NOMENCLATURE

A	=	cross sectional area of specimen [m^2]
a,b	=	lateral and side dimensions of pressure surface [cm]
b	=	specimen width [m]
D	=	fractal dimension [-]
D	=	diameter [cm]
D_a	=	apparent density [g/cm^3]
D_b	=	bulk density [g/cm^3]
D_{eq}	=	Blake's equation [m]
D_t	=	true density [g/cm^3]
$\bar{d}$	=	mean pore diameter at arbitrary pressure [m]
d_o	=	mean pore diameter at initial pressure [m]
E	=	empirical factor
e	=	strain [-]
F_o	=	function of porosity
F_1,F_2	=	defined in equations (3.33) and (3.34)
Kn	=	Knudsen number (=2 λ /d) [-]
K	=	permeability [m^2/s Pa]
K	=	Boltzmann's constant [J/molecule K]
L	=	specimen length or thickness [m]
L	=	span length [m]
m	=	hydraulic radius [m]
M	=	air molecular weight [kg/mole]
N(r)	=	number of subsections (square of side r) containing at least one small portion of any pore
ΔP	=	pressure drop across specimen [Pa]
P_1	=	upstream pressure [Pa]
P_2	=	downstream pressure [Pa]
P	=	average pressure ($P_1 + P_2$)/2 [Pa]
$\bar{P}$	=	absolute pressure [Pa]
P_o	=	porosity [-]
q	=	air flow through a single pore channel [mole/s]
Q	=	total air flow through porous material [mole/s]
r	=	representative scale of similarity ratio [-]
r_a	=	actual pore radius obtained from porosimeter [m]
r	=	pore radius calculated from experimental air flow through [m]

R	=	gas constant [Pa m^3/mole K]
R_f	=	force resistance [Kg cm/s^2]
S_v	=	specific surface area of particles [m^2/m^3]
S_{vo}	=	specific surface area of particles at atmospheric pressure [m^2/m^3]
T	=	absolute temperature [K]
t	=	testing time [s]
$\bar{v}$	=	thermal molecular velocity [m/s]
V	=	volume of gas [cm^3]
W	=	maximum load [Kg]
Z	=	constant used in equation (3.35) [=0.47]
Δ	=	displacement of bending [m]
λ	=	mean free path of gas molecules [m]
μ	=	viscosity of air [Pa.s]
ε	=	porosity [-]
γ	=	surface tension [dyne/cm]
θ	=	contact angle

Subscripts

c ; calculated, m ; measured, o ; initial, p ; pore, s ; surface, v ; volume

APPENDIX 1

PHYSICAL PROPERTIES

Test Method for Apparent Porosity, Apparent Density, Bulk Density and True Density.

This JIS R 2205-1974 specifies the test method for a burnt ceramic refractory which are as follows:

1. Equipment and Instruments.

1.1 Drying Equipment.

For drying, use an equipment of an electrical constant temperature dryer with an automatic temperature regulator capable of maintaining at 105 to 120°C.

1.2 Weighing Instrument.

1.2.1 For the measurement of bulk density, a balance capable of weighing of the unit of 1 gram is used.

1.2.2 For the measurement of true density, unit of 0.1 ml is used.

1.3 Boiling Equipment.

An equipment capable of maintaining water at the boiling point is used.

1.4 Pycnometer.
A glass pycnometer of 20 ml. capacity is used.

2. Test Specimen.

2.1 For the case of apparent porosity, apperent density and bulk density, a test piece is prepared from the sample of a ceramic refractory of the size approximately one half of an ordinary refractrory (230 mm x 60 mm x 115 mm.)

For the handling of the test piece, care should be excercised on the following points.

2.1.1 The sample has to be removed completely of any dust and other particles liable to detach.

2.1.2 Selected sample should be free from appearance of appreciable irregularly of surface.

2.2 For the case of true density, any foreign matters should be removed from the specimen surface and test specimen should be pulverized to the degree to pass the standard sieve of 6.73 mm specified in JIS Z 8801-Sieves for Testing Purposes, and take about 250 grams by the quartering method and next, pulverize it so that the total amount can pass through standard sieve 297 μm and take approximately 30 grams by the quartering method as the sample.

3. Operation.

3.1 For Apparent Porosity, Apparent Density and Bulk Density.

3.1.1 Dried Weight.

Dry the sample in a constant temperature drier at 105 to 120°C and weight when it reached to constant weight [1] by the dry weight, $W_1(g)$.

Note (1) : If no difference in measured weight of more than 1 gram is found, it is considered to be a constant weight.

3.1.2 Method of Saturation.

After measuring the dry weight, submerge the sample in a boiling equipment, and after boiling for more than 3 hours, cool it down to the room temperature, and let that be the saturated sample. There is no objection to assist cooling by the addition of water.

3.1.3 Weight in Water of Saturated Sample.

Measure the weight of sample suspended in water by wire of less than 1 mm diameter, and after substracting the weight of wire, let

that be the weight of sample in water, W_2 (g).

