

SOME PROBLEMS IN PROJECTING INDUSTRIAL DISTILLATION EQUIPMENTS

PURIFICATION OF 1,1,2,2-TETRACHLOROETHANE AND 1,1,2-TRICHLOROETHYLENE

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1. Introduction

On the basis of an industrial assignment, the problem of purifying, by distillation, of 1,1, 2,2-tetrachloroethane obtained during the additional chlorination of acetylene as well as of 1,1, 2-trichloroethylene obtained from the former compound by hydrolysis performed with lime milk, was investigated. In connection with this work, the vapour—liquid equilibria of several binary and pseudo-binary systems, respectively, were determined and problems of technical or technological nature were solved. In our opinion the short recapitulation of the experimental and projecting work can provide a useful survey for the technicians engaged in this field of the industry.

2. Experimental and projecting work

2.1 Technology for the purification of 1,1,2,2-tetrachloroethane by distillation

Before reviewing the work itself, the prescriptions for the final product are briefly summarized.

Production capacity:

10 000 t/year purified tetrachloroethane. Number of working hours:
8000 hours/year.

Supplies to be taken into consideration when projecting:

Industrial water: 25° C

Steam 7 ata

Brine -10—15° C

Electrical energy 220/380 V.

Quality prescription of purified tetrachloroethane:

The product shall be apt to employment in the process of production of the perchlorovinyl resin. For this purpose the crude tetrachloroethane shall be distilled by steam. The distillate shall be colourless, shall contain at least 90—97% of the basic material, and its boiling temperature has to range from 141° C to 148° C.

2.21 Analysis

Before reviewing our analytical investigations, on the basis of recent literature, the most important physicochemical properties of the individual components [1] are summarized.

Table I

Compound	Molecular weight	Boiling point	n_D^{20}	n_D^{20}	Specific heat (20°) Ccal/kg/°C
1,1-Dichloroethane	98.97	57.3	1.174	1.4166	—
1,2-Dichloroethane	98.97	83.6	1.257	1.4443	—
1,1,1-Trichloroethane	133.42	74.1	1.325	1.4377	—
1,1,2-Trichloroethane	133.42	113.5	1.443	1.4711	0.266
1,1,1,2-Tetrachloroethane	167.86	130.5	1.588	1.4830	—
1,1,2,2-Tetrachloroethane	167.86	146.3	1.600	1.4942	0.268
Pentachloroethane	202.31	162.0	1.709	1.5040	—
Hexachloroethane	236.76	187.1	2.091	—	0.174

The analysis of the individual products was performed as follows: 100 g of the product was separated into its components with the aid of super fractionation in a column having a rotary insert and a separating capacity of 20 theoretical number of plates, using a reflux ratio of 25 : 1. Then the individual distillates were identified by refraction measurements. The function of the column is described elsewhere [2].

The analysis by fine fractionation of crude tetrachloroethane produced industrially yielded the following results:

0.35% by weight azeotropic mixture of water and tetrachloroethane

0.55% by weight asymmetric tetrachloroethane

92.39% by weight tetrachloroethane

6.21% by weight of hexachloroethane

0.50% by weight rest (black, polymerisate, etc.).

If the azeotropic composition is separated into its single components, with respect to the composition of the crude tetrachloroethane, the values of Table II are obtained.

Table II

0.11%	by weight water
0.55% 1,1,1,2-Tetrachloroethane
92.63% 1,1,2,2-Tetrachloroethane
6.21% Hexachloroethane
0.50% Rest

2.22 Reaction of the tetrachloroethane products of different purities

Before beginning the corrosion tests, investigations were made to establish a method for determining the acid content causing the corrosion of individual products. The CARLISLE—LEVINE method was found to be the most suitable [3]; it consists in titrating with 0.01 *n* NaOH, in the presence of a phenolphthalein indicator. The results of the measurements are given in per cents of free HCl. The experimental data are shown in Table III.

