Mechanical atomization

Centrifuge atomization (rotation systems/ rotary spindle machines) The rotation systems involve a large disc mounted on the rotating spindles. The products are placed to the spindles and the disc (or table) rotating and pass over the automatic spray guns.

The guns are installed in the center of the rotary table and face outwards. An evacuator linked with paints traps will keep the spray mist. The coating will be painted on the opposite side of the item, which is placed on the spindles. This machine works well with electrostatic spraying equipment as a part of automatic production. The machines mainly paint for mass-produced, small and circular components like knobs and handles. (Becker Acroma 2007, 23.)

3 DRYING AND CURING

When the coating materials are in liquid form and applied to substrates, the transition will start from liquid to solid film. After applying coatings, the process of film formation begins and experience physical changes or chemical changes if cross-linking. Nevertheless, many elements affecting the film formation are temperature, humidity, air movement and radiation, which are known as environmental conditions. (Bulian & Graystone 2009, 290.)

3.1 Film formation process/drying of latex-based paint

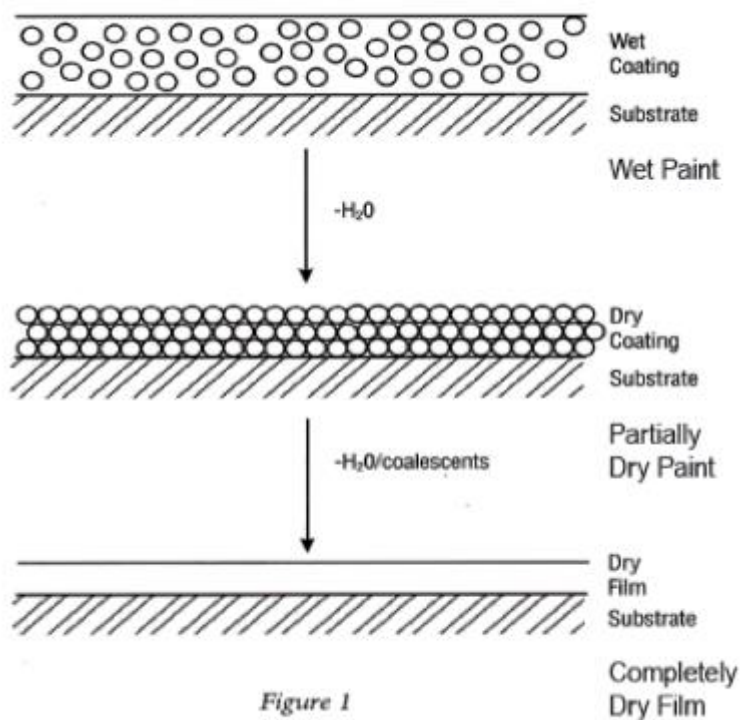


Figure 1

FIGURE 1. Drying stages of latex-based paint system (Lewarchik 2015)

In the first stage, water evaporates that leads to concentrating latex particles. The second stage will continue the evaporation of water and co-solvent until the latex particles pack and start to coalesce to form a film, which is called partially dry paint. Finally, the continued coalescence will form a continuous film which is completely dry paint film.

Both the temperature and humidity play important roles which are main influences to the drying of waterborne coatings containing water-organic solvent. Hence, they are must be carefully controlled and monitored. (Lewarchik 2015.)

3.2 Problems occurred from changing temperature and humidity

There are some problems happened from changing temperature and humidity that impact on drying:

- The slower drying times leads to sag or run paint, while thicker coatings result to more prone to wrinkling.
- As lower temperature condition, the paint does not penetrate entirely into the substrate. In hot condition, the paint surface can skin over while the lower layers have not dried yet, creating bumps or wrinkling on the surface. In case extremely high temperature, the paint will dry too fast and cause blistering or bubbling paint.
- The more moisture in the air, the longer time needed for water evaporation in an acrylic or latex paint. In high humidity case, the wood will absorb the moisture in the air that reduces the adhesion of the paint to the substrate and cause to peel or bubble in paint. (Hingst 2016.)

3.3 Drying methods

To accelerate the drying process and to minimize the risk of solvent emission that spread into working area, the process should be sealed as much as possible. The most common drying methods are briefly introduced below.

3.3.1 Thermally accelerated drying and curing

The heat from accelerated drying unit helps to decrease the drying times for various types of coatings, such as from water-based to polyester systems and NC-modified PU systems. When the surface temperature is over 50°C, it achieves extremely fast curing times. (Becker Acroma 2007, 34.)

3.3.2 Heat transfer

Heat transmission is used for wet film to speed up the curing process of all coating types. It will enhance the evaporation rate of solvent including water and create the possibility of chemical reactions, which separate into few methods below:

- Heat convection is made from domestic radiators taking air circulates in the room. Furthermore, a fan is attached to the set-up in order to force the air pass through a radiator, which is described as forced convection. The circulating hot air in a room or in a tunnel will heat the substrate of the items when they go over the room or tunnel.
- Radiation approaches a substrate, and then it will be penetrated and transferred into heat. For example, infrared radiation divided into short-wave, medium-wave and long-wave. However, only the sides of the object face to the radiation source are heated.
- Conduction heat is operated for preheating items in convection or radiation ovens in furniture industry. Then the substrate heats the film of lacquer generating a quick solvent evaporation, after that, the curing process begins. (Becker Acroma 2007, 34.)

3.3.3 Chamber driers and drying rooms

The coated products are usually placed on trolleys, on trestles or on the floor in chamber driers and drying rooms. This way is suitable for small industrial operations with very mixed production. (Becker Acroma 2007, 34.)

3.3.4 Tunnel driers

Tunnel drier is a kind of drying room but it is more advanced due to a tunnel involved. Trolleys move the lacquered products to tunnel drier; next, they will stand and be transported by overhead conveyer. There are different temperature zones in the tunnel, beginning with 20°C, and then temperature goes up from zone to zone, until achieves 70-80°C.

At the end of tunnel is a cooling zone, which subject to cool down the objects by using air at prevailing outdoor temperature. Tunnel driers usually go with drive chain, so that drier trolleys can move throughout the tunnel. (Becker Acroma 2007, 34.)

3.3.5 Vertical driers

Vertical driers are easy to cooperate with other driers or with automated spray applications. The highlights of this drier are low energy consumption, space saving and easy to associate with different types of combustion and catalytic cleaning systems.

After transferring the coated goods from conveyor to the drier, then they go vertically on the pallets through the drier. Same as tunnel driers, vertical driers also vary temperature zones and maximum temperature is 50-70°C which is most used. Nevertheless, the speed of air circulation can easily adjust. Because of long drying times, this oven is best utilization for medium and slow curing systems. (Becker Acroma 2007, 35.)

3.3.6 Flatline ovens

Flatline are most applied for NC, AC and water-based systems for over forty years and it has changed its layout in recent years. The older oven layout was Laminar air at low velocity and temperature with Laminar, or Jet air at high velocity and temperature with Pure IRM section and Jet air cooling.

The newer one has more equipment to match with water-based and water-based UV coatings. Keeping an open film while evaporating water, this is the best way to dry water-based goods. There are some methods to support that drying results, such as microwave, IR shortwave (NIR) and controlled humidity. Today, a modern oven includes one of these methods in association with Jet air and IR oven (or Speed oven).

The advantages of the layout developments are to reduce fiber raising, wood swelling and cut down the drying times. Flatline ovens can utilize for solvent-based systems as well if it is carried out some modification. (Becker Acroma 2007, 35.)

3.3.7 UV ovens

UV ovens are describes as curing ovens where UV reactive materials are cured by ultra violet light radiation. UV ovens can equip with mercury-vapor lamps that are efficient for clear lacquers or gallium doped, and for curing pigmented coatings. The power and wavelengths of lamps can simply adjust. The quality and light intensity of lamps have to be monitored and controlled to ensure the drying results. The lamps and reflectors should be maintained and cleaned regularly. Metering equipment is essential to control the process and achieves the complete drying film.

The benefits of applying UV ovens are no requirement for pre-heating the substrate, building evaporation or cooling zones; short curing times and energy efficiency as compared to conventional ovens using in finishing lines. Jet air cooling between the UV lamps is crucial when operating at optimum conveyor speeds or low speeds, or when coating resinous woods (pine, spruce). (Becker Acroma 2007, 35 - 36.)

4 PRACTICE

The test plan uses Design of Experiments (DOE) – Taguchi Design tool to find out which factor has strongest effect to drying of chosen waterborne paints. Glass-based materials are used to do the experiment first, after getting the results related to strongest affecting factors, there will be confirmation test. Finally, wood-based materials are tested for comparison between two types of wood materials applying by two different paints.

