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ABSTRACT

In conjunction with Gas-Cooled Reactor heat-transfer studies, local and mean heat-transfer factors are predicted from the heat transfer-mass transfer analogy using subliming naphthalene in air. Experimentation was conducted on 1-in.-dia septafoil rods in a 4-in.-dia flow channel with rod center-to-center spacings of 1.10, 1.25, and 1.40 in. at a Reynolds modulus of approximately 60,000. Ratios of local mass transfer to mean mass transfer for a given rod vary as much as from 0.7 to 1.3 (outer rod, 1.10-in. spacing). Mean values of the mass-transfer factor are, in general, above that predicted by the correlation $j = 0.023 N_{Re}^{-0.2}$; as much as 48% for the outer rod at 1.25-in. spacing. The data indicate that for maximum mass transfer and minimum variation of the mass-transfer factor, an optimum rod spacing exists; the best observed is at the 1.25-in. spacing. Experimentation conducted on an outer rod at 1.40-in. spacing with a swirl generator at the inlet to the cluster indicate an increase in mass transfer over that with straight flow through the same configuration (with a corresponding increase in pressure drop) but no appreciable decrease in mass-transfer variation around the periphery of the rod.

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NOMENCLATURE

c_p	specific heat of fluid at constant pressure, Btu/lb _m ·°F
d	rod diameter, in.
D	channel diameter, in.
D_e	equivalent hydraulic diameter (four times cross-sectional flow area divided by the "wetted" perimeter), ft
G	fluid mass velocity ($G = \rho V$), lb _m /hr·ft ²
h	heat-transfer coefficient, Btu/hr·ft ² ·°F
j	mass-transfer factor
j_H	heat-transfer factor
j_f	local mass-transfer factor
$\bar{j}_r$	mean mass-transfer factor for a particular rod
$\bar{j}_c$	mean mass-transfer factor for the seven-rod cluster defined by $\bar{j}_c = [6 \bar{j}_r \text{ (outer rod)} + \bar{j}_r \text{ (central rod)}] / 7$
k	fluid thermal conductivity, Btu/hr·ft·°F
k_D	diffusion coefficient of the subliming solid in that fluid, ft ² /hr
k_L	mass-transfer coefficient, ft/hr
M	molecular weight of fluid, lb _m /lb-mole
M_s	molecular weight of subliming solid, lb _m /lb-mole
p	static pressure of fluid in free stream, lb _f /ft ²
p_v	vapor pressure of the subliming solid at the solid-vapor interface, lb _f /ft ²
R	universal gas constant, 1545 lb _f ·ft/lb-mole·°R
S	center-to-center rod spacing, in.
T	fluid temperature, °R
T_v	temperature of the subliming solid at the solid-vapor interface, °R

NOMENCLATURE (Continued)

V	bulk mean fluid velocity, ft/hr
W_D	mass-transfer rate of the subliming solid, $\text{lb}_m/\text{hr}\cdot\text{ft}^2$
α	angle of measurement around rod, deg
γ	ratio of the length of the inner ligament (distance between the surfaces of the central and outer rods) to the length of the outer ligament (distance between the surfaces of the outer rod and the channel), $\gamma = (S - d) / \left(\frac{D - d}{2} - S \right)$
Δc	concentration difference of the vapor of the subliming solid from the solid-vapor interface to the mean free fluid stream, lb_m/ft^3
μ	fluid dynamic viscosity, $\text{lb}_m/\text{hr}\cdot\text{ft}$
ρ	mean fluid density, lb_m/ft^3
ρ_v	density of the vapor of the subliming solid at the solid-vapor interface, lb_m/ft^3
ρ_s	density of the subliming solid, lb_m/ft^3
N_{Pr}	Prandtl modulus, $c_p \mu/k$
N_{Re}	Reynolds modulus, $D_e G/\mu$
N_{Sc}	Schmidt modulus, $\mu/\rho k_D$
N_{St}	Stanton modulus, $h/c_p G$

INTRODUCTION

Two major objectives of the Gas-Cooled Reactor experimental heat-transfer program at the Oak Ridge National Laboratory are the determination of the over-all heat-transfer correlation for the septafoil fuel-element configuration and the evaluation of the surface temperature variation around the periphery of the individual fuel rods. Thus, local and mean values of the Colburn heat-transfer factor, j_H , are desired. An important aspect of this program is the determination of values of j_H as a function of rod spacing in the channel.

