

## Boerhaave's Furnace. Exploring Early Modern Chemistry through Working Models\*\*

Marieke M. A. Hendriksen\* and Ruben E. Verwaal\*

**Summary:** This article discusses the (re)construction and use of an Early modern instrument, better known as Herman Boerhaave's (1668–1738) little furnace. We investigate the origins, history and materiality of this furnace, and examine the dynamic relationship between historical study and reconstructing and handling an object. We argue that combining textual analysis with performative methods allows us to gain a better understanding of both the role of lost material culture in historical chemical practice, pedagogy, and knowledge production, and provide a deeper understanding of the embodied experiences and knowledge of historical actors. Having made and used two versions of Boerhaave's furnace, we provide insight in what present-day working models can tell us about historical materials and practices approximately three centuries ago.

**Keywords:** chemistry, pedagogy, Herman Boerhaave, (re)construction, working models, furnaces, experiment, foot stove

### 1. Introduction

Under our desks stands a modest yet most extraordinary wooden object (Figure 1). Made of smooth oak, roughly 24 by 24 centimetres wide and 37 cen-

---

M. M. A. Hendriksen, KNAW – Humanities Cluster, Korte Spinhuissteeg 3, Amsterdam 1012 GC, Netherlands, E-Mail: marieke.hendriksen@huc.knaw.nl

R. E. Verwaal, Durham University, Durham, UK, E-Mail: ruben.e.verwaal@durham.ac.uk

\*\* The authors would like to thank Herman den Otter, Lecturer in Conservation of Wooden Objects and Furniture at the University of Amsterdam, for his advice regarding the kind of oak to use, and André Hendriksen for making the full-size model, donating his time and carpentry skills to the project. Maartje ten Brummelaar we thank for donating left-over breast milk for our experiments, Wouter Eisen and David van der Linden for their practical support during the reconstructions and field research, and Thijs Hagendijk for his explanation of underlying modern chemical theory. We are grateful to the two anonymous reviewers and Katherine Hunt for their comments and suggestions regarding the contents and style of the paper. Finally, we would like to thank Julia Zwijnenburg, collections manager at Museum Gouda, for letting us photograph their nineteenth-century Boerhaave furnace in detail, and the staff at Veenpark Emmen for their patient explanation of the characteristics of various kinds of peat.


 © 2020 The Authors. Published by Wiley-VCH GmbH. This is an open access article under the terms of the Creative Commons Attribution Non-Commercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.



Figure 1: The working model of the Boerhaave furnace, 2018. Photo: Authors.

timetres tall, the bottom half of the rectangular box features a small door on hinges with four round holes, closed off by wooden plugs. Opening that door reveals a compartment clad with sheet iron. On the bottom is an earthenware bowl with some remnants of burnt peat. Opening the two hatches on top gives access to the upper compartment that can contain a glass flask or cucurbit, its neck sticking out of the hatch through a round hole. This hole can be plugged with a disk, and a small hatch can be removed from the top rim of the box, allowing the user to place a retort inside, its neck sticking out through the hatch. The two compartments are divided by a wooden partition with four small round holes in the corners and a bigger round hole in the middle covered with a removable grate, on which the vessel of choice rests. Two iron handles on either side enable the box to be lifted and moved. Carrying it around does require some strength though: without the flask, the box weighs 16 kilograms, which means moving it over a distance of more than a few meters requires a cart of some sort. Although this box resembles an oversized old-fashioned foot warmer, it in fact represents a key object in the history of chemistry education in the early modern Low Countries.

This article discusses this (re)construction of an Early modern instrument, better known as Herman Boerhaave's (1668–1738) little furnace, and asks how using it can help us answer historical questions as well as develop pedagogy.<sup>1</sup> This was a small peat stove that could be used for chemical experiments, and that—although only two nineteenth-century examples are found in museum collections—played an important role in the work of many generations of Dutch chemists (Figures 2 and 3).<sup>2</sup> We investigate the origins, history and materiality of this little furnace, and examine the dynamic relationship between reconstructing and handling an object, and historical study.

When making a reconstruction of a device like Boerhaave's furnace, we have to consider why it is worth going through the trouble of doing so while, paradoxically, in the past it was apparently not worth saving. Hence, this paper starts with an exploration of methodology and terminology relating to the (re)construction and use of historical chemical instruments. We introduce the term “working model” to resolve some of the complexities regarding the execution and integration of performative practices in the history of science. This is followed by an analysis of written and visual sources, providing us with a better understanding of the context in which Boerhaave furnaces were first made and used. Subsequently, the creation and use of a rough working model are introduced, followed by a discussion of a more detailed model of a Boerhaave furnace and a reworking of two of Boerhaave's processes. We argue that combining textual analysis with performative methods allows us to gain a better understanding of both the object biographies of lost material culture and the embodied experiences and knowledge of historical actors. In conclusion, we reflect on what a present-day model can tell us about historical materials and practices approximately three centuries ago, and discuss what these kinds of practices can add to research and pedagogy in the field.

## 2. Replicas, Working Models, and (Re)construction: Methodology and Terminology

Historical chemical instruments are particularly interesting candidates for reconstruction. Whereas historical scientific instruments have been the subject of academic reflection and analysis for many decades, chemical instruments have received limited attention. Frederic Holmes and Trevor Levere have suggested that this is due to a lack of material evidence.<sup>3</sup> Unlike many other scientific instruments, such as microscopes, telescopes, and air pumps, chemical instruments were rarely remarkably beautiful, often made from reusable materials, and built for temporary use. In short, few chemical instruments have stood the test of time. This problem of absence is not limited to the history of chemistry. After all, if we look at the material past, disappearance is the norm and conservation the excep-

<sup>1</sup> Boerhaave did not explicitly call this object an instrument. His use of the term “instrument” will be discussed in more detail in section 3. [m1] Seminal studies of Boerhaave and his work are Knoeff 2002; Lindeboom 2007. Boerhaave's chemistry has previously received attention in Powers 2012; Verwaal 2017; Hendriksen 2018.

<sup>2</sup> Inventory nr. A1000, Museum Gouda, Gouda; Distillator, V25790, 1800–1900, Rijksmuseum Boerhaave, Leiden.

<sup>3</sup> Holmes and Levere 2000.



Figure 2: Boerhaave furnace, 1800–1900, A1000, Museum Gouda, Gouda. Photo: Courtesy of Museum Gouda.

tion.<sup>4</sup> This imbalanced representation can easily lead to a distorted image of the past. That is why it is important, especially in the history of chemistry, that we not only write object biographies of still extant and unique objects, but that we also make attempts to reconstruct missing material culture.

Furthermore, the construction of a historical instrument can yield valuable information. Indeed, recent efforts in experimental history, where performative methods such as replication, reconstruction, and re-enactment are combined with analysis of historical sources, have yielded new insights, for example into the importance and acquisition of implicit and tacit knowledge.<sup>5</sup> A newly-made Boerhaave furnace enables us to check whether Boerhaave's claims that it is suitable for all kinds of experiments and chemical processes, from hatching eggs to distilling nitric acid, are indeed true. From this we can derive whether it was likely that students and amateurs regularly built and used these kinds of ovens. In short, we

---

<sup>4</sup> Adamson 2009, on 192.

<sup>5</sup> See, e.g., Smith 2016; Hagendijk 2018; Hendriksen 2019; Sibum 1995.

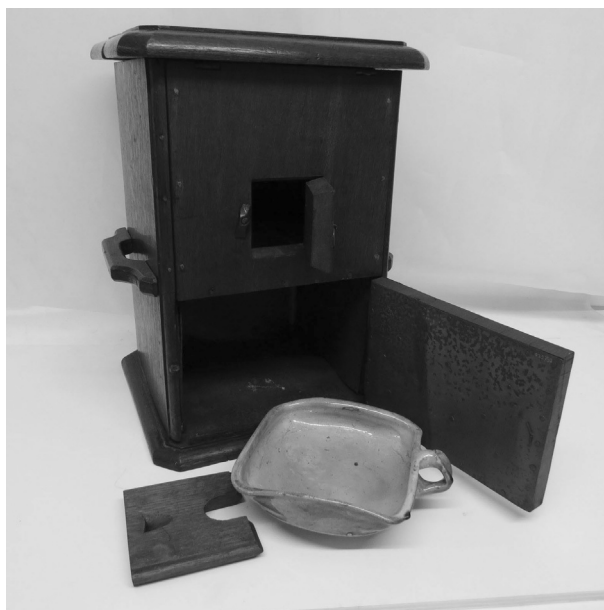


Figure 3: Distillator, 1800–1900, V25790, Rijksmuseum Boerhaave, Leiden. Photo: Courtesy of Rijksmuseum Boerhaave.

argue that making and using a Boerhaave furnace provides new insights into everyday chemical practice in the eighteenth-century Dutch Republic.