There are following steps that display how the tests are planned and made out the results.

4.1 Test plan for glass-based materials

In this step, glass pieces are used to make an experiment first before executing wood-based materials. The reason for using glass pieces instead of wood is that the paint will not penetrate or absorb to the substrate of the glass.

4.1.1 Choosing paints to be tested

There are two different kind of waterborne paints in this testing.

The paint number one (paint 1) is TEKNOS – Nordica Eko 3330-03 Base 1. This is an industrial topcoat for external uses such as wooden houses, garden furniture, fences and other outdoor purposes. The paint is only suitable for industrial use. (Teknos. NORDICA EKO 3330-03.)

The paint number two (paint 2) is SHERWIN-WILLIAMS – Laqva Top 30 Base A EG 1351-91513. This is a waterborne pigmented topcoat for internal uses such as furniture, joinery, shop fittings, wardrobe doors and commercial interiors. The paint is not designed for use in high wear or moist areas. (22croma. EG1351 Laqva Top.)

The paint sprayed on test pieces is approximately 100 grams \pm 10 grams in weight per square meter.

4.1.2 Choosing testing parameters and circumstances

As in the theory part, the drying of waterborne paint or film formation depends on the environmental elements like temperature, humidity, air movement and radiation. Therefore, the testing parameters and circumstances should be considered carefully.

4.1.2.1 Horizontal heating tunnel - infrared lamps

The heating tunnel in this test consists of two ovens with infrared lamps (IR lamps) and is divided into three zones: flash-off area, heating area and cooling area. In this case, the temperature and the speed line of ovens are taken into account.

The test has three various temperature phases for oven number 1 and oven number 2. There are 30/45, 45/50 and 55/60, respectively the temperature of oven 1/oven 2. The speed line of conveyor in the ovens is 4.5 meter/ minute (m/min). Furthermore, one IR lamp was turned on during processes, which can come up with a more productive result.

The Picture 1 in APPENDIX displays the layout of horizontal heating tunnel with infrared lamps.

4.1.2.2 Choosing flash-off time in flash-off area of tunnel

After spraying paint, glass pieces are transferred directly to the flash-off area in the drying tunnel. This zone allows air bubbles to escape from the liquid film. During the flash-off time, a significant amount of solvents will evaporate from the substrate before moving to the heating zone.

The flash-off times in this testing are considered as 0, 2 and 4 minutes.

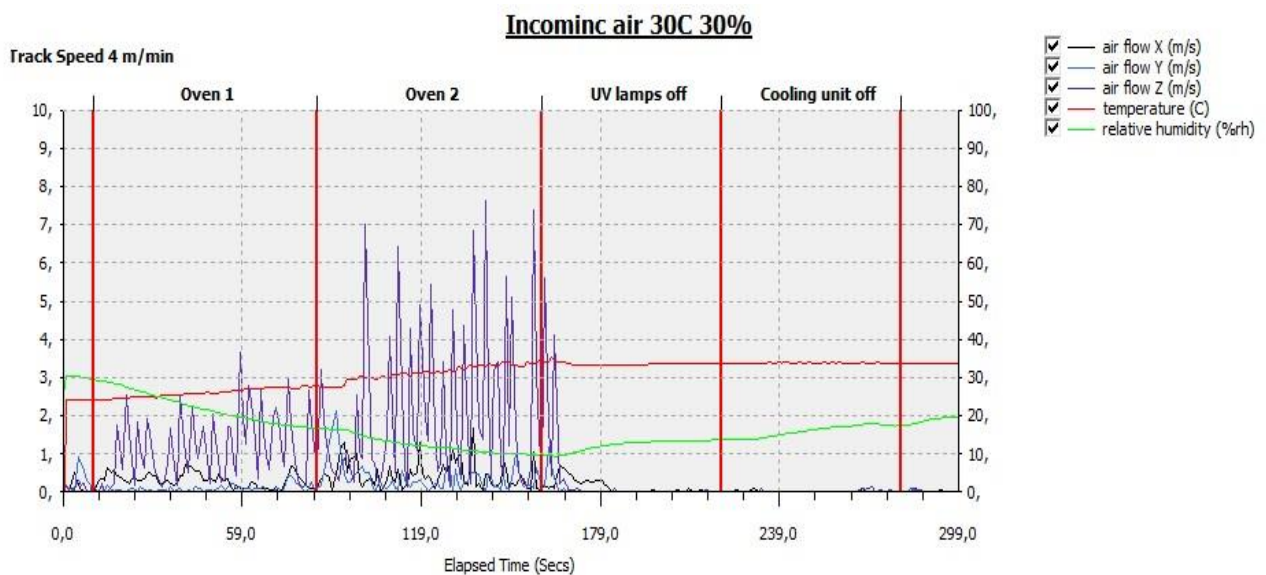
4.1.2.3 Drying test pieces at three different air humidity in drying ovens

The air movement in ovens is supplied through a system taking outside air and because water connects with humidifiers and other machines, the system will affect the relative humidity and temperature of supply air. Hence, in the drying oven, the air movement coming from nozzles pumping air at very high speeds, can be easily measured and changed by adjusting relative humidity and temperature on the system.

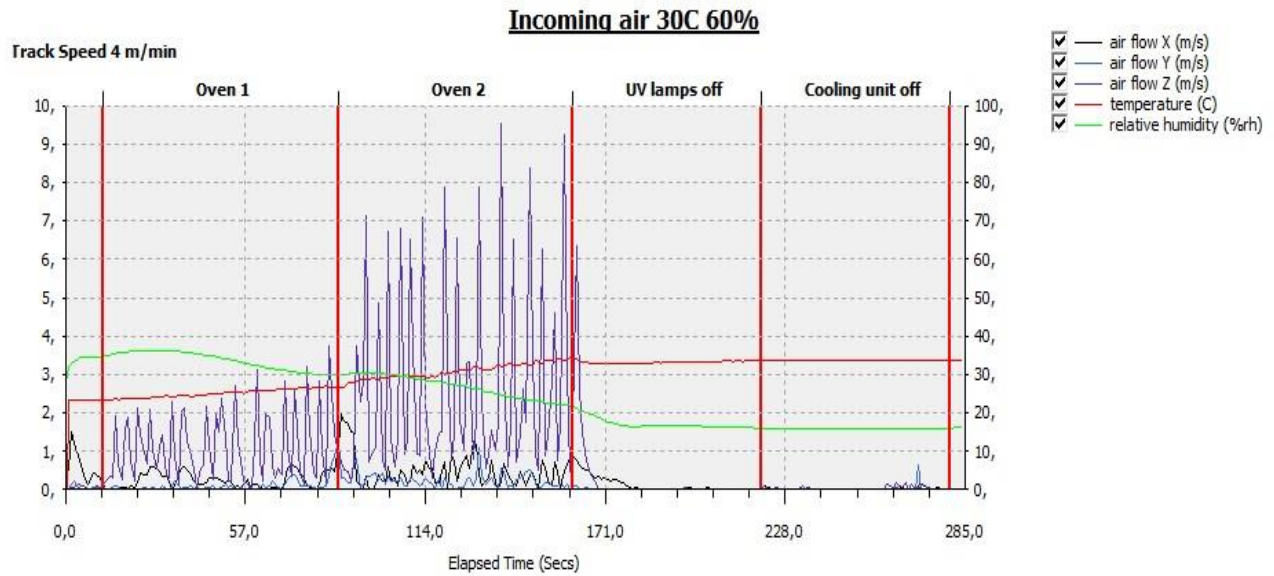
Relative humidity is described as the amount of moisture in the air in associated with the saturation point (or dew point), and its unit of measure is percent (Dresdner 1997, 144).

In the testing, the incoming air blowing in drying ovens has three different relative humidity circumstances: 30%, 60% and 90%, and keep the same temperature at 30°C.

The Graph 1 and Graph 2 display the conditions inside the oven during drying process. As we can see, the differences of two relative humidity lines between two graphs indicate obviously and remain the same temperature.



GRAPH 1. The incoming air at temperature 30°C and relative humidity 30% (Centria Puulaboratorio)



GRAPH 2. The incoming air at temperature 30°C and relative humidity 60% (Centria Puulaboratorio)

4.1.3 Calculate drying or evaporation percentage

In the testing, the experiments will run with glass-based and wood-based materials to calculate the drying percent of paint film in every experimented piece. It means how much percent of water and solvent in paint 1 and paint 2 has been evaporated after the drying process.

