# CHAPTER 9

# DISTILLATION
# IN
# PACKED COLUMNS

# CHAPTER - 9

# DISTILLATION IN PACKED COLUMNS

Information available about the applicability of the generalised correlations developed for gas absorption in packed columns to other operations like distillation is very limited. Hence it was thought desirable to make a systematic analysis of the "HETP" data on distillation in packed columns and propose a reliable design correlation for predicting the values of the height equivalent to a theoretical plate (HETP) based on the generalised correlations developed for $k_La$, $k_L$, $k_G$ and a for gas absorption in packed columns.

## 9.1.0 MODEL DEVELOPMENT FOR HETP :

Using the two film mass transfer model as well as the concept of the transfer unit and allowing for significant resistance to mass transfer in both phases, the overall transfer unit height ($H_{OV}$) during distillation results from individual phase transfer unit heights ($H_V$ and $H_L$) by the following interrelationship :-

$$H_{OV} = H_V + \lambda \quad H_L \tag{9.1}$$

where $\lambda$ = ratio of slopes of the equilibrium and operating lines. The integration of the general flux equation, coupled with the definition of the number of transfer units, leads to defining expressions for the heights of individial transfer units as follows:-

$$H_V = [G/(k_V\ a_d\ P\ M_{avg})] \qquad (9.2)$$

Where G is the gas flow rate (kg/$m^2$-s), $k_V$ is the true vapour side mass transfer coefficients (k mol/$m^2$s atm), $a_d$ is the effective interfacial area during distillation ($m^2/m^3$) and $M_{avg}$ is the average molecular weignt of the vapour phase (kg/k mol).

$$H_L = [L/(k_L\ a_d\ \rho_L)] \qquad (9.3)$$

Where L is the liquid flow rate (kg/$m^2$-s), $k_L$ is the true liquid side mass transfer coefficients (m/s) and $\rho_L$ is the liquid density.

The interrelationship between tne height equivalent to a theoretical plate (HETP) and the height of overall transfer unit in terms of vapour composition ($H_{OV}$) is expressed as under :

$$\mathrm{HETP} = \frac{\ln \lambda}{(\lambda - 1)} [H_{OV}] \qquad (9.4)$$

A combination of equations (9.1), (9.2), (9.3) and (9.4) gives the following relationship - model correlation - for predicting the values of HETP :-

$$\mathrm{HETP} = [\ \ln\lambda /(\lambda - 1)]\ [H_V + \lambda\ H_L] \qquad (9.5)$$

$$\mathrm{HETP} = \frac{\ln \lambda}{\lambda - 1} [(G)/(k_V.a_d.P.\ M_{avg}) + (\ \lambda\ )\ (L/(k_L a)_d.\ \rho_L)] \qquad (9.6)$$

Distillation involves vapour - liquid contact while gas absorption involves gas - liquid contact. Therefore hydrodynamically these two operations appear to be similar in nature. However the distillation operation is equimolar counter diffusion while the gas absorption is unidirectional. However this difference is expected to have little effect on the values of individual mass transfer coefficients. Therefore under identical/similar conditions, $k_G$ during gas absorption and $k_V$ during distillation are expected to be equal. Further under identical conditions, $k_L$ during gas absorption and $k_L$ during distillation are also expected to be the same. Therefore one can write the following relationships :-

$$k_G \text{ for gas absorption} = k_V \text{ for distillation} \tag{9.7}$$

$$k_L \text{ for gas absorption} = k_L \text{ for distillation} \tag{9.8}$$

Hence, the generalised correlations developed for predicting the values of $k_G$ and $k_L$ during gas absorption can be utilised for predicting the values of $k_V$ and $k_L$ during distillation under otherwise identical conditions.

The hydrodynamics of a packed column during gas absorption and distillation is expected to be similar in nature. Hence "the static area model" developed for the case of gas absorption in packed columns can be extended to the case of distillation in packed columns.

Consider a region in the rectifying section of a packed distillation column. The liquid reflux which trickles down over the packed bed acts as a working liquid to remove the less volatile component from the rising vapours. Thus the liquid trapped in the semistagnant/stagnant pockets in this section would get very quickly saturated and could come in thermodynamic equilibrium with the rising vapours. Since the semistagnant pockets are likely to lose their effectiveness very rapidly, the static area ($a_{st}$) is likely to be non-contributory during distillation. Thus in this region the effective interfacial area available for mass transfer during distillation is thus expected to be equal to $a_{dy}$ i.e. $a_d = a_{dy}$.

In the stripping section also, the semistagnant liquid pockets are stripped of the volatile component by the rising vapours very quickly and come into equilibrium with the vapours thus losing their effectiveness in contributing to the effective interfacial area for mass transfer during distillation. Thus in this region also the effective interfacial area available for mass transfer during distillation ($a_d$) is equal to $a_{dy}$ only i.e. $a_d = a_{dy}$.

It has been already discussed in detail that effective interfacial area during physical gas absorption is also equal to $a_{dy}$ only. Hence one can write different interrelations as under :-

$a_d$ = effective interfacial area during distillation = $a_{dy}$

$a_p$ = effective interfacial area during physical absorption = $a_{dy}$.

Therefore, $$a_d = a_{dy} = a_p \tag{9.9}$$

and also $$[k_L a]_{phy.} = k_L.a_{dy} = k_L.a_d = [k_L a]_{dist.} \tag{9.10}$$

Therefore, if the above analysis happens to be appropriate and sound then the generalised correlations developed for predicting the values of $a_p$ and $k_La$ during physical gas absorption can be utilised for predicting the values of $a_d$ and $[k_La]_{dist.}$ under otherwise identical conditions.

## 9.2.0 DATA BANK FOR THE "HETP" VALUES :

Although packed columns are extensively used for gas absorption operations, their applications in distillation operation has been rather restricted. That is why the experimental HETP data for distillation in packed columns avaliable in the literature is perhaps limited. The literature survey with respect to HETP data presented in Chapter - (2) : Literature Survey can be utilised conveniently to prepare a "Data bank" for HETP values. Tables (9.1) and (9.2) summarizes the literature information (116 - 121) on the HETP values in packed columns inclusive of other relevant information about physical properties of the distillation systems. This data bank primarily incorporates the effect of variables such as liquid and gas flow rates (L and G) on the values of HETP and also includes packing characteristics ($d_p$ and $a_t$) as well as the relevant physical properties of the system like surface tension ($\sigma$), slope of the equilibrium line to the operating line ($\lambda$), the average molecular weight of the vapour phase ($M_{avg.}$), liquid density ($\rho_L$), liquid viscosity ($\mu_L$), liquid diffusivity ($D_L$), vapour density ($\rho_V$), vapour viscosity ($\mu_V$) and vapour diffusivity ($D_V$).

This data bank reported in Table (9.1) consists of 110 data points with 17 different variations inclusive of system variations like ethyl benzene - styrene, n-heptane-toulene, ethanol-methanol etnanol - water, and n-heptane - cyclohexane. This data bank provided all of the model validation material for the present work.

## 9.3.0 RESULTS FOR THE PREDICTED VALUES OF HETP :-

The generalised correlation [Equation (9.6)] to be utilised for predicting the values of HETP during distillation requires the knowledge of tne following model parameters :-

(i) The value of volumetric liquid side mass transfer coefficient during distillation - $(k_L a)_{dist}$.

(ii) The values of liquid side and vapour side mass transfer coefficients during distillation ($k_L$ and $k_V$).

(iii) The value of effective interfacial area avaliable for mass transfer during distillation ($a_d$).

(iv) The values of height of liquid phase transfer unit ($H_L$) and height of vapour phase transfer unit ($H_V$) based on relevant values of physical properties of the system like $\rho_L$, $M_{avg}$, P, and tne superficial flow rates of vapour and liquid (G and L).

### Estimation of different model parameters :-

### (i) Estimation of $(k_L a)_{dist}$ :-

The generalised correlation developed in this investigation for predicting the values of $(k_L a)_{phy.}$ during physical absorption

## Table - ( 9.1 )

**Data bank for HETP : Distillation in packed columns.**

| No. | T<br>$^{o}C$ | P<br>atm a | $a_t$<br>$m^2/m^3$ | $\sigma$<br>mN/m | $M_{avg}$ | $\lambda$ | L<br>---kg/$m^2$s--- | G | HETP<br>m |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 73.3 | 0.131 | 330 | 25.9 | 105.42 | 0.933 | 0.938 | 0.932 | 0.271 |
| 2 | 73.3 | 0.131 | 330 | 25.9 | 105.46 | 0.912 | 1.042 | 1.025 | 0.213 |
| 3 | 73.9 | 0.131 | 330 | 25.9 | 105.37 | 0.949 | 1.130 | 1.121 | 0.277 |
| 4 | 73.9 | 0.131 | 185 | 25.9 | 105.37 | 0.965 | 0.733 | 0.740 | 0.405 |
| 5 | 73.3 | 0.131 | 185 | 25.9 | 105.42 | 0.958 | 0.948 | 0.967 | 0.302 |
| 6 | 72.8 | 0.131 | 185 | 25.9 | 105.44 | 0.928 | 1.146 | 1.140 | 0.262 |
| 7 | 73.3 | 0.131 | 185 | 25.9 | 105.42 | 0.939 | 1.178 | 1.178 | 0.262 |
| 8 | 72.8 | 0.131 | 142 | 25.9 | 105.48 | 0.918 | 0.368 | 0.367 | 0.561 |
| 9 | 73.3 | 0.131 | 142 | 25.9 | 105.48 | 0.922 | 0.621 | 0.621 | 0.512 |
| 10 | 72.8 | 0.131 | 142 | 25.9 | 105.50 | 0.913 | 0.919 | 0.916 | 0.418 |
| 11 | 72.8 | 0.131 | 142 | 25.9 | 105.46 | 0.927 | 1.076 | 1.076 | 0.357 |
| 12 | 72.8 | 0.131 | 142 | 25.9 | 105.48 | 0.927 | 1.153 | 1.159 | 0.354 |
| 13 | 73.3 | 0.131 | 142 | 25.9 | 105.44 | 0.926 | 1.265 | 1.255 | 0.393 |
| 14 | 72.8 | 0.131 | 142 | 25.9 | 105.37 | 0.952 | 1.390 | 1.383 | 0.491 |
| 15 | 73.3 | 0.131 | 95 | 25.9 | 105.46 | 0.895 | 0.365 | 0.352 | 0.706 |
| 16 | 73.9 | 0.131 | 95 | 25.9 | 105.46 | 0.941 | 0.578 | 0.586 | 0.689 |
| 17 | 73.9 | 0.131 | 95 | 25.9 | 105.48 | 0.915 | 0.897 | 0.890 | 0.594 |
| 18 | 73.3 | 0.131 | 95 | 25.9 | 105.50 | 0.921 | 1.178 | 1.185 | 0.488 |
| 19 | 73.3 | 0.131 | 95 | 25.9 | 105.50 | 0.918 | 1.332 | 1.335 | 0.424 |
| 20 | 73.9 | 0.131 | 95 | 25.9 | 105.50 | 0.916 | 1.409 | 1.409 | 0.402 |
| 21 | 72.8 | 0.131 | 95 | 25.9 | 105.48 | 0.922 | 1.508 | 1.508 | 0.424 |
| 22 | 58.9 | 0.066 | 95 | 27.3 | 105.45 | 0.927 | 0.192 | 0.192 | 1.143 |
| 23 | 58.9 | 0.066 | 95 | 27.3 | 105.47 | 0.916 | 0.669 | 0.666 | 0.893 |
| 24 | 57.8 | 0.066 | 95 | 27.3 | 105.49 | 0.914 | 0.890 | 0.890 | 0.716 |
| 25 | 56.1 | 0.066 | 95 | 27.3 | 105.51 | 0.916 | 1.009 | 1.018 | 0.582 |
| 26 | 57.2 | 0.066 | 95 | 27.3 | 105.51 | 0.908 | 1.102 | 1.102 | 0.530 |
| 27 | 55.6 | 0.066 | 95 | 27.3 | 105.47 | 0.919 | 1.198 | 1.198 | 0.591 |
| 28 | 54.4 | 0.066 | 95 | 27.3 | 105.40 | 0.943 | 1.230 | 1.230 | 0.866 |
| 29 | 100.0 | 1.000 | 190 | 14.9 | 98.01 | 0.834 | 0.913 | 0.947 | 0.277 |
| 30 | 100.0 | 1.000 | 190 | 14.9 | 98.01 | 0.879 | 1.235 | 1.352 | 0.235 |
| 31 | 100.0 | 1.000 | 190 | 14.9 | 97.88 | 0.872 | 1.469 | 1.595 | 0.204 |
| 32 | 78.7 | 1.000 | 190 | 22.0 | 40.46 | 0.733 | 0.392 | 0.392 | 0.213 |
| 33 | 78.7 | 1.000 | 190 | 22.0 | 40.25 | 0.725 | 0.588 | 0.588 | 0.227 |
| 34 | 78.7 | 1.000 | 190 | 22.0 | 40.18 | 0.722 | 0.783 | 0.783 | 0.232 |
| 35 | 78.7 | 1.000 | 190 | 22.0 | 40.25 | 0.725 | 0.979 | 0.979 | 0.227 |
| 36 | 78.6 | 1.000 | 190 | 22.0 | 40.67 | 0.732 | 1.175 | 1.175 | 0.207 |
| 37 | 78.6 | 1.000 | 190 | 22.0 | 40.72 | 0.733 | 1.371 | 1.371 | 0.201 |
| 38 | 78.6 | 1.000 | 190 | 22.0 | 40.72 | 0.733 | 1.567 | 1.567 | 0.210 |
| 39 | 78.8 | 1.000 | 190 | 22.0 | 40.00 | 0.717 | 1.763 | 1.763 | 0.244 |
| 40 | 78.9 | 1.000 | 190 | 22.0 | 39.21 | 0.694 | 1.958 | 1.958 | 0.305 |
| 41 | 78.9 | 1.000 | 142 | 22.0 | 39.41 | 0.699 | 0.392 | 0.392 | 0.287 |
| 42 | 79.0 | 1.000 | 142 | 22.0 | 39.21 | 0.694 | 0.588 | 0.588 | 0.305 |
| 43 | 79.0 | 1.000 | 142 | 22.0 | 39.17 | 0.693 | 0.783 | 0.783 | 0.335 |
| 44 | 79.1 | 1.000 | 142 | 22.0 | 38.96 | 0.690 | 1.175 | 1.175 | 0.329 |
| 45 | 79.0 | 1.000 | 142 | 22.0 | 39.21 | 0.695 | 1.371 | 1.371 | 0.299 |
| 46 | 78.9 | 1.000 | 142 | 22.0 | 39.48 | 0.702 | 1.567 | 1.567 | 0.280 |
| 47 | 78.9 | 1.000 | 142 | 22.0 | 39.63 | 0.706 | 1.763 | 1.763 | 0.268 |
| 48 | 78.8 | 1.000 | 142 | 22.0 | 39.91 | 0.714 | 1.958 | 1.958 | 0.259 |