Reconstructions and other performative methods have long been part of the history of science, art, and technology. Yet, with a few notable exceptions, until recently their application was mostly limited to museums and conservation laboratories.<sup>6</sup> Not all historians are keen to acknowledge the usefulness of such reconstructions. Some question the validity of replicas and reconstruction processes as no more than an entertaining interpretation, having no real relation to the past.<sup>7</sup> Indeed, we cannot shed our skin and put on that of our forebears, we cannot strip our minds of our knowledge and prejudices and take on theirs, we cannot experience smells, sounds, textures and tastes like they did. Yet the idea that written words and images provide a clear window on the past whereas non-vision-centred approaches of history are mere obstructive fences is not sustainable either. Both are, if anything, distorting mirrors, to paraphrase Carlo Ginzburg, and our task is to combine them to produce a more holistic understanding of history.<sup>8</sup>

Archaeological research has confirmed that the history of chemistry was one of raw materials, stones and metals, simple devices and sophisticated instruments, smells, tastes, and burns, lotions, potions and concoctions.<sup>9</sup> Our approach to the materials of the past should go beyond the words and images on the page. Hence,

<sup>6</sup> For discussions see, e.g., Staubermann 2011; Fors et al. 2016.

<sup>7</sup> Smith 2007.

<sup>8</sup> Ginzburg 1999, on 25.

<sup>9</sup> See, e.g., Martínón-Torres 2012; Martínón-Torres and Rehren 2007.

we need to rely on a complementary methodology: one that relies not just on hand-written documents, images, and printed texts, but also on what we would like to call the “working model”: an assemblage composed of a replica of a scientific instrument, the materials used and handled, and the sensorial dispositions brought to bear in the process of using the instrument. As we will demonstrate, a combination of traditional historical and various performative methods (attending to materials, replicating objects and re-working processes) is crucial to understand the object biographies of lost material culture and lived experiences of historical actors.

This working model approach allows us to consider to what extent written descriptions and our physical actions and sensations are in accordance with each other. Building upon recent efforts in material culture and experimental history, we argue that our replications function as a two-way street: as much as our modern furnace refers back to Boerhaave’s time, eighteenth-century texts help us to recognise the validity of our model. Our wooden furnaces are an attempt to construct modern versions of Boerhaave’s furnace. The lack of extant objects forces us to rely mainly on description and iconographic representation, an approach that is used in other studies of historical embodied practices and knowledge too.<sup>10</sup> Yet these furnaces are not meant to simply imitate the texts and engravings from the eighteenth century—even though they are certainly based on them. As working models they go beyond two dimensions and the one or two senses (sight and occasionally smell) of paper sources and museum objects; instead they are a three-dimensional space involving all senses, in which a multitude of raw materials can be brought together to create chemical processes. In essence, these objects are a space in which new effects and observations can be made. We would like to argue that the assemblage of our furnaces, the associated materials, and our actions and experiences constitute a working model.<sup>11</sup> The introduction of this term allows us to rethink the methodology of researching both material culture and experimental history.

How is our study of Boerhaave’s furnace different from the study of scientific instruments and objects? After all, object biographies have been part of history of science since the 1980s, and have helped us to better understand Early modern practices of discovery and experiment.<sup>12</sup> These studies gave a unique insight in the material culture of individual instruments, including their production by instrument makers in workshops as well as their role in epistemological and methodological questions.<sup>13</sup> Our furnaces, however, first of all allow us to study a kind of instrument often neglected, namely a chemical instrument. Most instrument-based studies look at philosophical instruments, such as the air pump, which were not only intricate and complicated, polished and beautiful, but also elite and exclusive, because they were neither used nor considered outside the domain of a handful of natural philosophers. Instead we investigate two models of a simple and unassuming chemical instrument, similar to ones which we know were dis-

---

<sup>10</sup> See, e.g., Jaquet and Deluz 2018 (video article), esp. 4:50–6:38.

<sup>11</sup> See the assemblage in Deleuze and Guattari 1987. See Barad 2007, on 26 for the concept of “agential realism.”

<sup>12</sup> Daston 2012.

<sup>13</sup> See, e.g., Bennett 1987; Anderson 1993.

tributed among a large number of students and chemists. Moreover, Boerhaave's furnace was not primarily designed to establish "elusive and hard-won" scientific concepts, such as the corpuscle, ether, or the vacuum.<sup>14</sup> Instead it was built to investigate materials that were readily available to ordinary people, such as rosemary and milk. These vegetal and animal substances were not limited to a closed space of scientific enquiry, but flowed freely from rural areas to city households. Thanks to a simple instrument, these materials were subjected to practical manipulations, revealing their properties through their physical presence and changes in colour, smell, taste, texture, and volume.<sup>15</sup>

Furthermore, and perhaps most importantly, our point of departure is not a single museum object, but rather a concept, an instrument primarily documented in word and image, with only two nineteenth-century physical examples remaining. In art-historical scholarship, the operative word to describe our furnaces would be "copy" or "replica." A replica (stemming from the eighteenth-century music term "a repeat," which is derived from the Latin *replicare*, "to repeat") is either a duplicate of an original or "an exact copy or model of something, especially one on a smaller scale."<sup>16</sup> Hjalmar Fors, Lawrence R. Principe and Otto H. Sibus have already expressed their concern with the word "replication," primarily because of its use in modern-day science. For scientists, replication means to exactly repeat an experiment to confirm results, or for students to demonstrate textbook knowledge. "When historians rework or reproduce a process or an experiment as a historiographical tool they are not replicating in these scientific or pedagogical senses, but are instead *seeking fresh historical information*."<sup>17</sup> We agree it is important to be aware of this distinction—which we highlight by using the word "model" rather than "replica."

### 3. Retracing the Origins of Boerhaave's Furnace

Before we move on to the historical context of Boerhaave's furnace, we need to discuss one detail about Boerhaave's own understanding of instruments. As Liba Taub emphasizes, definitions of "scientific instruments" are neither universally agreed nor historically stable.<sup>18</sup> Indeed, Boerhaave did not explicitly refer to the little furnace as an instrument. The typography in the table of contents of the *Elementa Chemiae* (1732) suggests that Boerhaave did consider furnaces to be instruments, but the first "instruments" he discusses are not objects, but the four Aristotelian elements earth, air, water, and fire, as well as menstruum.<sup>19</sup> In the section discussing the furnace, Boerhaave referred to it as a man-made machine, an *aedificata machina*, which was translated by a contemporary into English as "structure."<sup>20</sup> This understanding of the four elements as the instruments of physical

<sup>14</sup> Daston 2012, on 2.

<sup>15</sup> Klein and Spary 2010.

<sup>16</sup> Art. "Replica," in Stevenson 2010 (OED).

<sup>17</sup> Fors et al. 2016, on 93 (emphasis added).

<sup>18</sup> Taub 2019, on 453–467.

<sup>19</sup> Boerhaave 1732, vol. 1, on 124–669; Powers 2012.

<sup>20</sup> Boerhaave 1732, vol. 1, on 884. For the contemporary English translation, see Boerhaave 1741, vol. 1, on 588.

change and chemical analysis meant that Boerhaave saw fire as the great instrument of activity in the cosmos. To him, it was an imponderable material fluid, capable of passing into or out of normal weighty matter. Fire was the prime agent of chemical change, but it did not take part in chemical combination.<sup>21</sup> Confusingly, the terms “apparatus,” “machine,” and “instrument,” either with or without the adjective “philosophical,” were used from the mid-seventeenth century onwards to describe objects that we would now define as scientific instruments.<sup>22</sup> From this, and from comments by subsequent generations of chemistry professors to that effect, it appears that Boerhaave’s understanding of fire as an instrument was already considered somewhat archaic.<sup>23</sup> Hence, when we speak of instruments, we refer to material objects used in chemical experimentation, such as Boerhaave’s furnace, not to fire.

Boerhaave’s portable furnace stood in a long tradition of furnaces, and in turn inspired new designs. In order to understand how its materiality functioned within and shaped chemistry education and research, we need to be aware that furnaces have a long and complex history. Ancient Greek alchemical recipes, for example, state that existing furnaces, kilns, and ovens such as those used for glass-making, pottery, and baking bread could also be used for alchemical procedures.<sup>24</sup> In the Early modern period furnaces, the spaces in which they were used, and the tools and materials associated with them could be part of artisanal workshops or alchemical laboratories, or both at the same time.<sup>25</sup> Making furnaces was considered an art in itself, as illustrated by the existence of the *fournalistes*, an organized group of artisans in eighteenth-century Paris who specialized in building furnaces for a wide variety of professionals, ranging from metallurgists and distillers to black-, gold-, and silversmiths.<sup>26</sup> By the time Boerhaave first developed his furnace, he must have seen a wide variety of furnaces in various contexts.