Table III

Product	Acidity HCl%
Crude tetrachloroethane	0.080
Steam-distilled tetrachloroethane	0.009
Super-fractionated tetrachloroethane	0.001

2.23 Corrosion tests

The corrosion tests were made with plates of 6 × 4 cm. The plates were immersed into the substance to be tested, then after removing and rinsing with methanol, dried and the weight diminution (surrosion) measured.

The experimental data are given in Tables IV and V.

Table IV

Material	Corrosion in crude tetrachloroethane mg/cm ² /24 hours			
	20° C	60° C	100° C	146° C
Iron	0.35	0.41	0.52	0.48
Aluminium	0.13	0.18	0.28	0.28
Steel	0.26	0.29	0.34	0.37
Brass	0.32	0.45	0.82	1.28
Copper	0.40	0.47	0.44	0.51
V2A	0.19	0.22	0.20	0.25
Lead	0.88	1.35	2.76	3.41

On the basis of the tables the use of pure Al as material of the different equipments seems to be the most advantageous.

Table V

Material	Corrosion in steam-distilled tetrachloroethane, mg/cm ² 24 hours			
	20° C	60° C	100° C	146° C
Iron	0.47	0.52	0.53	0.50
Aluminium	0.09	0.12	0.08	0.15
Steel	0.23	0.27	0.41	0.38
Brass	0.27	0.52	0.74	1.02
Copper	0.29	0.33	0.51	0.89
V2A	0.09	0.14	0.28	0.41
Lead	0.71	0.99	1.75	1.97

2.3 Determination of vapour—liquid equilibria

In order to determine the length of the steam distillation equipment to be employed for purifying the crude tetrachloroethane, the determination of the vapour—liquid equilibria of the systems formed by the individual components detected by analysis proved to be necessary. The measurements were carried out in an equilibrium-measuring apparatus developed in our Institute [4]. Under the given circumstances the establishment of the complex quaternary equilibrium (water—1,1,1,2-tetrachloroethane—1,1,2,2-tetrachloroethane—hexachloroethane) had not to be taken into account from point of view of dimensioning either.

Table VI

Equilibrium of the system water—1,1,2,2-tetrachloroethane

Mole % of water		Equilibrium temperature °C
liquid phase	vapour phase	
0.99	22.91	131.5
3.10	62.22	116.0
3.15	80.41	95.3
8.20	80.20	94.0
14.13	79.95	94.1
46.90	80.20	94.1
63.00	80.20	93.9
82.21	80.20	94.0
94.90	80.31	94.5
99.00	93.12	97.9

To solve the projecting problem, the vapour—liquid equilibria of the binary systems water—1,1,2,2-tetrachloroethane, 1,1,1,2-tetrachloroethane—1,1,2,2-tetrachloroethane were measured. The equilibria of the individual systems are shown in Tables VI and VII.

Table VII

Equilibrium of the system 1,1,1,2-tetrachloroethane—1,1,2,2-tetrachloroethane

Mole % of 1,1,1,2-tetrachloroethane		Equilibrium temperature °C
liquid phase	vapour phase	
8.0	12.1	144.9
26.1	35.0	141.3
36.6	46.9	139.6
61.6	71.2	135.8
83.0	87.9	132.6

2.4 Projecting of the steam-distillation column for purifying tetrachloroethane

2.41 Determination of the column to be employed

Knowing the equilibrium data, the following conclusions can be drawn:

On the basis of Table VI it can be seen that for removing the azeotropic distillate, the height corresponding to one theoretical plate is completely sufficient in any concentration range, *e. g.* also in case of a water—tetrachloroethane molar ratio (87.3 mole% water, 12.7 mole% tetrachloroethane) to be employed while functioning of the column and determined below.

2.42 Determination of the diameter of the column to be employed

With a view to dimensioning the column, the most important task was to determine the capacity data of the column. Considering that a packed column seemed to be the most suitable for a steam-distillation equipment and that these columns are generally dimensioned on the basis of the SHERWOOD relation [5], this solution was chosen by the authors for the projection. The stages of the calculations are detailed as follows.

