With Compliments of the Author.

PAPER

ON

The Ventilation of Ships,

GIVEN BEFORE THE

U. S. Naval Institute,

BY

Passed Assistant Engineer G. W. Baird, U. S. N.

1880.

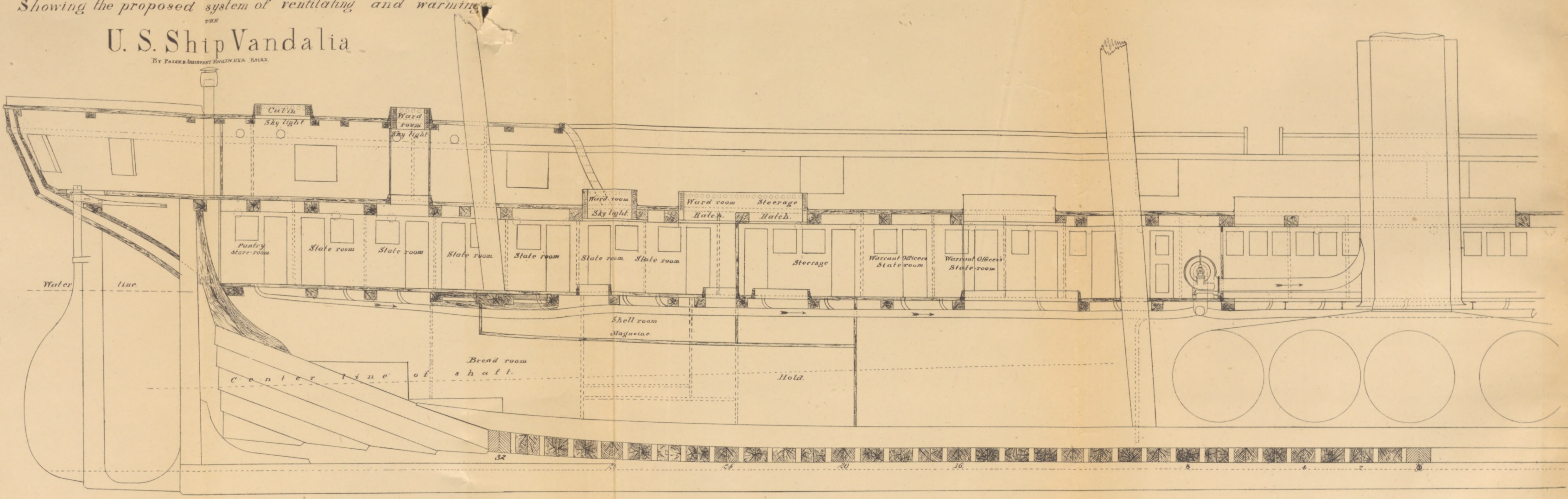
PRESS OF
THE CLAREMONT MANUFACTURING COMPANY,
CLAREMONT, N. H.

PLATE I

Showing the proposed system of ventilating and warming THE

U. S. Ship Vandalia

BY PASSED ASSISTANT ENGINEER BAIRD.



WASHINGTON BRANCH,

APRIL 13, 1880.

MEDICAL DIRECTOR T. J. TURNER, U. S. N., in the chair.

THE VENTILATION OF SHIPS.

BY PASSED ASSISTANT ENGINEER G. W. BAIRD, U. S. N.

MR. CHAIRMAN AND GENTLEMEN:—

I think that the carbonic acid exhaled from our lungs or produced by combustion on board ship is not nearly so injurious to health or comfort as the foul gases of the bilge or the organic matter from our exhalations. While serving on board the Pensacola—a vessel not over-crowded—we found the organic matter, deposited upon the knees, beams and ceiling of the vessel, on the berth deck, sufficiently thick to be wiped off by a pocket handkerchief, and clearly distinguished upon its surface.

In 1854 Dr. Thompson found that "the air of London when passed through oil of vitriol communicated a dark tinge to it, and if large quantities of air were passed through distilled water, the inevitable result was the formation of fungi." And Dr. R. Angus Smith, (Op. Cit. p. 217,) tested the air for organic matter and found the proportion in the air. This table, published in the *Chemical Gazette* of 1859, is as follows:—

LOCALITIES.	Number of grains of organic matter in 100 cubic inches of air.
Manchester, England,	52.9
In a pig-sty,	109.7
Thames, in warm weather,	58.4
Thames, Lambeth,	43.2
Thames, Waterloo bridge,	43.2
London, in warm weather,	29.2
London, after a thunder storm,	12.3
Northern Italy,	6.6
German Ocean,	3.3
Lake Lucerne,	1.4

It will be seen that the amount of organic matter varies considerably in different localities and under different circumstances, and I regret that I am unable to give the proportion of this poison found on board our ships. It is a subject now under investigation by the surgeons of the Navy, and, though the tests for it are complicated, I hope at no distant day to see a full analysis, as found on board all classes of our vessels, published by the Medical Bureau.

Pasteur supposed "that germs of infusoria were present in all air, and the cause of fermentation and putrefaction," and Van der Broeck, Shroeder and Deuch have confirmed his views. They found that almost all organic substances, even those of ready putrefaction, such as blood, fibrine, albumen, sugar, etc., were preserved unaltered when heated to the boiling point in a bottle, stopped by a loose plug of raw cotton, so that in cooling the entering air would be filtered and deprived of floating solid substances.

The amount of carbonic acid in the air seems to be as inconstant as that of organic matter. In the densely populated parts of Europe we find a much greater quantity than in any parts of America, excepting in the volcanic regions of South America. Dr. Wetherell estimates the mean amount of carbonic acid in the air, for all parts of the world, to be four parts in ten thousand, so that in estimating the amount of air necessary for the dilution of this gas to its normal, we will base our calculations on this fraction.

The quality of this gas appears to be more deadly than its quantity, for I have read that La Blanc found that "a bird died in a room containing less carbonic acid than existed in the air of many apartments he had examined; and a dog survived longer in air containing the enormous amount of nineteen hundred and ninety-one volumes per ten thousand of carbonic acid than in an atmosphere from burning charcoal in which three hundred and one volumes of this gas were present." The cause of the latter superior deadly effect was attributed, by competent authority, to the presence of the poisonous carbonic oxide, emitted by imperfect combustion.

The presence of carbonic acid on board ship, when produced by exhalation, is an indication of the presence of organic matter, and they bear, in that case, nearly a constant relative proportion to each other, so that the tests now being made on board our ships for carbonic acid may be relied upon as an index for organic matter as well. What this ratio is I am unable at present to say, but I hope soon to see published the work our surgeons are now doing on this subject.

Pettenkoffer, LaBlanc, Roscoe and others have made some very interesting experiments on the escape of carbonic acid through the crevices of rooms, condensation upon the surfaces of, and diffusion through the walls of apartments, but I have not been able to find any similar tests for organic matter. Dr. Wetherell, in his celebrated experiments found the carbonic acid in the public schools of Washington ranged from 9.342 parts in ten thousand, to 17.184 in ten thousand, and during the same month he found only from 4.275 to 7.355 parts in the United States Senate Chamber, and while there were no complaints from the schools of ill ventilation, we have heard many from the Capitol extension. There must have been some other offensive matter than the carbonic acid in the Senate and House of Representatives, and it may have been organic matter, for we are informed that Professor Leeds found decaying animal and vegetable matter in the very conduits which bring the air from the fans to the Senate Chamber and the House of Representatives.

On board ship we have more than this to contend with. On board all new ships, and also those which have been lately repaired, we find the bilge pumps frequently choked up by chips and shavings. As the bilges are cleaned and inspected before a vessel leaves the navy yard to commence a cruise, we naturally ask where these shavings come from? We observe they appear most abundant when the ship has considerable motion, and infer that they must have worked or fallen down from between the timbers where the ship is ceiled in. As this stuff decays it evolves gas abundantly. Letting water into the bilge and pumping it out daily will remove the bad odors, but if the watering be neglected for a single day the stench is worse than usual. In order to prevent the evolution of gases by the bilge we must keep it dry. The large amount of air received into a ship through the wind sails alone is more than enough to purify the air so that no trace of odor could be detected, were the air properly distributed; but this blast takes the most direct course to the nearest outlet and escapes, causing, in its passage, but feeble eddies in the other parts of the vessel. It is evident that we must *remove* these foul and poisonous gases first, and afterwards direct our attention to the supply of fresh air.

Direction of the Products of Respiration.—The question which now presents itself is whether it is better to remove foul gases through openings near the floor or near the ceiling.

Mr. Goldsworthy Gurney, who ventilated the House of Commons, informs us that the breath is forced downwards to the ground from the nostrils, and I believe he went so far as to declare that it took the direction of a definite mathematical curve. From the experiments of Roscoe, Dr. Wetherell, and others, we learn that the atmosphere, in large rooms occupied by man, is as rich in carbonic acid near the ceiling as at the floor. Those who advocate the system of ventilation by aspiration (or exhausting the foul air) have not always stated this fairly, having cited isolated cases of analyses instead of taking the mean of a great many observations. The first one who attacked this problem fairly was Dr. Wetherell himself, and I cannot do better than to quote him *verbatim*. "On March 27, 1865, at 1½ P. M., in the laboratory of the Smithsonian Institution, the temperature of which was 69.26° Fahr., a delicate thermometer, held in the hand for several minutes, indicated 95.36° Fahr. Held in the mouth, and observing the degree by the aid of a mirror, it indicated the same temperature. Upon smoking a pipe with a stem of wood six inches long, slowly, with the thermometer also in the mouth, the temperature did not sensibly rise. Having thus obviated a source of error from any supposed heat in the tobacco smoke, I experimented upon the air currents of the breath, both while sitting and standing, following them readily by the aid of the smoke. Before expulsion the smoke was held in the mouth for a short time to insure its temperature to be the same as that of the breath, and the hot pipe was held or placed aside. When the smoke is expelled gently from the nostrils, as in the act of breathing, it proceeds downward a foot or less, and then rises rapidly."

I think this experiment, which any one may easily repeat, should set aside the vicious theory that the heavy carbonic acid in the breath we exhale carries it rapidly and certainly to the floor. The many analyses of air taken from different parts of a large room do not show that its superior specific gravity carries it certainly downward. The carbonic acid probably diffuses itself rapidly with the pure air present, and its direction is affected very much more by natural air currents than by its superior weight. In his experiment the Doctor neglected to note whether or not the windows were open, or whether any currents were induced by the fire, which at that season was burning; and though he demonstrated fairly that the exhalations do not essentially flow downward, I think he has not proved the opposite.

