

MICROWAVE DRYING OF PAPER DOCUMENTS

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ABSTRACT

A new advanced microwave drying technology has been developed using a continuous dryer combined with an air cooler. Principle of the new technology consist in using microwave absorption filters made from special porous ceramics which act as both absorbent and transparent material for microwaves. Ceramic slabs reduce intensity of microwave radiation to such a extent which prevents overheating or creating hot-spots or other kinds of damages including red-heating of metallic objects. The technology has been tested on 2200 flooded books and documents of historical value within one month. All books and documents were recovered in high quality without any damage of gold printing, colored reproductions, metallic containing objects and other components sensitive to microwaves. Moreover, the technology also proven to kill moulds and their spores and therefore an additional disinfection was not necessary.

INTRODUCTION

In recent years Central Europe suffered from extensive flooding. In August 2002 in Prague about 70 libraries and institutions were flooded. Thanks to enormous help of volunteers 3 thousands of cubic meters of documents, books and archival records were washed and frozen in plastic bags waiting for drying and restoration. Drying of all these documents would take decades using current drying technology, e.g. vacuum freezing (lyophilization) or hot wet air drying.

In last decades we can see an increased interest in using microwaves to augment or replace existing conventional drying methods with microwave systems [1,2]. The concept of using the microwave drying has always been appealing and is currently used for drying of textile, leather, cotton, ceramic, tobacco, wood, pharmaceuticals, etc. It is known that microwave drying provides extremely high rate and it is energy saving compared to the current conventional technologies. However, the microwave drying of paper materials has met many technical problems. For instance, local heat damage of paper caused by metal objects presents a serious problem. Moreover, microwave field causes irreversible damage of the documents when so called hot-spots are created within the body of document. Metallic objects turn into lightening rods and they heat paper to extreme temperature. Therefore, according this method, they had to be detected and excluded from the drying process [3]. Similarly gold printed letters can be damage and evaporated by microwaves. Consequently some companies, e.g. BATELLE, Germany, decided to stop this research and after one year of running microwave drying they turned back to conventional drying technique using reduced pressure and heating [4]. According to our knowledge, the microwave drying technology of paper materials has not been commercialized up to now.

PRINCIPLES AND MECHANISM OF DRYING

Conventional drying

Conventional drying process proceeds from the surface to the center and it depends on thermal conductivity of material which is in case of paper very low. The limit factor is the speed of diffusion of water to the surface, where is evaporated. Regarding this capillary diffusion, conventional drying is slow, especially at the end of drying process, Fig. 1.

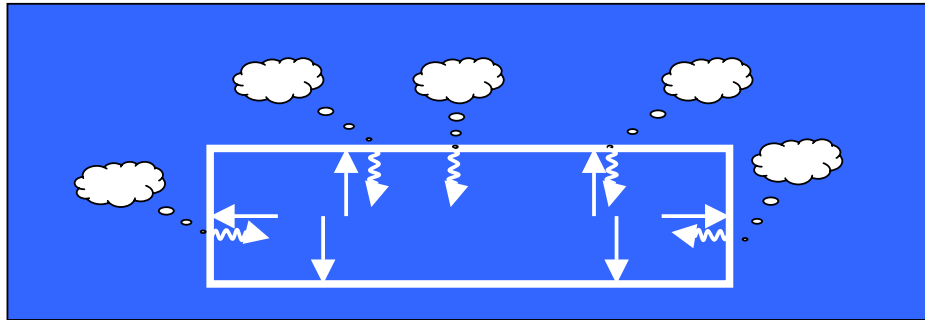


Figure 1. Mechanism of conventional drying

Microwave drying

Microwave drying proceeds by completely different mechanism, i.e. in completely opposite direction. Microwaves interact directly with the water molecules, create an internal heat in the center producing vapor pressure and therefore pressure gradient which „pumps“ water to the surface where is removed by hot air, Fig. 2.