Weight loss of test piece during the drying processes divided by Amount of sprayed paint on test piece, and then multiplied by 100, equals Drying percent of paint film.

$$\text{Drying percent of paint film} = \frac{\text{Weight loss of test piece during the drying process}}{\text{Amount of sprayed paint on test piece}} * 100$$

Based on that, we can easily calculate the average percent of drying, next make a comparison among the test to find out which paint has the most evaporation rate and compare how the drying of two paints sprayed on two wood-based materials.

4.2 Applying Design of Experiments (DOE) for test plan

After making the decision about paints, relative humidity of air movement in ovens, flash-off time and temperatures phases of oven 1/oven 2, the test plan used DOE – Taguchi Design Tool to analyze which level in each factor has strongest impact to drying of chosen paints.

4.2.1 Introduction of DOE

DOE stands for Design of Experiments, Designed Experiments or Experimental Design. A DOE can be defined as a series of runs (or tests), where make changes in purpose to the input variables at the same time to observe the change in the outputs (or responses). After analyzing a process, the results will find out which process input has a considerable influence on the process output, and which target level of those inputs help to achieve a desired result output.

The benefits of DOE are to decline design costs, product materials and labor complexity; minimize late engineering design changes; improve manufacturing cost savings and quality; reduce rework and scrap. (MoreSteam. Design of Experiments (DOE).)

4.2.2 Introduction of Taguchi method

Taguchi Method or Robust Design method was designed by Dr. Genichi Taguchi, a Japanese statistician and Deming prize winner, which aim to improve engineering productivity. Taguchi Method is a type of fractional factorial experimental designs, and is an aid to perform very limited number of experimental runs. (MoreSteam. Design of Experiments (DOE).)

There are two types of projects that are usually applied and analyzed by Taguchi methods. For instant, when a product does not meet the expected performance results, or when a large amount of concepts need to be narrowed down to a few. (Pavlik 2012.)

4.2.3 Components of Experimental Design

Three aspects of the process analyzed by DOE are factors, levels and responses. The three main components of this testing will be clarified and listed based on the selected parameters and circumstances:

Factors or inputs of process can be either controllable or uncontrollable variables. In this case, factors are paint, relative humidity, temperature and flash-off time.

Levels are the settings of each factor. For example, levels of paint are paint 1 and paint 2; levels of humidity are 30, 60 and 90 %; levels of temperature include 30/45, 45/50 and 55/60 degree Celsius; and levels of flash-off time are 0, 2 and 4 minutes.

Responses or output of the experiment is the measured outcomes influenced by the factors and their respective levels from experiments manually. For example, in this test, the measured values relate to the drying percent of paint film after the forced drying process in oven using glass-based pieces.

4.2.4 Creating Taguchi Design based on this testing

By selecting Minitab program – Stat – DOE - Taguchi – Creating Taguchi Design – Mixed Levels Design is chosen for this situation. After editing the data for one factor (Paint factor) with two levels and other three factors with three levels in each, there are 18 experimental runs taken into account in total as in the table below.

TABLE 1. The numbers of runs are classified in detail of which levels are applied for each run to make the experiments

Number of runs	Paint	Humidity	Temperature	Flash-off time
1	1	30	30/45	0
2	1	30	45/50	2
3	1	30	55/60	4
4	1	60	30/45	0
5	1	60	45/50	2

(Continues)

TABLE 1. (Continues)

6	1	60	55/60	4
7	1	90	30/45	2
8	1	90	45/50	4
9	1	90	55/60	0
10	2	30	30/45	4
11	2	30	45/50	0
12	2	30	55/60	2
13	2	60	30/45	2
14	2	60	45/50	4
15	2	60	55/60	0
16	2	90	30/45	4
17	2	90	45/50	0
18	2	90	55/60	2

In each runs, there are three experiments manually and those measured values are added in three columns next to Flash-off Time column. The measured values relate to the drying percent of paint film sprayed on the surface of glass pieces, which result from the evaporation of volatiles (water and solvent) after the forced drying process in oven.

TABLE 2. The measured values from experiments manually are added next to Flash-off Time column in the Taguchi Design table

Paint	RH	Temperature	Flash-off time	Output 1	Output 2	Output 3	SNRA1	MEAN1	SNRA2	MEAN2
1	30	30/45	0	48,0	48,2	50,0	32,9160	48,7333	32,9160	48,7333
1	30	45/50	2	50,0	46,6	47,9	28,9647	48,1667	28,9647	48,1667
1	30	55/60	4	50,5	47,6	48,5	30,3481	48,8667	30,3481	48,8667
1	60	30/45	0	48,0	47,6	48,5	40,5486	48,0333	40,5486	48,0333
1	60	45/50	2	47,1	47,5	48,6	35,7705	47,7333	35,7705	47,7333
1	60	55/60	4	49,5	48,6	47,0	31,6397	48,3667	31,6397	48,3667
1	90	30/45	2	47,4	47,2	46,5	39,9584	47,0333	39,9584	47,0333
1	90	45/50	4	48,0	47,6	47,0	39,5029	47,5333	39,5029	47,5333
1	90	55/60	0	48,5	48,0	48,5	44,4767	48,3333	44,4767	48,3333
2	30	30/45	4	52,9	52,1	51,0	34,7292	52,0000	34,7292	52,0000
2	30	45/50	0	50,0	48,6	48,9	36,4824	49,1667	36,4824	49,1667
2	30	55/60	2	49,0	50,5	49,0	35,1410	49,5000	35,1410	49,5000
2	60	30/45	2	48,1	49,1	48,1	38,4739	48,4333	38,4739	48,4333
2	60	45/50	4	48,5	47,9	49,5	35,5869	48,6333	35,5869	48,6333
2	60	55/60	0	48,6	48,5	47,9	42,1214	48,3333	42,1214	48,3333
2	90	30/45	4	48,5	47,6	51,0	28,8897	49,0333	28,8897	49,0333
2	90	45/50	0	48,1	47,7	47,2	40,4821	47,6667	40,4821	47,6667
2	90	55/60	2	48,1	47,5	48,5	39,5938	48,0333	39,5938	48,0333

4.2.5 Analyzing which factors and levels are the most influenced on evaporation rate of water by Taguchi Design

In Minitab, click Stat – DOE – Taguchi – Define custom Taguchi Design, then choose four factors (Paint, Humidity, Temperature and Time).

Next, selecting Stat – DOE – Taguchi – Analyze Taguchi Design and editing information, so that it will appear graphs and table evaluating which factors and levels are the most impacted on evaporation rate.

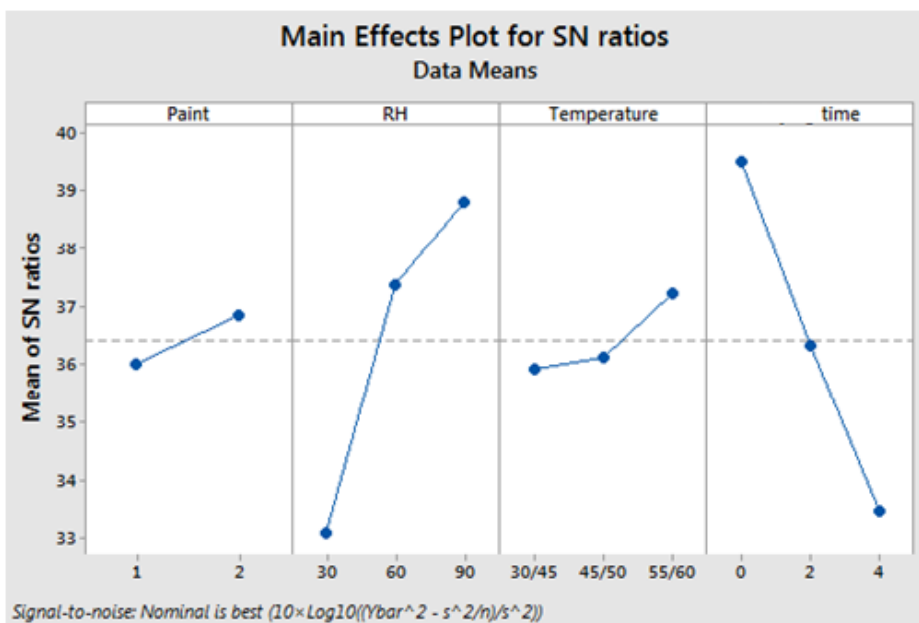
4.2.5.1 Main Effects Plots for S/N ratios

In Taguchi Design, not all factors which cause variability can be controlled. Control factors refer to those design and process parameters that can be controlled. Uncontrollable factors refer to noise factors, which cannot be controlled during production or product use; however, those can be controlled during experimentation.

