Sulphuric Utopias

A History of Maritime Fumigation

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5 Stabilizing Fumigation

In the course of 1902 and the Ottoman deratization crisis, British health and port authorities followed closely the French experience with the Clayton process. Triggered by Frank Clemow's hesitation over the method, on January 14 the *British Medical Journal* received a letter by Clayton himself addressing the issue of the damaging of goods by his method. Whereas, he argued, this was true empirically speaking, it was only the result of the reaction of moisture with the chemicals produced by his machine; keeping merchandise protected from atmospheric moisture would guarantee no damage done to them by the Clayton gas.[1] At the same time, Clayton argued, his gas had a singular effect on rats: "Rats and all vermin seek to escape from the pungent gas as soon as they smell it, and its effects are slow enough to allow them to leave their hiding places before they succumb. This is not the case with carbonic gas of course, and serious trouble has frequently been caused by rats dying from its effects behind ceiling and panels, with quite offensive consequences."[2]

Still the efficacy of the Clayton machine continued to raise a range of doubts. A most telling conflict of opinions implicated Patrick Manson, who declared the Clayton to be "most efficient means of clearing ships of rats and vermin."[3] This endorsement elicited a vitriolic response by the chief medical adviser of the Local Government Board, W. S. Power, who bluntly declared: "I would that Dr Manson's knowledge of administration—of sanitary measures in their application in practice—were parallel with his enthusiasm in parasitology. The Board would be thus saved some unnecessary correspondence with the Colonial and Foreign Offices."[4] In Power's opinion, what others saw as minor or temporary misgivings of Claytonization (for example, "in one instance, there was slight bleaching of a dry sample of coloured silk") in fact necessitated new experiments on the process to be conducted in the United Kingdom.[5]

As a result, by invitation of the Clayton Company (June 1903), experiments were conducted at the Royal Albert Docks under direction of the well-known bacteriologist and cofounder of the School of Hygiene and Tropical Medicine, W. J. Simpson, in the presence of Prof. Hewlett and Dr. Woolston of Kings Collect and Sir William Hooper of the India Medical Council. The experiment, using plague and cholera cultures, was performed on the steamer *Manora* on empty holds. Reporting on the experiment, the assistant secretary of the Marine Department, Peter Sampson, related that within fifteen minutes two rats, which had been placed in cages within the hold, were retrieved "quite dead," adding that "their eyes were of a peculiar purple colour and I have some reason for believing that one of the effects of the gas is to act upon the eyes of living creatures."[6] Besides these experimental animals, around 220 rats living in the hold were also found dead. Rather than being conclusive, this apparent success did not suffice to convince British authorities of the appropriateness of the Clayton process, as the experiments had been conducted on empty holds and not with in situ cargo. Yet such hesitation seemed well past its hour in light of renewed trouble from Istanbul.

Just a few days after Simpson's experiments, notice came from the Ottoman Empire of Dr. Duca Pasha's proposal that vessels containing dead rats and deriving from plague-infected ports should be repulsed to the nearest lazaretto, where the rats would undergo bacteriological examination.[7] The Istanbul Quarantine Council was given but a week to consider the proposal, a diktat that infuriated the British due to its significant economic consequences: "It is an innovation which will bear very hardly on shipping and the sole justification is the present fashionable theory of the dangers of infection by rats, a theory which so far as I know reposes on conjecture merely and may tomorrow be discarded in favour of some new idea."[8]

Even if not everyone agreed with the author of the British response, E. C. Belch, that the rat's relation to plague was simply a "fashionable idea," relentless Ottoman insistence on maximum deratization urged for renewed efforts of experimentation with the Clayton apparatus, this time under the supervision of Franck Clemow, the British delegate to the Istanbul Quarantine Council.[9] The Clayton experiment, which took place in Liverpool on

July 30, 1903, was performed on the four-hold steamship Westmoreland of 1,384 tons gross register. Such was the haste that it was performed with only twenty-four-hours notice.[10] Only the two front holds were fumigated, one with a capacity of 14,000 cubic feet and the other with 22,000. Both were emptied of cargo before fumigation, with no rats having been recently observed onboard, possibly due to the vessel being used for the transportation of cement. The experiment aimed at ascertaining the germicidal power of the Clayton on cultures of anthrax, cholera, glanders, and enteric fever, (but, possibly on account of the hasty process, no plague), and its effect on "delicate food-products," including ship's biscuits, tea, coffee, sugar, apples, grapes, one banana, carrots, and skinned potatoes. Contained in test tubes, all bacterial cultures were wrapped and packaged in different ways and exposed in different parts of the two holds.[11]

The Clayton was then used so that the gas was pumped into the hold for four hours and fifty minutes, the gas being delivered at half-hourly intervals by the Company's engineer at a concentration ranging between 10 and 15 percent. After the engine was stopped, the hatches were kept shut for another three hours and then left opened for seven and a half hours when air was pumped into the holds for two hours. The food articles were then removed and exposed to the air in Clemow's private hotel room. While sugar, coffee, tea, and biscuits remained unaltered, bananas were "reduced to a semi-liquid, gelatinous pulp, which flowed through rents in the skin."[12] Grapes turned from black to green with an acidic flavor. As for apples, potatoes, and carrots, they all appeared to have softened as a result of the operation. At the same time, the bacterial samples were taken to Thompson-Yates laboratories, where no growth was observed in any of them, in contrast to the control tubes, where "there was a luxurious growth."[13]

