

with a pressure of 50 to 60 volts was applied. The fusion of the mineral proceeded with the greatest ease. At the expiration of an hour and a half after the operation was started the temperature of the fused mass in the furnace was taken with the aid of Vanner's pyrometer. This temperature was found to be somewhat higher than 1900° C.

After this operation the slag was transferred to one crucible, while the metal was tapped into another crucible. Both crucibles were of course preheated. The slag was very fluid. The same day about three o'clock P.M. the contents of the cooled-down crucibles were examined.

A solid homogeneous ingot of metal weighing 1 kilogram, 620 grams, was found. The slag was black and had a vitreous fracture.

The analysis of the mineral was as follows:

Silicon.....	1.6		
Aluminum.....	traces		
Protoxide of iron.....	28.5	Fe =	22.18
Peroxide of iron.....	49.95	Fe =	34.97
Oxide of manganese.....	0.98		
Lime.....	0.37		
Magnesia.....	2.35		
Sulphuric acid.....	0.69	S =	0.027
Phosphoric acid.....	0.096	P =	0.042
Copper.....	0.012		
Arsenic.....	0.005		
Titanic acid.....	16.00		
Loss on ignition.....	0.068		
			100.00

The analysis of the metal was as follows:

Carbon, total.....	3.05
Manganese.....	1.52
Sulphur.....	0.01
Phosphor.....	0.11
Silicon.....	0.37
Iron.....	94.94
	100.00

There is, therefore, little doubt that titaniferous ores of less than 20 per cent. of titanic acid can be profitably smelted. All metallurgists agree that the qualities of the iron made from titaniferous ore and steel obtained from titanic pig metal are excellent. This fact gave Dr. Rossi the idea to use an alloy of iron and titanium made in the electric furnace as an improver of steel.

The addition of titanium to steel increases the transversal strength from 17 to 23 per cent. (average results given in pounds per square inch). Bars of one inch square, loaded at center, with 12 inches between support, were used for transverse strength tests. For tensile tests round bars 1 1/8 inches in diameter and from 18 to 24 inches long were used. The ferro-titanium added to the steel contained about 12 per cent. of titanium and from

6 to 8 per cent. carbon. About one pound to every 100 pounds were added in small portions. There seems to be no advantage in using a ferro-titanium containing more than 25 per cent. titanium. Titanium also increases remarkably the elasticity of steel.<sup>1</sup>

The function of titanium in steel consists in its high affinity for oxygen and especially nitrogen.

### VACUUM EVAPORATION.

By P. B. SADTLER.

Received July 1, 1909.

It is a notable fact that, in this country at least, the knowledge of construction and operation of vacuum evaporating apparatus is very limited. There are a few industries, among which are the glucose, cane and beet sugar industries, where the engineers are in general pretty thoroughly familiar with this subject. Outside of these industries ignorance of the basic principles of evaporation actually frequently prevents engineers and superintendents from obtaining the best results. Those operating vacuum apparatus in their plants are prone to drop the subject completely as soon as their apparatus has been "broken in," only to take up the subject again when something goes wrong or when increased capacity must be installed to meet the demands of a growing business. Besides this class there is a long, though gradually diminishing, list of factory owners and others who either have entirely neglected to consider this important subject, or who, on doing so, have been frightened by some obstacle that seemed unsurmountable.

In this article will be discussed only the form of evaporator in which saturated steam is the heating medium as no evaporation can at present be done by direct fire so well as in the approved types of boiler, where the steam for the evaporator is made. The reasons why direct fire evaporation does not as a rule pay will be discussed on a later page.

A closed evaporator heated by steam coils has the following advantages:

1. Less steam is used because the apparatus is smaller and there is no exposed surface of boiling liquid, hence the amount of radiation and consequent loss of heat is reduced.

2. When evaporating under vacuum the temperature of the system is so lowered as to be nearly

<sup>1</sup> Dr. Rossi's contribution to *Cassier's Magazine*, Sept., 1905.

down to that of the atmosphere, with the result that the radiation loss is decreased. In other words, if a liquid is boiled in an open pan under atmospheric conditions the boiling point may be 220° F., or 150° above average atmospheric temperature. In a single-effect vacuum evaporator the average temperature may be 138° or 68° above atmospheric temperature. The radiation from the open pan would compare with that of the vacuum pan as 150° to 68° roughly.

3. The above considerations, however, are of little importance compared with the fact that a vacuum evaporator, either single- or multiple-effect, may be run by using, as a heating substance, the *exhaust steam* from engines, pumps, etc., thus enabling certain establishments to run an evaporator at practically no cost for steam.

4. There are many liquids which should be kept below the temperature 280° to 300° of high pressure steam coils, or even below atmospheric boiling point 212° F. Among these are such as sugar, glucose, sugar of milk, milk, glue, glycerine, etc.