Therefore, Taguchi Method examines the control factors to reduce the effect of the noise factors, and use orthogonal arrays to determine the allocation of experimental factor as well as estimate the effects of factors on the response mean and variation. (Minitab 18 Support. Taguchi designs.)

The signal to noise ratios determines the optimal parameter settings, which make the process or product robust, or resistant to variation from the noise factors. Hence, the higher values of the signal-to-noise ratio (S/N), the smaller effect of the noise factors. (Minitab 18 Support. What is the signal-to-noise ratio in a Taguchi design?)

The Graph 3 below is generated by using Analyze Taguchi Design.



GRAPH 3. Main Effects Plots for Signal to Noise ratios

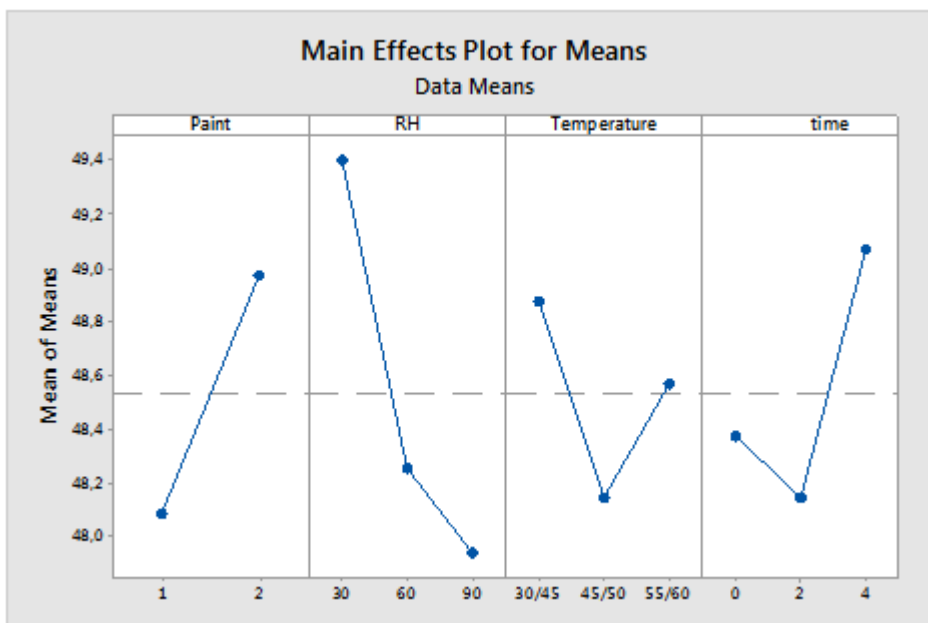
According to theory, the higher values of the signal-to-noise ratio (S/N), the less effects of the noise factors, which bring the optimum drying percent of waterborne paint products. The conclusion based on the GRAPH 3, the best method is using paint number 2 with RH 90%, temperature 55/60°C and flash-off time 0 minute.

4.2.5.2 Main Effects Plot for Means

The result got from Main Effects Plot for Means is more critical and influential for this practice because the mean brings better outcome for situation with few factor levels in each factor. In contrast, Signal to Noise ratios is suitable for a large number of factor levels.

In static Taguchi design, the mean is the average response for each combination of control factor levels. The goal, depending on the response, is to decide factor levels by either minimize or maximize the mean. (Minitab18 Support. What is the mean in a Taguchi design?)

This experimentation aims to maximize the mean to find out which control factor level in each factor has maximized mean. The graph below is generated by using Analyze Taguchi Design.



GRAPH 4. Main Effects Plot for Means

In this case, there are four control factors affect the drying of the paint. The means provides an estimation of the amount of volatiles evaporation after drying at each factor level. In order to maximize the drying result, it needs to determine which factor levels that result to largest means. Therefore, applying paint number 2 at RH 30%, temperature 30/45°C and flash-off time 4 minutes will carry out biggest mean.

4.2.5.3 Response Table for Signal to Noise Ratios and Response Table for Means

The Table 3 below is appeared simultaneously with those graphs above when selecting Analyze Taguchi Design in Minitab program.

TABLE 3. Ranked lists of four factors from the most important to the least important

Response Table for Signal to Noise Ratios
Nominal is best ($10 \times \text{Log}_{10}((\bar{Y}^2 - s^2/n)/s^2)$)

Level	Paint	RH	Temperature	time
1	36,01	33,10	35,92	39,50
2	36,83	37,36	36,13	36,32
3		38,82	37,22	33,45
Delta	0,82	5,72	1,30	6,06
Rank	4	2	3	1

Response Table for Means

Level	Paint	RH	Temperature	time
1	48,09	49,41	48,88	48,38
2	48,98	48,26	48,15	48,15
3		47,94	48,57	49,07
Delta	0,89	1,47	0,73	0,92
Rank	3	1	4	2

Based on Response Table for Signal to Noise Ratios, flash-off time is the most important factor that causes variation on drying of waterborne paints, followed by relative humidity. In contrast, RH affects the most on drying of paint products according to Response Table for Means followed by flash-off time. Temperature and Paint factors have less affection on the evaporation of volatiles during drying operation.

4.2.6 Analyzing the optimal drying percentage between two types of paints by Regression

Analysis

The goal of Regression Analysis is to identify and built a model for the relationship between a response variable and one or more predictor variables. (Minitab18 Support. Which regression and correlation analyses are included in Minitab?)

In other words, Regression Analysis aims to optimize a response or output variable, impacted by independent variables or input variables. (Periyasamy 2014)

In Minitab, click on Stat – Regression – Regression – Fit Regression Model. A Window appears, in Results, choose Expanded tables. After that, click Stat - Regression – Regression – Response Optimizer, a figure below appears and a new maximum mean can be able to be changed by moving the red line to the new black point.

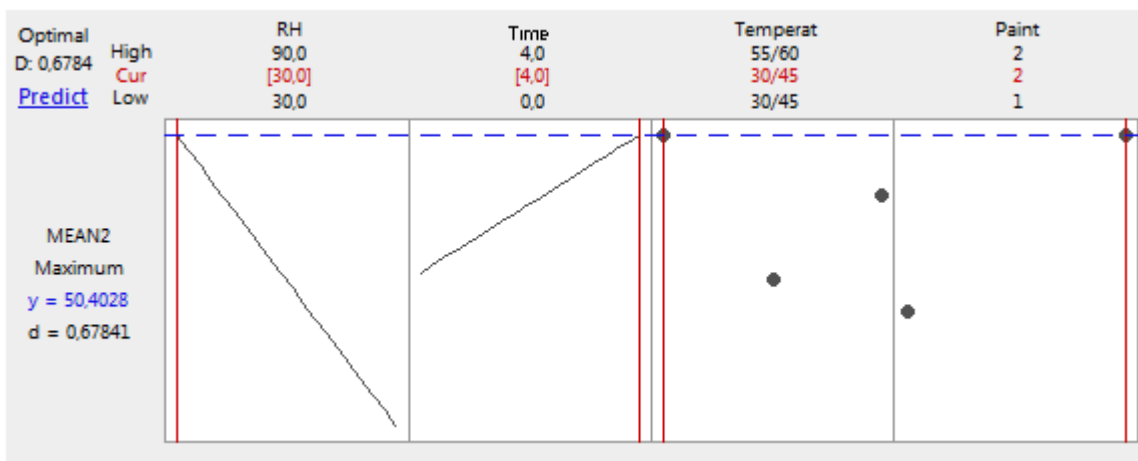


FIGURE 2. Response optimizer by using paint 2

In Figure 2, in order to optimize a response (the weight of water evaporation/drying percent) with the optimum mean equals 50.4028%, drying method should be used under conditions at RH 30%, flash-off time 4 minutes, temperature 30/45°C and paint 2.