Of particular interest was a peculiar aspect of the experiment, which involved rats that had been placed in the holds after being killed with typhoid bacilli. For this was the only case where the bacilli were not destroyed by the Clayton gas: "Cultures were made from the heart-blood of one of the rats, and a mixed growth of the typhoid (or enteric) bacillus and of the bacillus coli communis was obtained."[14] As a result, Clemow concluded that the Clayton gas had not penetrated the tissues of the cadavers. And still he remarked that this had failed to answer the main question of the experiment:

> Firstly, I had wished to employ rats inoculated with plague, but as it was thought that there might be some risk in exposing plague-infected rats, typhoid-infected rats were employed instead. Secondly, I had wished to use living rats, in order to determine whether the gases, after killing such rats, would also destroy the infective material in their blood and tissues. But both rats died before the time of the experiment. It is quite possible that, had they been placed alive in the hold, and inhaled a quantity of the sulphurous gases before death, a sufficient amount of the gases might have been absorbed in their blood to destroy the infection there.[15]

Although Clemow did demonstrate that the Clayton gas had considerable penetrating power, the value of his findings was immediately challenged by his superiors: "the experiments here recounted do not help us much, as they were conducted on an empty vessel and not one with cargo 'in situ.' Until this is done our knowledge remains 'in status quo.'"[16]

The inconclusiveness of the experiments, in the eyes of British authorities at least, meant that any official endorsement or legislation on the preferred or sanctioned means of fumigation was stalled. What followed instead was a series of international conferences where the question of fumigation and deratization assumed central stage, setting the pace for the cross-European stabilization of these processes with regards to maritime trade. What was at stake in these meetings were the rules applying to quarantine and fumigation that port authorities of the participating states would have to adopt against the spread of infectious diseases while keeping the minimization of detention time as a generally accepted economic objective.

The Brussels Medical Congress

The first of these meetings was the Brussels Medical Congress, held in September 1903. There, drawing on his experience with plague in Arabia, Dr. Frédéric Borel, later known for his study of cholera and plague in relation to the Hajj, stressed the importance of focusing on the problem of the rat and maritime trade.[17] In order for plague prevention to be effective, he argued, a new international agreement on the classification of boats needed to be reached, in his opinion, in the following distinct categories:

> 1) A boat which, even if it derives from an infected port, has mortality neither amongst humans nor amongst rats. For this boat, immediate freedom must be accorded; 2) A boat that in course of its route has human cases without rat

> mortality. We isolate the ill; as for the other passengers or the boat itself, we let them go free; 3) Finally, the boat which has mortality amongst rats, with or without human cases. This is the only one which is dangerous.[18]

To face the global peril posed by plague, Borel argued, it was necessary for port authorities to approach the destruction of rats on board of ships not as an exceptional measure but as what is "normal and regular. We need to destroy rats on board with the same regularity that we repaint a boat."[19] In other words, Borel propagated "a constant surveillance, a surveillance in all instances" of boats, which had "become veritable floating cities, entire cities, and cosmopolitan cities."[20]

On his part, the leading Pasteurian, Albert Calmette, also stressed the need to recognise the recently established importance of rats in the maritime propagation of plague, even when "there are no human cases onboard or the boat did not derive from a contaminated port." The goal that port authorities and the public health establishment should both and jointly aim for, Calmette argued, was for boat- and merchandise-related quarantine to be limited to "the time strictly necessary for the *destruction of rats and of insects* and in *complete disinfection of all the parts of the boat and the cargo*."[21] To achieve this, what was required was the employment of scientific and officially sanctioned methods. Only thus, Calmette argued, could the aim of the progressive reduction of detention time and the eventual abolition of quarantine be ultimately reached.

As part of the discussions on the modification of prophylactic measures by port authorities against plague, and quarantine rules in particular, Calmette noted the limited efficacy of carbonic acid and carbon monoxide as fumigating substances that were both dangerous and did not kill the key objective of fumigation: rat fleas. By contrast, he stressed, an apparatus existed that combined sulphuric acid and SO_2, giving excellent results. This was no other than the Clayton machine. Stating that fumigation led by this apparatus was superior to the generally inefficient practice of quarantine, Calmette's optimism was countered by a more cautious approach by Germany's delegate, Nocht, who presented three objections to the use of the Clayton machine. First, in order to kill all rats on board of a ship it would be necessary for the relevant port authority to introduce sulphuric gas at a concentration of 10 percent, which Nocht doubted the Clayton could achieve. This was based on his own experiment of placing one hundred rats in cages in a boat's hold and surrounding them with different commodities—an experiment that did not result in the death of all the rats. Nocht's second objection resolved that sulphuric disinfection only had superficial effects and did not destroy all plague bacilli, such as those found in the excrements and corpses of rats. Finally, Nocht repeated the oft-voiced opinion that sulphuric gas had a deleterious effect on commodities, which, though not manifesting any exterior alteration, presented considerable changes when examined chemically, with tea, tobacco, and wool in particular accumulating great quantities of the gas.[22]

