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The Development of a Multifunctional Vacuum Chamber

ABSTRACT

A multifunctional vacuum chamber was developed and installed in response to floods in 2002. Past experience from drying books in wood-drying chambers and by vacuum packing was evaluated in the development process. The chamber allows for three drying methods: vacuum freeze-drying, vacuum drying, and air drying with temperature and humidity control. Special heated, unglazed, ceramic tiles and a supporting construction with steel columns inside the chamber are used to keep books in place in the course of drying. Steel plates placed on the tops of the columns serve to weight the books and prevent deformation. An independent measurement system checks the drying parameters.

THE FLOODS AND THEIR AFTER-EFFECTS

Great floods in 1997 in Moravia and in 2002 in Bohemia took place about one-hundred years after the last great flood that affected Prague. Nobody remembered this event and people didn't believe that it could have happened. A long period without disasters meant that heritage institutions were not prepared for an event of such an extent. In Moravia several dozen libraries were affected, and we estimate that more than one hundred thousand books were damaged. No books were frozen, and several dozens of rare volumes were dried by quite unsophisticated ways.

The situation in Bohemia before the flood in 2002 was only slightly better. Several specialists sent warning signals against possible disaster on the Vltava River in Bohemia, which could cause similar widespread damage. Officials in Prague provided financial resources to build movable barriers against the great water on the right bank of the river, which protected the whole right side of the town. But the situation in libraries, archives, and other institutions was not satisfactory. Disaster plans did not exist and institutional preparedness for these events was on a very low level. Losses after the flood were huge. More than forty libraries were affected and eight-hundred thousand volumes were damaged. Approximately one hundred forty thousand volumes were then frozen. Moreover, many hundreds of thousands of archival documents and museum objects were damaged or soaked. On the whole, nearly two thousand square meters of paper documents of different types were placed in freezing plants.

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ACTIVITIES AFTER THE FLOODS

Shortly after the floods it was clear that there would be a need to use several drying methods. Among the paper documents were old prints, newspapers, magazines, and several types of paper such as historical paper, woodpulp paper, coated paper, and tracing paper. The worst damages were in the Prague Municipal Library (old prints, rare documents, newspapers, and monographs of the nineteenth and twentieth centuries), in the National Technical Museum (technical drawings and archival documents), and in the Czech Museum of Music (historical autographs, music scores, and rare publications). Because freezing was very expensive it was decided that modern publications could not stay in freezing chambers for a long time. The National Library, together with the National Archives, implemented a set of drying tests at the end of 2002, and the results helped with future decision making (National Library of the Czech Republic 2003). The tests of the drying methods showed that the best results were gained by the vacuum method. But because of the large number of modern publications contained in the freezing plants, we also needed to research an industrial method.

The first drying method that we had at our disposal was based on the use of vacuum-packing machines. This

method had been developed by British conservators several years before. The books were wrapped in a nonwoven textile and absorbent paper inside plastic bags in vacuum packing machines. Next, the wrapped books were placed on shelves for several days and then repacked. The soaked absorbent paper was replaced in the course of repacking. Vacuum packing was used for historical and rare books only. Disadvantages of this method were the long time of drying, the danger of book deformation under high pressure, and the imprinting of ink text or color images from one page to the next.

The large number of modern publications had to be dried by another method. We used two wood-drying chambers. The books were dried in special vehicles, between unglazed ceramic tiles. Each book was wrapped in a nonwoven textile and newspapers to prevent saturating the porous tiles. The books between the tiles were stacked in columns and each column was topped by a concrete block to prevent book deformation. The books were dried by circulated air that was warmed and humidified or dehumidified as necessary. Control of the drying process was adapted to our requirements and a special mobile telephone was used for transmitting the drying data parameters to a personal computer in the library. We specified that the beginning phase of drying take place at a higher temperature—about 60°C—to avoid mold growth. Around sixty-five thousand volumes were dried in these chambers in the course of several months.