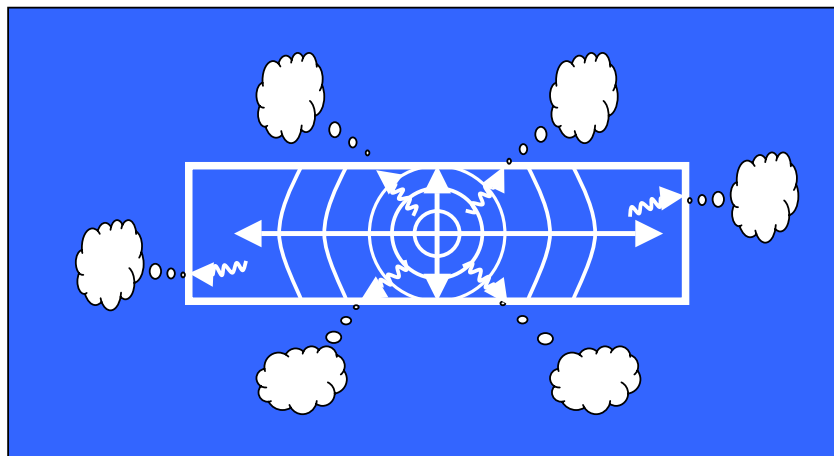


Figure 2. Mechanism of microwave drying

PROBLEMS OF MICROWAVE DRYING

After extensive flood in 2002, a project to develop fast and efficient drying of paper documents has been started to provide dried documents in a high quality. For this goal the following problems had to be eliminated:

1. Overdrying which causes reduction of lifetime of documents
2. Creation of hot-spots, i.e. local superheating leading to burning of paper
3. Red-heating of metallic objects (staples, wire stitches etc.)
4. Evaporating or burning of gold printing
5. Damage of coloured drawings and photographs
6. Elimination of non-homogeneity in interaction of microwave with different materials like glue, leather, plastics etc.

The problem of non-homogeneity of microwave field is generally known and it is a cause of most unsuccessful trials. In addition, it is almost impossible in a batch system to stop the drying in a right moment because if there is not enough moisture, fast excessive drying of paper starts immediately, Figs. 3,4.



Figure 3. Example of document damage by overheating and hot-spots in a batch dryer



Figure 4. Example of document damage by red-heating of metal staples in a batch dryer

DESCRIPTION OF ADVANCED MICROWAVE DRYING TECHNOLOGY

To solve out all the above problems of drying of paper documents we had to come with a completely new idea. We have installed on the bottom and on the top of the documents a special accessories, called absorption filters. They are special porous ceramic materials which partially absorb microwaves but they are also partially transparent for microwaves. They reduce intensity of microwave radiation to such an extent that is sufficient for drying of moisture but not sufficient for overheating or creating of hot-spots or cause other kinds of damages including red-heating of metal objects. Microwaves penetrate through the ceramic filters with a reduction of high intensity spots and are preferentially absorbed by the moisture creating internal regions of high pressure and forcing moisture to the surface. Then moisture is absorbed by porous ceramics and evaporates very fast from the surface in the form of steam even though the drying temperature is much lower than 100 °C and does not exceed 60-70 °C, Fig. 5.

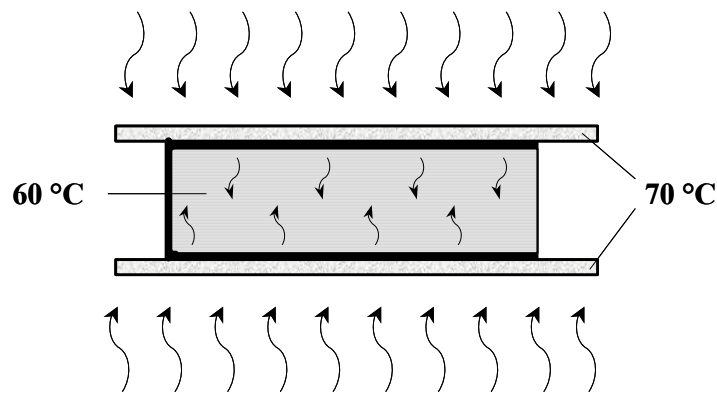


Figure 5. Controlling action of ceramic microwave filters

The power is distributed volumetrically and usual temperature profile is inverted, i.e the temperature gradient (**heat transfer**) and the moisture (**mass transfer**) operate simultaneously. The basic structure of the dried paper is not damaged. Possible irreversible damage of paper by overheating is eliminated by moving documents on a conveyer which almost eliminates non-homogeneity of microwave field. The speed of the conveyer is approx. 50 cm/min and the exposition of the document to microwave field is about 5 min. About each 20-30 seconds a book or document enters to the dryer and then passes 5 min in the heating zone. Leaving dryer, the temperature inside and outside of document is measured. Then it passes in an air cooler and moisture content is checked. If the moisture content is inbetween 10±2% (relative), the document is eliminated from drying process, if it is higher, the document re-enters to the dryer. Drying time depends on the weight of the document and moisture content. Moisture content usually varied between 30-130 % , it means 0.30-1.30 kg of water in 1 kg of dry document, the average was 60 %. Drying time of one document regarding to moisture content and drying temperature maximum 60-70 °C varied from 1 to 2.5 h. The drying capacity of dryer is 150-200 kg of wet documents per day (2 shifts). The speed of drying is 5 kg of water per hour. The drying process is presented on Fig. 6.