Although extensive heat-transfer experimentation is in progress utilizing electrically heated tubes, the problems of delivering power to the tube cluster and obtaining accurate surface temperature measurements are inherently difficult; thus, a flexible design to incorporate variable tube spacing into the experimental heat-transfer test section has proved to be impractical. Since the transfer of mass is analogous to the transfer of heat and a mass-transfer apparatus is more simply constructed and more versatile, an experiment based on the sublimation of a solid into a flowing gas was utilized to augment the data obtained from the heat-transfer experiments.

HEAT TRANSFER-MASS TRANSFER ANALOGY

In a manner similar to that used by Reynolds in developing the heat transfer-momentum transfer analogy and by Schmidt for the mass transfer-momentum transfer analogy, Lewis^{1,2*} obtained the heat transfer-mass transfer analogy. The validity of this analogy has been established through direct

* Superscript numbers refer to the Bibliography.

experimentation by many investigators,^{3,4,5,6,7,8} and the prediction of heat-transfer coefficients by mass-transfer measurements has been accepted as a useful tool in the field of experimental heat transfer.

In the dimensionless form of Chilton and Colburn,^{9,10} the mass-heat transfer analogy can be written as,

$$j_H = j \quad (1)$$

where j_H is the heat-transfer factor and j , the mass-transfer factor as defined in the following two equations:

$$j_H = \left(\frac{h}{c_p G} \right) \left(\frac{c_p \mu}{k} \right)^{2/3} = N_{St} N_{Pr}^{2/3} \quad (2)$$

and

$$j = \left(\frac{k_L}{V} \right) \left(\frac{k}{\rho k_D} \right)^{2/3} = \left(\frac{k_L}{V} \right) N_{Sc}^{2/3} \quad (3)$$

The mass-transfer coefficient, k_L , is defined by the equation

$$W_D = k_L \Delta c \quad (4)$$

In Eq. 4 the mass-transfer rate, W_D ($\text{lb}_m/\text{hr} \cdot \text{ft}^2$), is directly analogous to the heat-transfer rate, q/A ($\text{Btu}/\text{hr} \cdot \text{ft}^2$); and the concentration difference, Δc (lb_m/ft^3), corresponds to the temperature difference, Δt ($^{\circ}\text{F}$).

APPARATUS AND EXPERIMENTAL PROCEDURE

The mass-transfer test section consisted of a vertical cluster of seven 1.000-in.-dia aluminum rods $2\frac{1}{2}$ in. long suspended in a 4.000-in.-dia Plexiglas channel with air flow upward through the channel. The test section was preceded by a hydrodynamic entrance consisting of a flow straightening section and 3 ft of the empty Plexiglas channel. An air temperature measuring

thermocouple and a piezometric ring were located in this entrance region. Details of the installed test section are shown in Fig. 1.

One of the aluminum rods (hereafter referred to as the "active" rod) was coated with naphthalene over a 10-1/2-in. length beginning approximately 11 in. from the upstream end of the rod cluster. The mass removal was measured on the active rod at a position 9-1/2 in. from the upstream end of the naphthalene section. In the rod cluster, the flow cross-sectional area was 7.069 in.² and the total "wetted" perimeter was 34.56 in., yielding an equivalent hydraulic diameter of 0.8182 in. Thus, the hydrodynamic entrance length was approximately 13 hydraulic diameters and the "mass-transfer" entrance length was approximately 12 hydraulic diameters.

The cluster hanger was slotted, and three sets of top and bottom rod spacers were machined such that the center-to-center rod spacing could be set at 1.10, 1.25, or 1.40 in. Figs. 2 and 3 show details of the hanger and spacers for rod clusters at the 1.40-in. spacing ($\gamma = 4$)* and the 1.10-in. spacing ($\gamma = 1/4$), respectively.

Provision was made for a thermocouple to be embedded in the naphthalene near the section at which the mass removal was measured. The data have indicated that the naphthalene temperature rapidly equilibrates with the bulk temperature of the air stream and that the difference between the naphthalene temperature and the free stream air temperature was negligible.

Air flow was provided by a positive-displacement rotary blower capable of delivering up to 1,000 cfm of air at a pressure of 3 psig. A surge tank of approximately 30-ft³ capacity and an orifice run of 9 ft of 4-in. pipe

* γ is defined as the ratio of the length of the inner ligament (distance between the surface of the central and outer rods) to the length of the outer ligament (distance between the surfaces of the outer rod and the channel).