Boerhaave’s little furnace appears to originate in his room in the 1690s: “my simplest furnace,” Boerhaave reminisced in 1732, “I invented forty years ago, when I practised chemistry in no large study.”<sup>27</sup> The reason why a twenty-something Boerhaave needed such a furnace was because his room only had one chimney, whereas he wanted to perform various chemical experiments simultaneously. This little furnace proved to be the perfect solution.

Boerhaave introduced his furnace to his students when he started giving private lectures in chemistry from 1702 onwards. Unlike many other medical professors, Boerhaave used a style that was more pedagogical than prescriptive, stimulating students to think, observe and experiment for themselves.<sup>28</sup> Instead of starting

<sup>21</sup> On Boerhaave’s understanding of fire, also see Golinski 2003, on 389; Snelders 1993, vol. 1, on 59; Love 1974.

<sup>22</sup> Warner 1990, on 83.

<sup>23</sup> See Black 1803, vol. 1, on 286; Anderson 2006, on 252.

<sup>24</sup> Martelli 2011, on 309. For a more detailed discussion of the history of furnaces in artisanal practices, see Hagendijk (forthcoming).

<sup>25</sup> Dupré 2014, on vii–xix.

<sup>26</sup> Beretta 2014, on 201; Jaubert 1773, vol. 2, on 291–295.

<sup>27</sup> Boerhaave 1741, vol. 1, on 589–590; Boerhaave 1732, vol. 1, on 886–889.

<sup>28</sup> Knoeff 2010. Sources suggest that Boerhaave’s private lectures were more popular than the public lectures by Jacob le Mort (1650–1718), the formal *praefectus* of the laboratory and professor of chemistry. See Powers 2012, on 55–56, 89–91.



with the most difficult experiments with metals and minerals, he was convinced that students were better off if they learned chemistry through simpler processes, such as distilling herbs and flowers, and fermenting bodily fluids. But the Leiden university chemistry laboratory, established in 1669, was primarily a research lab, equipped with elaborate devices. These were too complicated for students, who in the eighteenth century could be as young as fourteen. Moreover, the brick-built furnaces were designed to create high temperatures, in which small and delicate materials like rosemary leaves would burn instantly.<sup>29</sup> What was needed was a furnace that was low-cost and user-friendly. The little furnace was the ideal pedagogical device for chemistry for it provided a gentle heat, yielded only little smoke, and was safe to use in a student's room. Furthermore, for a carpenter or even a handy student, as will be demonstrated below, it would not have been complicated to build such an oven for small-scale chemical experiments. It is safe to assume, therefore, that the little furnace was a convenient and attractive instrument for educational purposes.

Boerhaave was not the first to write in print about such a simple furnace. In 1719 the Amsterdam pharmacist's son and physician Willem van Ranouw (1673–1724) published *Cabinet of Natural History, the Sciences, Arts, and Crafts*, which included a description of “a very light Distillation oven of oak wood [...] that an Observer of Nature, to do experiments, can carry with him and use almost anywhere.”<sup>30</sup> Van Ranouw also included a detailed engraving showing a three-dimensional model of the furnace (Figure 4). This description comes very close to Boerhaave's furnace. Since Boerhaave had been doing chemical experiments for decades when his textbook was published, and he had already taught chemistry to many students, it is possible that wittingly or unwittingly, Van Ranouw described an oven after Boerhaave's design. Another possibility is that wooden distilling furnaces had been used in other contexts long before Boerhaave described them as his own invention. Yet Boerhaave's fame was much greater than Van Ranouw's, the design was never “patented,” as it were, and Van Ranouw died in 1724, so Boerhaave's claim did not lead to a priority debate. In fact, by the end of the century an instruction was published for “an improved Boerhavian furnace.”<sup>31</sup>

There are other indications that wooden furnaces similar to the design described by Boerhaave were in use throughout the Low Countries in the eighteenth century.<sup>32</sup> In a popular book printed in 1733, for example, in which an alchemist is ridiculed, a wooden distillery oven is mentioned that seems similar to the one in Boerhaave's description:

The Baron unlocked a wooden distilling cabinet, which was covered in thin iron plates on the inside, and fitted with a wooden plank in the middle on which an elongated flask could be put, which was fired, boiled, or baked from below.<sup>33</sup>

<sup>29</sup> Boerhaave 1732, vol. 2, experiment 1.

<sup>30</sup> Van Ranouw 1719, vol. 1, on 176v.

<sup>31</sup> Jongh 1798, on 34. The phrase “Boerhavian furnace” even entered Dutch dictionaries. See, e.g., “Stove” in Weiland 1799–1811, vol. 4, on 718.

<sup>32</sup> See, e.g., Voltelen 1775, on 19; Bosman-Jelgersma 1983, on 70.

<sup>33</sup> Weyerman 1984, on 272. Also see Hendriksen 2018.

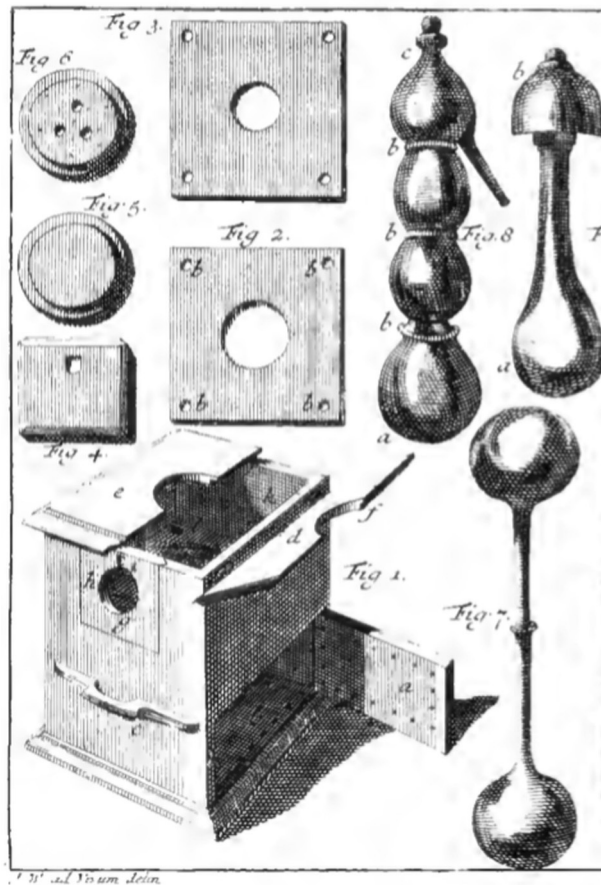


Figure 4: Engraving of a portable distilling oven in Van Ranouw, *Kabinet der natuurlyke historien*, Amsterdam: Strik 1719. Koninklijke Bibliotheek, The Hague.

Whoever the real inventor may have been, the little furnace is likely to have been inspired by ordinary foot warmers. These small stoves were very popular in the Dutch Republic. Historians have demonstrated widespread ownership among rich, poor, urban and rural households.<sup>34</sup> Filled with glowing coals or peat, little stoves were popular items to keep one's hands or feet nicely warm.<sup>35</sup> And coming in a wide variety of sizes and shapes—square, octagon, cylinder—we see foot stoves featured in literature, paintings, and inventories.<sup>36</sup> In the botanical garden at Leiden University, for example, stoves were placed under the tropical plants in the greenhouse to keep them warm and alive during cold winters.<sup>37</sup>

<sup>34</sup> Kamermans 1999, on 88, 144–147, 166–167.

<sup>35</sup> Francq van Berkhey 1769–1778, vol. 3, on 706–707, 1200.

<sup>36</sup> See, e.g., engraving in Cats 1625, frontispiece to part 4; Jean-Etienne Liotard, *Dutch girl at Breakfast*, c.1756, SK-A-5039, Rijksmuseum, Amsterdam.

<sup>37</sup> Cook 2007, on 327.