A staunch supporter of carbon-based solutions, Nocht also attacked Calmette's proposal to prove the efficacy of the Clayton by conducting experiments where tubes with plague bacilli would be placed inside goods in the hold of a boat. This, Nocht claimed, was both dangerous and unrealistic, insofar as "it is impossible to put the experimental tubes inside the deep parts of the boat, where one can find the rats."[23] As an alternative, he proposed the use of carbon monoxide pumped through the apparatus he developed and operated himself in the port of Hamburg.[24] Responding to Nocht, the veteran of fumigation experiments in Tunis, Langlois, stressed the need to distinguish between ordinary sulphurization of boats and "Claytonization," where the combination of SO_2+SO_3 "easily surpass 10%"—the disinfection of 45 boats in Dunkirk in this manner thus far had shown, in his experience, a total destruction of rats without altering or damaging merchandise, including fruit, tea, flour, and tobacco.[25]

Such deliberations, as they unfolded in the course of the Brussels Congress, were largely seen and acted out as preparatory discussions in anticipation of the International Sanitary Conference in Paris, which was to take place in December of the same year. However, the French, Pasteurian approach seemed to pre-empt this development insofar as only a few weeks after the conclusion of the Brussels proceedings, the President of France proceeded to issue a decree titled *The Destruction of Rats on Board of Ships Derived from Countries Contaminated with Plague, Before Unloading* (September 21, 1903). The decree stipulated that the destruction of rats from aforementioned countries was obligatory and that this should be affected by means of processes and apparatuses whose efficacy had been approved by the consultative committee of public hygiene of the Republic, and that it was immediately applicable in such harbors where these processes and apparatuses were in place.[26]

British Experiments

Faced with the embroiled debate in Brussels, the French presidential decree, and the impeding sanitary conference in Paris, British port authorities quickly moved to perform a range of new, more systematic experiments with the Clayton process. J. S. Haldane arrived in the port of Dunkirk on October 6, 1903, to witness the disinfection of *S.S. Bavaria*, a 3,006-ton cargo boat, by means of the Clayton machine. Haldane had inhabited a peculiar position in the history of hygiene, and his research and scientific practice were driven by a strong vision of social change.[27] In studies on the quality of air in densely populated parts of Dundee, in Scotland, Haldane had an interest in the toxicity of various gases, as he investigated their capacities to impair human environments. Furthermore, industry-based research in mine safety, the ventilation of tunnels, and poisoning by lighting gas had, as Steve Sturdy has shown, "established him firmly as the leading scientific expert on protective measures against noxious atmospheres in buildings and workplaces."[28]

The *S.S. Bavaria* had recently arrived in London from Calcutta, carrying cargo for the British capital, Glasgow, and Dunkirk. Having first made a stop in London, upon reaching Dunkirk its main bulk consisted of bales of jute, poppy seed, linseed, and pulse grain destined for the French harbor. The boat arrived the following day and without delay, within two hours of arrival, a Clayton apparatus was brought aside the vessel and disinfection commenced in the presence of J. B. Evans of the Clayton Company. First the machine was used to fumigate the boat's two storerooms, a process lasting thirty minutes. Haldane reported that "the whole space appeared to be pretty filled with gas. Ten rats and thousands of dead cockroaches were lying about the floors, &c., which appeared to have been very successful."[29] Following this, different compartments of the boat were treated in sequence. As these bore ventilators, "the gas was introduced by putting the hose down a ventilator, the return pipe being usually put through a partly-opened hatch, and the other ventilators closed with canvas."[30] An hour or so was spent fumigating each of the compartments until "the gas began to issue in a concentrated state from the hatch."[31] Without treating the engine room or stokeholds, the last compartment to be ventilated was the saloon. As by then dusk had fallen, electric lamps were turned on, and Haldane reported being able to "observe through the windows the behaviour of the gas in the saloon": "It gradually filled the room from below upwards, the upper surface of gas having a fairly well defined surface. Above this layer flies still alive could be observed until the upper level of gas reached them, when they were killed."[32]

Fostered by this eerie image, Haldane's interest was particularly held by the way gas functioned in relation to the cargo itself. Noting that the temperature of the bags of seed contained in the holds was about 100°F, Haldane observed that "the air would naturally circulate down the sides and upwards through the cargo; and the introduction of a heavy gas such as sulphurous acid, would increase this circulation."[33] However, as the cargo was tightly packed, the little time allowed for fumigation prohibited a thorough penetration of the cargo by the gas. This was a problem that chimed with other limitations that Haldane had observed in the process. Descending to the two holds of the boat, after their ventilators had been opened for several hours, he conducted a thorough examination that left much to be desired as regards the efficacy of the Clayton process, at least as operated in that instance. For upon reaching the holds, Haldane was met not with piles of rat corpses, as it had been hoped, but instead by the chirping of crickets, which had apparently survived fumigation, "doubtless because the treatment had been too hurried."[34] Worse even, live rats and mice were said to be discovered and killed post-fumigation by the boat's crew.

On the other hand, Haldane was satisfied to confirm the results of Drs. Duriau and David as regards the harmlessness of the process on the cargo. The French doctors were eager to show Haldane exposed and control samples, which "entirely bore out their published statements."[35] Only the brass fittings in the saloon appeared a bit tarnished; still this was but a superficial effect, easily removed. And yet, Haldane observed, the process left an "extremely unpleasant" odor on beddings and woollen materials:

> I slept in one of the staterooms after the disinfection, and although the bedding has been aired on deck, and all windows and doors left open for several hours, the atmosphere was most unpleasant. Two ladies who slept on board suffered considerably from catarrh of the air passages, caused by sulphurous acid given off from the bedding.[36]