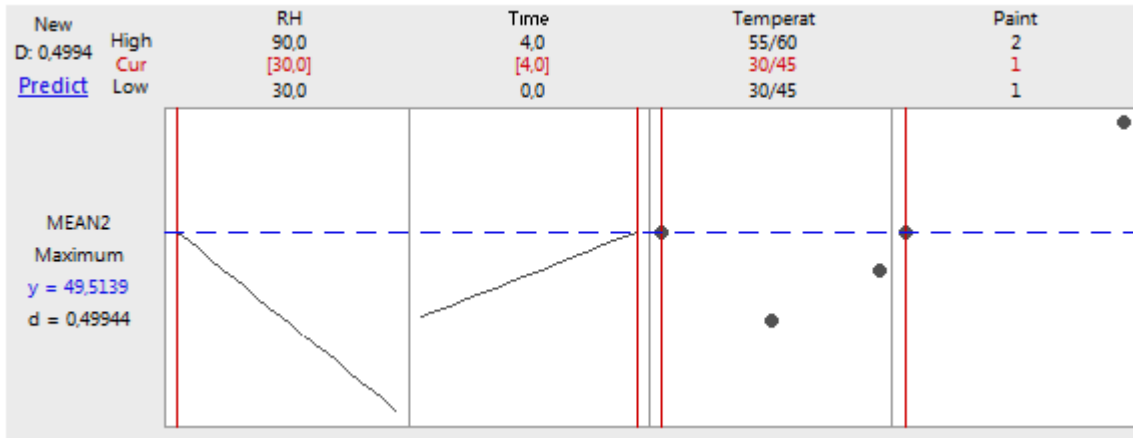


FIGURE 3. Response optimizer by using paint 1

In contrast to Figure 2, in Figure 3, drying method by using paint number 1 with the same factor levels, results to smaller mean (49.5139%) as compared to the value of paint 2 with same factor levels (50.4028%).

4.2.7 Analyzing the relationship among four factors by Factorial Design

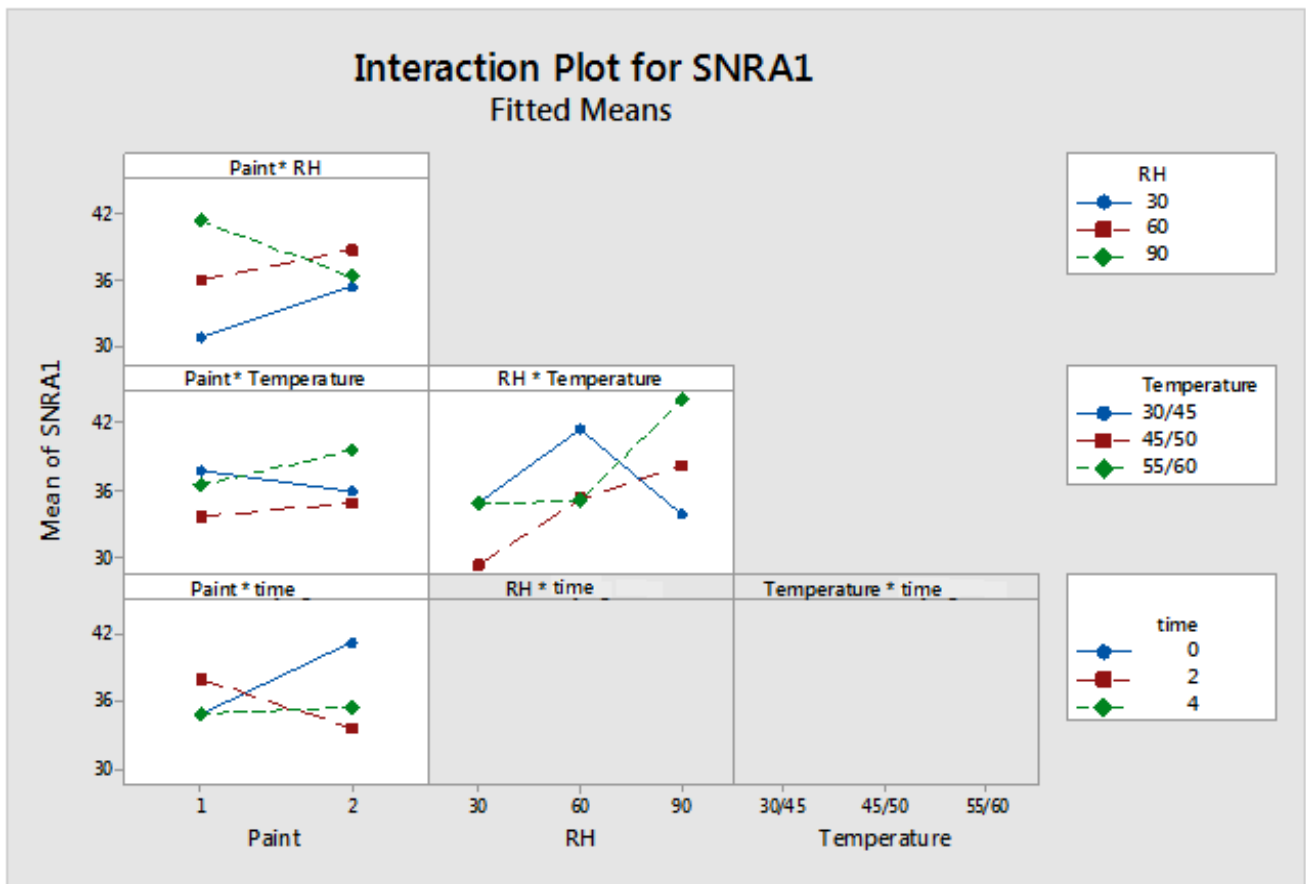
This situation uses DOE – Factorial - Analyze Factorial Design to analyze a designed experimentation. At the end, there are graphs displaying the best method to get the best drying percent for waterborne paint.

TABLE 4. The four last columns appears after editing Analyze Factorial Design in The worksheet data window

	Paint	RH	Temperature	Flash-off time	Output 1	Output 2	Output 3	SNRA1	MEAN1	SNRA2	MEAN2	StdOrder	RunOrder	Blocks	PtType
1	1	30	30/45	0	48,0	48,2	50,0	32,9160	48,7333	32,9160	48,7333	1	1	1	1
2	1	30	45/50	2	50,0	46,6	47,9	28,9647	48,1667	28,9647	48,1667	2	2	1	1
3	1	30	55/60	4	50,5	47,6	48,5	30,3481	48,8667	30,3481	48,8667	3	3	1	1
4	1	60	30/45	0	48,0	47,6	48,5	40,5486	48,0333	40,5486	48,0333	4	4	1	1
5	1	60	45/50	2	47,1	47,5	48,6	35,7705	47,7333	35,7705	47,7333	5	5	1	1
6	1	60	55/60	4	49,5	48,6	47,0	31,6397	48,3667	31,6397	48,3667	6	6	1	1
7	1	90	30/45	2	47,4	47,2	46,5	39,9584	47,0333	39,9584	47,0333	7	7	1	1
8	1	90	45/50	4	48,0	47,6	47,0	39,5029	47,5333	39,5029	47,5333	8	8	1	1
9	1	90	55/60	0	48,5	48,0	48,5	44,4767	48,3333	44,4767	48,3333	9	9	1	1
10	2	30	30/45	4	52,9	52,1	51,0	34,7292	52,0000	34,7292	52,0000	10	10	1	1
11	2	30	45/50	0	50,0	48,6	48,9	36,4824	49,1667	36,4824	49,1667	11	11	1	1
12	2	30	55/60	2	49,0	50,5	49,0	35,1410	49,5000	35,1410	49,5000	12	12	1	1
13	2	60	30/45	2	48,1	49,1	48,1	38,4739	48,4333	38,4739	48,4333	13	13	1	1
14	2	60	45/50	4	48,5	47,9	49,5	35,5869	48,6333	35,5869	48,6333	14	14	1	1
15	2	60	55/60	0	48,6	48,5	47,9	42,1214	48,3333	42,1214	48,3333	15	15	1	1
16	2	90	30/45	4	48,5	47,6	51,0	28,8897	49,0333	28,8897	49,0333	16	16	1	1
17	2	90	45/50	0	48,1	47,7	47,2	40,4821	47,6667	40,4821	47,6667	17	17	1	1
18	2	90	55/60	2	48,1	47,5	48,5	39,5938	48,0333	39,5938	48,0333	18	18	1	1

