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Design or improvement of fire hose drying system through technology research of fire hose maintenance sectors and other industrial sectors

EUROPEAN PROJECT SEMESTER 2010

FINAL REPORT

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Date:	4 June 2010

Abstract

In this project, provided by Rud. Prey GmbH & Co. KG, we focussed on methods for drying fire hoses, and based on this design or improve a fire hose drying system. Nowadays, many different systems for this purpose exist on the market. Thus, our first step was to find all systems and compare several common methods in a decision matrix. Next, we researched current drying technologies in industrial sectors such as, chemical, mechanical, radioactive, conductive, and convective drying. After evaluating them with respect to fire hoses, we concentrated on the applicable ones and performed experiments, in order to find the best combination of technologies. Power and energy calculations were made to support the results. Based on these results, we were able to suggest a combination of suction, microwave and hot air forced convection what could be easily integrated in the Horizontal Process Dryer of Prey.

Declaration of Authorship

I certify that the work presented here, is to the best of my knowledge and belief, original and the result of my own investigations, except as acknowledged.

Kiel, 4 June 2010 Christopher Dollarhide

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We also wish to convey special thanks to Mr. Warias (FTZ Steinburg), Mr. Jahns (BF Kiel) and Mr. Dettmer (FTZ Zeven) for giving us a detailed view into the working process of fire hose maintenance systems and equipment.

We are also very grateful for the opportunity given us by the University of Applied Sciences Kiel, by allowing us to work on this project. We would also like to thank our home universities for their encouragement during our studies and also their work on international relations, which made it possible for us to embark on an intercultural project like this.

Finally, a big thank you goes to all of the assisting teachers, Ms. Renate Hahn and Ms. Christine Boudin from the International Office at University of Applied Sciences Kiel, and our friends and parents who supported us during this enriching process.

Confidentiality Undertaking

This report is written to the University of Applied Sciences Kiel and to Rud. Prey GmbH & Co. KG. Due to firm secrets this report is not public and the selling of copies is prohibited.

Workload

In a technical project like this it is not always possible to divide tasks because some parts are closely connected and should or might have to be done by two or more team members. The experiments and suggestions were done as a team and discussions were made to ensure the understanding of all members throughout the project.

Performing the experiments for example was a task that was shared.

Simon Sirven, Christopher Dollarhide, and Carlos Alberto Herrer concentrated on both the results and conclusions of the experiments as well as, the power calculations for different drying methods tested during the experiments.

Christopher Dollarhide and Nadine Kunze wrote the Chapter about the Decision Matrix.

Egidijus Vitkus was focused on fire hoses as well as infrared, radio frequency and flash drying technologies.

Nadine Kunze did the work on the description of Rud. Prey GmbH & Co. KG and its drying systems, the thermodynamic part, convection drying technologies, and freeze and supercritical drying.

Carlos Alberto Herrer was responsible for the conduction and mechanical drying methods.

Simon Sirven wrote about competitors and their drying systems, as well as microwave and ultraviolet drying technologies.

Christopher Dollarhide did the corrections of the report, and was responsible for the chemical drying technologies.

History of the Project

The company, Rud. Prey GmbH & Co. KG, which is accredited for assigning this project, is specialized in the production of elevators and fire hose maintenance systems. They began building automatic hanging systems to dry fire hoses for fire departments in the year 1951. This was the beginning of their production in fire hose drying equipment. At this moment they are producing a large variety of products for fire departments, not only to dry fire hoses, but also to wash, test and roll them.

In this time, technologies and customers' needs are changing every day. It is important in the business of such niche products that, as a company, you are one step ahead of the competitors. It does not matter if you are the leading company, because if you hope to remain as so, you must always be looking to future technologies. If you are too focused on the superiority of your current work, it is sometimes very easy to overlook a new technology that could benefit the company if implemented, or hurt the company if found by a competitor sooner.

For this reason, the company gave a task for EPS students. They wanted to be certain that they currently have best products, and that they did not miss something, that could cardinally change all technology for fire hose drying equipment.

The aim of the project was to design new or improve an existing fire hose drying system. One of the tasks was to conduct the market research of existing drying technologies and evaluate all pros and cons, by looking in other industrial sectors for a possible adaptation of drying technologies to dry fire hoses.

In this project, we did a lot of research about competitors and their products. We searched for information about existing drying methods in other industrial sectors and experimented with available methods, such as microwave and infrared drying methods. We made conclusions about our experiments and drying methods.

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1. Introduction of the Project

1.1. Problem Description

The fire hose is the foremost used equipment to fight fires and its sound functioning must be guaranteed at any time. To ensure this, fire hoses must be pressure tested after each use. Before they are tested, textile fire hoses are soaked and washed. To prevent the textile material from mould, the fire hoses must be dried after the pressure test.

Companies from around the world have developed many drying techniques for fire hoses. Because of the diversity among fire departments, many machines exist to meet the specific needs of each department. Factors, such as the size of the department's building, the accessibility of a drying tower, the number and type of hoses that need to be dried, the costs, the energy consumption, the ergonomics, and the amount of time available to dry the hoses, need to be considered.

1.2. Purpose

Our goal was to design or improve a fire hose drying system using a technology that would be beneficial to the drying process, if incorporated. To do this, we took into account the needs of the consumer, considering all factors related to them. Existing machines were compared and experiments with drying technologies were made, in order to ultimately provide our company with the knowledge of the best existing system or suggest improvements that are feasible with fire hoses. We compared the effectiveness of each method, as well as energy consumption and cost. Design possibilities and suggestions were made for future implementation.

1.3. Work carried out

Our project followed a logical path, progressing step by step being sure to link the tasks and obtain the necessary information to move forward.

Before we began working, we needed to understand what exactly a fire hose was and how the drying systems worked. Our research started as a broad gathering of all related information about our company, their products, their competitors and their products, and other drying techniques used by other industrial sectors. This was primarily done through the internet, until we had a meeting with our company director, Mr. Thomas Prey. After this, we gained a better understanding of how the drying systems work and were able to focus our ideas.

Thus, we performed a market research, looking at the products of our company's competitors and making analysis of the advantages and disadvantages of those products. Also, we studied thoroughly the products of Rud. Prey and the technologies used by them.

In order to analyze the drying machines better, we visited a several fire departments throughout the semester, in Steinburg, Kiel and Zeven, where we were able to observe in detail how fire hose maintenance systems work and understand the specific operation of the cleaning and drying process.

Also, we created a set of criteria to evaluate the positives and negatives of each fire hose drying system. We combined our criteria with a decision making method, in order to compare similar existing technologies. Once the matrix was finalized, it was filled in to provide a rating of each system.

The next step was to further study the types of drying systems used in other industrial sectors to see if we could apply the technology to improve or design a fire hose drying system.

Theoretically it had to begin once all information was gathered about current fire hose drying systems, but throughout the course of the project we have been making changes and filling in the matrix. Final changes to the matrix were made within the last week and it was decided to include only the comparable drying cabinets in the German market. The idea of the matrix was to suggest either, improvements to be made to a current system, or a new design of a fire hose drying system but finally it can be used this to compare only the systems presented, and with subjectivity.

Once we researched all the information about the drying technologies in other industrial sectors, we examined each technology in detail to see if application to fire hoses was possible. After this we focused on those with which we had resources to perform tests, such as microwave, infrared, and heating by conduction. Experiments were made in order to get the necessary information to suggest a new drying method. With the initial results we were able to predict a possible drying method, and finally we performed an experiment to simulate the best combination.

2. Company Descriptions

2.1. Rud. Prey GmbH & Co. KG[1]

The company, Rud. Prey GmbH & Co. KG, is a medium-sized family-owned enterprise for common and special elevators and firefighting equipment; especially fire hose maintenance devices. It was founded in 1892 by Rudolf Prey I. in Kiel and is now run by Thomas Prey, great-grandson of Rud.Prey I., in the fourth generation. The company has 7 subsidiaries in northern Germany, 11 stations in Germany, 19 distributers in 13 European countries and 115 employees. The operating range for firefighting equipment and special elevators is worldwide and for common elevators it is northern Germany.

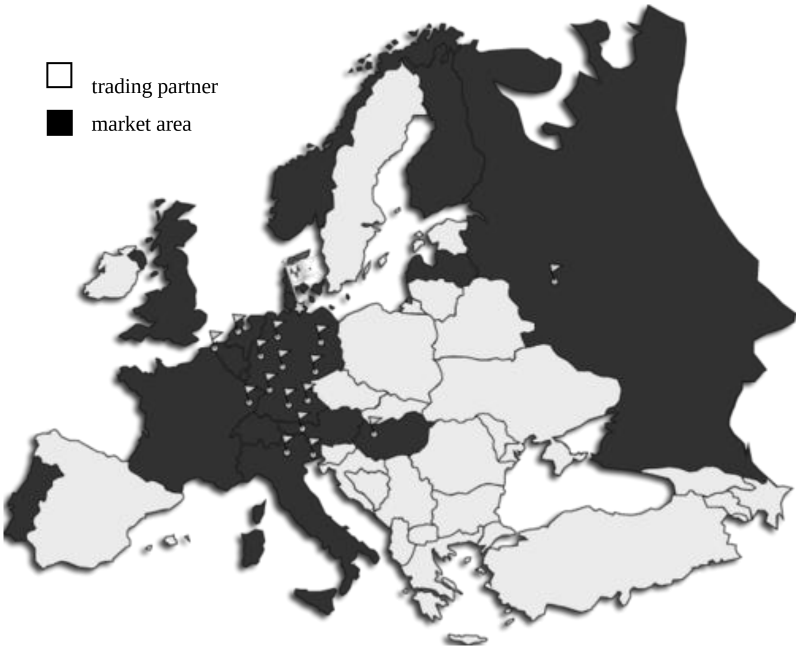


Fig. 1 Map of Prey's Working Area [1]

There are some important points which ensure the high quality standard and the good maintenance service through the whole life time of the Prey-products:

It is a family business, so all of the knowledge rests within the company. They improve their systems and service proposals in all sectors all the time. Nearly every part of their products is built in their own, relatively small, but very well-organized workshop where they use very modern and precise machines. They also have had an intern norm system since 1974, making it easy to maintain old products. Because of their knowledge, they are able to accomplish very difficult projects like the “Space Lift” at the EXPO in Hannover. The company implies outstanding quality at a good price-performance-ratio and a practical oriented and honest cooperation with their partners.

Innovations and projects specific to firefighting equipment

1951	1st worldwide automatic hanging device for fire hoses (based on an innovation of fire fighter Siegfried Dornbusch from Kiel)
1983	within the next two years: approximately 24 patents for fire hose maintenance techniques, thus Market leader in Europe for fire hose maintenance
1985	1st worldwide maintenance line for fire hoses (Verden an der Aller and Trostberg in Bavaria)

1991	design and construction of the 1st worldwide fire hose maintenance line with horizontal process-drying (Herzogenrath in Nordrhein-Westphalen)

Innovations and projects specific to elevators

1908	1st elevator of Prey is built
1910	city hall in Kiel: paternoster, tower elevator, empire elevator
1930	Marine Eherenmal Laboe: both elevators
1982	1st relieved glass elevator of Schleswig-Holstein at LEIK in Kiel
1997	a lot of innovations for data transfer for elevator relevant information, thus improves costumer's services & emergency calls (if you stuck in elevator)
1998	development of a satellite based emergency / failure coordination center, thus no persons for maintenance in area of elevator needed (RuPAS, QAS, VAS, PAS, DAS)
2000	"space lift" at the EXPO 2000, biggest (floor space: ca. 9x13m), heaviest (30t) a nd most complex elevator worldwide, transports over 200 persons per lift
Today	Hafen City Hamburg, Commercial Center CC01, 6 elevators
	CITTI Park, 3 elevators from parking garage to shopping mall
	New Schwedenkai-Terminal, 3 elevators

2.2. Competitors of Rud.Prey

In this section, we will give an overview of Prey’s competitors. The main competitors are located in Germany, but we were able to find two other companies: one in Austria and one in the United States. In addition, we have found four smaller companies in Spain, but information about these companies was not provided.

Fig. 2 Map of Prey's Competitors [2]

Ziegler (in Giengen next to Ulm)

Barth (in Fellbach next to Stuttgart)

Bockermann (in Enger near Bielefield)

Hafenrichter (in Auetal near Hannover)

Ziegler is a family-run company which was founded in 1891. The company has approximately 1000 employees today. Their business is firefighting vehicles, fire pumps and fire hoses. This hose program is supplemented by a full-range assortment of hose care equipment (including drying systems)[3].

Barth Feuerwehrtechnik was founded 110 years ago. They sell firefighting vehicles, firefighting equipment, mobile hose reels, and a range of products for hose care[4].

Bockermann Feuerwehrtechnik was founded in 1926. It produces many hose care products for washing, testing, drying and rolling the hose up[5].

Hafenrichter, the youngest company, was established in 1991. Their range of products covers all necessary products for hose maintenance (from washing to coiling up)[6].

Top Trock was founded in 1986. Its main office is in Graz, Austria. Their products are used to dry work clothing, sport gear, and fire fighting protective equipment[7].

Circul-Air Corp. is a manufacturer of cleaning, handling, drying and storage equipment for fire hose and turn out gear located in the city of Northbrook, Illinois, USA[8].

3. Fire Hoses

A fire hose is the primary piece of equipment used to deliver water or other fire retardants to the source of a fire in an attempt to extinguish it. Indoors, it can be permanently attached to a building's standpipe or plumbing system. The usual working pressure is between 8 to 20bar: bursting pressure can be up to 83bar. After each use, a fire hose is usually washed, tested by pressure, drayed, and rolled up. On occasion, fire hoses are used for crowd control. While still a common practice in many countries, it is no longer used in the U.S[9].

3.1. Pressure Testing New Hoses

Standards set by the National Fire Protection Association require that each length of new double jacket, rubber-lined attack hose must be pressure tested to 41,4bar, but most manufacturers test to 55,2bar. Subsequent to delivery, the hose is tested annually to 27,6bar by the fire department. When the fire hoses are under pressure it is easy to see leaks and to determine that the couplings are firmly attached. After testing the hose is drained, dried, rolled, and shipped to the customers[9].

3.2. Normal Pressure Testing

After each use the fire hose is pressure tested by the fire departments with 12bar [10].

3.3. Quality Control

In addition to the final pressure testing, each hose has to be checked and tested: visual inspections, ozone resistance tests, and accelerated aging tests, adhesion tests of the bond between the liner and inner jacket, determination of the amount of hose twist under pressure, dimensional checks, and many more[9].

3.4. Raw Materials

In the past, the most common natural fiber for fire hoses was cotton. Now, most modern hoses use a synthetic fiber like polyester or nylon filament. That is because the synthetic fibers have additional strength and better resistance to abrasion. The fiber yarns can be dyed in different colors. Coatings and liners include synthetic rubbers such as styrene butadiene, ethylene propylene, chloroprene, polyurethane. Different coatings and liners are for specific applications.

These compounds provide various degrees of resistance to chemicals, temperature, ozone, ultraviolet radiation, mold, mildew, and abrasion. Hard suction hoses are made of multiple layers of rubber and woven fabric encapsulating an internal helix of steel wire. Some hard suction hoses, which are flexible, use a thin polyvinyl chloride cover with a polyvinyl chloride plastic helix. Fire hose connections are made from brass or hardened aluminum. These kinds of connections are more frequently specified because they weigh less[9].

3.5. Modern Usage

New fire hoses are made of natural and synthetic fabrics and elastomers. These kinds of materials allow the fire hoses to be stored wet without rotting and to resist the damaging effects of exposure to sunlight and chemicals. Older fire hoses were also heavier than modern ones[9].

3.6. Types of Fire Hoses

There are few types of hose designed for different fire services. Discharge hoses are designed to operate under positive pressure. They include attack hoses, supply hoses, relay hoses, forestry hoses, and booster hoses. Suction hoses are designed to operate under negative pressure[9].

Attack hoses are fabric-covered and flexible. These hoses are used to bring water from the fire pumper to the nozzle. The nominal inside diameter ranges from 38mm to 76mm and the operating pressure can be up to about 27,6bar. The standard length is 15,3m[9].

Fig. 3 Attack Hose [11]

Supply and relay hoses have large-diameters, are fabric-covered, and are flexible. These hoses are used to bring water from a distant hydrant to the fire pumper or to relay water from one pumper to another over a long distance. The nominal inside diameter ranges from 89mm to 127mm. The operating pressure is between 13,8bar and 20,7bar, which is dependent on the diameters of the hoses. The standard length is 30,6m.[9]

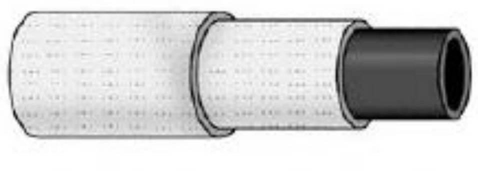


Fig. 4 Supply and Relay Hose [11]

Forestry hose is fabric-covered and flexible and used to fight fires where a lightweight hose is needed in order to maneuver it over steep or rough terrain like in grass, brush or trees. The nominal inside diameters can be 25mm or 38mm and it is designed to operate at a pressure up to 31,05bar. The standard length is 30,6m.[9]

Booster hose is a rubber-covered, thick-walled and flexible hose used to fight small fires. They have nominal inside diameters of 19mm or 25mm and an operating pressure up to 55,2bar. The standard length is 30,6m.[9]

Fig. 5 Booster Hose [11]

Suction hose. There are 2 types of suction hoses: hard suction and soft suction. Hard suction hoses are usually rubber-covered, semi-rigid, and supported with internal metal reinforcements. These hoses are used to suck water out of unpressurized sources, such as ponds and rivers, by means of a vacuum. Their nominal inside diameter is from 64 to 152mm. The standard length is 3,1m. Soft suction hose is actually a short length of fabric-covered, flexible discharge hose, and it is used to connect the fire pumper suction inlet with a pressurized hydrant.[9]

Fig. 6 Examples for Suction Hoses [11]

Size	Diameter [mm]	Length [m]	Capacity [l]
F	150	-	17,7 l/m
A	110	15/20	48/190
B	75	20/35 (35 just for Ladders)	88/155
C	42/52	15/30	42 mm: 21/42 52 mm: 32/64
D	25	5/15/30	2,5/7,4/14,7
HD	28	15	9,2

Table 1 Dimensions of Fire Hoses [12]

	Diameter [mm]	Length [m]
A	110	1,6/2,5
B	75	1,585
C	52	1,58

Table 2 Dimensions of Suction Hoses [12]

	Diameter [mm]	Length [m]	Pressure [bar]
Attack Hose	38/76	15,3	27,6
Supply and Relay Hoses	89/127	30,6	20,7 /13,8
Forestry Hose	25/38	30,6	31,05
Booster Hose	19/25	30,6	55,2
Suction Hose	64/152	3,1	-

Table 3 Working Pressure of different Fire Hoses

3.7. Cause and Prevention of Damage in Fire Hoses

Mechanical Damage

Mechanical damage is the damage suffered for actions in its manipulation or use, such as wears, scratches, damage from the warmth or cracks in the inner layer.

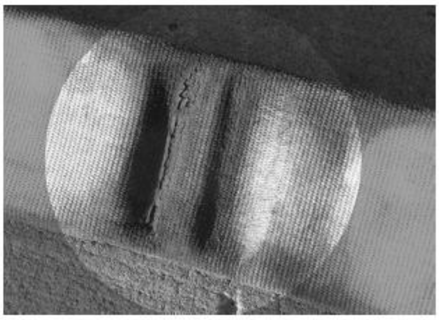


Fig. 7 Mechanical Damage of a Fire Hose [11]

Thermal Damage

The thermal damage is a result of prolonged Sun exposure. Also, it is caused by exposure of the hose to excessive heat or by direct contact with fire.

Fig. 8 Exposure of Fire Hoses to the Sun [11]

Below are some suggestions on how to avoid thermal damage:

- Protecting the hose from excessive exposure to heat, fire, or the Sun.
- Not leaving the dry hose in a warm place.
- Drying the hose with moderate temperature.
- Keeping the cover of the hose dry.
- Using the hose frequently and keeping it safe from the Sun.

Organic Damage

Mould can appear in the fabric cover of the hose when the surface of the hose is not totally dried before storage.

Fig. 9 Organic Damage [11]

Below are some suggestions on how to avoid organic damage:

Washing and drying all the hoses, specifically the fabric covered, after each fire.

Using the hoses that haven't been used in ninety days

Chemical Damage

Chemical products and steam damage the rubber on the inside of the hose [11].

4. Drying Systems

4.1. Rud. Prey Drying Systems

Hanging System (since 1951)

This system is the easiest, cheapest way to dry other than just laying the hose on the ground to dry. No energy is needed for the drying process, only for electricity to hang the hoses. The hoses dry in 2-3 days in summer and 1-1,5 weeks in winter, when no heated air is used. The hanging system can be used with the hose folded in half, or completely stretched out in half or full towers. It works with a central control of the device from the ground, but also with remote control, thus it is able to be operated by one man. It can be used in combination with all other hose maintenance devices and it is usable for all hoses due to patented adaptors for nearly every hose (Fig. 11). These adapters are also useful when selling the hanging system to other countries with different hoses [1].

Technical data

- Minimum tower height: half tower 11,5 to 12,25m, full tower: 21,5 to 23m for 20m hoses plus 0,5m for lower ventilation
- Dimensions: 0,93 x 1,56 x 0,65m (Length x Width x Height)
- Capacity from 10-1000 hoses (variable capacity and expansion possibilities)
- Electrical connection: 400V AC – 50Hz – 0,25kW – 16A
- Upstroke speed: 0,05 to 0,6m/s frequency controlled, stepless variable

Fig. 10 Prey, Automatic Hanging System, ASA [1]

Fig. 11 Different Adapters for Fire Hoses [1]

Circulating Cabinet (Fig. 12)

This drying cabinet works with a preconditioned air current: Warm dry air is passed over the wet hoses from the top and warm wet air is vented out the bottom (counter flow principle). A small opening when removing the dry hose, or putting in a wet hose, reduces the loss of heat. The Circulating Cabinet can be combined with all other hose maintenance systems [1].

Technical data

- Dimensions: 750 x 750 x 2250mm (Length x Width x Height)
- Weight: approx. 130kg
- Electrical connection: 400V / AC – 50Hz – 6,0kW
- Noise: 65dB(A) (like a conversation 1m away from you)
- Hoses/drying process: up to 7 in rotation system
- Drying performance: 8 to 12 B/C hoses per hour (depends on surface material) resp. 56 to 84 hoses per 7-hours-day

- Dries 800g water from remaining humidity in a previously dried hose
- Usable for B/C/D/(A)-hoses
- Location: freestanding, no need of walls

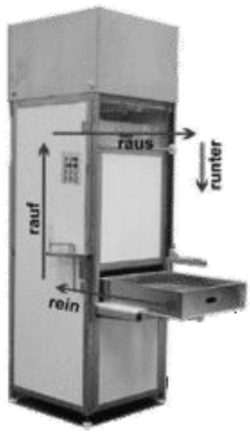


Fig. 12 Prey, Circulating Cabinet, SDT [1]

Vacuum Dryer

The Vacuum Dryer sucks the water from the surface of the hose and is used prior to the rolling of the hose on the Rotational maintenance system (Fig. 13). It is a simple, cheap way to dry hoses. As option, you can finish the drying process in the Circulating Drying Cabinet or in the tower [1].

Fig. 13 Prey, Horizontal Rotating System, RSPZ [1]

Horizontal Process Dryer (since 1991)

The Horizontal Process Dryer is a complete maintenance system with drying (Fig. 14) and it is unique on the fire hose maintenance market. The maintenance process takes place in four steps:

- Hose is washed with high pressure water (up to 90bar) [13]
- Hose is dried from the outside with warm dry pressurized air, very close to the flattened hose
- Hose is pressure tested with 12bar
- Remove the water on the inside by blowing hot dry air through it (this also dries the outside)

Technical data

- Dimensions: 23,5/24,5 x 0,85m (Length x Height)
- Hoses/drying process: up to 4
- Location: freestanding on the floor or on wall brackets
- Average energy use: 19kW
- Usable for B/C/D/(A)-hoses
- 1 man to operate
- Average performance: 12 / 16 B-hoses (depends on 2/4 hose machine) completely maintained in one hour

Fig. 14 Prey, Horizontal Process Dryer, SPS-H [1]

4.2. Competitor's Fire Hose Drying Systems

	Automatic hanging system	Hose drying cabinet	Automatic systems	Manual systems
Barth Feuerwehrtechnik	Yes	Yes	No	No
Bockermann Feuerwehrtechnik	Yes	Yes	Hose drying fan	Hose drying ring
Hafenrichter	Yes	Yes	Hose drying system AST/HST	No
Ziegler	Yes	Yes	Modular hose car unit MSP	Inclined system, Manual live ring
Top Trock	No	Yes	No	No
Circul-Air Corp.	No	Yes	No	No

Table 4 Overview of Competitor's Systems

Automatic Hanging Systems

All the German companies offer their own fully automatic hanging systems to dry fire hoses. In this kind of product, the customer needs to build a tower with a height about 25m. Here, the drying can take 2 or 3 days without energy, using only outside air and windows for ventilation. The drying time depends on the season, the material of the hoses and the tower (fire department sometimes uses a system to heat the air) [10].

These systems need only one person to operate and have a good corrosion resistance. The main difference between them is the hose adapters, which determine what kind of hoses can be dried and the run time. Other that this, they are similar in capacity, weight, functions and the power to work.

Barth offers the Bart-Lifturmatic III, with a capacity of 40-80 hoses for 5, and up to 20, rails (Fig. 15). A unique quality of this system is found in the security. There is a wear-resistant electro-mechanical security lock which is adjusted to the weight of the operator. This prevents the operator from "hitting the roof" [4].

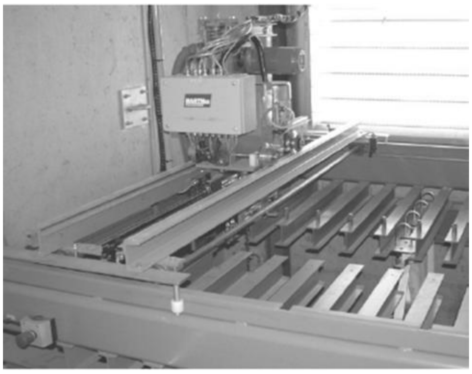


Fig. 15 Barth, Automatic Hanging System, Bart Lifurmatic III [4]

Bockermann has two automatic hanging systems: One is a ring system and the second is the more usual rectangular slotted system. The first, "Hose Hanging System LKA-V" is only compatible with B and C hoses [5].

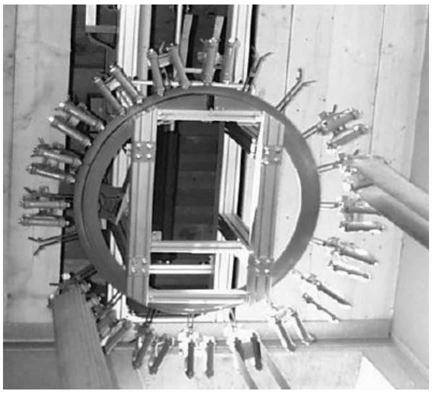


Fig. 16 Bockermann, Automatic hanging System, LKA-V [5]

Technical data

- Hanging opening at least 1,30 x 2,00m
- Capacity max. 40 hoses
- Weight of unequipped device approx. 200kg
- Weight of equipped device approx. 1000kg
- Ring diameter 1,05m
- Electrical connection 400V 16A

- Lift speed 5-22m/min. ED 60%
- Corrosion protection: aluminum/enamel

The second, SBA, is a hanging system that is always adapted to the tower. It is compatible with all types of hoses using many different adapters. The selling point of Bockermann is an ergonomical and a friendly design that provides a high level of comfort for operators.

Fig. 17 Bockermann, Different Adapters for Hose hanging System SBA

Hafenrichter also produces two hanging systems: the SAH and the SRS. Both of these products have the same characteristics.

Technical Data

- Connected load: 2,9kW
- Electrical connection: 380 V, 3 phases
- Protective equipment: residual current circuit breaker / IP 54
- Rated Power: 1,7kW
- Bearing load of the chain tension: 125kg
- Lifting speed: variable 20 – 2m/min
- Capacity: between 44 and 60 hoses.
- Dimensions: 1,25 x 2,75m (Width x Length), Width depends of tower dimensions
- Necessary cross section of the tower: 1,4 x 2,8m (Width x Length), Width depends of tower dimensions
- Weight (charged): approx. 2750kg

The difference between the SAH and the SRS are the adapters. The SAH does not use adapters. Therefore, the capacity of the SAH is lower with typically only 7 tracks, whereas, the SRS can bear 60 hoses in a classic tower.

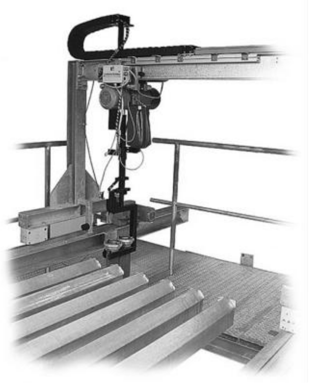


Fig. 18 Hafenrichter, Hanging system SAH without adapters [14]

Ziegler produces the following 3 hanging systems:

- Hose suspension VSV-LB
- Hose suspension VSV-C
- Semi Automatic Live ring

Both systems, the VSV-LB and VSV-C, have the same common functions. They differ by their systems and their adapters. Both can bear a maximum (depending of the tower) of 120 hoses, for all kind of hoses and couplings. Safety, speed and possibility to arrange the hoses in different order are the main selling points of Ziegler.