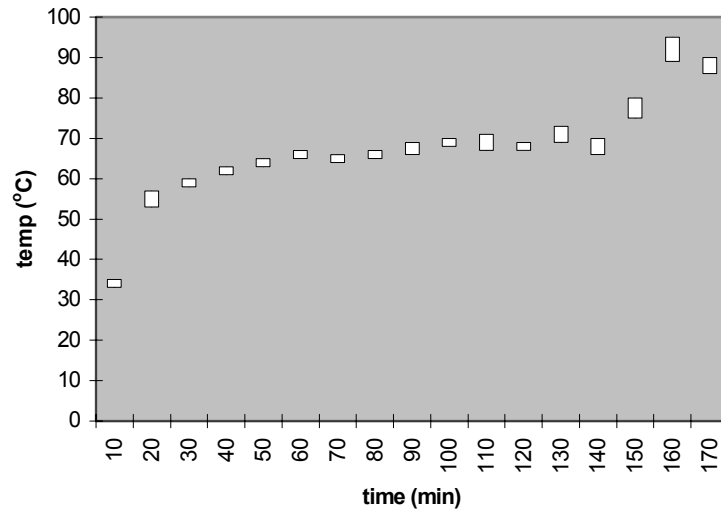


Figure 6. Example of drying process

DESCRIPTION OF DRYING EQUIPMENT

The drying equipment consists of 2 parts: microwave dryer and air cooler. In one cycle a sample of document passes both parts. Conveyers of both parts are synchronized. The length of both parts is the same amounting 6.5 meters. The microwave power is 8 kW supplied by 10 magnetrons. Both dryer and cooler are equipped with exhaust system to protect staff against a possible contact with contaminated air. Moreover, the dryer is equipped with 2 smoke detectors, which open 2 water jets in emergency case. Smoke can appear in the case when the staff make a mistake and stop moving of conveyer in heating zone. This accessory protects the equipment against damage. The equipment is a mobile type, i.e. it can be simply transported to requested place where it is necessary to dry valuable documents quickly and in high quality. The equipment is presented in Figs. 8, 9 and 10.

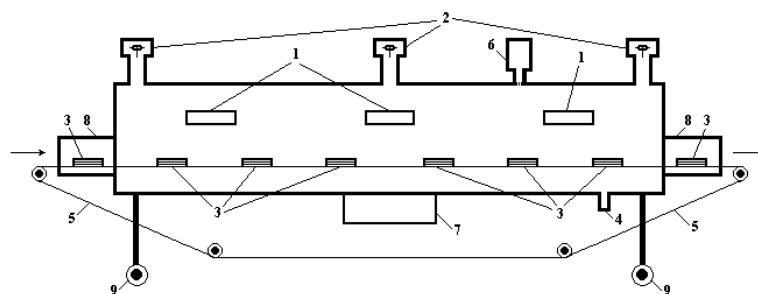


Figure 8. Scheme of microwave drying equipment

1-magnetrons; 2-ventilators; 3-documents; 4-water outlet; 5-conveyor; 6-smoke detector; 7-control panel; 8-reflection zone; 9-wheels

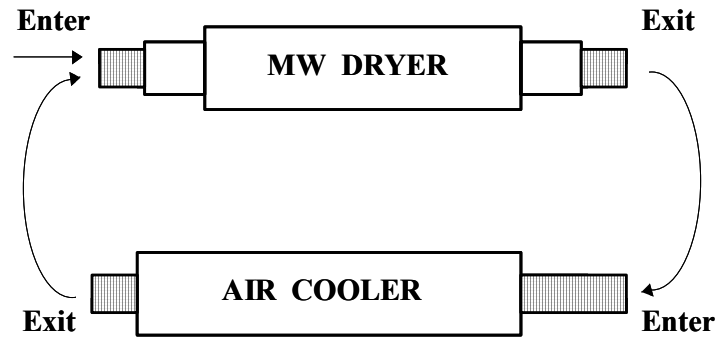


Figure 9. Schematic design of drying unit



Figure 10. Photo of microwave drying equipment

DESCRIPTION OF DRYING PROCESS

Frozen book or document (temperature -18 to -25 °C) is taken out from the plastic bag and placed on the conveyer. After 11 min the sample leaves dryer defrosted and re-enters to the dryer again. After a few passings when the temperature reach 60 °C, the sample is placed on the conveyer of air cooler and then re-enters again into dryer. During drying process the temperature and moisture content is regularly checked each 11 min, i.e. after each passing of the dryer or cooler. The temperature should not exceed $60-70$ °C with respect to the possible reduction of mechanical properties of paper. When the sample reaches a final moisture content ($10\pm 2\%$) it is eliminated from drying process. The function of the air cooler is to cool the sample from $60-70$ °C to $40-50$ °C to be able to re-enter into heating zone of the microwave dryer. Examples of dried books and documents are presented in Fig. 11.

