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The Drying of Gas by Calcium Chloride

Laboratory of Research, Solvay & Co.

Now that calcium chloride is currently used in the laboratory as a drying agent for gas, it has scarcely been the object of analogous applications in industry, for various reasons. In the following will be found the results of experiments tending to utilize on a large scale, to effect not only complete drying, but a reduction of the quantity of water contained in the gases treated. A series of tables and diagrams make it possible to resolve the problems which are posed in practical industry.

Introduction:

Calcium chloride is frequently used in laboratories as drying agent for gases: they are made to pass under a bed of porous granules of anhydrous calcium chloride. The gases coming out are extremely dry insofar as the layer of chloride contains still a sufficient quantity of anhydrous chloride.

This process has not received important industrial applications. It is, in fact, rather costly for the following three reasons:

—The quantity of water fixed per kilogram of $CaCl^2$ is relatively weak, for the chloride loses its efficacy in proportion as it is hydrated.

—The apparatus necessarily proceeds irregularly, for the hydrated calcium chloride is solid and its replacement by new chloride demands a considerable cost of labor.

—Anhydrous calcium chloride in porous granules is a relatively expensive substance.

The question changes aspect completely when one desires not a complete drying of the gas but a reduction of the quantity of water contained; one can then utilize the calcium chloride industrially, bit by bit, at little cost, and regulate the operation in such manner that the water is evacuated at the state of saturated solution. In such a case the installations can work continuously and no supervision is necessary.

Arrangements of this kind have already been recommended. They have been little used up to the present, doubtless because of the lack of sufficient technical date to determine the dimensions of the apparatus and to foresee the cost in calcium chloride. The results which we present here have the short aim of filling this void. They result from a profound experimental study of the question.

Calcium chloride can serve in the drying of all gas not reacting chemically with it. The results which we give bear on the drying of air.

Drying Apparatus:

The drying apparatus consists of a simple cylindrical column of iron filled with calcium chloride at 73-75% $CaCl^2$, crushed to bits of 25 to 50 mm. It is to be noted that particles such as are used as antidust are not suitable for this purpose because the particles unite too easily under the effect of humidity. The calcium chloride rests on a grille in a box covered with metallic mesh with holes of 2 mm. The gas to be dried is injected under the grille by a lateral pipe permitting as equal distribution as possible in all sections of the apparatus. At the base of the apparatus is adapted a siphon permitting evacuation of the chloride solution. The dried air leaves by a tube set in the top cover.

In practice, the feeding of the chloride apparatus will not be continuous. Drying leads to a consumption of chloride, the height of this will progressively diminish and it will be necessary to place a new charge in the apparatus at the moment or the heightof charge will no longer be sufficient to assure the result desired.

Functioning of the Apparatus:

If one considers a column of drying functioning normally, one can distinguish two zones:

—The first occupies the lower part of the apparatus and has only a slight height. It is in this zone that the major part of the fixation of water takes place. The complete operation, condensation of water vapor and dissolution of chloride, being exothermic, the temperature of air increases strongly and as the surface of radiation is weak, the maximum temperature attained at the higher level of this zone is only slightly lower than that corresponding to an adiabatic operation.

—The second zone carries on all the rest of the changing of chloride, Its height being less, the heat losses by radiation are more important; the cooling which results has the effect of increasing the hygrometric degree of the air; but because of the presence of chloride, there is excess fixation of water with release of heat, which slows the cooling of air.

The water vapor condensed forms, on the surface as grains, a saturated solution which rolls to the base of the apparatus where it is evacuated in continuous fashion by siphon.

For the unitary output of air enclosed between 700 and 3.500 kg. of dry air/h/m^2 (1), air, on leaving the apparatus, is in hygrometric balance with the chloride solution saturated at the governing temperature at the peak of the piling up of the chloride. Its content in humidity is then a functionof its temperature. That is why the temperature is an essential factor in the question of drying.

The curves of fig. 1 give the variations of the quantity of water contained in air in hygrometric balance with the saturated solutions of $CaCl^2$, as a function of temperature. One sees that the content of water vapor of air in hygrometric balance with the saturated solutions $CaCl^2$ is much stronger, and the increase of this content more rapid, the higher the temperature.

This diagram gives also, for each temperature, the content limit in water of air, which one attains by drying by means of calcium chloride following the process which we are studying. If one desires to obtain more dry air, he must have recourse to another drying agent.