Fig. 1 is a transverse section of the fifth state room on the port side of the Vandalia's ward room, which is opposite a hatch and is near a wind sail. By means of a delicate Casella anemometer I have been enabled to ascertain the direction of the air from the wind sail, and

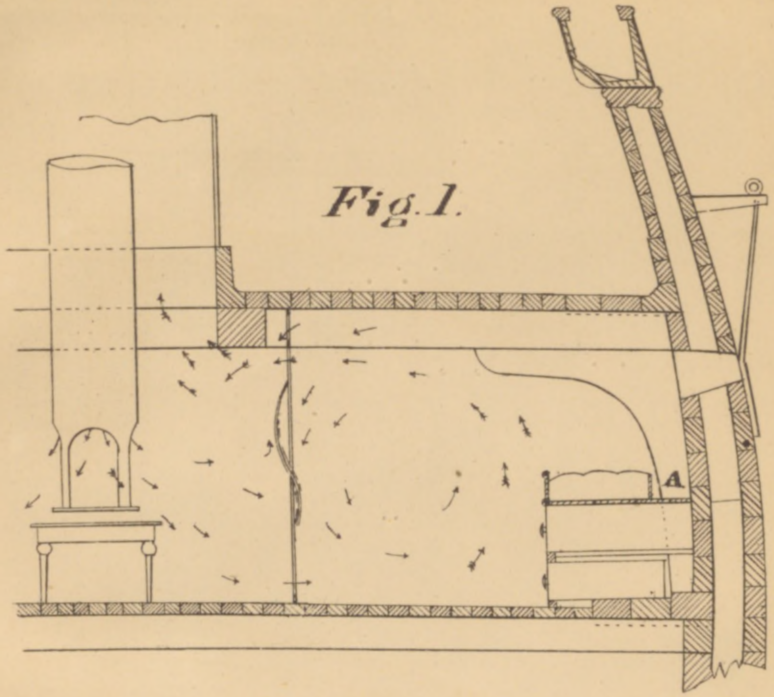


Fig. 1.

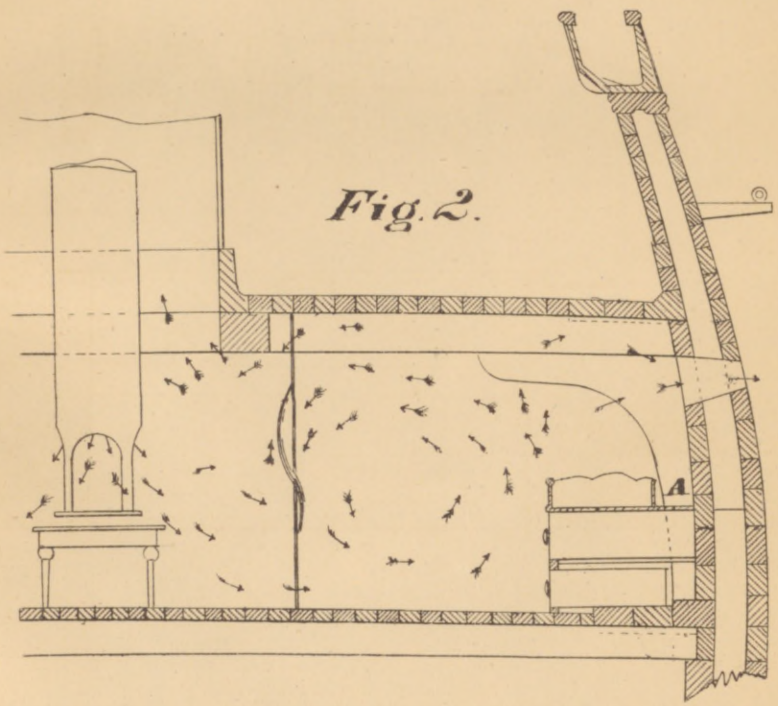


Fig. 2.

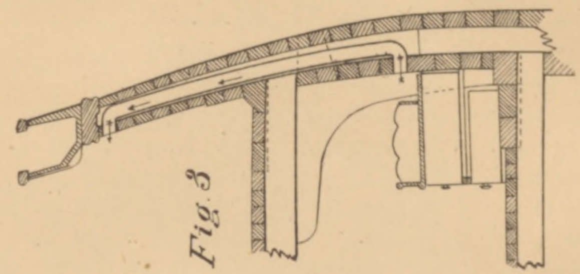


Fig. 3

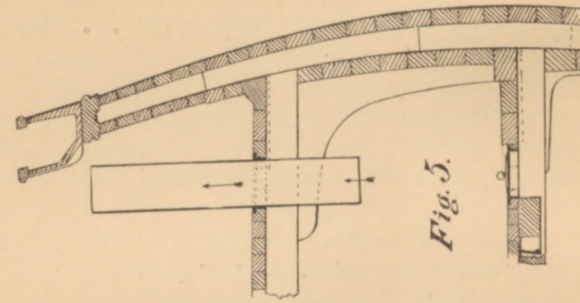


Fig. 5.

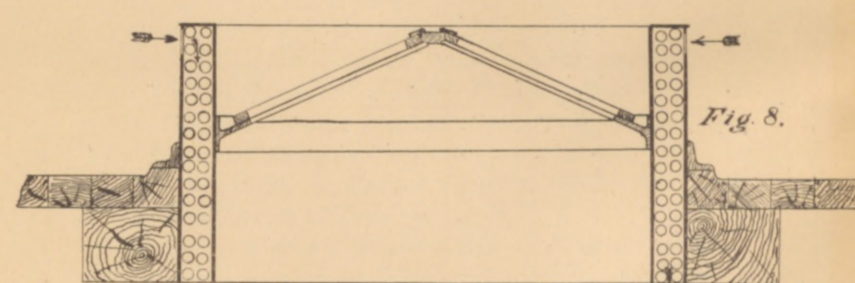


Fig. 8.

have indicated it in fig. 1 by arrows. The anemometer used is so sensitive that its vane moves freely in a current of air that will not perceptibly deflect the flame of a candle. The curtain was kept open both at the top and bottom, in order to permit a free circulation of the air, and when the air port was closed there could not be found the slightest current above the berth. On one occasion, when the air port was closed, the observations, which were taken immediately on rising, showed 19.036 parts of carbonic acid in a specimen of air taken from behind the berth, (at A, fig. 1,) while a volume of air from the wind sails of 11,016 cubic feet per hour was flowing through the room, in the path indicated by the arrows. On another occasion, with the air port open, similar observations showed 6.662 parts of carbonic acid while 21,600 cubic feet of air per hour flowed through the room, in the paths indicated by the arrows in fig 2. The analyses for carbonic acid were made by Assistant Surgeon George Arthur, who employed Park's method, while the air currents were measured by the writer.

It is evident from the above experiments that the exhalations should be breathed into the air current, or that we must sleep in a draught if we would breathe pure air. In order to supply an outlet for the vitiated air which accumulates behind the berths, Dr. Arthur proposes an exhaust tube, as shown in fig. 3. With natural ventilation or with a forced blast there can be no doubt that Dr. Arthur's tube would be of great value in exhausting the impure air, and with ventilation by mechanical aspiration this tube would reverse its action and supply the fresh air. From the direction taken by the currents, as delineated in fig. 1, it would appear that Arthur's tube is well located, and also that the exhaust tubes on board the Richmond, which are above and back of the berths, are properly placed, but I think we should not lose sight of the necessity of quickly drying the decks, and I would, therefore, recommend placing the exhaust openings in the floor, and depend on Arthur's tubes as inlets. From the experiments referred to above, made with the air port closed, and again with it open, we have another evidence that the air currents take the direction of least resistance; and in order to uniformly disseminate the pure air, and to insure its reaching every part of the ship, we must remove the impure gases from the points where they are generated, and it is obvious that we must employ some system of aspiration, either natural or artificial.

Quantity of Air.—Not many years ago it was believed that the quantity of air needed to keep an apartment wholesome was merely equal to the amount exhaled, which is about 12 cubic feet per hour;

but a set of experiments to determine the quantity necessary to dilute the carbonic acid exhaled by the lungs to something near the normal quantity, indicated that 3 cubic feet per minute, or 180 per hour, would be sufficient. Later observers concluded that the necessary amount would be that which would dissolve the aqueous vapor expelled by the lungs and skin, thus preventing the hygrometric condition of the air from rising too far above that of the surrounding atmosphere, and that 5 cubic feet per minute, or 300 per hour, would be sufficient.

Assuming that the air admitted upon the berth deck of a ship be mixed by at once diluting the carbonic acid present, we will find it an easy matter to calculate what the volume of that air shall be. Let us take an example from the steam sloop Văndalia, one of our latest ships, and one that is considered to have relatively good ventilation. On the 12th of August, 1879, Assistant Surgeon Geo. Arthur collected a jar of air from the middle of the ward room, and by subsequent analysis (by Park's method,) found it to contain 6.983 parts of carbonic acid in 10,000 parts. At the same date and hour, the writer found the quantity of air (as measured by a Casella anemometer,) admitted into the ward room to be 96,780 cubic feet per hour or 9,678 cubic feet for each of the ten occupants, which is vastly more than is necessary to keep the air at the purity found by Dr. Arthur. Assuming the air supplied by the wind sails to contain 4 parts of CO_2 per 10,000, which is the normal, we have all the data necessary to ascertain the volume of air essential to keep the air at the above mentioned purity.

Let Q = the quantity of air, in cubic feet, to be supplied.

n = the number of men, - - - - 10

a = the number of cubic feet of carbonic acid exhaled per hour per man, - - - - 0.686

b = the fraction of carbonic acid normal to the atmosphere, - - - - - 0.0004

c = the fraction of carbonic acid found in the air of the apartment, - - - 0.0006983

Then

$$na+Qb = (Q+na)\,c$$

$$na+Qb = Qc+nac$$

$$na-nac = Q\,(c-b)$$

$$Q = \frac{na-nac}{c-b} \qquad (1)$$

And, substituting the numerical value for the letters in the formula, we have

$$\frac{(10\times 0.686)-(10\times 0.686\times 0.0006983)}{0.0006983-0.0004}=22{,}981,$$

or $\frac{22{,}981}{10}=2{,}298$ cubic feet of air per hour per man. Roscoe made this calculation by a different method, and, as it has been adopted by Dr. Wetherell and others, it will not be out of place to verify the above results by comparison with Roscoe's method.