5. Greater temperature differences may be attained in single effects, hence greater capacity for a given size apparatus.

6. When multiple-effect evaporators are used, the steam economy is increased to such an extent as to make the steam consumption run as low as 1/5, in some cases, of the actual amount of water evaporated from the liquid. There are some industrial concerns at present which could not operate and pay dividends without multiple-effect evaporators in constant use.

#### MULTIPLE-EFFECT PRINCIPLE.

The most primitive illustration of a multiple-effect evaporator is seen in an organic laboratory every day. Frequently a so-called volatile substance is put into a flask connected to a condenser and heated by a steam bath in which water is boiled. The vessel containing the boiling water is the first effect of a double-effect evaporator and the flask containing the low-boiling substance is the second effect. In the case of large scale work instead of boiling off a naturally volatile substance in the second effect, we boil off water whose vapor above it is kept at reduced pressure, thus making the water a relatively low-boiling substance. Thus in practice we have a succession of pans or effects, the coils of each one of which gets its heating vapor from the liquid of the preceding pan. The first pan of the series takes its

heating vapor from the original source, the boiler or exhaust pipe of an engine; the last effect gives up its vapor to a condenser in which the highest vacuum is maintained. An important point to be borne in mind is, that every effect is the condenser that brings about the pressure reduction necessary for the operation of the preceding pan.

The most popular and universally serviceable evaporator is the triple effect, although they are in daily operation on a large scale up to sextuple effect. In fact, multiple-effect water stills have been operated in twelve successive effects. A definite determination of the number of effects to use to obtain the best economy when working on any given solution, is difficult to make. The best tests, of course, are those made on the large evaporators and as some expense and annoyance to the owner may result, the proper scientifically conducted tests are not carried out. One can, therefore, only go by the judgment of the designers and experts in this field in determining the best layout for economical multiple-effect evaporation.

#### STEAM CONSUMPTION.

Before discussing at length the factors governing the steam consumption in an evaporator, it is well to state several fundamental facts to be proven later:

1. *The number of effects used in an evaporative system does not necessarily bear any relation to the evaporative capacity of the system.*

2. *A given amount of water at the boiling point to be evaporated requires a corresponding amount of steam to evaporate it irrespective of the form or size of the vessel in which the evaporation is accomplished.* Speaking broadly, a pound of water evaporated requires that a pound of steam be condensed in a single effect.

3. *The capacity of a heating surface is dependent on the temperature of the steam and not the pressure resulting therefrom.*

4. *An evaporator should not be considered as a heat engine, as it does no external work.*

To get the best idea of the heat transactions in the evaporator, we should consider one effect at a time. Also, for simplicity, assume that the effects are of the same construction and bear in mind that each one is the condenser to produce the vacuum in the preceding effect. For every pound of dry steam entering the coils of the first effect, there is one pound of vapor produced by

the evaporation of the solution which we assume enters at the boiling temperature. As only a fraction of the total amount of water is to be evaporated in the first effect, the solution passes partly concentrated into the next effect. But as a lower pressure, and consequently lower temperature, is being maintained in the second effect, the solution passes in a superheated condition to the next effect, where a certain amount of evaporation takes place, due to the lowering of the pressure. Therefore in the second effect we have to expect the evaporation of another pound, plus increment due to the changing part of the heat of the liquid into heat of vaporization. Likewise in the third effect there is produced evaporation to the extent of a pound, plus two increments. In other words, the latent heat of a pound of steam is transferred through the heating surfaces of one effect after another, the amount of steam being, however, gradually increased by the spontaneous evaporation of the solution passing from one effect to another successively in a superheated condition. Finally this heat passes into the cooling water of the condenser and is lost. If we were to assume that there was no radiation of heat from the system and that pure water were being boiled, the above conditions would be always true and, in a sextuple effect, a single pound of initial heating steam would accomplish the evaporation of between six and seven pounds of water.

In actual fact, however, we have to contend with the consumption of heat in two other directions:

1. In concentrating any solution we have to accomplish the partial separation of a liquid from a solid. There is, of course, a certain solution pressure against which we must work, and the actual amount of energy expended in this way is measured by the free energy of the chemical reaction of solution. This is not considerable when we concentrate to ordinary density. Hence it may be said that *the total reversible energy expended in evaporation is equal to the free energy of reaction.*

2. There is a radiation loss from each effect depending on the number of effects, their temperature with respect to atmospheric temperature, the amount and quality of the insulating covering used and other conditions such as degree of exposure of the apparatus to the weather.

These losses are cumulative from one effect to another so that where a solution has boiling points

appreciably above that of water, it is not economical to attempt the operation of more than a limited number of effects.