Fig. 1. Mass-Transfer Test Section Mounted in the Flow Channel.

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Fig. 2. Rod Cluster with 1.40-in. Center-to-Center Spacing ($\gamma = 4$).

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Fig. 3. Rod Cluster with 1.10-in. Center-to-Center Spacing ($\gamma = \frac{1}{4}$).

were located between the blower and the test section. Details of the air supply and flow measuring system are shown in Fig. 4.

After preliminary tests with a number of compounds, technical grade naphthalene was chosen as the mass-transfer material. Auxiliary experiments demonstrated that when molten naphthalene was rapidly frozen a fine crystalline structure was formed which could be easily and accurately machined to a smooth surface. The vapor pressure of naphthalene at test temperatures is in the desired range, and it is inexpensive and relatively safe to handle. The sublimation of naphthalene into air has been used for similar experimentation by other investigators^{3,5,6,7,8} and its physical properties are sufficiently known for precise experimentation.*

Naphthalene was formed on the active rod by the following procedure: The mass-transfer section of the rod was first machined to a diameter of 59/64 in. and lightly knurled. The rod was then precooled and dipped into molten naphthalene. The adhering layer of naphthalene was machined off to a uniform outside diameter of 1.000 in. (corresponding to the diameter of the remainder of the rod), producing a 0.039-in.-thick surface of naphthalene in that region. Details of this procedure are shown in Fig. 5.

After the active rod was prepared, the naphthalene section was carefully wrapped with aluminum foil to prevent undesired pretest sublimation. Although only one active rod was used for each run, several were prepared simultaneously to expedite experimentation. Before each run, the active rod used for that run was allowed to attain thermal equilibrium with the ambient temperature. It was then unwrapped and placed in the profilometer shown in Fig. 6. The rod was oriented by a pin passing through the 360-deg

*The physical properties are given in Appendix B.

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Fig. 4. Air Supply and Flow Measuring System.

Fig. 5. Stages of the Active Rod for Mass-Transfer Experimentation.

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Fig. 6. Active Rod Being Traversed in the Profilometer.

protractor and an 1/8-in.-dia hole through the downstream end of the rod. The reading of the precision dial indicator was recorded at 5-deg intervals around the periphery of the rod. The dial indicator had previously been calibrated using a solid rod of known diameter. The active rod was then placed in the rod cluster and orientated with respect to an adjacent "dummy" rod by means of a positioning pin. During a run, data were recorded as to the air flow, air and naphthalene temperatures, and the duration of the run. During any given run, the recorded temperatures were observed to increase gradually with the final temperature being significantly higher than that noted at the beginning of the run. For all properties, except the naphthalene vapor pressure,* sufficient accuracy was obtained by evaluating the properties at a mean temperature for the run. Since the vapor pressure is strongly affected by temperature, it was necessary to establish the mean naphthalene vapor pressure by numerical integration. After completion of the run, the active rod was removed from the cluster, carefully wrapped with aluminum foil, and allowed to equilibrate with the ambient temperature. It was then repositioned in the profilometer and traversed at 5-deg intervals as before. The decrease in radius at any angular position during the run is a measure of local mass transfer at that point.

Experimentation to date has been conducted with an active rod, first in one outer position and then in the central position for rod center-to-center spacings of 1.40, 1.25, and 1.10 in. ($\gamma = 4, 1, \text{ and } 1/4$) with straight flow through the test section. The effect of an inlet swirl generator (creating a "right-hand" helical flow concentric with the flow channel) on a peripheral

*See Appendix A for derivation of the equation used for the reduction of data.

rod at a 1.40-in. spacing was also studied. Duplicate runs were made at each condition to evaluate the precision of the data. For all runs, the Reynolds modulus was near 60,000. In these initial experiments, the active peripheral rod was maintained in a fixed orientation in the channel; in future studies, the active rod will be successively placed in the remaining five peripheral positions.