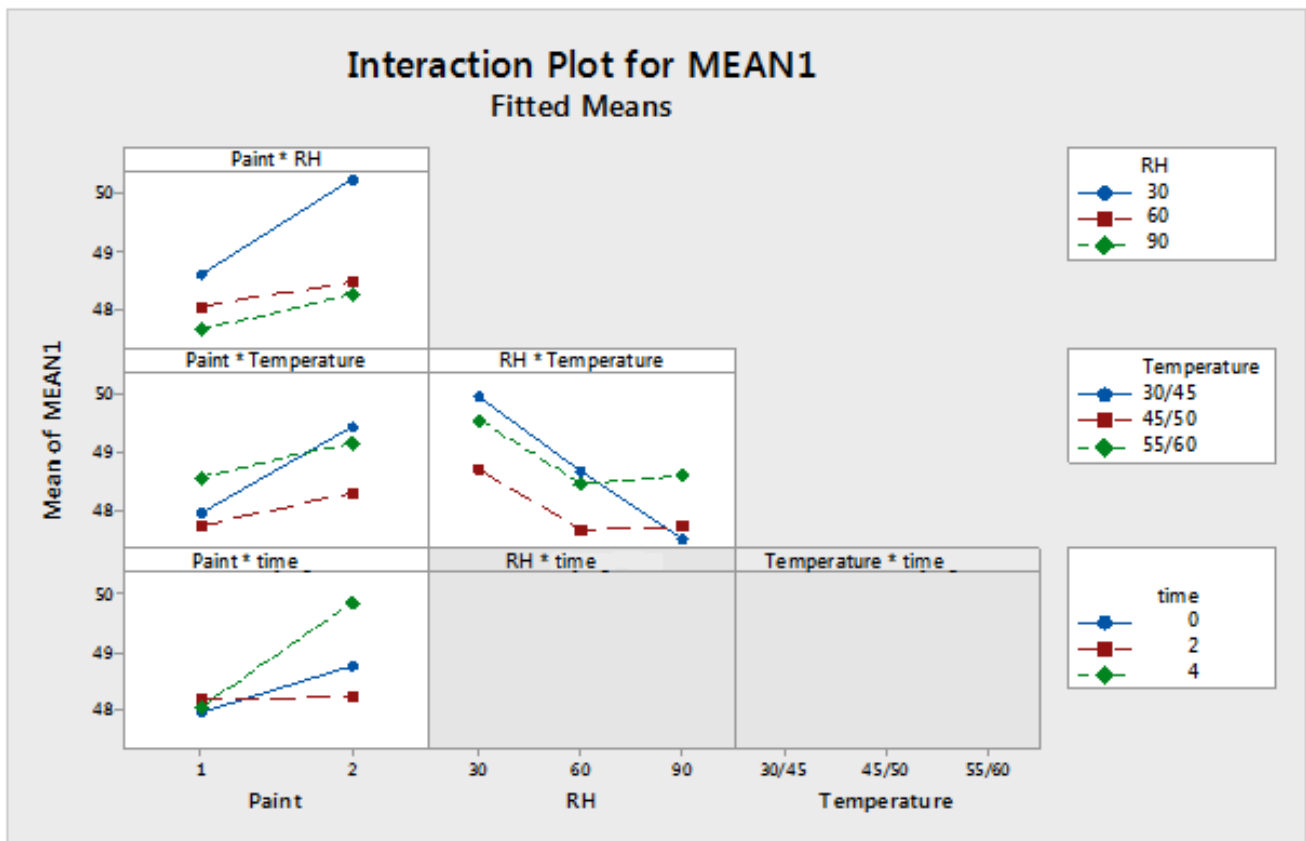
To know more about the influence of one factor depends on other factor levels by using Interaction Plot, click Stat – DOE – Factorial Plots and the graphs below present the possible interactions.

In Interaction Plot graph, if the difference in slope between the lines is greater, there is a higher degree of interaction. In case parallel lines are displayed, there is no interaction.



GRAPH 5. The Interaction Plot results based on Signal to Noise Ratios

The plots in the Graph 5 indicate a moderate interaction between Paint and RH, a small interaction between Paint and Temperature and a slightly strong interaction between Paint and flash-off Time. The lines fluctuating in the RH and Temperature graph shows no interaction between those factors.



GRAPH 6. The Interaction Plot results based on Mean

The results got from Interaction Plot for Mean is more important for this practice than Interaction Plot for Signal to Noise Ratio. Because of the Mean is suitable for this situation and carries out more accurate results, while Signal to Noise Ratio suits for practice with huge figures.

The Graph 6 indicates no interaction between Paint and RH due to parallel lines, as well as between RH and Temperature due to fluctuating lines. Small interactions are presented in between Paint and Temperature and in between Paint and Time.

To identify the best solution to achieve biggest mean, click Stat – DOE – Factorial – Response Optimizer.

TABLE 5. The Response Optimization for Means table by Factorial Design

Response Optimization: MEAN1

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
MEAN1	Maximum	47,0333	52		1	1

Solution

Solution	Paint	RH	Temperature	time	MEAN1 Fit	Composite Desirability
1	2	30	30/45	4	52	1

Multiple Response Prediction

Variable	Setting
Paint	2
RH	30
Temperature	30/45
time	4

Response	Fit	SE Fit	95% CI	95% PI
MEAN1	52,00	*	(*; *)	(*; *)

The best solution based on Response Optimization for Mean to achieve evaporation rate is using paint 2, RH 30%, flash-off time 4 minutes and temperature 30/45°C. This answer is as same as the answer given by Regression.

4.3 Confirmation test

According to the results from Regression and Factorial Design analyze, we know that drying method using paint 2 at relative humidity 30%, temperature 30/45 degree Celsius and flash-off time 4 minutes has the biggest drying percent result.

The confirmation test aims to confirm whether the result from Regression and Factorial Design analyze is same with the reality test.

The table below comprises measured values from confirmation test happening on glass pieces with paint 2 at relative humidity 30%, temperature 30/45 degree Celsius and flash-off time 4 minutes. The total drying time is approximately from 8 minutes 33 seconds to 8 minutes 37 seconds.

TABLE 6. The data is collected from three experiments in conditions based on the results from Regression and Factorial Design analyze for the confirmation test

	Weight before g	Weight after spraying g	Amount of sprayed paint g	Weight after drying g	Amount of paint after drying on piece g	Weight loss during the drying g	Drying %	Amount of sprayed paint g/m ²	Area m ²
Paint 2	120.89	121.90	1.01	121.40	0.51	0.50	49.50	101.00	0.01
Paint 2	120.08	121.08	1.00	120.59	0.51	0.49	49.00	100.00	0.01
Paint 2	121.38	122.37	0.99	121.88	0.50	0.49	49.49	99.00	0.01
Average							49.33		

Conclusion, in Regression method, the optimal mean of drying percentage equals 50.4028 % at RH 30%, flash-off time 4 minutes, temperature 30/45 degree Celsius and with paint number 2.

The drying percent result from confirmation test is 49.33%, which closes to the percentage from Regression method. Therefore, Regression method performed the correct circumstances to accomplish the best evaporation rate of water from paint number 2.

4.4 Comparison test with wood-based materials

In this test, the materials of wood will be chosen, and then, the comparison test will examine in order to make the comparison between two different paints sprayed on two different wood-based materials.

The reasons for using glass-based material before wood-based are no penetration of the paint into glass pieces and can easily examine the evaporation rate of water and solvent. While wood is common material and used in coating, the paint will absorb into wood then let it dry under selected drying methods, which bring better adhesion and properties than applying on glass.

There are two kind of materials using in this test is Wood and MDF (medium-density fiberboard). The paint sprayed, on Wood pieces and MDF pieces, is approximately 100 grams \pm 10 grams in weight.

According to Regression method, paint 1 and paint 2 will achieve the best drying outcome if both paints are cured under specific conditions (relative humidity 30%, temperature 30/45 degree Celsius and flash-off time 4 minutes).

4.4.1 Comparison of paint 1 applied on MDF and paint 2 applied on Wood at the same drying conditions

The experiments below were conducted in order to evaluate which paint applied on which wood-based material will achieve the most evaporation rate.

TABLE 7. Paint 1 applied on MDF pieces at relative humidity 30%, temperature 30/45 degree Celsius and flash-off time 4 minutes