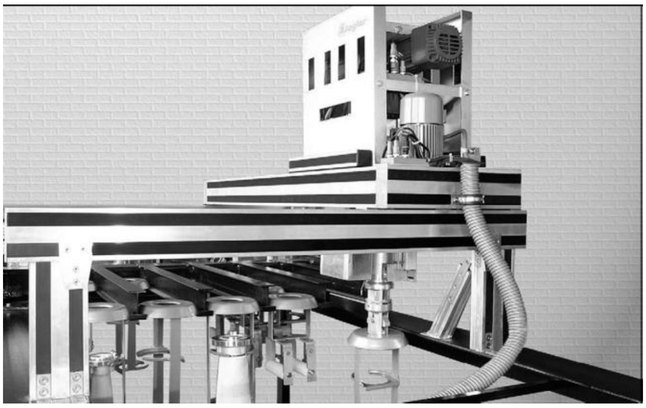


Fig. 19 Ziegler, Hose Hanging System VSV-C

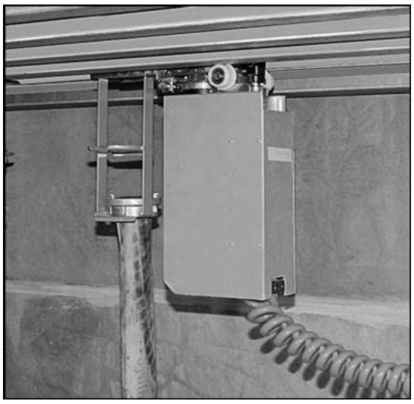


Fig. 20 Ziegler, Hose Hanging System VSV-LB

The VSV-C can be bought for 40, 80 or 120 hoses. On the contrary, the VSV-LB adapts to the size of tower, for a maximum of 120 hoses. Two different “double suspensions disk” are available:

Fig. 21 Ziegler, Adapter for VSV-C

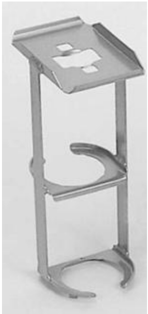


Fig. 22 Ziegler, Adapter for VSV-LB

The third hanging system of Ziegler, the semi automatic live ring, is different than the other systems because the forward movement of the chariot, for suspending and removing the hoses from the hose suspension ring, is actuated manually via a control lever with a cable pull. Other movements are automatic with the operator using the control board (from the floor of the tower) to load hoses or rotate the ring [3].

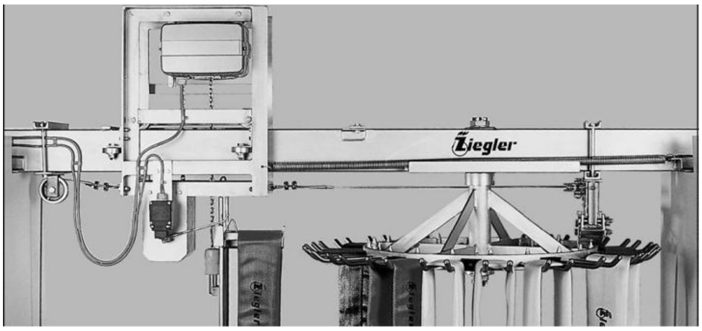


Fig. 23 Ziegler, Semi Automatic Ring for 20 Hoses, HDK 20 [3]

Ziegler sells four kinds of this product (Weight approx.200kg):

- HDK20 for 20 hoses (1,8x1,0x0,7m)
- HDK30 for 30 hoses (2,2x1,3x0,7m)
- HDK40 for 40 hoses (2,5x1,65x0,7m)
- HDK20A for 20 hoses of size A (1,9x1,1x0,7m)

Drying Cabinet

All the competitors of Prey make a drying cabinet, which is the second most common drying system in fire departments after the use of air. It too is a basic system because it is composed of a cabinet, a heater, shelves for the hoses, and often a fan to circulate the heat. With many of these dryers, it is possible to use it for clothes or as a room heater with the doors open as well. Also, it is possible to add fixed rollers to make the system more mobile.

The **Barth** cabinet is distinguished by the hose carrying basket, which simplifies the load and the storage of hoses (Fig. 25). In addition, it's possible to put a ventilation system on the cabinet to transport the humid air out of the building [4].

Fig. 24 Barth, Drying Cabinet [4]

Specifications

- For hoses up to a diameter of 110mm, 20m length
- Capacity: 8 shelves so 16 hoses max
- Drying Time: between 5 and 8 hours
- Dimensions: 1,98 x1,0 x 0,86m (H x W x D)
- Electrical Connection: 230V - 3,3kW with time switch

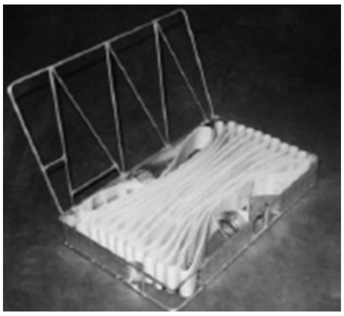


Fig. 25 Barth, Hose Carrying Basket

The **Bockermann** cabinet, contrary of Barth cabinet, has a fan and a control thermostat that monitors the temperature. Heating is done with a pressure ventilator and a radiator that is installed on the cabinet. Also, the STS 821 has a transparent acrylic glass door, which useful when checking the drying progress [5].

Fig. 26 Bockermann, Drying Cabinet, STS 821 [5]

Specifications

- Capacity: 10 shelves
- Dimensions: 2,04 x 1,25 x 1,25m (H x W x D)
- Air delivery: 45m^3/min.
- Heating power: 6kW
- Weight: approx. 250kg

The hose drying cabinet from **Ziegler** is equipped with a fan and a thermostat. The temperature of the air flow inside does not exceed 38°C [3].

Fig. 27 Ziegler, Drying Cabinet, STS 10-W [3]

Specification

- Capacity: 10 shelves
- Dimensions: 2,11 x 1,34 x 1,15m (H x W x D)
- Weight:190kg
- Drying time: 3 to 4 hours
- Electrical connection: 6kW - 400V/16A

The drying cabinet system from **Circul-Air Corp**. has capacity to dry 10 fire hoses, each one in a removable galvanized steel shelf. To dry this number of fire hoses, the machine must operate for 12hours. A timer then shuts down the dryer automatically. It uses less energy and never damages the hose.

It uses fresh air that is drawn over 1kW heater strips (thermostatically controlled) to dry the hoses. An axial fan mounted on the top moves the air. The variable dryer settings can maintain an optimum hose drying temperature. As an alternative to the warm air settings available, the ambient air setting can dry without heat. [8]

Fig. 28 Circul-Air-Corp., Drying Cabinet [8]

Finally, there is the drying cabinet from **Top Trock** GF900, which can dry between 8 and 16 fire hoses. It works with a warm-air blower operating at 230V approx. 1,3kW. It has a warranty of either 2 years or 5000 operational hours. Furthermore, it complies with the device safety regulations. The cabinet is made from zinc-plated sheet steel, powder-coated baked, with 8 extendable stainless steel grids. The rails are made from zinc and the air distribution pipes from stainless steel. It has a valve system to choose either inside or outside drying, and a lateral external junction for inside drying of the hoses. Its dimensions are: 0,95 x 1,95/2,13 x 0,6m (W x H x D) [7].

Manual Hanging System from Bockermann and Ziegler

Air is used to dry for the following systems, therefore a simple system to hang the hoses is all that is needed. These systems are manually operated, requiring the operator to load the hoses and often lift the system. It does not necessarily need to be used with tower, and is most often used in a high building or outside.

Fig. 29 Bockermann, Slewing Ring, STK 510/20 [5]

Specifications

- For B and C hoses
- Weight for 16 hoses: 11kg
- Weight for 20 hoses: 14kg

To complete the range, Bockermann also sells two electric chain hoists or pulleys, but these products are only accessories and not actual drying systems [5].

The manual live ring from Ziegler, which is basically HDK system without control board, is operated from the floor of the tower by pulling a cable to raise the hoses [3].

Fig. 30 Ziegler, Manual Live Ring, MDK 20 [3]

As with the HDK system, Ziegler offers several options with the manual system (Weight approx. 150kg):

- MDK20 for 20 hoses: 1,8 x 1,0 x 0,5m
- MDK30 for 30 hoses: 2,2 x 1,3 x 0,5m
- MDK20A for 20 hoses of size A: 2,2 x 1,3 x 0,5m

Fig. 31 Ziegler, Inclined Drying System for 20 Hoses

Ziegler also offers an ingenious inclined drying system (for 10, 16 or 20 hoses) for fire departments without tower.

Automatic Drying System from Ziegler

This system is not only a drying system but complete hose care system, where the hose is washed, tested, and dried without intervention of the operator [3]. For inside drying, they use a patented ball covered with fibers to clean and dry [15].

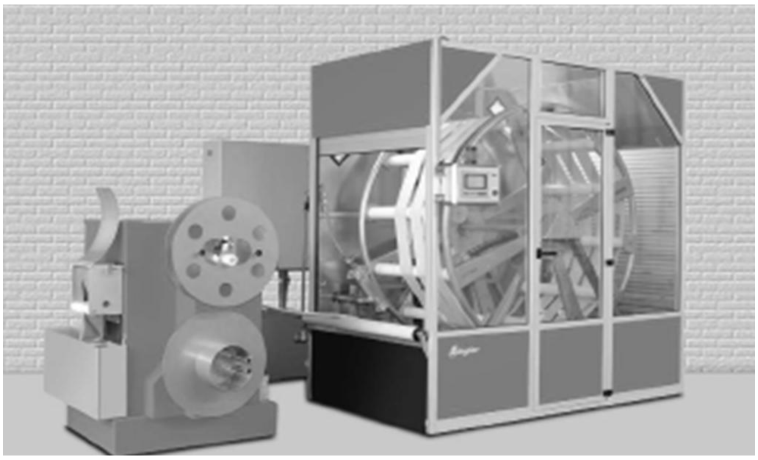


Fig. 32 Ziegler, Modular Hose Care Unit, MSP [3]

Specification

- Floor Surface: 12m²
- Capacity: 8-9 hoses per hour
- For A/B/C/D hoses

Hose Drying Fan from Bockermann

Another original system, from Bockermann, is this fan (Fig. 33). It blows warn air inside the hose, with the temperature being controlled by a thermostat. It can be used for hoses of the size B, C, or D. With a maximum heating power of 6kW, four synthetic hoses can be dried in approximately 2 hours [5].

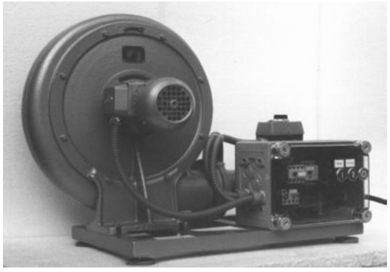


Fig. 33 Bockermann, Hose Drying Fan [5]

Three designs are available:

- One Hose Connection (TG 810):
  - Motor: 380V - 0,37kW
  - Total pressure difference: 1,6kPa
  - Flow volume: 0,08m^3/s
  - Total heating power: 1,5kW
  - Weight: approx. 38kg.
- Two Hose Connection (TG811):
  - Motor: 380V - 0,75kW
  - Total pressure difference:1,6kPa
  - Flow volume: 0,30m^3/s
  - Total heating power: 3kW
  - Weight: approx. 50kg
- Four Hose Connection (TG812):
  - Motor: 380 Volt
  - Total pressure difference: 2,0kPa
  - Flow volume: 0,66m^3/s
  - Total heating power: 6kW
  - Weight: approx. 65kg

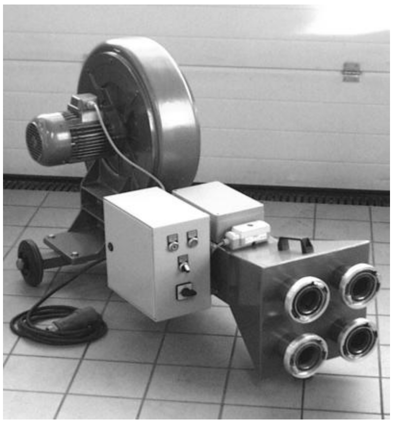


Fig. 34 Bockermann, Four Hose Drying Fan, TG 812 [5]

Automatic Drying System from Hafenrichter

Hafenrichter produces a system similar to a drying cabinet, yet more sophisticated. Two systems are available: a fully automatic AST and a semi automatic HST [6]. We do not have precise information about how hoses are dried, but it takes place with a hot air current [15].

Specifications of systems AST / HST

- Electrical Connection: 4kW - 380V
- Floor surface: approx. $4m^2$
- Dimensions AST: approx. 1,98 x 1,12 x 0,98m (H x W x D)
- Dimensions HST: approx. 1,98 x 1,95 x 0,98m (H x W x D)
- Weight: approx. 450kg
- For Hoses B/ C/(A)
- Capacity / h: approx. 10 B-hoses
- Cost per hose: approx. 0,10€

Fig. 35 Hafenrichter, Semi Automatic System, HST [6]

5. Decision Matrix

In order to determine the best solution to the project, it was necessary to develop a set of decision criteria to use as a basis for comparing the current drying processes and any designed processes in the future. In addition, this will permit us to determine which ideas in the market are interesting to inspire us. An important remark is that this matrix is for the German market, German fire departments, and German companies. The criteria are a combination of product specifications and performance, specific to the drying process and containing the essential factors. Along with this, a method was also developed to evaluate each drying process. A rating of 1-10 is given to each criteria point and, based on the weight of each criteria category, a rating for each product was determined. It provides information regarding the positive and negative aspects of each drying method. The rating can then be used to compare each method and, more importantly, assess which technology is the best. A decision matrix was created in Microsoft Excel to combine the criteria and method. Below is the criteria being used to evaluate the drying processes are described.

5.1. Compatibility

It is important to be aware of what drying methods work with what hoses. As fire-fighters use several types and sizes of hoses, knowledge of whether the hose will be compatible with the process is needed. Usual hoses in Germany are 20m-A-hoses, 20m-B-hoses, 35m-B-hoses and 15m-C-hoses. But 20m-B-hose and 15m-C-hose are excluded of Matrix because they are essential, and all systems work with these types; without this compatibility, the system will not sell.

5.2. Cost

The cost (in €) of drying will be viewed from the perspective of the consumer. Three areas will be included in the category of cost:

- Machine Cost (initial purchase)
- Operation Costs (drying 1 hose)
- Maintenance Costs (once/year)

The cost of implementing a new technology into a company is of great significance and thus, this section of the criteria is broad to offer a more complete evaluation of each product.

5.3. Design/Ergonomics

It is important to consider the functionality of the drying system. This section will examine the areas considered significant to the consumer:
- Aesthetics
- Comfort
- Ease of Operation
- Safety

The appearance of the machine (including the infrastructure required of it), the comfort of the operator, the amount of technical knowledge or training needed to operate the machine, and the safety when operating the machine are all necessary points to consider when comparing technologies. It is a very subjective area when gathering this data.

5.4. Energy

In this section, the amount of energy, required of the machine, to dry 1 hose (chosen standard) will be considered. The energy use will be specific to the process of drying and will exclude energy needed for other hose maintenance processes, which are often in combination with the drying process. This is important from an environmental and resource usage perspective. It will also be closely related to the cost of operation for each method. We used the unit, [kWh/hose],to compare.

5.5. Noise

The loudness of the drying system was difficult to evaluate for all known technologies without a personal experience, but it is important in this category to know what systems may cause hearing loss, or require ear protection. The data for noise measurements was used as comparison, where all measurements were taken with 1 meter distance from the source and given units of [dB(A)].

5.6. Space

The size, in meters, of the drying system and the space that it requires to dry the fire hoses is important for the consumer to know. In fire departments space is often limited; therefore a drying system with less space demands may likely be a better choice. A better rating will be given to a system that uses less space. We consider only floor space, because the height will never impact the choice, as all of them can enter a normal building.

5.7. Speed

The rate at which hoses can be dried will be evaluated in this category. The amount of time to dry 1 hose (in [min] for a 20m B hose) for each system will be used as grounds for comparison.

We filled in the matrix with different systems decided upon with Mr. Prey. We did not compare the hanging system, as it makes no sense. We are aware that the hanging system is the best way to dry fire hose. It is the first consideration of fire departments and the best solution if a tower is available. To fill in the matrix we used differences sources and assumptions later discussed and cited in the report.

5.8. Drying Systems Power Calculation

Formula:

$$Power = \frac{Energy}{Time}$$

Parameters:

$$P = Power\ [W]$$
$$E = Energy\ [J] or\ [Wh]$$
$$t = Time\ [s] or\ [h]$$

2 Hose Horizontal Process Dryer from Prey

The process dryer operates at a power of 9 kW to dry 2 hoses and requires a time to 10 min to dry (Appendix D).

$$P = 9\ kW$$
$$t = 10\ \mathrm{min} = 0{,}167\ h$$

*The time [t] is that to dry 2 hoses

Thus, the energy needed per hose is calculated below:

$$E = 9\ kW * \frac{0{,}167\ hr}{2\ hose} = 0{,}75\ kWh$$

Circulating Cabinet from Prey

The circulating drying cabinet operates at a power of 5,5 kW (Appendix D). It requires approximately 40 minutes to dry 7 hoses.

$$P = 5{,}5\ kW$$
$$t = 40\ min = 0{,}667\ h$$

*The time [t] is that to dry 7 hoses

Therefore, the energy needed to dry one hose is:

$$E = 5{,}5\ kW * \frac{0{,}667\ h}{7\ hose} = 0{,}52\ kWh$$

Automatic Cabinet from Hafenrichter

The AST from Hafenrichter operates with a power of 4 kW during the drying process. It is said to be able to dry 10 hoses in one hour [6].

$$P = 4\ kW$$

$$t = 1\ h$$

*The time (t) is that to dry 10 hoses

Thus, the energy needed to dry one hose is:

$$E = 4\ kW * \frac{1\ h}{10\ hose} = 0{,}4\ kWh$$

Ziegler Automatic System

We assume that the power of the vertical rotating system from Ziegler is 9,3kW the same than the rotating system from prey (Appendix D). In addition, the speed to dry is 10 B hoses per hour [3].

$$P = 9{,}3kW$$

$$t = 1h$$

*The time (t) is that to dry 10 hoses

Thus, the energy needed to dry one hose is:

$$E = 9{,}3kW * \frac{1h}{10\ hoses} = 0{,}93\ kWh$$

5.9. The Decision Matrix

Matrix is adapted to report concerning the format and everything!

5.10. Conclusion about the Matrix

As you can see in the matrix, the results are not satisfactory; many things are assumed, estimated, or subjective. The main aim of the matrix was compare our suggestion with the systems of the market, but several factors made that impossible.

First of all, this project is only considering the drying system, but most of the machines being used are not only to dry. Thus, it becomes difficult to compare the drying methods. Secondly, companies do not openly display the specific characteristics and performance of their products, which makes it difficult to precisely rate certain aspect of some systems. In addition, many systems are similar because the principles behind the technologies are copied, and therefore the interest is lessened. Finally, our level of investigation was limited and accurate data was unable to be collected to discover all prices, the comfort, and the ease of operation. The matrix, at the beginning of the project, was useful and our primary focus, but as we progressed it became clear that such a complex comparison would be impossible and the information gathered does not help us on our project.

6. Thermodynamics

There exist three ways to transform fluids to vapor: evaporation / vaporization, sublimation and overheated vapor (Fig. 36).

First, it is important to explain the difference between evaporation and vaporization. Evaporation is the changing from fluid to vapor below the boiling point, whereas vaporization takes place at this temperature. Above this temperature, every fluid vapor is produced from evaporation. The pressure increases until a certain temperature dependent maximum value, the so called saturation vapor pressure, is reached. If this pressure is reached, the vapor and the fluid are in equilibrium (this means the pressure of fluid and vapor are the same and thus, the vapor is saturated). Until this maximal vapor pressure the fluid is able to evaporate. To increase the evaporation rate, you must increase the volume or the temperature of the vapor, or remove the saturated vapor from the surface. With these methods a layer of unsaturation is kept, allowing more fluid to evaporate. If too little fluid is given at a certain temperature, vapor does not reach the saturation vapor pressure and thus, the vapor remains unsaturated [16].
For drying this implies that as long as the vapor layer stays unsaturated it is possible to dry. This means, that you need to add air current and / or heat to keep the drying process running. Without these additional methods drying takes much more time because the saturated vapor needs to diffuse to the surrounding unsaturated air.

Another possibility for transforming a fluid into vapor is sublimation which takes place by “looping” through the solid state of aggregation. The process is given in two steps. At first, the pressure and temperature are lowered just below the triple point of water (0,01°C, 0,0061bar) [17] to freeze the water. The temperature is then increased a little as the pressure remains. The ice becomes vapor without passing through the liquid phase. As a drying technology this refers to the process of freeze drying or lyophilization.

The third way for achieving vapor is by overheating. Like sublimation, you have two steps to transform fluid into vapor. First, you increase the temperature and pressure to the critical point of water (373,95°C, 220,6bar) [17]. Now, the change-over from fluid to vapor is constant, meaning that there is no separation of the liquid and the gaseous phase. Next, you slowly decrease the pressure to ambient pressure. The vapor in the mixture expands and thus, the vapor pressure decreases allowing more water to evaporate. This method is known as supercritical drying [17] [18].

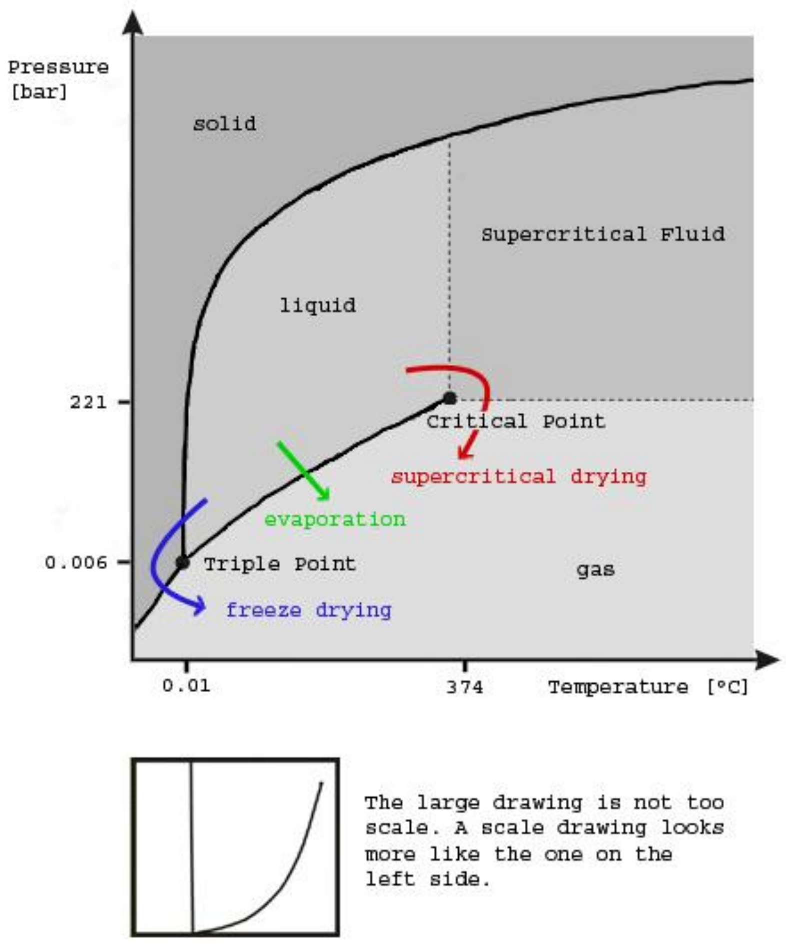


Fig. 36 Phase Diagram of Water [12]

7. Drying Methods

7.1. Mechanical Drying Technologies [19]

Before discussing mechanical drying methods, we must state that these kinds of dryers are actually not dryers, because instead of evaporating the humidity of materials, they only remove the water.

Several mechanical methods are available to reduce the amount of water in materials. We will speak about the four most common techniques which are: air knives, squeezing, suction, and centrifugation.

The technique selected for drying is influenced by the type of material, the quantity of the material that is going to be processed, and how the process is going to be used. For example, in the case of the textile industry, many delicate fabrics are damaged by being squeezed between two rollers, or damaged by spinning in a centrifuge. Thus, since the suction through vacuum slots cause less damage, it is most suitable, and often used for drying delicate fabrics. Another example is that centrifugation is normally limited to batch processes.

Air Knives

In an air knives machine the natural or heated air flows with high pressure through a very thin nozzle and blows away the surface water. A smoother, less porous surface will allow more water to be removed using this technique. The effectiveness of this method is greater when the nozzle is closer to the surface of the material being dried. However, this is not a proper drying technology, due to the fact that it only blows away the water instead of evaporating it.

Squeezing

It consists of removing the water from a wet material by applying pressure on two opposite sides of the material to dry and moving it in the opposite direction of the material.

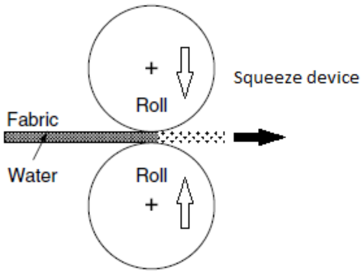


Fig. 37 Principle of Squeezing Rolls

Suction

The principle of suction involves getting the water out of the wet material by changing the pressure.

Centrifugation

Normally, centrifugation is used for separating different phases or ingredients in fluids. The process of centrifugation achieves this separation by means of the accelerated gravitational force generated by a rapid rotation.

In relation to the aim of removing water from a textile, the material is spun in order to expel the water from it. The centrifugal force during the spinning process drives the heavier substances to the outer edge of the radius. Thus, after a while you will receive separated phases [20].

There are a lot of applications of mechanical drying methods, but the most important and frequently used are:

- Textile industry
- Paper industry

Specific to the use of air knives:

- Drying a car at the end of a car wash
- Drying bottles and cans after filling or washing

Specific to the use of centrifugation:

- Solutions
- Pharmaceutical and medical Industry

Advantages

- Cheap technology because they do not require the use of air or water
- Simple mechanisms

Disadvantages

- Most of the products dried by these methods are not totally dried
- Sometimes air convection is needed to dry completely
- Possibility of deforming the product
- Too much noise

Specific disadvantage of using air knives:

- Additional need of a compressor

Currently, air knives, squeezing, and suction methods are used to dry fire hoses. Rud. Prey GmbH & Co. KG has experimented with these methods for fire hoses, but the results showed that air knives and squeezing was not as efficient as drying by suction. (Appendix D)

Due to the inconvenience that these methods do not dry totally, they are used in the pre-drying process, in order to remove most of the water from the hose before it is dried completely with another technology.

Centrifugation could theoretically work to dry fire hoses because the fire hose is made of textile fibers, and however a large force would be needed to rotate the hose. Regardless of the axis chosen to rotate the hose around, this method would be unsuccessful in a process system to dry fire hoses.

7.2. Convection

Natural Air Free Convection

The free convection of natural (i.e. unconditioned) air happens every day in our weather systems. It is the movement due to differences in temperature or pressure. As the air gets warmer, it rises and cooler air replaces it. The same happens with pressure differences. The air flows from high to low pressure areas, and the "empty" space of the higher pressure area is filled up with new air. In both cases an air circulation, called wind, is generated. This wind, however minimal, is enough to blow away the layer of water saturated air directly over the surface being dried. The evaporating rate, with respect to the partial pressure difference of water to air, increases. This means that more water can evaporate from the material in a defined time.

Applications

- Hanging clothes on a clothesline on a windless day or indoor
- Drying food outdoors on fences or similar
- Tower for fire hoses

This drying technology has been used for drying fire hoses for a very long time. It is the easiest way to dry, because you do not need additional devices to induce drying. This is the only disadvantage of free convection: You need more time to dry than by using an artificial source of heat and/or wind.

Natural Air (forced convection)

Forced convection is essentially the same principle as free convection, but due to the forced air current the saturated layer is removed faster, allowing more water can evaporate.

Applications

- Hanging clothes outdoor on a windy day
- Tower for fire hoses with fan on the ground

Shown in the examples for application, this is a common method in use to dry fire hoses. A disadvantage is the additional fan required to make this condition, which consumes energy and produces noise.

Hot Air (free convection)

The process of free convection with hot air is similar to that of free convection with natural air. Instead of air at ambient temperature, artificially heated air is used. Thus, the temperature of the material and the water increases, producing a faster rate of evaporation.

Applications

- Putting wet clothes on radiator
- Drying chamber for food (fruits, corn, herbs, etc.)
- Drying cabinet without fan for fire hoses

As you can see above, free convection with hot air is an easy and common way to dry fire hoses. It is faster than with natural air, but because of the heating, you need more energy to dry.

Hot Air (forced convection)

Hot air with forced convection is a “double improvement” of natural air with free convection. On one hand you have the additional heat to increase the temperature of the water; on the other hand you have the forced convection which blows away the surface layer thus, increasing the rate at which the water can evaporate.

Applications

- Laundry dryer
- Food and textile industry
- Circulating Cabinet of Prey
- Horizontal Process Dryer of Prey
- Drying cabinet with heater and fan

Of these examples you can see that this method is a very common way of drying; be it in industrial processes, households, or for fire hoses. An advantage of this method is that the drying time decreases enormously. But for this advantage, you have to accept the costs for energy and additional devices, such as fans and heaters.

7.3. Conduction

Drying with conduction is an indirect drying method, because the heat is transferred to the wet solid through a retaining wall. The speed of drying depends on the contact established between the wet material and hot surface, the time of contact, and the temperature of the hot surface.

In contrast with indirect drying, a larger quantity of hot air is necessary for "direct drying" in order to obtain the necessary evaporation. In indirect drying, heat is transferred by, for example, steam to the wall, which then transfers the heat to the material on the other side of the wall. All the heat transferred by the wall is used to dry the product and it does not leave the system like hot air that needs to leave through ventilation, thus making indirect drying a much more efficient process than direct drying.