#### DIAGRAMS.

To illustrate several cases of heat transactions obtaining in an evaporator:

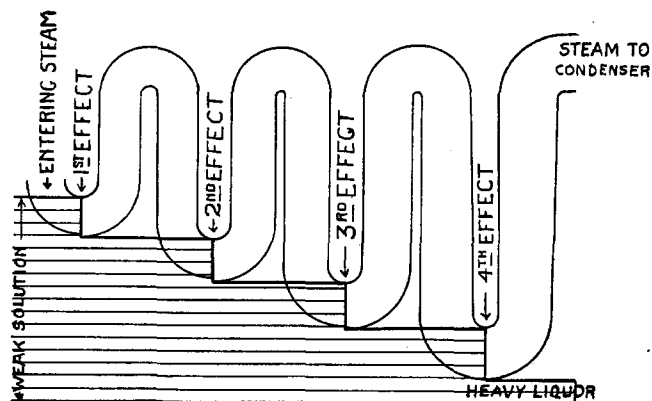


Fig. 1.

Figure 1 shows a multiple effect heat diagram similar to that of Hausbrand for pure water in a quadruple-effect evaporator, where it is assumed that the difference in temperature from one effect to another is infinitesimal and where water enters at boiling temperature and the vessels do not radiate heat.

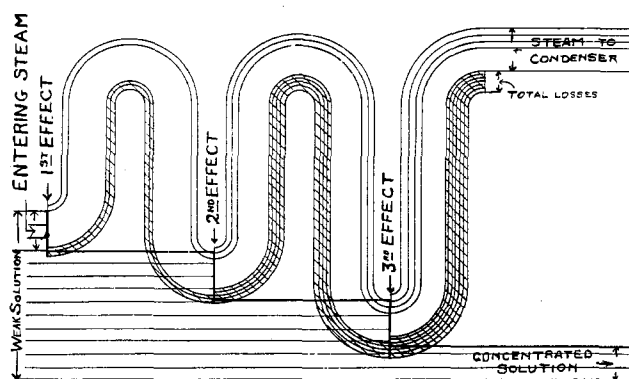


Fig. 2.

Figure 2 shows a heat diagram for a triple effect where the assumptions are made that the solution enters at atmospheric temperature, the solution has an appreciable excess in boiling temperature over that of water, and there is an appreciable temperature difference from one effect to another. The white areas represent the steam condensing and causing evaporation; the shaded areas represent the heat and energy losses as expressed in steam. The areas shown are not

definitely measurable or calculable, but merely in the diagram show the tendencies existing in an evaporation system.

The heat transferences taking place in a multiple effect are altered in character to a great extent by the method of feeding the solution to be concentrated and the method of preheating if such is necessary. There are four ways of feeding the solution to the evaporator:

1. The dilute solution is fed entirely into the first effect and passes successively from one effect to another at higher and higher concentrations.
2. The dilute solution is fed in equal amounts separately into each effect, and boiled in each at the same concentration.
3. The dilute solution is fed entirely into the last effect and passes back to the first effect, a method known as running backward.
4. The dilute solution is pumped into the whole evaporator before starting and boiled in batches.

While inquiring into the relation, merits and advantages of these methods, let us consider at the same time the methods of bringing the dilute liquor to the boiling point and the bearing of these methods upon the heat transactions.

While in many cases a recently completed chemical reaction or industrial process leaves the dilute solution at a temperature approaching the boiling point, such as we find to be the case in certain mercerizing work, in electrolytic soda work or packing house rendering, there are other cases such as brine evaporation or sugar evaporation where the most efficient process necessarily includes the preheating of dilute solutions. In general, it may be said that running a comparatively cool solution into an evaporating apparatus decreases its efficiency and interferes with proper operation.

The usual method of preheating in running a multiple-effect concentrating evaporator as mentioned, in case 1, above, is to employ a steam heater to preheat the solution entering the first effect by the use of live or exhaust steam. Frequently it is assumed that it is quite sufficient to turn on a little extra steam and run the solution cold into the evaporator. When this is done a portion of the heating surface of the effect, into which the cold solution is run, plays the part of a preheating apparatus. An evaporator is an expensive article to use as a preheater.

Where evaporating at equal densities, as in the second case above, there may be attached to each

effect a countercurrent heater in which the water of condensation, flowing from an effect, partly preheats the liquor being pumped into the effect. It can readily be perceived that the amount of heat that can be transferred to the solution from the water of condensation is insufficient to bring the former up to the required boiling point. This method is only applicable to precipitation work, as in multiple-effect salt evaporators.

When "running backwards" preheating is not often the practice as the boiling point of the last pan, the one which the solution enters, is not very high and the step up in temperature from one pan to another is not very great. This method has the advantage, other things being equal, that in the pan with the densest solution, there is the highest temperature, which tends towards better circulation and consequently higher efficiency. In using this method it is necessary to pump the liquid out of one effect into the next. The fact that steam is used to do the pumping need not have much bearing on the question, as it must be borne in mind that the exhaust steam from pumps is available for evaporation purposes.