For a limited time some institutions obtained vacuum chambers for both vacuum drying methods: vacuum freezing and vacuum drying. All chambers were equipped with heated iron shelves and were able to dry only several dozen volumes at a time. Their main disadvantages were improper book placement and the occasional defrosting of paper documents in the course of drying in the lyophilization chamber without the operator knowing it. These problems were not acceptable to us. The Institute of Chemical Process Fundamentals built a drying workshop using microwaves.

VACUUM CHAMBER DEVELOPMENT, COMPARTMENTS, AND FEATURES

The disadvantages of the vacuum packing method, coupled with the unsatisfactory outcomes of drying in vacuum chambers at our disposal, led to our development of a special vacuum chamber adapted for drying books and other paper documents. We specified the following functions before we began developing our vacuum chamber:

- Three drying methods (vacuum freezing, vacuum drying, air drying with temperature and humidity control)
- Disinfection
- Reconditioning
- Book preparation and loading in the course of drying.

Our main requirements to ensure the best results for drying included: the use of ceramic tiles inside the chamber, the proper insertion and loading of the books in columns, and the preheating of the tiles in such a way that the heat could be transmitted to the books. A team of librarians and other specialists developed the vacuum chamber, with funding for the development and design, manufacture, and installation provided by the Andrew W. Mellon Foundation. The Ministry of Culture funded putting the chamber into service. Before the installation of the chamber in its dedicated room, we had to implement some construction.

The main components of the vacuum chamber (figs. 1–2) are:

a. Construction of the chamber and load-bearing support
   The chamber is a stainless-steel cylinder equipped with two doors with reinforcement on both sides. Load-bearing construction compensates for the weight distribution on the floor and the installation of all the compartments.
b. Book placement system
   The system consists of a removable, supporting steel construction, columns for book placement, heating tiles, and connectors. Books are placed inside the columns between pairs of heating tiles. The steel plates are placed on the top of each column on the last pair of tiles as a loading mechanism. Each column has small wheels that enable movement to support the construction.
c. Vacuum pump
   The vacuum pump is adapted for permanent operation. It can evacuate moisture from the chamber directly or through the freezer.
d. Freezing system
   The freezing system is a combination of the freezer (freezing chamber) and the freezing source. The system sublimates the water vapor. The temperature inside the freezer reaches from -60°C to +20°C, at a pressure of 0.5 mbar or higher.
e. Climate control system
   The climate control system is used for air drying with temperature and humidity control and for reconditioning. It is fitted for heating, cooling, humidifying, and dehumidifying.
f. Nitrogen supply system
   In the course of disinfection the system supplies nitrogen inside the chamber by a butanol carrier to prevent the creation of an explosive mixture. It consists of two nitrogen tanks and a special valve designed to be freeze-resistant.
g. Vaporizer
   The vaporizer is a special, vacuum-resistant glass container that is heated in order to facilitate the evaporation and dispersion of butanol (or another liquid) into the chamber.

Fig. 1. The multifunctional vacuum chamber (view from the front side)

h. System for waste-water gathering
This system collects the waste water into a special glass container.

i. Control system and software
The control system enables us to establish drying parameters, to combine drying methods, to control the running of the chamber, and to ensure that the parameters are not exceeded. The most important parts are the sensors for measuring the parameters inside the chamber and on its surface the switchboard, the "control" PC, and the software.

j. Independent measurement system
Good drying results depend on the accuracy of the drying parameters—above all on pressure, temperature, and relative humidity. We decided therefore to construct an additional, independent measuring system based on the usage of special sensors in a control ("signal") book and in several other places inside the chamber, as well as a tensiometer for recognizing weight (water) loss. Data obtained from this system are accessible on the control PC and by internet transmission to dedicated remote PCs of key personnel. We monitor the humidity of the books after drying manually. We also monitor the space around the chamber with two digital cameras.

Fig. 2. The multifunctional vacuum chamber (view from the opposite side)

The main chamber's parameters are specified in table 1.