Rotary Drum Dryer

Rotary dryers are horizontal cylindrical drums made of metal outer walls on which steam or hot water flows to heat the surface. The material to be dried is put inside, and when it comes in contact with the hot walls of the drum, its temperature increases and its humidity evaporates. The material is stirred by rotating the drum. A series of rotating blades attached to a horizontal central axis are used to remove and constantly renew the surface evaporation and thus increase the drying time. Steam generated by evaporating the humidity passes through an opening in the top where is travels to a condenser [21].

Applications

- Foods
- Solutions, suspensions and pastas

Advantages

- Less expensive than convection dryers

Disadvantages

- It is applicable for a limited amount of products (small products and solutions)

This method could not work to dry fire hoses because of the shape of the machine. The rotating blades would not permit the drying of a fire hose inside the machine. Such a process would not be logical considering the size of a fire hose. It is only used to dry either solutions or small piece of food like seeds.

Shelf Dryer

A shelf dryer is a cabinet with dishes or shelves inside, made of cast iron or steel, into which either hot water or steam flows, providing the necessary heat to evaporate the water of the wet material that is resting on these shelves. Thus, the heat is conducted up through the solid metal shelves. After this, the steam generated by the drying usually goes to a condenser.

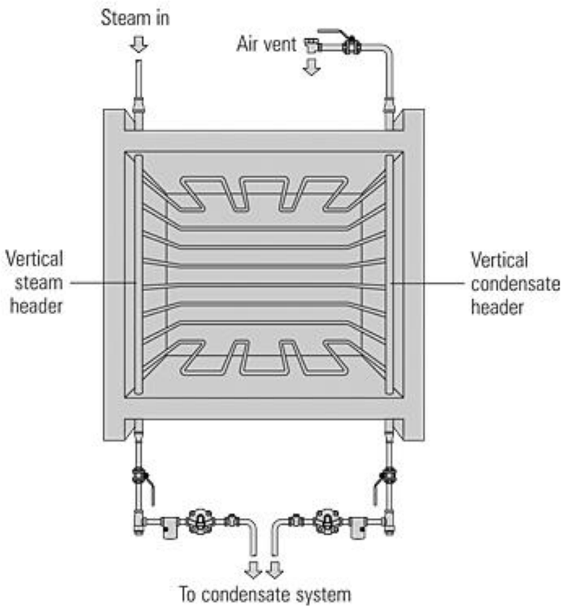


Fig. 38 Principle of a Shelf Dryer [22]

Applications

- Textile industry

- Wood
- Foods

Advantages

- Less expensive than the convection dryers

Disadvantages

- Drying is not uniform for big products

It is not possible to dry fire hoses with this technology because the hose would not be dried in a uniform manner. The area in contact with the shelf would likely be the only part which dries, and if time allowed for the heat to transfer to the entire surface of the hose, much energy would be wasted.

Hot Cylinders

This kind of indirect dryer works using the same principle: the transfer of heat to the material directly by a hot surface. It is made of a determined number of cylinders, into which either steam or warm water flows. In this case, the evaporation of water that occurs on the surface of the material to dry, escapes directly to the atmosphere without the need of a condenser in the machine.

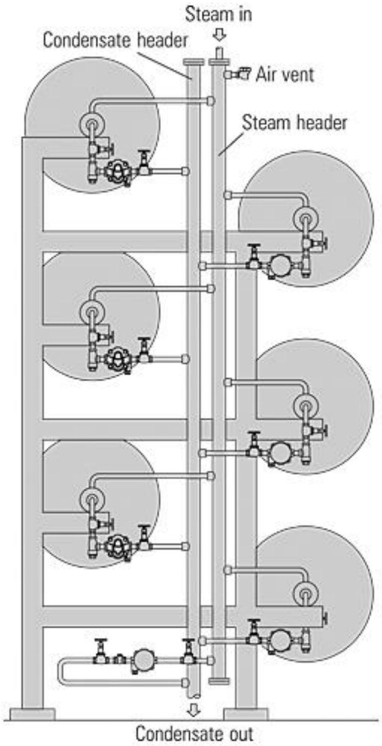


Fig. 39 Principle of heating Cylinders with Steam [22]

In main industries, like in paper or textile industries, the hot cylinders are used as rolls in the pressing process.

Applications

- Paper industry
- Textile industry

Advantages

- Less expensive than the convection dryers
- Can work in open space

Disadvantages

- Possibility to burn the material because of the direct contact

Dry by Cylinder Heated by Electric Induction

One particular and recent technology to heat the hot cylinders is to use electromagnetic induction. This technology arose because of the need to decrease the energy used to heat the cylinders with the traditional drying processes (hot water or steam). Induction heating is a method for continuous and rapid heat.

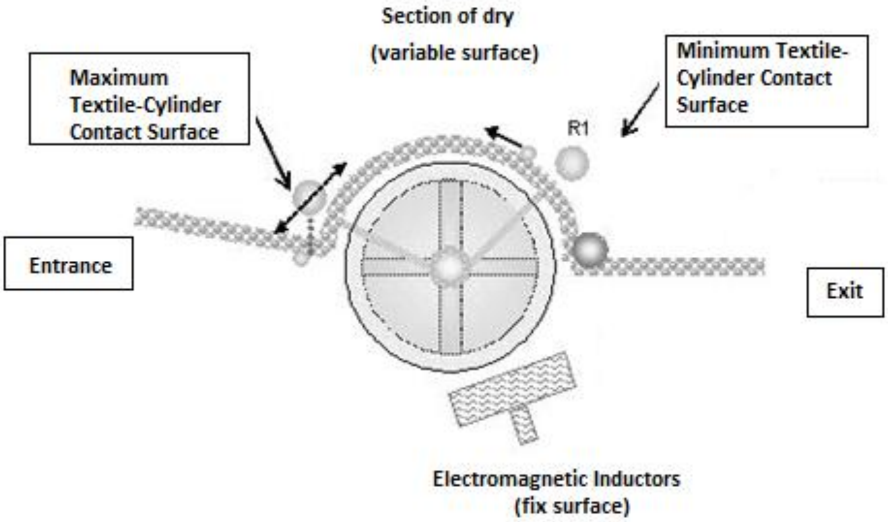


Fig. 40 Principle of Drying by Induction heated Cylinders [23]

The process involves contacting the wet fabric in motion with a rotating hollow metal cylinder whose surface is heated by electrical induction. The process uses electrical currents induced in the material to produce heat. The basic elements of an induction heating system are an AC generator, an induction coil, and the material will be heated or treated. The generator sends alternating current through the coil, generating a magnetic field. When metal piece is inside the coil, the magnetic field induces currents to this piece, generating precise amounts of clean heat and without any contact between the coil and it [23].

Applications

- The same applications than the traditional technologies to heat the cylinders

Advantages

- Less consumption of energy than the traditional technologies to heat the cylinders

Disadvantages

- The same disadvantages as the traditionally technologies to heat the cylinders

This technology could work to dry fire hoses. The size, the shape, and the materials of the products that are dried by hot cylinders are similar to those of the fire hoses. Thus, we will investigate this technology by making some experiments.

Drying under Vacuum

There is a variable of some of the drying methods that consists of drying the materials in the same way, but in a hermetic place with the vacuum inside to dry the material faster. The vacuum is made by a mechanical pump.

So far, this relatively new method works in the indirect dryers like a rotary drum dryer and a shelf dryer. Also, it can work in a microwave machine dryer. These methods, that can operate under vacuum, at pressures below atmospheric pressure, allow the product to be dried at lower temperatures, in the absence of oxygen. They are able to reduce the boiling point of the water and then quickly convert the humidity into steam.

The air does not pass through or recirculate in these machines, and therefore the steam is collected in order to be condensed elsewhere.

There is a wide range of applications for this method including, damage prevention to heat-sensitive product components, or evaporation of solvents at low temperatures. Also, foods can benefit from such careful treatment. The evaporation takes place within a few seconds without the risk of oxidation. In this way, the enzymes and proteins in the food are preserved and new protein formation is prevented. Chemical products, too, can be used in a dryer from a vacuum process and undergo the drying treatment [21].

Applications

- All heat-sensitive products
- Foods
- Chemical products

Advantages

- Can dry at lower temperature

Disadvantages

- So expensive to obtain the vacuum
- Too much difficulty to build the machine

7.4. Radiation Drying Methods

We will start with some information about radiation and finish with different drying technologies which use radiation methods.

Wave Definition

An electromagnetic wave is similar to a particle flowing without mass, as photons. They move at the speed of light inside a vacuum (c_0). A wave is characterized by the distance it covers in one oscillation: its wavelength (λ) or its frequency (f). Below is the formula which links these physical quantities.

$$\lambda = \frac{c_0}{f}$$

$$f = frequency\ [Hz]$$

$$\lambda = \text{wavelength [m]}$$

$$\mathrm{c_0} = \text{speed of light}\ \left[\frac{\mathrm{m}}{\mathrm{s}}\right] = 3 * 10^8\ \mathrm{m/s}$$

Electromagnetic Spectrum

According to the wave definition we can classify waves in different categories, as we can see below (but these limits are more or less arbitrary and depend of sources):

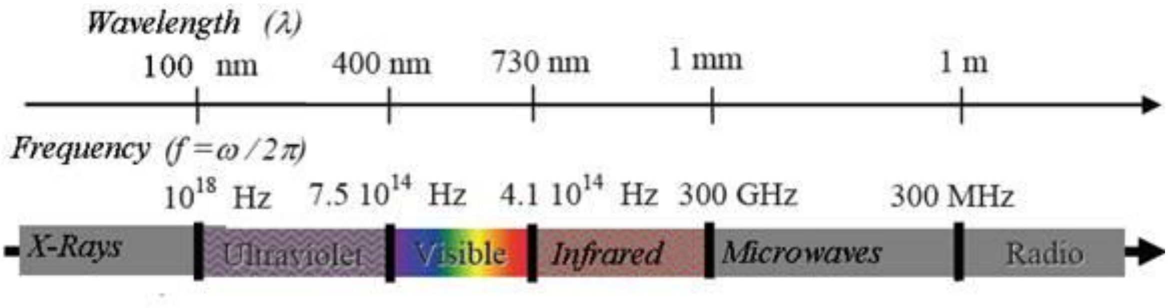


Fig. 41 Electromagnetic Spectrum [24]

Energy information

All these radiations go through air without sensible energy loss; the energy is absorbed only by matter, so losses are less important than with usual methods. In addition, the power can be focused on some parts of the receiver and the regulation is instantaneous. To finish, the energy of a wave depends of its frequency, thus the more frequency requires more energy.

Ultraviolet

In this section we will define what ultraviolet radiation is, see different applications, and conclude to see if it is possible for it to be adapted to dry fire hoses. We will develop only the characteristics of ultraviolet in reference to drying and not to other applications.

If we look at the electromagnetic spectrum we see that ultraviolet waves have wavelengths between 100nm and 400nm. Three types of ultraviolet light exist: C ultraviolet (from 100nm to 280nm), B ultraviolet (280nm to 315nm) and A ultraviolet (315nm to 400nm). The power of a wave increases when its wavelength decreases, thus C rays are the most powerful. Around us, ultraviolet rays are created by the sun and can cross the atmosphere or clouds (C ultraviolet is stopped by the ozone layer). In addition, ultraviolet follow rules of optic laws (can be reflected by a mirror for example).

About energy, ultraviolet is the most powerful radiation and it acts directly on electrons. Indeed, an ultraviolet ray can remove an electron from the external layer of electrons and thus drives a chemical reaction. It is the reason why ultraviolet light dries by polymerization.

For humans, ultraviolet rays produce the necessary, Vitamin D, when they contact the skin. However, overexposure can lead accelerated aging in the skin and sunburn. They can also be the cause of cancer (principally B ultraviolet) and they have an impact on eyes [25].

Ultraviolet Lamp

Most of ultraviolet sources are lamps (principally). The gas inside drive the principal wavelength of rays created. Thus, from the mercury, we get a majority of C ultraviolet; with halogens, we get principally A and B ultraviolet. To finish the size of such lamps is important; around 10mm to 2m is possible.

Fig. 42 UV-Lamp “Starfire” from Phoseon (Oregon, USA) [26]

Specifications

- Size: 75x20mm
- Spectrum: 395nm
- Power: 4W/cm²

The power of lamp is not enough to determine the energy received because the distance from the source drives this energy. We can find in the market products ranging from 7µW/cm² to 300W/cm² [27].

Drying Applications

- Printing sectors for dry ink
- Manicure to dry nail varnish

Ultraviolet drying systems present the best advantage of being cheap and particularly efficient for products sensible to polymerization [28].

We cannot envision a method to dry a fire hose with ultraviolet radiation because of the principle of this drying method.

Infrared

Infrared radiation refers to wavelengths between 1nm to 730nm. All warm matter (temperature higher to 0°K) emits an amount infrared radiation (principle of infrared cameras) which is a carrier of calorific energy. Thus, infrared has no influence to the human body. On the matter, infrared radiation has less energy than ultraviolet so it creates an electronic agitation around the atom, which in turn, creates heat. We distinguish between three kinds of infrared radiation: short-wavelength (from 0,73 µm to 2µm), mid-wavelength (from 2µm to 4µm) and long-wavelength (from 4µm to 10mm). Short-wavelength is the most penetrating and is able to travel through transparent glass.

To create infrared radiation, we use a heater source where the temperature is changed in order to change the wavelength of the radiation. This simple method of creating infrared radiation is at the origin of the number of different technologies, and therefore with industrial application, a long case study must be performed. We are presenting an overview of each of them. Two different transmitters are used: electric transmitters and gas transmitters [29] .

Electric Transmitter

This kind of transmitter works by the Joule effect and thus, they are easy to regulate. To create short-wavelength infrared radiation we need a high temperature, therefore, lamps with tungsten filament are used to reach a temperature around 1500°C-2000°C.
To create mid-wavelength infrared radiation the temperature doesn't need to be high, but the principle remains the same. There are many ways to do this. Silica tubes with filament on the inside, used as a resistor, can reach temperature of 800°C-1200°C. Stainless-steel tubes (still with an intern resistor) can be temperatures between 700°C and 800°C. We can also find transmitters using ceramic materials.

Gas Transmitter

In this case the principle is different than electric transmission. A wall is heated by combustion and the radiation is released from the radiant surface (Fig. 43). They create mid and long-wavelengths which correspond to temperatures between 500°C and 1200°C.

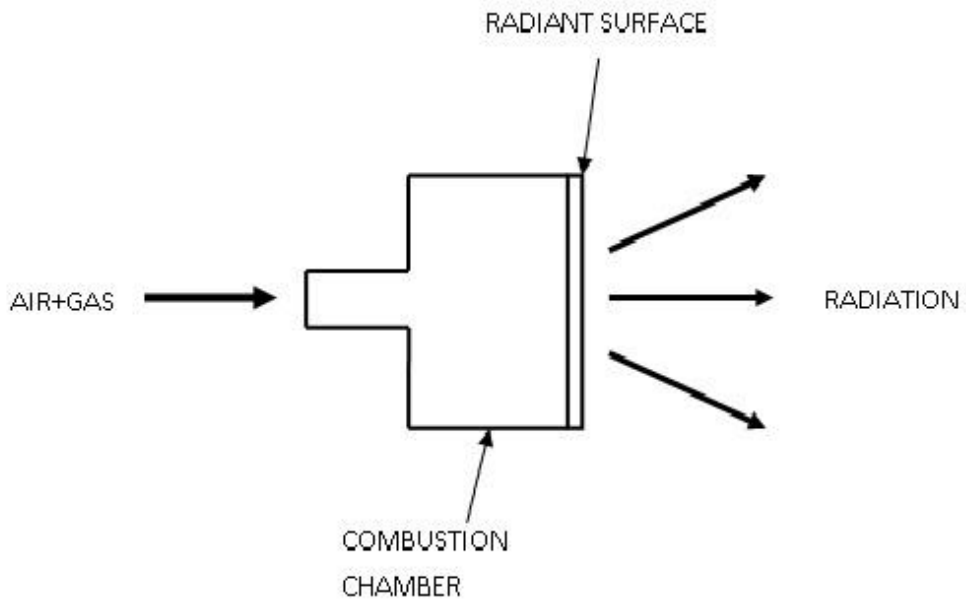


Fig. 43 Principle of a Gas Transmitter [30]

For this technology, systems differ by the burner which can be ceramic, or metallic, but the aim is to always keep the most constant possible temperature [30] [31].

Applications

Infrared systems are used in many sectors:

- Agricultural
- Food
- Glass
- Medical
- Paint
- Pharmaceutical
- Paper
- Plastics
- Rubber
- Textile

This drying method is efficient (like all the radiation methods) because of its effect directly on the matter. In addition, infrared is easy to manipulate (geometric optic laws) and is not harmful to people. On the contrary, this technology is not common and requires knowledge to

use it effectively. The heating success depends on matching the emitted wavelength with the absorption spectrum of the material to be heated and its shape. Lastly, the efficiency depends on the relative position (distance and angle) of the emitter and the receiver.
This can pose minor problems to drying fire hoses, but it could be adapted. In industry, there exist infrared radiation technologies to dry textile.

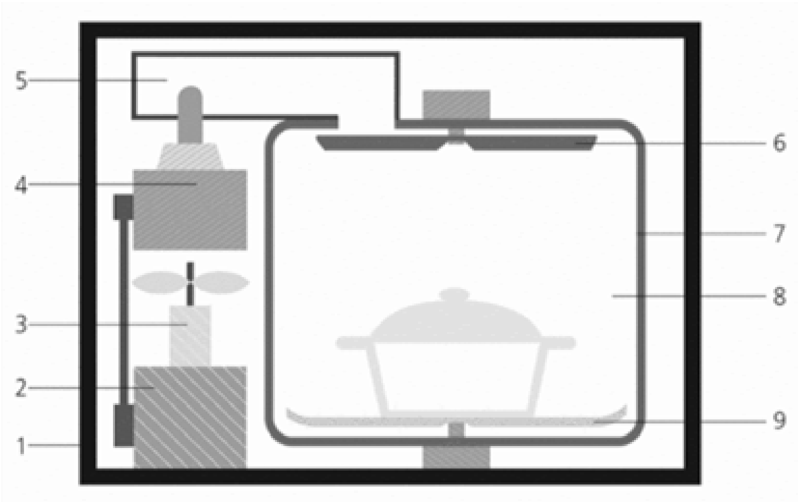
Microwaves

We are going to present the principle of Microwave technology, some applications of this method for drying, and some examples of machines used in different industries. We will develop only microwave information concerning ovens and not that concerning radar or other applications.

Microwaves range from 300GHz to 300MHz theoretically. Microwave ovens used in industry or as a household appliance operate with a frequency of 2.45GHz, which corresponds to a wavelength of approximately 10cm. Some of them use 915MHz (cf table), for big power.
When a microwave goes through matter, it is able to move molecules which are sensitive to electric fields. A molecule that is very sensitive to this perturbation is the water molecule, among others. The molecule is “rushed” by the electric field and starts to run around itself with high speed. During the movement, the molecule shocks molecules around it. In the molecular world, movement is heat and thus, microwaves are able to heat matter.
Metallic objects reflect microwaves, and in each angular or pointed corner of the metal, some gradients of electric field are created. These gradients cause electric arc [24].
For humans, microwaves are dangerous because of the elevation of the temperature on the eyes in particular.

MW Oven Technology

A power transformer changes the alternating current into high direct current to supply the magnetron. The magnetron changes the electric energy into electromagnetic energy. Created waves go through the waves guide to reach the heating chamber. Waves reach the object directly or indirectly (by walls). Below are two figures of a domestic microwave oven to show the components and operation. The same principle works in an industrial microwave oven [32].



1: Case

2: Power transformer

3: Fan for diffusion

4: Magnetron

5: Waves guide

6: Rotative reflector

7: Metallic reflector

8: Heating chamber

9: Rotative plate

Fig. 44 Components of a MW Oven [32]

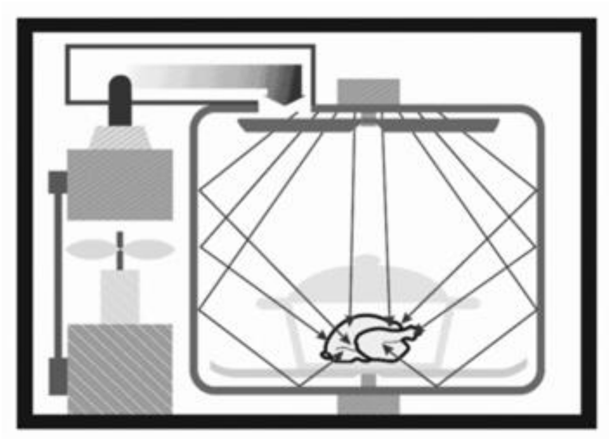


Fig. 45 Operation of a MW Oven [32]

The magnetron has not a 100% output, below characteristics of different magnetrons.

Generator	Power [kW]	Frequency [GHz]	Power Output [%]
Domestic Magnetron	0,5-1	2,45	60-70
Industrial Magnetron	5-15	2,45	60-70
Industrial Magnetron	50	0,915	60-70

Table 5 Power and Output of MW Ovens [24]

Drying Applications

Microwave drying systems (which appeared soon after the Second World War) can be found in all industrial sectors because of positive points that we will develop later:

- Food-processing industry
- Chemical
- Paper-making industry
- Pharmaceutical industry
- Textile
- Printing
- Building

Microwave drying presents advantages over conventional, thermal heating/drying methods. First of all, the process speed is increased and the energy conversion is efficient. In a microwave drying system, energy couples directly to the material being heated. It is not wasted in heating the air, the walls of the oven, conveyors, etc. Also the energy source is not hot and thus, savings in plant cooling may be realized. In addition, a good and rapid process control is possible (in a domestic oven the time to switch off is 10µs after push the button) and floor space requirements are less (it is due to a more rapid heating by microwave energy). To finish, microwave drying can be conveniently combined with other drying methods and this often occurs (such as hot air drying, freeze-drying, vacuum drying, etc.). At the same time, microwave drying presents some significant disadvantages to be considered. The drying is unequal because it depends directly on the water quantity in the product. An unequal distribution of water in the product would result in unequal heating. Also, it can be dangerous to humans, so a good maintenance is required. And to finish, the product must not contain any metal (this is important in the case of fire hoses) [33].

To conclude, the method of microwave drying can be interesting to dry hoses and is an avenue of research for the future.

Radiofrequency

Radio frequency radiation (RF) is a rate of oscillation in the range of 3Hz to 300GHz. Such dryers are working in a high frequency area, which is between 30-300MHz.

In a radio frequency drying system the RF generator creates an alternating electric field between negative and positive electrodes. The wet material is conveyed between these electrodes where the alternating energy causes polar molecules in the water to continuously re-orient them to face opposite poles, much like the way magnets would move in an alternating magnetic field. We find a similar principle in the microwave, but the frequency changes and the method of creating the magnetic field too.

Consequences on the human body are the same as microwaves.

Radio Frequency Dryer

A radio frequency dryer (Fig. 46) is mainly made up of a generator which, being fed with electricity, produces the RF electromagnetic field. In addition, a drying chamber (a closed cabinet for batch-wise processes or a tunnel for continuous processes) is fitted with the electrodes to deliver the RF energy to the product.

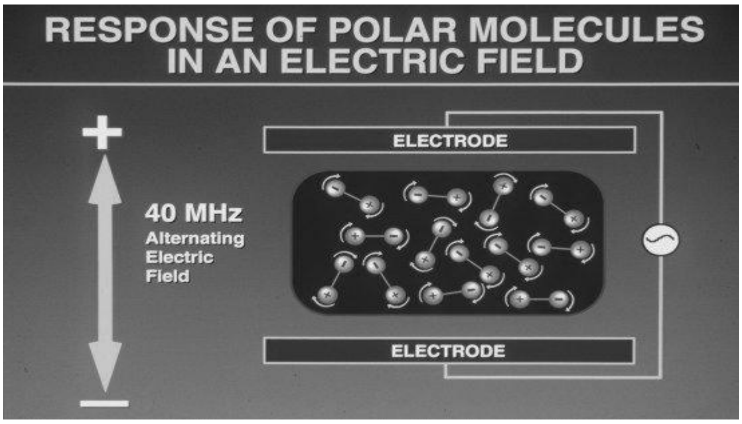


Fig. 46 Description of a Radio Frequency Drying System with a Product between the Electrodes

Applications

- Textile
- Glass
- Ceramic
- Paper

Radiofrequency presents same characteristics as microwaves, and because it directly affects the water molecule, it can be controlled precisely. At the same time, the heat is generated only where the water is and may produce irregular heating.
RF could be adapted for fire hoses drying technology, because this drying type is already adapted to dry textile. For more information how it works with fire hoses is important to do further investigations.

7.5. Chemical Drying Methods

The method of removing water from a material or substance by exposing it to a chemical is readily used in both industry and the laboratory. The initial study of chemical drying methods led to two main techniques used: solvents and drying agents (in particular inorganic salts). This section will discuss these two methods and their applicability to fire hoses.

Solvents

When referring to a solvent in the case of drying, it can be described as a fluid, usually a liquid that has the ability of dissolving other substances, without chemically changing the solution. Both organic and inorganic solvents exist. The process of solvation usually occurs when a polar solvent is used to dissolve an inorganic salt by surrounding the molecules of the solute and interacting with them [34]. This method is rarely used as a method as a means of removing water from the surface of an object. The amount of solvents that exist was far too numerous for us to consider, and thus the use of acetone, because of its miscibility with water, was the solvent of choice when discussing this method.

Application

Using solvents to dry, as needed for this project, is not an applicable science found in industrial sectors. The use of solvents can be found primarily in paints and inks, where a fast and even drying time is needed. They are also used as strong cleaners applied in the dry cleaning process. However, the drying mentioned with paints, adhesives, inks, and rubber is not referring to the removal of water from the product, but the evaporation of the solvent from the solution[35].

Conclusion

Although, there is currently no method which distinctly uses solvents as a means of removing water from the surface of a textile, it is still possible to imagine how such a method could work with fire hoses. As mentioned, acetone is miscible with water, and therefore, if after the hose was washed it was covered in a layer of acetone, it would be expected that the acetone would mix and form a solution with the water, which would lower the temperature required to remove the liquid from the surface. The advantages of solvents are numerous when used in their current application methods, but the only advantage to using a solvent when drying a fire hose would be the decreased energy needed to evaporate the solution from the surface. This also, only works with solvents that are miscible with water, like acetone. If implemented into a fire hose drying method, it would be wise to consider the greatest disadvantage of solvents and that is flammability. If the solvent is not completely removed from the fire hose before it is rolled up, it may become unsafe to use especially for fighting fires[36].

Drying Agents

Drying agents are typically insoluble, inorganic salts, which hydrate upon exposure to water. The amount of water absorbed is depended on the molecular structure of the drying agent. Many drying agents exist and each is unique in its ability to remove water. The efficiency is assessed based on intensity, capacity, and velocity. The safety of inorganic substances varies, and thus it important to know the hazards associated with the applicable one[37].

Application

Inorganic salts are primarily used in organic synthesis reactions as a means of removing water from an organic liquid. They can be used as desiccants by removing water from the air in sealed containers. Sodium and Potassium Carbonate are both used in agriculture for drying hay and alfalfa after it has been cut[38].

Conclusion

Although the typical current use of drying agents is to remove water from another liquid or gas, its ability to remove water from solids makes it a feasible method for drying fire hoses. For implementation it would be suggested to Magnesium Sulfate, as it has a high capacity for water, is safe for the environment, and has a low reactivity[39]. This salt can also be purchased as Epsom Salt at the supermarket in its heptahydrated form thus, a relatively inexpensive drying agent. Before adapting to fire hoses, it would be necessary to experiment with the absorption capability of all possible salts. However, a benefit to the use of salts is that they can be dehydrated after use, and thus reduce waste[40]. The only problem with this becomes: Is it better to use energy to dry the hose, or dry the salt after it has been used? Additional pressure may also need to be applied to remove water imbedded in the textile. Drying with this method would require a process to remove the salt, filled with water, from the surface of the hose, perhaps by a high pressured air nozzle, or suction method. This method would be strongly suggested for future experimentation, as time and resources did not allow us to work physically with this method.

7.6. Other Drying Methods

Freeze Drying

Freeze drying happens in two steps. First, the temperature must be decreased to just below the triple point of water (0,01°C, 0,0061bar) [17]. At this point the water is frozen. After this, the temperature is increased by a small amount as the pressure remains constant. The water thus, sublimates, transforming directly from ice to vapor.

Applications for Freeze Drying:

- Pharmaceutical and medical industry
- Drying of food like soups, vegetables
- Recovery of soaked paper documents

This technology requires a lot of energy as you have to nearly create a vacuum. This is an unreasonable method to dry fire hoses because of its complexity and requirements for operation.

Supercritical Drying

This drying process happens in two steps. First, the temperature and pressure are increased to reach the critical point of water (373,95°C, 220,6bar). Now, the water exists as a homogenous mixture of the liquid and gas phases (densities are equal). In the second step, the pressure is slowly decreased to ambient pressure thus, evaporating the water [17].

Applications for supercritical drying:

- Microsystem technologies
- Scientific experiments

Like freeze drying this technology is too complex for drying fire hoses and therefore not applicable. Additionally, the high temperature would cause stress and damage to the material. It is an expensive way to dry due to the requirements of high pressure and temperature.