In spite of constant airing, Haldane complained that his clothes continued to smell "very distinctly" even three weeks following fumigation.[37] This made him suspect that had fumigation lasted longer, for SO_2 to sufficiently penetrate the cargo, the seeds contained therein would also have acquired the unpleasant odor, rendering the unloading of the cargo a particularly unpleasant job. Haldane thus concluded that, while effective in empty holds, "there is no satisfactory evidence as yet that it is practicable, without considerable delay and inconvenience, to make it equally effective in holds which are full."[38]

Prompted by these results and needing to know more about how the Clayton operates and the degree of its efficacy or harm, the Medical Office of the Local Government Board instructed Dr. John Wade to conduct experiments with the machine so as to ascertain the "percentage of sulphur dioxide required to kill rats and insects in a reasonable time," "its action on pathogenic bacteria, especially those of plague," "the manner in which sulphur dioxide and 'Clayton gas' penetrate cargo," and, finally, "the damage, if any, likely to be done to the cargo and appointments of a ship during the process."[39] In order to conduct experiments with the Clayton machine, Wade hired an experimental plant on a wharf at Blackpool, England, from the Clayton Company. The plant, originally designed for demonstrations of the fire-extinguishing capacities of the machine was converted accordingly.

Wade gave an evocative, and indeed rather impressionistic, image of the Clayton in operation:

> When the generator was working freely the surplus gas streamed from under the caves as a white fog, which, on calm days, fell rapidly to the ground, and then spread slowly like mist. On windy days it was impossible to work except on the windward side of the shed, the gusts of gas ejected from the building rendering the air in the immediate neighbourhood quite unbearable.[40]

In a manner befitting long-standing traditions of medical heroics, Wide decided to determine the maximum percentage of endurable SO_2 by experimenting on himself: "After the shed had been fully charged with gas, the doors were opened, and as soon as the interior could be seen, I endeavoured to enter and take a sample of the air."[41] Wade had to wait until SO_2 concentration had fallen to 0.2 percent to enter the shed, and even then he soon had to exit the premises as "the gas was practically irrespirable": "[A] little later, when the sulphur dioxide had fallen to 0.1 per cent., the smarting of the eyes, although still painful, was no longer so acute as to interfere with vision, and the air could be breathed with some difficulty. It gave rise to marked bronchitis and nasal catarrh the next day, accompanied by severe headache."[42] Wade reasoned that while people like the generator's mechanic developed tolerance to the gas, its distinctive smell, allegedly "perceptible at 0.01 per cent," as well as the visibility of sulphur trioxide safeguarded the boat crew from the approaching gas.

In order to ascertain the effect of the Clayton on bacteria, Wade conducted experiments using strips of sterilized cigarette and filter paper and pellets of sterilized cotton-wool soaked in cultures of cholera, typhoid, plague, anthrax, and shiga. Exposing such cultures to different percentages of SO_2 and for differing time periods, Wade took care so that they were wrapped, thus simulating the practical conditions in the hold of a ship. In this way, his trial replicated Calmette's original germicidal experiments on the *René*. Each experimental "envelope" contained a full bacterial set, and was further "wrapped up in several thicknesses of cotton wadding, and then made into a small parcel with wrapping-paper. Finally, each parcel was wrapped in several thicknesses of blanket, making a bundle about nine inches long as a little less in diameter."[43] Indeed, Wade went so far as to place two of the wrapped packages in a locked steel trunk filled up with clothes or blankets. The key question of these experiments was to test the Clayton Company's claim that the gas generated by Claytonization "is more efficient as bactericide than pure sulphur dioxide diluted with air."[44] Wade concluded that his experiments demonstrated that, whereas in the case of plague such difference was negligible, "a slight but distinct superiority in the toxic power of the Clayton gas as regards typhoid germs" was evident; this he attributed tacitly to the dampness of the material exposed to the gas.[45]

Experiments on rats performed by Dr. M. S. Pembrey, a physiology lecturer at Guy's Hospital, London, had already shown that the maximum percentage of SO_2 tolerated by rats without incurring death was around 0.2 percent, with young rats being more susceptible to the gas. Wade concluded that "the uniform diffusion of 0.5 cent. of sulphur dioxide through the hold will kill the rats within 2 hours" and that, as a result, the Clayton Company's recommendations for six to seven hours of exposure with 0.10–0.12 percent SO_2 was sufficient, with the provision, however, "*that the gas penetrates into every part of the cargo*."[46]

These results led him to conclude that while effective on an empty hold, the Clayton process faced distinct limitations when faced with holds bearing densely packed cargo. This, he reasoned, was due to the propensity of the gas to be absorbed by material, especially wool, tea, coffee powder, cocoa, and flour. In the case of wool, which he considered a prime locus of SO_2 absorption, Wade claimed that "a bale of compressed wool would absorb at least 10 times its volume of the undiluted gas," which it would then give up upon exposure to air.[47] Given this extensive absorption, the penetration of the gas into the totality of the loaded hold required what Wade thought was a very long time. To ascertain the precise span of the latter, further experiments were conducted with bales of wool provided by the Clayton Company, which also gave technical support in constructing an experimental apparatus through which gas could be inserted directly into the bales. After several experiments with wool and jute bales, Wade concluded that, no matter how tight the packaging, SO_2 was indeed able to penetrate this material with such rapidity and to such extent that there is no "possibility of distributing throughout a [jute or wool] loaded hold a percentage of sulphur dioxide to kill every rat," which could easily find refuge from the gas between bales and sacks.[48] On the other hand, no such limitation was shown to apply to cargoes of cotton, which bore none of the absorbent qualities of the other material. In conclusion, Wade claimed that when it came to empty holds, all rats and insects could be destroyed by means of a fumigation with 0.5 percent of SO_2 over a period of less than two hours—a result, however, untenable in loaded cargo conditions due to the high and rapid absorbability of the gas. Among different bacteria, plague was deemed optimally destroyed at a concentration of 2 percent over a six-hour exposure, while typhoid, being more resistant, required twenty-four hours under the same concentration. Confirming Robert Koch's older experiments, anthrax, on the other hand, was deemed to be immune to SO_2.