Table - 9.1 ( contd.)

| No. | T<br>°C | P<br>atm a | $a_t$<br>$m^2/m^3$ | $\sigma$<br>mN/m | $M_{avg}$ | $\lambda$ | L<br>---kg/$m^2$s--- | G | HETP<br>m |
|---|---|---|---|---|---|---|---|---|---|
| 49 | 78.9 | 1.000 | 142 | 22.0 | 39.55 | 0.702 | 2.154 | 2.154 | 0.274 |
| 50 | 101.7 | 1.633 | 62 | 15.2 | 85.54 | 0.702 | 3.540 | 3.536 | 0.660 |
| 51 | 99.4 | 1.633 | 62 | 15.6 | 85.32 | 0.688 | 2.697 | 2.698 | 0.787 |
| 52 | 99.4 | 1.633 | 62 | 15.6 | 85.21 | 0.683 | 3.096 | 3.101 | 0.787 |
| 53 | 102.8 | 1.633 | 62 | 14.5 | 87.33 | 0.799 | 3.544 | 3.547 | 0.660 |
| 54 | 72.8 | 0.131 | 350 | 25.9 | 105.46 | 0.927 | 1.378 | 1.378 | 0.271 |
| 55 | 72.2 | 0.131 | 350 | 25.9 | 105.41 | 0.944 | 1.655 | 1.655 | 0.256 |
| 56 | 72.2 | 0.131 | 207 | 25.9 | 105.46 | 0.927 | 1.172 | 1.172 | 0.421 |
| 57 | 72.2 | 0.131 | 207 | 25.9 | 105.39 | 0.950 | 1.432 | 1.432 | 0.357 |
| 58 | 72.2 | 0.131 | 207 | 25.9 | 105.39 | 0.950 | 1.659 | 1.659 | 0.329 |
| 59 | 72.2 | 0.131 | 207 | 25.9 | 105.44 | 0.934 | 1.854 | 1.857 | 0.344 |
| 60 | 73.9 | 0.131 | 148 | 25.9 | 105.48 | 0.997 | 0.346 | 0.374 | 0.564 |
| 61 | 73.9 | 0.131 | 148 | 25.9 | 105.48 | 0.957 | 0.619 | 0.642 | 0.512 |
| 62 | 73.9 | 0.131 | 148 | 25.9 | 105.48 | 0.946 | 0.908 | 0.932 | 0.485 |
| 63 | 73.9 | 0.131 | 148 | 25.9 | 105.48 | 0.938 | 1.139 | 1.158 | 0.454 |
| 64 | 73.3 | 0.131 | 148 | 25.9 | 105.48 | 0.936 | 1.349 | 1.370 | 0.430 |
| 65 | 72.8 | 0.131 | 148 | 25.9 | 105.50 | 0.976 | 1.472 | 1.568 | 0.399 |
| 66 | 73.9 | 0.131 | 148 | 25.9 | 105.46 | 0.928 | 1.893 | 1.893 | 0.338 |
| 67 | 73.3 | 0.131 | 148 | 25.9 | 105.40 | 0.873 | 2.131 | 1.970 | 0.387 |
| 68 | 73.9 | 0.131 | 115 | 25.9 | 105.48 | 0.922 | 0.318 | 0.318 | 0.518 |
| 69 | 75.0 | 0.131 | 115 | 25.9 | 105.48 | 0.923 | 0.555 | 0.555 | 0.546 |
| 70 | 74.4 | 0.131 | 115 | 25.9 | 105.48 | 0.886 | 0.940 | 0.904 | 0.543 |
| 71 | 73.9 | 0.131 | 115 | 25.9 | 105.46 | 0.930 | 1.141 | 1.144 | 0.533 |
| 72 | 74.4 | 0.131 | 115 | 25.9 | 105.48 | 0.912 | 1.357 | 1.342 | 0.515 |
| 73 | 73.9 | 0.131 | 115 | 25.9 | 105.46 | 0.928 | 1.511 | 1.511 | 0.509 |
| 74 | 73.9 | 0.131 | 115 | 25.9 | 105.48 | 0.922 | 1.553 | 1.553 | 0.475 |
| 75 | 73.9 | 0.131 | 115 | 25.9 | 105.48 | 0.922 | 1.765 | 1.765 | 0.430 |
| 76 | 72.8 | 0.131 | 115 | 25.9 | 105.46 | 0.914 | 1.948 | 1.921 | 0.433 |
| 77 | 72.8 | 0.131 | 115 | 25.9 | 105.44 | 0.951 | 2.008 | 2.048 | 0.472 |
| 78 | 65.0 | 1.000 | 350 | 19.0 | 36.58 | 0.911 | 1.790 | 1.758 | 0.222 |
| 79 | 63.9 | 1.000 | 350 | 19.0 | 36.58 | 0.914 | 1.884 | 1.857 | 0.201 |
| 80 | 63.9 | 1.000 | 350 | 19.0 | 36.58 | 0.915 | 1.933 | 1.907 | 0.174 |
| 81 | 63.9 | 1.000 | 350 | 19.0 | 36.83 | 0.938 | 1.966 | 1.947 | 0.183 |
| 82 | 62.8 | 1.000 | 207 | 19.0 | 34.74 | 0.799 | 1.444 | 1.445 | 0.323 |
| 83 | 63.3 | 1.000 | 207 | 19.0 | 35.04 | 0.817 | 1.779 | 1.850 | 0.320 |
| 84 | 62.8 | 1.000 | 207 | 19.0 | 35.04 | 0.817 | 1.926 | 1.926 | 0.308 |
| 85 | 62.8 | 1.000 | 207 | 19.0 | 35.14 | 0.822 | 2.323 | 2.323 | 0.311 |
| 86 | 62.8 | 1.000 | 207 | 19.0 | 35.87 | 0.873 | 2.562 | 2.562 | 0.250 |
| 87 | 65.0 | 1.000 | 148 | 19.0 | 36.32 | 0.896 | 1.668 | 1.648 | 0.390 |
| 88 | 64.4 | 1.000 | 148 | 19.0 | 36.32 | 0.898 | 2.031 | 2.012 | 0.378 |
| 89 | 63.9 | 1.000 | 148 | 19.0 | 36.81 | 0.923 | 2.625 | 2.563 | 0.302 |
| 90 | 63.9 | 1.000 | 148 | 19.0 | 37.33 | 0.962 | 2.672 | 2.605 | 0.274 |
| 91 | 65.6 | 1.000 | 115 | 19.0 | 35.86 | 0.859 | 0.909 | 0.897 | 0.558 |
| 92 | 65.6 | 1.000 | 115 | 19.0 | 35.97 | 0.877 | 1.091 | 1.087 | 0.549 |
| 93 | 65.6 | 1.000 | 115 | 19.0 | 35.86 | 0.868 | 1.360 | 1.355 | 0.530 |
| 94 | 63.3 | 1.000 | 115 | 19.0 | 36.20 | 0.897 | 2.740 | 2.740 | 0.415 |
| 95 | 65.0 | 1.000 | 115 | 19.0 | 35.97 | 0.879 | 2.925 | 2.923 | 0.405 |
| 96 | 63.9 | 1.000 | 115 | 19.0 | 35.97 | 0.879 | 3.025 | 3.022 | 0.421 |
| 97 | 78.3 | 1.000 | 207 | 22.0 | 41.73 | 0.805 | 0.294 | 0.294 | 0.235 |
| 98 | 78.3 | 1.000 | 207 | 22.0 | 41.94 | 0.802 | 0.391 | 0.391 | 0.216 |
| 99 | 78.3 | 1.000 | 207 | 22.0 | 42.01 | 0.801 | 0.587 | 0.587 | 0.210 |
| 100 | 78.3 | 1.000 | 207 | 22.0 | 41.93 | 0.802 | 0.783 | 0.783 | 0.217 |

Table – 9.1 ( contd.)