To augment the efficacy of drying, a lowering of the temperature of air at the moment where it leaves the chloride would always be favorable. The drying operation being exothermic, the temperature of air at the peak of accumulation of chloride will be much higher than the temperature, and the hygrometric degree of air will be higher.

—Each time that it will be economically possible, there would be interest in cooling the humid air before its entrance into the drying apparatus. After this preliminary cooling, there would eventually be condensation of part of the water vapor. In act, saturation at 20°C for example, corresponds to only 54,6° hygrometric at 30°C. and 31,5° hygrometric at 40° centigrade.

Consumption of calcium chloride:

In industrial production, all water taken off as air passes the state of chloride solution, the consumption of chloride is directly proportional to the quantity of water fixed; that is to say to the production of output of air by the difference between the quantities of water contained in the air before and after drying. The consumption of chloride depends equally on the concentration of the solution leaving the apparatus. This concentration increases with the temperature of air on drying.

In an apparatus such as we have previously described, in which the air to be dried is injected directly under the calcium chloride, the consumption is important and varies from 1.7 to 3,0 kg./kg. fixed water for the output units contained between 720 and 3,500 kg. of dry air/h/m^2 and the initial temperatures vary from 20 to 40° centigrade. The consumption is strongly reduced by effecting preliminary drying of air by means of the solution of $CaCl^2$ which rolls from the drying column. The operation can be easily effected by placing at the base of the drying column a scrubber equipped with Raschig rings. Air entering at the lower part of the apparatus crosses the accumulation of Raschig rings on which the solution drops proceeding from the drying by chloride in the height of the apparatus. In this zone, which functions as scrubber, the air already yields a part of its water vapor to the solution. As a result the solution which rolls to the base of the apparatus is more diluted than that which dries without scrubber. The consumption of chloride will then be reduced. We have verified that economy on consumption attains 50% for a scrubber of 1m. in height. There is scarcely any advantage in utilizing a higher scrubber.

If, for reasons of encumbrance, it is not possible to superpose in the same apparatus the part functioning as scrubber and the part filled with chloride, the scrubber will be placed alongside the other. This disposition will necessitate the installation of a pump to retake the solution rolling to the base of the apparatus to the chloride and drive it back to the summit of the scrubber.

Resolution of problems of industrial drying:

After having rapidly seen the functioning method of a drying column, we will approach the industrial problems posed.

It is necessary, for example, to calculate the efficacy one can attain from drying a quantity of air in determined conditions, in an apparatus of which the dimensions are fixed in advance. More frequently it is necessary to determine the dimensions of a drying apparatus, which permits ...

treated under imposed conditions.

As the feeding of chloride will bd discontinued, the quantity of chloride to introduce at the time of each recharging should be calculated in such a manner that the frequency of recharging will be in agreement with the necessities of the service. We may add that lessening the encumbrance of the apparatus, as much in sections as in height, entails always increasing the frequency of chargings. When industrial problems are resolved, it will then be necessary to adopt a solution conciliating these other matters.

In some cases, it will be necessary, to obtain the result imposed, to dry two or more times with intermediate refrigeration. From the point of view of consumption of chloride, it would always be interesting to adopt a drying apparatus bearing a scrubber, as we have indicated previously.

In order to permit rapid resolution of problems of drying which would occur in practice, we have established a certain number of tables and diagrams for which we will show the use.

In order not to complicate the tables and diagrams, we have calculated and traced for a total constant pressure of 760mm. Hg, to an ambiant temperature of 20°C. and have adopted drying apparatus in iron, which will be the usual case. This choice is justified by the fact that variations of total pressure and ambiant temperature are in general weak and do not influence the results very much.

The tables and diagrams which we present will suffice largely for the solution of industrial problems. They have been established for an apparatus without scrubber.

In the case of adoption of an apparatus bearing a scrubber of 1 m. in height, the qualities of air dried (temperature and content in water) will scarcely be modified, but the consumption of chloride will be only half of that resulting from our tables.