3.1.4 Weight of Water Saturated Sample.

Take the water saturated sample out of the water, and after wiping the surface quickly with damp cloth to remove water, measure the weight and let that be the water saturated weight, W_3 (g).

Remark: For damp cloth, use cloth well saturated with water after subjecting it wringing.

3.1.5 The weight is measured accurately to 1 gram.

3.2 For True Density.

3.2.1 Testing Method.

Let the sample dry according 1.3.1.1 and weigh 8 to 12 grams and put it into a 50 ml pycnometer P (g) previously weighed, and measure the weight, let that be P_1 (g).

Next, put in about the half quantity of the distilled water or pure water and heat it gently over a hot bath, and after removing bubbles in the water, cool it down to the normal temperature. Add distilled water or pure water up to the marked line, and let that be P_3 (g).

3.2.2 The weight (g) is accurately weighed to 4 places of decimal point.

4. Calculation.

4.1 Apparent Porosity.

The percentage of apparent porosity ε is calculated by the following formula, and the value rounded off to 1 place of dicimal point according to JIS Z 8401-Rules for Rounding off Numerical Values.

$$\varepsilon = \frac{W_3 - W_1}{W_3 - W_2} \times 100 \qquad \text{(A1-1)}$$

4.2 Apparent Density.

The apparent density, D_a is calculated from the following formula, and the value rounded off to 2 places of decimal point according to JIS Z 8401.

$$D_a = \frac{W_1}{W_1 - W_2} \qquad \text{(A1-2)}$$

4.3 Bulk Density.

The bulk density, D_b is calculated from the following formula, and the value rounded off to 2 places of decimal point according to JIS Z 8401.

$$D_b = \frac{W_1}{W_3 - W_2} \qquad \text{(A1-3)}$$

4.4 True Density.

The true density, D_t is calculated from the following formula, and the value rounded off to 2 places of decimal point according to JIS Z 8401.

$$D_t = \frac{P_1 - P}{(P_1 - P) - (P_3 - P_2)} \qquad \text{(A1-4)}$$

where, P_2 ; weight (g) of the pycnometer filled with distilled water or pure water.

Test Method for Compressive Strength.

This JIS R 2206-1974 specifies test method for compressive strength of a ceramic refractory.

1. Equipment and Instruments.

1.1 Drying Equipment.

For drying, use an equipment of electrical constant temperature dryer with automatic temperature regulator of maintaining at 105 to 120°C.

1.2 Compressive Strength Tester.

1.2.1 The testing machine should have the maximum crushing capacity of at least 50 tons as maximum with a variable oil pressure system without transmitting pulsation to pressing plate at the time of loading.

1.2.2 The tolerance on graduation is $\pm$ 1/100 for the respective load.

1.2.3 The pressure surface should be of polished treated steel with the hardness of more than 70 % of shore.

1.2.4 The pressure surface should be provided with a spherical seat and of the construction to permit upper and lower pressing plate to be parallel when pressed.

1.3 Length Gauge.

The length gauge capable of measuring to the unit of 0.5 mm is used.

1.4 Weighing Instrument.

The balance capable of weighing to the unit of 1 gram is used.

2. Test Specimen.

2.1 Prepare 2 test pieces in cubical form having 60 mm a side from the original refractory. For the ordinary shape of brick, 2 pieces of half size can be cut from the lengthway to make test pieces.

2.2 When it is not possible to take the above stated test piece, take largest 2 cubical test pieces possible from the specimen, and let that be the test piece.

2.3　As a rule, the test piece should be capable of being pressed in right angle directed to the pressure direction when the sample refractory was made, and prepared so that the top and bottom faces to be parallel and smooth.

Further, in case of a burnt refractory, at least more than one side of the burnt surface should be left.

2.4　The number of test pieces used for the test should be 2 pieces.

3.　Operation.

3.1　The capacity of a testing machine is adjusted that the load tested will be found within 15 to 85% of capacity.

3.2　The test piece which had been previously dried to the constant weight [1] at 105 to 120ºC before, then it was used as the test piece.

Note(1): If no difference in measured weight of more than 1 gram is found, it is considered a constant weight.

3.3　The dimensions of pressure surface should have been tested to the unit of 0.5 mm for each test piece[2], and if necessary, a piece of paper is inserted on the pressure surface to equalize the pressure.

Note(2): The measurement of dimension should conform to JIS R 2202　Measuring Method for Dimensions of Refractory Bricks.

3.4　The speed for the application of weight should be 10 to 15 Kg/cm^2 min as standard and obtain the maximum load W (Kg) when the test piece is crushed.

4.　Calculation.

The compressive strength , C (Kg/cm^2) is calculated by the following formula, and rounded off to the full number according to JIS Z 8401-Rules for Rounding off Numerical Values.

$$C = \frac{W}{a \times b} \qquad\qquad \text{(A1-5)}$$

where ,　W : maximum load (Kg)

　　　　　a,b : lateral and side dimensions of pressure surface

Testing Method for Permeability to Gases of Refractory Bricks.

This Japanese Industrial Standard specifies the testing method for permeability of gases of refractory bricks of which permeability is not less than 5×10^{-15} m^{2}s Pa (average air hole diameter 0.1 μm).