| No. | T<br>°C | P<br>atm a | $a_t$<br>$m^2/m^3$ | $\sigma$<br>mN/m | $M_{avg}$ | $\lambda$ | L<br>---kg/$m^2$s--- | G | HETP<br>m |
|---|---|---|---|---|---|---|---|---|---|
| 101 | 78.3 | 1.000 | 207 | 22.0 | 41.81 | 0.804 | 0.978 | 0.978 | 0.227 |
| 102 | 78.3 | 1.000 | 207 | 22.0 | 41.72 | 0.805 | 1.174 | 1.174 | 0.237 |
| 103 | 78.3 | 1.000 | 207 | 22.0 | 41.65 | 0.806 | 1.370 | 1.370 | 0.244 |
| 104 | 78.4 | 1.000 | 207 | 22.0 | 41.52 | 0.807 | 1.566 | 1.566 | 0.258 |
| 105 | 78.4 | 1.000 | 207 | 22.0 | 41.48 | 0.807 | 1.761 | 1.761 | 0.263 |
| 106 | 78.4 | 1.000 | 207 | 22.0 | 41.52 | 0.807 | 1.957 | 1.957 | 0.258 |
| 107 | 78.3 | 1.000 | 207 | 22.0 | 41.76 | 0.804 | 2.153 | 2.153 | 0.233 |
| 108 | 78.3 | 1.000 | 207 | 22.0 | 42.18 | 0.770 | 2.348 | 2.348 | 0.210 |
| 109 | 78.3 | 1.000 | 207 | 22.0 | 41.98 | 0.802 | 2.427 | 2.427 | 0.213 |
| 110 | 78.4 | 1.000 | 207 | 22.0 | 41.59 | 0.806 | 2.505 | 2.505 | 0.250 |

Relevant details regarding Table – 9.1 :

| Data No. | System and Packing characteristics. |
|---|---|
| 1-28 | Ethylbenzene and Styrene. Steel R.R., $\sigma_c$ = 75 mN/m, No.1-3, $d_p$ = 0.015 m, No.4-7, $d_p$ = 0.025 m, No.8-14, $d_p$ = 0.035 m, No.15-28, $d_p$ = 0.05 m, Ref.(118). |
| 29-31 | n Heptane and Toluene. Ceramic R.R., $\sigma_c$ = 61 mN/m, $d_p$ = 0.025 m, Ref.(119). |
| 32-49 | Ethanol and Water. Ceramic R.R., $\sigma_c$ = 61 mN/m, No.32-40, $d_p$ = 0.025 m, No. 41-49, $d_p$ = 0.035 m, Ref.(120). |
| 50-53 | Cyclohexane and n Heptane. Ceramic R.R., $\sigma_c$ = 61 mN/m, $d_p$ = 0.075 m, Ref.(121). |
| 54-77 | Ethyl benzene and Styrene. Steel Pall Rings., $\sigma_c$ = 75 mN/m, No.54-55, $d_p$ = 0.015 m, No.56-59, $d_p$ = 0.025 m, No.60-67, $d_p$ = 0.035 m, No.68-77, $d_p$ = 0.05 m, Ref.(118). |
| 78-96 | Ethanol and Methanol. Steel Pall Rings, $\sigma_c$ = 75 mN/m, No.78-81, $d_p$ = 0.015 m, No.82-86, $d_p$ = 0.025 m, No.87-90, $d_p$ = 0.035 m, No.91-96, $d_p$ = 0.05 m, Ref.(118). |
| 97-110 | Ethanol and Water. Steel Pall Rings, $\sigma_c$ = 75 mN/m, $d_p$ = 0.025 m, Ref.(120). |

[Equation (8.6)] was utilised to estimate the values of $(k_La)_{dist.}$ Based on the values of L, $a_t$, $\rho_L$, $\mu_L$, $\sigma$ , $\sigma / \sigma_c$ and $D_L$ reported in Tables (9.1) and (9.2), the values of $(k_La)_{dist.}$ were calculated under otherwise identical conditions for all the 110 data points under consideration. These values of $(k_La)_{dist.}$ are reported in Table (9.2).

(ii) Estimation of $a_d$ :-

The generalised correlation developed in this investigations for predicting the values of $a_p$ during physical absorption [Equation (7.7)] was utilised to estimate the values of effective interfacial area during distillation ($a_d$). Based on the values of L, $a_t$, $\mu_L$ $\rho_L$, $\sigma$ and ( $\sigma / \sigma_c$) reported in Tables (9.1) and (9.2), the values of $a_d$ were calculated under otherwise identical conditions for all the 110 data points under consideration. These values of $a_d$ are reported in Table (9.2).

(iii) Estimation of $k_V$ :-

The generalised correlation developed in this investigation for predicting the value of the true gas side mass transfer coefficient during physical absorption [Equation (8.11)] was utilised to predict the values of $k_V$. Based on the values of G, $a_t$ $\mu_G$, $\rho_G$, and $D_G$ reported in Tables (9.1) and (9.2) the values of $k_V$ were calculated under otherwise identical conditions for all the 110 data points under consideration and are also reported in Table (9.2)

(iv) Estimation of $H_L$ and $H_V$ :-

Knowing the value of $(k_La)_{dist.}$ and the corresponding values of L and $\rho_L$ from Tables (9.1) and (9.2), the value of $H_L$ were

## Table -( 9.2 )

## Predicted values of mass transfer coefficients inclusive of physical properties of liquids and vapours.

| No. | $\rho_L$<br>kg/m$^3$ | $\mu_L$<br>mNs/m$^2$ | $D_L$<br>× $10^9$<br>m$^2$/s | $\rho_V$<br>kg/m$^3$ | $\mu_V$<br>× $10^3$<br>mNs/m$^2$ | $D_V$<br>× $10^6$<br>m$^2$/s | $a_d$<br>m$^2$/m$^3$ | $k_V$<br>× $10^3$<br>kmol/m$^2$sa | $k_La$<br>× $10^3$<br>s$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 822.9 | 0.390 | 3.569 | 0.480 | 7.689 | 23.400 | 94.2 | 6.023 | 15.044 |
| 2 | 822.9 | 0.390 | 3.573 | 0.480 | 7.692 | 23.400 | 99.7 | 6.436 | 16.265 |
| 3 | 824.5 | 0.390 | 3.569 | 0.480 | 7.698 | 23.470 | 104.2 | 6.852 | 17.248 |
| 4 | 822.9 | 0.390 | 3.569 | 0.480 | 7.698 | 23.470 | 55.5 | 4.513 | 9.438 |
| 5 | 822.9 | 0.390 | 3.569 | 0.480 | 7.689 | 23.400 | 63.8 | 5.445 | 11.394 |
| 6 | 822.9 | 0.390 | 3.566 | 0.480 | 7.679 | 23.330 | 70.8 | 6.111 | 13.095 |
| 7 | 822.9 | 0.390 | 3.569 | 0.480 | 7.689 | 23.400 | 71.8 | 6.253 | 13.368 |
| 8 | 829.3 | 0.390 | 3.569 | 0.480 | 7.681 | 23.330 | 31.8 | 2.427 | 4.993 |
| 9 | 829.3 | 0.390 | 3.575 | 0.480 | 7.693 | 23.400 | 42.3 | 3.508 | 7.335 |
| 10 | 829.3 | 0.390 | 3.571 | 0.480 | 7.682 | 23.330 | 52.3 | 4.604 | 9.772 |
| 11 | 829.3 | 0.390 | 3.567 | 0.480 | 7.680 | 23.330 | 57.0 | 5.154 | 10.965 |
| 12 | 827.7 | 0.390 | 3.569 | 0.480 | 7.681 | 23.330 | 59.2 | 5.430 | 11.539 |
| 13 | 829.3 | 0.390 | 3.571 | 0.480 | 7.690 | 23.400 | 62.2 | 5.740 | 12.354 |
| 14 | 830.9 | 0.390 | 3.558 | 0.480 | 7.675 | 23.330 | 65.4 | 6.146 | 13.213 |
| 15 | 826.1 | 0.390 | 3.573 | 0.480 | 7.692 | 23.400 | 24.1 | 2.146 | 4.071 |
| 16 | 826.1 | 0.390 | 3.579 | 0.480 | 7.703 | 23.470 | 30.9 | 3.064 | 5.706 |
| 17 | 824.5 | 0.390 | 3.581 | 0.480 | 7.704 | 23.470 | 39.3 | 4.106 | 7.882 |
| 18 | 824.5 | 0.390 | 3.577 | 0.480 | 7.694 | 23.400 | 45.5 | 5.017 | 9.627 |
| 19 | 822.9 | 0.390 | 3.577 | 0.480 | 7.694 | 23.400 | 48.7 | 5.455 | 10.536 |
| 20 | 822.9 | 0.390 | 3.583 | 0.480 | 7.705 | 23.470 | 50.2 | 5.662 | 10.987 |
| 21 | 824.5 | 0.390 | 3.569 | 0.480 | 7.681 | 23.330 | 52.1 | 5.942 | 11.527 |
| 22 | 840.5 | 0.470 | 2.840 | 0.256 | 7.385 | 43.000 | 16.1 | 2.747 | 2.009 |
| 23 | 842.1 | 0.470 | 2.841 | 0.256 | 7.386 | 43.000 | 31.6 | 6.558 | 5.020 |
| 24 | 842.1 | 0.470 | 2.833 | 0.256 | 7.364 | 42.820 | 36.9 | 8.049 | 6.181 |
| 25 | 842.1 | 0.470 | 2.821 | 0.256 | 7.330 | 42.430 | 39.5 | 8.851 | 6.760 |
| 26 | 838.9 | 0.470 | 2.830 | 0.256 | 7.353 | 42.690 | 41.5 | 9.346 | 7.225 |
| 27 | 842.1 | 0.470 | 2.813 | 0.256 | 7.316 | 42.290 | 43.3 | 9.919 | 7.657 |
| 28 | 848.5 | 0.470 | 2.798 | 0.256 | 7.289 | 42.000 | 43.9 | 10.108 | 7.783 |
| 29 | 656.4 | 0.230 | 5.694 | 3.202 | 8.136 | 3.933 | 92.9 | 0.774 | 24.061 |
| 30 | 656.4 | 0.230 | 5.694 | 3.202 | 8.136 | 3.933 | 109.5 | 0.993 | 30.037 |
| 31 | 656.4 | 0.230 | 5.642 | 3.202 | 8.166 | 3.933 | 120.3 | 1.113 | 33.965 |
| 32 | 771.7 | 0.500 | 5.638 | 1.399 | 9.169 | 15.280 | 40.5 | 1.334 | 6.920 |
| 33 | 771.7 | 0.500 | 5.554 | 1.392 | 9.174 | 15.270 | 50.5 | 1.775 | 9.250 |
| 34 | 771.7 | 0.500 | 5.527 | 1.390 | 9.178 | 15.280 | 59.0 | 2.173 | 11.396 |
| 35 | 771.7 | 0.500 | 5.554 | 1.392 | 9.174 | 15.270 | 66.6 | 2.539 | 13.457 |
| 36 | 770.1 | 0.500 | 5.670 | 1.405 | 9.163 | 15.270 | 73.5 | 2.875 | 15.546 |
| 37 | 769.1 | 0.500 | 5.706 | 1.410 | 9.160 | 15.270 | 80.0 | 3.198 | 17.465 |
| 38 | 769.1 | 0.500 | 5.706 | 1.410 | 9.160 | 15.270 | 86.0 | 3.512 | 19.263 |
| 39 | 774.6 | 0.500 | 5.463 | 1.383 | 9.185 | 15.290 | 91.5 | 3.842 | 20.542 |
| 40 | 779.7 | 0.500 | 5.177 | 1.355 | 9.211 | 15.300 | 96.8 | 4.167 | 21.596 |
| 41 | 778.1 | 0.500 | 5.250 | 1.362 | 9.205 | 15.300 | 33.1 | 1.203 | 5.780 |
| 42 | 779.7 | 0.500 | 5.170 | 1.354 | 9.212 | 15.310 | 41.3 | 1.602 | 7.724 |
| 43 | 779.7 | 0.500 | 5.165 | 1.353 | 9.213 | 15.310 | 48.2 | 1.960 | 9.535 |
| 44 | 782.9 | 0.500 | 5.100 | 1.345 | 9.220 | 15.320 | 60.1 | 2.609 | 12.756 |
| 45 | 779.7 | 0.500 | 5.180 | 1.354 | 9.212 | 15.310 | 65.4 | 2.898 | 14.399 |
| 46 | 778.1 | 0.500 | 5.278 | 1.365 | 9.202 | 15.300 | 70.3 | 3.172 | 16.033 |
| 47 | 776.5 | 0.500 | 5.332 | 1.370 | 9.198 | 15.300 | 75.0 | 3.441 | 17.573 |