The hypothesis that Boerhaave improved upon the foot warmer should be placed in the context of its multiple innovations over the course of the eighteenth century. The little stove was far from a single-purpose object. As opposed to stationary fireplaces, this highly mobile heat source was used at home, brought along to church, inside carriages, and on canal boats. This ultimately developed into a separate winter profession: before Sunday service, so-called *stovenzetters* placed little stoves in church and filled them with glowing coals (Figure 5). Some physicians, however, grew increasingly sceptical of the excessive use of stoves, fear-



Figure 5: Woman carrying a little stove, ink drawing by Harmen ter Borch, 1648–1677. Object no. BI-1887-1463-128A. Rijksmuseum, Amsterdam.

ing the potential bad effects of hot moisture on people's health, making them lazy, languid, and sluggish, or so they argued.<sup>38</sup>

Despite such warnings, artisans and carpenters constructed innovative designs by which the little stove was adapted for specific purposes: embellished coffee and tea stoves tied in with the introduction of these fashionable drinks imported from the colonies, and hexagonal baby or health chairs (*tonnestoelen*) smartly caught excrement in the back, while the front was equipped with a stove to keep the baby's feet warm.<sup>39</sup> As Simon Werrett has recently demonstrated, all sorts of domestic and mundane materials were combined into ingenious bricolages and apparatus for experimental service in early modern science.<sup>40</sup> Hence it is not unreasonable to also place Boerhaave's little furnace in this context. As a student, Boerhaave likely transformed a foot stove into a scientific instrument by placing a glass flask on top of the stove, making it a highly effective and safe furnace for chemical study. Portable chemical furnaces appear to have been an eighteenth-century innovation, with Boerhaave's design as one of the earliest examples.<sup>41</sup>

So how did Boerhaave's design function in practice? In the eighteenth century, students and researchers did not buy their laboratory equipment in specialized shops. As Werrett showed, they made do with whatever materials were available, and only if this failed would they order equipment from specialized craftspeople, such as carpenters, blacksmiths, glass blowers, and instrument makers. So how important is it to follow Boerhaave's instructions for creating a chemical furnace as precisely as possible to end up with an instrument that works in the way he describes? Can something be cobbled together with domestic materials at hand, or does one have to place an order with a specialist?

#### 4. Reconstructing an Initial Model

To answer this question, we first created a model of Boerhaave's furnace ourselves in the summer of 2018. As we will demonstrate, this model further supports the hypothesis that Boerhaave's furnace started as an adaptation of an ordinary foot warmer. Although we had no carpentry skills to speak of, we expected to be able to construct a Boerhaave furnace with materials from thrift stores, Marktplaats.nl (a Dutch version of eBay), and basic DIY tools from the local home improvement store. We acquired multiple second-hand foot warmers, some sheet iron, an iron cutter, a saw, a hammer, a file, a chisel, sanding paper, superglue, small hinges, and nails. On an overcast August day, we got together in one of the authors' backyard, and started transforming two foot warmers into a stacked wooden box, resembling the structure—but not the size—of Boerhaave's furnace. We sawed off the bottom of one-foot stove and removed the glued top with a chisel, accidentally splitting it in half roughly down the middle. This part became the top hatch.

<sup>38</sup> Francq van Berkhey 1769–1778, vol. 3, on 706.

<sup>39</sup> Tea stove, c.1775–1800, BK-16153; tea stove, 1760, BK-1983-1, Rijksmuseum, Amsterdam; Chair, V03706, 1800–1900, Rijksmuseum Boerhaave, Leiden. On the baby chair, see Francq van Berkhey 1769–1778, vol. 3, on 1282, 1285.

<sup>40</sup> Werrett 2019, on 13.

<sup>41</sup> Werrett 2019, on 105–107. For more on the eighteenth-century development of portable furnaces, see, e.g., Anderson 1998; Anderson 1993.

Subsequently, we widened the middle hole in the top of both stoves, made a door in the bottom one by re-using the bottom of the top one, and attached it with small hinges. Then we glued the stoves on top of one another. Finally, we placed an earthenware cup bought at a thrift store at the bottom, and put a modern borosilicate glass flask purchased from an online shop selling laboratory equipment in the top compartment. Our first model was born (Figure 6).



Figure 6: Creating a furnace from two old stoves, August 2018. Photo: Marieke Hendriksen.

Although appearing a bit clumsy due to poor carpentry skills, this first furnace did not disappoint in terms of performance. With only barbecue charcoal available at the time, we found that we could quite easily warm water in the flask in the top compartment by placing glowing coals in the earthenware cup in the bottom half. This showed the ease with which two foot warmers could be transformed into one little furnace, capable of performing basic chemical processes like heating fluids. Moreover, it allowed us to think about the function of working models in researching object biographies and historical scientific practice.

First, our furnace brings us closer to the original. In his 1935 *The Work of Art in the Age of Mechanical Reproduction*<sup>42</sup>, Walter Benjamin described how visual works of art have a certain “aura”—a distance, a veil, or a barrier between us viewers and the genius of the artist, which makes the work of art unique and special. Although mechanical reproductions on a massive scale destroy this uniqueness and aura, they are nevertheless vague reminders of the experience of seeing the original. Our working model is of course neither mass-produced nor made after a work of art, but it refers nevertheless back to an original once put together by Boerhaave himself. Our working model allows us to experience the original notion of a portable furnace in completely new ways, namely by constructing it and interacting with it, handling and sensing materials, and performing experi-

<sup>42</sup> Benjamin 2008.

ments. It shares in and adds to the aura and hermeneutic circle of the disappeared historical originals, becoming a stand-in for eighteenth-century portable wooden furnaces.<sup>43</sup>

Furthermore, the working model is not an attempt at a replication of a Boerhaave furnace; it is the replication of a concept and of a constellation of practices, namely the making and using of small chemical furnaces by eighteenth-century students, researchers, and carpenters. Benjamin wrote about how certain forms of art were made from the start to be reproduced, like literature and photography. As the description in the *Elementa* shows, Boerhaave's furnace was intended to be reproduced too. He called it the "simplest furnace" not only for its purpose, but also for its design.<sup>44</sup> Inventory records show how every household owned at least one or more foot stoves, so carpenters must have been well aware of their designs. Even the illustration given in Boerhaave's chemical textbook (Figure 7) was not so much a life-like depiction of the furnace as a schematic, technical drawing for students or carpenters to interpret.<sup>45</sup> Boerhaave's furnace, in short, was not one specific object, but a concept designed to be reproduced, adapted, and used over and over again.

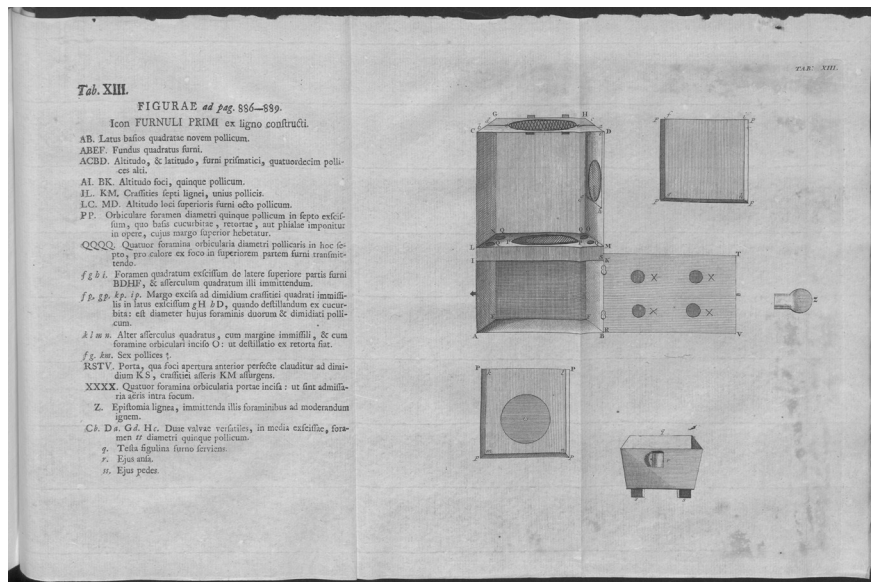


Figure 7: The plan for the furnace in Boerhaave, *Elementa Chymiae*, vol. 1 (Leiden: Severinus, 1732), table XIII. Courtesy of Leiden University Library.

<sup>43</sup> Although Benjamin and Gadamer were writing about works of art rather than historical instruments, we think these theories can successfully be applied to understand the latter as well. On the aura of replicas in art, see Kamien-Kazhdan 2018. On the principle of the hermeneutic circle, see Gadamer 2006.

<sup>44</sup> Boerhaave 1741, vol. 1, on 589–590; Boerhaave 1732, vol. 1, on 886–889.

<sup>45</sup> For the differences between life-like and schematic and technical drawings, see, e.g., Swan 1995; Bredekamp et al. 2015.

## 5. Reconstruction Taken Further: A More Detailed Model

Our first model served primarily as a proof of concept: it showed the possibility of creating a working chemical furnace from two foot stoves. However, the stoves we used were decorative twentieth- and twenty-first-century objects, much smaller than most eighteenth-century foot stoves and the measurements described by Boerhaave. Using it to perform experiments was possible, but we wanted to know if a furnace based on a combination of Boerhaave's description, the image he provided, and the nineteenth-century example in the collection of Museum Gouda, built using tools and materials that were as historically accurate as possible, would work significantly differently or not.<sup>46</sup> Was Boerhaave's furnace in its ideal materialization really as user-friendly and effective as he claimed it was?