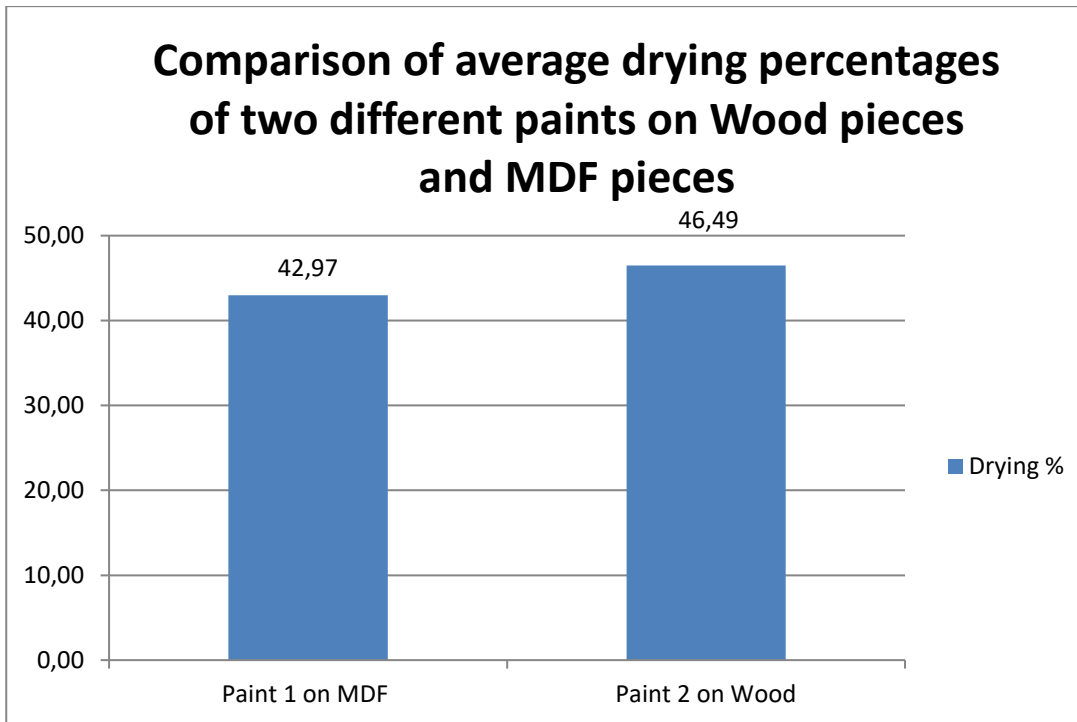
	Weight before g	Weight after spraying g	Amount of sprayed paint g	Weight after drying g	Amount of paint after drying on piece g	Weight loss during the drying g	Drying %	Amount of sprayed paint g/m ²	Area m ²
Paint 1	112.90	113.92	1.02	113.51	0.61	0.41	40.20	102.00	0.01
Paint 1	113.14	114.07	0.93	113.65	0.51	0.42	45.16	93.00	0.01
Paint 1	113.35	114.36	1.01	113.92	0.57	0.44	43.56	101.00	0.01
Average							42.97		

TABLE 8. Paint 2 applied on Wood pieces at relative humidity 30%, temperature 30/45 degree Celsius and flash-off time 4 minutes

	Weight before g	Weight after spraying g	Amount of sprayed paint g	Weight after drying g	Amount of paint after drying on piece g	Weight loss during the drying g	Drying %	Amount of sprayed paint g/m ²	Area m ²
Paint 2	121.37	122.42	1.05	121.94	0.57	0.48	45.71	105.00	0.01
Paint 2	119.75	120.84	1.09	120.35	0.60	0.49	44.95	109.00	0.01
Paint 2	118.19	119.24	1.05	118.73	0.54	0.51	48.73	105.00	0.01
Paint 2	121.46	122.53	1.07	122.03	0.57	0.50	46.73	107.00	0.01
Average							46.49		

TABLE 9. The average drying percentages collected from two prior comparison tables

	Drying %
Paint 1 on MDF	42.97
Paint 2 on Wood	46.49



GRAPH 7. The comparisons of average drying percentages of paint 2 sprayed on Wood pieces and paint1 sprayed MDF pieces

As we can see from the (GRAPH 7), paint 2 used on Wood pieces has absolutely higher drying result than paint 1 used on MDF pieces, corresponding to 46.49% and 42.97 %.

4.4.2 Comparison of paint 1 sprayed on Wood and paint 2 applied on MDF with the same drying methods

The experimental runs below were conducted in order to find out which paint applied on which wood-based material will achieve the most evaporation rate.

TABLE 10. Paint 1 applied on Wood pieces at relative humidity 30%, temperature 30/45 degree Celsius and flash-off time 4 minutes

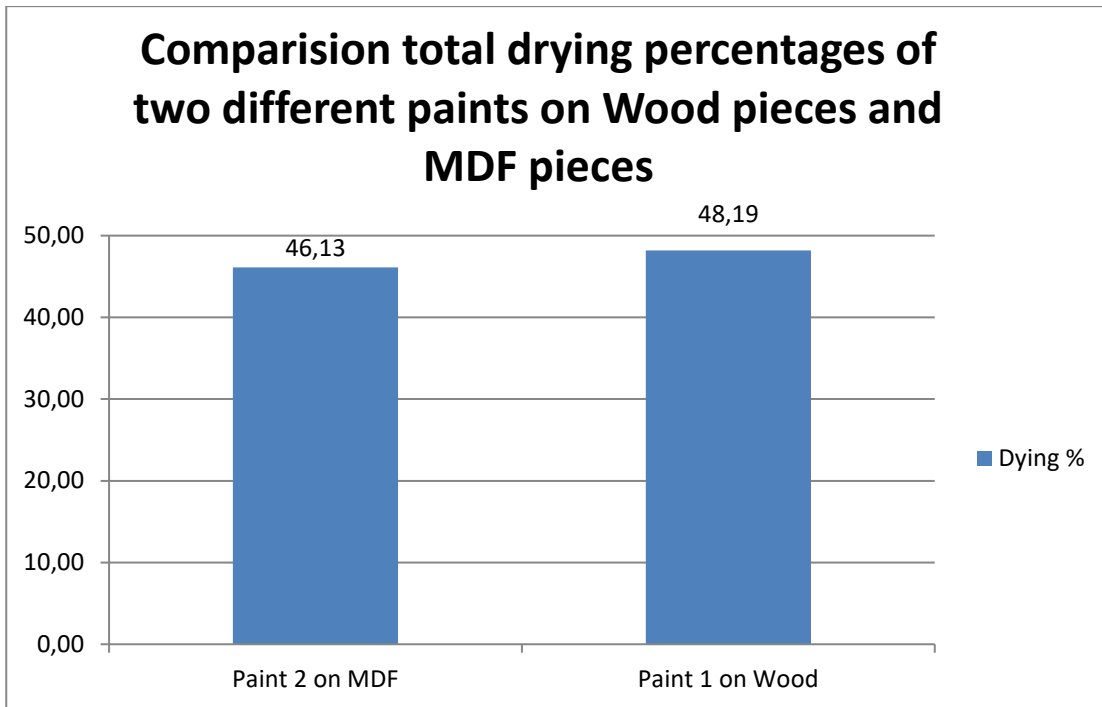
	Weight before g	Weight after spraying g	Amount of sprayed paint g	Weight after drying g	Amount of paint after drying on piece g	Weight loss during the drying g	Drying %	Amount of sprayed paint g/m ²	Area m ²
Paint 1	121.13	122.17	1.04	121.69	0.56	0.48	46.15	104	0.01
Paint 1	118.62	119.64	1.02	119.15	0.53	0.49	48.04	102	0.01
Paint 1	120.00	120.95	0.95	120.47	0.47	0.48	50.53	95	0.01
Paint 1	117.82	118.84	1.02	118.35	0.53	0.49	48.04	102	0.01
Average							48.19		

TABLE 11. Paint 2 applied on MDF pieces at relative humidity 30%, temperature 30/45 degree Celsius and flash-off time 4 minutes

	Weight before g	Weight after spraying g	Amount of sprayed paint g	Weight after drying g	Amount of paint after drying on piece g	Weight loss during the drying g	Drying %	Amount of sprayed paint g/m ²	Area m ²
Paint 2	119.84	120.94	1.10	120.43	0.59	0.51	46.36	110	0.01
Paint 2	120.67	121.71	1.04	121.24	0.57	0.47	45.19	104	0.01
Paint 2	119.89	120.94	1.05	120.45	0.56	0.49	46.67	105	0.01
Paint 2	120.79	121.87	1.08	121.37	0.58	0.50	46.30	108	0.01
Average							46.13		

TABLE 12. The average drying percentages collected from two prior comparison tables