Flash Dryers

“Flash dryers are the most economical method for drying solids that have been de-watered or inherently have low moisture content. Also known as "pneumatic dryers," they are the simplest gas suspension dryers with the smallest carbon footprint. A single operation provides mixing, heat transfer, and mass transfer to dry a solid. Residence time within the dryer is very short, usually <3s, producing almost immediate surface drying.

Feeds are:

- Moist, powdery, granular, or crystallized
- Wet solids discharged from centrifuges, rotary filters, and filter presses
- Small in particle size
- Reasonably dry, friable, and not sticky

Due to the very rapid drying process, flash dryers are not suitable for diffusion-controlled drying processes. Figure 1 shows a typical drying curve as obtained in a fixed or fluidized bed; the constant drying-rate area where surface moisture is removed is ideal for the flash-drying operation. The process is strictly controlled by the heat input without a residence-time requirement; the drying occurs "in a flash" [41].

Flash drying systems are designed based on feed and product characteristics, available or permissible heating source, and operational safety requirements. Such systems can be designed in a closed-cycle arrangement suitable for evaporation of organic solvents rather than water. The drying gas is inert (typically nitrogen), and the solvent evaporated in the flash dryer is subsequently condensed.

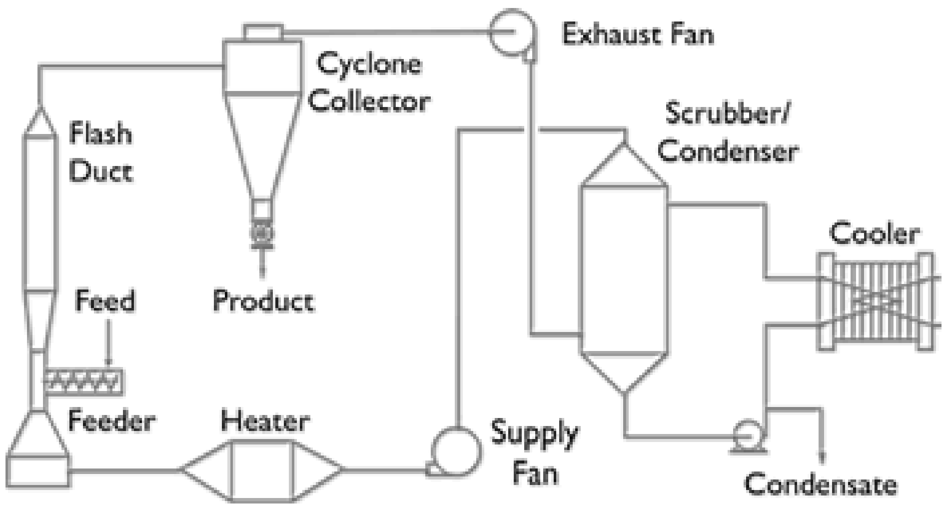


Fig. 47 Components of a Flash Dryer [41]

Advantages

- Relatively simple in operation
- Take little space
- Generally require lower capital investment than other types of dryers
- Excellent choice for processing heat-sensitive or easily oxidized feed materials
- Product inventory in the flash-drying system is very low
- Easy to change product or product grade with minimum downtime
- Control of the flash-drying process is very simple
- Control system responds very quickly to operational changes

Disadvantage

- Not applicable to dry fire hoses

This drying technology cannot be adapted to dry fire hoses. Due to the very rapid drying process, flash dryers are not suitable for diffusion-controlled drying processes. It is good to dry powder.

8. Experiments

In order to know if the methods, which we have studied, will work properly with fire hoses, we have performed several experiments using these technologies. Our first test was with a microwave oven. We then, experimented with an iron to simulate a conduction scenario of heater cylinders. Experiments were made with and without forced convection. Our final test was with an infrared lamp, and again we experimented both with and without forced convection. We also examined the effect of color on temperature using infrared heat.

The three tested technologies (microwave, conduction, and infrared), and the experiments within each technology are described below. The materials needed to test each method of drying, and the procedures of each experiment are listed.

8.1. Microwave

Experiments and Results

Materials

- Microwave Oven (1kW AEG Micromat)
- Infrared Camera (FLUKE Ti32)
- Scale (Satorius Type 1547)
- Several pieces of hose; varying in size
    - Hose ‘A’: 18cm in length
    - Hose ‘B’: 18cm in length
    - Hose ‘C’: 18cm in length
    - Hose ‘D’: 17,1cm in length
- Bucket of Water
- Holders made of plastic and glass

1st Experiment

The goal of the first experiment was to measure the temperature (T [ºC]) versus the time (t[s]) of the hose during the drying process. The procedure was as follows:

1. Weigh the dry hose and measure the length
2. Soak the hose in water for 10 min
3. Weigh the wet hose
4. Remove the excess water on the wet hose by standing the hose vertically for 2 min on each side (Fig. 48)
5. Weigh the pre-dried hose
6. Put hose with the holder in the microwave oven for an interval of 10 or 20s
7. Open the door of the microwave oven
8. Take a picture of inside and outside of the hose

We repeated this operation after each interval until the maximum temperature of 150°C was reached. We performed this experiment twice, once with the piece of hose ‘A’, held by a holder made of plastic, and the second time with the piece of hose ‘C’, held by a glass saucer.

Fig. 48 Remove of Excess of Water

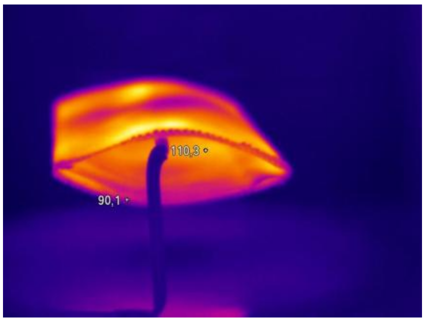


Fig. 49 Take IR Picture of the Inside

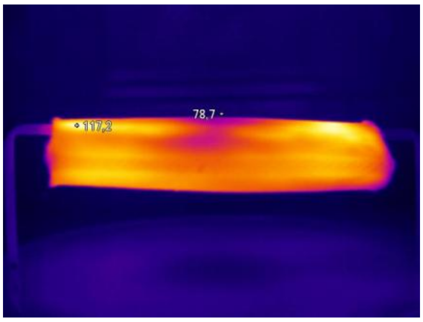


Fig. 50 Take IR Picture of the Outside

Results: Hose 'A':

t [s]	0	10	20	30	40	50	60	70	90	110	130	150	170
Energy [KWh]	0,0000	0,0028	0,0056	0,0083	0,0111	0,0139	0,0167	0,0194	0,0250	0,0306	0,0361	0,0417	0,0472
Tmin [°C]	18,4	21,11	25,94	39,61	43,39	43,83	48,11	53,50	52,33	50,28	48,83	48,17	66,78
Tmax [°C]	24,9	23,39	47,33	62,67	64,00	66,83	77,11	63,50	80,06	74,33	76,00	91,72	148,11
Taverage [°C]	21,6	22,25	36,64	51,14	53,69	55,33	57,10	58,50	59,80	62,31	62,42	69,94	107,44

Table 6 Results Hose 'A', Outside

t [s]	0	10	20	30	40	50	60	70	90	110	130	150	170
Energy [KWh]	0,0000	0,0028	0,0056	0,0083	0,0111	0,0139	0,0167	0,0194	0,0250	0,0306	0,0361	0,0417	0,0472
Tmin [°C]	18,7	20,50	32,28	36,78	48,00	42,33	50,44	47,61	53,89	51,22	67,17	52,39	79,11
Tmax [°C]	24,6	23,39	43,50	57,78	63,11	64,00	66,11	70,00	69,94	65,28	78,94	119,44	149,28
Taverage [°C]	21,7	21,94	37,89	47,28	55,56	56,37	58,28	58,81	61,92	63,80	73,06	85,92	114,19

Table 7 Results Hose 'A', Inside

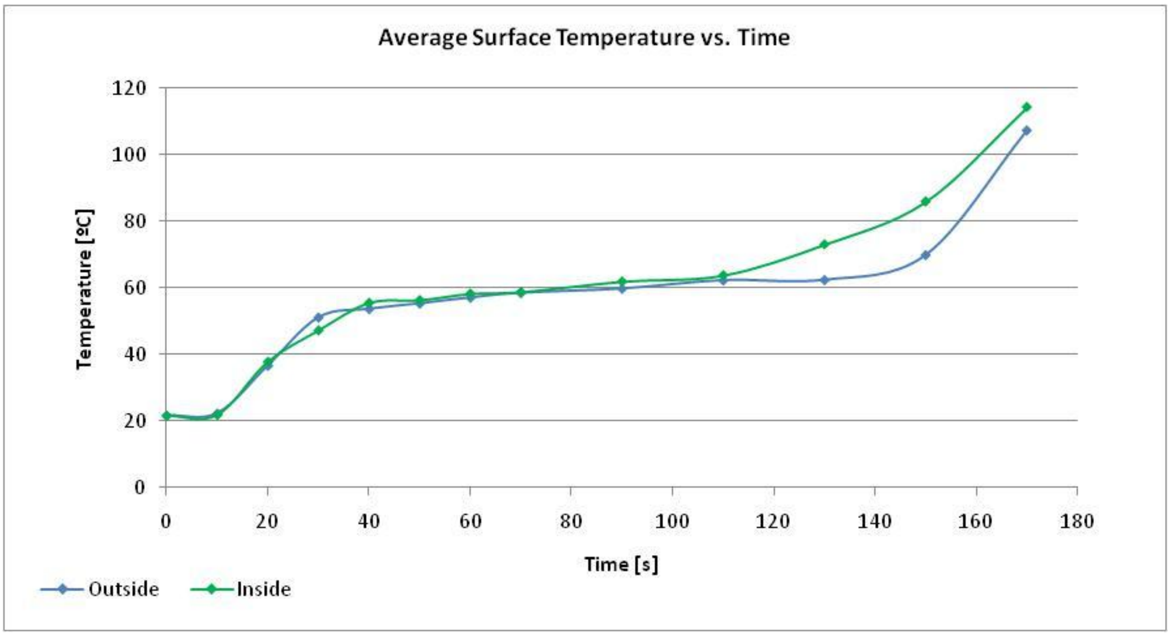


Fig. 51 Average Surface Temperature vs. Time, Outside, Inside

From Fig. 51, we can see the temperature increase in four distinct steps:

1. 0-10s: The temperature does not increase because the first ten seconds are not enough to start drying the hose due to the amount of water and its cold temperature.
2. 10-50s: The temperature increases fast because of the water molecules being heated on the surface.
3. 50-120s: The temperature remains constant as the water evaporates from the surface, which has a temperature of about 60°C.
4. 120-170s: Most of the water has evaporated and the energy heats up the surface and damages it (Fig. 52).

The temperature on the inside of the hose is almost always hotter because there is less water on the inside than on the outside of the hose. Also, the temperature during the last 50 seconds starts to increase earlier than the outside because it becomes dry sooner.

The time is proportional to the energy costs and will therefore produce a similar graph as above when the temperature is plotted against the energy. As the temperature increases, the energy consumption increases proportionally as time. This will be the case for all Temperature vs. Time plots, which can be found in Appendix A.1.

During this experiment, the holder made of plastic was deformed because of the excess heat of the microwave. This caused damage to the hose, as the hot plastic scorched the outer surface. A glass saucer was used for the remaining experiments where a holder was required.

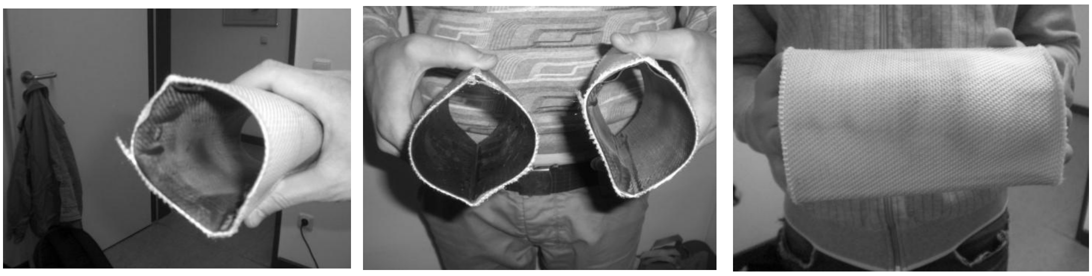


Fig. 52 Damaged Hose due to long-term Exposure of Microwaves

Results: Hose 'C'

t [s]	0	15	30	45	60	75
Energy [KWh]	0,0000	0,0042	0,0083	0,0125	0,0167	0,0208
Tmin [°C]	18,5	45,33	43,17	50,61	50,61	50,11
Tmax [°C]	24,9	71,44	70,56	67,39	69,67	64,72
Taverage [°C]	21,6	52,70	56,86	59,00	60,14	63,50

Table 8 Results Hose 'C', Outside

t [s]	0	15	30	45	60	75
Energy [KWh]	0,0000	0,0042	0,00833	0,0125	0,01667	0,02083
Tmin [°C]	18,6	43,56	51,61	51,67	54,61	64,72
Tmax [°C]	25,7	50,61	66,33	81,39	90,56	95,39
Taverage [°C]	21,6	47,08	58,97	66,53	72,58	80,06

Table 9 Results Hose 'C', Inside

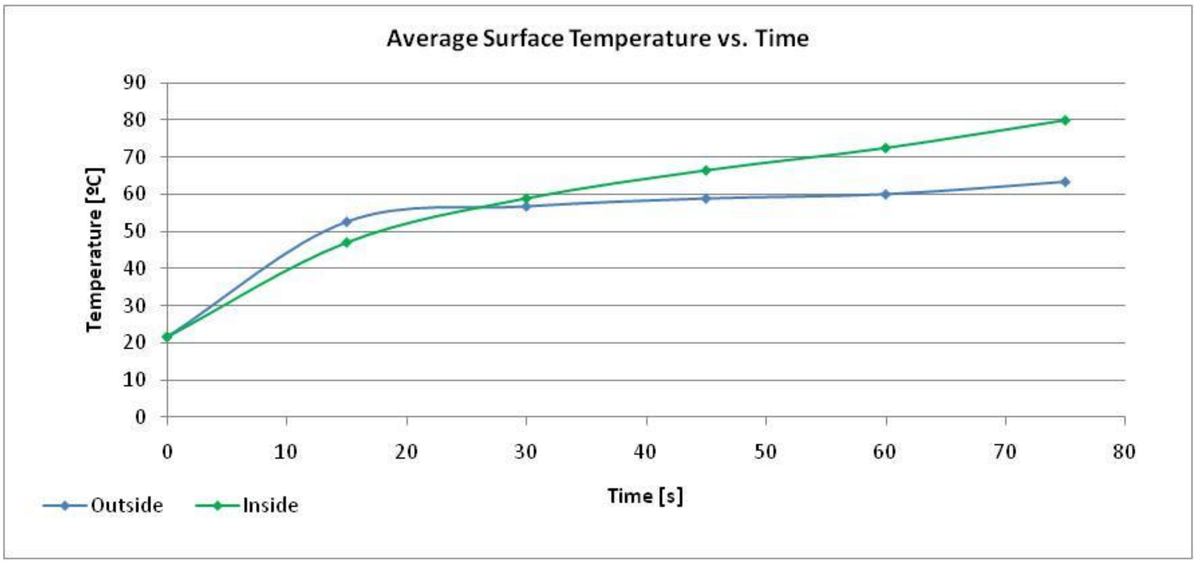


Fig. 53 Average Surface Temperature vs. Time, Outside and Inside

In this experiment the temperature on the outside surface is almost constant after the first 20 seconds because the microwaves are evaporating the water. On the contrary, the inside heats up faster and more constantly because there is less water that remains on the inner surface.

2nd Experiment

The goal for the second experiment was to measure the mass (Mass [g]) versus the time (t [s]) and calculate the difference of mass with these data. Our procedure, similar to the first experiment is as follows:

1. Weigh the dry hose
2. Soak the hose in water for 10 min
3. Weigh the wet hose
4. Remove the excess water on the wet hose by standing the hose vertical for 2 min on each side (Fig. 48)
5. Weigh the pre-dried hose
6. Put the hose in the microwave oven as described in the results of the each experiment
7. Take the hose out of the oven after an interval of 20 s
8. Weigh the hose and put it back into the oven

We repeated the operation until the hose was dry. We performed this experiment twice: once with Hose ‘B’ and once with Hose ‘C.’ Hose ‘B’ stood vertical in the microwave (Fig. 54), whereas Hose ‘C’ was horizontally supported by a glass on each end. Also, with Hose ‘C’, instead of taking the mass instantly after 20s of exposure in the microwave, we attempted to simulate forced convection by shaking the piece for 20s after each interval of microwave radiation, and before the weight was taken.

Fig. 54 Hose 'B' vertical in MW Oven

Results Hose 'B':

Mass of dried hose: 89,36g.

Mass of wet hose: 104,84g.

Mass of pre-dried: 100,87g.

t [s]	0	20	40	60	80	100	120
Energy [KWh]	0	0,00556	0,01111	0,01667	0,02222	0,02778	0,03333
Mass [g]	100,87	99,61	96,6	93,8	91,64	90,49	89,72
Δ Mass [g]	0	1,26	4,27	7,07	9,23	10,38	11,15

Table 10 Results Hose 'B'

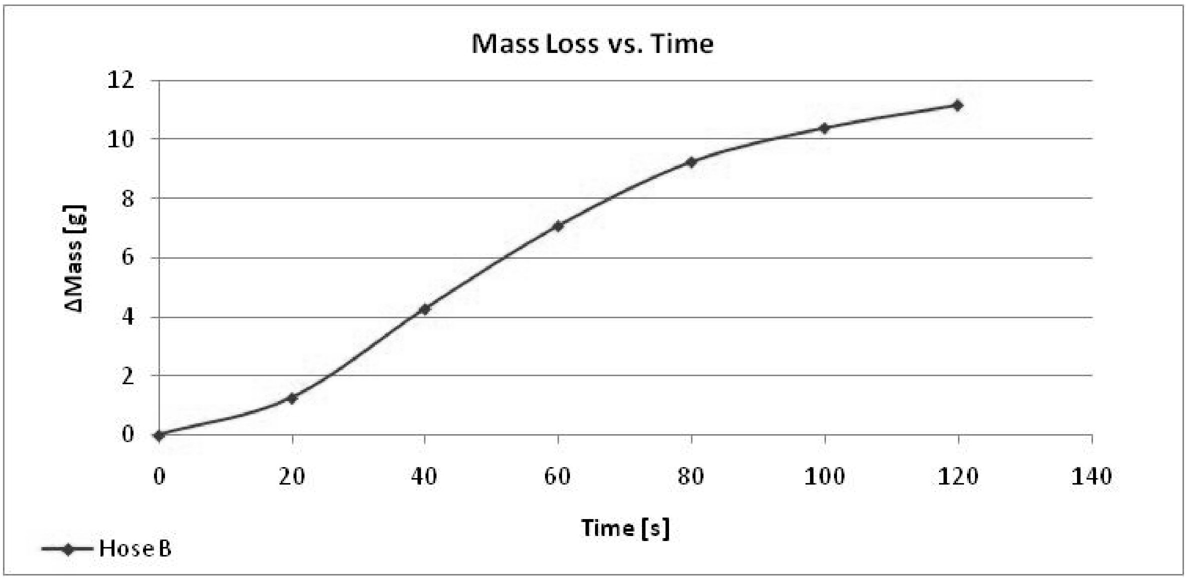


Fig. 55 Mass Loss vs. Time, Hose 'B'

For this test, it took 2 minutes of microwave exposure to come with 0,40g of our initially dry hose. From the graph (Fig. 55) three phases can be predicted. As the water begins to heat in the first 20s, little mass is lost. Over the next 80s, the majority of the water is removed. And during the last 20s, the hose loses the least amount of water. After drying, the upper part of the rubber side of the hose was damaged because the distance between the top of the hose and the microwave was too short.

Results Hose 'D':

Mass of dried hose: 85,16g.

Mass of wet hose: 100,15g.

Mass of pre-dried: 97,00g.

t [s]	0	20	40	60	80	100	120
Energy [KWh]	0	0,00556	0,01111	0,01667	0,02222	0,02778	0,03333
Mass [g]	97	94,36	92,19	90,33	88,65	87,65	86,25
Δ Mass [g]	0	2,64	4,81	6,67	8,35	9,35	10,75

Table 11 Results Hose 'D'

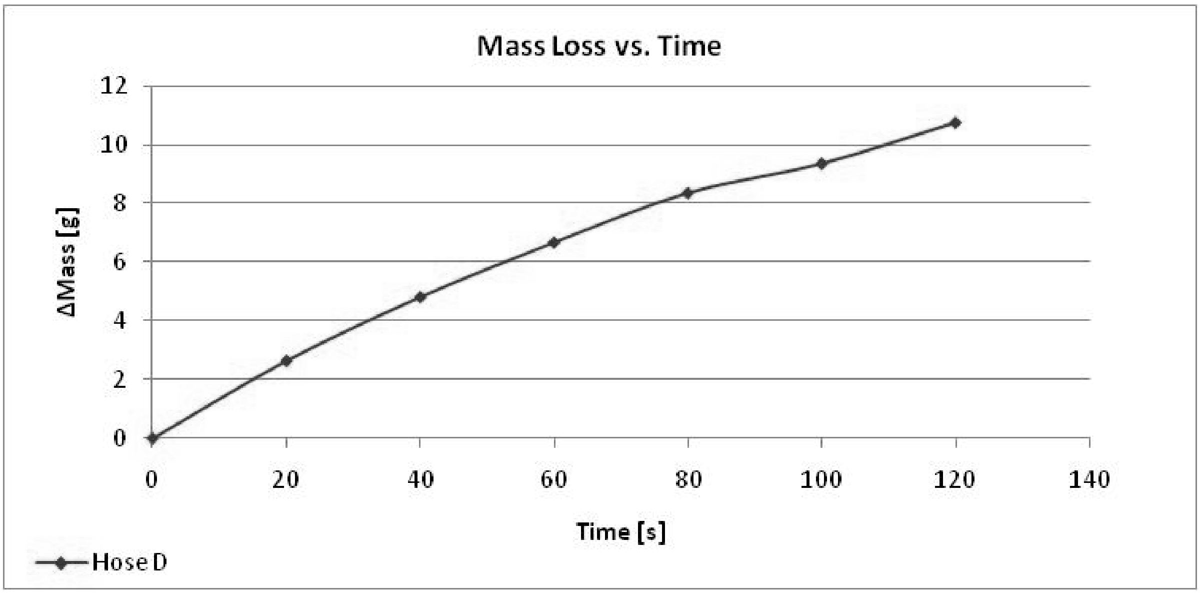


Table 12 Mass vs. Loss, Hose 'D'

For this test we can see that the amount of time to dry the hose was approximately the same as the test before. However, shaking the hoses in between the microwave exposure and weighing, provided more consistent mass loss over the same period of time. No damage occurred to the hose after this experiment.

Applying Microwaves for a real Case

From our experiments with microwaves, we have made a transposition to a 20m B hose to calculate the cost needed to dry a hose using microwaves. A ratio of length was used to estimate a magnitude by which the results would be expected to increase. We also calculated the operational speed of a system equipped with a given powered microwave. Our results from Experiment 2 Hose 'B' were used. The cost used for the energy usage was 21,36cents/kWh[42].

Results:

t [s]	0	2222,22	4444,44	6666,67	8888,89	11111,1	13333,3
Energy [KWh]	0	0,61728	1,23457	1,85185	2,46914	3,08642	3,7037
Mass [g]	11207,8	11067,8	10733,3	10422,2	10182,2	10054,4	9968,89
Δ Mass [g]	0	140	474,444	785,556	1025,56	1153,33	1238,89
Cost (EURO)	0	0,13185	0,2637	0,39556	0,52741	0,65926	0,79111

Table 13 Results for applied Microwave

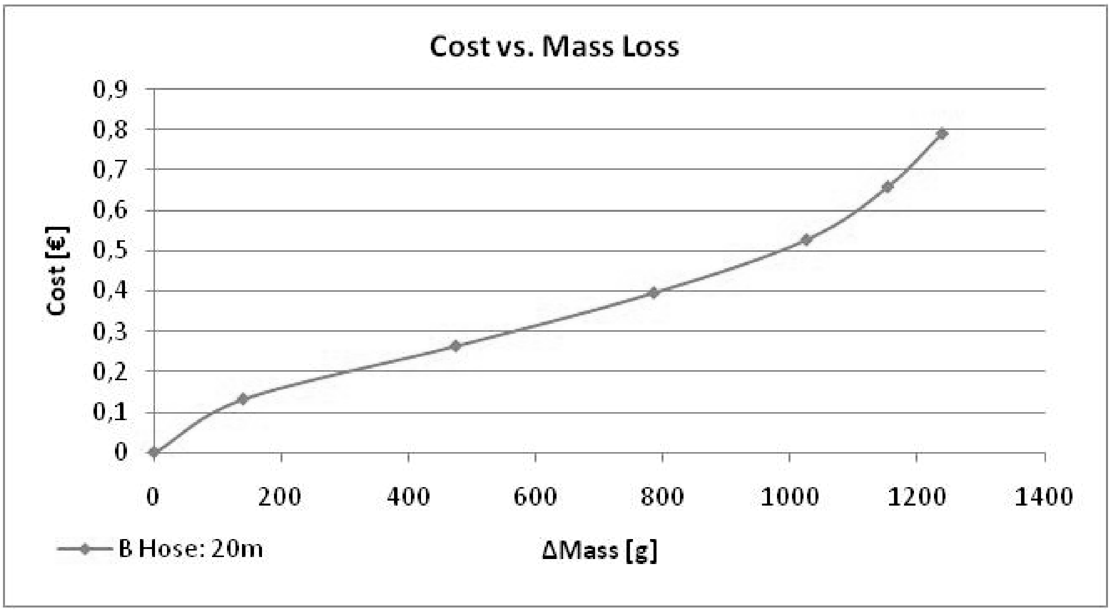


Fig. 56 Cost vs. Mass Loss, B Hose, 20m

According to Fig. 56, the price to dry one 20m B hose using microwaves is almost 80cents. This process, with a 1kW microwave oven, would require more than 3,5 hours to remove 1238,89g of water.

Operational speed

According to the rule showed in the Appendix A.3, the microwave is a proportional system. We can use the following calculation for creating a microwave power versus operating speed graph.

Power microwave: 1kW*:*

For a 0,18m piece of hose we spend 120s to dry. Thus, for 0,10m (length of the microwave) we spend:

$$t_1 = \frac{0{,}10m * 120s}{0{,}18m} = 66{,}67s$$

Now ,the speed can be easily calculated:

$$s_1 = \frac{0{,}10m}{66{,}67s} = 0{,}0015\,{}^{m}/_{s}$$

Power microwave: 2kW:

The speed that the hose must run through the microwave of 1kW of power is 0,0015m/s. Now, we calculate this speed for a microwave of 2kW:

$$s_2 = \frac{2kW * 0{,}0015\,{}^{m}/_{s}}{1kW} = 0{,}0030\,{}^{m}/_{s}$$

Finally, the formula to find the speed at power n in function of the power is the following:

$$s_n = P_n * \frac{0{,}18m}{120s}$$

S_n: speed at power n (m/s)

P_n: power n (kW)

Length of piece	0,1	m	* Speed and time to dry hose are not dependent on length							
Power[kW]	0,0001	1	2	3	4	5	10	20	30	40	50
time to dry piece [s]	6,67E+05	66,7	33,3	22,2	16,7	13,3	6,7	3,3	2,2	1,7	1,3
Speed [m/s]	0	0,0015	0,0030	0,0045	0,0060	0,0075	0,0150	0,0300	0,0450	0,0600	0,0750
time to dry hose [s]	1,33E+08	13333,3	6666,7	4444,4	3333,3	2666,7	1333,3	666,7	444,4	333,3	266,7

Table 14 Results, 20m B Hose

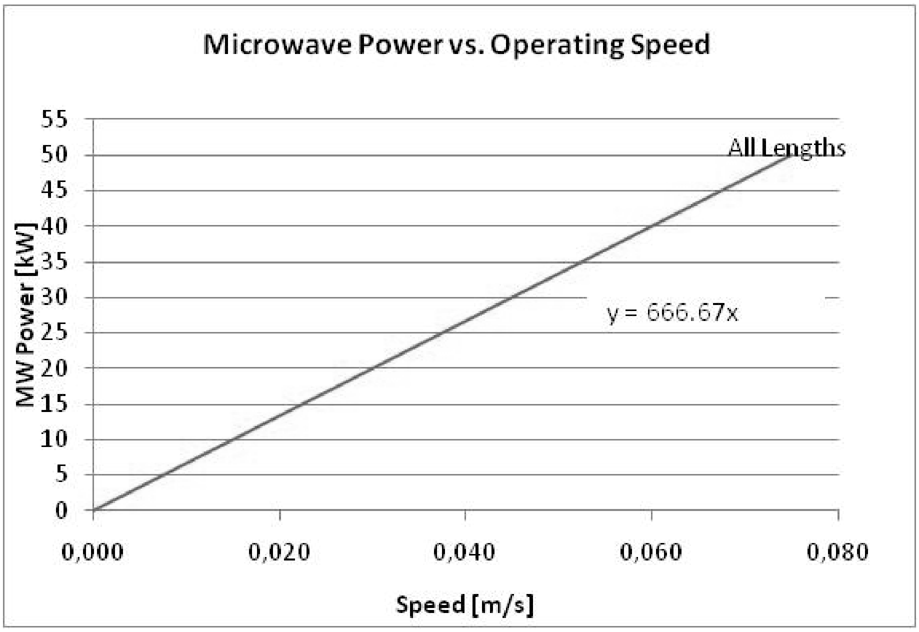


Fig. 57 Microwave Power vs. Operating Speed

This graph allows one to determine the maximum operating speed when drying the hose with varying powered microwaves. For example, if a 20kW microwave was implemented, the operating speed must be no greater than 0.03m/s to dry a 20m hose. The relationship shown in Fig. 57 is not dependent on the length (size dimensions) of the machine.