DRYING TECHNIQUES

Frozen or wet books are wrapped in a nonwoven textile and filter paper and are inserted into a steel column between pairs of heating tiles. A steel plate is placed on the top of each column and the tiles are interconnected by cables with connectors to the top or sides of the chamber (figs. 3–5). The control book is placed on the tensiometer and the sensors of the independent measurement system are put in place. The temperature of the tiles is established on the switchboard and the chosen drying method is set up

Table 1. Vacuum chamber parameters

outer dimensions (length x width x height)	245 x 156 x 220 cm
volume (in liters)	3,230 L
temperature	-5 up to +60°C
temperature inside the freezer	down to -60°C
lowest pressure	0.5 Mbar
output of vacuum pump	40 m^3/hr.
number of books dried per cycle	1 to 216
average drying time	14 days
drying costs per volume	USD$5 to $15
average energy consumption	675 kW

Fig. 3. Connecting cables to the heating tiles

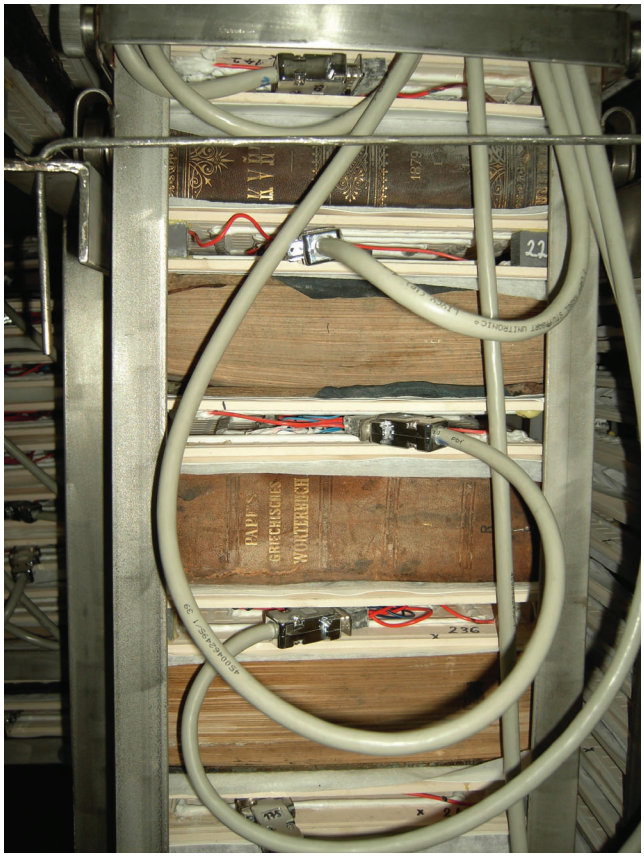

Fig. 4. Books stcked in a column

and started on the computer. Each drying method runs automatically.

Vacuum Freezing

Frozen books are dried under the triple point in a vacuum of 1–5 mbar and at a temperature under the freezing point. Ice in the frozen books must not melt in the course of drying. The tiles are warmed up and water vapor is drained away by the vacuum pump through the freezer. The pump needs to be defrosted every six to eight hours at the beginning of the process. The water vapor is drained directly from the chamber at this time.