Table 9.2 ( contd.)

| No. | $\rho_L$ kg/m$^3$ | $\mu_L$ mNs/m$^2$ | $D_L$ × $10^9$ m$^2$/s | $\rho_V$ kg/m$^3$ | $\mu_V$ × $10^3$ mNs/m$^2$ | $D_V$ × $10^6$ m$^2$/s | $a_d$ m$^2$/m$^3$ | $k_V$ × $10^3$ kmol/m$^2$sa | $k_La$ × $10^3$ s$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|
| 48 | 774.9 | 0.500 | 5.432 | 1.380 | 9.187 | 15.290 | 79.4 | 3.694 | 19.165 |
| 49 | 778.1 | 0.500 | 5.298 | 1.366 | 9.201 | 15.300 | 83.6 | 3.964 | 20.294 |
| 50 | 683.6 | 0.281 | 4.439 | 4.899 | 8.552 | 2.395 | 86.4 | 0.872 | 29.658 |
| 51 | 685.2 | 0.293 | 4.206 | 4.707 | 8.520 | 2.369 | 73.1 | 0.734 | 22.873 |
| 52 | 688.4 | 0.295 | 4.161 | 4.707 | 8.526 | 2.369 | 78.5 | 0.809 | 25.042 |
| 53 | 666.0 | 0.254 | 5.159 | 4.787 | 8.465 | 2.408 | 90.6 | 0.885 | 34.597 |
| 54 | 829.3 | 0.390 | 3.567 | 0.480 | 7.680 | 23.330 | 120.7 | 7.648 | 20.534 |
| 55 | 827.7 | 0.390 | 3.556 | 0.480 | 7.665 | 23.260 | 133.3 | 8.696 | 23.452 |
| 56 | 830.9 | 0.390 | 3.562 | 0.480 | 7.669 | 23.260 | 77.2 | 5.826 | 14.053 |
| 57 | 830.9 | 0.390 | 3.554 | 0.480 | 7.664 | 23.260 | 86.0 | 6.704 | 16.262 |
| 58 | 830.9 | 0.390 | 3.554 | 0.480 | 7.664 | 23.260 | 93.2 | 7.433 | 18.118 |
| 59 | 830.9 | 0.390 | 3.560 | 0.496 | 7.667 | 23.260 | 99.0 | 7.934 | 19.672 |
| 60 | 826.1 | 0.390 | 3.581 | 0.480 | 7.704 | 23.470 | 31.7 | 2.398 | 4.876 |
| 61 | 826.1 | 0.390 | 3.581 | 0.480 | 7.704 | 23.470 | 43.4 | 3.502 | 7.472 |
| 62 | 826.1 | 0.390 | 3.581 | 0.480 | 7.704 | 23.470 | 53.5 | 4.543 | 9.903 |
| 63 | 826.1 | 0.390 | 3.581 | 0.480 | 7.704 | 23.470 | 60.5 | 5.290 | 11.692 |
| 64 | 826.1 | 0.390 | 3.575 | 0.480 | 7.693 | 23.400 | 66.3 | 5.952 | 13.228 |
| 65 | 826.1 | 0.390 | 3.571 | 0.480 | 7.682 | 23.330 | 69.5 | 6.543 | 14.096 |
| 66 | 826.1 | 0.390 | 3.579 | 0.480 | 7.703 | 23.470 | 79.7 | 7.461 | 16.972 |
| 67 | 826.1 | 0.390 | 3.568 | 0.480 | 7.688 | 23.400 | 85.0 | 7.677 | 18.486 |
| 68 | 826.1 | 0.390 | 3.581 | 0.480 | 7.704 | 23.470 | 25.5 | 1.780 | 4.044 |
| 69 | 826.1 | 0.390 | 3.592 | 0.480 | 7.727 | 23.600 | 34.4 | 2.627 | 6.097 |
| 70 | 826.1 | 0.390 | 3.586 | 0.480 | 7.716 | 23.540 | 45.9 | 3.699 | 8.974 |
| 71 | 826.1 | 0.390 | 3.579 | 0.480 | 7.703 | 23.470 | 51.0 | 4.364 | 10.337 |
| 72 | 826.1 | 0.390 | 3.586 | 0.480 | 7.716 | 23.540 | 56.0 | 4.878 | 11.749 |
| 73 | 826.1 | 0.390 | 3.579 | 0.480 | 7.703 | 23.470 | 59.4 | 5.302 | 12.699 |
| 74 | 822.9 | 0.390 | 3.581 | 0.480 | 7.704 | 23.470 | 60.3 | 5.405 | 12.966 |
| 75 | 826.1 | 0.390 | 3.581 | 0.480 | 7.704 | 23.470 | 64.6 | 5.911 | 14.239 |
| 76 | 818.1 | 0.390 | 3.567 | 0.480 | 7.680 | 23.330 | 68.3 | 6.275 | 15.289 |
| 77 | 830.9 | 0.390 | 3.566 | 0.480 | 7.679 | 23.330 | 69.2 | 6.563 | 15.614 |
| 78 | 752.5 | 0.450 | 4.173 | 1.185 | 8.502 | 9.170 | 172.0 | 3.587 | 31.150 |
| 79 | 754.1 | 0.450 | 4.159 | 1.169 | 8.471 | 9.115 | 176.8 | 3.751 | 32.285 |
| 80 | 754.1 | 0.450 | 4.159 | 1.169 | 8.471 | 9.115 | 179.3 | 3.822 | 32.904 |
| 81 | 754.1 | 0.450 | 4.184 | 1.185 | 8.476 | 9.115 | 180.9 | 3.855 | 33.411 |
| 82 | 755.7 | 0.450 | 3.934 | 1.169 | 8.402 | 8.998 | 106.8 | 2.679 | 19.931 |
| 83 | 754.1 | 0.450 | 3.978 | 1.169 | 8.424 | 9.025 | 119.7 | 3.183 | 23.355 |
| 84 | 754.1 | 0.450 | 3.972 | 1.169 | 8.408 | 8.998 | 125.0 | 3.275 | 24.741 |
| 85 | 754.1 | 0.450 | 3.984 | 1.169 | 8.410 | 8.998 | 138.4 | 3.734 | 28.433 |
| 86 | 754.1 | 0.450 | 4.071 | 1.169 | 8.426 | 8.998 | 145.9 | 3.997 | 30.882 |
| 87 | 752.5 | 0.450 | 4.148 | 1.201 | 8.497 | 9.107 | 92.0 | 2.655 | 19.277 |
| 88 | 754.1 | 0.450 | 4.141 | 1.201 | 8.481 | 9.080 | 102.3 | 3.055 | 22.254 |
| 89 | 754.1 | 0.450 | 4.184 | 1.201 | 8.475 | 9.052 | 117.6 | 3.618 | 27.007 |
| 90 | 754.1 | 0.450 | 4.234 | 1.201 | 8.485 | 9.052 | 118.7 | 3.659 | 27.522 |
| 91 | 752.5 | 0.450 | 4.105 | 1.217 | 8.504 | 9.072 | 55.7 | 1.429 | 10.848 |
| 92 | 752.5 | 0.450 | 4.117 | 1.217 | 8.506 | 9.072 | 61.5 | 1.635 | 12.419 |
| 93 | 752.5 | 0.450 | 4.105 | 1.217 | 8.504 | 9.072 | 69.3 | 1.908 | 14.573 |
| 94 | 755.7 | 0.450 | 4.115 | 1.217 | 8.448 | 8.964 | 101.3 | 3.127 | 24.396 |
| 95 | 752.5 | 0.450 | 4.111 | 1.201 | 8.490 | 9.045 | 105.0 | 3.287 | 25.589 |
| 96 | 755.7 | 0.450 | 4.097 | 1.233 | 8.459 | 8.991 | 106.8 | 3.331 | 26.176 |
| 97 | 761.3 | 0.500 | 6.125 | 1.445 | 9.125 | 15.240 | 40.3 | 1.023 | 6.677 |
| 98 | 760.2 | 0.500 | 6.178 | 1.453 | 9.125 | 15.240 | 47.2 | 1.249 | 8.283 |

Table 9.2 ( contd.)

| No. | $\rho_L$ kg/m$^3$ | $\mu_L$ mNs/m$^2$ | $D_L$ × $10^9$ m$^2$/s | $\rho_V$ kg/m$^3$ | $\mu_V$ × $10^3$ mNs/m$^2$ | $D_V$ × $10^6$ m$^2$/s | $a_d$ m$^2$/m$^3$ | $k_V$ × $10^3$ kmol/m$^2$ sa | $k_La$ × $10^3$ s$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|
| 99 | 759.8 | 0.500 | 6.196 | 1.454 | 9.125 | 15.240 | 58.8 | 1.658 | 11.171 |
| 100 | 760.2 | 0.500 | 6.174 | 1.452 | 9.125 | 15.240 | 68.7 | 2.029 | 13.772 |
| 101 | 760.5 | 0.500 | 6.146 | 1.447 | 9.125 | 15.240 | 77.6 | 2.375 | 16.186 |
| 102 | 761.3 | 0.500 | 6.121 | 1.444 | 9.125 | 15.240 | 85.6 | 2.701 | 18.465 |
| 103 | 761.3 | 0.500 | 6.103 | 1.443 | 9.125 | 15.240 | 93.1 | 3.010 | 20.646 |
| 104 | 763.7 | 0.500 | 6.072 | 1.438 | 9.125 | 15.250 | 100.0 | 3.310 | 22.710 |
| 105 | 763.7 | 0.500 | 6.062 | 1.436 | 9.125 | 15.250 | 106.6 | 3.596 | 24.741 |
| 106 | 763.7 | 0.500 | 6.072 | 1.438 | 9.125 | 15.250 | 112.9 | 3.870 | 26.752 |
| 107 | 761.3 | 0.500 | 6.132 | 1.446 | 9.125 | 15.240 | 119.0 | 4.126 | 28.837 |
| 108 | 759.8 | 0.500 | 6.196 | 1.454 | 9.125 | 15.240 | 124.8 | 4.376 | 30.902 |
| 109 | 759.8 | 0.500 | 6.189 | 1.454 | 9.125 | 15.240 | 127.0 | 4.478 | 31.637 |
| 110 | 761.3 | 0.500 | 6.090 | 1.440 | 9.125 | 15.250 | 129.2 | 4.596 | 32.119 |

estimated and are reported in Table (9.3). Knowing the values of $k_V$, $a_d$ and also knowing the corresponding values of P, $M_{avg.}$ and G from Tables (9.1) and (9.2), the values of $H_V$ were estimated. These values of $H_V$ are also reported in Table (9.3).