Conclusion

From our experiments with temperature and mass, we concluded that microwave technology is a feasible method to dry fire hoses. However, factors that need to be considered when using microwaves include: the space between the surface of the microwave and the surface of the hose, the other materials in the microwave that are also being exposed to the radiation, and the use of forced or free convection. Caution should also be taken not to exceed temperatures about 150°C, as damage is likely to occur. Once the water has been removed from the hose, it is necessary to stop exposure time to prevent such high temperatures. Forced convection during the microwave process did not speed up the drying process as expected, but it does allow for a more controlled and constant rate of mass loss. The time to dry a fire hose completely with microwaves is greater than the current existing methods. The power requirements for microwaves are high and thus costs to operate this equipment would be higher than current methods. Also, it would not be recommended to use microwaves for an entire drying process.

8.2. Conduction

We performed 4 experiments with an iron to simulate a system by conduction, where perhaps the hose would pass over a system of heated cylinders in a process. Effects due to temperature were evaluated as well as the effect of forced convection on mass loss. The temperature of the iron was adjusted using a setting of full power and half power, and the forced convection was simulated using a hair dryer.

Experiments and Results

Materials

- Scale (Satorius Type 1547)
- Infrared Camera (FLUKE Ti32)
- Iron (Philips Mistral HI 312, 1200-1450W)
- Hair dryer (BomannCB 870, 1800W)
- Bucket of Water
- Several pieces of hose; varying in size:
  - Hose 6: 19,2cm in length
  - Hose C: 18cm in length
  - Hose 4: 17,5cm in length

Experiments

1. Iron with half power of 1325W
2. Iron with full power of 1450W
3. Iron with full power of 1450W, plus hair dryer
4. Iron with half power of 1325W, plus hair dryer

1st Experiment: Iron half Power, 1325W (Hose '6')

1. Weigh the dry hose
2. Soak the hose in water for 10 min
3. Weigh the wet hose
4. Remove the excess water from the wet hose by standing the hose vertically for 2 min on each side
5. Weigh the pre-dried hose
6. Heat by conduction for 10s each side
7. Take a picture with an IR camera and weigh the hose on the scale
8. Repeat steps 6 and 7 until the hose is dry or damaged

Results

Mass of dried hose: 95,51g.

Mass of wet hose: 114,18g.

Mass of pre-dried: 108,07g.

Time [s]	0	20	40	60	80	100	120	140
Tmin [°C]	18,2	24,2	24,3	24,3	25,1	25,4	25,2	25
Tmax [°C]	25	53,5	57,6	61	67,8	67,2	57,3	55,4
Tavg [°C]	21,2	37,2	43,1	47,5	53,8	53,4	47,9	47,1
Mass [g]	108,07	107,23	106,65	105,93	105,14	104,33	103,13	102,38
Δ Mass[g]	0	0,84	1,42	2,14	2,93	3,74	4,94	5,69

Time [s]	160	180	200	220	240	260	280	300	320
Tmin [°C]	24,7	24,9	25,6	24,9	24,6	24,9	25,1	25,2	25,6
Tmax [°C]	50,7	60,9	60,1	62,1	53,9	58	67,8	69,1	69,5
Tavg [°C]	43,6	50,5	46,4	49,9	44,6	47,3	52,8	55,3	55
Mass [g]	101,52	100,75	99,74	99,03	98,38	97,77	97,16	96,66	96,31
Δ Mass[g]	6,55	7,32	8,33	9,04	9,69	10,3	10,91	11,41	11,76

Table 15 Results, Hose '6' Half Power

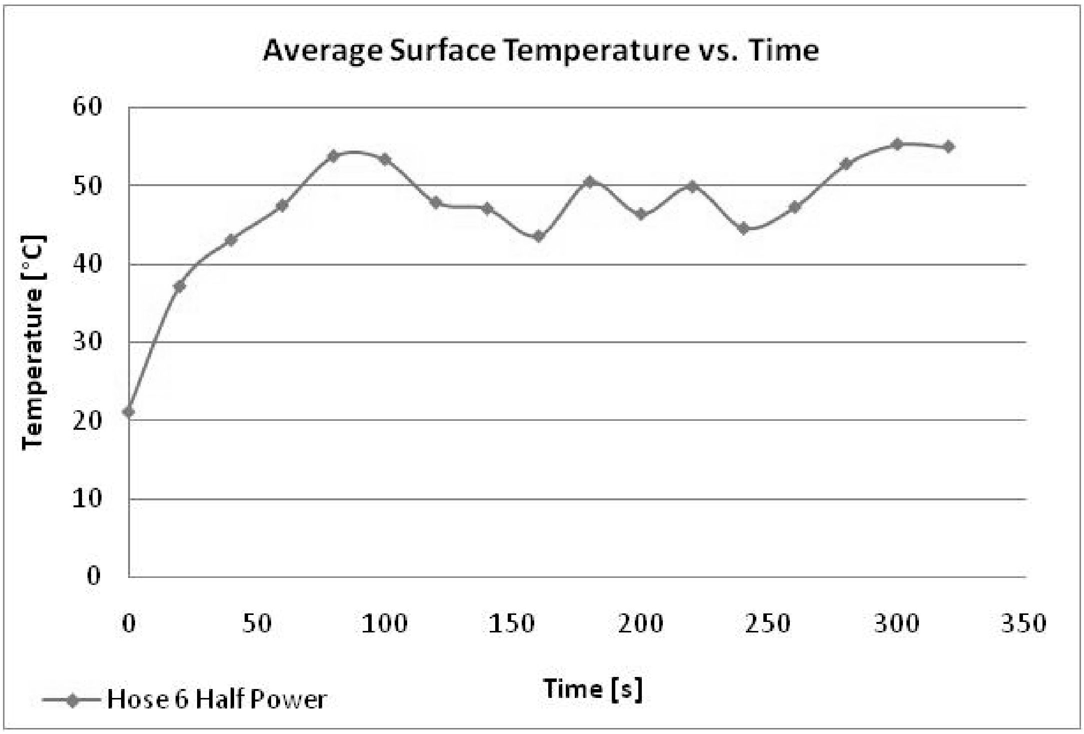


Fig. 58 Average Surface Temperature vs. Time, Hose '6' Half Power

When examining the graph (Fig. 58), it is clear that the iron quickly heats the hose until the temperatures become nearly the same. From100s to the end, the temperature on the surface of the hose increases and decreases with time regularly, because of the inconsistent heating of the iron. The fluctuations in the graph are due to the heating up and cooling down of the iron as it reaches the set point temperature.

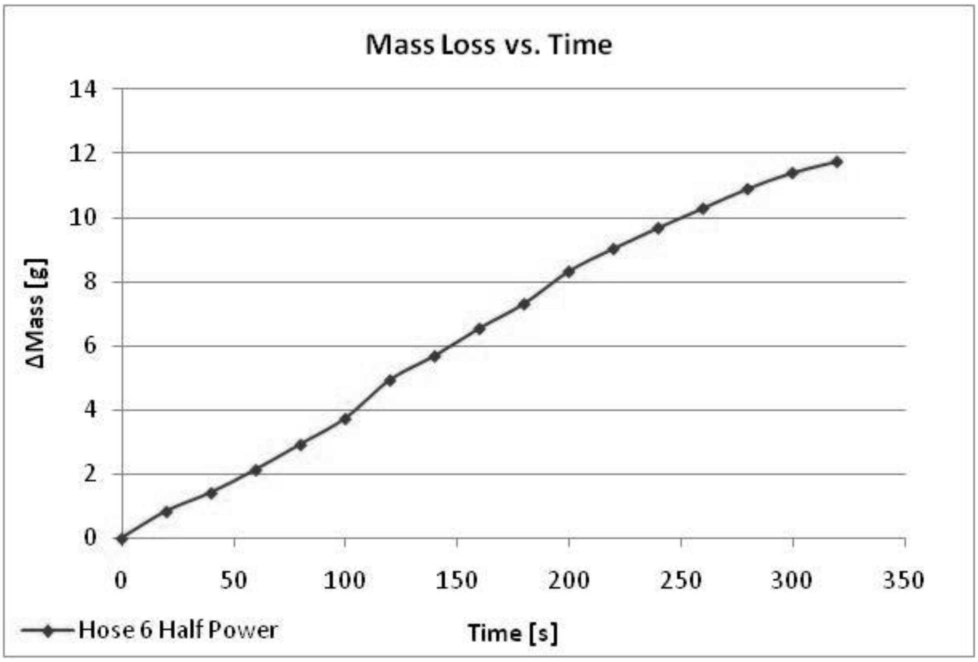


Fig. 59 Mass Loss vs. Time, Hose '6' Half Power

The overall mass loss with respect to time was constant and produced linear results, with the iron at half power (Fig. 59). This does not however, represent the individual mass loss from each 20 second interval. The fluctuation in temperature would have a more obvious effect in this area. After doing the experiment the hose was dried after 320 seconds and without damage.

2nd Experiment: Iron full Power, 1400W (Hose 'C')

1. Weigh the dry hose
2. Soak the hose in water for 10 min
3. Weigh the wet hose
4. Remove the excess water from the wet hose by standing the hose vertically for 2 min on each side
5. Weigh the pre-dried hose
6. Heat by conduction for 10s each side
7. Take a picture with an IR camera and weigh the hose on the scale
8. Repeat steps 6 and 7 until the hose is dry or damaged

Results

Mass of dried hose: 85,97g.

Mass of wet hose: 96,76g.

Mass of pre-dried: 99,66g.

Time [s]	0	20	40	60	80	100
Tmin [°C]	18,7	25,3	26,6	24,7	25,3	25,4
Tmax [°C]	24,2	135,1	91,5	77,9	124,7	116,9
Tavg [°C]	21,4	54	59,1	56,4	57,1	73,2
Mass [g]	96,76	95,14	92,73	90,14	88,4	87,01
Δ Mass[g]	0	1,62	4,03	6,62	8,36	9,75

Table 16 Results, Hose 'C' Full Power

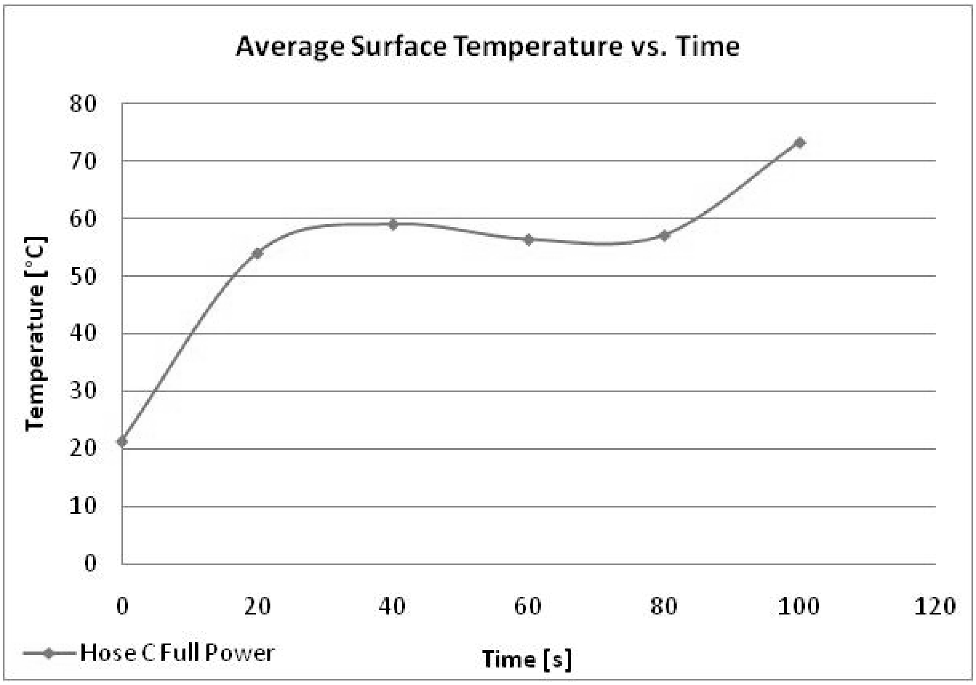


Fig. 60 Average Surface Temperature vs. Time, Hose 'C' Full Power

This figure shows the temperature of the hose with respect to time. Because the iron was operating at full power, the temperature is drastically changed within the first 20 seconds. The fluctuation of the temperature can again be seen here, but only once, because of the short time needed to dry the hose.

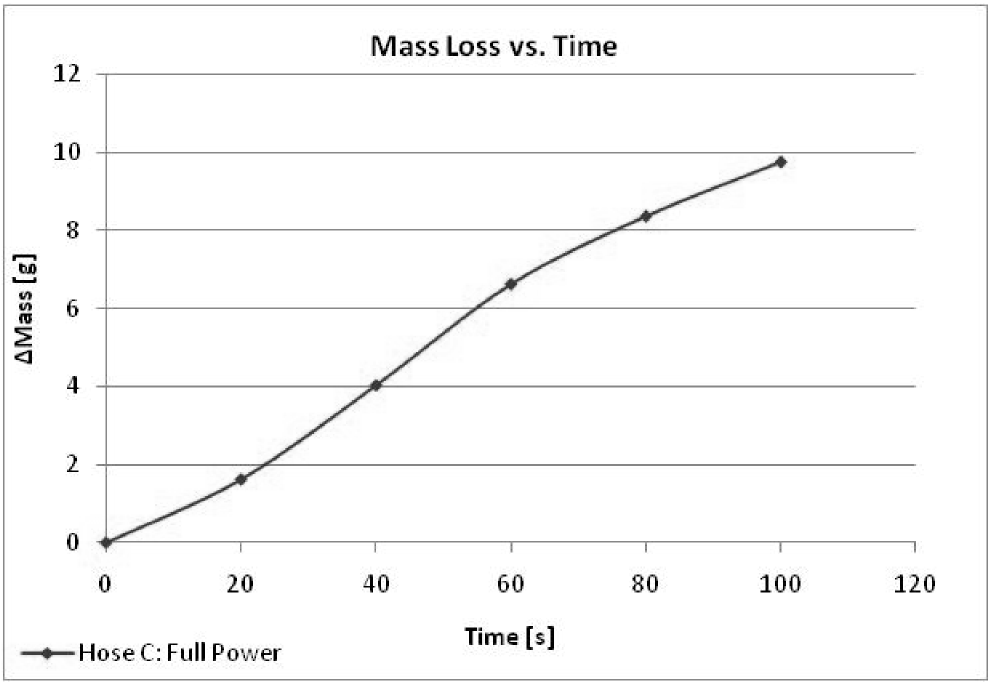


Fig. 61 Mass Loss vs. Time, Hose 'C' Full Power

It only took 100s to dry the hose piece using full power, but as a result of the intensive amount of heat, the hose became damaged. The fibers on outer jacket of the hose begin to shrink if excess heat is applied once the water is removed.

3rd Experiment: Iron full Power + Hair Dryer (Hose '6')

1. Weigh the dry hose
2. Soak the hose in water for 10 min
3. Weigh the wet hose
4. Remove the excess water from the wet hose by standing the hose vertically for 2 min on each side
5. Weigh the pre-dried hose
6. Heat by conduction for 10s each side
7. Dry by convection 10s with hair dryer (distance 15cm)
8. Take a picture with an IR camera and weigh the hose on the scale
9. Repeat steps 6 through 7 until the hose is dry or damaged

Results

Mass of dried hose: 95,51g.

Mass of wet hose: 111,98g.

Mass of pre-dried: 107,04g.

Time [s]	0	20	40	60	80	100
Tmin [°C]	18,5	25,6	26,1	25,7	26,6	25,2
Tmax [°C]	24,4	48,1	52,7	106,5	57,2	83,8
Tavg [°C]	21,7	37,3	45	46,6	42,9	55,8
Mass [g]	107,04	104,98	102,14	100,03	97,77	95,58
Δ Mass[g]	0	2,06	4,9	7,01	9,27	11,46

Table 17 Results, Hose '6' Full Power with Hair Dryer

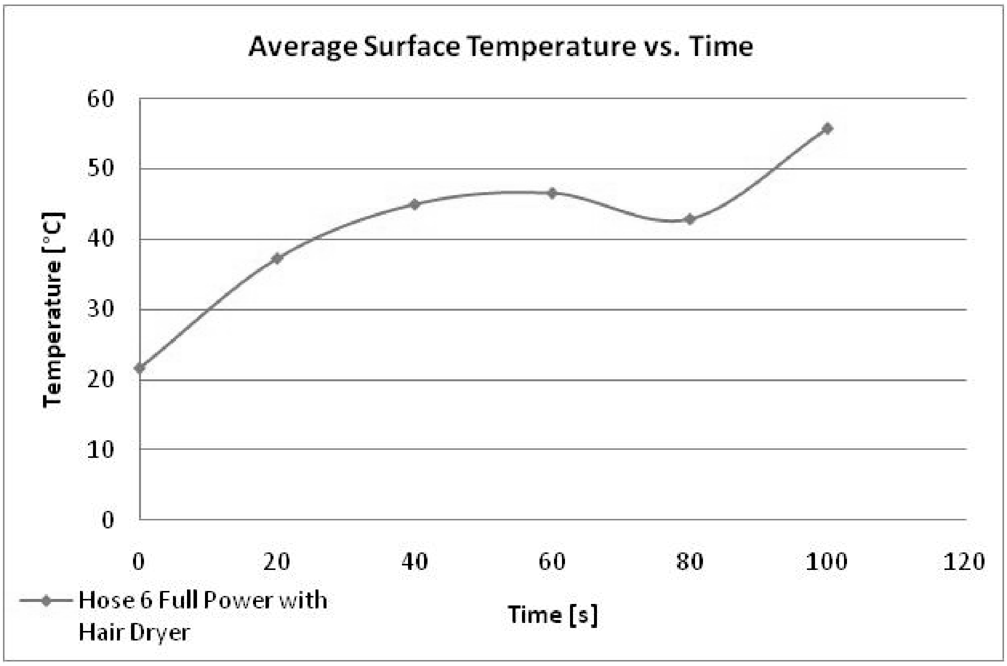


Fig. 62 Average Surface Temperature vs. Time, Hose '6' Full Power with Hair Dryer

Compared to the 2nd experiment without the hair dryer, this shows how the influence of forced convection results in lower surface temperatures. It is consistently 10°C lower than without. The curve of temperature for this experiment has a slower initial increase than the experiment without the hair dryer, but the pattern of temperature change is almost identical.

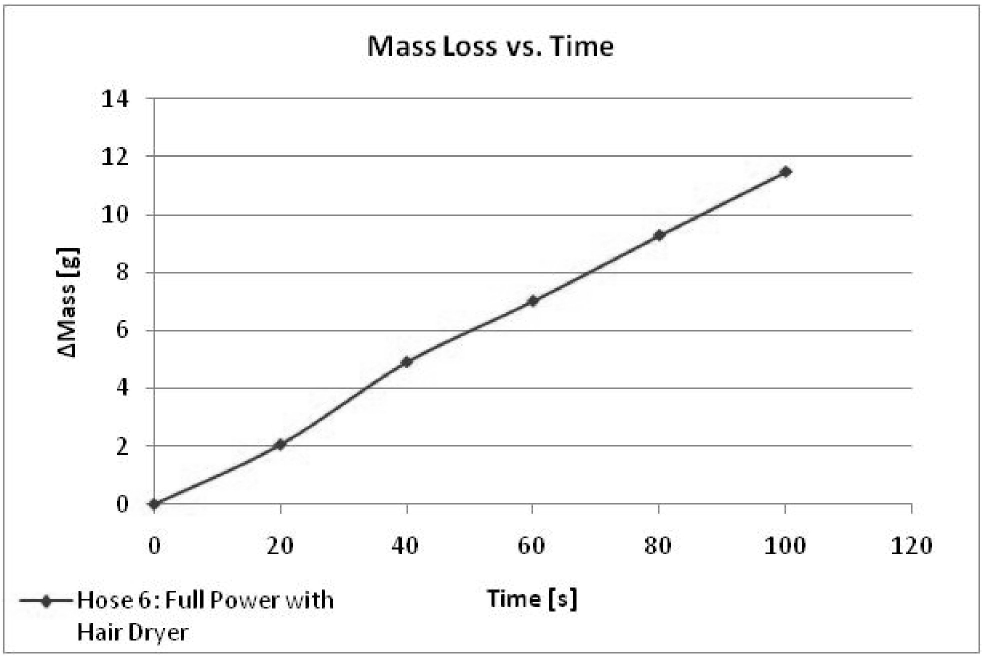


Fig. 63 Mass Loss vs. Time, Hose '6' Full Power with Hair Dryer

After doing the experiment, the hose was dried and without damage. In the same amount of time, the experiment with the hair dryer managed to remove nearly 1 more gram of water than the experiment without.

4^{th} Experiment: Iron half Power + Hair Dryer (Hose '4')

1. Weigh the dry hose
2. Soak the hose in water for 10 min
3. Weigh the wet hose
4. Remove the excess water from the wet hose by standing the hose vertically for 2 min. on each side
5. Weigh the pre-dried hose
6. Heat by conduction for 10s each side
7. Dry by convection 10s with hair dryer (distance 15cm)
8. Take a picture with an IR camera and weigh the hose on the scale
9. Repeat steps 6 through 7 until the hose is dry or damaged

Results

Mass of dried hose: 86,33g.

Mass of wet hose: 102,51g.

Mass of pre-dried: 97,80g.

Time [s]	0	20	40	60	80	100	120
Tmin [^{o}C]	18,5	24,2	25,8	25,7	23,8	23,6	25,8
Tmax [^{o}C]	25	38,8	42,1	38	37,2	39,1	41,1
Tavg [^{o}C]	21,7	29,8	31,7	31,5	32,8	33,8	34,9
Mass [g]	97,8	96,75	95,71	94,71	93,91	93,18	92,25
Δ Mass[g]	0	1,05	2,09	3,09	3,89	4,62	5,55

Time [s]	140	160	180	200	220	240	260
Tmin [^{o}C]	25,6	25,7	25,6	24,2	25,7	25,7	25,6
Tmax [^{o}C]	41,3	43,9	41,9	45,3	46	49,4	47,1
Tavg [^{o}C]	35	37,7	35,8	37,2	38,2	39,1	38,2
Mass [g]	91,33	90,54	89,91	89,02	88,3	87,71	87,28
Δ Mass[g]	6,47	7,26	7,89	8,78	9,5	10,09	10,52

Table 18 Results, Hose '4' Half Power with Hair Dryer

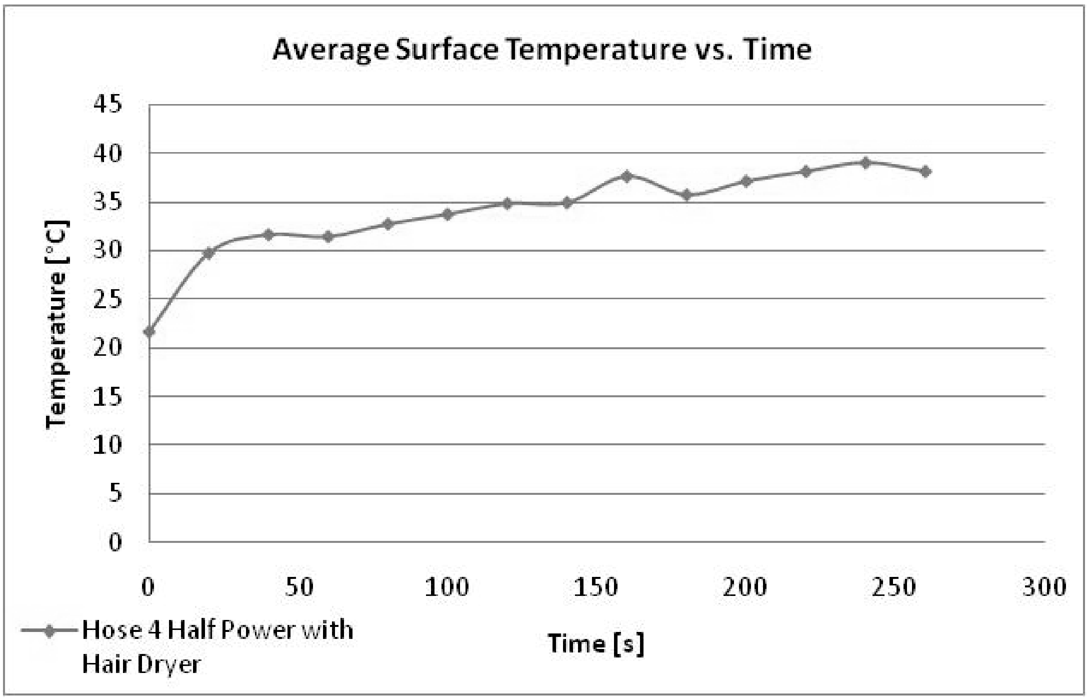


Fig. 64 Average Temperature vs. Time, Hose '4' Half Power with Hair Dryer

This graph again shows the lower surface temperature of the hose as a result of the convection applied for 20s after heating. The changing temperature of the iron has less of an effect on the surface temperature of the hose and a more steady increase is seen throughout the drying process (Fig. 64).

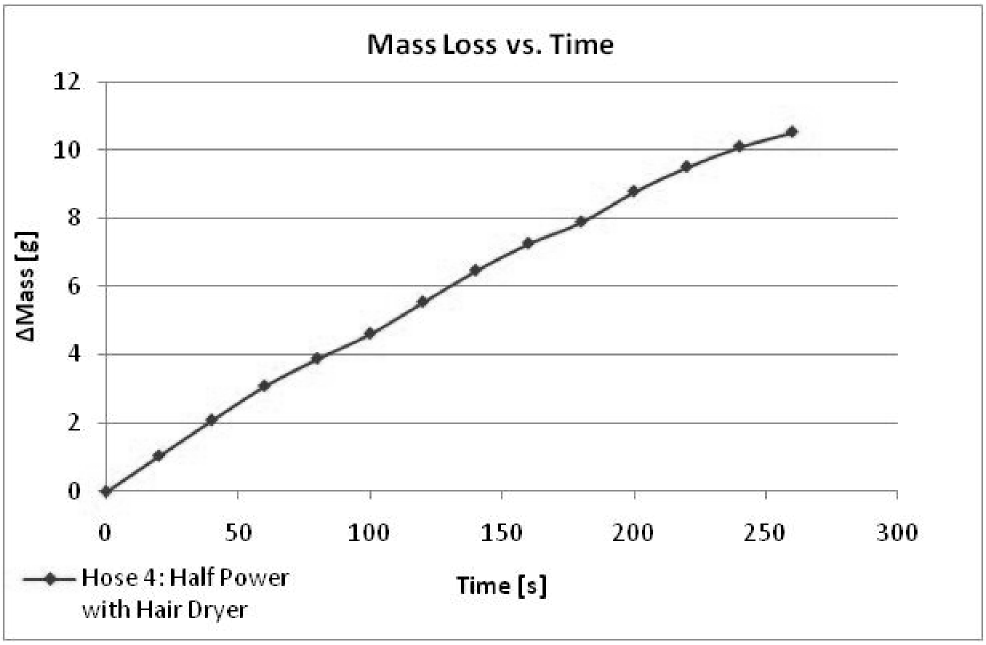


Fig. 65 Mass Loss vs. Time, Hose '4' Half Power with Hair Dryer

The hose was within 1g of the initial dry weight of the hose after 260s (Fig. 65). With half power the hose dried 1 minute faster using forced convection than without. Also, this result produced a dry hose without damage.

Conclusion

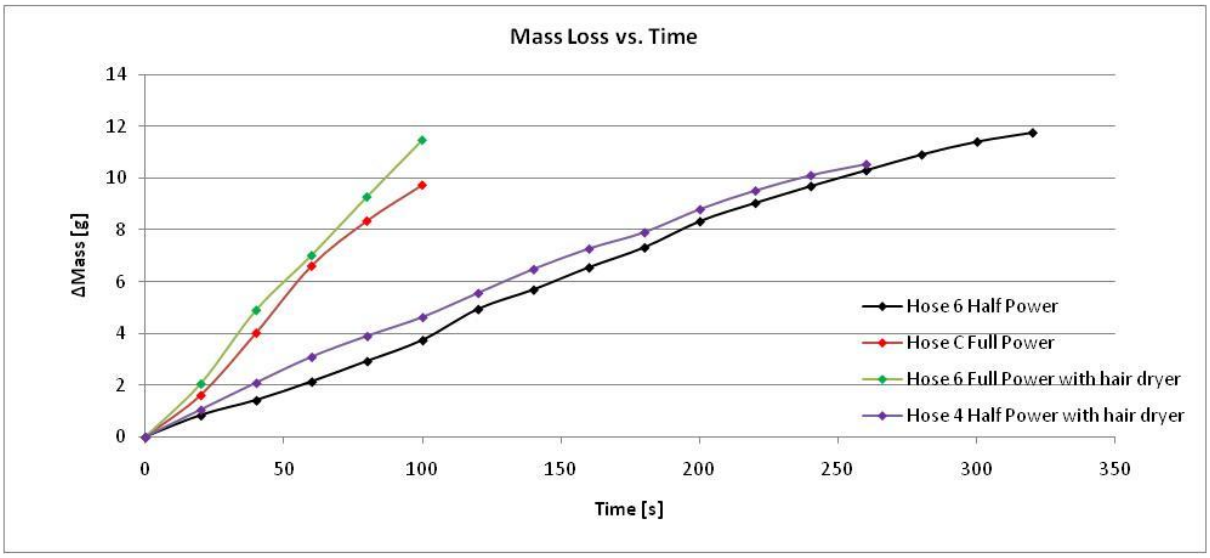


Fig. 66 Mass Loss vs. Time, Conclusion

With full power we can see that it takes less time to lose water than half power, but we saw the damage that can be created. The amount of time needed to dry using full power is approximately three times less. From this graph, it is shown that the mass loss, for both power scenarios, is only on average 1 gram more with forced convection than without.