As regards the question of damage caused by Claytonization to cargo, Wade noted that the dampness observed post-treatment in textile materials and fabrics was radically reduced if these were suspended vertically, or covered even by a single layer of thin tissue paper. Similar protection was afforded in this manner against the damaging effects of SO_2. In any case, even when goods were permanently damaged, no residual odor was observed, contradicting Haldane's report, which Wade attributed to the probable presence of small quantities of selenium in the gas. As regards foodstuffs, Wade confirmed that tobacco, fresh fruit, and vegetables, as well as powders (but not sugar or salt) were among those critically impaired. Of particular interest to him was flour, which not only seemed to be losing its odor and taste as a result of fumigation, but also evinced reduced ability to "raise," thus making it useless for breadmaking.

Faced with these results, in their joint follow-up report, Haldane and Wade sought to compare the Clayton process with other processes of rat destruction in ships. First, they admitted that the Clayton method "possesses very distinct advantages": markedly, the fact that Claytonization worked by means of the law of gravity, with the gas finding its way to the bottom of the holds due to being heavier than air. At the same time as obviating any risk of fire or explosion, and having a very low risk of asphyxiation, the use of SO_2 was deemed superior to carbon monoxide, both in terms of its visibility to the naked eye and in its ability to kill insects. Still, if the Clayton apparatus was deemed to provide an efficient method of disinfection, this was conditioned upon the penetration rate in practice. Hence, in light of Wade's findings, the report expressed its reservation as regards the actual, practical efficacy of the machine as applied to loaded ships. The methods compared to the Clayton were the following:

a) Burning sulphur on shipboard, which could only be used on empty holds and was deemed to be effective against plague in particular, but a tedious task involving a high risk of fire.
b) Liquid sulphurous acid, employable in both empty and loaded holds, which was deemed somewhat less damaging than Claytonization yet not obviating the latter's absorption/penetration problems.
c) Carbon monoxide, which, having already received the attention of the Medical Officer of the Local Government Board and doctors like Nocht, was being currently used for rat destruction on loaded vessels in Hamburg—a cheap and easy-to-use substance, CO's advantage was that it was not absorbed by cargo. On the other hand, the substance was dangerous to humans due to being odorless and, under certain conditions, explosive, while having no disinfectant or insecticidal action. In Hamburg, an apparatus was used so as to obviate such problems by transforming CO to CO_2.
d) Carbonic acid, which was safer but required large quantities to kill rats while not killing insects.

It would be thus fair to say that, in Wade and Haldane's view, circumstantial factors benefitted different fumigation methods:

> If all vessels from plague-infected ports, whether known to be infected or not, were to be treated, the question of expense of materials and of the damage producible by the sulphur process would be a very serious one, and probably the carbonic oxide process would be preferable on the while in cases of known infection of vessels, the treatment with carbonic oxide would doubtless need to be followed by a separate disinfection process. The question of a certain amount of damage by the sulphur process on vessels actually infected with plague, of which there are likely to be very few, is of no great importance, particularly as disinfection will be needed in any case. In view of all the circumstances we think, therefore, that a sulphur dioxide process will be most generally useful.[49]

If, as a result, Wade and Haldane advocated the use of the Clayton as particularly useful in large English ports, doubt still lingered regarding the efficacy of the method on loaded cargo, and more experience was deemed necessary so as to ascertain the optimal duration of the treatment. In case this proved to be too long, then an option would be to add carbon monoxide (aka carbonic oxide) to the gas in the holds. In that case, it was suggested "The diminished proportion of oxygen in the interior of the cargo treated by the Clayton process would greatly increase the poisonous action of the carbonic oxide on the rats, which could thus be destroyed with certainty, while at any rate a certain proportion of the cargo would also be disinfected."[50]

Held only weeks after the conclusion of the British experiments with the Clayton, the sanitary conference in Paris promised to be the decisive moment for an international decision on the optimal fumigation method in the quest of a quarantine-free future for maritime trade. As had often been the case, however, rather than reaching a consensus, the international meeting only came to confirm scientific discord.

The Paris International Sanitary Conference (1903)

Coming together for the first time since the 1897 International Sanitary Conference in Venice, where international maritime quarantine rules had been discussed and defined, twenty-five nations gathered in Paris in December 1903. This was the first legislating international sanitary meeting to tackle the case of the rat's implication in the spread of plague. Indeed, the person internationally recognized as the canonical summarizer of the 1897 sanitary conference, Adrien Proust, stressed that while the purpose of the 1903 conference was to codify existing regulations, as passed in 1897, the discovery of the role of the rat and its flea in the propagation of plague had led to the need to discuss the effective measures of vector destruction, or even germicide, on board of ships.