To simplify the language, we will use the following notations:

Notations	Units	Meaning
to	°C	Temperature of air being dried
uo	°hygrometric	Hygrometric degree of air being dried
Po.	gr./kg. dry air	Water vapor content of air being dried
ta	°C	Temperature of adiabatic drying
ts	°C	Temperature of air at higher level of calcium chloride
us	°hygrometric	Hygrometric degree of air at higher level of chloride
Ps	gr./kg.dry air	Water vapor content of air after drying
A	kg.dry air/h	Output of air related to dry air
Al	kg.dry air/h.m^2	Unit output of air related to dry air
D	m	Diameter of the column at dessicc
H	m	Height of flow of calcium chloride

Usually, it is a question of determining the dimensions of an apparatus in which one desires to pass M m^3/h. of air at °C. and at uo degrees hygrometric. The efficiency of drying should be such that the hygrometric degree of air treated, returned to the same temperature, should equal u.

The weight of dry air being a quantity which is constant in the course of drying, we have the output and quantities of water contained in the air per kilogram of dry air.

Tables I and II give a review of usual data concerning yield in kilograms of dry air containing P gr. of water per kilogram of dry air.

Figure 2 gives immediately the temperature of adiabatic drying, ta, as a function of the state of initial air (temperature and hygrometric degree).

Table I.-- Weight of dry air contained in 1 m^3 of humid air for different temperatures and different hygrometric degrees. (Total pressure of humid air: 760mm.Hg). Weight of dry air, kilograms.

Table II.--Variation of the quantity of water in the air as a function of the temperature and hygrometric degree.(Total pressure of humid air: 760 mm.Hg). Quantity of water in air, gr./kg. dry air.

Table III.-- Lowering of chloride in the apparatus as a function of initial conditions.

Table IV.-- Consumption of commercial calcium chloride as a function of conditions of drying.

We recall that the temperature of issuing air is close to ta. It is important, then, to know ta, since the water content of treated air depends on ts. It is the content corresponding to hygrometric balance with the solution saturated in calcium chloride.

Maximum content of water in issuing air, Ps maximum, being imposed, the diagram of figure I gives the ts maximum of air at the end of drying.

It should be noted that Ps maximum and ts maximum correspond to the minimum height of the flow of chloride, that is to its height immediately before recharging. Immediately after the recharging, the height is maximum. Ps and ts corresponding at this moment are minimum. In the course of functioning of the apparatus between two chargings, Ps and ts increase progressively to attain their maximum values at the moment of recharging.

The diagram of fig. 3 lets us choose the dimensions of the apparatus. This diagram gives the temperature of issuing air, ts, as a function of unitary output of dry air for differing adiabatic temperatures. Furthermore, to each ta there are two corresponding curves subject to the relative dimensions of the drying column; one of the curves corresponds to an $\frac{H}{D} = I$, the other to an $\frac{H}{D} = 3$. The isoadiabatic curves are traced from 5 , 5°C. but one can interpolate between these values. For values of $\frac{H}{D}$ comprised between I and 3, interpolation is permitted; extrapolationis equally in the neighborhood of these values.

This diagram shows immediately if the drying is possible with a single column. Sufficient for this is that ts minimum corresponding to the curve of the ta of the problem and $\frac{H}{D} = 3$, be lower than the ts maximum found on the diagram of figure I. In the contrary case one should use two columns with intermediate refrigeration.

The diagram of figure 3 will show the possibility of adopting either an apparatus of large diameter and little height, or an apparatus of small diameter and great height. Only local necessity in connection with encumbrance of the apparatus will permit judicious choice. We may add that the height deduced from the diagram corresponds to the minumum height of the flow of chloride underneath whichit should not fall.

The actual height of apparatus should be calculated taking into account the consumption of chloride and desiderata concerning the frequency of rechargings.

Table III gives lowering of chloride in the apparatus as a function of initial conditions (temperature and unitary flow of air to be dried). To obtain actual lowering of chloride in the apparatus in cm/24 hours, you must multiply the lowering, given in the table, by the difference (Pe-Ps) of quantities of water contained in air before and after drying.

From the actual lowering of chloride, one deduces the total height of the apparatus.

We add that the total height thus calculated should be increased in the neighborhood of 3% to take into account the increase of consumption due to the fact that following the difference in height of flow of chloride between two rechargings, the consumption is strongest immediately after recharging, and then diminishes.

Also, for technical reasons, one cannot tolerate only very weak variations in hygrometric degree of dried air, it is necessary either to adopt an apparatus of greater diameter and consent to frequent rechargings, or envisage continuous feeding of chloride.