Boerhaave's description of the portable furnace is detailed and matches the technical drawing provided: it provides exact measurements, specifies the materials to be used (dry oak), and where holes and hatches should be placed.<sup>47</sup> A wood conservation specialist was consulted about which type of oak we should purchase; eventually we chose quartered high-quality European oak, which set us back about three hundred euros.<sup>48</sup> Although this is a considerable amount of money, oak was likely to have been relatively cheaper in the eighteenth century, as there simply was more supply. We asked a skilled carpenter to create a furnace that resembled Boerhaave's description as much as possible. He prepared to do so by discussing the materials with us, reading our Dutch translation of Boerhaave's instructions, studying the drawing, and closely observing the nineteenth-century furnace in Gouda, taking notes and photos to be consulted in case ambiguities arose from Boerhaave's instructions. This resulted in a sturdy furnace of solid dried oak, ready for use in August 2018, and much larger than the furnace we created from coal stoves (Figure 8).

Many of the experiments that Boerhaave described in his chemistry textbook, for which the furnace could be used, required a moderate degree of heat—one might say a cool rather than a hot oven. Two previously mentioned examples are the distillation of rosemary, and the hatching of eggs, which Boerhaave said he believed his furnace could be used for too. The kind of egg is not specified, but for chicken eggs, the ideal temperature for hatching is 37,6° Celsius. Could we attain that temperature with our furnaces? Boerhaave stated that the furnace should be fuelled by a glowing Dutch coal (*Batavi prunam candefactam*), first burnt until it yields no more smoke. This, he claimed, will produce an equable, moderate heat, which may be kept up for near twenty-four hours.<sup>49</sup> Historical research shows that Boerhaave likely meant a specific kind of peat from near Leiden in the province of Holland, that is no longer harvested in that region.<sup>50</sup> What peat is avail-

<sup>46</sup> Herman den Otter, Lecturer in Conservation of Wooden Objects and Furniture at the University of Amsterdam, advised us about the kind of oak to use. André Hendriksen researched historical carpentry tools and techniques, as well as historical fittings, to approach the materiality of eighteenth-century Boerhaave furnaces as much as possible.

<sup>47</sup> Boerhaave 1732, vol. 1, on 884–889; Boerhaave 1741, vol. 1, on 588–590. For a more detailed discussion of the instructions, see Hendriksen 2017.

<sup>48</sup> Personal e-mail correspondence with Herman den Otter, 21/22 March 2018.

<sup>49</sup> Boerhaave 1732, vol. 1, on 888.

<sup>50</sup> Van Tielhof 2005.



Figure 8: Model 1 and 2. Photo: Authors.

able now comes from Ireland or Germany, and its quality and composition are different than those of the peat Boerhaave preferred.<sup>51</sup> We therefore ordered Irish peat online, and started experimenting with barbecue charcoal. This indeed allowed us to establish a fairly constant heat of around 30° Celsius in the large furnace for an hour or so (Figure 9). It was tricky to keep the heat constant though, as the charcoal had to be reduced to glowing before it could be put into the furnace, where it burned relatively fast. This immediately taught us another lesson about the furnace: stoking and managing fire, heat, draft and combustion in a furnace can be complex and requires serious skill and continuous monitoring.<sup>52</sup> Although the Boerhaave furnace is relatively easy to manage, it does call for constant attention. Hatching a chicken egg in it would require at least two people taking shifts to constantly tend to the heat source for three weeks. Hence it seems unlikely the furnace was really used for this purpose, unless when situated in a collaborative space such as a laboratory or shared student housing.

When the Irish peat arrived, we compared peat and charcoal side by side, and indeed, the peat was a little easier to manage than the charcoal, burning slower and more steadily. The sensory experience of burning peat was very different to that of burning charcoal. The strong smell of the burning peat penetrated our clothing and hair, which brought a new understanding of the smellscape of both Early modern spaces for experimental chemistry and eighteenth-century Dutch cities, where peat was the main fuel for heating houses and cooking.<sup>53</sup> This is particularly relevant as one of the main purposes of the furnace and its “gentle and equable heat” was the condensation distillation of herbs and flowers; smells that,

<sup>51</sup> Hendriksen 2020.

<sup>52</sup> Hagendijk 2020.

<sup>53</sup> William 2019, on 42 has argued that habituation and sensitization to smells brought with it connotations of class, yet the use of peat was so pervasive that it seems unlikely that this was a strong class indicator.



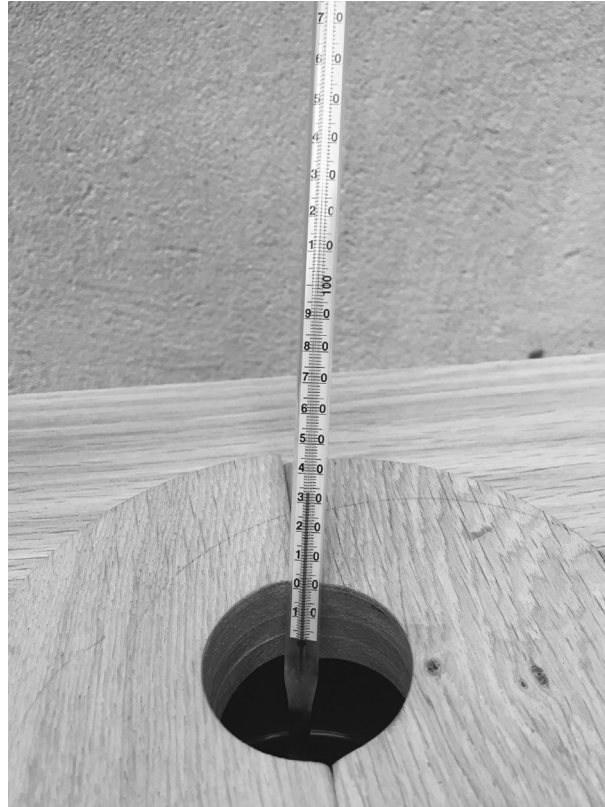


Figure 9: Charcoal: A stable 30° Celsius, 9 September 2018. Photo: Authors.

it would appear, are easily overpowered by that of the peat.<sup>54</sup> Take rosemary, for example, the evergreen aromatic shrub. Distilled atop a “violent fire” it would have been turned to flame, smoke, and ashes. But when rosemary instead was distilled at “summer-heat” (approximately 30 °C), the mild operation would instead reveal the most volatile, fragrant and aromatic part of the plant ordinarily exhaled in summer. The same process could be applied to Angelica, basil, and all other aromatic plants.<sup>55</sup> Yet scheduling restraints meant that the experiments had to be performed on 31 December 2018. It turned out that the most difficult aspect of this project was not the building of the furnaces or the sourcing of the necessary materials, but the absence of what Boerhaave obviously did have: cheap labour in the form of young assistants, who could take turns keeping the furnaces going day and night (Figure 10). Lacking cheap labour, seasonal herbs, and time to take turns managing a multiple-day distillation process, we opted for different kinds of experiments that could be performed within one day and could be achieved using the more efficient furnace in combination with peat.

<sup>54</sup> Boerhaave 1732, vol. 1, on 888; Boerhaave 1741, vol. 1, on 590

<sup>55</sup> Boerhaave 1732, vol. 2, on 14–20; Boerhaave 1741, vol. 2, on 9–13.



Figure 10: Students and assistant in the Leiden laboratory, in Boerhaave, *Institutiones et experimenta chemiae* (Paris, 1724). Ghent University Library.

## 6. Reworking Boerhaave's Processes

Our furnaces can be considered replicas, but they possess a unique capacity as working models: the fully realised construction not only bears a likeness to the original, but it also is capable of testing hypotheses by performing historical scientific procedures, simultaneously gaining sensory input and new experiences. Our objective with Boerhaave's furnace, therefore, was on the one hand to use the technology of the models to move beyond the textual descriptions of Boerhaave's processes and focus on the know-how required to conduct these experi-

ments; and on the other to use the working models to gain a better understanding of their role in developing and confirming specific chemical theories. Our eyes quickly fell on Boerhaave's experiments with milk from both human and non-human mammals. As a professor of medicine, Boerhaave was fascinated with the central role of milk in medicine, from female digestion, chylication and secretion, to its nourishing and health-giving qualities in newborns and patients. Indeed, Boerhaave soon realised that newborn mammals can grow solely on breastmilk. "Milk, therefore, appeared to be the first thing to be examined."<sup>56</sup> From the sources we know that Boerhaave taught his students that by subjecting milk to chemical inquiry, they not only learned how to perform chemical operations themselves, but also gained insights into physiology. We therefore discuss our application of Boerhaave's furnace in the study of milk, demonstrating how present-day experiments can inform our interpretation of Early modern textual sources.