2.42.1 *Quantity of the water necessary for steam-distillation.* The given capacity amounts to 1000 t distilled tetrachloroethane per annum. In case of 8000 working hours per annum this means the production of 1.25 t/hour distilled tetrachloroethane. Considering the composition of the crude product, the feeding of 1.35 t/hour crude tetrachloroethane can be taken into account. The composition of the azeotrope is as follows: 30.3% by weight

water and 69.7% by weight tetrachloroethane; therefore the quantity of water necessary per hour for the formation of the azeotrope is:

$$1.35 \frac{3.03}{6.97} = 0.589 \text{ t.}$$

The impurities of crude tetrachloroethane also take up water and their water requirement is slightly different from that of the tetrachloroethane, but on calculating the necessary quantity of water these facts were neglected.

2.42.2 Quantity of steam for thermal purposes. In order to establish a favourable distillation efficiency, the heat quantity necessary for distillation is ensured also by directly blowing in steam.

The evaporation heat of the tetrachloroethane amounts to 55.07 Ccal/kg [1]. According to the given data steam of 7 ata pressure is available. The heat content of the 164° C steam of 7 ata pressure amounts to 662 Ccal/kg and the heat content of the 94° C steam withdrawn together with the hetero-azeotropic mixture amounts to 637 Ccal/kg.

The heat quantity necessary to warm 1350 t tetrachloroethane from 20° up to 94° and to evaporate the 94° tetrachloroethane amounts to $1350 \cdot 0.27(94-20) + 1350 \cdot 55.07 = 101\,400$ Ccal. The heat quantity to be dissipated from the apparent heat of the steam fed to form the azeotropic mixture is as follows: $589(662-637) = 14\,700$ Ccal. The heat quantity of $101\,400 - 14\,700 = 86\,700$ Ccal/hour necessary for evaporation is transferred to the system by the latent heat of the steam injected as an excess.

The heat quantity released during condensations of the saturated steam of 7 ata pressure amounts to $662-94 = 568$ Ccal/kg.

Consequently, in order to condensate $\frac{86\,700}{568} = 153$ kg steam of 7 ata pressure shall be blown in per hour.

Accordingly, the total steam requirement amounts to $589 + 153 = 742$ kg/hour.

In consequence of the non-fully equilibrium contact of the vapour and the liquid and the heat transfer different from 100%, the theoretical steam requirement has to be multiplied with a safety factor. On the basis of literature data the gross steam utilization is about 75%; therefore later on the injection of $\frac{742}{0.75} \cong 1000$ kg steam per hour is projected.

2.42.3 Determination of vapour velocity in the column. At first the flooding vapour velocity associated with the system was determined with the above-mentioned SHERWOOD relation:

$$\log \frac{u^2 a d_g \mu^{0.16}}{g f^3 d_f} = -0.073 - 1.75 \left[\left(\frac{F}{G} \right)^{1/4} \left(\frac{d_g}{d_f} \right)^{1/8} \right]$$

where u = flooding vapour velocity, m/sec
 a = specific surface of the packing used, m^2/m^3
 g = gravitational acceleration, m/sec^2
 f = empty proportion of the packing, m^3/m^3
 d_g = specific gravity of the vapour, kg/m^3
 d_l = specific gravity of the liquid, kg/m^3
 F = mass velocity of the liquid, kg/m^2 hour
 G = mass velocity of the vapour, kg/m^2 hour
 μ = viscosity of the liquid, cpoise

Considering that the distillation is carried out without a reflux, the quotient F/G is determined in a manner different from the usual one. Thus, it is not possible to determine the absolute values of the numerator and denominator; the value of the quotient, however, can be calculated as follows.

The quantity of the liquid flowing down the tower is composed of the contamination considered, for the sake of simplicity, as pure hexachloroethane, as well as of the condensate of the steam in excess.