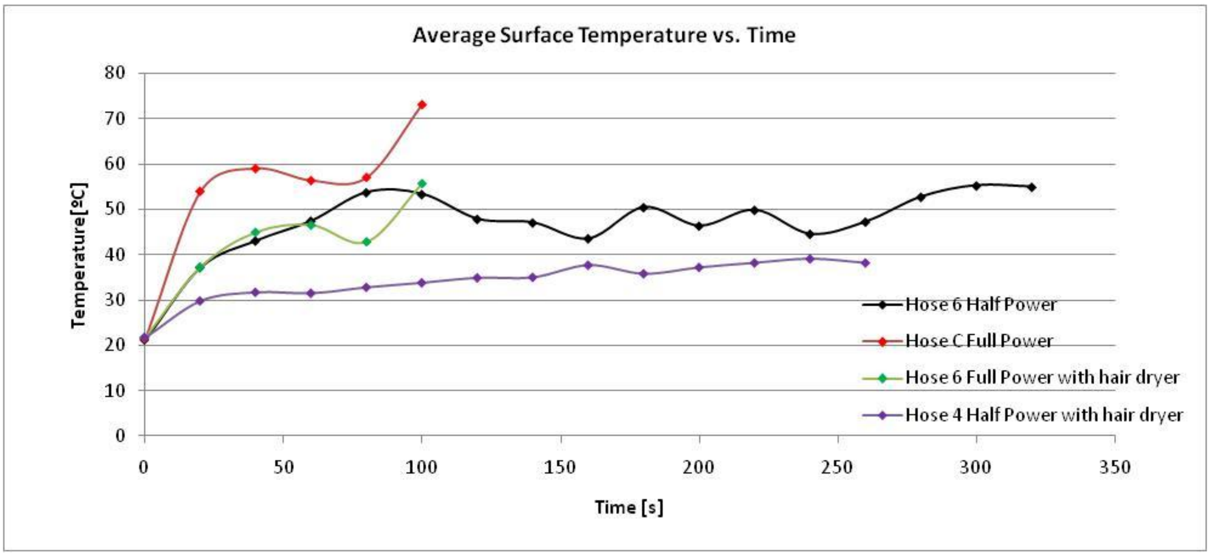


Fig. 67 Average Surface Temperature vs. Time, Conclusion

With the temperature, it is easier to see the importance of moving the evaporated water from the hose using forced convection. This simple process allows a low enough temperature for the hose to be dried using the full powered iron.

With the results from the conduction experiments, it was concluded that we were unable to accurately simulate a process that could be used to dry fire hoses. The inconsistency in the experiments from the equipment gives reason to find these results invalid. Because of the fluctuating temperature, it was impossible to determine the power being used by the iron at all times. Thus, we are unable to calculate the energy consumption and costs of such method. Our results do, however, provide a comparison of different approaches to drying by conduction. he benefit of forced convection can be seen, as well as the advantage and disadvantage of using more heat to dry. If the results were accurate, it would be recommended to dry fire hoses using highly heated cylinders to increase time, with forced convection to move the steam from the area and prevent the hose from becoming damaged.

8.3. Infrared (IR)

To test the efficiency of infrared drying, we performed the following three experiments. Our inability to experiment with an actual infrared dryer led us to conduct these experiments using an infrared lamp of 100W, primarily used to heat the human body. Of the three experiments, two were done to examine the effect of forced and free convection, and the last was done to examine the effect of a different color being heated.

Experiments and Results

Materials

- Scale (Satorius Type 1547)
- Infrared Camera (Fluke Ti32)
- Hair Dryer (Bomann CB 870, 1800W)
- Infrared Lamp (Philips Infraphil, 100W)
- Bucket of Water
- Small circular piece of dry hose with a diameter of 8cm

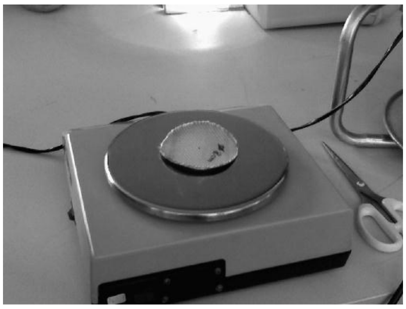


Fig. 68 Circular Piece of Hose on the Scale

Experiments

1. IR lamp alone
2. IR lamp with a hair dryer
3. IR lamp on the black surface of the same piece

1st Experiment: IR Lamp alone (Circle)

1. Weigh the dry hose
2. Soak the hose in water for 10 min
3. Weigh the wet hose
4. Remove the excess water from the wet hose by standing the hose vertically for 1 min on each side
5. Weigh the pre-dried hose
6. Heat by infrared radiation in 1 min intervals
7. Take a picture with an IR camera and weigh the hose on the scale
8. Repeat steps 6 and 7 until the hose is dry or damaged

Results:

Mass of dried hose: 9,59g.

Mass of wet hose: 11,48g.

Mass of pre-dried: 10,92g.

Time [min]	0	1	2	3	4	5	6	7	8
Energy [KWh]	0,0000	0,0017	0,0033	0,0050	0,0067	0,0083	0,0100	0,0117	0,0133
Tmin [°C]	18,3	26,6	35,4	30,1	27,1	31,6	26,4	31,2	30,5
Tmax [°C]	25	49,8	55,8	55,7	61,5	56,5	61,1	74,2	86,3
Tavg [°C]	22	42,2	48,6	47,9	47,4	48,4	48,7	56	65,2
Mass [g]	10,92	10,74	10,53	10,3	10,11	9,93	9,75	9,67	9,61
Δ Mass[g]	0	0,18	0,39	0,62	0,81	0,99	1,17	1,25	1,31

Table 19 Results, Circular Piece, IR

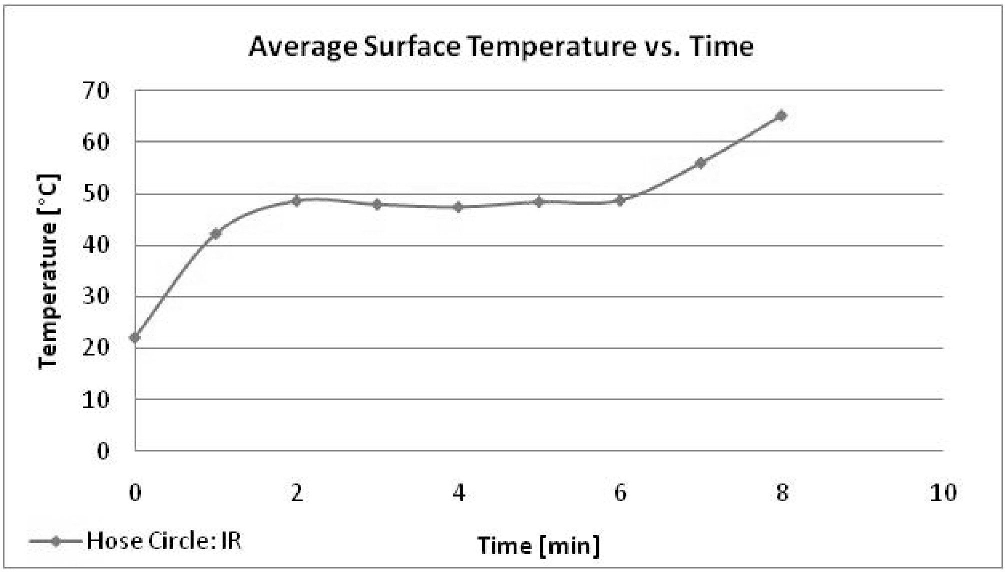


Fig. 69 Average Surface Temperature vs. Time, Circle, IR

With the infrared lamp, the three phases first noticed with the microwave are again evident (Fig. 69). The temperature of the surface increases sharply at the beginning and end of the trial, but remains constant for the middle 4 minutes of the experiment. A similar, energy comparison can be found in Appendix B. This includes those for both Experiment 1 and 2 for the infrared methods.

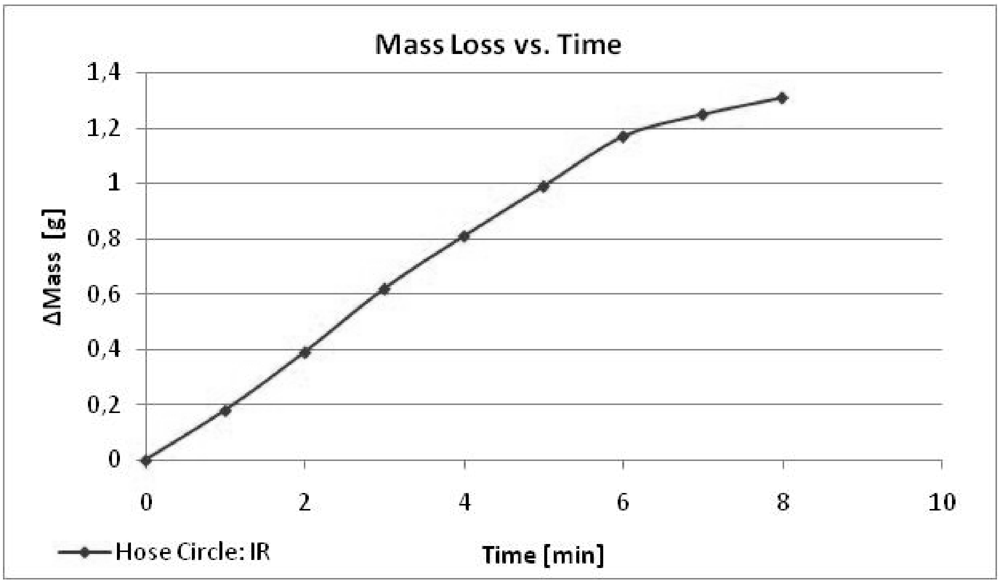


Fig. 70 Mass Loss vs. Time, Circle, IR

The mass loss for the infrared drying steadily increases until there is 0,2g of water left in the material. At this point (around 6 minutes) the increased exposure becomes a waste of energy as little water is left to be removed.

2nd Experiment: IR Lamp + Hair Dryer (Circle)

1. Weigh the dry hose
2. Soak the hose in water for 10 min
3. Weigh the wet hose
4. Remove the excess water from the wet hose by standing the hose vertically for 1 min on each side
5. Weigh the pre-dried hose
6. Heat with the IR lamp for 1min while the hair dryer blows air from 30 cm away
7. Take a picture with an IR camera and weigh the hose on the scale
8. Repeat steps 6 and 7 until the hose is dry or damaged

Results

Mass of dried hose: 9,59g.

Mass of wet hose: 11,52g.

Mass of pre-dried: 11,03g.

Time [min]	0	1	2	3	4	5	6
Energy [KWh]	0,0000	0,0017	0,0033	0,0050	0,0067	0,0083	0,0100
Tmin [°C]	18,1	25	25	28,9	28,3	32,4	27,5
Tmax [°C]	24,8	37,3	38,9	37,9	43,1	51	56,2
Tavg [°C]	21,9	32,8	34,2	33,3	35,3	39,9	44,3
Mass [g]	11,03	10,71	10,39	10,09	9,88	9,71	9,65
Δ Mass[g]	0	0,32	0,64	0,94	1,15	1,32	1,38

Table 20 Results, Circle, IR with Hair Dryer

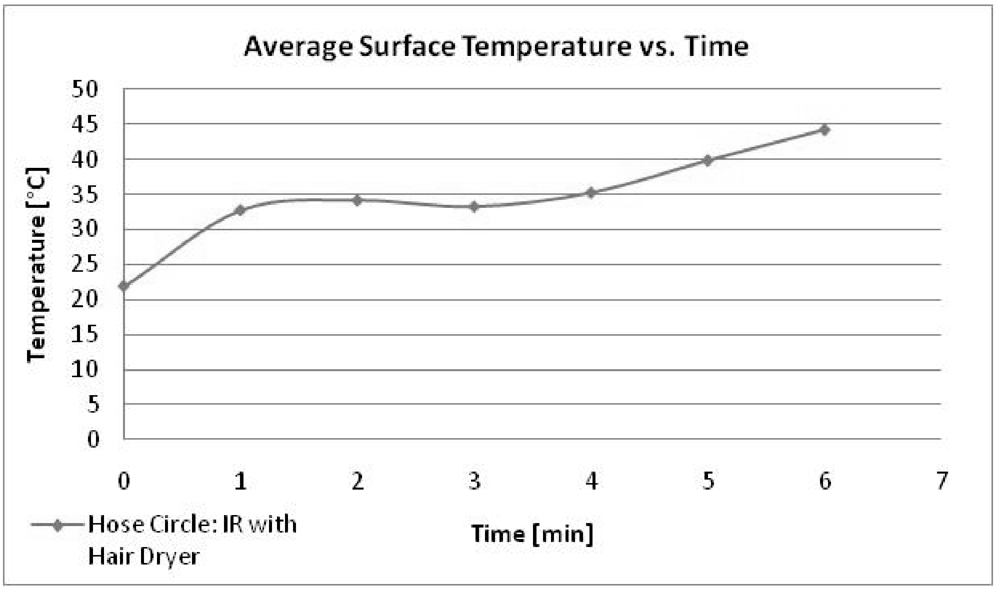


Fig. 71 Average Surface Temperature vs. Time, Circle, IR with Hair Dryer

This graph, although similar to the first with the three phases, has a slower rate of changing temperature at the beginning and end. By the end of the experiment, the average surface temperature does not exceed 45°C.

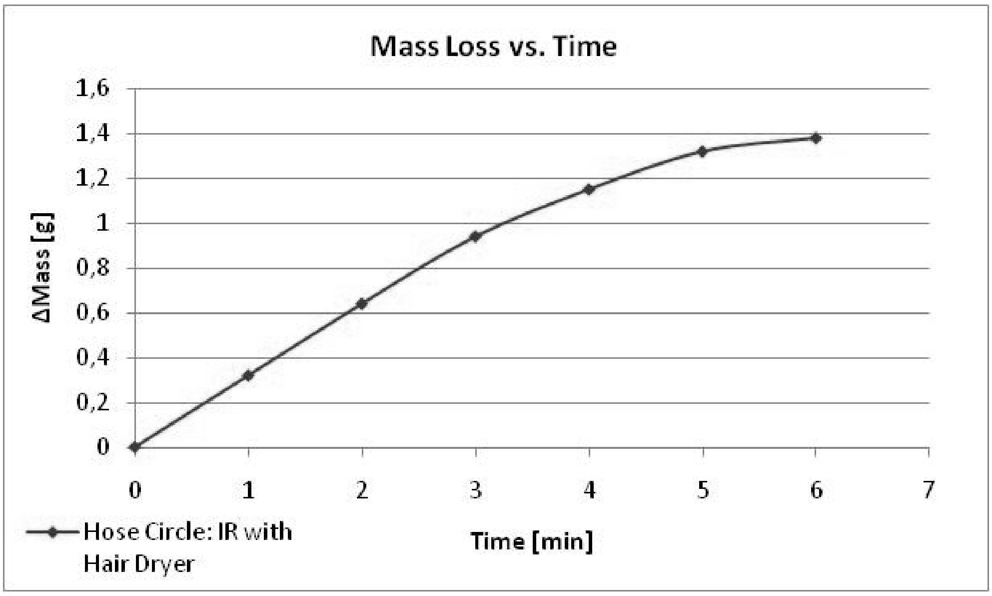


Fig. 72 Mass Loss vs. Time, Circle, IR with Hair Dryer

With the addition of the hair dryer, the hose circle dried in 6 minutes. As the mass of water in the hose decreases, more time and energy is needed to remove the remainder.

3^{rd} Experiment: IR Lamp on black Surface (Circle)

This experiment was done without weighing the hose after each 1 minute interval. The goal was to examine the effect of color on temperature. The following procedure was performed:

1. Weigh the dry hose
2. Soak the hose in water for 10 mn
3. Weigh the wet hose
4. Remove the excess water from the wet hose by standing the hose vertically for 1 min on each side
5. Weigh the pre-dried hose
6. Heat with the IR lamp for 1min
7. Take a picture with IR camera after 1 min of heating
8. Repeat until damage or maximum temperature is reached

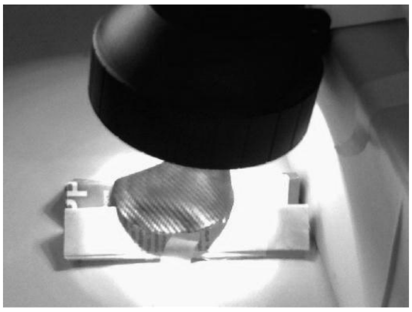


Fig. 73 Black Side of the Hose, IR

Results:

Mass dried hose: 9,59g.

Mass wet hose: 11,42g.

Mass pre-dried: 10,97g.

Time [min]	0	1	2	3	4
Energy [KWh]	0,0000	0,0017	0,0033	0,0050	0,0067
Tmin [°C]	18,6	24	25,6	25	26,1
Tmax [°C]	25	82,2	114,6	114,8	109,8
Tavg [°C]	21,4	57,2	74,7	73,4	74,1

Table 21 Results, Circle, IR

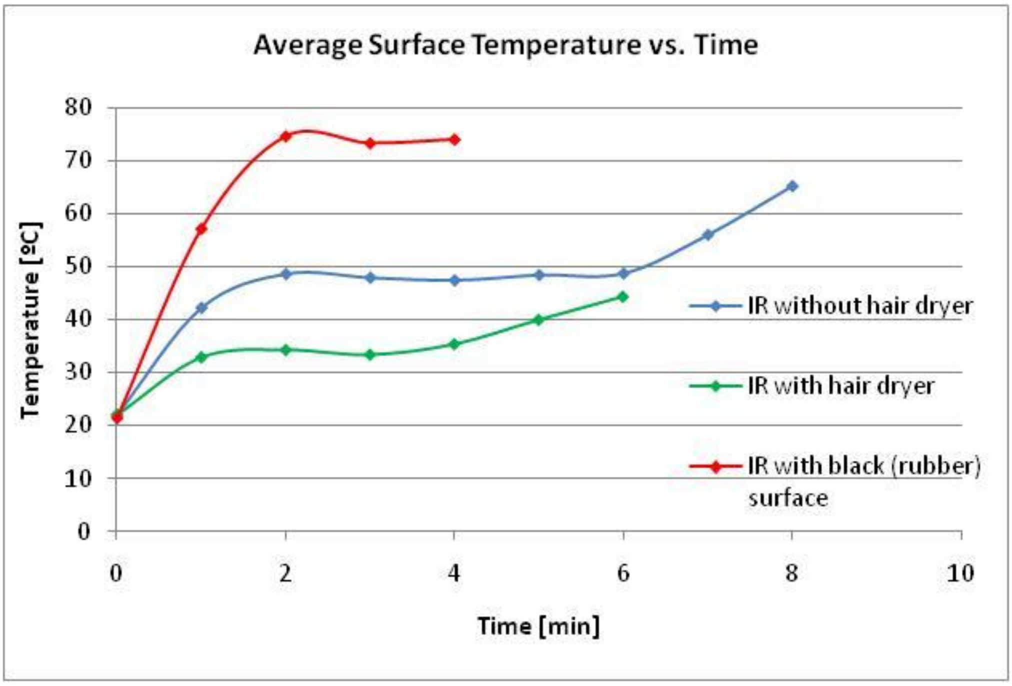


Fig. 74 Average Surface Temperature vs. Time, Circle

We can see the effect of the color on the surface being heated (Fig. 74). Black absorbs light instead of white, which reflect light. As a result the black surface becomes hotter than the other. We can see the different between both surfaces. The black surface is nearly 25°C warmer than IR drying without hair dryer, within the first two minutes. This comparison also shows the difference between the drying with and without forced convection. The hose was only damaged in the last experiment with the black surface. (Fig. 75).

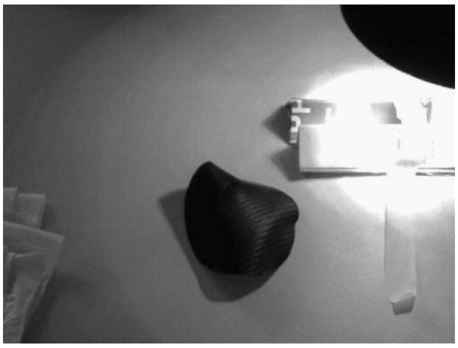


Fig. 75 Damaged Circle due to long-term Exposure of IR

Applying Infrared for a real Case

In order to estimate the cost and energy usage of implementing an infrared drying method to dry fire hoses, we have used our experimental data from the first infrared experiment. We have made a transposition to a 20m B hose to calculate the cost needed to dry an entire hose using infrared drying. We already know that the cost of a 1KWh is 21,36cents.

Results:

Time [min]	0	937,4223	1874,845	2812,267	3749,689	4687,111	5624,534	6561,956	7499,378
Energy [KWh]	0	1,56237	3,124741	4,687111	6,249482	7,811852	9,374223	10,93659	12,49896
Mass [g]	10236,65	10067,92	9871,057	9655,45	9477,339	9308,603	9139,867	9064,874	9008,628
Δ Mass[g]	0	168,736	365,5947	581,2018	759,3121	928,0481	1096,784	1171,778	1228,023
Cost [EURO]	0	0,333722	0,667445	1,001167	1,334889	1,668612	2,002334	2,336056	2,669779

Table 22 Results, 20m B Hose

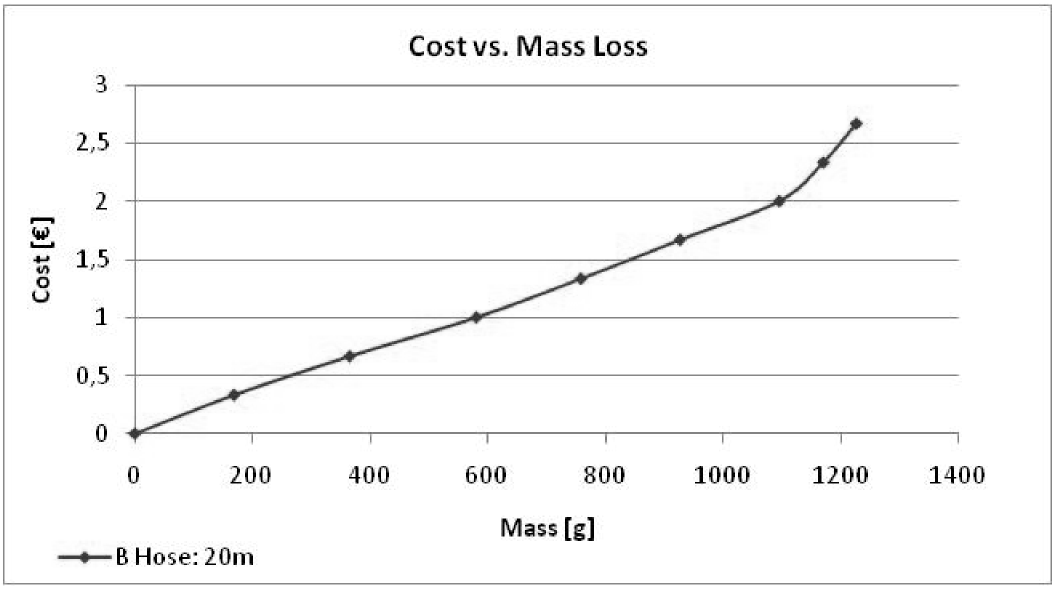


Fig. 76 Cost vs. Mass Loss, 20m B Hose

From this graph, a linear relationship can be found for the first 1100 grams of water, but the energy required to remove the last 100 grams causes the price to increase faster toward the end (Fig. 76). It would cost approximately 2,67€ to dry one 20m B hose completely with infrared drying using a similar technique to that of the experiment. This result has to take cautiously because our lamp was not optimized to heat a hose but to heat the body, we know which importance has it in the case of infrared radiation (see the description of infrared radiation)

Operational speed

For this part we used in the case of microwave a proportional rule (Appendix A.3). This rule does not work for infrared because of its principle.

Conclusion

From the results, we can conclude that infrared heating effectively dries the hoses without damage. However, this method is rather time consuming. With the addition of forced convection, we are able to reduce the temperature of the hose while drying and speed up the drying process. We would expect different results with different colored hoses, and damage may result if the temperature of the inside rubber exceeds 70ºC. It is important to note that our results are representative of an infrared lamp (for heating), not an infrared dryer (for drying). The principle is the same, but the energy and efficiency are not.

9. Suggestions

From our results, our first conclusion is that microwave and infrared drying are expensive methods when compared to current methods. Because of this, and the possible damage caused by long exposure with these methods, we would not recommend a process that solely dries a fire hose with one of these methods. Thus, our suggestion is to incorporate such a method into an existing process, using it just after a mechanical method has pre-dried the hose. This would be represented by the first phase of the drying process, where the powerful method is used to quickly raise the temperature of the water molecules. For example, according to the graph below (Fig. 77), we would use the infrared for approximately the first 1 minute and 30 seconds.

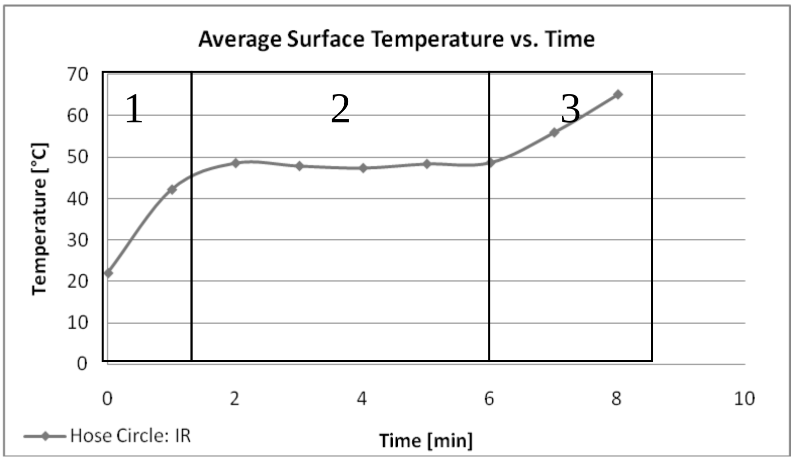


Fig. 77 Average Surface Temperature vs. Time, IR

Phase 1 The material is heated and the water starts to evaporate.

Phase 2 The water continues to evaporate because of the heat produced in phase one. The temperature remains or increases slowly during the entirety of the phase.

Phase 3 All water has evaporated and the temperature on the surface increases extremely.

The objective of this step would be to heat the water quickly in a short period of time, and then remove the remaining liquid and vapour using a system that requires less energy and does not cause damage to the hose.

We would suggest the following three step process. A mix of one method from each of the 3 steps would be recommended. Below are listed the possible methods with which we have experimental data:

Pre-drying: Mechanical methods	Heating of water: Powerful methods	Evaporation: Air convection
• Vacuum	• Infrared	• Forced
• Centrifugation	• Iron	• Natural
• Wipe	• Microwaves	
• Air knives		
• Squeeze rolls		

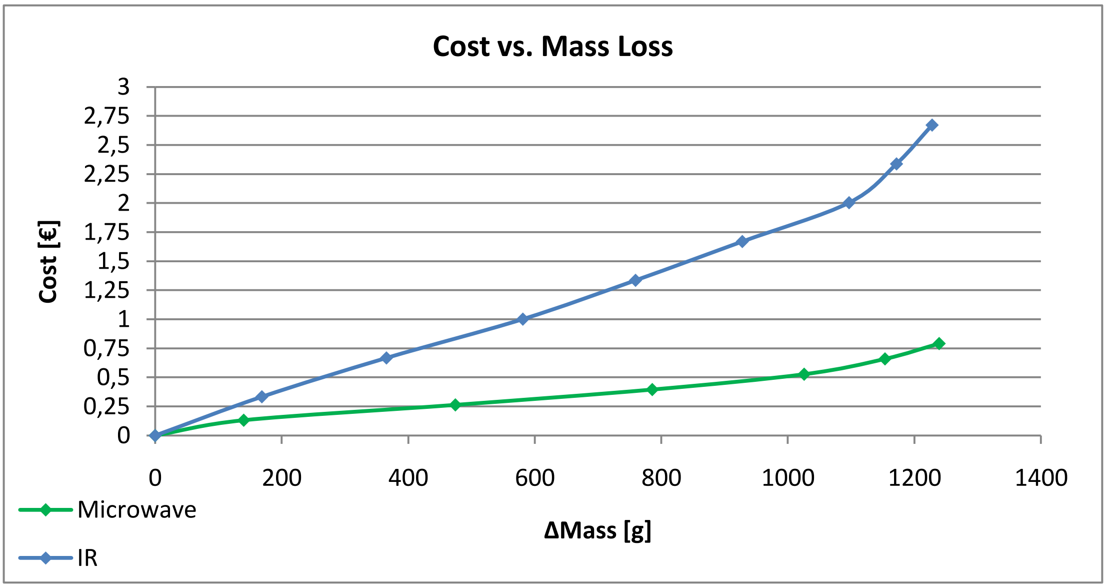


Fig. 78 Cost vs. Mass Loss, MW, IR

According to the experimental results we determined the best technology for the "Powerful method" to be microwave heating because it provided a faster drying time and was cheaper than infrared. The microwave heated the water faster and with less energy.

First we must decide which technology should be suggested for pre-drying. Rud. Prey has already performed experiments testing the majority of the mechanical methods (Appendix D), and from their results, it is clear that suction is the most effective method of pre-drying a fire hose.