Table IV gives consumption of commercial chloride at 72-75% $CaCl^2$ in kilograms per kilogram of fixed water. Knowing the unitary output of air and the quantity of water taken off by drying, one deduces the hourly consumption.

We recall again that the consumption thus calculated corresponds to an apparatus in which the humid air to be dried is introduced at the base of chloride flow.

This consumption will be reduced by 50% by using an apparatus bearing an scrubber of 1 m. in height.

First example

What are the dimensions of an apparatus to be used in treating 1.300 m^3/h of air at 31°C and 90°hygrometric, so that the hygrometric degree of air dried, returned to 31°C will not be more than 56?

Table I permits calculation of A:

$$A = 1{,}115 \times 1.300 = 1.450 \text{ kg./h.}$$

(1 m^3 humid air at 31°C and 90°hygrometric contains 1,115 kg. dry air).

Table II gives:

Po = 25,6 gr./kg. dry air;
Ps = 15,6 gr./kg. dry air.

The diagram of figure I shows that in order never to have Ps $>$ 15,6 it is necessary that the maximum ts be $<$ 53,5.

With the aid of the diagram of figure 2, one finds ta = 55° centigrade.

We then consult the diagram of figure 3. One sees that ts = 53,5 is greater than the ts minimum corresponding to an apparatus of $\frac{H}{D} = 3$.

Drying is then possible with a single column.

From the point of view of dimensions of apparatus, we envisage three cases.

A) First case. — Local utilization necessitates an apparatus of low height.

This condition entails a weak unitary output, thus a rather large diameter.

By extrapolation, one finds on the diagram of figure 3 that for the unitary output of 720 $kg./h.m^2$, it is necessary that $\frac{H}{D} > 0{,}65$ in order that $kg/h/m^2$ ts $<$ 53,5.

The section of the apparatus should be equal to $\frac{1450}{720} = 2\ m^2$, of which D = 1,60 m.

The minimum height of flow of chloride should be equal to 1,60 x 0,65 = 1,04 m.

With the aid of table III, one finds that the lowering of chloride is equal to 4,58 cm./24h. for 1 gr. of fixed water per kilogram of dry air.

The lowering of chloride is then equal to:

$$4,58\ (25,6 - 15,6) = 45,8 \text{ cm./24 hours.}$$

Thq initial height should be equal to:

$$1,04 + 0,46 = 1,5 \text{ meters;}$$

if one recharges one a day.

While taking into account the increase of 3%, one must give to the initial flow a height of 1,55 meteres.

After progressive lowerin; of the chloride level, Ps continues increasing in the course of functioning and oscillates between Ps minimum and 15,6.

Ps minimum corresponds to the beginning of the action, immediately after recharging, and corresponds to a $\frac{H}{D} = \frac{1,55}{1,60} = 0,97$.

After figure 3, ts minimum corresponding to ta = 55, Al = 720 and $\frac{H}{D} = 0.97$ is equal to 52,8° centigrade.

One then deduces Ps minimum = 15,1 (see figure I).

Between two rechargings of chloride, Ps will vary from 15,1 to 15,6 g./kg. dry air.

Consumption of chloride. -- In accordance with Table IV, consumption of chloride will be equal to:

$$2,33\left(25,6 - \frac{15,1 + 15,6}{2}\right)\frac{1450}{1000} = 34,6 \text{ kg./hour}$$

At each recharging, it will be necessary then to introduced in the apparatus 34,6 x 24 = 830 kg. commercial chloride of calcium.

Thus, in resume, an apparatus is necessary of about 1,6 m. in diameter and about 2 m. in height to take into account the place necessary to inject air under the grille.

One must load on the grille a layer of chloride of 1,55 m. in height.

The apparatus will be recharged after 24 hours of action by introduction of 830 kg. of calcium chloride.

B) Second Case.-- For lacc of space, one desires an apparatus of low section.

This condition imposes the choice of a large output of unitary air.

We will adopt A = 3.500 kg./h./m^2 which fixes at 0,73 m. the diameter of the apparatus.

By interpolation, one finds on the diagram of figure 3 that with the output of air adopted, ts $<$ 53,5 when $\frac{H}{D} >$ 1,63.

The minimum height of the layer of chloride is equal to 1,63 x 0,73 = 1,20 m. approximately.