The quantity of the hexachloroethane discharged as a bottom product amounts (together with the contamination) to $1.350 \cdot 0.0671 = 0.091$ t/hour.

The quantity of the fed steam is 1.000 t/hour.

The quantity of the steam withdrawn, together with the azeotropic mixture, amounts to

$$1.250 \frac{30.3}{69.7} = 0.543 \text{ t/hour.}$$

Thus, in the liquid phase $1.000 - 0.543 = 0.457$ t/hour water is left over; as a matter of course, this excess of water is drained off, intermittently or continuously.

Accordingly, the total liquid flow is as follows:

$$F' = 0.091 + 0.457 = 0.548 \text{ t/hour.}$$

The quantity of the streaming vapour is given by the hetero-azeotropic distillate formed from the fed crude tetrachloroethane and water:

$$G' = \frac{1.250}{0.697} = 1.793 \text{ t/hour}$$

The quotient of the two values is identical with the quotient of the mass velocities; consequently:

$$\frac{F'}{G'} = \frac{F}{G} = 0.306$$

$$\left(\frac{F}{G}\right)^{1/4} = 0.744.$$

The apparent molecular weight of the azeotrope was necessary for the calculation of vapour density. The calculation is the following:

$$0.802 \cdot 18.02 = 14.4$$

$$0.198 \cdot 167.86 = 33.2$$

Mean molecular weight = 47.6

$$d_g = \frac{47.6 \cdot 273}{22.4 \cdot (273 + 94)} = 1.58 \text{ kg/m}^3.$$

When determining the specific weight of the heterogeneous liquid phase, the specific weight of the aqueous phase amounting to about 1000 kg/m³, that is a specific weight less favourable from the point of view of charging the column, was used for the calculations.

$$\frac{d_g}{d_f} = 0.00158$$

$$\left(\frac{d_g}{d_f}\right)^{1.8} = 0.446.$$

As regards the viscosity of the liquid phase, the viscosity determined experimentally by the authors of the 94° water saturated with hexachloroethane was taken into consideration, the value of which was:

$$\mu = 0.380 \text{ cp}$$

$$\mu^{0.16} = 0.857$$

For packing the column the use of 25 × 25 × 3 mm ceramic Raschig rings is proposed. According to literature data [7], in case of this sort of packing the values a , f , and f^3 are as follows:

$$a = 200 \text{ m}^2/\text{m}^3$$

$$f = 0.74 \text{ m}^3/\text{m}^3$$

$$f^3 = 0.405$$

When substituting these values, the following equations are obtained:

$$\log \frac{u^2 \cdot 200 \cdot 1.58 \cdot 0.857}{9.81 \cdot 0.405 \cdot 1000} = -0.073 - (1.75 \cdot 0.744 \cdot 0.446)$$

and from this

$$\log 0.0738 u^2 = -0.654$$

$$u = 1.74 \text{ m/sec}$$

The column can be charged with 55–60% of the flooding vapour velocity.

Accordingly, the allowable vapour velocity amounts to 1.0 m/sec.

The quantity of the vapour streaming up in the column amounts to 1793 kg/hour = v .

On the basis of the afore-said, the mass velocity of the vapour is:

$$V = 1.0 \cdot 3600 \cdot 1.58 = 5700 \text{ kg/hour m}^2$$

The cross section of the column is as follows:

$$K = \frac{v}{V} = 0.315 \text{ m}^2$$

Consequently, the diameter of the column amounts to

$$A = 2 \sqrt{\frac{0.315}{3.14}} = 0.633 \text{ m}$$

For the sake of safe operation the diameter of the column is fixed to 0.700 m.

3. Technology for the purification of 1,1,2-trichloroethylene by distillation

The aim of this work was to project an apparatus suitable for separating and purifying, respectively, the 1,1,2-trichloroethylene obtained during the lime-milk hydrolysis of tetrachloroethane and the 1,1,2,2-tetrachloroethylene (perchloroethylene) obtained as a by-product.