For the last step, we would suggest forced convection because it requires less time than natural convection and ultimately achieves the same level of dryness. Although forced convection requires additional use of energy, the time saved is more important when considering a process system.

Thus, our suggestion is the following:

For pre-drying, we suggest to use suction. For the next step, use microwaves to achieve the evaporation temperature faster than with existing technologies. After this, we recommend using forced convection because it is cheaper than using microwaves for the whole evaporation process.

10. Experiment of Our Suggestion

In order to test the suggestion made from the initial experiments, a final experiment was performed using the three suggested processes. Our objective was to see if the efficiency would be greater than using only microwave radiation. Several experiments were made, and we hoped to find the most effect time interval for microwave drying. This would theoretically provide a small scale example of a hypothetical machine. For this experiment we wanted to determinate:

- Time to dry a piece of hose
- Power that we need to dry
- Mass Loss vs. Time to see the efficiency of the method

10.1. Experiment and Results

Materials

- Vacuum cleaner with 0,93K watts of power (Ribo-GmbH T90)
- Microwave oven with 900 watts of power (Siemens HF24022)
- Hair dryer with 1800Wwatts of power (Boman CB870)
- Scale (Satorius Type 1547)
- 2 pieces of dry 'B' hose with a length of 20 centimeter (Hose '11' and Hose '12')
- Bucket of water

Procedure of the Experiments

The goal for the four experiments was to measure the mass (Mass[g]) versus the time (t[s]) and calculate the difference in mass as the hose dried. Our procedure was the same in each experiment, and it is as follows:

1. Weigh the dry hose
2. Soak the hose in water for 10 minutes

3. Weigh the wet hose
4. Remove the excess water on the wet hose by suction, using the vacuum cleaner specified above for 5 seconds on each side of the hose
5. Weigh the pre-dried hose
6. Put the hose in the microwave oven
7. Take the hose out of the oven after the time described in the explanation of each experiment
8. Weigh the hose
9. Blow the fire hose with a hair dryer at full power for 10 seconds on each side
10. Weigh the hose after each 20 second interval until it becomes dry or damaged.

1st Experiment: Fire hose '11'

Three Phase Procedure:

- 1st Step: After weighing the dry hose, 5 seconds of suction was performed on each side of the hose and it was weighed.
- 2nd Step: The hose was placed for 40 seconds inside the microwave oven and weighed afterward.
- 3rd Step: Forced air convection was applied for 10 seconds on each side of the hose and weighed every 20 seconds until the hose was dry.

Results:

Weight of dry hose:	101,51g.
Weight of wet hose:	120,24g.
Weight of the hose after Suction:	115,82g.
Weight of the hose after Microwave:	113,54g.

t [s]	0	20	40	60	80	100	120	140	160	180	200	220	240	260
Mass [g]	113,54	111,41	110,1	108,85	107,71	106,95	105,95	105,17	104,43	103,83	103,19	102,76	102,35	101,76
Δ Mass [g]	0	2,13	3,44	4,69	5,83	6,59	7,59	8,37	9,11	9,71	10,35	10,78	11,19	11,78

Table 23 Data Collection for Experiment Suggestion 1

While drying the hose with the hair dryer, it was noticed that heat was being transferred to the areas surrounding the hose.

2nd Experiment: Fire hose '12'

Three Phase Procedure:

- 1st Step: After weighing the dry hose, 5 seconds of suction was performed on each side of the hose and it was weighed.
- 2nd Step: The hose was placed for 50 seconds inside the microwave oven and weighed afterward.
- 3rd Step: Forced air convection was applied for 10 seconds on each side of the hose and weighed every 20 seconds until the hose was dry.

Results:

Weight of dry hose:	101,82g.
Weight of wet hose:	120,68g.
Weight of the hose after Suction:	115,95g.
Weight of the hose after Microwave:	113,27g.

t [s]	0	20	40	60	80	100	120	140	160	180	200	220
Mass [g]	113,27	110,19	108,67	107,44	106,36	105,38	104,51	103,76	103,12	102,6	102,28	101,94
Δ Mass [g]	0	3,08	4,6	5,83	6,91	7,89	8,76	9,51	10,15	10,67	10,99	11,33

Table 24 Data Collection for Experiment Suggestion 2

Again, the surface of the table and materials surrounding the experiment increased in temperature, as the air from the hair dryer was not focused to the fire hose alone.

3th Experiment: Fire hose '12'

Three Phase Procedure:

- 1st Step: After weighing the dry hose, 5 seconds of suction was performed on each side of the hose and it was weighed.
- 2nd Step: The hose was placed for 50 seconds inside the microwave oven and weighed afterward.
- 3rd Step: Forced air convection was applied inside the hose with the hair dryer in 20 second intervals and weighed after each until the hose was dry.

Results:

Weight of dry hose:	101,82g.
Weight of wet hose:	121,58g.
Weight of the hose after Suction:	116,60g.
Weight of the hose after Microwave:	113,48g.

t [s]	0	20	40	60	80	100	120	140	160	180	200
Mass [g]	113,48	112,11	111,36	110,9	110,49	110,15	109,75	109,35	109,02	108,63	108,27
Δ Mass [g]	0	1,37	2,12	2,58	2,99	3,33	3,73	4,13	4,46	4,85	5,21

Table 25 Data Collection for Experiment Suggestion 3

This experiment was stopped after 200 seconds because the data showed that we would need too much time to completely dry the outside of the hose using forced air convection on the inside. Thus, we stopped the experiment and we concluded that the blowing of hot air is more efficient on the superficial area of the hose.

10.2. Graphs and Conclusions:

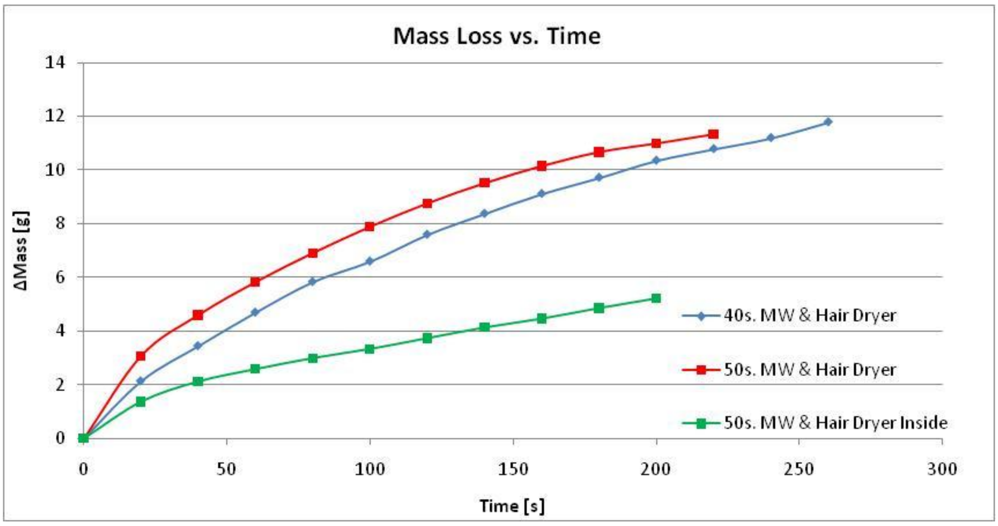


Fig. 79 Result of Mass Loss for Experiment Suggestion

In this graph we can see the comparison between the three experiments carried out in relation to the mass loss versus the time to dry. The curves show at time equal to zero that start of the forced convection process via hair dryer. In general, the convection method used on the outside of the hose was more effective than on the inside. When the 40 and 50 s experiments are compared, it shows that 40 s of drying with the microwave is slower and 50 seconds provides better results. By increasing the time of microwave exposure by 10 s, we were able to increase the overall drying time by more than 30 s. This can be explained by the greater efficiency of microwaves over forced convection in our experiment. In our suggestion we proposed the use of microwaves in the first phase of the drying process (approximately 40 s) because of the high level of energy consumption during the complete process.

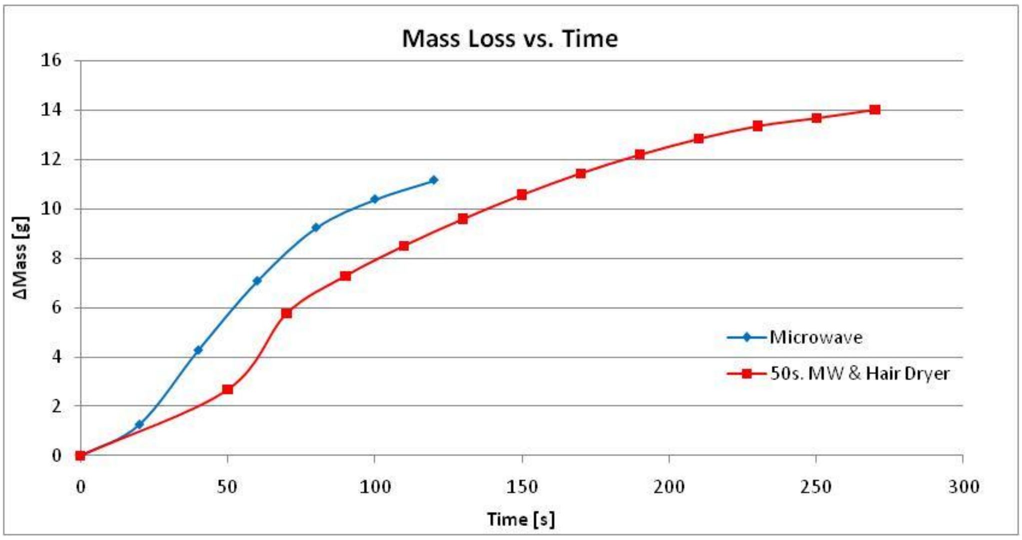


Fig. 80 Comparison of Microwave Drying alone and with the Combination

This graph shows the relationship between our proposed drying method and the initial experiment of only microwave exposure. The following data was used to generate this relationship.

t [s]	0	50	70	90	110	130	150	170	190	210	230	250	270
Mass [g]	115,95	113,27	110,19	108,67	107,44	106,36	105,38	104,51	103,76	103,12	102,6	102,28	101,94
Δ Mass [g]	0	2,68	5,76	7,28	8,51	9,59	10,57	11,44	12,19	12,83	13,35	13,67	14,01

Table 26 Data for Entire Drying Process as a Result of the First Experimental Suggestion

t [s]	0	20	40	60	80	100	120
Mass [g]	100,87	99,61	96,6	93,8	91,64	90,49	89,72
Δ Mass [g]	0	1,26	4,27	7,07	9,23	10,38	11,15

Table 27 Data from the Initial Microwave Experiment 2

We compared both experiments to verify if our suggestion is a more effective system. This would mean that the combination experiment removed at least the same amount of water, dried in less time, and used less energy. But, according to the results from the experiments, this is not the case.

However, we were unable to compare the energy consumption of both experiments because drying with the hair dryer is not an efficient method as we saw and the energy used only to dry the hose is impossible to determine. Thus, we cannot see the efficiency of our suggestion because we cannot compare it with the microwave experiment. We were unable to make the transposition of a 20 meter B hose with our suggestion.

Despite of this, we continue suggesting our improvement because the hose was not damaged and dried completely. Unlike the microwave experiment, when the hoses finished the drying process, they were damaged. Also, energy is only one aspect to be consider when developing a drying method and although we are unable to know exactly the power usage, time to dry, and water mass loss of an entire hose, the principle of remains the same and our suggested method would be effective.

11. Conclusion

The start of this report describes fire hoses, which are the foremost used equipment to fight fires. They are washed and tested regularly, and therefore need to be dried. Hoses are composed of synthetic material or cotton on the outside and rubber on the inside. The absorption of water into the material during the washing process must be removed before storage, to prevent damage from mould.

In addition, all hose drying technologies in the market from Rud. Prey and their competitors are presented. The best way to dry a hose is a hanging system, which needs a tower. Although, simple, efficient (natural air convection), and cheap with high capacity, these systems require nevertheless a tower. The tower's height can be up to twenty-five meters, which is not allowed or possible in some fire department. For this reason companies have developed alternative systems, which include drying cabinets or automatic drying systems integrated into the hose care process. All machines incorporate a technique of forced air convection to dry completely.

Our project was created to design, suggest, or improve an existing hose drying system, using research from other industrial sectors. Six methods, found primarily in textile, food-processing, and paper industries, are able to dry: three radiation methods (infrared, microwave and radiofrequency), a conduction method (using heat rolls), a chemical method (with inorganic salts) and a mechanical method (centrifuge).

Experiments show limits to these technologies, as they are expensive to dry completely and present the possibility of damaging the hose. According to a usual drying process (Fig. 77), the best way to dry is through a combination of methods, and thus one step is added to the usual drying system: after pre-drying by suction, the water is heated up by microwave radiation. The hose is finally dried by forced air convection. This method is theoretically efficient but the last experiment does not confirm this assumption, because of the waste of energy noticed during the experiment.

In conclusion, this project remains open ended, as the process of improvement and design will never end. Our results show a positive step toward the possibility of a unique technology being used to dry fire hoses. With our suggestions, the next step for the company would be to think about adding this method into a current drying process for a 20 meter B hose. Also, experimentation of drying with radio frequency and chemical drying agents, which was not experimented with, should be performed. The first step is completed; Rud.Prey has the information of beneficial methods, the tools to continue the development of this project, and the resources to carry out the design.

12. List of Figures

13. List of Tables

14. Bibliography

[1]. www.Rud.Prey.de. [Online] [Cited: May 25, 2010.]

[2]. www.Informatik.Uni-Frankfurt.de. [Online] [Cited: February 25, 2010.] http://www.informatik.uni-frankfurt.de/~osman/german-cities.html.

[3]. www.Ziegler.de. [Online] [Cited: May 31, 2010.]

[4]. www.barth-feuerwehrtechnik.de. [Online] [Cited: May 31, 2010.]

[5]. www.Bockermann-Feuerwehrtechnik.de. [Online] [Cited: May 16, 2010.]

[6]. www.Hafenrichter.de. [Online] [Cited: May 20, 2010.]

[7]. www.TopTrock.com. [Online] [Cited: April 14, 2010.]

[8]. www.Circul-Air-Corp.com/products.php. [Online] [Cited: March 29, 2010.]

[9]. Cengage, Ed. Stacey L. Blachford. Gale. *How Products are Made.* Nowember 22, 2006.

[10]. Warias, Mr. FTZ Steinburg, April 8, 2010.

[11]. Mangueras Contra Incendios. Santo Domingo, D.N. : Academia del Cuerpo de Bomberos del Distrito Nacional, 2009.

[12]. www.Wikipedia.org. [Online] [Cited: June 2, 2010.] http://de.wikipedia.org/wiki/Feuerwehrschlauch.

[13]. Dettmer, Mr. FTZ Zeven, May 27, 2010.

[14]. Jahns, Mr. BF Kiel, April 19, 2010.

[15]. Böll, Ms. Rud. Prey GmbH & Co. KG, Kiel, June 1, 2010.

[16]. Krutina, M.F.H. *Allgemeine Meteorologie – Wolken und Niederschlagskunde.* WDS Langen : s.n., 2005.

[17]. G.Cerbe, H.-J. Hoffmann. *Einführung in die Thermodynamik.* 13th Edition, 2002.

[18]. Kuchling, H. *Taschenbuch der Physik.* 17th Edition, 2001.

[19]. Mujumdar, A. S. *Handbook of industrial Drying.* s.l. : CRC Press, 3rd Edition, 2007.

[20]. www.lenntech.es. [Online] [Cited: May 4, 2010.] http://www.lenntech.es/centrifugacion.htm.

[21]. www.gmfgouda.com. [Online] [Cited: May 3, 2010.] http://www.gmfgouda.com/drum-dryer/info-drum-dryer.html.

[22]. www.spiraxsarco.com. [Online] [Cited: May 2, 2010.] http://www.spiraxsarco.com/resources/steam-engineering-tutorials/steam-traps-and-steam-trapping/selecting-steam-traps-industrial-dryers.asp.

[23]. www.scielo.cl. [Online] [Cited: May 2, 2010.] http://www.scielo.cl/scielo.php?pid=S0718-07642008000400006&script=sci_arttext.

[24]. Grossin, D. *Développement du Procédé de Chauffage Micro-Ondes en vue de l'Elaboration de Céramiques à Propriétés Electriques Particulieres.* Université Caen : s.n., 2006.

[25]. www.TRS-online.com. [Online] [Cited: May 20, 2010.]

[26]. www.phoseon.com. [Online] [Cited: May 5, 2010.]

[27]. www.honleuv.fr. [Online] [Cited: May 15, 2010.]

[28]. www.futura-sciences.com. [Online] [Cited: May 12, 2010.]

[29]. www.trs-online.com. [Online] [Cited: May 13, 2010.] http://www.trs-online.com/ir-uv.php.

[30]. www.radiantpanelassociation.org. [Online] [Cited: May 10, 2010.] http://www.radiantpanelassociation.org/i4a/pages/index.cfm?pageid=1 .

[31]. www.ademe.fr. [Online] [Cited: May 12, 2010.] http://www.ademe.fr/entreprises/energie/procedes/docs/Complet_ERadiant.pdf.

[32]. Publique, Office Fédéral de la Santé. *Four à Micro-Ondes.* Swiss : s.n., 2009.

[33]. Jambhale, A. S. *Microwave Drying System with High-Tech Phase Controller: A Modified Applicator.* 2008.

[34]. Solvents Explained. *AmericanChemistry.* [Online] 2010. http://www.americanchemistry.com/s_acc/sec_solvents.asp?CID=1483&DID=5586.

[35]. How do Solvents Work? *European Solvents Industry Group.* [Online] 2010. http://www.esig.org/en/about-solvents/what-are-solvents/how-do-solvents-work/.

[36]. Safety and Health Tips: Solvents. *United States Department of Labor: Occupational Safety & Health Administration.* [Online] August 29, 2007. http://www.osha.gov/SLTC/solvents/index.html.

[37]. Drying Agents. *Sigma-Aldrich.* [Online] Sigma-Aldrich Co., 2010. http://www.sigmaaldrich.com/chemistry/aldrich-chemistry/tech-bulletins/al-143/drying-agents.html.

[38]. Weiss, Bill. Chemical Drying Agents in Harvesting Legume Hay. *The Ohio State University Extension.* [Online] http://ohioline.osu.edu/agf-fact/0011.html.

[39]. The Interactive Lab Primer. *Chemistry for Our Future.* [Online] http://chem-ilp.net/labTechniques/DryingAgentsForLiquids.htm.

[40]. Drying Agents. [Online] September 22, 2009. http://www.chem.ucla.edu/~bacher/Specialtopics/Drying%20Agents.html.

[41]. Inc., GEA Process Engineering. www.niroinc.com. [Online] [Cited: June 2, 2010.] http://www.niroinc.com/food_chemical/flash_drying_concepts.asp.

[42]. Stadwerke Kiel. [Online] January 03, 2010. http://www.stadtwerke-kiel.de/index.php?id=privatkunden__strom__strombasis.

[43]. *Consejo De Federaciones De Bomberos Voluntarios De La Republica Argentina.* 2006.

[44]. Magnesium Sulfate. *Material Safety Data Sheet.* [Online] J.T. Baker, May 19, 2008. http://www.jtbaker.com/msds/englishhtml/m0234.htm.

[45]. Lab Techniques. *CU Boulder Organic ChemistryUndergraduate Courses.* [Online] http://orgchem.colorado.edu/hndbksupport/drying/drying.html.

[46]. Solvents Drying and Drying Agents. *AnalChem Resources.* [Online] http://delloyd.50megs.com/moreinfo/drying.html.

[47]. www.bepex.com. [Online] [Cited: May 2, 2010.] http://www.bepex.com/indirectdrying.htm.

15. Appendices

15.1. Appendix A: Microwave Experiments

A.1 Complementary Graphs of the 1st Experiment

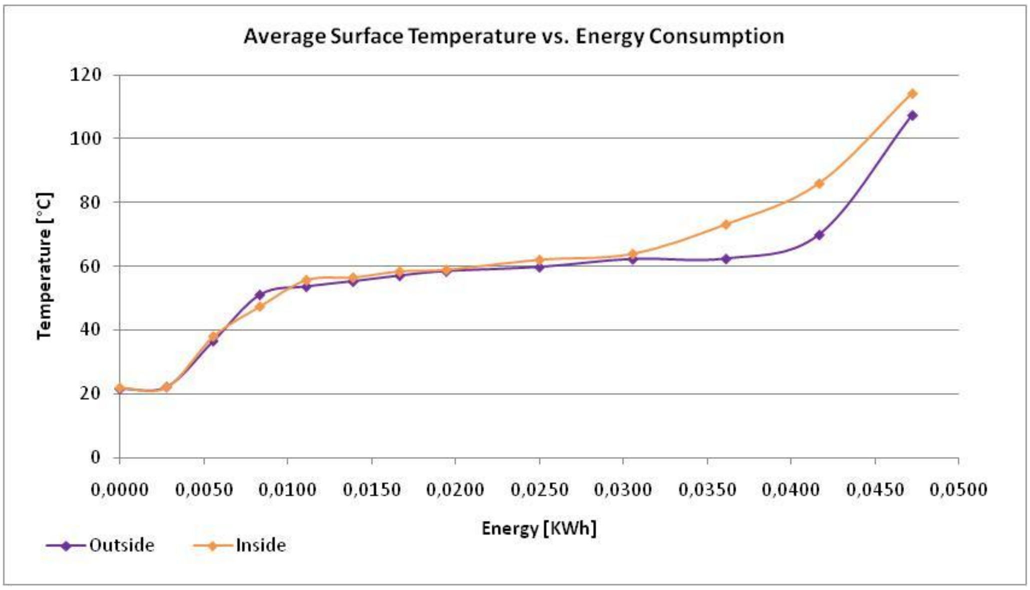


Fig. 81 Hose 'A' Average Surface Temperature vs. Energy Consumption

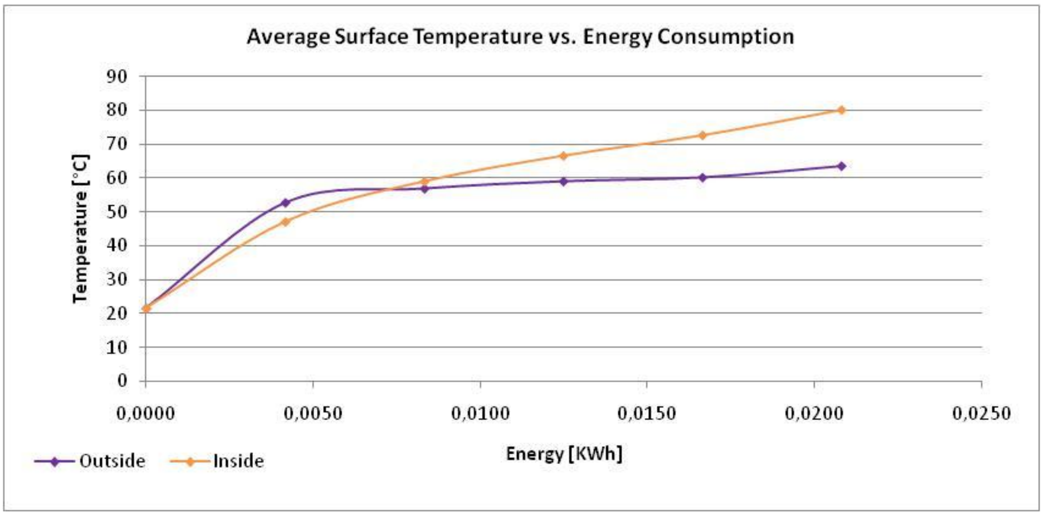


Fig. 82 Hose 'C' Average Surface Temperature vs. Energy Consumption

A.2 Complementary Graphs of the 2^{nd} Experiment

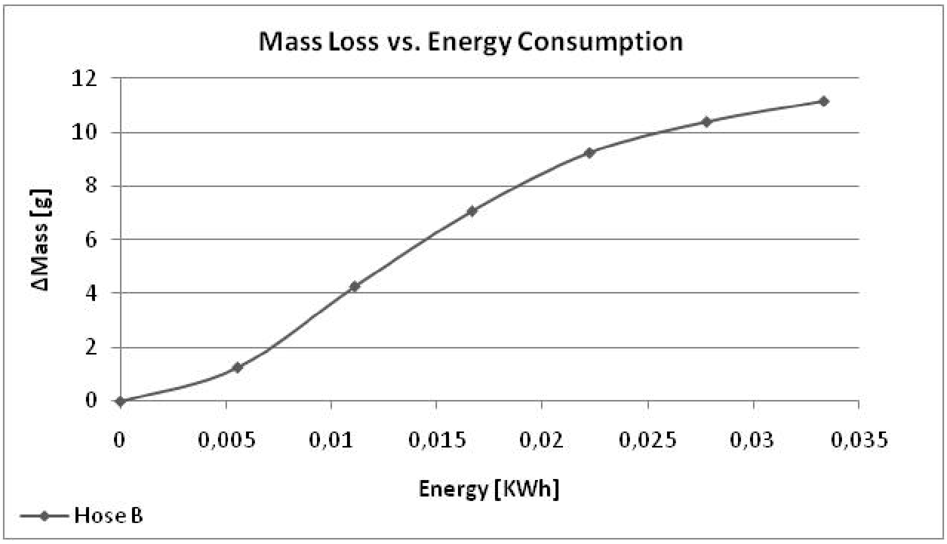


Fig. 83 Hose 'B' Mass Loss vs. Energy Consumption

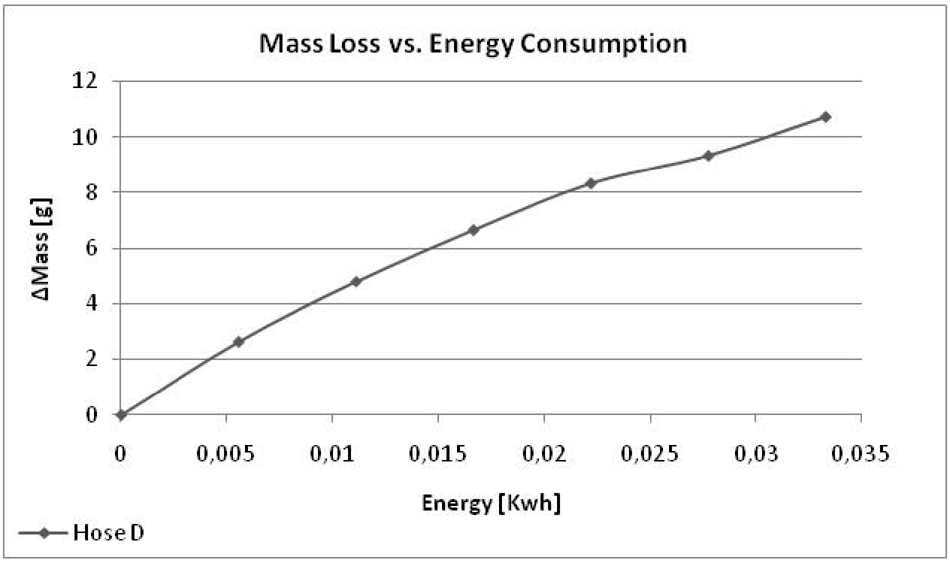


Fig. 84 Hose 'D' Mass Loss vs. Energy Consumption

A.3 Interpretation of the Graph: Microwave Power vs. Operating Speed.

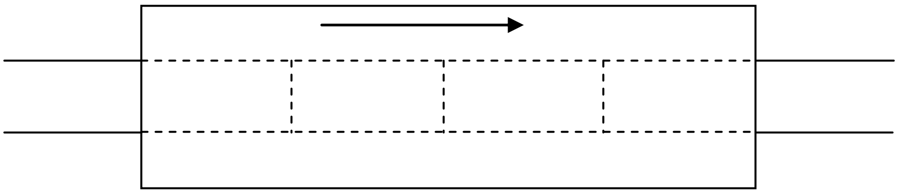
The result, at first glance, is strange because the speed of the hose does not depend of the size (in meters) of the microwave. The below explanation will clarify this:

In both cases we considered:

- Microwave power: 1kW
- Process speed: 1m/s

These numbers are used just as an example for explaination.

Case 1. Size of the Hose in Microwave: 4m



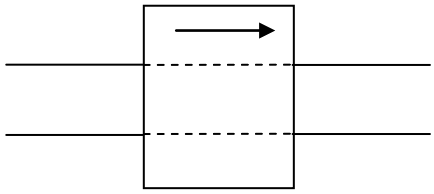
In this case, 4m of hose are in the microwave at the same time, and each 1m section of hose does not receive 1kW, but only 250W (1000/4) and this exposure is for 4s. Therefore, the piece receives:

$$E(kWh) = P(kW) \times T(h)$$

$$E_1 = 0.250 \times \frac{4}{3600}$$

$$\underline{E_1 = 0.277\ Wh}$$

Case 2. Size of the Hose in Microwave: 1m



In this case 1m is in the microwave so:

$$E_2 = 1 \times \frac{1}{3600}$$

$$\underline{E_2 = 0.277Wh}$$

Thus, the size does not influence the speed for a given powered microwave.