Prediction of HETP by using model correlation : [Equation (9.6)] :-

Knowing the values of model parameters - $(k_L a)_{dist.}$, $k_V$, $a_d$ $H_V$ and $H_L$ and knowing the corresponding value of $\lambda$ [reported in Tables (9.1), (9.2) and (9.3)] the values of HETP during distillation were predicted using the model correlation [Equation (9.6)] and are reported in Table (9.3) along with the values of HETP during distillation obtained from HETP data bank for distillation Table (9.1). A typical sample calculation for obtaining the predicted values of HETP using a procedure consisting of eight steps is illustrated in Appendix - A.1.4.

The values of HETP during distillation were also predicted using the model correlation [Equation (9.6)], however using the other basis as $a_d = a_w$ and $(k_L a)_{dist.} = k_L . a_w$. These predicted values of HETP are reported in Table (9.4) along with the values of HETP during distillation obtained from HETP data bank for distillation.

## 9.4.0 COMPARISON BETWEEN EXPERIMENTAL VALUES BASED ON DATA BANK AND THE PREDICTED VALUES OF HETP :-

The experimental values of HETP obtained from data bank and the predicted values of HETP using the model correlation [Equation (9.6)] are reported in Table (9.4) for the following two cases :-

## Table - ( 9.3 )

## Results inclusive of processing parameters for HETP : Distillation in packed columns.

| No. | T<br>°C | L<br>-- kg/m²s -- | G | $H_L$<br>m | $H_V$<br>m | $H_{OV}$<br>m | HETP<br>m<br>exp. | HETP<br>m<br>pred. | % err<br>($a_d = a_p$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 73.3 | 0.938 | 0.932 | 0.076 | 0.119 | 0.189 | 0.271 | 0.196 | 27.8 |
| 2 | 73.3 | 1.042 | 1.025 | 0.078 | 0.115 | 0.186 | 0.213 | 0.195 | 8.6 |
| 3 | 73.9 | 1.130 | 1.121 | 0.079 | 0.113 | 0.189 | 0.277 | 0.194 | 30.1 |
| 4 | 73.9 | 0.733 | 0.740 | 0.094 | 0.213 | 0.305 | 0.405 | 0.310 | 23.5 |
| 5 | 73.3 | 0.948 | 0.967 | 0.101 | 0.201 | 0.298 | 0.302 | 0.304 | -0.9 |
| 6 | 72.8 | 1.146 | 1.140 | 0.106 | 0.190 | 0.289 | 0.262 | 0.300 | -14.5 |
| 7 | 73.3 | 1.178 | 1.178 | 0.107 | 0.190 | 0.290 | 0.262 | 0.299 | -14.2 |
| 8 | 72.8 | 0.368 | 0.367 | 0.089 | 0.343 | 0.425 | 0.561 | 0.443 | 21.0 |
| 9 | 73.3 | 0.621 | 0.621 | 0.102 | 0.303 | 0.397 | 0.512 | 0.413 | 19.3 |
| 10 | 72.8 | 0.919 | 0.916 | 0.113 | 0.275 | 0.378 | 0.418 | 0.396 | 5.2 |
| 11 | 72.8 | 1.076 | 1.076 | 0.118 | 0.265 | 0.374 | 0.357 | 0.389 | -9.0 |
| 12 | 72.8 | 1.153 | 1.159 | 0.121 | 0.261 | 0.372 | 0.354 | 0.387 | -9.4 |
| 13 | 73.3 | 1.265 | 1.255 | 0.123 | 0.254 | 0.368 | 0.393 | 0.383 | 2.7 |
| 14 | 72.8 | 1.390 | 1.383 | 0.127 | 0.249 | 0.369 | 0.491 | 0.378 | 22.9 |
| 15 | 73.3 | 0.365 | 0.352 | 0.109 | 0.492 | 0.589 | 0.706 | 0.623 | 11.8 |
| 16 | 73.9 | 0.578 | 0.586 | 0.123 | 0.447 | 0.562 | 0.689 | 0.580 | 15.9 |
| 17 | 73.9 | 0.897 | 0.890 | 0.138 | 0.399 | 0.525 | 0.594 | 0.549 | 7.7 |
| 18 | 73.3 | 1.178 | 1.185 | 0.148 | 0.374 | 0.511 | 0.488 | 0.532 | -9.2 |
| 19 | 73.3 | 1.332 | 1.335 | 0.154 | 0.363 | 0.504 | 0.424 | 0.526 | -24.1 |
| 20 | 73.9 | 1.409 | 1.409 | 0.156 | 0.358 | 0.501 | 0.402 | 0.523 | -30.0 |
| 21 | 72.8 | 1.508 | 1.508 | 0.159 | 0.352 | 0.498 | 0.424 | 0.519 | -22.5 |
| 22 | 58.9 | 0.192 | 0.192 | 0.114 | 0.626 | 0.732 | 1.143 | 0.760 | 33.5 |
| 23 | 58.9 | 0.669 | 0.666 | 0.158 | 0.462 | 0.607 | 0.893 | 0.634 | 29.0 |
| 24 | 57.8 | 0.890 | 0.890 | 0.171 | 0.431 | 0.587 | 0.716 | 0.614 | 14.3 |
| 25 | 56.1 | 1.009 | 1.018 | 0.177 | 0.418 | 0.581 | 0.582 | 0.607 | -4.2 |
| 26 | 57.2 | 1.102 | 1.102 | 0.182 | 0.408 | 0.573 | 0.530 | 0.602 | -13.4 |
| 27 | 55.6 | 1.198 | 1.198 | 0.186 | 0.400 | 0.571 | 0.591 | 0.595 | -0.7 |
| 28 | 54.4 | 1.230 | 1.230 | 0.186 | 0.398 | 0.574 | 0.866 | 0.591 | 31.7 |
| 29 | 100.0 | 0.913 | 0.947 | 0.058 | 0.134 | 0.183 | 0.277 | 0.200 | 28.0 |
| 30 | 100.0 | 1.235 | 1.352 | 0.063 | 0.127 | 0.182 | 0.235 | 0.194 | 17.3 |
| 31 | 100.0 | 1.469 | 1.595 | 0.066 | 0.122 | 0.179 | 0.204 | 0.192 | 6.1 |
| 32 | 78.7 | 0.392 | 0.392 | 0.073 | 0.179 | 0.233 | 0.213 | 0.271 | -27.0 |
| 33 | 78.7 | 0.588 | 0.588 | 0.082 | 0.163 | 0.223 | 0.227 | 0.260 | -14.7 |
| 34 | 78.7 | 0.783 | 0.783 | 0.089 | 0.152 | 0.216 | 0.232 | 0.254 | -9.5 |
| 35 | 78.7 | 0.979 | 0.979 | 0.094 | 0.144 | 0.212 | 0.227 | 0.248 | -9.3 |
| 36 | 78.6 | 1.175 | 1.175 | 0.098 | 0.137 | 0.209 | 0.207 | 0.243 | -17.1 |
| 37 | 78.6 | 1.371 | 1.371 | 0.102 | 0.132 | 0.206 | 0.201 | 0.240 | -19.4 |
| 38 | 78.6 | 1.567 | 1.567 | 0.106 | 0.127 | 0.205 | 0.210 | 0.238 | -13.4 |
| 39 | 78.8 | 1.763 | 1.763 | 0.111 | 0.125 | 0.205 | 0.244 | 0.241 | 1.3 |
| 40 | 78.9 | 1.958 | 1.958 | 0.116 | 0.124 | 0.205 | 0.305 | 0.244 | 19.9 |
| 41 | 78.9 | 0.392 | 0.392 | 0.087 | 0.249 | 0.310 | 0.287 | 0.369 | -28.9 |
| 42 | 79.0 | 0.588 | 0.588 | 0.098 | 0.227 | 0.294 | 0.305 | 0.352 | -15.4 |
| 43 | 79.0 | 0.783 | 0.783 | 0.105 | 0.212 | 0.285 | 0.335 | 0.340 | -1.4 |
| 44 | 79.1 | 1.175 | 1.175 | 0.118 | 0.193 | 0.274 | 0.329 | 0.328 | 0.5 |
| 45 | 79.0 | 1.371 | 1.371 | 0.122 | 0.185 | 0.269 | 0.299 | 0.321 | -7.6 |

Table - 9.3 ( contd.)