With the aid of table III, one finds that the lowering of chloride is equal to 26,3 x 10 = 262 cm., when a period of 24 hour recharging is adopted.

The initial height would then be in this case (1,2 plus 2,6) 1,03 equals 3,9 m. corresponding to an $\frac{H}{D}$ initially equal to 5,34.

The height thus obtained is very large. One can eventually reduce it by consenting to a frequency of rechargings.

We admit, for example, a period of recharging at twelve hours.

The lowering of chloride is equal this time to 1,3m and in consequence

Initial H equals (1,2 plus 1,3) 1,03 equals 2,60 m.

which corresponds to an initial D equals 3,56.

We call attention to the fact that we have verified that the loss of charge of a column of 3 m. in height, full of chloride in grains of 15 5o 25 mm. is very weak. For a unitary output of 3,200 m^3/h./m^2 the loss of charge is only 2k mm. Hg, or 380 mm. of water.

The diagram of figure 3 shows that if $\frac{H}{D}$ equals 3,56, ts equals 59,7° C and in consequence initial Ps equals 14,3 (see diagram of figure I).

Between two successive rechargings, Ps will vary then from 14,3 to 15,6. The median Ps is thus equal to 15 and Po -- Ps equals 25,6 -- 15 equals 10,6.

Consumption of chloride. -- According to table IV, the consumption of chloride between two rechargings is equal to: $2,75 \times 10,6 \times \frac{1450}{1000} \times 12$ equals 508 kg.

In adopting this solution, an apparatus of about 3 m. is necessary and one of about 0,73 m. in diameter. One must load, on the grille a layer of chloride of 2,6 m. in height. The apparatus will be recharged after 12 hours of action, by introduction of 510 kg. of calcium chloride.

C) Third case. -- There is interest in this case in utilizing an intermediate output of air, so as not to adopt excessive values in either diameter or height of the apparatus.

Let us examine for example the solution of the problem posed, in adopting a unitary output of air of 2,000 kg. of dry air/h./m^2.

In this case S equals $\frac{1.450}{2.000}$ equals 0,725 m^2 and D equals 0,96 m.

The diagram of figure 3 shows that, in this case $\frac{H}{D}$ minimum equals 1,3, which corresponds to H minimum equals 1,25 meteres.

In accordance with table III, the lowering of chloride is equal to 13,74 x 10 equals 137 cm./24 h, thus initial H equals (1,25 plus 1,37) 1,03 equals 2,70 m. and $\frac{H}{D}$ equals 2,81.

By interpolation on diagram of figure 3, one finds that when $\frac{H}{D}$ equals 2,81, ts equals 51,6°C.; to this ts minimum corresponds a Ps minimum equals 14,2 (diagram of figure I).

Between two successive rechargins, the content in water of the air dried will vary from 14,2 to 15 9. Px median is then equal to 14,9.

Consumption of chloride. -- Using table IV, hourly consumption of commercial chloride is equal to:

$$2,53\ (25,6 -- 14,9)\frac{1450}{1000} \text{ equals } 39,2 \text{ kg.}$$

The consumption of chloride in twenty four hours is then equal to 941 kilograms.

In summary, the apparatus would have about 3 m. height and 0,96 m. diameter. A layer of chloride 2,7 m. in height should be loaded on the grill and the apparatus recharged every 24 hours, introducing 940 kg. of calcium chloride.

Second Example

What are the dimensions of the apparatus to be used in treating 800m^3/h. of ait at 25°C. and 90° Hygrometric, so that the hygrometric degree of dried air left at 20°C, will not be more than 50?

We can, as formerly, calculate A by means of table I:

A equals 1,152 x 800 equals 921,6 kg./hour

Table II gives the following:

Pe equals 17,8 gr./kg. dry air;
Ps equals 7,1 gr./kg. dry air.

The diagram of figure I shows that in order that Ps $<$ 7,1, it is necessary that ts be $<$ 35° centigrade.

With the help of the diagram of figure 2, we find ta equals 45,8° centigrade.

Now consulting the diagram of figure 3, we can see (by interpolation) that for ta equals 45,8 and $\frac{H}{D}$ equals 3, ts is always $>$ 35; we cannot then attain the desired result using an apparatus constituted of a single column. Two columns must be used with intermediate refrigeration.