RESULTS

A summary of the mean mass-transfer factors obtained from the fourteen runs made is presented in Table 1. For each individual run, the mean mass-transfer factor, $\bar{j}_r$, around the periphery of the active rod was determined by numerically integrating the equation

$$\bar{j}_r = \frac{1}{360} \int_0^{360} j_\theta d\theta \quad (5)$$

The maximum deviation from a Reynolds modulus of 60,000 was $\pm 4\%$; to effect a comparison, the mean rod mass-transfer factors were corrected to $N_{Re} = 60,000$ by the relationship $\bar{j}_r \sim N_{Re}^{-0.2}$. The percentage difference between corrected values of $\bar{j}_r$ for duplicate runs ranged from 0.7% (Runs 1a and 1b) to 9.0% (Runs 3a and 3b), indicating a rather high degree of precision. A complete summary of the mass-transfer data corrected to a Reynolds modulus of 60,000 and averaged for the respective pairs of runs is given in Table 2. The cluster mean mass-transfer factor $\bar{j}_c$ was calculated from the relation,

$$\bar{j}_c = [6 \bar{j}_r (\text{outer rod}) + \bar{j}_r (\text{central rod})] / 7 \quad (6)$$

which assumes that the value of $\bar{j}_r$ obtained from the active outer rod is typical of that which would be obtained from any of the six outer rods. The

Table 1. Mean Mass-Transfer Factors for the Individual Runs

Run No.	Rod Spacing, in.	γ	Active Rod	N_{Re}	$\bar{J}_r$	* $\bar{J}_r$	$\bar{J}_r$, Avg.* of Runs a and b	$\bar{J}_r$, Per Cent* Difference of Runs a and b
1a	1.40	4	Outer	57,700	0.00314	0.00312	0.00313	0.7
1b	1.40	4	Outer	57,700	0.00316	0.00314		
2a	1.40	4	Central	60,100	0.00320	0.00320	0.00323	1.6
2b	1.40	4	Central	59,500	0.00326	0.00325		
3a	1.25	1	Outer	61,000	0.00393	0.00394	0.00377	9.0
3b	1.25	1	Outer	61,400	0.00358	0.00360		
4a	1.25	1	Central	61,600	0.00317	0.00319	0.00316	1.9
4b	1.25	1	Central	62,200	0.00311	0.00313		
5a	1.10	1/4	Outer	61,600	0.00289	0.00290	0.00300	6.2
5b	1.10	1/4	Outer	62,500	0.00306	0.00309		
6a	1.10	1/4	Central	61,100	0.00216	0.00217	0.00216	1.2
6b	1.10	1/4	Central	61,200	0.00214	0.00215		
7a**	1.40	4	Outer	59,400	0.00358	0.00358	0.00362	2.3
7b**	1.40	4	Outer	58,600	0.00368	0.00366		

*Corrected to $N_{Re} = 60,000$ by $\bar{J} \sim N_{Re}^{-0.2}$.

**With right-hand helical swirl generator.

Table 2. Average Mass-Transfer Factors Corrected to $N_{Re} = 60,000$

Run No.	γ	Active Rod	$\bar{j}_r$	Deviation	$\bar{j}_c$	Deviation	$\bar{j}_r/\bar{j}_c$	$j_\theta/\bar{j}_r$ max.	$j_\theta/\bar{j}_r$ min.	$j_\theta/\bar{j}_c$ max.	$j_\theta/\bar{j}_c$ min.
				from $\bar{j}_r = 0.00255^*$ (%)		from $\bar{j}_c = 0.00255^*$ (%)					
1	4	Outer	0.00313	+22.7	0.00314	+23.1	1.00	1.13	0.73	1.13	0.73
2	4	Central	0.00323	+26.7			1.03	1.04	0.96	1.07	0.99
3	1	Outer	0.00377	+47.8	0.00368	+44.3	1.02	1.10	0.93	1.12	0.95
4	1	Central	0.00316	+23.9			0.86	1.04	0.95	0.89	0.82
5	1/4	Outer	0.00300	+17.6	0.00288	+12.9	1.04	1.28	0.71	1.33	0.74
6	1/4	Central	0.00216	-15.3			0.75	1.12	0.88	0.84	0.66
7**	4	Outer	0.00362	+42.0				1.11	0.71		

* Calculated from Eq. 7 for $N_{Re} = 60,000$.

** With swirl generator.

percentage deviation of $\bar{j}_r$ and $\bar{j}_c$ from the correlation

$$\bar{j} = 0.023 N_{Re}^{-0.2} \quad (7)$$

at a Reynolds modulus of 60,000 is also tabulated. The ratios $j_g/\bar{j}_r$ and $j_g/\bar{j}_c$ versus the peripheral angle α^* are plotted in Figs. 7 through 10. In these figures the extended co-ordinate lines on the left side of the graphs are associated with the $j_g/\bar{j}_r$ scale, while the similar extensions on the right side of the graphs denote the scale for $j_g/\bar{j}_c$.