The total consumption of heat in a multiple effect is composed of the energy consumed in actual separation of the liquid and the solid in solution; the radiation of heat from the walls of the vessel; the heat passing away in the circulating water of the condenser; and the heat passing away in the condensation water. In a test on an evaporator these can all be determined by actual measurement except the energy of evaporation and the radiation loss. There is always considerable doubt as to just what the latter amounts to in various types of evaporator and with various coverings. It is possible to measure it by special test, though this is rarely done. The energy of evaporation may be calculated for certain solutions and simply depends on a formula which may be derived from the gas laws.

It is shown by Nernst in the last edition of his "Theoretical Chemistry" that the energy expended in evaporation is

$$K \times R \times T \times (C - C'),$$

where  $R$  = the gas constant,  $T$  = the absolute temperature,  $C'$  = initial concentration, and  $C$  = the final concentration both expressed in mols. of salt per mol. of water.  $K$  is a constant quantity for any given substance in solution. For certain inorganic salts these constants have been deter-

mined, being derivable from the vapor pressure curves.

#### EFFICIENCY AND EVAPORATIVE CAPACITY.

A heat engine is an apparatus that transforms a portion of the heat received into dynamic energy. An evaporator is not a heat engine, therefore, but if the assumption be correct that solution is a chemical combination of solvent and solute, an evaporator transforms heat into chemical energy. When following this analogy between a heat engine and an evaporating system, we find that as a matter of fact the efficiency or the quantity  $\frac{Q-Q'}{Q}$ , where  $Q$  is the heat entering and  $Q-Q'$  is the heat transformed in chemical energy, is very low. The heat disposed of through other channels is very great. For instance, the latent heat of the entering steam eventually finds its way in large part into the circulating water of the condenser. Therefore, it will readily be seen that if, as we have shown above, this energy demanded for evaporation is entirely dependent upon absolute temperature and degree of concentration, *no one type of evaporator has more efficiency than another, but the efficiency is entirely dependent upon the solution and its attendant physical conditions.*

This matter of efficiency is noted here as there is an erroneous conception among some evaporator engineers as to the meaning of the word efficiency. It has been the practice among some to speak of the relative amount of evaporation per unit area of heating surface as the efficiency of an evaporator. The difficulty with using the term efficiency where the term capacity or duty would be more applicable, is that it leads those unacquainted with the principles to the idea that greater or less consumption of heat obtains in different types of evaporators. In different types of evaporators the evaporative capacity does vary considerably, but it is not the purpose of this article to discuss this side of the question, as the relative merits and demerits of different makes of machinery demand a separate article.

Before discussing the subject of capacity and the calculation of heating surface, it is well to approach the subject from the point of view of transmission of heat through the heating surface.

#### HEAT TRANSMISSION.

Heat transmission is measured by four fundamental factors, namely, temperature, weight, space,

and time. To be more specific, the common combination of units, in which we express heat transmission, is British thermal units, per square foot, per hour. Therefore, the coefficient of the heat transmission of a medium would be the figure which gives the number of British thermal units passing per hour from a warmer to a colder substance through one square foot of the medium for which we desire the coefficient.

It will readily be seen that the ability of the medium to transmit heat in a greater or less degree is governed by the following factors, namely, nature of the material, thickness of the medium, difference in temperature of the warmer and the colder substance. Hence, we have

$$h = k \frac{(t-t')}{d} m,$$

where  $h$  is heat transmitted,  $m$  is the time during which transmission takes place,  $d$  the thickness of the transmitting medium,  $t-t'$  difference in temperature, and  $k$  a constant dependent on the nature of the material.

From the above we see that

$$k = \frac{d \times h}{(t-t')m},$$

whence we are able to determine a constant  $k$  for any material by determining  $d$ ,  $h$ ,  $(t-t')$ , and  $m$  for one square foot of heating surface. For practical purposes, where for a given material the limits of the factor  $d$  are quite narrow, this is omitted and the constant becomes

$$k = \frac{h}{(t-t')m}.$$

In the case of the transference of heat from one substance to another, for evaporative purposes, we have several possibilities: that of heat passing *from* a liquid, *from* steam, or *from* other gases; also heat passing *to* a body of liquid or *to* a film of liquid.

In evaporation work the case of heat passing from a liquid is not of very wide importance. Other things being equal  $k$  would be high in this case, but the difficulties involved in this method of heating necessarily outweigh those of steam heating. A high-boiling liquid may be heated and made to pass through heating tubes, giving a high transference constant, but the velocity necessary for its passage through the tubes is great enough to make the idea unworthy of consideration.