We are going to show the action to follow for determining the dimensions of the two apparatuses.

We will simultaneously calculate for the casees of two extreme unitary yields of 720 and 3,500 kg./h.m^2 so as to be able to choose judiciously the dimensions to use.

As the drying is done in two apparatuses, it is logical to divide the quantity of water in half between the two. The content of water in the air leaving the first apparatus should then be $<$ 12,5 gr./kg., which implies that ts $\angle$ 49,4°C (see diagram of figure 1).

Now, we have seen that ta equals 45,8°C. It results that whatever the dimensions of the apparatus, the quantity of fixed water will be greater than half of the total water to be retained in the two times. In consequence, the height of the layer of chloride should be as little as possible.

Experiments have shown that, in order to have regular functioning, the layer of chloride should not be less than 0,5 m. in height. Then H minimum equals 0,5 metero.

To facilitate the text, we will indicate in a table, the following successive operations leading to results of drying, with tables or diagrams consulted between parenthesis. (see table of prededing page).

We are going to suppose now that the air leaving these two columns passes into a refrigerant, at the end of which the temperature is reduced to 25°C.

As at no moment, can the value of Ps at the end of two times be higher than 7,1, we will calculate from the second apparatus while supposing that Pe (2nd time) is equal to Ps maximum (first time).

In those conditions, table II shows that:

-----to Pe equals 9,75 corresponds a hygrometric degree equal to 50 at 25° centigrade,

-----to Pe equals 9,93 corresponds a hygrometric degree equal to 51 at 25° centigrade. We can now begin calculating the apparatus of the second time.

		Second time
A_1 720		3,500
ue 50		51
te 25		25
ta ...(diagr. figure 2)	33,6	33,9

We see that it is useless to pursue the calculation. In fact, whatever, the apparatus, ts at the end of the second time will be lower than 33,6 and therefore the correspondings P_s will be notably lower than 7,1.

While admitting even that the fact of having a water content of dried air, lower than the required value, be compatible with the technical demands, there would result a useless consumption of chloride.

In order to a value closer to 7,1 the water content of dried air, one can send only a part of the air to be dried into the two columns, or send the total air into the first column and a part only into the second. These two methods of operation lead to the same consumption of chloride; the first permits a light reduction of diameter of the two columns, the second permits reducing to a minimum the diameter of the column of drying effected the second time.

We are going to continue the calculation using as example the second solution.

Determination of the quantity of air to pass into the second apparatus necessitates knowledge of the maximum quantity of water contained in the air on leaving this apparatus.

To arrive at this, we need the aid of diagram in figure 3, to determine the ts maximum for the output considered, while adopting H equals 0,5 m. and D equals the diameter of the apparatus of the first time.

One easily deduces Ps maximum, A and D to use. We then continue the calculation taking H equals 0,5.

We give here following the calculations. (See table on page following).

One has then the dimensions for the two extreme outputs. Their comparison will permit choosing judiciously an intermediary output for which the calculation will be made in the same manner.

In the examples given, we put ourselves uniquely in the point of view of using the tables and diagrams; but, in practice, it is certain that the apparatus used always have a scrubber. There will result from this a lessening of consumption of chloride and a lessening either of height of apparatus or frequency of rechargings.

In practice, with a scrubber of 1 m. in height, consumption of chloride will be reduced by half, and therefore, if one maintains the same initial height of the layer of chloride as in the case of an apparatus without scrubber, the length of time between two consecutive rechargings will be doubled; if, on the contrary, there is little interest in spacing the rechargings, the height of the apparatus may be reduced.

Conclusions

Drying of gas by calcium chloride is an operation necessitating a very simple apparatus and is effected without supervision.

The diagrams and tables presented make possible the solving of problems of drying air as presented in Industrial practice. It is possible to determine whether a problem can be solved by drying in one single or in several machines, and to calculate the dimensions necessary as well as consumption of calcium chloride and frequency of rechargings.

There is always interest, from the point of view of result of drying as well as consumption of chloride, in refrigerating the gas before its entrance into the drying apparatus and in using an apparatus containing a scrubber.

It is necessary to note that, even at a strong unitary output of 3.000 to 3.200 $m^3/h./m^2$ of humid air, there is no chloride dust, granted that, especially with large unitary outputs, the grains in the whole column are recovered immediately with a film solution.