DISCUSSION

In general, the circumferential mass-transfer patterns observed in these studies were in agreement with predictions based on qualitative estimates of the flow in a septafoil channel. Thus, for the central rod, the ratio $j_g/\bar{j}_r$ showed a six-lobed "sinusoidal" variation with an increasing amplitude as the peripheral rods were moved in toward the central rod. Similarly, the outer rods showed minima in the $j_g/\bar{j}_r$ curves in the regions of restricted flow (the regions of closest approach to adjacent surfaces). The data show a slight, though consistent, asymmetric mass-transfer pattern (see particularly the outer rod in Fig. 9) which may manifest a flow maldistribution. While the cause of this is not clear, it may result from insufficient flow straightening upstream of the mass-transfer test section. Since care was exercised to maintain uniform upstream flow conditions, this asymmetric mass-transfer pattern may imply that the surface temperature

* α rotates clockwise for the peripheral rod and counterclockwise for the central rod from a common zero at the radius joining the centers of the rods (the point of closest approach of the two rods).

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Fig. 7. Local Mass-Transfer Factor Ratios for the 1.40-in. Center-to-Center Rod Spacing ($\gamma = 4$).

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Fig. 8. Local Mass-Transfer Factor Ratios for the 1.25-in. Center-to-Center Rod Spacing ($\gamma=1$).

Fig.9. Local Mass-Transfer Factor Ratios for the 1.10-in. Center-to-Center Rod Spacing ($\gamma = \frac{1}{4}$).

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Fig.10. Outer Rod Local Mass-Transfer Factor Ratios for the 1.40-in. Center-to-Center Spacing ($\gamma = 4$) with Right-Hand Helical-Swirl Generator.

distribution may be strongly affected by the inlet flow conditions to the individual rod clusters. Hence, relative orientation of successive rod clusters in the reactor core may be very important. This should be investigated.

Inspection of the last two columns of Table 2 shows that the range of j_g/j_c between maximum and minimum values is the smallest at the rod spacing for which $\gamma = 1$ (a variation between 0.82 and 1.12 as compared with 0.73 to 1.13 for $\gamma = 1/4$). The data also show that this is the spacing for which $\bar{j}_c$ is the greatest. Hence, from the standpoint of maximum over-all transfer of heat and minimum variation in heat-transfer factors, there is an optimum rod spacing near $\gamma = 1$. Data previously reported¹¹ indicate no significant variation in pressure drop versus rod spacing for this type of configuration over the range $\gamma = 0.256$ to 4.10.

When considered with relation to the design of a reactor, there are other factors which can influence the choice of the best fuel-rod spacing; e.g., nonuniformity in the fluid temperature in any plane perpendicular to the flow, the tendency toward "hot-streaking", and nonuniform power generation due to neutron shielding of the central rod by the outer rods. Considering the latter of these factors, a lower rate of heat removal around the central rod is sufficient to maintain surface and fluid temperatures equal to those surrounding the peripheral rods. This is compatible with the results of the present experimentation which indicate that, for $\gamma < \sim 4$, the average heat-transfer coefficient for the central rod is less than that for the outer rods. Exact knowledge of the power profile across the fuel rod cluster is needed in order to estimate optimum fuel-rod spacing for maximum heat transfer and near uniform fuel-element surface temperature.

Introduction of a swirl generator at the cluster entrance resulted in an increase in $\bar{j}_r$ for the outer rod of 16% above that attained with straight flow at the same rod spacing ($\gamma = 4$). However, this gain in heat transfer was accompanied by a substantial increase in the pressure drop. The variation in $j_g/\bar{j}_r$ was unchanged, ranging from 0.71 to 1.11 as compared to 0.73 to 1.13 for the straight flow data. An interesting feature of the swirl experiment is the abrupt rise observed in $j_g/\bar{j}_r$ at $\alpha = 205$ deg and the following sharp minimum at $\alpha = 225$ deg. It is postulated that, since the swirl creates cross-flow, this break from the straight flow pattern results from a flow separation on the trailing side of the rod. It is possible that the effects of such a separation on the rod surface temperatures (as evidenced through rod bowing) may render swirl generators infeasible for septafoil arrangements.