The hope was that such measures might be able to rid vessels of diseases like plague, yellow fever, and cholera, thus bringing about an immense advantage for international sea trade. Yet, as expressed by the French delegation, this required a radical revision, in light of recent scientific developments, of the definition of "unaffected" boats (*navires indemnes*): "In Venice, in 1897, we only concerned ourselves with ships from the still contaminated or suspect regions of the Far East. The term unaffected [*indemne*] was applied to ships which, although originating from contaminated areas, had had no sick persons during the voyage."[51]

As of recently, however, the role of the rat on maritime plague had been connected with observations that plague could break out onboard a ship even up to sixty days after it had left a contaminated harbor, making the disease's incubation period in humans irrelevant. Indeed the establishment of the rat as a key player in the maritime propagation of plague exposed a paradox, aptly embodied in the key seafaring crossing of the Suez: "A vessel, conveying a patient isolated on board, and whose presence is almost no longer dangerous, will be quarantined. A vessel infected with plague-rats, which offers much more peril may freely pass the Canal."[52] As a result, and in order to bring back to the notion *indemne* its true meaning, Proust proposed the following redefinitions:

A. As *unaffected,* the ship from an uncontaminated district which has not stopped at contaminated ports, which has not had a confirmed or suspected case of cholera, yellow fever or plague, and on which no plague-infected rats have been found.

B. As *suspect,* the ship from a contaminated origin, or having stopped in contaminated ports, but which has neither confirmed nor suspected cases of cholera, yellow fever or plague, and on board of which the presence of plague-infected rats has not been observed.

C. As *infected,* the ship from a contaminated or uncontrolled district which has stopped at contaminated or uncontaminated ports and which has presented confirmed or suspected cases of cholera, yellow fever or plague or on which plague-rats have been found or observed from the time of departure or arrival.[53]

For a port to be considered as no longer contaminated, a bacteriological examination of rats living therein was deemed necessary; only when these proved to be free from plague could a hitherto infected port be declared unaffected. But what was the role of rat destruction in this scheme of things? Proust harbored visions of deratization apparatuses being installed in every port—a duty that, in the eyes of many of his colleagues, should burden ship companies and not the state and its port authorities. As the Belgian delegate's statement demonstrates, the vision entailed here was uniquely utopian, pointing not simply to the limitation but to the abolition of quarantine: "In order to obtain progressively the reduction of the duration and even, if possible, the total abolition of quarantines, encourage shipping companies and ship-owners to complete the destruction of rats and insects on board their ships after each complete unloading of the cargo holds under the control of sanitary administration."[54] Upon deliberation, the "technical Commission" of the conference thus agreed on a new classification:

> A ship which has plague on board or has had one or more plague cases for seven days is to be considered *infected*. A ship which there have been cases of plague at the time of departure or during the voyage, but no new cases have occurred during seven days, is to be considered *suspect*. A ship which has had neither dead nor cases of plague on board, both before departure and during the voyage or at the time of arrival, is to be considered as unaffected, even if it arrives from a contaminated port. Ships aboard which the presence of plague-infected rats is or has been in place, shall be subjected to special measures.[55]

Still what remained a contentious issue was whether the observation of a rat epizootic in a given harbor should be made notifiable in the same way as human cases were. The position was defended by Proust in opposition to a broad consensus that epizootics should be noted only in case of human outbreaks. The reason for this was that Proust's proposed regulation would be difficult to implement and would, as a result, favor countries that simply did not conduct tests on rats, thus potentially raising interstate suspicion that could be detrimental to trade.

At the same time, in light of the centrality of the rat, a heated debate unfolded regarding the optimal method of deratization. While the leading Pasteurian, Albert Calmette, argued that the conference did not need to decide over one process or another, and that each country should be free to decide for itself, he still insisted that from among the three proposed deratization methods (H_2CO_3, SO_2, CO_2), only one had disinfecting qualities: the Clayton. This direct endorsement was, however, immediately met by strong opposition led by the German delegate and associate of Nocht (better known as the discoverer of the causative agent of typhoid fever, *salmonella typhi*), Georg Theodor August Gaffky. Recalling Robert Koch's old anthrax experiments, Gaffky maintained that the aim of these processes was deratization and not disinfection, casting doubt on the germicidal properties of sulphuric acid. Moreover, pointing at Nocht's opinion that sulphuric acid damages the boat's metal plates, Gaffky stressed that the effects of these gases on goods had not been adequately established.

German opposition only came to underline a broader confusion, as Calmette was quick to point out: the mistaken equation of the Clayton gas with sulphuric acid, H_2SO_4, when in fact the former was sulphur dioxide, or SO_2. Upon Calmette's question on the subject, Nocht, who was also present at the meeting, specified that indeed his own experiments had been with sulphuric acid and not the Clayton gas, still maintaining, however, that the same deleterious effects would probably result from the latter. Calmette was quick to explain that while open-air production of sulphuric acid would lead to such damage, the production of the gas inside the Clayton apparatus left surfaces unharmed. He stressed that any confusion between "the gas produced by the Clayton apparatus and that results from the open air combustion of sulphuric acid" should be avoided, "the former having, because of the special conditions in which it is obtained, a much higher concentration to which it owes an incomparably superior disinfecting power. While its content reaches 9, 10, 12 and even 1 p. 100, that of the gas produced by combustion in the open air does not exceed 3 to 4 per cent."[56]

Nocht, however, insisted in his attack on the Clayton, this time from a financial point of view, arguing that Calmette had himself said that "flour impregnated with sulphurous acid became unfit for bread-making, but that it was sufficient to aerate it to restore its properties."[57] How, Nocht objected, would this be possible in the case of flour contained in barrels or bags, without "removing from the recipients the guarantees resulting from the trademark of those products"? Nocht stressed that, as a result, "in Germany the use of sulphurous acid would certainly give rise to claims which would result for the State by the payment of heavy indemnities."[58] The German opposition was to find an unexpected ally in the British delegate who, in a move that relied on a selective reading of the experiments conducted by Haldane and Wade over the previous months, stressed the inconclusive nature of experiments regarding the time required for the Clayton to bring about the complete deratization of ship holds.