Let V represent the volume of air free from carbonic acid that would be required, and a = the fraction which the impurity of the air (0.04 per cent.) is of the limit of the impurity in the mixture (0.06983 per cent.), and let Q = the volume of normal air required.

Then $Q = V+Va+Va^2+Va^3\times Va^4+ \quad . \quad Va^n \quad .$ (2)

It will be sufficient to calculate the first five terms only of this expression:

$$0.06983 : 99.93017 :: 6.86 : V = 9{,}817$$

$$a=\frac{0.04}{0.06983}=0.5728$$

$a^2 = 0.328$
$a^3 = 0.188$
$a^4 = 0.107$

$V = 9817$
$Va = 5623$
$Va^2 = 3219$
$Va^3 = 1845$
$Va^4 = 1050$
$Q = 21554$

or 2,155.4 cubic feet per hour per man, instead of 2,298 as found by formula (1), though it will agree nearer and nearer the farther it is followed.

But let us compare the volume of air actually admitted with the quantity essential to preserve the purity mentioned. We find that a Casella anemometer, purchased from respectable dealers in Philadelphia, (Queen & Co.), verified by the U. S. Signal Office in Washington, indicated the enormous quantity of 96,780 cubic feet per hour, or $\left(\frac{96{,}780}{22{,}981}=\right)$ 4.2 times the necessary amount. Had this 96,780 cubic feet of air per hour mingled with and diluted the carbonic acid in its passage through the ward room, Dr. Arthur would have found very much less of that poisonous gas in his analyses. By transposing from formula (1) we can calculate the number of parts of CO_2 he would have found, viz.

$$c = \frac{na + bQ}{Q + na} \quad . \quad . \quad . \quad (3)$$

and by substituting the numerical values we will have

$\left(\frac{10 \times 0.686 + 96780 \times 0.0004}{96780 + 10.686} = \right)$ 4.71 parts in 10,000, or an atmosphere almost as pure as that outside the ship.

It may be now asked, why does not this great quantity of air whirled into the ship through the wind sails accomplish its object? The question has been answered many times. The air, after leaving the wind sails, takes the shortest and most direct route to the nearest outlet and escapes, and all the benefit we derive from it is by the eddies it creates; and the only way to utilize it is by causing it either to enter in a larger number of smaller jets or, what is equivalent, cause it to escape through a large number of separate openings.

Now let us take an example from the berth deck of the Vandalia, the place where the sailors are berthed. Their hammocks are swung side by side, from the beams over head, leaving an unobstructed passage for the air underneath, and there are no such bulk heads between them as between the officers' berths. An observation was taken at 5.30 A. M. Sept. 22, 1879, a few minutes after the men left their hammocks. The wind was on the port bow, and was blowing at the rate of 600 feet per minute. There were 5 air ports open on the weather side, through which the mean velocity of the air entering was 125 feet per minute, and, as each air port presented an area of 0.306 square feet, the aggregate volume of air entering through them was, in cubic feet per hour, 11,475. There were two wind sails in use at this part of the deck, each presenting an area of 2.75 square feet through which the mean velocity of the wind was 287.5 feet per minute, making, in cubic feet per hour, 94,875, or a total of (11,475+94,875 =) 106,350.

There had been berthed there that night 130 men, so that the air per man was $\left(\frac{106,350}{130} = \right)$ 818 cubic feet per hour. The carbonic acid found on this occasion by Dr. Arthur was 13.18 parts in 10,000, whereas, had the fresh air been thoroughly mixed with the air on the deck, it would have been (from formula 3)

$$\left(\frac{na + Qb}{Q + na} = \frac{130 \times 0.686 + 106,350 \times 0.0004}{130 \times 0.068 + 106,350} = \right) 12$$

parts in 10,000, or a quantity very much nearer the theoretical than that found in the ward room.

In order to ventilate the berth deck of this fine sloop by means of an exhaust fan, we have first to determine the size of the fan, conduits and registers. There are 120 established billets on the berth deck for hammocks, besides rooms for four warrant officers, steerage capacity for twelve officers, and ward room quarters for twelve more, making a total of 148 persons. Allowing each one 2,298 feet of air per hour, we will require $(2298 \times 148 =)$ 340,104 cubic feet.

We find exhaust fans advertised by the Boston Blower Co., (fig. 4,) capable of producing a velocity of 75 feet per second,* which is 270,000 feet per hour.

The area of a conduit or of the exhaust fan opening to pass 340,104 cubic feet per hour at 270,000 linear feet per hour is $\left(\frac{340,104}{270,000} = \right)1.26$ square feet, or $(1.26 \times 144 =)$ 181.44 square inches, or a tube having a diameter of 15¼ inches, nearly. The nearest regular merchantable size to this would be the 45-inch exhaust fan, the opening of which is 15¼ inches diameter. It would be advisable to place the fan as near the deck as practicable, having four branch pipes, one running forward on each side of the deck, and one running aft on each side.

The diameter of the main conduit, if of circular section, would be equal to the induction opening of the fan, i. e. 15¼ inches, (and if of square section it would be 13½ inches,) while the four branch openings would be 6¾ inches each. In practice it would be necessary to increase the four branch pipes to 8½-in. diameter, to prevent the resistance of surface friction and *contracted vein* from becoming greater than in the main pipe.

In order to discharge the same quantity of air from each state room, the registers or openings, into the main conduit from these rooms would necessarily increase in size the farther they were placed from the fan. The size of openings cannot be calculated without experimental data, and I can find no record of any experiment on similar tubes with a number of openings. There would, however, be no mechanical difficulty involved in this, for registers or inlet valves would necessarily be placed at each opening, and after the fan had been put in use the valves could be graduated and stops put at the limit.

Now let us consider the value of the air shafts with which our vessels are sometimes provided, and also the air jacket that surrounds the smoke pipes of all our steamers.

In July, 1879, the Vandalia towed a section of dry dock from Chester, Pa., to Pensacola, Fla., which so retarded the vessel's speed that

* At 1,400 revolutions per minute.

no draught was perceptible in the wind sails, and the temperature on the berth deck rose to an uncomfortable height; the surgeon's test for carbonic acid indicated a larger amount of that gas than usual. The men could not sleep well in their hammocks, and many of them were permitted to sleep on the spar deck under the cover of the awnings; the firemen and coal heavers were becoming enervated, and two of them fainted at their work, from exhaustion. We then improvised a chimney on each side of the deck, by removing a deck plate and placing over the hole one of the coal shutes, as shown in figure 5. These shutes are cylindrical in form, are made of rolled plate iron, and are 15½ inches internal diameter and 8 feet in height. Owing to the interference of the hammock netting we were compelled to lower the shute 3 feet below the surface of the deck, leaving us an exposed height of only 5 feet, and only this height is effective for draught. When these shutes were secured in position it was found that a light breeze abeam would cause a downward current in the lee chimney and a strong upward current in the one on the weather side, no doubt from the deflection of the air from the slanting surface of the hammock netting. But when there was no perceptible wind there was an upcast draught in the coal shute as well as in the permanent chimneys over the engine room, ward room and shaft alley.

On the 2d of August I suspended a thermometer inside the coal shute, and another near the top, in the external air, the former indicating 87.6° Fahrn.—the mean of a number of observations—and the latter 84°, the difference being 3.6 degrees: and a number of readings of the anemometer gave a corrected mean velocity of 46.92 feet per minute, which gave a total volume of 3,570 cubic feet of air discharged per hour from this simple and inexpensive device. The volume of air discharged from a chimney varies according to the difference of weight of the air inside and of that outside. This was, I believe, discovered by Montgolfier, the inventor of the balloon. He taught that the draught was equal to the velocity of a body which had fallen through a space equal to the difference of the height of two columns of air of the same weight (and of equal base) the one being of the temperature inside the chimney and the other that of the external atmosphere.

Let H = the height of chimney, in feet.

H′ = the height of the heated column of air of equal weight.

T = the temperature inside the chimney.

t = the temperature of the external air.

A cubic foot of air expands 0.0020276 times its volume, on being warmed one degree, so that we have

$$H'-H = H\ (T-t)\ 0.0020276 \qquad (4)$$

and, consequently, the theoretic velocity will be

$$V = \sqrt{2gH\ (T-t)\ 0.0020276} \qquad (5)$$

By substituting numbers for the letters in formula (5) we will find a velocity of 1.533 feet per second, or sufficient to have discharged 6,954 cubic feet per hour, instead of 3,570, as determined by the anemometer. The result recorded is the mean of a number of observations taken when the wind was not blowing, and, as far as could be seen, they were not influenced by any other cause than the difference of temperature between the outside and inside of the chimney. The velocity of the air through the chimney can never reach the theoretic value, for the reason that it is retarded not only by the resistance of the surface of the chimney but by the *contracted vein*, and also by any object upon the lower deck which in any way obstructs the passage of the air to the chimney. I had spent much time in experimenting upon the velocities of air through iron shafts, under varying conditions, with a view to making an empyrical formula for practical purposes, when I found in General Morin's *Etudes sur la Ventilation*, that that distinguished engineer employed a separate experimental value (K) for a co-efficient for each and every shaft. Representing this quantity by K, we have for the correct velocity for our chimney

$$V' = K\sqrt{2gH\ (T-t)\ 0.0020276} \qquad (6)$$

and in this case the value of K becomes 0.5101.

There are six places in the deck of the Vandalia where these chimneys can be fixed, whereby ($6\times.3570 =$) 21,420 cubic feet of air per hour would be discharged from the sleeping quarters of the men, not only purifying the air on the deck, but reducing its temperature. At the after end of the ward room of the Vandalia there is a copper ventilator 12 inches in diameter and 9½ feet in height. Its lower end is contracted by adjacent wood work, its upper end by an elaborate hood, and near the middle of the shaft it is further reduced in area by a metallic grating. During cool weather, when the ward room was kept much warmer than the external air, the current was quite strong in this shaft. The wind did not seem to increase the velocity of the air, nor did it retard it, owing probably to the construction of the covering. It was effective even in warm weather. On one occasion, while lying in the harbor of Aspinwall, (15th September, 1879,) when the temperature on deck was 80° and in the ward room 86°, I measured a velocity of 1.405 feet per second, which amounted to a discharge of nearly 4,000 cubic feet of air per hour. This ventilator is over the pantry, and is doubly valuable in removing the odors of that apartment from the ward room. Situated near the ventilator is a similar one which connects with the bread room. As the bread room is ceiled in, and no air can get in to supply the ventilator, it is of no use.