A number of refinements in the experimental apparatus are planned. Of high priority is an improvement in the technique of measuring the local mass removal. The mean mass-transfer factors presented in this report are significantly higher than predicted by the correlation $\bar{j} = 0.023 N_{Re}^{-0.2}$. Some of this discrepancy may be due to sublimation during the handling and traversing times incident to the actual mass-transfer run. A new profilometer which will allow much shorter traverse times is being considered. This new device will also make possible simultaneous traverses at several longitudinal positions on the active rod.

CONCLUSIONS

1. The mass-transfer technique has demonstrated its facility for rapidly estimating the relative local and average heat transfer for the individual rods in a septafoil geometry. In particular, it has been established that some perturbations are readily detectable.

2. From the standpoint of maximum over-all transfer of heat and minimum variation in heat-transfer factors, there is an optimum rod spacing near $\gamma = 1$.

3. Surface temperature structure of the septafoil geometry could be significantly affected by inlet flow conditions; hence, orientation of successive rod clusters in the reactor core could be of importance.

4. The use of swirl generators to produce mixing of the flow does not seem to be useful for this type of geometry.

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APPENDIX A

Derivation of Equation Used for the Reduction of Data

For this experimentation, the maximum mass transferred per unit mass of flowing air was 3.8×10^{-6} mole naphthalene/mole air. Since the flow rate was high ($N_{Re \text{ min.}} = 57,700$), it was believed to be reasonable to assume that the naphthalene vapor concentration in the bulk free air stream was negligible; therefore,

$$\Delta c = \rho_v - 0 = \rho_v \quad (8)$$

The maximum naphthalene vapor density was quite low ($\rho_{v \text{ max.}} = 1.2 \times 10^{-4}$ lb_m/ft³); therefore, it was considered to obey the perfect gas law, or

$$\rho_v = \frac{p_v M_s}{R T_v} \quad (9)$$

The working fluid was air at normal atmospheric conditions and was therefore considered to obey the perfect gas law, or

$$\rho = \frac{pM}{RT} \quad (10)$$

Since experimentation has shown that $T_v \approx T$ and by definition $V = G/\rho$, using Eqs. 4, 8, 9, and 10,

$$\frac{k_L}{V} = \frac{W_D}{G} \frac{p}{p_v} \frac{M}{M_s} \quad (11)$$

All terms of the right-hand side of this equation are either known physical properties of the working substances or experimental quantities that are easily measured by standard techniques.

APPENDIX B

Physical Properties of Naphthalene

Chemical Formula: $C_{10}H_8$

Molecular Weight¹²: 128.16

Melting Point¹²: $80.22^{\circ}C$

Density of Solid⁷: $1.078 \pm 0.012 \text{ gr/cm}^3$ at $68^{\circ}F$

Although the density of naphthalene is usually given as 1.145 gr/cm^3 at $68^{\circ}F$,¹² this is a true density and in experimentation that determines mass removal by measuring a volume change, the apparent density (due to minute cracks and bubbles) is required. Sherwood and Träss⁷ measured the apparent density of similarly formed naphthalene and their value was used for this experimentation.

Diffusion Coefficient¹³:

$$k_D = k_{D_0} \left(\frac{T}{T_0} \right)^2 \left(\frac{p_0}{p} \right)$$

where $k_{D_0} = 0.199 \text{ ft}^2/\text{hr}$, $T_0 = 492^{\circ}R$, and $p_0 = 2116 \text{ psfa}$.

Vapor Pressure¹⁴:

$$\log_{10} p_v (\text{mm Hg}) = 11.450 - \frac{6713}{T(^{\circ}R)}$$

Various investigators have used different formulae for the vapor pressure, all of the form

$$\log_{10} p_v (\text{mm Hg}) = A - \frac{B}{T(^{\circ}R)}$$

The available constants are listed in the following table:

<u>A</u>	<u>B</u>	<u>Reference</u>
11.439	6713	5
11.845	6943	6
11.550	6777	7
11.755	6881	8
11.450	6713	14

Since in the temperature range of interest, all of these formulae yield values of vapor pressure that differ by less than $\pm 2\%$, the International Critical Table constants ($A = 11.450$ and $B = 6713$) were used as applicable for this experimentation.

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