The demands against the individual products are as follows:

Prescribed quality of the purified trichloroethylene:

“Trichloroethylene content of the product: at least 99%.

Appearance: colourless, transparent liquid.

Specific gravity at 20° C: 1.460–1.465 g/ml.

Boiling range: 84–88° C.

Stability: for 48 hours the product must not corrode the polished surface of steel.”

Prescribed quality of the perchloroethylene (1,1,2,2-tetrachloroethylene) obtained as by-product:

- a) Perchloroethylene content of the product: at least 99%.
- b) Specific gravity at 20° C: 1.619—1.624 g/ml.
- c) Boiling range: 117—121° C.
- d) Stability: for 48 hours the product must not corrode the surface of a polished steel plate.

3.1 Test of crude dichloroethylene

The composition of the raw products of hydrolysis of an industrial sample was tested by superfractionating and refraction measurements. The results of the tests are shown in Table VIII.

Table VIII

0.01% by weight water (according to <i>K. Fischer</i> 0.013% by weight)
0.73% by weight trans-dichloroethylene (from this 0.43% by weight in the azeotropic mixture)
97.03% by weight trichloroethylene
1,58% by weight tetrachloroethylene
0.65% by weight symmetrical tetrachloroethane

3.2 Corrosion tests

The corrosion tests were carried out with 6 × 4 cm plates. The test method was described in the documentation relating to the distillation of tetrachloroethane. The experimental data are shown in Table IX. The given values are averages of two measurements over 72 hours.

Table IX

Material	Corrosion in crude trichloroethylene	
	20° C	87° C
	mg/cm ² /24 hours	mg/cm ² /24 hours
Iron	± 0.00	0.01
Aluminium	± 0.00	± 0.00
Steel	± 0.00	0.02
Brass	0.01	0.04
Copper	± 0.00	0.02
V2A	0.01	0.01
Lead	0.18	0.29

On the basis of the tables it can be seen that the rate of corrosion is slight and that common steel can be used for the individual equipments.

3.3 Determination of vapour—liquid equilibria

The technology for the purification of trichloroethylene and perchloroethylene was projected to determine the vapour—liquid equilibria. The equilibrium measurements were made with materials either isolated, by the authors, in purest quality or of BDH c. p. quality.

For dimensioning the columns, the equilibrium data of the systems trans-1,2-dichloroethylene—trichloroethylene, trichloroethylene—perchloroethylene, and perchloroethylene—1,1,2,2-tetrachloroethane had to be determined. The measurements were carried out with the aid of the above-mentioned equipments.

3.31 Equilibrium of the system trans-1,2-dichloroethylene—trichloroethylene

When measuring the equilibria the analyses of the vapour and liquid samples were made by using the diagram refractive index against composition previously determined. The experimental data are shown in Table X.

Table X

Equilibrium of the system trans-1,2-dichloroethylene—trichloroethylene

Mole% dichloroethylene		Equilibrium temperature, °C
liquid phase	vapour phase	
3.1	13.1	84.9
8.0	24.2	82.0
17.5	41.6	76.1
25.0	53.1	73.1
31.8	61.7	69.3
49.9	78.1	62.9
61.5	85.6	59.0
70.0	90.0	56.2
77.9	93.2	53.2
91.5	97.9	50.5

3.32 Equilibrium of the system trichloroethylene—perchloroethylene

A paper recently relating to this system appeared yielding reliable data [8]. Therefore, the authors carried out only a few control measurements, the results of which are shown in Table XI.

Table XI

Equilibrium of the system trichloroethylene—perchloroethylene

Mole% trichloroethylene		Equilibrium temperature, °C
liquid phase	vapour phase	
2.8	7.1	119.2
25.2	49.6	107.6
41.6	68.1	101.7
69.9	87.0	93.2
86.1	94.9	89.7
96.5	98.8	87.6
98.7	99.6	87.1

The values experimentally determined were in good agreement with the literature data.