Putting the models to work entails reading and doing the textual instructions. As recorded in his chemistry textbook—a process "shewing that boiling Milk will strongly coagulate with acids"—the students had to perform the following processes in their study of milk:

Gradually pour spirit of nitre, or any other acid, to a quantity of milk boiling over the fire, and no conflict will be made thereby; but the liquor will presently divide into two very different parts, the one thinner, and the other much thicker than milk, notwithstanding the action of the fire upon the matter.<sup>57</sup>

These descriptions immediately point out the first benefit of using working models, namely that they reveal an approximation of what Early modern chemical processes looked, felt, sounded, and smelled like that cannot be gained from the text. Of course, we do not experience them in the exact same manner as historical actors would have, but that goes for the text as well. When ready to experiment, we lit peat in the fireplace. Once it was hot, glowing, and smoking, we put some in an earthenware bowl, carried it outside to the furnaces, and used tongs to place it in the bottom compartments of the furnaces to let them heat up. Meanwhile we poured fresh, unpasteurized cow's milk in a glass vessel and placed it in the furnace and allowed it to heat up gradually. We added clear white wine vinegar to the heated milk and parts of the mixture indeed slowly coagulated into curd.<sup>58</sup> While all we have are laboratory notes and textual summaries, the working model is insightful in that it actually gives a sensory experience of the process of milk curdling at a low temperature. Improving upon adjectives like "thinner" and "thicker," the

<sup>56</sup> Boerhaave 1741, vol. 2, on 185; Boerhaave 1932, vol. 2, on 299. See also Orland 2012; Verwaal 2020.

<sup>57</sup> Boerhaave 1741, vol. 2, on 187–188; Boerhaave 1932, vol. 2, on 301–302.

<sup>58</sup> We used vinegar instead of the suggested "spirit of nitre." This is because making spirit of nitre ourselves would involve over-particular raw materials and elaborate chemical procedures, the recipe of which can be found in Boerhaave 1741, vol. 2, 247–248, 253–254; Boerhaave 1932, vol. 2, on 392–393, 401. Furthermore, Boerhaave claimed that "any other acid" would suffice, suggesting such diverse acids like vinegar, spirit of salt, oil of vitriol, the juice of sorrel, barberries, citron, etc. Boerhaave 1741, vol. 2, on 187–188; Boerhaave 1932, vol. 2, on 301–302.



Figure 11: Clots in raw cow's milk heated with vinegar. Photo: Authors.

working model provides a new level of detail, and unlocks experience and understanding unattainable from extant source materials (Figure 11).<sup>59</sup>

The working model expands the historian's methodology in which our interests as historians and experimenters today accentuate the motivations and experiences of past subjects. Besides providing a visual and tactile experience of extant descriptions, our furnaces demonstrate the opportunities and limitations that Early modern students must have encountered while working portable wooden furnaces. As we were able to experiment in the comfort of home on Boerhaave's 350th birthday, 31 December 2018, we realised that it was likely that students performed small experiments in their rooms, rather than in the chemical laboratories of Dutch universities. These laboratories usually consisted of no more than one or two rooms, filled with various brick furnaces.<sup>60</sup> On the other hand, the limitations of the furnaces became clear too. They must have limited the choice of materials with which experiments were conducted. Boer-

<sup>59</sup> A description of this coagulation process in terms of casein micelles can be found on <https://www.cheesescience.org/coagulation.html>, an online science guidebook hosted by Pat Polowsky.

<sup>60</sup> Van Spronsen 1975.

haave's furnace was the perfect device to conduct experiments with vegetal and animal materials, such as plants and bodily fluids. Minerals, stones and metals need much higher temperatures, which are impossible to reach with these wooden furnaces.

Thirdly, the models function as technical devices that provide insights in the outcome of various chemical processes described in textbooks and manuscripts. How can chemistry reveal the essential properties of milk? What results were gained? Considering our first experiment with clotting milk, we were basically imitating the cheese-making process—a more than common practice in the Early modern Dutch Republic. Boerhaave, however, assigned physiological significance to this process. For the cheese could harden and burn, smelling like bone—proving that even the hardest parts of a baby's body could have their origin in milk. "This is a strange change of so fluid a matter as milk, but is, perhaps, the origin of all the solids in the body."<sup>61</sup> The variability and unique qualities of the white fluid, in other words, was perceived as extraordinary.

The notion that our furnaces function as technical devices and reveal the outcome of experimental results is perhaps best shown in a second experiment. Described by Boerhaave as the process "Recent cow's milk coagulates, turns yellow, and red, by boiling over the fire with fixed alkali," we were sceptical about the outcome of this one. Boerhaave's textbook summarised the experiment as follows:

...boil it [new cow's milk] in a clean vessel, and by degrees drop oil of tartar *per deliquium* into it; it will thus begin to turn yellow, the more so as more alkali is added, and the boiling continued, so as to pass from a faint yellow into a red colour.<sup>62</sup>

We basically repeated the first experiment, but instead of using cow's milk, we used human breast milk donated by a friend.<sup>63</sup> Instead of vinegar we added a fluid alkali, namely ammonia, as no "fixed" (solid) alkali was at hand.<sup>64</sup> We poured the milk in the glass flask and placed it in the furnace made by the carpenter. After the white fluid had heated up, we mixed in the ammonia. Slowly the mixture indeed turned yellow, then a dark orange—and was about to turn red (Figure 12).<sup>65</sup> At this point the experiment was unfortunately interrupted by climatological circumstances, which gave us experiential insight in the difficulty of successfully managing a Boerhaave furnace for hours on end.

This experiment surely made it more plausible to eighteenth-century eyes that milk and blood were closely related. Via this relatively simple process, Boerhaave

<sup>61</sup> Boerhaave 1741, vol. 2, on 188; Boerhaave 1932, vol. 2, on 301–302.

<sup>62</sup> Boerhaave 1741, vol. 2, on 188; Boerhaave 1932, vol. 2, on 302–304.

<sup>63</sup> No babies were hurt in performing this experiment; the breast milk consisted of donated left-overs of pumped milk no longer fit for consumption.

<sup>64</sup> Boerhaave suggested the use of "any fixed alkali, as the salt of tartar, or its oil," so the use of ammonia is justified, like our use of vinegar rather than the spirit of nitre in the first experiment. See Boerhaave 1741, vol. 2, on 187–188; Boerhaave 1932, vol. 2, on 301–302. On making salt of tartar, see Boerhaave 1741, vol. 2, on 139–142; Boerhaave 1932, vol. 2, on 223–227.

<sup>65</sup> As this experiment fails when pasteurized milk is used, microbes present in raw milk such as *serratia marcescens* are likely to be responsible for the reddening of the raw milk. We thank Thijs Hagendijk for this suggestion.



Figure 12: Raw breast milk heated with ammonia. Photo: Authors.

also confirmed a theory about a common illness: milk fever. The milk from mothers suffering from fever “becomes yellow, saline, thin and sanious.”<sup>66</sup> It also explained why Dutch cows gave yellow milk during the 1714 outbreak of cow fever.<sup>67</sup>

Our models, in short, not only gave us a better understanding of Boerhaave’s furnace in its historical context and its biography, they also provided us with partial access to the embodied experiences of Early modern users of similar small furnaces, and with a better understanding of how observations and experiments shaped chemical theory. Our study of Early modern chemistry was supported and became partly dependent on the technology of the working model. We literally put our furnaces to work to gather knowledge for the benefit of our understanding of Early modern chemistry.

---

<sup>66</sup> Boerhaave 1741, vol. 2, on 189; Boerhaave 1932, vol. 2, on 302.

<sup>67</sup> *Ibid.*

## 7. Conclusion

The use of performative methods, such as these working models, in the history of science is methodologically complex and potentially problematic because of the impossibility of repeating history and reliving the experiences of historical actors. Their use should be tested and refined further in future research. Yet this paper demonstrates that if the goal is not exact replication but a deeper understanding of historical objects, materials, theories and practices, working models can be highly effective. If we are willing to acknowledge that complete historical accuracy in performative practices is a fallacy, this opens up new perspectives for understanding the past. Working models are material, practical, and sensory approximations of absent historical objects, practices and experiences. Rather than a stable end product, they are intricate processes of trial and error, which force the researcher to explore and question sources on a level that is impossible in any other way.