| No. | T<br>$^{o}C$ | L<br>-- $kg/m^2s$ -- | G | $H_L$<br>m | $H_V$<br>m | $H_{OV}$<br>m | HETP<br>m<br>exp. | HETP<br>m ($a_d = a_p$)<br>pred. | % err |
|---|---|---|---|---|---|---|---|---|---|
| 46 | 78.9 | 1.567 | 1.567 | 0.126 | 0.178 | 0.266 | 0.280 | 0.316 | -12.7 |
| 47 | 78.9 | 1.763 | 1.763 | 0.129 | 0.172 | 0.264 | 0.268 | 0.312 | -16.4 |
| 48 | 78.8 | 1.958 | 1.958 | 0.132 | 0.167 | 0.261 | 0.259 | 0.308 | -18.8 |
| 49 | 78.9 | 2.154 | 2.154 | 0.136 | 0.164 | 0.260 | 0.274 | 0.309 | -12.6 |
| 50 | 101.7 | 3.540 | 3.536 | 0.175 | 0.336 | 0.459 | 0.660 | 0.545 | 17.5 |
| 51 | 99.4 | 2.697 | 2.698 | 0.172 | 0.361 | 0.479 | 0.787 | 0.574 | 27.0 |
| 52 | 99.4 | 3.096 | 3.101 | 0.180 | 0.351 | 0.473 | 0.787 | 0.569 | 27.7 |
| 53 | 102.8 | 3.544 | 3.547 | 0.154 | 0.310 | 0.433 | 0.660 | 0.484 | 26.8 |
| 54 | 72.8 | 1.378 | 1.378 | 0.081 | 0.108 | 0.183 | 0.271 | 0.190 | 30.0 |
| 55 | 72.2 | 1.655 | 1.655 | 0.085 | 0.103 | 0.184 | 0.256 | 0.189 | 26.2 |
| 56 | 72.2 | 1.172 | 1.172 | 0.100 | 0.188 | 0.281 | 0.421 | 0.292 | 30.5 |
| 57 | 72.2 | 1.432 | 1.432 | 0.106 | 0.179 | 0.280 | 0.357 | 0.287 | 19.4 |
| 58 | 72.2 | 1.659 | 1.659 | 0.110 | 0.173 | 0.278 | 0.329 | 0.285 | 13.4 |
| 59 | 72.2 | 1.854 | 1.857 | 0.113 | 0.171 | 0.277 | 0.344 | 0.286 | 16.9 |
| 60 | 73.9 | 0.346 | 0.374 | 0.086 | 0.356 | 0.441 | 0.564 | 0.442 | 21.6 |
| 61 | 73.9 | 0.619 | 0.642 | 0.100 | 0.305 | 0.401 | 0.512 | 0.410 | 20.0 |
| 62 | 73.9 | 0.908 | 0.932 | 0.111 | 0.277 | 0.382 | 0.485 | 0.393 | 19.0 |
| 63 | 73.9 | 1.139 | 1.158 | 0.118 | 0.261 | 0.372 | 0.454 | 0.384 | 15.4 |
| 64 | 73.3 | 1.349 | 1.370 | 0.123 | 0.251 | 0.366 | 0.430 | 0.378 | 11.9 |
| 65 | 72.8 | 1.472 | 1.568 | 0.126 | 0.249 | 0.372 | 0.399 | 0.377 | 5.6 |
| 66 | 73.9 | 1.893 | 1.893 | 0.135 | 0.230 | 0.355 | 0.338 | 0.369 | -9.0 |
| 67 | 73.3 | 2.131 | 1.970 | 0.140 | 0.218 | 0.340 | 0.387 | 0.364 | 6.1 |
| 68 | 73.9 | 0.318 | 0.318 | 0.095 | 0.506 | 0.594 | 0.518 | 0.619 | -19.4 |
| 69 | 75.0 | 0.555 | 0.555 | 0.110 | 0.443 | 0.544 | 0.546 | 0.566 | -3.8 |
| 70 | 74.4 | 0.940 | 0.904 | 0.127 | 0.385 | 0.497 | 0.543 | 0.528 | 2.8 |
| 71 | 73.9 | 1.141 | 1.144 | 0.134 | 0.371 | 0.496 | 0.533 | 0.514 | 3.6 |
| 72 | 74.4 | 1.357 | 1.342 | 0.140 | 0.355 | 0.482 | 0.515 | 0.505 | 2.0 |
| 73 | 73.9 | 1.511 | 1.511 | 0.144 | 0.347 | 0.480 | 0.509 | 0.499 | 2.0 |
| 74 | 73.9 | 1.553 | 1.553 | 0.146 | 0.344 | 0.478 | 0.475 | 0.498 | -4.7 |
| 75 | 73.9 | 1.765 | 1.765 | 0.150 | 0.334 | 0.472 | 0.430 | 0.492 | -14.4 |
| 76 | 72.8 | 1.948 | 1.921 | 0.156 | 0.324 | 0.466 | 0.433 | 0.487 | -12.6 |
| 77 | 72.8 | 2.008 | 2.048 | 0.155 | 0.326 | 0.473 | 0.472 | 0.485 | -2.6 |
| 78 | 65.0 | 1.790 | 1.758 | 0.076 | 0.078 | 0.147 | 0.222 | 0.154 | 30.6 |
| 79 | 63.9 | 1.884 | 1.857 | 0.077 | 0.077 | 0.147 | 0.201 | 0.154 | 23.4 |
| 80 | 63.9 | 1.933 | 1.907 | 0.078 | 0.076 | 0.147 | 0.174 | 0.154 | 11.3 |
| 81 | 63.9 | 1.966 | 1.947 | 0.078 | 0.076 | 0.149 | 0.183 | 0.154 | 15.9 |
| 82 | 62.8 | 1.444 | 1.445 | 0.096 | 0.145 | 0.222 | 0.323 | 0.248 | 23.3 |
| 83 | 63.3 | 1.779 | 1.850 | 0.101 | 0.139 | 0.221 | 0.320 | 0.244 | 23.7 |
| 84 | 62.8 | 1.926 | 1.926 | 0.103 | 0.134 | 0.219 | 0.308 | 0.241 | 21.6 |
| 85 | 62.8 | 2.323 | 2.323 | 0.108 | 0.128 | 0.217 | 0.311 | 0.239 | 23.1 |
| 86 | 62.8 | 2.562 | 2.562 | 0.110 | 0.122 | 0.218 | 0.250 | 0.234 | 6.5 |
| 87 | 65.0 | 1.668 | 1.648 | 0.115 | 0.186 | 0.289 | 0.390 | 0.305 | 21.8 |
| 88 | 64.4 | 2.031 | 2.012 | 0.121 | 0.177 | 0.286 | 0.378 | 0.302 | 20.2 |
| 89 | 63.9 | 2.625 | 2.563 | 0.129 | 0.164 | 0.283 | 0.302 | 0.294 | 2.5 |
| 90 | 63.9 | 2.672 | 2.605 | 0.129 | 0.161 | 0.285 | 0.274 | 0.290 | -5.7 |
| 91 | 65.6 | 0.909 | 0.897 | 0.111 | 0.314 | 0.410 | 0.558 | 0.442 | 20.8 |
| 92 | 65.6 | 1.091 | 1.087 | 0.117 | 0.301 | 0.403 | 0.549 | 0.430 | 21.6 |
| 93 | 65.6 | 1.360 | 1.355 | 0.124 | 0.286 | 0.394 | 0.530 | 0.422 | 20.4 |
| 94 | 63.3 | 2.740 | 2.740 | 0.149 | 0.239 | 0.372 | 0.415 | 0.393 | 5.2 |
| 95 | 65.0 | 2.925 | 2.923 | 0.152 | 0.235 | 0.369 | 0.405 | 0.393 | 3.0 |
| 96 | 63.9 | 3.025 | 3.022 | 0.153 | 0.236 | 0.371 | 0.421 | 0.395 | 6.1 |

Table - 9.3 ( contd.)

| No. | T $^{\circ}C$ | L -- $kg/m^2s$ -- | G | $H_L$ m | $H_V$ m | $H_{OV}$ m | HETP m exp. | HETP m pred. | % err $(a_d = a_p)$ |
|---|---|---|---|---|---|---|---|---|---|
| 97 | 78.3 | 0.294 | 0.294 | 0.058 | 0.170 | 0.217 | 0.235 | 0.241 | -2.7 |
| 98 | 78.3 | 0.391 | 0.391 | 0.062 | 0.158 | 0.208 | 0.216 | 0.232 | -7.4 |
| 99 | 78.3 | 0.587 | 0.587 | 0.069 | 0.143 | 0.199 | 0.210 | 0.222 | -5.4 |
| 100 | 78.3 | 0.783 | 0.783 | 0.075 | 0.134 | 0.194 | 0.217 | 0.216 | 0.6 |
| 101 | 78.3 | 0.978 | 0.978 | 0.079 | 0.127 | 0.191 | 0.227 | 0.213 | 6.4 |
| 102 | 78.3 | 1.174 | 1.174 | 0.084 | 0.122 | 0.189 | 0.237 | 0.210 | 11.1 |
| 103 | 78.3 | 1.370 | 1.370 | 0.087 | 0.117 | 0.188 | 0.244 | 0.209 | 14.4 |
| 104 | 78.4 | 1.566 | 1.566 | 0.090 | 0.114 | 0.187 | 0.258 | 0.207 | 19.5 |
| 105 | 78.4 | 1.761 | 1.761 | 0.093 | 0.111 | 0.186 | 0.263 | 0.207 | 21.5 |
| 106 | 78.4 | 1.957 | 1.957 | 0.096 | 0.108 | 0.185 | 0.258 | 0.206 | 20.2 |
| 107 | 78.3 | 2.153 | 2.153 | 0.098 | 0.105 | 0.184 | 0.233 | 0.205 | 12.0 |
| 108 | 78.3 | 2.348 | 2.348 | 0.100 | 0.102 | 0.179 | 0.210 | 0.203 | 3.3 |
| 109 | 78.3 | 2.427 | 2.427 | 0.101 | 0.102 | 0.183 | 0.213 | 0.203 | 4.4 |
| 110 | 78.4 | 2.505 | 2.505 | 0.102 | 0.101 | 0.184 | 0.250 | 0.205 | 18.2 |

## Table - ( 9.4 )

**Comparison between experimental values based on data bank and predicted values of HETP.**

| No. | T | L | G | HETP exp. | HETP pred. ( case I ) $a_d = a_p$ | % err | HETP pred. ( case II) $a_d = a_w$ | % err |
|---|---|---|---|---|---|---|---|---|
| 1 | 73.3 | 0.938 | 0.932 | 0.271 | 0.196 | 27.75 | 0.100 | 63.28 |
| 2 | 73.3 | 1.042 | 1.025 | 0.213 | 0.195 | 8.61 | 0.101 | 52.61 |
| 3 | 73.9 | 1.130 | 1.121 | 0.277 | 0.194 | 30.10 | 0.102 | 63.32 |
| 4 | 73.9 | 0.733 | 0.740 | 0.405 | 0.310 | 23.52 | 0.167 | 58.85 |
| 5 | 73.3 | 0.948 | 0.967 | 0.302 | 0.304 | -0.88 | 0.172 | 43.13 |
| 6 | 72.8 | 1.146 | 1.140 | 0.262 | 0.300 | -14.50 | 0.175 | 33.12 |
| 7 | 73.3 | 1.178 | 1.178 | 0.262 | 0.299 | -14.22 | 0.176 | 32.99 |
| 8 | 72.8 | 0.368 | 0.367 | 0.561 | 0.443 | 20.99 | 0.221 | 60.60 |
| 9 | 73.3 | 0.621 | 0.621 | 0.512 | 0.413 | 19.33 | 0.227 | 55.66 |
| 10 | 72.8 | 0.919 | 0.916 | 0.418 | 0.396 | 5.24 | 0.234 | 44.00 |
| 11 | 72.8 | 1.076 | 1.076 | 0.357 | 0.389 | -9.01 | 0.236 | 33.76 |
| 12 | 72.8 | 1.153 | 1.159 | 0.354 | 0.387 | -9.40 | 0.238 | 32.69 |
| 13 | 73.3 | 1.265 | 1.255 | 0.393 | 0.383 | 2.67 | 0.239 | 39.11 |
| 14 | 72.8 | 1.390 | 1.383 | 0.491 | 0.378 | 22.90 | 0.240 | 51.01 |
| 15 | 73.3 | 0.365 | 0.352 | 0.706 | 0.623 | 11.77 | 0.332 | 52.95 |
| 16 | 73.9 | 0.578 | 0.586 | 0.689 | 0.580 | 15.87 | 0.337 | 51.15 |
| 17 | 73.9 | 0.897 | 0.890 | 0.594 | 0.549 | 7.69 | 0.346 | 41.77 |
| 18 | 73.3 | 1.178 | 1.185 | 0.488 | 0.532 | -9.19 | 0.353 | 27.60 |
| 19 | 73.3 | 1.332 | 1.335 | 0.424 | 0.526 | -24.12 | 0.357 | 15.82 |
| 20 | 73.9 | 1.409 | 1.409 | 0.402 | 0.523 | -29.96 | 0.358 | 10.95 |
| 21 | 72.8 | 1.508 | 1.508 | 0.424 | 0.519 | -22.48 | 0.360 | 15.06 |
| 22 | 58.9 | 0.192 | 0.192 | 1.143 | 0.760 | 33.52 | 0.349 | 69.50 |
| 23 | 58.9 | 0.669 | 0.666 | 0.893 | 0.634 | 29.03 | 0.368 | 58.80 |
| 24 | 57.8 | 0.890 | 0.890 | 0.716 | 0.614 | 14.31 | 0.376 | 47.57 |
| 25 | 56.1 | 1.009 | 1.018 | 0.582 | 0.607 | -4.20 | 0.380 | 34.78 |
| 26 | 57.2 | 1.102 | 1.102 | 0.530 | 0.602 | -13.42 | 0.383 | 27.84 |
| 27 | 55.6 | 1.198 | 1.198 | 0.591 | 0.595 | -0.70 | 0.384 | 35.01 |
| 28 | 54.4 | 1.230 | 1.230 | 0.866 | 0.591 | 31.72 | 0.383 | 55.78 |
| 29 | 100.0 | 0.913 | 0.947 | 0.277 | 0.200 | 27.97 | 0.124 | 55.18 |
| 30 | 100.0 | 1.235 | 1.352 | 0.235 | 0.194 | 17.34 | 0.127 | 45.76 |
| 31 | 100.0 | 1.469 | 1.595 | 0.204 | 0.192 | 6.12 | 0.130 | 36.42 |
| 32 | 78.7 | 0.392 | 0.392 | 0.213 | 0.271 | -27.02 | 0.128 | 39.91 |
| 33 | 78.7 | 0.588 | 0.588 | 0.227 | 0.260 | -14.66 | 0.133 | 41.54 |
| 34 | 78.7 | 0.783 | 0.783 | 0.232 | 0.254 | -9.47 | 0.136 | 41.18 |
| 35 | 78.7 | 0.979 | 0.979 | 0.227 | 0.248 | -9.33 | 0.139 | 38.86 |
| 36 | 78.6 | 1.175 | 1.175 | 0.207 | 0.243 | -17.11 | 0.140 | 32.36 |
| 37 | 78.6 | 1.371 | 1.371 | 0.201 | 0.240 | -19.37 | 0.143 | 29.13 |
| 38 | 78.6 | 1.567 | 1.567 | 0.210 | 0.238 | -13.35 | 0.145 | 31.08 |
| 39 | 78.8 | 1.763 | 1.763 | 0.244 | 0.241 | 1.28 | 0.150 | 38.67 |
| 40 | 78.9 | 1.958 | 1.958 | 0.305 | 0.244 | 19.87 | 0.155 | 49.22 |
| 41 | 78.9 | 0.392 | 0.392 | 0.287 | 0.369 | -28.87 | 0.184 | 35.72 |
| 42 | 79.0 | 0.588 | 0.588 | 0.305 | 0.352 | -15.35 | 0.189 | 37.94 |
| 43 | 79.0 | 0.783 | 0.783 | 0.335 | 0.340 | -1.41 | 0.193 | 42.46 |
| 44 | 79.1 | 1.175 | 1.175 | 0.329 | 0.328 | 0.48 | 0.200 | 39.20 |