The amount of air exhausted from over the boilers by means of the smoke pipe jacket is considerable. On the 2d December I made an experiment on the Vandalia's jacket (figure 6) the result of which I record:

Date of experiment, . . .	December 2d, 1879.
Total height of the jacket, in feet, . . .	14½
Height of jacket above the dead plate, in feet, . . .	5
Depth of jacket below the dead plate, in feet, . .	9½
Net area (A) of cross section of the jacket, in square feet,	10.78
Net area between the outer edge of the jacket and the inner edge of the canopy, ...	9.05
Temperature (T) on deck, ...	44
Temperature (T′) around the jacket, between decks,	88.25
Mean temperature (T″) surrounding the jacket $\left(\frac{9.5\ T'+5T}{14.5}=\right)$	73
Mean temperature inside the jacket, . . .	87.41
Mean measured velocity of escaping air, in feet, per second,	3.736

By substituting this experimental velocity in formula (6), and by transposing and dividing, we have 0.716 for the value of K. In this case it must be remembered that not only the velocity is greater, but the surface, as compared with the area of the ventilator, is enormously larger than in the former example.

The contraction of the outlet of the jacket, by too small diameter of the canopy, probably retards the outflow still more. Yet, under the disadvantageous circumstances, there were in the experiment recorded 145,000 cubic feet of air discharged per hour, or sufficient to ventilate for 63 men. The standing part of the present smoke pipe is 23 feet, and there is no reason why the jacket can not be made the same height. Nor is there any reason why it should not be made 8½ feet in diameter, or nearly the whole width of the boiler hatch, as shown in figure 7.

Assuming the conditions to exist as in the previous example, this arrangement would discharge 300,000 cubic feet per hour, or sufficient ventilation for 130 men—the entire number billeted upon the berth deck.

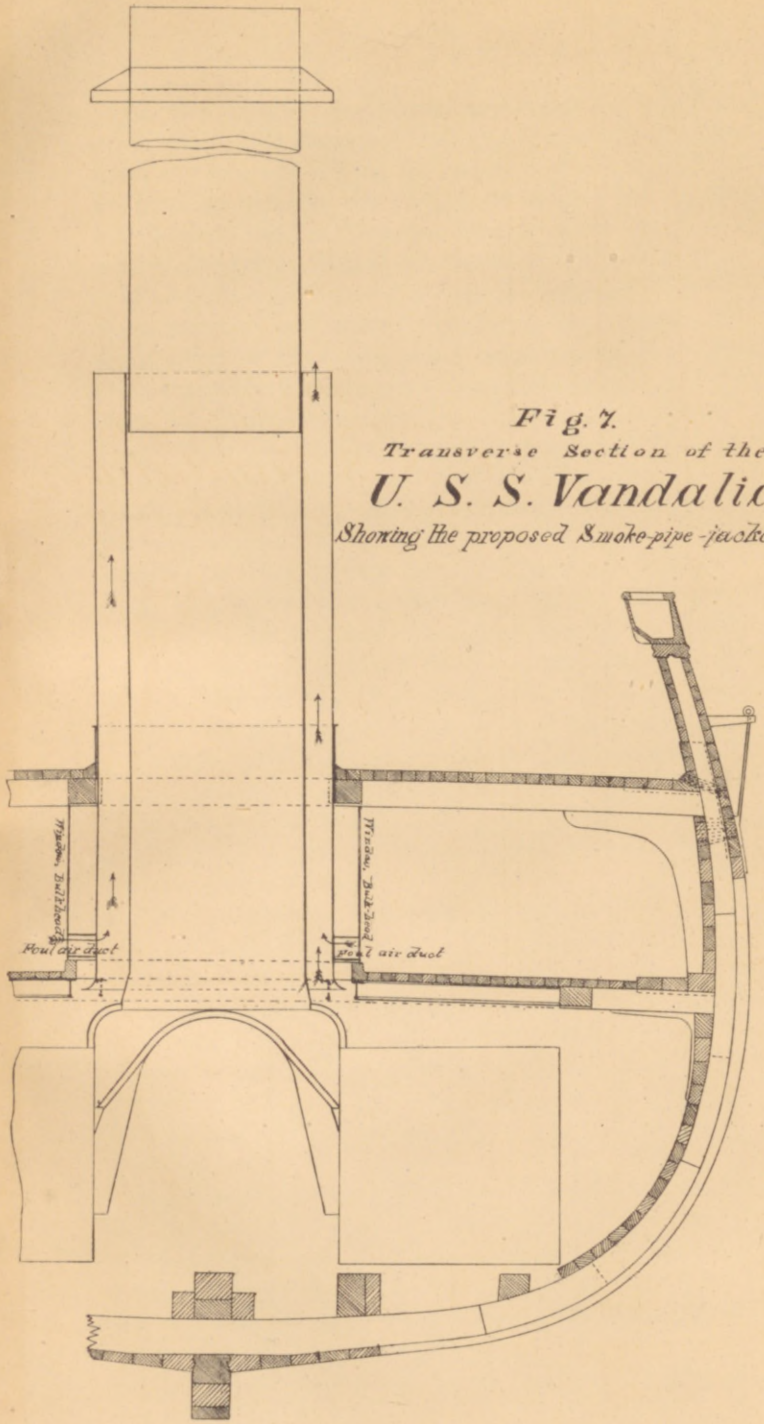


Fig. 7.
Transverse Section of the
U. S. S. Vandalia,
Showing the proposed Smoke-pipe-jacket.

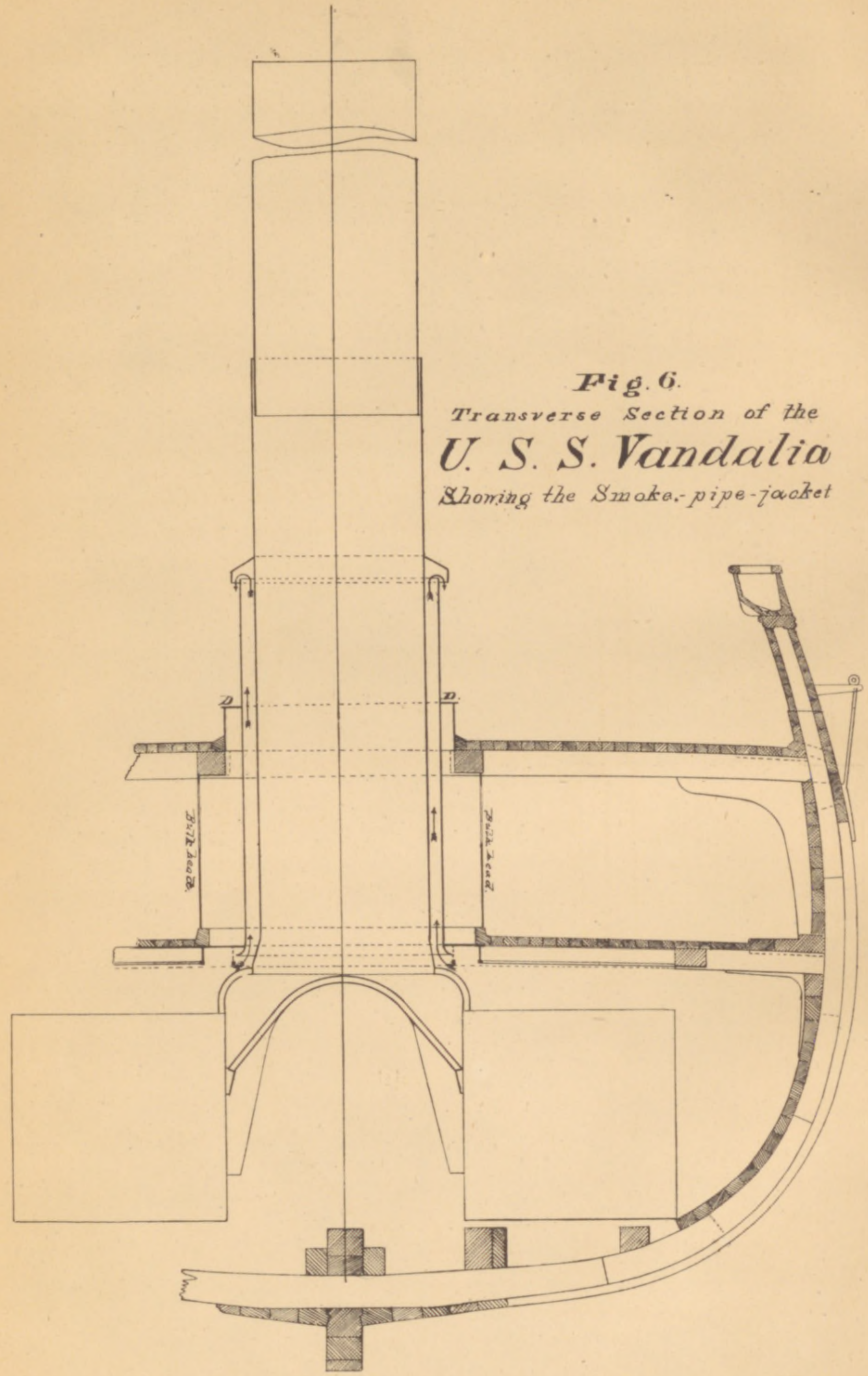


Fig. 6.
Transverse Section of the
U. S. S. Vandalia
Showing the Smoke-pipe-jacket

The only objection that now presents itself to me is that the amount of air drawn into the jacket from around the boilers might rob the furnaces and seriously impede the rate of combustion, and, consequently, the potential power of the engine. In meeting this objection we may introduce air ducts to the jacket, from the berth deck, and then, if necessary, contract the area of the bottom of the jacket.