In this paper, we have demonstrated that working models function as a two-way street. They can approach the outcomes and phenomena documented in historical sources (milk mixed with an alkali and heated at body temperature will turn red). Conversely, claims and theories described in historical texts (milk is the foundational material of all bodily materials, such as blood and bone) can be supported, understood, and complemented through the use of working models. As others have argued before us and as this paper confirms, such projects do enhance our understanding and sensation of the past; they make our historical understanding more holistic, less linear and text-based.<sup>68</sup> For example, these working models help us to understand why Boerhaave was such a popular teacher; with the help of a furnace based on his design, students could learn by doing. Moreover, we gained a better understanding not only of eighteenth-century Dutch chemical practices and pedagogy, but also of eighteenth-century smellscape, of the role of apparatus and fuel in chemical experiments, and their role in the experimental and experiential support for physiological theories that seem outlandish to the modern reader.

In history of science research, a working model can thus make the immaterial material, the abstract concrete. A working model can allow us to develop informed reflections about the construction and use of lost material culture, and can function as a testing ground for various hypotheses. The goal of using working models in history of science research is not exact replication of eighteenth-century smellscape, objects, experiments, experiences, or materials, but an integrated embodied and cerebral understanding of the material culture, lived experiences and practices of historical actors.

Finally, we would like to make a plea for use of working models in history of science education and public outreach. Hasok Chang has already argued that historical experiments can complement science and science education.<sup>69</sup> The impact of working models in education and public outreach should not be underestimated, because they are an easily accessible 3D-expression of historical events and the

---

<sup>68</sup> Smith and Beentjes 2010; Hendriksen 2015, on 1–9; Bilak et al., 2016.

<sup>69</sup> Chang 2011.

scholars' research. Even now that nearly every conference room is equipped with state-of-the-art audio-visual technology, physical objects like the furnaces discussed in this paper are still useful. They allow audiences to share in the experience of handling them and make abstract concepts and histories, otherwise far removed in time, near and tactile. For example, in 2019 we demonstrated one of our furnaces at the 8th *Gewina Woudschoten Conference for the History of Science*, to general acclaim from the audience. Spectators saw the model being moved and handled as we explained the form and purpose of its parts. The spectators' gaze was easily directed to specific details of the working model as we simultaneously explained and demonstrated the use of the top lid and the glass flask inside. As the milk was slowly coming to a boil, spectators became handlers themselves, touching the furnace, opening and closing it, inhaling the distinct smell of peat. Direct contact with the object also spurred a series of audience questions, such as "what is this for?" and "did you also try...?"

In education and public outreach, in short, working models are effective and attractive when appropriately introduced and explained. They can double as demonstration models: their three dimensions and the embodied experience they provide overcome the limitations of words and projected images, as audiences can observe, listen, smell, and touch, hence experiencing an approximation of historical objects and practices *as if* they are presented with a historical object.

The fact that there is a long tradition of philosophical apparatus or scientific instruments being used pedagogically makes this use all the more fitting.<sup>70</sup>

## Objects

Boerhaave furnace, 1800–1900, A1000, Museum Gouda, Gouda.

Chair, 1800–1900, V03706, Rijksmuseum Boerhaave, Leiden.

Distillator, 1800–1900, V25790, Rijksmuseum Boerhaave, Leiden.

Dutch girl at Breakfast, Jean-Etienne Liotard, c.1756, SK-A-5039, Rijksmuseum, Amsterdam.

Model of Boerhaave furnace, Marieke Hendriksen and Ruben Verwaal, 2018, private collection.

Model of Boerhaave furnace, André Hendriksen, 2018, private collection.

Tea stove, c.1775–1800, BK-16153, Rijksmuseum, Amsterdam.

Tea stove, 1760, BK-1983-1, Rijksmuseum, Amsterdam.

## References

- Adamson, Glenn, "The Case of the Missing Footstool: Reading the Absent Object," in *History and Material Culture*, ed. Karen Harvey (London: Routledge, 2009), 192–207.
- Anderson, Robert G. W., J. A. Bennett, and W. F. Ryan (eds.), *Making Instruments Count: Essays on Historical Scientific Instruments Presented to Gerard L'Estrange Turner* (Aldershot: Ashgate, 1993).
- Anderson, Robert G. W., "Furnace," in *Instruments of Science: An Historical Encyclopedia*, ed. Robert Bud and Deborah Jean Warner (New York and London: Garland, 1998), 251–252.
- Anderson, Robert G. W., "Boerhaave to Black: The Evolution of Chemistry Teaching," *Ambix* 53 (2006): 237–254.

---

<sup>70</sup> See, e.g., Warner 1990, on 84; Heering et al. 2000.



- Barad, Karen, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning* (Durham, NC: Duke University Press, 2007).
- Benjamin, Walter, *The Work of Art in the Age of Mechanical Reproduction* trans. J.A. Underwood (London: Penguin, 2008).
- Bennett, J. A., *The Divided Circle: A History of Instruments for Astronomy, Navigation, and Surveying* (Oxford: Phaidon-Christie's, 1987).
- Beretta, Marco, "Between the Workshop and the Laboratory: Lavoisier's Network of Instrument Makers," *Osiris* 29 (2014), 197–214.
- Bilak, Donna, Jenny Boulboulé, Joel Klein, and Pamela H. Smith, "The Making and Knowing Project: Reflections, Methods, and New Directions," *West 86th* 23 (2016): 35–55.
- Black, Joseph, *Lectures on the Elements of Chemistry*, ed. John Robison (2 vols., Edinburgh and London: Longman and Rees, and William Creech, 1803).
- Boerhaave, Herman, *Elementa Chemicæ: Quae Anniversario Labore Docuit, in Publicis, Privatisque, Scholis* (2 vols., Leiden: Isaac Severinus, 1732).
- Boerhaave, Herman, *A New Method of Chemistry: Including the History, Theory and Practice of the Art*, trans. Peter Shaw, 2nd edn. (2 vols., London: T. Longman, 1741).
- Bosman-Jelgersma, Henriette A., *Poeders, pillen en patiënten: Apothekers en hun zorg voor de gezondheid door de eeuwen heen* (Amsterdam: Sijthoff, 1983).
- Bredenkamp, Horst, Vera Dünkel, and Birgit Schneider (eds.), *The Technical Image: A History of Styles in Scientific Imagery* (Chicago: University of Chicago Press, 2015).
- Cats, Jacob, *Houwelyck: Dat is de gansche gelegentheyt des Echten staets* (Middelburg: J. Pietersz van de Venne, 1625).
- Chang, Hasok, "How Historical Experiments Can Improve Scientific Knowledge and Science Education: The Cases of Boiling Water and Electrochemistry," *Science & Education* 20 (2011): 317–341.
- Cook, Harold J., *Matters of Exchange: Commerce, Medicine, and Science in the Dutch Golden Age* (New Haven: Yale University Press, 2007).
- Daston, Lorraine, "Introduction: The Coming into Being of Scientific Objects," in *Biographies of Scientific Objects*, ed. Lorraine Daston (Chicago: University of Chicago Press, 2000), 1–14.
- Deleuze, Gilles, and Félix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia*, trans. Brian Massumi (Minneapolis, MN: University of Minnesota Press, 1987).
- Dupré, Sven (ed.), *Laboratories of Art: Alchemy and Art Technology from Antiquity to the 18th Century* (Cham: Springer, 2014).
- Franq van Berkhey, Johannes le, *Natuurlyke historie van Holland* (9 vols. in 13, Amsterdam: Yntema en Tieboel, 1769–1778).
- Fors, Hjalmar, Lawrence M. Principe, and H. Otto Sibum, "From the Library to the Laboratory and Back Again: Experiment as a Tool for the History of Science," *Ambix* 63 (2016): 85–97.
- Gadamer, Hans-Georg, "The Ontology of the Work of Art and its Hermeneutic Significance," in *Truth and Method*, trans. Joel Weinsheimer and Donald G. Marshall, 2nd edn. (London: Continuum, 2006), 102–171.
- Ginzburg, Carlo, *History, Rhetoric, and Proof* (Hanover, NH: University Press of New England, 1999).
- Golinski, Jan, "Chemistry," in *The Cambridge History of Science*, vol. 4, ed. Roy Porter (Cambridge: Cambridge University Press, 2003), 375–396.
- Green, Harvey, "Cultural History and the Material(s) Turn," *Cultural History* 1 (2012): 61–82.
- Hagendijk, Thijs, "Learning a Craft from Books: Historical Re-Enactment of Functional Reading in Gold- and Silversmithing," *Nuncius* 33 (2018): 198–123.
- Hagendijk, Thijs, "T(h)inking with Texts: Rethinking Early Modern Instructional Texts through Reconstructive Research" (PhD thesis, Utrecht University, 2020).
- Hagendijk, Thijs, "Don't Blame the Text: Reproducing Rosichiero Glass from Antonio Neri's Recipes (1612) and Johannes Kunckel's Ensuing Commentary in the *Ars Vitrarya Experimentalis* (1679)" (forthcoming).
- Heering, Peter, Falk Rieß, and Christian Sichau (eds.), *Im Labor der Physikgeschichte: Zur Untersuchung historischer Experimentalpraxis* (Oldenburg: Universität Oldenburg Verlag, 2000).
- Hendriksen, Marieke M. A., *Elegant Anatomy: The Eighteenth-Century Leiden Anatomical Collections* (Leiden: Brill, 2015).