Table - 9.4 ( contd.)

| No. | T | L | G | HETP exp. | HETP pred. $a_d = a_p$ | % err ( case I ) | HETP pred. $a_d = a_w$ | % err ( case II) |
|---|---|---|---|---|---|---|---|---|
| 45 | 79.0 | 1.371 | 1.371 | 0.299 | 0.321 | -7.62 | 0.202 | 32.41 |
| 46 | 78.9 | 1.567 | 1.567 | 0.280 | 0.316 | -12.68 | 0.203 | 27.53 |
| 47 | 78.9 | 1.763 | 1.763 | 0.268 | 0.312 | -16.38 | 0.205 | 23.57 |
| 48 | 78.8 | 1.958 | 1.958 | 0.259 | 0.308 | -18.84 | 0.206 | 20.51 |
| 49 | 78.9 | 2.154 | 2.154 | 0.274 | 0.309 | -12.62 | 0.210 | 23.33 |
| 50 | 101.7 | 3.540 | 3.536 | 0.660 | 0.545 | 17.53 | 0.521 | 21.11 |
| 51 | 99.4 | 2.697 | 2.698 | 0.787 | 0.574 | 27.03 | 0.519 | 34.06 |
| 52 | 99.4 | 3.096 | 3.101 | 0.787 | 0.569 | 27.67 | 0.527 | 33.01 |
| 53 | 102.8 | 3.544 | 3.547 | 0.660 | 0.484 | 26.77 | 0.467 | 29.25 |
| 54 | 72.8 | 1.378 | 1.378 | 0.271 | 0.190 | 29.99 | 0.103 | 62.17 |
| 55 | 72.2 | 1.655 | 1.655 | 0.256 | 0.189 | 26.19 | 0.105 | 58.87 |
| 56 | 72.2 | 1.172 | 1.172 | 0.421 | 0.292 | 30.53 | 0.169 | 59.84 |
| 57 | 72.2 | 1.432 | 1.432 | 0.357 | 0.287 | 19.41 | 0.172 | 51.78 |
| 58 | 72.2 | 1.659 | 1.659 | 0.329 | 0.285 | 13.40 | 0.175 | 46.82 |
| 59 | 72.2 | 1.854 | 1.857 | 0.344 | 0.286 | 16.86 | 0.180 | 47.82 |
| 60 | 73.9 | 0.346 | 0.374 | 0.564 | 0.442 | 21.63 | 0.216 | 61.67 |
| 61 | 73.9 | 0.619 | 0.642 | 0.512 | 0.410 | 19.97 | 0.224 | 56.33 |
| 62 | 73.9 | 0.908 | 0.932 | 0.485 | 0.393 | 18.99 | 0.230 | 52.56 |
| 63 | 73.9 | 1.139 | 1.158 | 0.454 | 0.384 | 15.44 | 0.234 | 48.38 |
| 64 | 73.3 | 1.349 | 1.370 | 0.430 | 0.378 | 11.94 | 0.238 | 44.58 |
| 65 | 72.8 | 1.472 | 1.568 | 0.399 | 0.377 | 5.64 | 0.240 | 39.77 |
| 66 | 73.9 | 1.893 | 1.893 | 0.338 | 0.369 | -8.95 | 0.247 | 27.11 |
| 67 | 73.3 | 2.131 | 1.970 | 0.387 | 0.364 | 6.07 | 0.249 | 35.68 |
| 68 | 73.9 | 0.318 | 0.318 | 0.518 | 0.619 | -19.38 | 0.313 | 39.68 |
| 69 | 75.0 | 0.555 | 0.555 | 0.546 | 0.566 | -3.82 | 0.318 | 41.67 |
| 70 | 74.4 | 0.940 | 0.904 | 0.543 | 0.528 | 2.76 | 0.328 | 39.63 |
| 71 | 73.9 | 1.141 | 1.144 | 0.533 | 0.514 | 3.63 | 0.330 | 38.09 |
| 72 | 74.4 | 1.357 | 1.342 | 0.515 | 0.505 | 1.99 | 0.335 | 34.95 |
| 73 | 73.9 | 1.511 | 1.511 | 0.509 | 0.499 | 2.04 | 0.337 | 33.75 |
| 74 | 73.9 | 1.553 | 1.553 | 0.475 | 0.498 | -4.73 | 0.339 | 28.79 |
| 75 | 73.9 | 1.765 | 1.765 | 0.430 | 0.492 | -14.39 | 0.342 | 20.39 |
| 76 | 72.8 | 1.948 | 1.921 | 0.433 | 0.487 | -12.60 | 0.345 | 20.22 |
| 77 | 72.8 | 2.008 | 2.048 | 0.472 | 0.485 | -2.65 | 0.345 | 26.98 |
| 78 | 65.0 | 1.790 | 1.758 | 0.222 | 0.154 | 30.59 | 0.087 | 60.70 |
| 79 | 63.9 | 1.884 | 1.857 | 0.201 | 0.154 | 23.44 | 0.088 | 56.29 |
| 80 | 63.9 | 1.933 | 1.907 | 0.174 | 0.154 | 11.34 | 0.088 | 49.16 |
| 81 | 63.9 | 1.966 | 1.947 | 0.183 | 0.154 | 15.90 | 0.088 | 51.70 |
| 82 | 62.8 | 1.444 | 1.445 | 0.323 | 0.248 | 23.33 | 0.150 | 53.48 |
| 83 | 63.3 | 1.779 | 1.850 | 0.320 | 0.244 | 23.71 | 0.154 | 52.00 |
| 84 | 62.8 | 1.926 | 1.926 | 0.308 | 0.241 | 21.57 | 0.154 | 50.00 |
| 85 | 62.8 | 2.323 | 2.323 | 0.311 | 0.239 | 23.14 | 0.157 | 49.37 |
| 86 | 62.8 | 2.562 | 2.562 | 0.250 | 0.234 | 6.52 | 0.156 | 37.63 |
| 87 | 65.0 | 1.668 | 1.648 | 0.390 | 0.305 | 21.81 | 0.200 | 48.68 |
| 88 | 64.4 | 2.031 | 2.012 | 0.378 | 0.302 | 20.18 | 0.205 | 45.75 |
| 89 | 63.9 | 2.625 | 2.563 | 0.302 | 0.294 | 2.54 | 0.209 | 30.86 |
| 90 | 63.9 | 2.672 | 2.605 | 0.274 | 0.290 | -5.74 | 0.206 | 24.99 |
| 91 | 65.6 | 0.909 | 0.897 | 0.558 | 0.442 | 20.76 | 0.274 | 50.83 |
| 92 | 65.6 | 1.091 | 1.087 | 0.549 | 0.430 | 21.60 | 0.276 | 49.73 |
| 93 | 65.6 | 1.360 | 1.355 | 0.530 | 0.422 | 20.41 | 0.282 | 46.84 |
| 94 | 63.3 | 2.740 | 2.740 | 0.415 | 0.393 | 5.20 | 0.297 | 28.30 |

Table - 9.4 ( contd.)

| No. | T | L | G | HETP exp. | HETP pred. ( case I ) $a_d = a_p$ | % err | HETP pred. ( case II) $a_d = a_w$ | % err |
|---|---|---|---|---|---|---|---|---|
| 95 | 65.0 | 2.925 | 2.923 | 0.405 | 0.393 | 3.00 | 0.301 | 25.69 |
| 96 | 63.9 | 3.025 | 3.022 | 0.421 | 0.395 | 6.12 | 0.304 | 27.61 |
| 97 | 78.3 | 0.294 | 0.294 | 0.235 | 0.241 | -2.70 | 0.107 | 54.62 |
| 98 | 78.3 | 0.391 | 0.391 | 0.216 | 0.232 | -7.41 | 0.108 | 49.93 |
| 99 | 78.3 | 0.587 | 0.587 | 0.210 | 0.222 | -5.39 | 0.111 | 47.08 |
| 100 | 78.3 | 0.783 | 0.783 | 0.217 | 0.216 | 0.59 | 0.114 | 47.42 |
| 101 | 78.3 | 0.978 | 0.978 | 0.227 | 0.213 | 6.42 | 0.117 | 48.49 |
| 102 | 78.3 | 1.174 | 1.174 | 0.237 | 0.210 | 11.12 | 0.120 | 49.46 |
| 103 | 78.3 | 1.370 | 1.370 | 0.244 | 0.209 | 14.45 | 0.122 | 50.01 |
| 104 | 78.4 | 1.566 | 1.566 | 0.258 | 0.207 | 19.54 | 0.124 | 51.86 |
| 105 | 78.4 | 1.761 | 1.761 | 0.263 | 0.207 | 21.46 | 0.126 | 52.02 |
| 106 | 78.4 | 1.957 | 1.957 | 0.258 | 0.206 | 20.21 | 0.128 | 50.35 |
| 107 | 78.3 | 2.153 | 2.153 | 0.233 | 0.205 | 12.02 | 0.130 | 44.31 |
| 108 | 78.3 | 2.348 | 2.348 | 0.210 | 0.203 | 3.30 | 0.131 | 37.68 |
| 109 | 78.3 | 2.427 | 2.427 | 0.213 | 0.203 | 4.37 | 0.132 | 38.16 |
| 110 | 78.4 | 2.505 | 2.505 | 0.250 | 0.205 | 18.16 | 0.133 | 46.81 |

CASE I : Basis for calculating the values of HETP was as under :- Effective interfacial area during distillation $(a_d)$ = Effective interfacial area during physical absorption $(a_p)$. Further $(k_L a)_{dist.} = (k_L a)_{phy.}$

CASE II : Basis for calculating the values of HETP was as under :- Effective interfacial area during distillation $(a_d)$ = Wetted surface area $(a_w)$. Further $(k_L a)_{dist} = (k_L)\ (a_w)$.

The comparison between the values of HETP from data bank and the predicted values of HETP using the two different basis [Cases (I) and (II)] performed for some typical observations from Table (9.4) reveals the following :-

(I) Observation (5) : System - Ethylbenzene and Styrene.