In the case of saturated steam there is not the

same necessity for an appreciable velocity directly in relation with the walls of the heating tubes, though this is very desirable. Unlike the case of direct heating, the effect is obtained by the latent heat of vaporization. Although the heating of the liquid is not due to difference in temperature between the steam and the liquid being heated, there must be a quite appreciable difference in temperature to make effective use of the latent heat. The larger the difference in temperature the greater is the heat transmission of the metal walls.

As water dissolves air to a small extent the steam from the boiler always contains air in greater or less amount. This air tends to lessen the heat transmission so that it will be found in practice that better boiling takes place in the heating coil, where the velocity is considerable.

It can readily be seen, therefore, that the presence of *air in the heating steam is detrimental*. Just as air reduces the heat transmission so also does the water produced by condensation of the steam. The heat conductivity of water is far below that of a metal, so that a *steam coil containing a layer of water is not fully effective*.

The usual case of heating by other gases than steam is direct firing of boilers or evaporators, or the utilization of waste heat from furnaces, incinerators, etc. Here the transmission of heat is due to the difference in temperature and *the velocity of the gas*. It will readily be seen that if a body of cooled inert, non-condensable gas stays in contact with the wall of the heating surface the efficiency of the locality where that takes place is greatly reduced. On the other hand, in the case of steam the pressure back of the heating steam is cause for constant supply of the steam, which gives up its latent heat to the wall of the heating surface. A non-condensable gas, to be equivalent in effect to a condensable gas, like steam, must be led against the heat-transferring wall with considerable velocity to cause the rapid removal of cooled gas and prevent lodging of cooled gas in any small corners or devious places.

Very little can be determined as to the theoretical side of the transmission of heat to different solutions and solids. In general, it may be said that the completeness of the circulation of the liquid, the consequent rapidity of the disposal of the steam formed at the contact between the liquid and the heating surface, and the degree of mobility of the liquor are the chief factors for considera-

tion here. More can be said later of interest and of value from a practical standpoint.

The heat transmission may be said to be greater when the liquid is in contact with the heating surface in as thin layers as possible. This is accomplished by allowing the liquor to spray or trickle over the heating surface or by bringing the liquor in contact with the surface in the form of a foam. When a film is in contact with the heating surface the evaporation may be said to be local; hence there is a local cooling tendency and consequent greater temperature difference between the liquor heated and the heating gas. This it will be seen will increase the heat transmission.

There has been an erroneous notion prevalent among some engineers that the evaporative capacity of a heating surface of any given form and area is inversely proportional to the thickness of the wall of the heating tube and proportional to the heat conductivity of the particular metal used. This idea is quite wide of the mark, as decided by results. If two otherwise equal evaporators be installed in which one has heating tubes of 20-gauge and the other 15-gauge, such a theory would require that the latter would have half the evaporative capacity of the former, 15-gauge being twice as thick as 20-gauge. As a matter of fact the difference due to this variation in thickness is negligible. However, the difference between the evaporative capacities of two heating surfaces of different metals is measurable if two metals of widely different conductivities be chosen, but even then the difference is not great as might be supposed.

Kent gives, among others, the following conductivities:

Silver.....	1000
Copper (rolled).....	845
Iron (wrought).....	436
Steel.....	397

In spite of these figures the evaporative factor of copper tubes is only 10 per cent. to 15 per cent. greater than that of steel tubes.

To explain these facts we must consider that the resistances of the metallic wall to the passage of heat are threefold, namely, (1) resistance of entry of heat into the metallic wall, (2) resistance to passage through the wall, (3) resistance to the exit from the metal to the boiling solution. Let these resistances produce conductivities  $a$ ,  $b$ , and  $d$ , respectively. Let  $C$  represent the evaporative factor of the metal by experiment.

$\frac{I}{C} = \text{total resistance} = K \left[ \frac{I}{a} + \frac{I}{b} + \frac{I}{d} \right]$  or the sum of the three resistances.

$$C = \frac{I}{K \left[ \frac{I}{a} + \frac{I}{b} + \frac{I}{d} \right]}$$
 where  $K$  is an arbitrary

constant. Conductivity  $a$  is effected by the ease with which the steam for heating is carried off and also the velocity of the steam; conductivity  $b$  is constant for a given metal; conductivity  $d$  is dependent upon the solution being handled, its boiling point, mobility, scaling properties, etc.