15.2. Appendix B: Infrared Experiments

B.1 Complementary graphs of the 1st experiment:

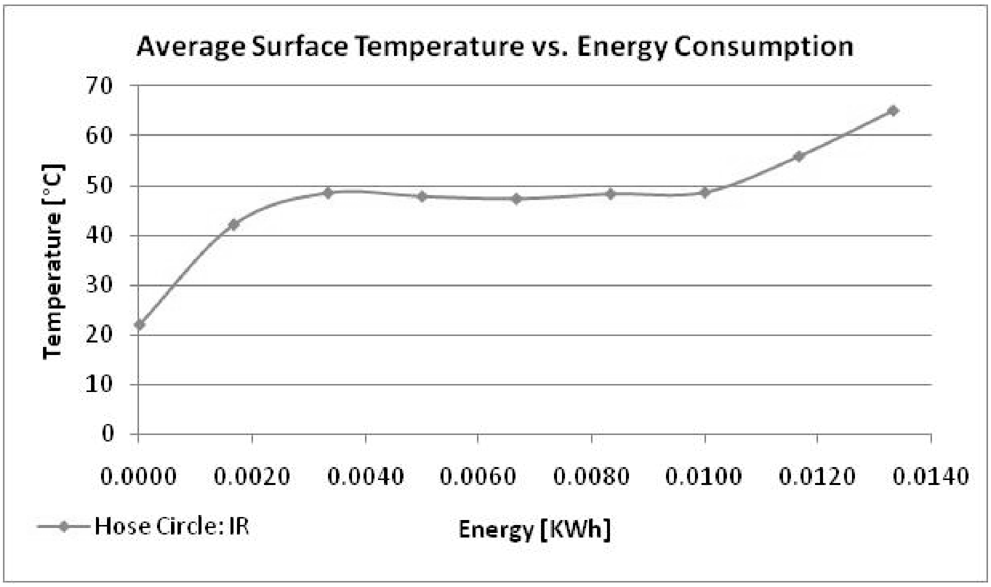


Fig. 85 Average Surface Temperature vs. Energy Consumption, IR

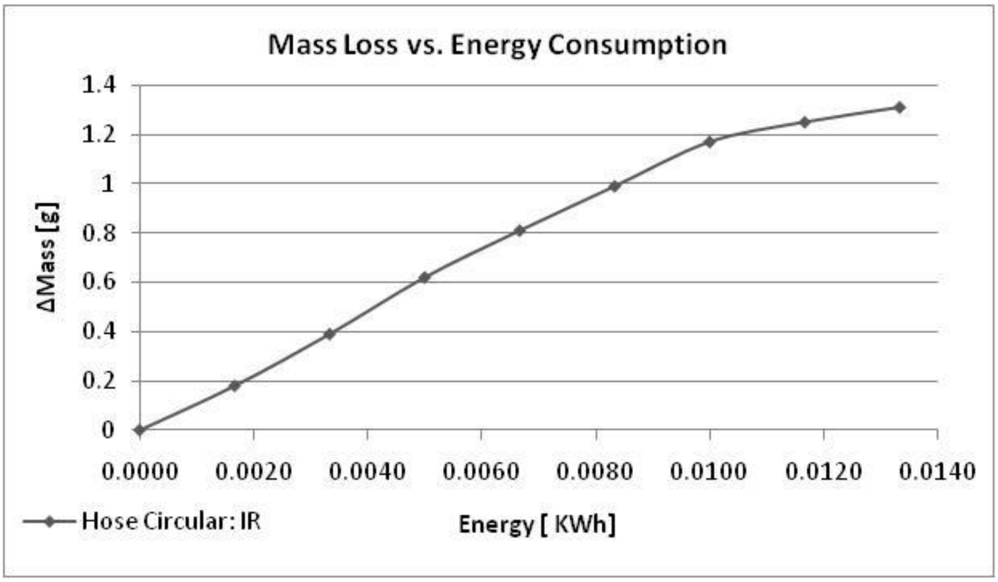


Fig. 86 Mass Loss vs. Energy Consumption, IR

B.2 Complementary graphs of the 2^{nd} experiment:

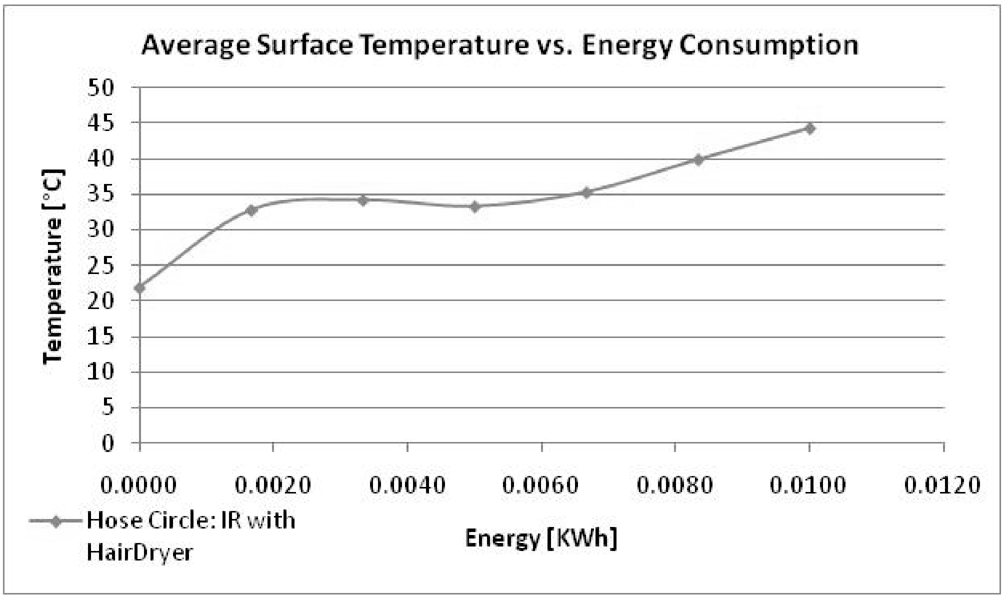


Fig. 87 Average Surface Temperature vs. Energy Costs, IR with Hair Dryer

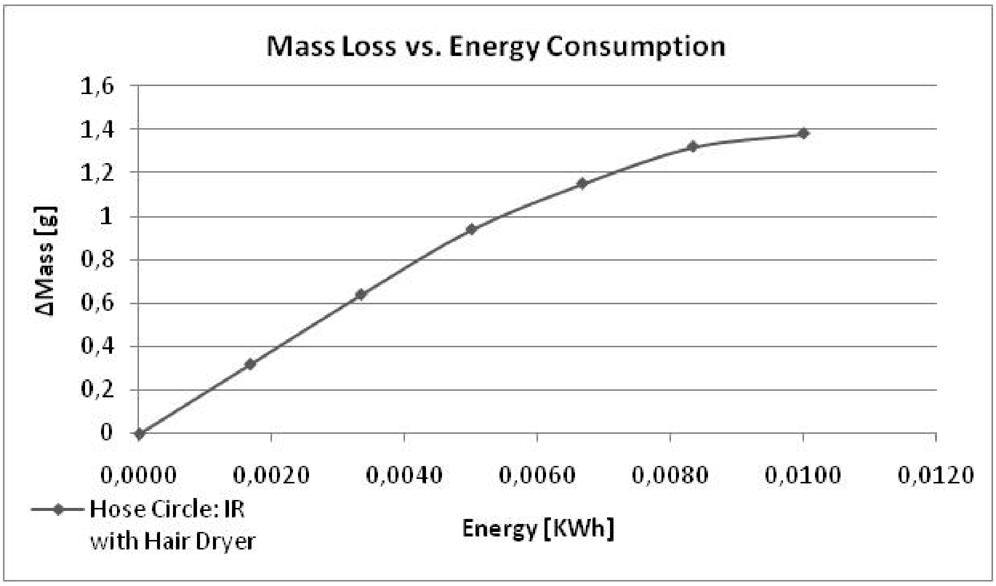


Fig. 88 Mass Loss vs. Energy Consumption, IR with Hair Dryer

15.3. Appendix C: Fire Department Visit Notes

C.1 FTZ in Steinburg

Date: 8 April 2010

We visited the fire department in Steinburg where they train new fire fighters. They use the drying system for all hoses of fire departments around Steinburg. They use the Hanging system of Rud.Prey to dry with a maintenance system to clean and test.

Use:

- 6000 hoses of 103 fire departments
- Easy to use and to understand how it works so easy to find where comes from a problem

Working time:

- 2/3 days to dry in summer
- 1/1.5 weeks to dry in winter (with a system to heat air)
- 10 min working time (without drying time)

Hoses:

- 17 lanes, 22B or 25 C hoses per lane
- Approximately 400 hoses

Maintenance:

- One time per year
- More at the beginning because of small problems

Safety:

- Hose can fall down when a push arm sensor is broken or if adapters aren't use right

Prize:

- 135000€ (+taxes): hanging + maintenance

Positive things:

- Fast
- Cheap to dry
- Possible to leave a lot of hoses in the same time

Negative things:

- Dangerous sometimes

Improvements:

- Maintenance sheet in the middle of hanging device for use all the lanes quickly
- Roll

C.2 Main Fire Department in Kiel

Date: 19 April 2010

Global information:

Automatic hanging system from Hafenrichter

- Hose capacity in all Kiel fire dep. and trucks:
  - Approx. 1200 B hoses +- 50
  - Approx. 1200 C hoses +- 50
  - Seven 35 meter hoses for ladders (it is not allowed to have a coupling on the ladder, this is why these hoses are so long)
  - Time for washing = time for hanging hose up

Maintenance system (horizontal street):

- Maintenance street for up to 20 m long hoses (B-hoses)
- Day capacity for maintenance process: up to 80 hoses per 8-h-day
- Pressure testing at 12 bar for 2-3 minutes (will be updated to 16 bar)
- Breaking of the hose:
  - 80 % breaks near to the coupling
  - Rest: damage in hose itself because of pre-damages when a car drives over the hose or it is pulled trough fire or broken glass
- Water for pressure testing is used for approx. 4 weeks (is stored in two 50 litter basins under the maintenance. street)

Automatic hanging system:

- Full tower (25 m high) for up to 140 hoses
- 14 lanes (10 B hoses or 13 C hoses per lane)
- Adaptor just for transporting the hose, in lane it hangs on coupling
- 3 or 4 days for drying (depends of the weather etc.)
- In winter: heater for warm up the air, but needs a lot of energy
- For ventilation: 2 windows can be open at the top of tower and 2 doors on the floor (manual opening/closing)

- Maintenance interval: 1 time / year
- If something is broken they repair it themselves (time to get service from company: approx. 4 weeks)

What brakes in this system?

- Adaptor is not well positioned in the positioning pipe of the crane –> pos. pipe deforms

Fire hoses:

- B hose: 75 mm of diameter
- C hose: 42 or 52 mm of diameter, but in future only 42 mm of hoses, because it is easier to handle for the fire fighter
- Bright yellow as new color for the hoses, because it is easier to see at night
- Difference between wet and dry hose: approx. 1 kg -> textile fabric don't absorb much water
- For hose material it is not bad to be rolled up or stored wet, but it starts to smell if there is not enough ventilation
- Approx. 50 to 100 hoses gets broken per year
- Hose life time is up to 30 years

Hose basket:

- 3 C hoses inside, clutched together
- Fix top end of hose and run -> hoses unfold themselves out of the basket
- Easy and fast way to lay out hoses

Improvements:

- Maintenance street:
  - You cannot stop the running process (4-edge-program)
  - Wagon for pulling the hoses drives always till the end of the street to stop the washing machine (even if the hose is just 5 meter long…)
  - Wagon takes 2 minutes to drive from end to start of street
  - You cannot change the speed of the wagon
- Hanging system:

- Positioning system in the crane takes too long
- Fire department has idea to make it faster, but if they do it, they would lose the warranty for the system
  - For folding the hose at the half:
    - Push button when hose touches the ground so system knows the length of it
    - Let hose more down to the half and roll it up doubled
    - Problem: imprecise for 10 to 15 cm

Fire fighting cars:

- Special cars:
  - Container system -> easy and fast to equip the cars (3 minutes)
  - Container for heavy load (including a crane) for car crashs, trees etc., chemical accidents,

- Standard fire fighting cars:
  - Fire extinguishing cars with 2000 litter water basin, 6 persons
  - With ladder, 2 persons
  - Leading car, 2 persons
  - Standardized packing system for all of the equipment in every car in Kiel

Miscellaneous:

- Costs for maintenance street + hanging system: approx. 100,000 Euro
- Additional use of tower as radio station for fire fighting cars and mobile phones
- 6 years ago: Prey system, but it was too old -> new system -> open tendering for new system -> Hafenrichter was cheaper than Prey so they get the assignment
- Old Prey system hold more than 200 C hoses
- For becoming a fire fighter you first have to do an apprenticeship as metalworker, electrician, mechanician

C.3 FTZ in Zeven

Date: 27 May 2010

Drying system: Horizontal Process Dryer for 4 hoses

Cost of Machine: 115000€

Maintenance: once/year, pay extra

Personal Comments:

- Ease of operation, Comfort, and Safety are very good
- Problem is the noise (78dB)
  - Insulation box for water pump (pressure testing) to reduce
  - Suggestion to have pumps and loud machines in different room
- Only twice the roll-up device has broken
  - Overall is a positive
  - Shorter drying time
- Filling hoses with water up to 3 bar takes too long

Test Pressure: 12bar

Drying Time:

- 10-15min – new hoses
- 20-30min – old hoses

Air Temperature while drying: 60°C

155 Fire Departments in Area:

- 4000 hoses total
- 5500-6000 maintained per year

Hoses Dried/day:

- 35-40 – old hoses / Up to 80 – new hoses

15.4. Appendix D: Company Documents

5.9 The Decision Matrix

DECISION MATRIX: DRYING METHODS															
		Cat. Wt	Weight[1]	Process Dryer [RUD. PREY]			Circulating Cabinet [RUD. PREY]			AST [Hafenrichter] [2]			MSP [Ziegler] [3]		
Compatibility (Hose)		6			0,3			0			0,45			0,45	
	A (20m)		3	yes, need adapter	5	15	no	0	0	yes, as option	5	15	yes, as option	5	15
	B (35m)		3	yes, as option	5	15	no	0	0	yes	10	30	yes	10	30
Costs [€]		54			2,22			5,36			3,88			3,18	
	Machine (initial purchase) [4]		50	115 000	4	200	12 500	10	500	10 000	10	500	82 000	6	300
	Operation (Drying 1 hose) [5]		2	0,16	6	12	0,11	8	16	0,09	9	18	0,20	4	8
	Maintenance (Once/year) [6]		2	1500 [7]	5	10	no maintenance [8]	10	20	no maintenance	10	20	1500	5	10
Design/Ergonomics [9]		12			1,03			1,12			0,9			0,69	
	Aesthetics		1	ok	5	5	ok	5	9	ok	5	5	ok	5	9
	Comfort		3	good	9	27	good	9	27	ok	5	15	not good	4	12
	Ease of Operation (Training)		3	2 days [10]	7	21	some minutes [11]	10	30	some minutes	10	30	2 days [12]	7	21
	Functionality		3	Very good	10	30	very good	10	30	good	8	24	ok	5	15
	Safety		2	very good	10	20	very good	10	20	good	8	16	good	8	16
Energy [kWh/Hose]		5			0,25			0,4			0,35			0,15	
	Energy to Dry 1 hose [13]		5	0,75	5	25	0,52	8	40	0,4	7	35	0,93	3	15
Noise [dB(A)] in 1m Distance		2			0,02			0,1			0,1			0,06	
	Machine Operation		2	88 [14]	1	2	70 [15]	5	10	70	5	10	80 [16]	3	6
Space (Machine Requirements) [m]		14			0,77			1,4			0,98			0,77	
	Length		7	24,5	2	14	0,75	10	63	2	7	49	3	6	42
	Width		7	0,85	9	63	0,75	10	63	2	7	49	4	5	35
Speed [min]		7			0,63			0,42			0,42			0,7	
	Time to Dry 1 hose		7	10 [17]	9	63	37	6	42	40	6	42	7,5 [18]	10	70
Total		100				**5,22**			**8,8**			**7,08**			**6**
										Circulating Cabinet			Vertical rotating system		

General information from websites and advertising fliers

1 Source: determined by Mr Prey (Meeting on 10 May 2010)
2 Assumption: same kind of system as Circulating Cabinet of Prey, so nearly the same data
3 No clear data, so assumptions are used, comparison to Rotating System of Prey
4 All prices from Mr. Prey (Meeting on 10 May 2010)
5 Actual Price of 1 kWh in Kiel is 21.36 cent (Source: Stadtwerke Kiel, StromBasis-Contract, 28 May 2010)
6 Maintenance costs depend very strong on sort of Inspection and distance between company and system
7 Estimated Price for a general inspection for a 2-Hose-Horizontal Process Dryer located in Bavaria (Source: Ms. Böll from PREY, 28 May 2010)
8 Source: Instruction Handbook of Circulating Cabinet, page 5
9 Very subjective data Source: visit of fire departments and Rud. Prey (Appendix C)
10 Source: Mr. Dettmer from FTZ Zeven, 27 May 2010
11 Source: Ms. Böll from Prey, 28 May 2010
12 Assumption: seems as substantial/complicate as Horizontal Process Dryer of Prey, so same time for training is needed
13 Data see Power Calculation
14 Source: Schallmessung SPS-H from Prey (received from Ms. Böll, 28 May 2010)
15 Assumption: 70 dB(A) correspond with noise of vacuum cleaner in 1m distance (Source: http://www.sengpielaudio.com/TableOfSoundPressureLevels.htm)
16 Assumption: 80 dB(A) correspond with noise of Kerbside of busy road in 5m distance
17 20m-B-Hose with synthetic textile surface, approx. 3 years old (Source: Mr. Dettmer, FTZ Zeven, 27 May 2010)
18 Source: http://www.ziegler.de/fileadmin/pdf/06/kap06_kompl_dt.pdf , page 4-5

Versuchsbericht

Thema: **Einfluß verschiedener Effekte auf die Entfeuchtung beim RSPZ-Pflegeprozeß**

Ort: Werkhalle Rud. Prey, Kiel

Datum: 28. + 29.11.2002 sowie
18.12.2002 (Nässeabsaugung)

Teilnehmer: Heine, Böll

1 Versuchszweck

Gegenüber einer konventionellen Turm- oder Prozeßstraße wird der Schlauch in einem RSPZ in ganz anderer Art durch die Anlage geführt und gehandhabt. Durch die Art der Behandlung ergibt sich möglicherweise ein Potential für eine zufriedenstellende Trocknung des Schlauch-Außenmantels, welcher der einer Prozeßstraße nahe kommt. Sollte dies der Fall sein, so hätten wir mit dem RSPZ einen Wettbewerbsvorteil, da wir für die Außenentnässung kein zusätzliches Trocknungsgerät wie z.B. Fa. Hafenrichter einsetzen müssen. Optimierungsmaßnahmen würden nur einen geringen zusätzlichen Aufwand erfordern, da ja alle Behandlungsschritte durchlaufen werden müssen!

Der Einsatz des Schlauch-Durchlauftrockners wäre dann eine Option, welche nur bei einem hohen Trocknungsanspruch durch die FW zur Anwendung kommt.

Die Art der Schlauchbehandlung sowie die Beobachtungen / Effekte sind unter "Erkenntnisse" aufgeführt.

2 Versuchsdurchführung

Als Versuchsmaterial dienen 3 typische Schläuche mit unterschiedlicher Oberflächenstruktur:

Nr	Größe	Länge	Gewicht (trocken)	Farbe	Fabrikat / Bezeichnung	Innen-Restnässe nach Auswalkung	Feuchte fühlbar bis Restfeuchtegehalt
1	C 52	15,0 m	5643 gr	rot	Parsch Synthetik 3Z Color	104 gr	150 gr
2	B	19,5 m	9884 gr	weiß	Weico Diamant SL	232 gr	263 gr
3	B	16,65	16111 gr	weiß	Bund ZS	246 gr	250 gr

Der zu prüfende Schlauch wird mit dem RSPZ gepflegt, wobei anfangs bereits nach dem Einschleppen der Prozeß abgebrochen und der Schlauch gewogen wird. Danach wird der Prozeß von neuem gestartet, wobei dann der Prozeß einen Behandlungsschritt weiter geführt wird. Auf diese Weise werden die Effekte der einzelnen Behandlungsschritte in Folge erkennbar.
Die während der Versuche eingehaltenen Zykluszeiten sind im Anhang aufgeführt.

3 Erkenntnisse

Die Restfeuchtigkeit wurde durch wiegen des Schlauchmaterials erfaßt. Bei den angegebenen Gewichten ist zu beachten, daß die Wiederholgenauigkeit zwischen mehreren gleichartigen Prozessen bei ±15 gr liegt.

Die in obiger Tabelle angegebene Innennässe nach dem Auswalken wurde durch Differenzwägung mit zwischengeschalteter Innentrocknung ermittelt.
Die nachfolgenden Behandlungsweisen haben folgenden Effekt auf die Mantelentnässung:

3.1 Schlauch steht senkrecht

Der Schlauch wird nach dem Vorweichen in eine senkrechte Position gedreht. Die Nässe kann nicht auf dem Mantel stehenbleiben.
Dieser Behandlungsschritt ist der Ausgangspunkt für die weiteren Effekte.

3.2 Nässe wird in SWM nach unten abgefeuert

Wie bei 3.1 ist das Saugvermögen des Gewebe-Schlauchmantels maßgeblich für den Effekt. Bei dem nur wenig saugfähigen Schlauch Nr. 2 wird eine geringfügige Entnässung gegenüber 3.1 beobachtet. Bei den Schläuchen Nr.1) und 3) tritt eine Befeuchtung auf.
Fazit: **Effekt vernachlässigbar klein!**

3.3 Auswalkeinrichtung mit leerem Schlauch

Gegenüber den vorangegangenen Behandlungsschritten tritt bei allen Schläuchen nur eine geringfügige Entnässung knapp über der Wiederholgenauigkeit auf.
Fazit: **Effekt vernachlässigbar klein!**

3.4 Auswalkeinrichtung mit gefülltem Schlauch

Die Schläuche Nr. 1) und 2) weisen eine Gewichtszunahme von 130 gr (C-Schlauch) bzw. 45 gr (B-Schlauch) auf. Diese ist jedoch auf die Vergrößerung der Innen-Nässe zurückzuführen. Beim saugfähigen Schlauch Nr. 3 ist eine Gewichtsabnahme zu notieren, obwohl hier die Innennässe höher sein dürfte.
Bei allen Schläuchen läßt sich etwas stauende Nässe vor der Auswalkrolle – und zwar nur im unteren Schlauchdrittel – beobachten. Diese kann nicht schnell genug und nicht vollständig nach unten ablaufen. Die Nässe wird mit um die Auswalkrolle gezogen. Nur beim Schlauch Nr. 3) ist die Wassermenge so groß, daß sie in geringer Menge an der Auswalkeinrichtung ablaufen kann.
Fazit: **Effekt gering!**

3.5 Druckprobe mit Auswalkung

Steht der Schlauch unter Prüfdruck, dann wird das Außengewebe stark gepreßt. Das enthaltene Wasser gelangt an die Oberfläche und läuft außen teilweise ab. Das nach Außen gepreßte Wasser läßt sich als Wasserfilm bzw. als Tropfen an der Oberfläche beobachten.
Die Entnässung beträgt ca. 100g beim C-Schlauch und 200gr beim B-Schlauch (beide Gewebearten!) und übertrifft damit alle im Pflegeprozeß vorangegangenen Effekte. Nach erfolgter Druckprobe läßt sich an der Auswalkrolle auch keine stauende Nässe mehr wie unter 3.4 beobachten.
Der von der Auswalkrolle auf den Wickler gezogene Schlauch ist im unteren Drittel fühlbar feuchter als an der Oberkante.
Am unter Prüfdruck stehenden Schlauch Nr. 1) wurde exemplarisch die Außennässe mit einem Tuch abgewischt. Die Restfeuchte ließ sich damit um weitere 150 gr. verringern. Hier besteht noch Potential!
Fazit: **Bedeutender Effekt !**

3.6 Druckprobe ohne Auswalken

An Stelle der Auswalkeinrichtung wurde der Schlauch hier nur auf den Wickler umgelenkt.
Bei allen Schläuchen wird eine Gewichtszunahme notiert, welche die positive Wirkung des Effektes 3.4 wieder aufhebt. Diese Gewichtszunahme liegt in der Erhöhung der Innennässe begründet.
Fazit: **Effekt Nachteilig!**

3.7 Absaugeinrichtung

Es kam eine verbesserte Absaugdüse zum Einsatz, welche optimal kleine Saugspalte gewährleistet. Somit bleibt ein hoher Unterdruck während des Absaugens erhalten. Die zwischen Schlauch und Düse einströmende Luft hat damit immer eine maximale Geschwindigkeit und kann dadurch die Feuchtigkeit aus der obersten Gewebeschicht mitreißen.
Gegenüber 3.5 läßt sich die dort vorhandene Restfeuchte um weitere ca. 10% vermindern - beim saugfähigen Schlauch Nr. 3) sogar um 20%! Dies entspricht der dortigen Wirkung des "Außen-Abwischens" unter Prüfdruck.
Eine Halbierung der Zuggeschwindigkeit während des Absaugens bringt nur eine Verbesserung in Größenordnung der Meßgenauigkeit.
Der Trocknungseffekt der Absaugung ist bei praxisgerechten Zuggeschwindigkeiten hauptsächlich von der Außenfeuchte des Schlauchmantels abhängig. Der Effekt der Absaugung überdeckt den der Druckprobe unter 3.5!
Fazit: **Bedeutender Effekt!**

3.8 Nachtrockenstrecke

Die Erprobung wird wegen folgender theoretischen Überlegungen verworfen:
Bei einer Heißluftbeaufschlagung wird das Wasser durch Verdunstung abgeführt. Die Verdunstungswärme muß dem Schlauch zwischen Auswalkeinrichtung und Wickler über die Heißluft zugeführt werden. Dabei wird dem ca. 1m langen Schlauchstück eine Wärme von

$Q = \alpha \times A \times (T1 - T2)$

$Q = 30 \times 0{,}15 \times (70 - 15)$

$\underline{\underline{Q = 396\ \text{W}\ \ (\text{J/s})}}$

zugeführt.

mit :

$\alpha = 30$ W/m²×K	Wärmeübergangszahl
$A = 0{,}12\text{m} \times 1\text{m} \times 2 = 0{,}24$ m²	Schlauchoberfläche
T1= 70°C	Heißlufttemperatur
T2= 15°C	Schlauchoberflächentemp.

Unter der Voraussetzung, daß der Herauszieh- /Auswalk- und Trocknungsprozeß 60 Sekunden dauert, läßt sich mit dieser Wärme während dieser Zeit im Idealfall folgende Wassermenge verdunsten:

$$m = \frac{Q \times t}{c_P}$$

$$m = \frac{396\ \text{J/s} \times 60\ \text{s}}{2.500.000\ \text{J/kg}}$$

$\underline{\underline{m = 0{,}0095\ \text{kg}\ \ (9{,}5\ \text{gr})}}$

mit:
Q = auf den Schlauch übertragene Wärme (s.o.)
t = Trocknungszeit
c_P = 2.500.000 J/kg Verdunstungswärme von Wasser

Bei dieser stark vereinfachten Rechenweise sind weitere negative Einflüsse wie die Erwärmung des Schlauchmaterials und des Wassers, noch gar nicht berücksichtigt!
Hauptursache der geringen Trocknungsleistung ist die kleine heißluftbeaufschlagte Schlauchoberfläche.

Fazit: **Ungeeignet!**. Hoher Aufwand, geringe Wirkung!

4 Fazit

Der Einfluß der Behandlungsschritte auf die Entnässung des Außenmantels wurden deutlich hervorgehoben.
Als wichtigster und zuverlässiger Einzeleffekt dieser Untersuchung ist die Nässeabsaugung hervorzuheben.
Mit vergleichsweise geringen Eigenfertigungs-Kosten von ca. 600€ bringt diese Technik die Schlauchoberfläche auf ein gleichmäßiges Feuchtigkeits-Niveau und überdeckt damit alle vorangegangenen Einzeleffekte.
Dieses Feuchtigkeits-Niveau ist nahezu unabhängig von der Zuggeschwindigkeit und dem Nässegehalt des zu entfeuchtenden Schlauches. Es besteht kein zusätzlicher Handhabungsaufwand.
Die Nässeabsaugung empfiehlt sich bei der Anwendung des RSPZ ohne Turm.

Trotz dieser guten Wirkung ist das Trocknungsergebnis gegenüber einer 4-Schlauch-Prozeßstraße deutlich schlechter. Nur bei saugfähiger, offenporiger Schlauchoberfläche wie bei Schlauch Nr. 3) läßt sich das Trocknungsergebnis als gleichwertig bezeichnen.
Um genaue Zahlen anzugeben, müßten die Trocknungsergebnisse der 4-SPS-H wiederholt werden. Die vorliegenden Messungen stammen aus dem Jahre 1993 und berücksichtigen nur annähernd Einflüsse wie z.B. Altersänderung der Oberflächenstruktur und Schlauchkürzung durch zwischenzeitliche Beschädigung.

5 Auf einen Blick...

In nachfolgender Tabelle wurden die Restfeuchte-Werte um den Betrag der Innen-Nässe korrigiert.

		Restfeuchte in gr. bei...		
Nr.	Trocknungsverfahren	Schlauch Nr. 1) C52, 15m, Leicht	Schlauch Nr. 2) B, 19,5m, leicht	Schlauch Nr. 3) B, 19,65m, schwer
1	RSPZ-Durchlauf mit Druckprobe	960 gr	1522 gr	2662 gr
2	wie 1) mit Nässeabsaugung	811 gr	1415 gr	2119 gr
3	RSPZ-Durchlauf ohne Druckprobe	1070 gr	1721 gr	2836 gr
4	wie 3) mit Nässeabsaugung	767 gr	1413 gr	2334 gr
5	4-SPS-H ohne Heizung	---	1106 gr	2600 gr
6	4-SPS-H mit Heizung 10 kW	---	891 gr	2495 gr

Anhang: - Meßprotokoll Entfeuchtung
- Meßprotokoll Zykluszeiten für Schläuche Größe "B" und "C"