	Drying %
Paint 1 on Wood	48.19
Paint 2 on MDF	46.13



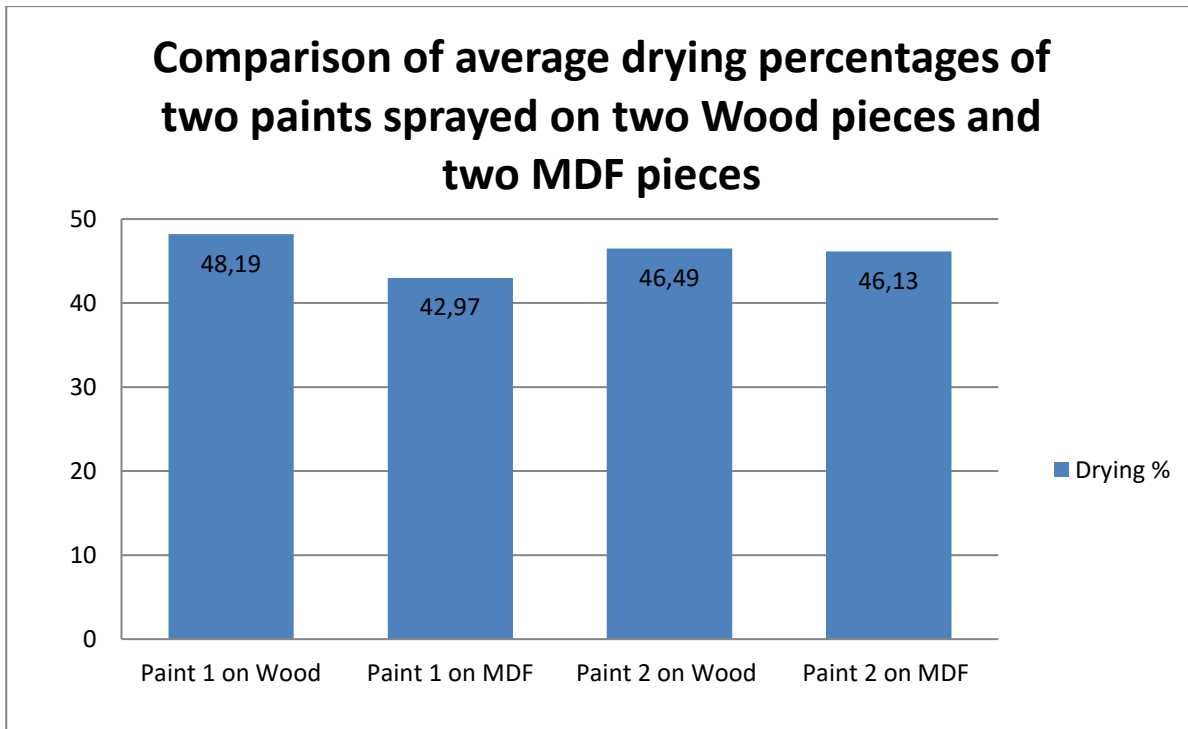
GRAPH 8. The comparison of average drying percentages of paint 1 sprayed on Wood pieces and paint 2 sprayed MDF pieces

As a result, the drying percentage of paint 1 sprayed on Wood material is higher comparing to paint 2 on MDF material, 48.19% and 46.13% respectively.

4.4.3 Results

TABLE 13. The summary table of average drying percentages collected from experiments

	Drying %
Paint 1 on Wood	48.19
Paint 2 on Wood	46.49
Paint 2 on MDF	46.13



GRAPH 9. The summary comparison of average drying percentages of two paints sprayed on two Wood pieces and on two MDF pieces

With the right paint on the right material, in this practice, paint 1 applied on Wood and paint 2 applied on MDF, have reached the best drying result (48.19% and 46.13% respectively), while paint 1 used on MDF pieces and paint 2 used on Wood pieces have so far smaller values (corresponding to 42.97% and 46.49%).

Hence, when the right paint is painted on the right material, it will lead to the most evaporation rate of volatile components (including water and solvent).

However, the result from Wood and MDF materials tests, have not achieved the same values that were analyzed by Regression method. For example, paint 1 should get 49.5139% of drying but in reality testing, it was 48.19% of drying. And paint 2 should achieve the drying with 50.4028% which is pretty much bigger value than 46.13% of drying in real experiment.

According to the Graph 9, the Wood-based pieces allow the paint, either paint 1 or paint 2, to dry faster as compared to the MDF-based pieces. The reason might come from the material of the Wood.

5 CONCLUSION AND DISCUSSION

The aim of this thesis is to verify how humidity and temperature affect on drying of waterborne paint products for case study of Centria Puulaboratorio. The experiments took place in laboratory with two different types of chosen waterborne paints sprayed on two types of materials (glass-based and wood-based). The testing experimented on glass pieces first to research at which parameters of temperature, air humidity and flash-off time carrying the most evaporation rate. After that wood-based pieces (MDF and wood) were used to confirm if those parameters would have the same results with glass testing.

The data was collected during the experiments and analyzed by Designed Experiments. In this case study, the Mean is more influent category and more accuracy figures than Signal to Noise ratios. To research which paint at which factors levels giving higher drying percent, the Main Effects Plot for Means graph was applied, as well as the Response Optimization for Means table displayed the same results.

Based on those figures of the Means from Taguchi Design, Regression and Factorial Design analyze, the confirmation test will confirm whether the analyzed results same with the reality test. The final results has been worked out and indicated that the outdoor waterborne paint suits for Wood materials and the indoor waterborne paint matches for MDF materials, which are dried under specific conditions; also showed how temperature, air humidity and flash-off time have been changed to achieve the goals.

In brief, we know that adjusting the parameters of temperature and humidity affects on how paint dries. Even though other factors do not have huge impact as temperature and air humidity, they still partially decide on the drying of the paint, such as flash-off time, ventilation system, radiation and different paint colors. Therefore, in order to achieve the goals of drying film coatings and avoid problems occurring, the parameters and circumstances should be considered to suit for the selected paint and material.

The outcome got from testing with chosen paints at specific conditions on wood-based material, should be compared with other testing in another finishing company in order to get more accuracy. Furthermore, these results might be precise for only selected paints (paint 1 and paint 2) and on Wood

and MDF pieces, if spraying by other paint or on other wood material, the result can be slightly different.

For future tests, I would like to make another laboratory test with another indoor waterborne paint and another outdoor waterborne paint, as well as keep the same parameters and circumstances to research and check whether I can get the same evaporation rate as I did in this thesis or not.

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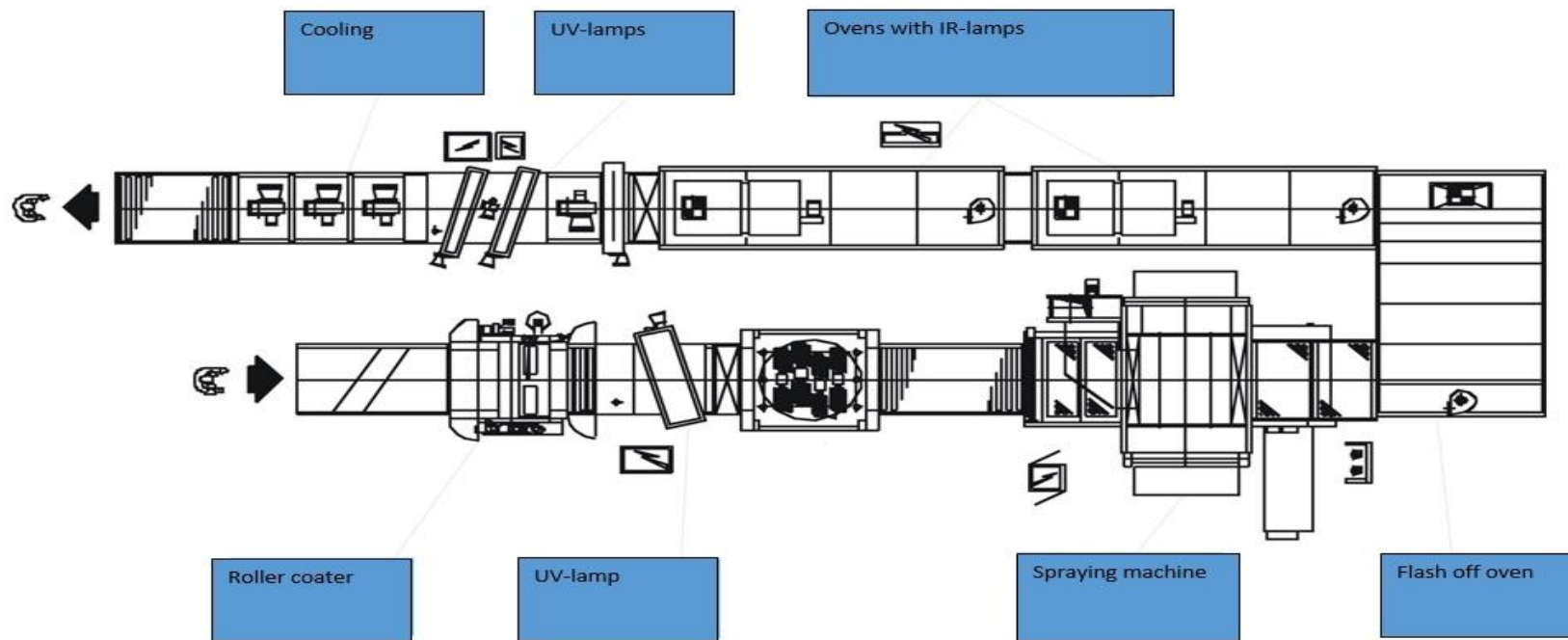
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PICTURE 1. The layout of the finishing line (Centria Puulaboratorio)