#### CALCULATION OF HEATING SURFACE.

The amount of heating surface necessary in an evaporator to be used for any given class of work depends on the following factors: 1. The amount of water to be evaporated, (2) the number of effects desired, (3) the initial steam pressure, (4) the boiling points of the solution to be evaporated, (5) the evaporative factor for a given type of machine, and for a given solution to be evaporated,

In calculating the amount of water to be evaporated, it is merely necessary to obtain from tables or analysis, the per cent. of solids in the dilute and the concentrated liquor. From this we can obtain the amount of water to be evaporated. When the number of effects in which the evaporation is to be done is determined, a calculation should be made of the water evaporated in each effect and from that, what the concentration should be maintained at, in each effect. When these concentrations are known the corresponding boiling points should be found from a good table of boiling points or by experiment, or a curve such as shown in Fig. 3 for certain grades of caustic

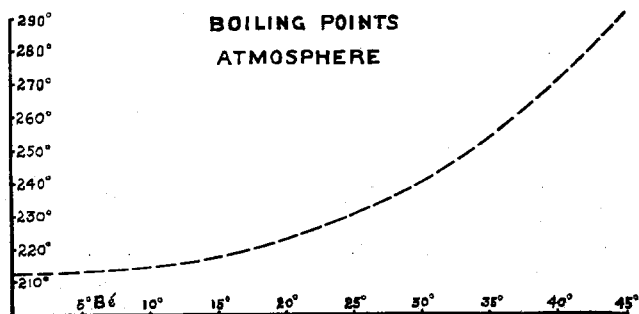


Fig. 3.

soda washings may be used. The *degrees of excess boiling* temperature is the total of each of these boiling points less  $212^{\circ}$  F. In other words, if the boiling points in three effects of a triple effect are respectively  $214^{\circ}$ ,  $220^{\circ}$ , and  $236^{\circ}$ , the

excess boiling temperature is  $(214 - 212) + (220 - 212) + (236 - 212) = 34^{\circ}$ .

From the steam tables of pressure and temperature the *total temperature range* should be found. Or it will be found very useful to use a curve as shown in Fig. 4 where the pressures and

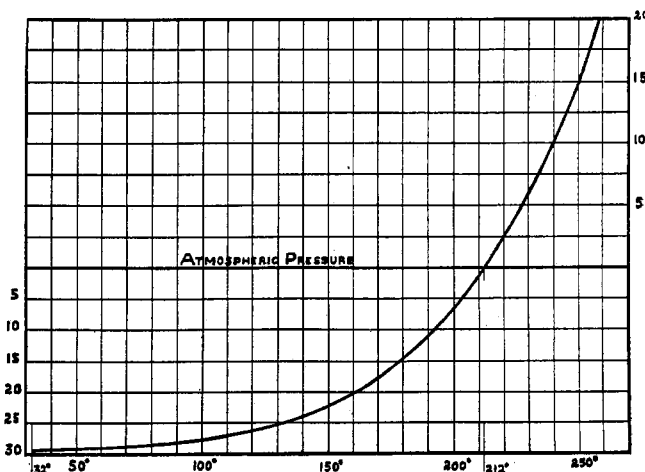


Fig. 4.

temperatures are plotted. Readings from such a plot compare favorably in accuracy with actual steam gauge readings on the evaporator. This temperature range then equals the temperature corresponding to initial steam pressure minus the temperature of steam pressure corresponding to vacuum maintained in the last effect.

The *evaporative factor* is a constant quantity. The total temperature range less the excess boiling is the *effective range*. This divided by the number of effects equals the *average effect difference*. The evaporative factor is derived from experience and from operative tests on the type of apparatus best adapted and on the given class of liquor to be evaporated. Probably the same factor would hold, for instance, on all submerged tube evaporators of the general type of those under discussion and would hold for either caustic soda solutions or carbonate of soda solutions, scaling conditions, etc., being otherwise the same. In fact the same constant quantity could be used, and has been used, in designing evaporators for a large range of inorganic chemical solutions, such as sodium chloride, sodium hydrate, sodium carbonate, sodium sulphate, sodium phosphate, sodium acid phosphate, sodium thiosulphate, potassium chloride, potassium hydrate, ferrous sulphate, calcium acetate, etc. However, in cases of tannic acid, sugar, glucose, glycerine, black liquor, or resinates of soda, packing house tank water, garbage

tank water, etc., somewhat different conditions obtain and the factor varies. The factor also differs slightly for different materials for the heating surface, that for copper or aluminum being distinctly higher than that for iron.

To specify the units on which this factor is generally based we might say that it is expressed as gallons of water evaporated, per square foot of heating surface per degree difference in temperature per hour.

If C = evaporative factor

E = average effect difference

W = gallons evaporated

T = time in hours during which evaporation proceeds

S = square feet of heating surface

$$C = \frac{W}{E \times T \times S}.$$

Hence, if we find from experience or trial tests the value of C and we calculate E and W, as explained above, it is easy to obtain the required heating surface.

The successful designing of an evaporator is dependent first on the recognition of certain chemical and physical facts relating to the substance to be evaporated; second, on whether or not due regard is paid to certain thermal and thermodynamic principles involved; and third, on certain mechanical features that arise in the construction. It is not to be supposed that either an engineer, familiar with the best boiler practice, or a chemist, familiar with laboratory or open-pan evaporation in the works, could successfully design a multiple-effect evaporator. But certain facts in regard to design should certainly aid either a chemist or engineer in procuring the proper design or making a purchase.