WARMING.—During cold weather we keep our ships warm partly by steam radiators, and partly by excluding the external air. The opening of doors or sky lights, or the temporary removal of hatch hoods, creates considerable inconvenience to those quartered near them, while those who are located near the steam coils complain of excessive heat. With the whole ship closed up, and but little motion in the air, we find it uncomfortably cold near the sides of the ship and uncomfortably warm near the heaters. On board the Trenton the heaters in the ward room contained nearly one square foot of surface to each 100 cubic feet of space in that apartment, and were sufficient to keep the mean temperature in the ward room at 74°, with the hatches wide open, while the external atmosphere was 30°. Nearly the same condition obtained on board the Vandalia. The area of a heater of this kind designed for ship warming may be safely proportioned by dividing the volume of the apartment, in cubic feet, by 100.

In order to uniformly disseminate heat throughout a vessel we must either have a large number of small heaters, spaced at regular intervals, or warm the air as it enters the ship. The former would encumber the floor, while the latter would require aspirating machinery to make it a success.

Early in December last, when the vessel was warmed by the radiators, and when the sky lights and hatches were closed, Dr. Arthur found 19 parts of CO_2 in the air of the ward room, which, from formula (1), would indicate that only 456.4 cubic feet of air per hour for each of the 12 occupants passed through the ward room. This is about one-fifth of the necessary amount. It appears, then, that, if we supply 2,300 feet per hour to each of the 12 men in that apartment, and if we wish to warm the air as it enters, we must increase the surface of the heaters five fold.

For example, the wardroom contains 7,417 cubic feet, and multiplying this by .05 we have 370.85 square feet required for the heater. The hatch coamings are of iron, and the sky light of the ward room is 5 feet square, in the clear. By putting 2 coils of 1¼-inch pipe inside that coaming, as in fig. 8, employing 16 full convolutions in each, we can get 200 feet, or half the necessary area in the single sky light. It will then be necessary to encase the whole coil with sheet iron, except at the bottom, and to place inlet holes near the top. It must be added that this form of heater would not work unless an in-current of air be created by mechanism in the ship. It would work admirably on board the Richmond.

I have given fig. 8 merely as an example, and wish to state that I would not, if designing the heaters, place the entire surface in a single hatch, because the velocity of heated air issuing would be too great. General Morin recommends that the velocity of the incoming air should not exceed $1\frac{2}{3}$ feet per second. It would be more convenient to place a coil in each of the three hatches; and, by having the casing large enough to leave 2 inches on each side of the pipe we could get sufficient area to reduce the velocity to about $2\frac{2}{3}$ feet per second when the fans were inducing the full amount of air. Of course this could be diminished at any time by slowing down the fan, and that would only be necessary when persons were compelled to sit near the warm air inlet. The advantage of saving the floor room, now encumbered by steam heaters, is of some importance, while the convenience of being able to sit under a sky light to read or write and at the same time enjoy a pleasant temperature will make life on board ship more agreeable.

Moisture.—The hygrometric condition of the atmosphere we inhabit is of almost as much importance as its temperature, or its freedom from poisonous or deleterious gases.

In cold weather the atmosphere is proportionately free from moisture, hence the true time to supply moisture is not when it is warm, as in spring or summer, but in winter, when it is warmed artificially. After securing a sufficient quantity of air its temperature and moisture are of next importance. If cold air be heated in summer by natural causes it absorbs a proportionate share of moisture from the lakes, rivers and the ground, or from the sea, and thus reaches us in a salubrious condition. On the contrary, if cold and dry air be artificially warmed without receiving additional moisture its increased power to absorb moisture renders it offensive.

"Warmed air," says Prof. Wyman, "without increased moisture, is; apt to produce unpleasant sensations in the chest, which are often attributed to too great heat." In cities there is more than four times as much water held in the air at 75° than at 32°, though I doubt if the difference is so great at sea.

Dry air is an active absorbent of water. Many a shower which is precipitated from a cloud never reaches the ground, and the north winds of Europe, robbed of their moisture in passing over the chilled surfaces of the Alps, are dry and arid when they reach the coast of Africa, where they are re-warmed to a degree far exceeding the dew point, the result of which is the rainless region of the great Sahara.

The relative humidity of the atmosphere is expressed in "percentages of the saturation of the air for moisture at any given temperature." If a cubic foot of air, saturated with moisture, be warmed, its humidity is reduced from one hundred to, say, seventy; and, conversely, if a cubic foot of air whose relative humidity is seventy be chilled, its humidity is increased up to its saturation, when it becomes again one hundred.

For example, on board the Vandalia, on the coast of Syria, in July, 1878, the observed temperature of the dry bulb thermometer was 84°, that of the wet bulb 63°, difference, 21°. This corresponds respectively to 12.376 and 6.361 grains of moisture in the air, or a relative humidity of

$$\left(\frac{6.361 \times 100}{12.376} = \right) 51.3.$$

From Dr. Charles M. Wetherell's report on the ventilation of the Capitol, I copy the following:

TABLE OF THE MEAN PROPORTION OF AQUEOUS VAPORS IN THE AIR OF HALLE, GERMANY.

	Tension in millimeters of the aqueous vapor, measuring absolute humidity.	Relative humidity.
January	4.509	85.0
February	4.749	79.9
March	5.107	76.4
April	6.247	71.4
May	7.836	69.1
June	10.843	69.7
July	11.626	66.5
August	10.701	61.0
September	9.560	72.8
October	7.868	78.9
November	5.644	85.3
December	5.599	86.2

"Thus," continues the Doctor, "as the tension, or absolute humidity, increases with the year, the relative humidity decreases."

The following table* expresses in Troy grains, the weight of vapor

* Guyot No. X, Smithsonian Meteorological Tables.

contained in a cubic foot of saturated air at the different temperatures of Fahrenheit:

TABLE SHOWING THE NUMBER OF GRAINS OF WATER CONTAINED IN A CUBIC FOOT OF AIR AT DIFFERENT TEMPERATURES.

Temperature of the air.	Vapor in grains.	Temperature of the air.	Vapor in grains.	Temperature of the air.	Vapor in grains.	Temperature of the air.	Vapor in grains.
0	0.545	59	5.566	72	8.521	85	12.756
5	0.678	60	5.756	73	8.797	86	13.146
10	0.841	61	5.952	74	9.081	87	13.546
20	1.298	62	6.154	75	9.372	88	13.957
30	1.968	63	6.361	76	9.670	89	14.378
32	2.126	64	6.575	77	9.977	90	14.810
40	2.862	65	6.795	78	10.292	91	15.254
45	3.426	66	7.021	79	10.616	92	15.709
50	4.089	67	7.253	80	10.949	93	16.176
55	4.860	68	7.493	81	11.291	94	16.654
56	5.028	69	7.739	82	11.643	95	17.145
57	5.202	70	7.992	83	12.005	96	17.648
58	5.381	71	8.252	84	12.376	97	18.164

In the West Indies, the relative humidity on board ship frequently reaches 100°, even in summer time; and, during rain storms, when the hatches are covered, the atmosphere below is not only mephitic from the respirations of the men, but is saturated with moisture: there can then be no absorption by the air, consequently the heat is oppressive. But the rapidity of evaporation from the body depends upon the low relative humidity of the air at high temperature and of the action of currents of air. With too great dryness of air, particularly at higher temperatures, and especially in strong draughts, a greater degree of evaporation than is consistent with health will ensue. There is then a happy mean in the relative humidity which is consistent with health and comfort, and for the determination of this point we must look to the surgeons of the Navy, who are now pursuing the subject with increased interest and vigor.

To supply the necessary hydration to the air is an easy matter, and requires but a simple device—an ordinary stop-cock. I do not think water could be used very successfully on board ship, as the spray would necessarily require space that could not be spared; but a jet of steam would do the work most effectively and economically. The experiments, on the absorption of gases by water, made at Mare Island in 1870,* demonstrated very satisfactorily the rapidity with which gases

* Journal of the Franklin Inst., Jan., 1872.

and water, or more particularly air and steam, combine as the steam is in the act of condensing.

TABLE COMPILED FROM THE ATMOSPHERIC OBSERVATIONS ON BOARD THREE SIMILAR VESSELS, DURING THE SAME PERIOD, TWO OF THEM HAVING NATURAL VENTILATION AND THE THIRD HAVING EXHAUST FANS.

		Hartford.	Pensacola.	Richmond.
10 P. M. Observations of January, 1879.	Height of Barometer in inches of mercury,	29.92	30.01	30.13
	Temperatures. *Spar Deck.* Dry bulb,	68.75	78.00	60.70
	Temperatures. *Spar Deck.* Wet bulb,	61.72	77.10	56.80
	Temperatures. *Berth Deck.* Dry bulb,	73.20	83.48	66.56
	Temperatures. *Berth Deck.* Wet bulb,	66.90	79.37	57.74
	Temperatures. Difference between the spar deck and berth deck,	6.45	5.48	5.86
	Relative humidity on the spar deck,	90.25	94.47	89.02
	Relative humidity on the berth deck,	91.89	94.65	88.68
	Carbonic acid in the air of the berth deck in 10,000ths,	30.30	8.19	10.09
10 P. M. Observations of February, 1879.	Height of Barometer in inches of mercury,	29.90	30.15	29.95
	Temperatures. *Spar Deck.* Dry bulb,	71.15	70.25	48.00
	Temperatures. *Spar Deck.* Wet bulb,	65.35	67.40	45.00
	Temperatures. *Berth Deck.* Dry bulb,	74.17	77.45	53.60
	Temperatures. *Berth Deck.* Wet bulb,	68.38	72.80	48.20
	Temperatures. Difference between the spar deck and berth deck,	3.02	7.20	5.60
	Relative humidity on the spar deck,	91.22	92.83	83.92
	Relative humidity on the berth deck,	92.21	93.37	85.24
	Carbonic acid in the air of the berth deck in 10,000ths,	10.25	7.676*	10.80
10 P. M. Observations of March, 1879.	Height of the Barometer in inches of mercury,	30.02	30.05	30.10
	Temperatures. *Spar Deck.* Dry bulb,	69.44	62.17	65.10
	Temperatures. *Spar Deck.* Wet bulb,	62.78	59.32	59.00
	Temperatures. *Berth Deck.* Dry bulb,	76.60	72.82	72.84
	Temperatures. *Berth Deck.* Wet bulb,	66.43	67.01	66.20
	Temperatures. Difference between the spar deck and berth deck,	7.16	10.65	7.74
	Relative humidity on the spar deck,	90.50	97.59	89.30
	Relative humidity on the berth deck,	91.39	92.02	91.60
	Carbonic acid in the air of the berth deck, in 10,000ths,	9.193	6.745	17.54

* 2.76 on the spar deck 27th of February.