PHOTO-DOCUMENTATION OF THE PRODUCTS

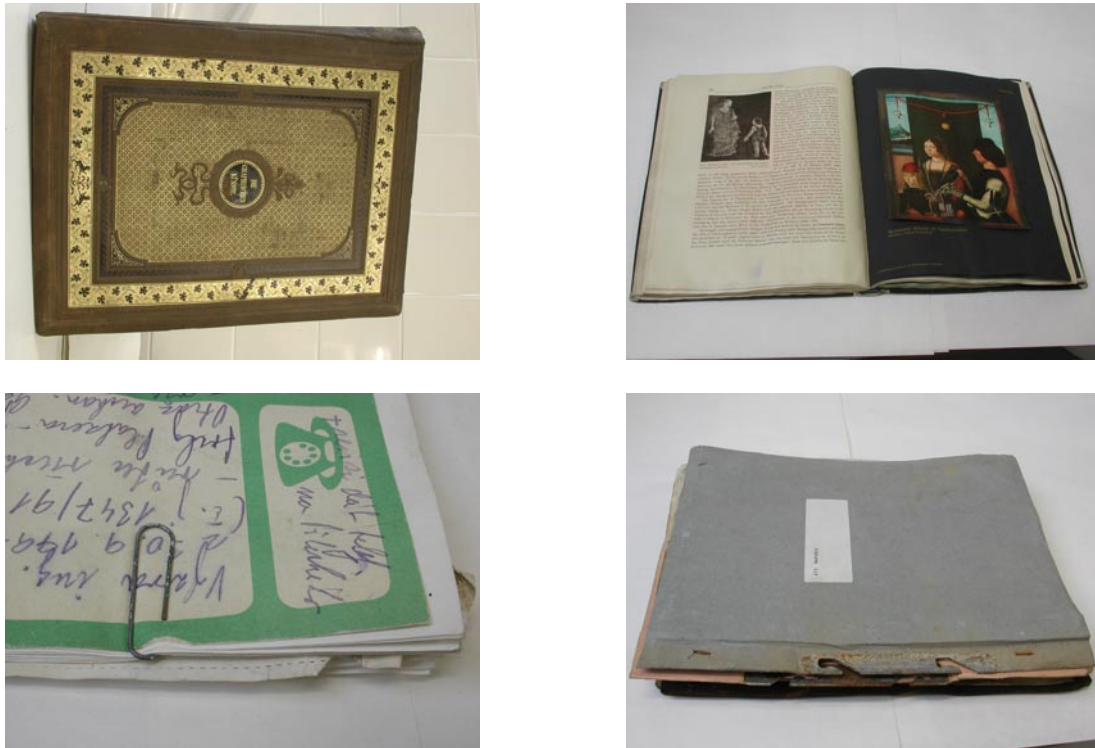


Figure 11. Examples of dried books and documents

ADVANTAGES OF ADVANCED MICROWAVE DRYING TECHNOLOGY

As was mentioned above, the presented advanced microwave drying technology eliminates all problems which up to now prevented use of microwave drying for paper documents and similar subjects. The main advantage of continuous drying process is a running control of the drying process, which proceeds under optimal conditions using absorption filters which secure optimal and safe conditions of drying.

Other advantages can be summarized as follows:

1. High speed compared to batch microwave or conventional drying technologies
2. Uniformly dried paper materials
3. Energy saving due to selective action of microwaves to moisture
4. High quality product
5. Scalable and mobile
6. Simultaneous disinfection effect

CONCLUSIONS

We believe that Advanced Microwave Drying Technology could revolutionize and improve ability to process water damage books and documents because it introduces completely a new concept of solution into problem of rescue of flooded books and documents. This technology has much better characteristics compared to microwave batch process either under atmospheric or reduced pressure condition or compared to conventional vacuum freezing (lyophilization) or wet hot air drying method. All these mentioned methods were found slower and more costly. To protect all pertinent intellectual property we have patented and extended patent protection in addition to the Czech Republic (5) in EU, USA and Canada [6]. More information can be obtained on the web site www.drying.midkiff.cz and e-mail hajek@icpf.cas.cz.

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