As the principal purpose of an evaporator is to concentrate a solution of some sort, it will be readily seen that the chemical and physical laws governing concentrated solutions will be of importance. These are only known qualitatively and the quantitative laws which govern the chemistry of dilute solutions are inapplicable.

As most measurements of the concentration of solutions in the works are made with a hydrometer we generally speak of concentrating between certain limits in degrees, Baumé, Twaddell, Brix, salinometer, or specific gravity. It is, therefore, necessary to obtain or devise tables or curves showing the relation of these units of concentra-

tion with the percentage of solid matter in solution. The purpose of this is to obtain accurate information as to the actual amount of water that is going to be evaporated in a unit of time. This is especially important in cases where the vapor arising from the solution is the source of heat in the succeeding effect of the evaporator.

Of equal or greater importance, is a table or curve for a given solution which shall accurately show the relation between the boiling point of the solution and its concentration. It has been shown above, that the boiling point of a solution at any period of its progress through the evaporator has a direct bearing upon the size of the evaporator. A boiling point curve is generally obtained by taking simultaneous readings upon a hydrometer and thermometer, while boiling a solution actively under atmospheric conditions. This may best be accomplished in a laboratory where accurate means of determination are provided. After this curve is obtained a correction should be made for temperature at boiling to bring the hydrometer readings to the same temperature standard.

In cases where a substance is intended to precipitate from solution, during the process of evaporation, there should be used in conjunction with the above table also a table of solubilities of the substance at different temperatures.

The thermodynamic data necessary consist of the regular steam engineer's tables, showing the relations between temperature, pressure, heat of liquid, heat of vaporization, etc.

There are other chemical and physical data of which account must be taken in designing. The more information obtainable in regard to possible incrustation and scaling of heating surface, the clearer will be the idea as to what mechanical features to introduce for the removal of scale and as to what excess capacity to allow for this contingency. As in boiler practice, one of the greatest sources of annoyance is the deposition of gypsum on the tubes. This annoyance is encountered in the salt industry especially; on account of the peculiar solubility relation of gypsum, it is found more expedient to evaporate at low temperature with large heating surface, thus minimizing the scale. Another similar case is that of soda washings in pulp mills, where cooking liquor is evaporated for soda recovery. If the lime used in the course of the process is high in silica and alumina, these find their way to the evaporator and deposit in a dense fibrous scale. If such possibilities as



these are to arise, it is found expedient to have the heating surface in excess of the calculated area and easily removable from the evaporator for cleaning purposes. Moreover, it should be removable where corrosion is expected. There are some chemical solutions which corrode iron at the higher temperatures but are inactive at lower temperatures. In these cases the heating surface bears the brunt of the destruction in the evaporator.

Another important question is, as to the nature of a solution's activity under boiling conditions. In other words, does the boiling solution tend towards entrainment or foaming, or spattering? These points must be known beforehand, as they decidedly influence the proportioning of the evaporator.

#### PROPERTIES OF LIQUIDS AS AFFECTING CONSTRUCTION.

In some industries the multiple-effect evaporator is among the largest and most expensive of the installations in the factory. Where a large evaporator is to be built for constant use, great attention should be paid to details of its design and construction. The liquids commonly evaporated in any quantity can be divided into two classes: those that foam on boiling and those that do not. It may be said in general that a liquor that entrains (or sprays and passes over with its vapor) does not foam, and a foaming liquor does not entrain. Also it is noticeable that solutions of alkaline reaction tend to foam while those of acid reaction tend to entrain. Most sugar juices and glucose come under the latter class. To provide against losses due to entrainment in an evaporator there are to be mentioned such methods as the use of baffle plates, catchalls, and high-vapor dome. The so-called film evaporators are subject to the difficulty in this respect that the vapor space allowed is invariably small and from the time a portion of the vapor leaves the boiling solution it carries with it a large amount of spray in suspension in its rapid passage through tortuous channels of small cross-section. The simpler types of evaporator whose construction is more like that of a tank are open to the objection often, that the vapor is drawn off from a dome directly over the boiling surface. In these simpler types of evaporators it can be arranged easily to have the sectional area large enough to make the rising of the vapor

slow and the height of the dome sufficient to cause practically all the entrainment to drop back. In order not to cause any inversion or possible discoloration in the sugar juices it has been found advisable to have as little as possible of the juice in actual transit through the apparatus. This is accomplished by two principal methods: one by having a rather shallow bank of tubes in which the tubes are packed in the tube sheets as closely together as possible; another by spraying the juice over the heating surface, collecting it underneath and pumping it back again to the spray. This latter method rather subjects the juice to loss from entrainment, unless the vapor dome is extremely high.