THE FIRE ROOM. The temperature of the fire rooms of our ships frequently rises to 120°, and in some cases has reached 150°. This heat is communicated to that part of the berth deck adjacent to the fire room, and that part of the berth deck which surrounds the boiler hatch is particularly uncomfortable as sleeping quarters. You have only to press your hand against one of the panes of glass in the bulk-head to satisfy yourself of the amount of heat that must pass through. The bulk head proper, the coamings and the deck, being of thick wood, conduct the heat very much slower than the thin glass, but, having a great capacity for heat, retain it a long time after the fires are extinguished.

The length of the boiler hatch is considerable; and, to preserve the strength of the vessel as much as possible, the deck beams are carried across the hatch, reducing the area considerably, and not only diminishing the supply of air to the fires but hindering the escape of the heated air and gases, for both up and down currents exist in the boiler hatches. To correct these evils I would suggest that double windows be substituted for the single panes now used in the bulk-head of the boiler hatches, which will reduce the conduction very much. The wood work of the deck over the boiler as well as inside the bulk head may be covered with a non-conductor such as asbestos. The smoke pipe jacket may be made of greater diameter and height, (fig. 7,) and the deck beams might be made of iron instead of wood, which would reduce their size and obstruction to currents very much. A practice antagonistic to ventilation is to cover the boiler hatch immediately around the smoke pipe with a thick cast iron dead plate, which prevents the escape of the hot air which always surrounds the smoke pipe. In designing these things we have kept in a beaten path, and it is now time to amplify them. Fig. 6 is a transverse section of the Vandalia, showing the uptakes of the boiler, the smoke pipe and the jacket, as they exist. At D the dead plate is shown which supports the jacket. The arrows indicate the natural direction of the current of air. On the top of the jacket (fig. 6) is shown the canopy, or umbrella, as it is sometimes called, the object of which is to keep out the rain, and also to give a finish to the jacket; but as this device retards the outflow of the heated air it needs to be modified.

Fig. 7 represents a similar section of the same vessel, showing the jacket enlarged, as I would propose it, with the canopy riveted to the moving part of the pipe, instead of the standing part, as in fig. 6, and the canopy is so placed as to cover the jacket only when the pipe is lowered.

THE MECHANICAL MEANS OF VENTILATION ALREADY INTRODUCED INTO THE NAVY.—*Beaumont's Exhaust Fan.*—The first attempt at ventilation in the Navy, by any kind of machinery that I have any knowledge of, was made by Lieut. (now commodore) J. C. Beaumont, in 1853.

Lieut. Beaumont's arrangement was an exhaust fan, and was applied exclusively to the magazines of vessels. In 1856 he constructed one, in the New York navy yard, for the frigate Wabash (to which vessel he was attached), and it worked "to the entire satisfaction of all hands." It was used during the entire cruise, and received a favorable mention in a paper by Medical Director R. T. Maccoun, in 1858. "My ventilator," continues Beaumont, "was in use on board the Wabash as late as 1863, having been used on board that vessel during three successive cruises."

Beaumont's ventilator was an ordinary rotary, centrifugal fan, but he connected the pipe to the center opening, making it an exhaust fan, and by running the pipe into the magazine he kept the air there quite fresh, requiring but two men to turn it. The following is a copy of the official correspondence concerning Beaumont's ventilator:

NAVY DEPARTMENT, 10 May, 1853.

CAPTAIN H. PAULDING:

Your letter of the 5 inst., with a report of the cost of the air pump made under the direction of Lieut. J. C. Beaumont has been received. You will be pleased to have the air pump examined by a competent board of officers, and its merits tested, and report to the Bureau. Yours, &c.,

W. B. SHUBRICK.
Chief of Bureau.

NAVY YARD, WASHINGTON, May 11, 1853.

GENTLEMEN:

You will be pleased to examine the air pump made in this yard, under the direction of Lieut. J. C. Beaumont, and have its merits tested, and report the result to me in writing.

Very Respectfully,
H. PAULDING, *Commandant.*

Com'd'r S. H. POWELL,
Lieut. E. G. TILTON,
Master C. V. MORRIS.

NAVY YARD, WASHINGTON, 12 May, 1853.

SIR:

In obedience to your order of the 11th inst. we have examined the air pump made in this yard, under the direction of Lieut. J. C. Beaumont. We believe it will be very useful in our men-of-war and merchant vessels, and to answer all the purposes for which it is intended. Very Respectfully, &c.,

S. H. POWELL, *Com'd'r.*
E. G. TILTON, *Lieut.*
C. V. MORRIS, *Master.*

Beaumont's system was then adopted by the Navy Department, but in erecting the machines the pipe leading to the magazine was led, no doubt by mistake, from the discharge side of the fan, making it send a blast into the magazine instead of exhausting the foul air from that apartment, thus making the machine do the opposite to what the inventor intended. Workmen continued to erect and connect the magazine ventilators on the forced blast principle, and Beaumont's invention, system and labors were soon forgotten.

The Monitor.—The next essay was in the little iron clad steamer Monitor. During her encounter with the Merrimac the crew suffered from the effects of ill ventilation, and the vessel was subsequently taken to Washington, where the Chief of the Bureau of Steam Engineering, (Mr. Isherwood,) improvised an apparatus which worked very well. He caused a rotary blower, (a Dimpfel blower, I think,) which was in store at the yard, to be put on board the vessel, as near amidships as possible, leading pipes from the after half of the vessel to the suction side of the blower, and discharging the air into the forward half of the ship. He built his conduits of light sheet iron (galvanized, I believe,) and had small registers at intervals for the admission and discharge of air.

The Later Monitors.—In the Monitor ships that followed the original vessel by that name a forced blast was employed. It is the same method as employed in the Capitol at Washington, and in large buildings generally. Why Mr. Erricsson, the distinguished engineer who designed those vessels, preferred that system I am not prepared to say; and, though I prefer the opposite system, I am glad to acknowledge that the ventilation of those vessels is measurably good.

The Despatch.—In 1874, the Secretary of the Navy, having made a voyage on board the Despatch, found the air in the cabin very bad. He accordingly gave the Engineer-in-Chief of the Navy an order to devise some means to ventilate the cabins. Mr. W. W. Wood was then Chief of the Bureau of Steam Engineering. He called Chief Engineer Robie and myself in consultation in this matter, and we visited the Despatch which was then lying at the Navy Yard. We found on board a rotary blower for creating an artificial draught in the boilers, so that we had only to arrange for conduits under the floor, connecting to the suction side of the blower, (a rotary fan,) and to provide registers which we placed in the floor. This arrangement has worked very well, changing the air rapidly without making a strong draught.

The Richmond.—In March, 1878, the Secretary of the Navy appointed a board, consisting of medical inspector T. J. Turner, commander J. R. Bartlett, chief engineer David Smith, and constructor B. E. Fernald, "to examine and ascertain the best system of ventilation by mechanical means or otherwise," etc., etc.

The board recommended that the system of ventilation by aspiration be adopted, and that the most approved exhaust fans with independent engines be employed. This is essentially what had been done in the Monitor and in the Despatch, so that the Richmond is the third vessel in the Navy ventilated on that system. The Board explained in their report a plan of the conduits, where they were to lead, *et cetera*, and where and how they should receive and discharge the air. The Richmond was designated to receive the mechanical ventilation, and it was placed on board at the Boston Navy Yard during the year 1878. The exhaust fans required were larger, I believe, than any regular merchantable size, and the patentee, Mr. Sturtevant, designed and built those two especially for the Richmond, with the engines bolted to the frames of the fans, and connected directly to the fan shafts. The chief engineer of the Richmond reports favorably on the smooth working of the apparatus, and states that while they are in use there is no smell of bilge water gases, and that the washed decks are soon dried by the rapidly passing currents of air. But the analysis of the air of the berth deck, from specimens collected at 10 P. M., while the men are berthed, as reported by the surgeon of the vessel, indicate very little improvement over the Hartford, (a sister ship) for the same period, and the air on board the Richmond was not as pure as that on board the Pensacola (a sister ship) during the same period.

The purity of the external atmosphere, of course, has a great deal to do with this, as has, also, the opening of the air ports, and the employment of wind sails. I think the better method of testing the efficiency of the Richmond's ventilation would be to institute a series of experiments on board that vessel, taking a large number of specimens of the air simultaneously, for analysis, both with and without the exhaust fans in operation and with the men in their hammocks ; and it would be well at the same time to analyze the external atmosphere for carbonic acid.

In 1876 chief engineers Newell, Robie and Dungan were appointed to devise the ventilating machinery for the Miantonomah, which vessel was then being rebuilt. The ventilating machinery of the original vessel was designed by chief engineer Isherwood, and consisted of rotary blowers situated under the turrets and driven by steam engines through the intervention of belts. The blowers were not arranged to exhaust. On the 29 June, 1876, the Messrs. Newell, Robie and Dungan submitted their report, which was adopted.

The system devised and now in use on board that vessel is novel, inasmuch as the fans are reversible, i. e., by shifting the valves in the blower openings the fan changes from a blower to an exhaust fan. These fans, which are 7 feet in diameter, are intended to be run up to 500 revolutions per minute, with a capacity of 20,000 cubic feet of air for each, or 40,000 cubic feet for the two machines.

They are driven by direct acting engines, bolted to the blower frames, (fig. 9,) * and are arranged under the turrets (fig. 10).

The duty of the blower will be to supply air to the furnaces, as well is to ventilate the ship. The furnaces are intended to burn 5,000 pounds of coal per hour, which will require ($5,000 \times 24 \times 0.075 =$) 9,000 cubic feet of air. Deducting this from the capacity of the fans at 500 revolutions, $40,000 \times 60 = 2,400,000$ we will have (2,400, 000—9,000 =) 2,391,000 cubic feet left. The complement is intended to consist of 34 officers and 285 men, or a total of 319 people: therefore the amount of air allowed is $(\frac{2,391,000}{319}) = 7,495$ cubic feet each individual. The engine power to drive these blowers up to 500 revolutions per minute is more than ample.