- Hendriksen, Marieke M. A., "Met Boerhaave naar de bouwmarkt: Over een chemisch oventje en het nut van historische reconstructies," in *Dingen die ergens toe dienen: Verhalen over materiële cultuur van wetenschap*, ed. Esther van Gelder Erik Jorink, Ilja Nieuwland, Marlise Rijks, and Alice Spruit (Hilversum: Verloren, 2017), 90–93.
- Hendriksen, Marieke M. A., "Boerhaave's Mineral Chemistry and Its Influence on Eighteenth-Century Pharmacy in the Netherlands and England," *Ambix* 65 (2018): 303–323.
- Hendriksen, Marieke M. A. "Criticizing Chrysopoeia? Alchemy, Chemistry, Academics and Satire in the Northern Netherlands, 1650–1750," *Isis* 109 (2018): 235–253.
- Hendriksen, Marieke M. A., "Casting Life, Casting Death: Connections between Early Modern Anatomical Corrosive Preparations and Artistic Materials and Techniques," *Notes and Records: The Royal Society Journal of the History of Science* 73 (2019), 369–398.
- Hendriksen, Marieke M. A., "Boerhaave's Furnace: The Search for Peat," *The Medicine Chest*, 20 April 2020, online: <https://mariekehendriksen.nl/2020/04/20/boerhaaves-furnace-the-search-for-peat/> (accessed 16 July 2020).
- Holmes, Frederic L., and Trevor H. Levere (eds.), *Instruments and Experimentation in the History of Chemistry* (Cambridge, MA: MIT Press, 2000).
- Jaquet, Daniel, and Vincent Deluz, "Moving in Late Medieval Harness: Exploration of a Lost Embodied Knowledge," *Journal of Embodied Research* 1, no. 1 (2018), 20:49, online: <http://doi.org/10.16995/jer.7> (accessed 16 July 2020).
- Jaubert, Abbé, *Dictionnaire raisonné universel des Arts et Métiers* (4 vols., Paris: P. F. Didot, 1773).
- Jongh, J. C. de, "Beschrijving van een verbeterd Boerhaviaansch destilleer-stoofje," *Nieuwe algemene konst- en letter-bode* 2 (1798): 34–36.
- Kamermaans, Johan, *Materiële cultuur in de Krimpenerwaard in de zeventiende en achttiende eeuw* (Hilversum: Verloren, 1999).
- Kamien-Kazhdan, Adina, *Remaking the Readymade: Duchamp, Man Ray, and the Conundrum of the Replica* (London: Routledge, 2018).
- Klein, Ursula, and Emma C. Spary (eds.), *Materials and Expertise in Early Modern Europe: Between Market and Laboratory* (Chicago: University of Chicago Press, 2010).
- Knoeff, Rina, *Herman Boerhaave (1668–1738): Calvinist Chemist and Physician* (Amsterdam: Edita, 2002).
- Knoeff, Rina., "Herman Boerhaave at Leiden: Communis Europae praeceptor," in *Centres of Medical Excellence?*, ed. Ole Peter Grell, Andrew Cunningham, and Jon Arrizabalaga (Farnham: Ashgate, 2010), 269–286.
- Lindeboom, Gerrit A., *Herman Boerhaave: The Man and His Work*, ed. M. J. van Lieburg (Rotterdam: Erasmus, 2007).
- Love, Rosaleen, "Herman Boerhaave and the Element-Instrument Concept of Fire," *Annals of Science* 31 (1974): 547–559.
- Martelli, Matteo, "Greek Alchemists at Work: 'Alchemical Laboratory' in the Greco-Roman Egypt," *Nuncius* 26 (2011): 271–311.
- Martinón-Torres, Marcos, and Thilo Rehren, "Trials and Errors in Search of Mineral Wealth: Metallurgical Experiments in Early Colonial Jamestown," *Rittenhouse* 21 (2007): 82–97.
- Martinón-Torres, Marcos, "The Archaeology of Alchemy and Chemistry in the Early Modern World," *Archaeology International* 15 (2012), 53–56.
- Orland, Barbara, "The Fluid Mechanics of Nutrition: Herman Boerhaave's Synthesis of Seventeenth-Century Circulation Physiology," *Studies in History and Philosophy of Biological and Biomedical Sciences* 43 (2012): 357–369.
- Powers, John C., *Inventing Chemistry: Herman Boerhaave and the Reform of the Chemical Arts* (Chicago: University of Chicago Press, 2012).
- Sibum, H. Otto, "Reworking the Mechanical Value of Heat: Instruments of Precision and Gestures of Accuracy in Early Victorian England," *Studies in History and Philosophy of Science* 26 (1995): 73–106.
- Smith, Mark M., "Producing Sense, Consuming Sense, Making Sense: Perils and Prospects for Sensory History," *Journal of Social History* 40 (2007): 841–858.
- Smith, Pamela H., and Tonny Beentjes, "Nature and Art, Making and Knowing: Reconstructing Sixteenth-Century Life-Casting Techniques," *Renaissance Quarterly* 63 (2010): 128–179.
- Smith, Pamela H., "Historians in the Laboratory: Reconstruction of Renaissance Art and Technology in the Making and Knowing Project," *Art History* 39 (2016): 210–233.

- Snelders, H. A. M., *De Geschiedenis van de Scheikunde in Nederland* (2 vols., Delft: Universitaire Pers, 1993).
- Staubermann, Klaus (ed.), *Reconstructions: Recreating Science and Technology of the Past* (Edinburgh: NMS Enterprises, 2011).
- Stevenson, Angus (ed.), *Oxford Dictionary of English*, 3rd edn. (Oxford: Oxford University Press, 2010).
- Swan, Claudia, "Ad Vivum, Naer Het Leven, from the Life: Defining a Mode of Representation," *Word & Image: A Journal of Verbal/Visual Enquiry* 11 (1995): 353–372.
- Taub, Liba, "What is a Scientific Instrument, Now?," *Journal of the History of Collections* 31 (2019): 453–467.
- Tullett, William, *Smell in Eighteenth-Century England: A Social Sense* (Oxford: Oxford University Press, 2019).
- Van Tielhof, Milja, "Turfwinning en Proletarisering in Rijnland 1530–1670," *Tijdschrift voor Economische en Sociale Geschiedenis* 2 (2005): 95–121.
- Van Ranouw, Willem, *Kabinet der natuurlyke historien, wetenschappen, konsten en handwerken* (Amsterdam: H. Strik, 1719).
- Van Spronsen, J. W., "The Beginning of Chemistry," in *Leiden University in the Seventeenth Century*, ed. Th. H. Lunsingh Scheurleer and G. H. M. Posthumus Meyjes (Leiden: Universitaire Pers, 1975), 328–343.
- Verwaal, Ruben E., "The Nature of Blood: Debating Haematology and Blood Chemistry in the Eighteenth-Century Dutch Republic," *Early Science and Medicine* 22 (2017): 271–300.
- Verwaal, Ruben E. "Increasing and Reducing: Breastmilk Flows and Female Health," in *Lifestyle and Medicine in the Enlightenment*, ed. James Kennaway and Rina Knoeff (London: Routledge, 2020), 223–239.
- Voltelen, Floris Jacobus, *Observationes chemico-medicae de lacte humano, ejusque cum asinino et ovillo comparatione* (Utrecht: A. van Paddenburg, 1775).
- Warner, Deborah Jean, "What is a Scientific Instrument, When Did It Become One, and Why?" *The British Journal for the History of Science* 23 (1990): 83–93.
- Weiland, Petrus, *Nederduitsch taalkundig woordenboek* (11 vols., Amsterdam: J. Allert, 1799–1811).
- Werrett, Simon, *Thrifty Science: Making the Most of Materials in the History of Experiment* (Chicago: University of Chicago Press, 2019).
- Weyerman, Jacob Campo, *De levens byzonderbeden van Johan Hendrik, Baron van Syberg*, ed. André Hanou and Hanna Stouten (Deventer: Sub Rosa, 1984).