To Calmette's support came Proust who claimed that, since its application in Dunkirk, forty-five boats had so far been thus fumigated with no recorded damage. Proust distributed the report he coauthored with Faivre to the delegates. He and other French delegates proposed, in light of the different available methods, that the conference should adopt the following formula: "In the present state of science, the means which have been recommended as effective are Clayton gas, carbon monoxide, and carbonic acid." However, Gaffky objected that this would appear like an endorsement of the first, when the deleterious effects of sulphuric acid were in fact in question. Governments, he suggested, should just be allowed to choose whatever method they wanted.[59] With delegates from different countries quickly taking sides along the Franco-German divide, the chairman of the Commission proposed the following compromise:

> In the present state of science, the means which have been recommended as the most efficacious for the destruction of rats on board ships are:
>
> 1. A mixture of sulphurous acid and sulphuric anhydride, propelled under pressure in the holds, and assuring the stirring of the air, together with a concentration of sulphurous acid equal to at least 8 per cent. 100 per cubic meter of air.
> 2. A mixture of carbon monoxide and carbonic acid.
> 3. Carbonic acid.
>
> It is advisable to organise in the ports a scientifically rigorous control, making it possible to ensure, for each disinfection operation, that the rats and the insects have been completely destroyed.[60]

But even this formula was rejected as unacceptable, as the British delegate claimed that it misinformed insofar as "it presupposes an acknowledgment of efficiency," while Gaffky, doubting the role of fleas in the spread of plague, suggested the removal of any reference to insects.[61] As a result, the closing paragraph of the statement was thus revised: "It is necessary to organise in the ports a check to ensure, for each disinfection operation, that the rats were completely destroyed. This control is not required when the operation is carried out by the health service," and was unanimously adopted.[62]

As a result of the acrimonious divide, delegates at the Paris Sanitary Conference proved unable to come to a meaningful consensus regarding a single optimal method of vessel fumigation. However, the conference may indeed be said to have achieved a stabilization of maritime fumigation. For this was the first time that this process, irrespective of the method advanced by different parties, was endorsed at the political and legislative level afforded by the conference. Rather than simply remaining an international aspiration, maritime fumigation had, by means of the 1903 International Sanitary Conference, become an internationally stabilized legislative and practical field. The impact of this would soon be felt across the globe.

Globalizing the Clayton

On May 4, 1906, following the advice of the Paris Sanitary Conference, a Presidential decree made the destruction of rats on all French ports obligatory before unloading of cargo for vessels arriving from or having touched at plague-contaminated ports, as well as for vessels having received via transfer from another ship merchandise exceeding fifty tons from a contaminated country.[63] Most importantly, according to the decree, the destruction of rats should be carried out "exclusively by an apparatus the efficiency of which has been recognized by the Superior Council of Hygiene."[64] Besides the Clayton, in the course of the following years these would include the Marot (from 1905), an apparatus using liquid SO_2 (see chapter 6), and the Gauthier-Deglos apparatus (from 1907), a machine employing sulphur and coal dust with the help of a ventilator that, by sucking out the air in the holds, forced the introduction of the gas into the vessel.

Besides vessels that had not touched upon plague-infected ports, also exempt from these measures were declared such vessels "that only land passengers in French ports without docking and which sojourn only several hours," and vessels that stop at French ports for less than twelve hours and discharge less than 500 tons of cargo (as long as rat-guarding measures are observed).[65] However, the decree also included in this exempted category more ambiguous cases, such as vessels that had travelled for sixty days since departing from a contaminated port without touching any other port in the meantime and where "nothing of a suspicious sanitary nature" had been observed onboard.[66] Similarly exempt were vessels that, in spite of having touched upon a contaminated port, could "prove that they neither berthed alongside the quay or landing stages, nor embarked merchandise," as well as vessels of a similar origin whose captain could certify that it had undergone deratization at departure following processes approved by the French sanitary authorities.[67] According to the French decree, obligatory deratization concerned holds, bunkers, and crew and emigrant quarters, as well as third- and fourth-class compartments, but excluded first- and second-class compartments and officers' cabins, as well as salons and dining rooms. The cost of the operation was to be borne by the shipowners, as already established by law since 1896.[68]