The CHAIRMAN:—When it is proposed to consider the various methods proposed for the ventilation of ships the forms of apparatus can be grouped for the purposes of study under three classes:

1st. Those that take the air out, or act on the Vacuum principle;

2d. Those that force the air in, acting on the Plenum principle: and

3d. A class composed of a mixture in varying degrees of the first and second classes. These are here considered in the opinion of your chairman to be grouped in the order of their frequency, usefulness and efficiency.

It is not proposed to consider at this time the necessity that exists for pure air on ship-board—air at least of the purity of that on the spar deck—nor to show by scientific mathematical demonstration the quantity required by the individual or demanded of masses of men, considering the surroundings when in enclosed spaces, nor to demonstrate to you from statistics the disease producing influence of impure air; for it is known to you all that the necessity for pure air is the constant iteration of every sanitary observer. Very slow has been the progress in the direction of practial application of the means for securing proper ventilation below the spar deck, although, as I shall show, the appliances proposed are numerous.

Of the first class of apparatus those that take the air out of a vessel are the most numerous as well as the most efficient. The removal of a volume of foul air is followed immediately by a volume of fresh air, impelled by the *vis-a-tergo* of the air, almost always a constant dependent, of course, upon barometic pressure.

It follows in this method that the mean change from a static (i. e. the air below deck) to a dynamic (i. e. the external air) condition makes the static head almost a dynamic one, and so merges this class into the second, or that class of apparatus which forces the air into a vessel.

This class has always a *vis-a-fronte* element to deal with, which will vary according to circumstances from a zero of resistance until even P (pressure) will = R (resistance) and the ventilation = 0.

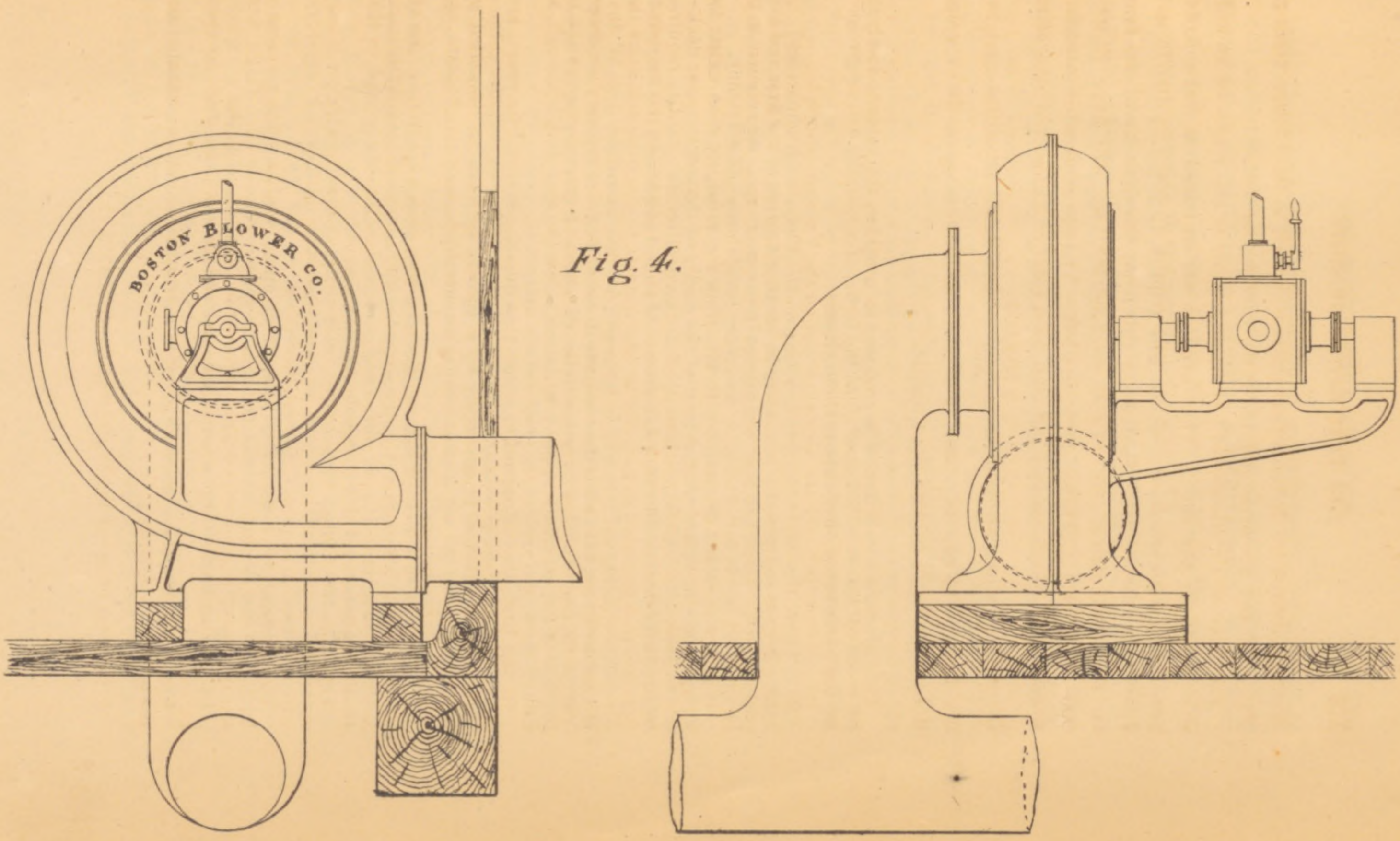
These remarks are applicable to air circulating in tubes. The element of friction of the air in conduits has not here been considered. Those who are interested in such subjects are referred to the work of Peclet.

Of the third class there are too few, and reference will be made to them hereafter.

Under the first class are to be grouped exhaust fans, bellows, tubular and the automatic systems.

* From the report of the Engineer-in-Chief-for 1879.

Fig. 4.



Under the second class the means used are, windsails, cowls, shafts et cetera.

And under the third class are to be placed the various fans reversible in action so as to act on either the vacuum or plenum principle, air-ports, et cetera.

I may here make the statement that the presence of a hatch does not exert much influence in an apartment otherwise closed.

Under such conditions there is about as much ventilation as in an uncorked bottle, for it has been stated by an eminent scientific ship builder that "the influence of an ordinary hatch to an otherwise closed hold is not felt much beyond a radius of eleven feet."

To those members of the Institute desiring to pursue the subject I respectfully offer this short résumé of authorities who have proposed methods for ship ventilation, or adopted suggestions of others having direct bearing upon this matter.

Agricoca—De Re Metallica—describes a mechanical apparatus for ventilating mines by injecting air with a rotatory fan, thus anticipating De-Sagulier, Commodore Beaumont, and Brindjonc apparatus for ships.

In 1664 Dr. Henshaw, in his book called "Oerochalinos" published in Dublin, adopted one of Boyle's speculations, using a bellows to pump air in or out of a room. This was an anticipation of Commodore Barron's patent in 1835 for pumping the air out of a vessel by means of a smith's bellows.

In 1723 De Sagulier invented his wheel; and in 1741 Hales invented his "Ship's lungs," which in some measure resembles the apparatus of Henshaw.

At this same date comes the persistent, undaunted brewer, Samuel Fulton, assisted by his friend Dr. Mead, with his Thermo-ventilating apparatus.

Sutton published an "Historical account of a new method of extracting air from ships," which, with slight alteration of dates, would almost apply to the present time. In 1741, also, Sir Martin Triewald, a Swedish engineer, invented a machine to draw bad air from under the decks of the Swedish ships blockading St. Petersburg, and in 1742 his method was adopted by the French. I have not been able to obtain a description of this apparatus.

Of the French inventors, Du Monceau, Wittig and Wazon have suggested Thermo-ventilators. Damboise, Nouahier and Giffard propose cowls. De-Cante (1870) suggests a method by compressed air. Of the others proposing means for securing the ventilation of vessels, I may mention Villiers, Kerauden, Brindejonc, Iouchon, Simon Defaix, Peyre, Ichiele and Williams, Poisenille (1846), Mondesir (1869) and Beaumaoir (1875).

To these already mentioned of English inventors must be added, Boyle and Arnott, whose method with variations, the principle remaining the same, has found its exponent in the hollow masts of the Spartan. Edmunds, 1865, by aspirating tubes; Dr. J. D. MacDonald, Prof. Naval Hygiene at Netley, Dr. Harry Leach, and the Napier system, as it is called, which the speaker of this evening modified in some particulars, in 1873.

Our own countrymen have not been idle in this direction. Commodore Barron, in 1835, McDonald 1841, Knight, 1847, Emerson, 1848, Robinson, 1850 and 1854, Bulkley, 1850, Sexton and Ennis, 1851, Thompson, '54, Bahr, '55, Knecht, '56—'58, Covel, '64, Burnett, Wells, and Woodward in '65, Wheeler, '67, Vanderbilt, '69, Sampson, '71, A. W. Thompson, '73, Jones, '76, Keating and Yaum in '78, nor must I omit the apparatus of Sir J. Liston Foulis in 1879, nor the cowl of Dr. Owens, U.S.N. nor Dr. Gibbs, U.S.N., modified wind-sail.

Of the Automatic variety of apparatus I may mention those of Thiers and Roddy 1871—1877, Delano U.S.N., '78, and Norton 79.

Of the inventors of modified air ports there must be noticed Sinclair 1864, Fernald, U.S.N. '77, Wilson, U.S.N. '79.

It is said that chief engineer J. W. King proposed a plan for ventilating vessels in 1859, and chief engineer Isherwood has reported (1879) upon a plan proposed by D. C. Green, Esq., of N. Y.

As to the system of mechanical ventilation in the vessels of the monitor variety it is too well known to you all to demand more than this recognition.

The tendency at the present time is almost entirely towards the methods of the first class—extracting the air from the vessel, and in the course of some observation and a good deal more study, I give my adhesion, under the usual reservations upon scientific matters, to those methods.

One more statement in conclusion. To-day I have reason to know that two of our vessels are well ventilated—the Richmond and Lancaster. Of my share in this advance it does not become me to speak. I have the satisfaction, however, of knowing that there has been secured to some of my mess and ship mates, and I trust in the future will be secured to all my fellow-officers, the extinction of the remembrance of the foul and "stuffy" atmosphere of a berth deck by a liberal supply of pure air. One side of the naval sanitary triangle has been drawn—Ventilation—the other two, cleanliness and dryness, must soon be limned. When completed, health and its attendant comfort, as elements of an increased efficiency, are secure.