In dealing with soda solutions the problems arising are of a very different nature from those in sugar work. Under the head of soda solutions we may include, among other important cases, the evaporation of sodium carbonate, sodium phosphate, pure caustic soda and caustic soda containing brine (electrolytic), black liquor (pulp-mill), mercerizing soda, etc. Except in the case of the more concentrated liquor of the last effect these are all more or less foamy when boiling. The use of baffle plates alone does not accomplish the prevention of loss when foaming takes place. It has been found that the only sure and efficient way to deal with foam, that is to cause it to subside, is to break the individual bubbles by application of heat. Hence the evaporator should be built in such a way that the heating surface is in a high bank above the level of the liquor evaporating. On operating the apparatus it may easily be found by trial what is the proper level of liquid shown in the gauge glass to prevent the foam from rising much above the top of the tubes and yet keep the tubes covered. About the most difficult liquors to handle in this respect are those in pulp-mills or mercerizing plants. In these cases it is necessary to have the heating tube bank almost half the height of the evaporator.

In salt industries there are two main difficulties which have to be met by the designer of an evaporator: first, the salt has to be removed from the apparatus constantly as it precipitates from solution; second, scale that deposits upon the heating surface has to be removed periodically. In order to render the removal of precipitated salt simple and rapid it has been found best to construct the evaporator with a hopper-shaped bottom having

either one or two hoppers leading through a valve at their lowest point into a receiver where the salt is separated by draining through a false bottom. Another method consists in precipitating the salt continuously down a barometric leg under the evaporator, draining it and conveying it from the bottom by a closed elevator. This latter method is generally most efficient when working on a very large scale. In salt evaporation work, shut-downs are frequently necessary every day because of the constant deposit of gypsum upon the heating surface. This happens to such an extent that the evaporative capacity of the apparatus is reduced to a point where it no longer pays to operate. Ready means of access should be provided so that the heating surface may be thoroughly cleaned, or arrangements should be made for rapid pumping and boiling of suitable chemicals for the disintegration of scale.

There are certain acid salts which require special construction in order to line the evaporator with lead. This lead lining has never been done on a very large scale. In principle it consists in first pickling in sulphuric acid the plates of the machine, these being built with flanges that can be bolted together. The pickled surface is then given a tin coating. A sheet of lead of the proper thickness and size is coated with tin. The two tinned surfaces are laid together and the lead hammered to fit. Then the lead is "sweated" on by heating the iron from the outside to the melting point of the tin plating, which is lower than that of the lead. In this way the lead lining becomes attached to the steel by a homogeneous weld. Where the flanges are bolted together the contact of the two lead surfaces generally prevents leakage, but can be made more sure by the process of lead-burning.

It is generally most expedient to work out the size of the heating bank from the amount of heating surface determined upon before deciding upon the general dimensions of the shell of the evaporator. The first thing to consider is the bore of tubing to be used. If we are dealing with a vertical type of evaporator where the tubes are expanded into two horizontal tube sheets, the bore of the tubing is determined by the nature of the liquid which is to be evaporated in them and the magnitude of the work to be accomplished. In the case of the horizontal type of evaporator where the steam is in the inside of the tubes and the liquor

on the outside, there has been found a ratio of length to diameter for which the steam that condenses within gives a maximum evaporative capacity. If the tubes are too long and constricted, the steam will condense before it can pass to the far end of them, and a certain amount of heating surface is thereby wasted. It is usual to decide upon a certain length and diameter of tubing, however, arbitrarily from experience. It is then easy to decide, from the nature of the solution and taking into account the temperature differences and rate of evaporation, the proportioning of the heating bank. In a vertical effect when the length, diameter and centre line distances are decided it is merely a question of filling a certain number of tubes in the minimum sized circle.

Tubes may be attached to the tube heads or tube sheets by one of two methods, that of packing them in or expanding them in. To pack the tube in the tube sheet well, the hole in the sheet must be countersunk conically to admit of the forcing in of the rubber packing. This rubber ring is pressed in by a metallic plate so that it is forced against the hole in the tube sheet and against the tube. This plate is held to the sheet by a stud bolt, and is arranged to hold down four, six or eight packing rings simultaneously.

When tubes are expanded into the tube sheet, it is expected that they are to be removed at no time during their life, whereas packed tubes can be easily removed, cleaned and repacked. Tubes expanded into the tube sheets properly make a perfectly steam-tight joint for almost any pressure or vacuum. The tubes are extended through the sheets a slight distance and are beaded over and are expanded by a special tool for this purpose. The Prosser expander rolls a corrugation in the tube, just inside of the sheet and beads it outside the sheet. In this way the sheet is braced against pressure from within or without. The Dudgeon expander rolls the tube flat against the side of the hole and beads it over on the outside. This method is not as effective in results, but is less of a strain on the metal of the tube.

I hope at a later date it may be possible to go more deeply into the practical side of this subject, presenting as far as possible the best solutions to problems arising from day to day.