3.33 Equilibrium of the system tetrachloroethylene—1,1,2,2-tetrachloroethane

The experimental measuring data are shown in Table XII.

Table XII

Equilibrium of the system perchloroethylene—1,1,2,2-tetrachloroethane

Mole% perchloroethylene		Equilibrium temperature, °C
liquid phase	vapour phase	
6.0	11.3	144.3
18.4	31.9	140.2
30.5	48.5	136.6
52.0	70.6	130.7
57.8	75.0	129.1
66.6	81.8	127.0
81.2	91.0	124.0
90.0	95.7	122.5
96.0	98.4	121.5
98.2	99.3	121.3

3.4 Dimensioning of the principle distillation equipment

For lack of space, the projecting work performed on the basis of equilibrium measurements cannot be described in details. By way of illustration only the calculations relating to the column serving the purification of trichloroethylene are published.

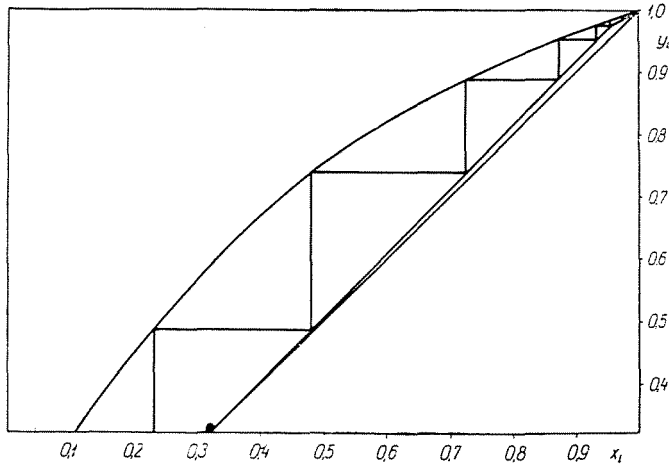


Fig. 1. Dimensioning of the column for separating the mixture trichloroethylene-tetrachloroethylene (stripping section)

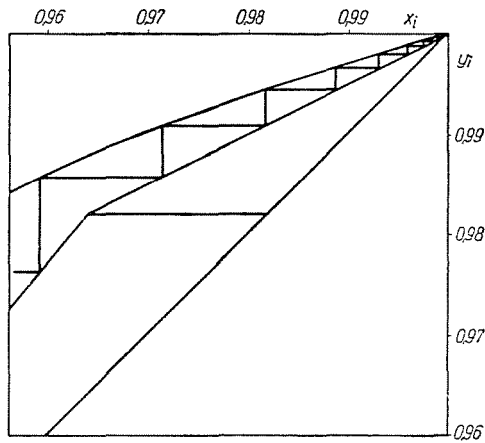


Fig. 2. Dimensioning of the column for separating the mixture trichloroethylene-tetrachloroethylene (rectifying section)

3.41 Determination of the length of column

As residue product of the dichloroethylene-stripping column 1558 kg mixture of the following composition is obtained:

- 98.20 mole% trichloroethylene,
- 1.28 mole% tetrachloroethylene,
- 0.52 mole% tetrachloroethane.

This mixture is fed into the column for the distillation of trichloroethylene.

Consequently, the starting data to be used, while projecting the trichloroethylene column are as follows:

Feeding: $B = 1558$ kg/hour $= 11.84$ kg mole/hour. The concentration of trichloroethylene in the fed substance:

$$x_B = 0.982$$

According to the prescribed quality relating to the boiling point, the distillate may contain only 0.01% tetrachloroethylene, thus

$$x_D = 0.9999$$

For the sake of the least possible material-loss it is prescribed that 99% of the trichloroethylene comes to the top. Accordingly,

$$D = 11.83 \cdot 0.982 \cdot 0.99 = 11.50 \text{ kg mole/hour.}$$

The composition of the residue can be calculated on the basis of material balance:

$$M = B - D = 11.83 - 11.50 = 0.33 \text{ kg mole/hour.}$$

According to the specific material balance valid for the column:

$$B \cdot x_B = D \cdot x_D + M \cdot x_M$$

Substituting the values determined above the concentration of trichloroethylene in the residue is obtained:

$$x_M = 0.3582.$$

On the basis of theoretical consideration the reflux ratio shall be 1 : 1.