Medical Inspector GIBBS. I fully agree with the main feature of the instructive address to which we have listened this evening, and hope that the practical points may be adopted in our service, as fast as vessels are built or repaired. That we are sadly behind in our labors, in securing the practical advantages of ventilation in our ships of war is a most humiliating and painful fact. Having already written and labored somewhat extensively in this field I will confine myself to supplementing the speaker's remarks by describing the peculiarities of the fire-room hatch of H. M. Ship "Volage", which I visited on the south Atlantic station.

This hatch, between the berth and spar decks, was unincumbered with bulk heads, and the spar deck hatch was dedicated to aiding the ventilation in this part of the ship. In order to describe it intelligibly, the fire room hatch on the berth deck may be imagined to be divided into three parts. The central part comprised about one half of the area of the whole hatch, and, of course, included the smoke pipe etc. The two ends of the hatch, comprising about the other half of the hatch, were open spaces. The central half was covered with iron, sloping from a point about on a level with the spar deck, down to the quadrangular coaming, where it was secured. In fact this covering resembled an inverted hopper with the smoke pipe passing up through its centre. In this situation there was no obstruction to the passage of air through the spar deck of the hatch, and one half of the corresponding berth deck hatch was open to the descending current, where an upward current was forced beneath this hopper arrangement around the smoke pipe.

The officers of the ship informed me that there was never any annoyance experienced on the berth deck on account of the escape there of gases, ashes etc. The automatic ventilation of ships, I would add, by any aspirating device which we now possess, depending upon the force of winds or waves, has not, in my experience, been marked by any satisfactory result; and I would urge in the name of every hour I have lived in a vessel of war, and of every page I have read, endorsed by every conclusion I have reached in much reflection upon this subject, that a ship shall never be commissioned which is not provided with such a system of mechanical ventilation as now exists in the Richmond, or its equivalent.

Lieut. J. T. SULLIVAN: I am familiar with several types of automatic ventilators, but there is one form which I have had in use at my home for some time, and in studying its usefulness there I have been led to think that it might be applied with equal success on board ship. The ventilating apparatus or "cap" consists of four principal pieces; the dome, collar, band and tube. The collar encircles the upper extremity of the tube, and while rising above the tube increases its diameter, becoming bell shaped. The dome has a diameter across its mouth or base equal to the greatest diameter of the collar, and when in place it is supported a short distance above and directly over the collar, leaving an opening all the way around between them. The band is somewhat broader than this opening and of greater diameter than the collar, so that in position it encircles the opening but does not come in contact with the main structure except at the points where it is secured.

In operation the "cap" works as an aspirator, and the external air currents, no matter in which direction they move, whether vertically, diagonally or horizontally, produce a tendency to vacuum in the tube, and consequently an upward and outflowing current. This process continues as long as there is any agitation of the external air, and the velocity of the exhaust current is increased as the wind increases. Applied to an apartment, its tendency to exhaust the air creates the desired circulation.

The correct principle of ventilation being to supply means for lifting or pumping the impure air out, as then fresh air will take its place, it would seem that the device described is well adapted to accomplish this process. Fitted to a vessel, in suitable sizes for the different locations, they would occupy, and with proper connections, they would insure an almost continuous circulation through its holes, bilges, store rooms and apartments. In selecting situations for them, advantage can be taken of their power to act whether they are placed right side up, up side down or sidewise; and for this reason they could be run along underneath the hammock rail, on the outside of the ship, and project only a few inches. These would serve to ventilate the holds, bilges, *et cetera*, while others of greater capacity could be distributed about the decks, and one of sufficient size to cap the smoke stack would do good service, not only in the process of ventilation and in exciting a strong draft for the fire, but in protecting the interior of the smoke stack and its dependencies from the weather.

P. A. Eng. ROELKER: Mr. Chairman, I wish to call attention to that portion of Mr. Baird's paper which gives an account of experiments made by him on the velocity of air currents in ventilating shafts temporarily fitted to openings in the deck. These experiments show how large a quantity of air may be discharged through such improvised air ducts, or by making use of the annular space between the chimney and its outer casing, as proposed by Mr. Baird, when the temperature below decks exceeds by but a few degrees the temperature of the outside air. Such means of ventilation are, of course, purely auxiliary, and are not intended to take the place of systematic mechanical ventilation; but, in the absence of the latter, means may be found in nearly every vessel for improvising temporary ventilating shafts which will exhaust large quantities of the vitiated air below decks. Since the majority of our naval vessels will remain, necessarily, without mechanical ventilation, for years to come, it is to be hoped that the facts presented by Mr. Baird will induce others to apply in a similar manner the means at hand to the ventilation of our vessels, and I have no doubt that Mr. Baird will feel rewarded for his labors if the interesting paper read by him tonight produces this immediate practical result.

Lieutenant TANNER: It will, perhaps, be of interest to those present if I give a short account of my own experience with ventilators in sea going ships. When I took command of the Pacific mail steamer City of Peking, I found that she had been fitted with ventilating apparatus which extended to all parts of the ship except the main passenger saloons, which, being light and well up above the water, where air could circulate naturally, were considered not to require artificial ventilation. The draught was furnished by large blowers in the fire rooms, connected to circulating pipes, having at proper intervals small ports fitted with shutters. Particular attention had been paid to the ventilation of the cargo and passenger decks; the latter requiring a very frequent change of air, owing to the number of Chinese that were transported each trip. On my arrival in Yokohama on my first trip I found a couple of Italian merchants who were in great trouble with regard to the transportation of a heavy invoice of silk-worm eggs. Hitherto the Pacific Mail company had refused to take this sort of freight, on account of the risk of losing a great part of it on the long passage to San Francisco. It is absolutely necessary that silk-worm eggs shall be kept in a cool place, where air can circulate freely about them: otherwise, if the temperature rises above a certain point, the eggs will hatch and the cocoons are spoiled. Having tested the ventilating apparatus thoroughly on the trip, I was very confident that it fully answered all that could be required of it. I therefore made overtures to the merchants, and succeeded in underbidding rival lines, and secured the cargo, which was valued at over half a million of dollars. This cargo I transported with absolute safety to San Francisco. Every morning on my round of inspection through the ship I would start the blowers and open the connections on the cargo deck, and in twenty minutes I could bring down the temperature 10°. It was only necessary to ventilate for about ten minutes three or four times in the twenty-four hours, and the temperature of my cargo would be kept at a constant point. Thus in one trip this apparatus paid a dozen times over the cost of putting it in the vessel. The Chinese passengers were frequently very much annoyed by the draught when their bunks happened to be in the vicinity of the ventilating ports, and, as they could not close the shutters, they resorted to stuffing their hats or clothing into the ports. The draught was so strong that no amount of jamming would hold their things in position, and every thing they put in would be drawn straight to the fire-room. Showers of hats, pantaloons and shirts were not infrequent in the stoke hole. Notwithstanding the airy position of the passenger saloons, the lack of proper ventilation was readily noticeable at sea. Passing from one of the ventilated apartments to the saloon, its "stuffiness" was quite appreciable, although, compared with the apartments of our men-of-war, these saloons were extremely well ventilated.

Lieutenant VERY: In going over H. M. ironclad Dreadnought, I was especially struck with the excellence of the ventilating apparatus, which was apparently of the same type as that mentioned by Lieut. Tanner. The circulating pipes ran along under the shelf pieces of the main deck so as to be just above the head, and in the state rooms just over the bunks. The ports, of which there was one to each room besides a number elsewhere, throughout the storerooms, engine rooms, berth deck and holds, were closed by shutters, so that the draught at any one place could be regulated. Another feature noticeable on this ship was the absence of engine room bulkheads. The heat from engine and fire rooms was forcibly *drawn* straight up through the uptake jacket apparently, at any rate it could not distribute itself about the decks. I noticed this same feature on the Russian ironclad frigate Minin, and I also remember that whilst a midshipman on the Asiatic squadron I commented on the absence of fire and engine room bulkheads on the French ironclad Belliqueuse, remarking that it must be very hot on the berth deck and in the steerages, owing to the escape of hot air. I was corrected by one of the French officers, who told me that on the contrary the deck was better ventilated. This of course was not due to the absence of the bulk head, but to the arrangement overhead by which the hot air was drawn straight up, taking with it the vitiated atmosphere below decks. With our present system of fire room ventilation, cold air is forced down the ventilators and rushes immediately to the fires, leaving the vitiated air to grow and spread itself throughout the ship. Bulkheads are of but little service, as the heat is refracted from their outer surface and vitiates what little fresh air there may be circulating. As for wind-sails, they are simply a God-send to the officer who is able to point the muzzle into his stateroom door. Beyond a small radius their effects are so diminished as to amount to almost nothing.

P. A. Eng. Baird: I have had some experience in automatic ventilators, but have never seen the exact device sketched by Mr. Sullivan. We had a very smoky galley pipe on board the Trenton, and it was effectually cured by an aspirating hood which I made on the principle of the air injector which I had previously patented for my distilling apparatus, and which is probably well known to all the gentlemen present. So far as the history of the principles of ventilation are concerned, and to whom the original invention is due, I must admit that I was not well posted, and have, therefore, to thank our chairman for his able chronological arrangements of the dates of those inventions. My part in this matter commenced in 1863, and has been the part of an engineer and not that of an inventor. I have not been able to find recorded the experiments of anybody, except myself, upon the velocities due to difference of temperature in the smoke pipe jacket, nor has any person, so far as I can find, ever attempted to combine the carbonic acid analyses taken on ship board with the experimental draught of the wind-sails, and to put the same to any practical use. Nor is there published, to my knowledge, any data which will guide our mechanics in the proportioning of exhaust fans and tubes for ships. I have viewed this problem from an engineering stand point, and have sought to put it in a practical shape. The paper I wrote on this subject in 1873 (*vide* Sanitary and Medical Report III, Bureau of Medicine and Surgery for 1873 and 1874, and also the Report of the Secretary of the Navy for 1873,) has been favorably received by the officers of the Navy, and I do not hesitate to say that the ventilating machinery on board the Richmond is an indifferent imitation of that proposed by myself.