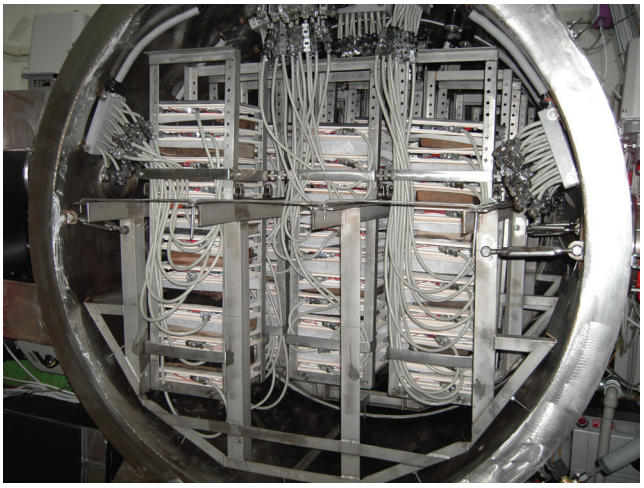

Fig. 5. Chamber prepared for standard drying

Vacuum Drying

Wet books are dried above the triple point in a vacuum of approximately 20 mbar and at a temperature above the freezing point. The control system prevents boiling water from reaching the books or the books from becoming frozen. The tiles are warmed up and vapors are drained away directly by the vacuum pump or through the freezer.

Air Drying with Temperature and Humidity Control

Frozen or wet books are dried under normal pressure by flowing air. Air temperature and humidity are adjusted by the climate control system. The temperature needs to be circa 60°C at the beginning of the drying process to prevent mold growth. The tiles are not warmed up and the vacuum pump and freezer do not operate. Since there is the danger of water condensation on relatively colder surfaces, the control system needs to be set up carefully.

Reconditioning

Reconditioning is needed after vacuum freezing and vacuum drying because the documents are over-dried. It is a process similar to air drying.

DISINFECTION

Our intention was to use butanol for book disinfection, particularly as a mold inhibitor. Butanol is effective against mold and other microbiological agents and it is used for this purpose in special disinfection boxes. It is not harmful to the books or the operators. The main disadvantages are its potential explosiveness in certain mixtures with air and the fact that it is effective on the book surface only. We

expected that using a vacuum would encourage deeper butanol penetration into the paper.

At the beginning of the disinfection process, any gas inside the chamber is evacuated from the chamber and butanol is evaporated by the vaporizer. Next the chamber is slowly filled with nitrogen to prevent creating an explosive mixture. The first tests were not successful; we had used too little butanol, which was not effective. For the following tests, we exchanged the fan on the chamber roof for another adapted for explosive materials. In the next phase we would like to test other materials for disinfection.

ADVANTAGES AND DISADVANTAGES OF THE DRYING METHODS

Vacuum freeze-drying is the most convenient method for documents containing writing ink and color printing because it does not cause bleeding. Vacuum drying is most suitable for other printed documents. Both vacuum methods cause the paper to become over-dried and documents need to be conditioned afterwards. The interrupted interfiber bonds do not recover themselves in the course of vacuum freeze-drying whereas in other two methods they do. In vacuum freeze-drying tracing paper loses its transparency. Drying in controlled air is the cheapest method, convenient for documents that need not be preserved for a long time. Mechanical properties of paper deteriorate about ten to twenty percent, depending on the drying time, because of the requirement for a higher temperature at the beginning of this process.

DRYING LARGE-FORMAT DOCUMENTS

The chamber also may be adapted for drying large-format documents such as maps and technical drawings (fig. 6). We use a large wooden table (100 cm x 200 cm) for this purpose which we lay down on the supporting construction. We can dry several flat documents between layers of filter paper. The ceramic tiles are placed on top of the last layer of the filter paper as a weight and a heat source.

CONCLUSION

The vacuum chamber was developed, manufactured, and installed between September 2003 and July 2005. Testing operations took nearly one year, up to August 2006, and standard operation started in August 2006. In all, 1,077 old prints and rare publications from the Municipal Library Collections were dried in the years 2006 and 2007. From February 2007 onwards, the special paper documents of the National Technical Museum are being dried (Neuvirt 2006).

In the next phase, we would like to further exploit the chamber's properties. The combination of nitrogen, a vacuum, and changes in temperature and relative humidity could be used to kill insects found in books or wooden artifacts. The chamber allows for the implementation of diverse tests and research. Most importantly, however, the chamber will be at our disposal for every disaster in the future.

Fig. 6. Preparing the chamber for the drying of large-format documents

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