For a column packed with 0.025m steel Raschig rings, under conditions of T = 73.3°C, P = 0.131 atm a, $\lambda$ = 0.958, L = 0.948 kg/m$^2$-s. and G = 0.967 kg/m$^2$-s, the experimental data bank value of HETP is reported as 0.302m. Under identical conditions the predicted value of HETP for Case (I) wherein $a_d = a_p$ turns out to be 0.304 m and the corresponding value of % error is -0.88. While under identical conditions, the predicted value of HETP for Case (II) wherein $a_d = a_w$ turns out to be 0.172 m and the corresponding value of % error is 43.13.

(II) Observation (31) : System - n Heptane and Toluene.

For a column packed with 0.025m ceramic Raschig rings, under conditions of T = 100°C, P = 1.0 atm a., $\lambda$ = 0.872, L = 1.469

$kg/m^2$-s and G = 1.595 $kg/m^2$-s, the experimental data bank value of HETP is reported as 0.204m. Under identical conditions, the predicted value of HETP for Case (I) wherein $a_d = a_p$ turns out to be 0.192m and the corresponding value of % error is 6.12. While under identical conditions the predicted value of HETP for Case (II) wherein $a_d = a_w$ turns out to be 0.130 m and the corresponding value of % error is 36.42.

(III) Observation (89) : System - Ethanol and Methanol.

For a column packed with 0.035m steel Pall rings under conditions of T = 63.9°C, P = 1.00 atm abs, $\lambda = 0.923$, L = 2.625 $kg/m^2$-s and G = 2.563 $kg/m^2$-s, the experimental data bank value of HETP is reported as 0.302 m. Under identical conditions, the predicted value of HETP for Case (I) turns out to be 0.294 m and the corresponding value of % error is 2.54. While under identical conditions the predicted values of HETP for Case (II) wherein $a_d = a_w$ turns out to be 0.209 m and the corresponding value of % error is 30.86.

(IV) Observation (100) : System - Ethanol and Water.

For a column packed with 0.025 m steel Pall rings under conditions of T = 78.3, P = 1.00 atm, $\lambda = 0.802$, L = 0.783 $kg/m^2$-s and G = 0.783 $kg/m^2$-s, the experimental value of HETP is reported as 0.217m. Under identical conditions, the predicted value of HETP for Case (I) wherein $a_d = a_p$ turns out to be 0.216 m and the corresponding value of % error is 0.59. While under identical conditions the predicted value of HETP for Case (II) wherein $a_d = a_w$ turns out to be 0.114 m and the corresponding value of % error is 47.42.

Similar trend is observed for all the other 106 observations which are compared in Table (9.4). If one assumes that the effective interfacial areas during distillation are equal to the wetted surface areas and then one predicts the values of HETP by the model correlation : Equation (9.6), the predicted values of HETP thus differ considerably from the HETP values obtained from data bank. However, when one assumes that the effective interfacial areas during distillation are equal to the effective interfacial areas during physical absorption and then one predicts the values of HETP by the model correlation : Equation (9.6), the predicted values of HETP compare fairly well with the HETP values obtained from the data bank as could be seen from all the 110 observations compared in Table (9.4). The statistical analysis of the values of HETP predicted by the model correlation using the two different basis [Case (I) and Case (II)] can be described as follows :-

| | CASE I | CASE II |
|---|---|---|
| % $E_{avg}$. | 6.28 | 41.93. |
| % $E_{abs}$. | 14.72 | 41.93. |
| % $S_{dev}$. | 7.87 | 10.59. |

From the above statistical analysis, it is clear that effective interfacial areas during distillation ($a_d$) are expected to be equal to effective interfacial areas during physical absorption i.e. $a_{dy}$. Thus similar to physical absorption, during distillation operation also the static areas are expected to be ineffective for mass transfer.

Therefore, for all the 110 data points under consideration, one should use model correlation [Equation (9.6)] for predicting the values of HETP using basis as $a_d = a_p$ [Equation (9.9)] and $(k_La)_{dist.} = (k_La)_{phy}$ [Equation (9.10)].

The detailed statistical analysis of the model correlation [Equation (9.6)] can be described as follows :-

(i) The total number of data points used in the model correlation is 110, with 17 variations inclusive of system variations like ethyl benzene-styrene, n-heptane-toulene, ethanol-methanol, ethanol-water and n-heptane - cycloxhexane.

(ii) The values of % $E_{avg}$, % $E_{abs}$ and % $S_{dev}$ were 6.28, 14.7 and 7.87 respectively.

(iii) Out of 110 data points, 85 % of the predicted values of HETP were within ± 25 % of the experimental data bank values, 70 % were within ± 20 % and 65 % were within ± 15 %.

(iv) Only 5 % of the points registered deviations greater than ± 30 % with the value of maximum deviation being 33.5 %.

Figure (9.1) shows a parity plot wherein the HETP values predicted for Case (I) [utilising the various generalised correlations for $k_La$, $a_p$, $k_G$ and $k_L$ developed in this investigation for the case of gas absorption] are plotted versus the HETP values from data bank. The satisfactory data fit in Figure - (9.1) clearly reflects that the model correlation can correlate satisfactorily all the data points obtained from various sources covering a wide range of variables as mentioned earlier. The above mentioned satisfactory data fit also indicates the following :-

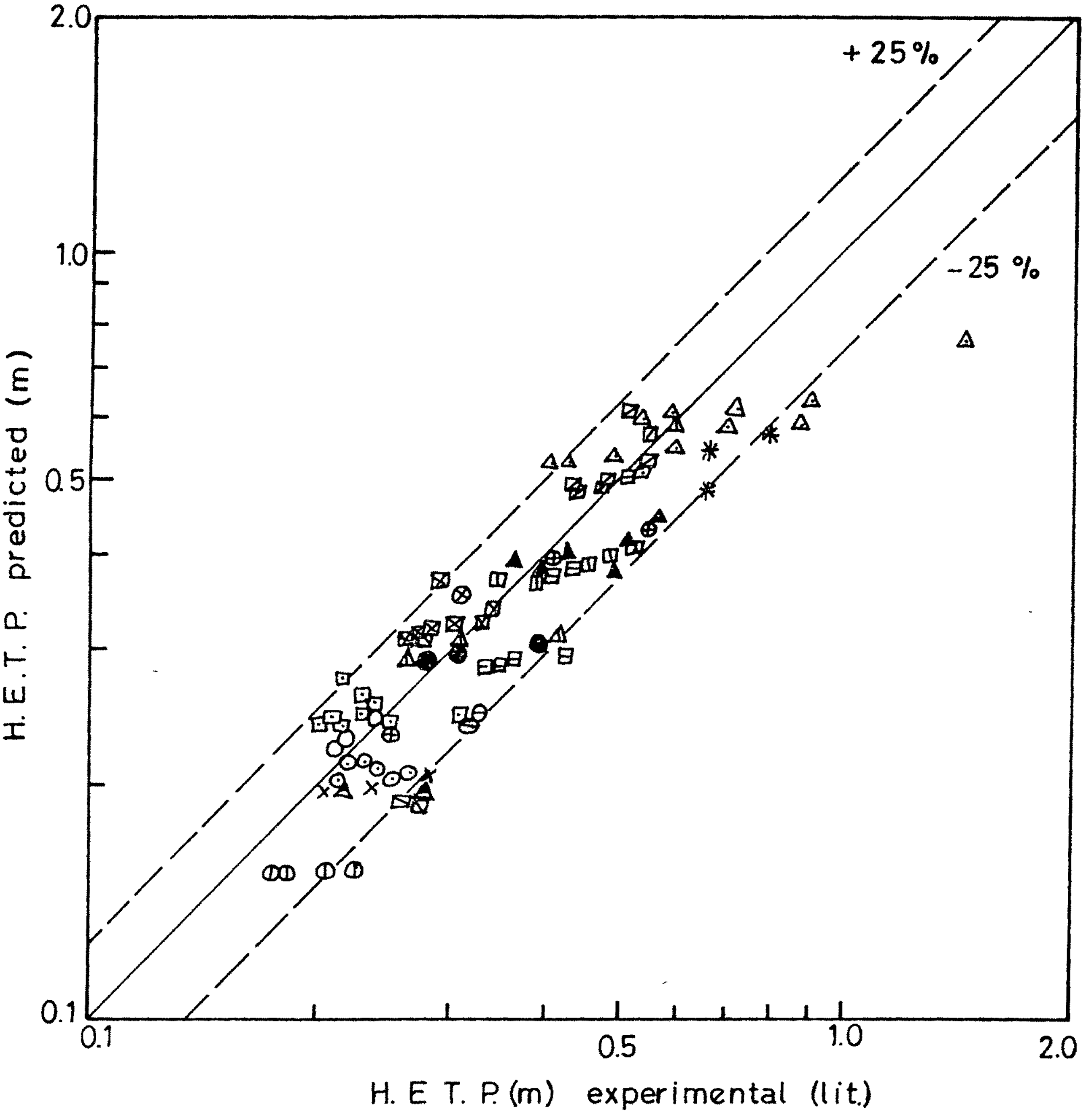

Fig. 9.1 HEIGHT EQUIVALENT OF THEORETICAL PLATE. COMPARISON OF THE PREDICTED vs. EXPERIMENTAL (LIT.) DATA.

## LEGENDS FOR FIG. 9.1

| Data No. | Relevant Information | Symbol |
|---|---|---|
| 1-7 | Billet (118), Ethylbenzene - Styrene, Steel R.R., 15mm, 25mm. | ◭ ◮ |
| 8-28 | Billet (118), Ethylbenzene - Styrene, Steel R.R., 35mm, 50 mm. | ▲ △ |
| 29-31 | Clump (119), n Heptane - Toluene, C.R.R., 25mm. | X |
| 32-49 | Kirschbaum (120), Ethanol - Water, C.R.R., 25mm, 35 mm. | □ ⧄ |
| 50-53 | Silvey (121), Cyclohexane - n Heptane, C.R.R., 75mm. | ✱ |
| 54-59 | Billet (118), Ethylbenzene - Styrene, Steel Pall ring, 15mm, 25mm. | ⧅ ⊟ |
| 60-77 | Billet (118), Ethylbenzene - Styrene, Steel Pall ring, 35mm, 50mm. | ◫ ⧄ |
| 78-86 | Billet (118), Ethanol - Methanol, Steel Pall ring, 15mm, 25mm. | ⦶ ⊖ |
| 87-90 | Billet (118), Ethanol - Methanol, Steel Pall ring, 35mm, 50mm. | ● ⊕ |
| 97-110 | Kirschbaum (120), Ethanol - Water, Steel Pall ring, 25 mm. | ○ |

(i) The volumetric liquid mass transfer coefficient during physical absorption [$(k_La)_{phy}$] and that during distillation [$(k_La)_{dist}$] are expected to be comparable/equal.

(ii) The distillation operation is equimolar counter diffusion while the gas absorption is undirectional ; but this difference in any case has little effect on the values of $k_L$ and $k_V$. Hence the true liquid side and gas/vapour side mass transfer coefficients during physical absorption and distillation are also expected to be comparable/equal.

(iii) The values of effective interfacial area during physical absorption and that during distillation are also expected to be equal/comparable.

Thus, it can be concluded that the generalised correlations developed for $k_La$, $k_G$, $k_L$ and 'a' for the case of physical gas absorption in packed columns can be extended to distillation in packed columns. The comparison between the HETP values based on data bank and the HETP values predicted using these generalised correlations appears to be also quite satisfactory.

Hence, it will be interesting to obtain the data on HETP during distillation with chemical reaction. The values of effective interfacial area during distillation with chemical reaction and the values of effective interfacial area during chemical absorption are expected to be comparable. Hence, while predicting the values of HETP during distillation with chemical reaction probably, one will have to use the basis as $a_d = a_c$ and $(k_La)_{dist.} = (k_La)_{chem.}$