From these data the mole number of the liquid passing through the rectifying section per unit of time is as follows:

$$F = R \cdot D = 11.50 \text{ kg mole/hour.}$$

The quantity of vapour:

$$G = F + D = 23.00 \text{ kg mole/hour.}$$

From these data the equation of the operating line can be determined. According to the known relation

$$x_n = F/G \cdot x_{n+1} + D/G \cdot x_D$$

After substitution

$$y = 0.5 x_{n+1} + 0.50$$

For the sake of diminishing the length of the column, the fed raw material be saturated vapour. In this case the value of q determining the position of the lower operating line is zero because no heat quantity has to be transferred to the fed material. In accordance with the afore-said the line q is horizontal

and it crosses the higher operating line in the point $x = 0.964$, $y = 0.982$. On connecting this point of intersection with the point $x_M = y_M = 0.3582$ the operating line of the stripping section is obtained. These stages are shown in *Figs. 1* and *2*. To increase the reliability, one section of the equilibrium curve to be seen in *Fig. 2* is shown enlarged in *Fig. 1*; thus the stages of plotting can easily be followed.

Starting from the point $x_D = 0.9999$ and taking the stages, it turns out that about 15 theoretical plates are needed altogether and the feeding must take place on the tenth plate from the top.

To determine the plate efficiency the value of molar average viscosity must be known; according to the authors' measuring data, this value amounts to 0.35 poise. On the basis of equilibrium data the mean value of relative volatility is 2.9.

From these data, the plate efficiency turns out to be 45% on the basis of both DRICKAMER's [9] and O'CONNEL's [10] nomograms.

Consequently, in the practice round $\frac{15}{0.45} = 33$ plates were needed, and the feeding should take place on the 22nd plate from the top.

3.42 Determination of the diameter of column

The diameter of the column is calculated on the basis of determining the permissible maximum vapour velocity (mass velocity). The calculations were carried out with the BROWN-SOUDERS relation [11] according to which

$$G' = 0.305 \cdot C \sqrt{d_g(d_f - d_g)}$$

According to COULTER's nomogram [12], in case of a plate spacing of 280 mm the value of C in the formula amounts to 260.

The specific gravity of the vapour is calculated in the usual manner:

$$d_g = \frac{131.4}{22.41} \cdot \frac{273}{(273 + 87)} = 4.46 \text{ kg/m}^3.$$

The specific gravity of the liquid is:

$$d_f = 1350 \text{ kg/m}^3$$

Accordingly, the mass velocity of the vapour is as follows:

$$G' = 0.305 \cdot 260 \sqrt{4.46 \cdot 1345.54}$$

$$G' = 6190 \text{ kg/m}^2 \text{ hour}$$

The quantity of vapour ascending in the rectifying section has already been calculated above:

$$G = 23.00 \text{ kg mole/hour} = 3014 \text{ kg/hour.}$$

On the basis of the two data, the cross section of the column is:

$$K = \frac{3014}{6190} = 0.49 \text{ m}^2.$$

From this the diameter of the column is:

$$A = 2 \sqrt{\frac{0.49}{3.14}} = 0.79 \text{ m.}$$

The column was dimensioned for the rectifying section; therefore a safety allowance of 10% could be considered as satisfactory [13]. Consequently, the actual diameter of the column is 870 mm.

4. Summary

Some problems on the dimensioning of an equipment necessary by distillation and purification to separate solvent mixtures produced on commercial scale, were discussed. By summarizing the methods of experimental work and calculations a review has been given on the stages of the work of this type.

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