Outside France, the period following the 1903 International Sanitary Conference witnessed the adoption of the Clayton in many ports, occasionally even in the service of deratization campaigns on land. Indeed the decades following 1903 mark a peak in global preoccupation with rats and deratization on both sea and land. What fueled this was a growing international antagonism over hygienic modernity, with claims of a lack thereof by opposing nations or empires functioning as an important tool in maritime trade competition.[69] This is not to say that deratization efforts were cynical. Far from it, all evidence points to the fact that it was a goal seriously aspired to by public health as well as port authorities, reaching such climaxes as the mass campaign launched in Denmark for the total eradication of the species. There, calls for a legislation for the extermination of the rat in the Danish Kingdom had been in place since 1898, but were only enacted through the signing of a law by the Danish King in March 1907, following an aggressive campaign by the president of the Society for the Destruction of Rats, Emil Zuschlag.[70] The national war on the rat led to massive efforts of extermination; the grand total of rats caught and handed in for a reward between the start of the campaign in July 1907 until January 1909 being no less than 1,557,656, not including rats destroyed directly by the government.[71] It was an event that elicited global fascination and contributed considerably to the utopian fantasy of rat-free harbors, cities, and even nations. If efforts to emulate the Danish example proved less than successful, they still marked a pattern emerging in Western Europe and North America, while also affecting the colonies: rendering deratization a civic duty.[72] Most importantly, when it comes to the global war against the rat in *terra firma*, the deratization hype accompanied and fueled, both financially and affectively, a surge for "building out the rat."[73] As a result of a widespread agreement that fumigation of buildings was not effective, due to the manifest difficulty in sealing the latter effectively and to the danger posed to humans, while such practices were not altogether abandoned, they rapidly gave their place to rat-proofing as the catchword of urban hygienic reform and modernity across the globe.[74]

In the field of maritime sanitation, in the years following the 1903 International Sanitary Conference, the Clayton machine was widely adopted across the globe.[75] This included, for example, the Ottoman purchase of a Clayton machine for use in the key port of Jeddah in the spring of 1909, and the application of the Clayton in the port of Amoy the same year.[76] Similarly the Clayton was employed in the port of Trieste for vessels arriving from the Far East.[77] In Peru, the adoption of the Clayton machine was made compulsory by the country's government, so that after 1903 three sanitary stations became operative—in Ilo, Callao, and Paita respectively. Brazil in turn imported various machines that were brought into practice both in the port of Rio de Janeiro as well as on its streets.[78] All operated the Clayton machine on vessels derived from infected ports. But this was not enough. The Peruvian government also made it compulsory to install and operate Clayton machines on passenger steamers, with Pacific Steam Navigation Co., Cia Sud de Vapores and W. R. Grace & Co. complying with the decree. The American consul in Callao contrasted the impressive onboard results of this method to the disappointing failure of applying methods such as poisoning, trapping, and using pathogens, such as the Danyz virus, against rats in the harbor wharfs and buildings of the Peruvian port.[79] This global adoption of the Clayton was not, however, a frictionless process. Indeed, as we can see from a brief examination of the case of French Indochina, it involved pressing financial questions.

The application of the Clayton proved to be desirable across the French colonies, but in particular in Indochina, where plague had become a recurring problem since the first outbreak of the disease in the coastal town of Nha Trang in 1898.[80] In August 1908, following his meeting with the director of the Institut Pasteur, Émile Roux, the newly appointed Governor General of Indochina (GGI), Antony Wladislas Klobukowski, urged the superior council of hygiene of the colony to take every measure so as to adopt the most practical apparatuses for disinfection against plague. Responding to the GGI's question on whether Clayton-driven sulphurization of all cargo suspect of harboring rats and insects was in place, the council informed him that this was indeed already effective in Saigon, where it was applied when merchandise arrived from infected ports, especially Hong Kong during the summer months, when the Crown Colony suffered from its seasonal outbreaks of the disease.[81] However, the GGI and his agriculture director insisted on the need to sulphurize not only cargo ships but also junks (traditional Chinese sail boats), as these, in their opinion, posed an even greater threat than international steamships.[82] In practice, the key problem to this expansion of the use of the Clayton was financial. The cost of a type-B Clayton apparatus, suitable for such small vessels and deemed to be desirable for Nha Trang's port, was estimated to be at least 25,000 francs at the time—something that, the GGI admitted, Annam's budget could not afford. Could this then be considered an expense for the colony's general rather than regional or local budget? This faced the opposition of the Director General of Finances in the colony, who objected that such expenses did not fall under the umbrella of "general public health" and yet accepted for such purchase to be listed under the general budget expenses of local budgets, hence being indirectly funded by the central colonial budget.[83] Soon enough, at the session of the council on October 28, 1908, the general employment of the Clayton for the defense of the colony against plague was decided. The following were deemed necessary: two type-D Claytons (one on rails, the other riverine) for Hanoi, and two type-M Claytons for the border posts of Moncay and Ha-Giang, in Tonkin; one type-A Clayton for the maritime station of Tourane, and three type-D Claytons for Phantiet, Hue, and Bangoi, the last two on rails, in Annam; one type-D Clayton for Cholon and one type-M for Mytho in Conchinchine; one type-A Clayton for the maritime station of Pnom-Penh and one type-M for Battambang in Cambodia; one type-D apparatus for the riverine station of Khone, in Laos; and one type-M apparatus for the Fort-Bayard station in the French enclave of Guangzhouwan, in China.[84]

We can see here, in a nutshell, that the global expansion of the Clayton depended on a key design feature of the apparatus: its availability in different forms and sizes so as to fit different needs and aims. And yet, if during the years following the 1903 International Sanitary Conference, the Clayton had consolidated its global spread, by the turn of the first decade of the twentieth century it could no longer claim a monopoly of mechanized sulphur-based fumigation. A number of other apparatuses had started making their appearance in the global market, leading the way to a proliferation of different sulphur-based procedures and machines. Among them was a French invention, which promised an innovative electrification of SO_2 to increase its capacity for the purpose of disinfestation and deratization. Developed and tested in France, the Aparat Marot found its most expansive application in Argentina, where the *higienistas* aimed to transfer the hygienic model city of Buenos Aires into the twentieth century.