1. Apparatus and Equipment.

1.1 Testing Apparatus.

1.1.1 Test Piece Holder.

The test piece holder to serve shall be capable of hermetically sealing up the circumference of a test piece as shown in figure A1-1.
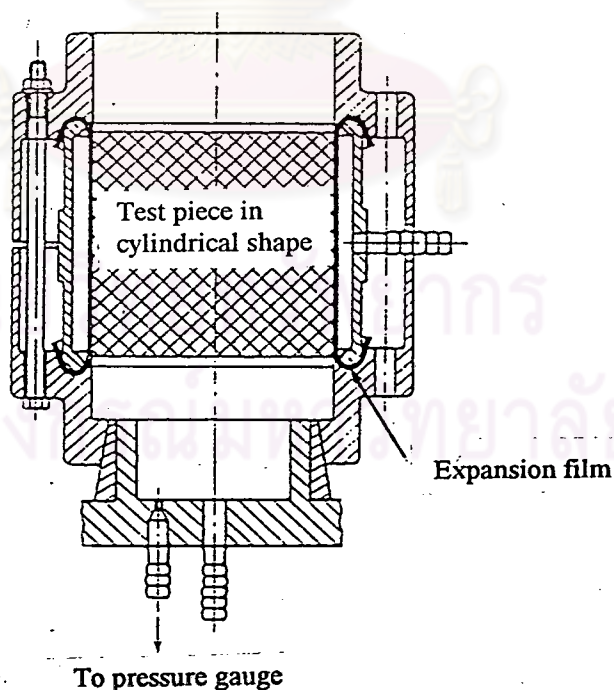

Figure A1-1 Example of Test Piece Holder

1.1.2 Pressure Measuring Device.

As the measuring device of pressure, use either a mercury manometer or a water manometer, or else a pressure gauge with the measurement error rate of within 1% of full scale. With this device, the pressure difference between the two sides of the test piece shall be measured.

1.1.3 Flow Quantity Measuring Device.

As a device for measuring flow quantity, use a flow meter with flow quantity measurement accuracy of 1% or finer or a water replacement device with a scaled tube.

1.1.4 Supply of Air or Inert Gas.

To supply pressurized air or inert gas under pressure or suction, use a storage unit under a certain pressure or such devices as give a certain pressure to air or inert gas by means of replacement of water.

1.1.5 Structure of Testing Devices.

As for the construction of the testing device, good air tightness shall be ensured and, especially in the piping system, the pipes shall be shortened to the minimum size to reduce pressure loss.

In addition, the airtightness of the testing devices shall be verified by the blank test (refer to figures A1-2 and A1-3).
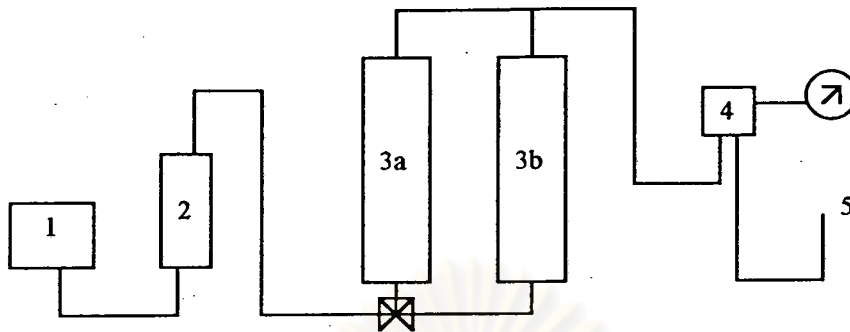
Figure A1-2   Example of Arrangement of Gas Permeability Rate Measuring Devices (Extrusion Type)

1. air or inert gas source
2. drier
3. flow meter (a) 0 to 200 cm/min   (b) 200 to 1,500 cm/min
4. cylinder type test sample holder
5. U-shaped manometer
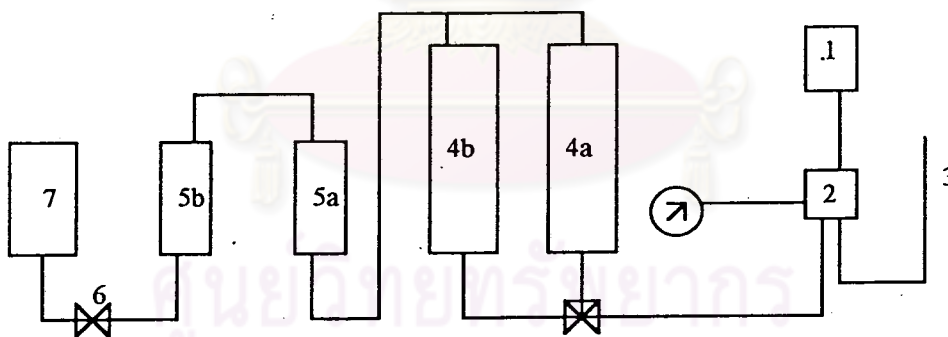
**Figure A1-3   Example of Arrangement of Gas Permeability Rate Measuring Devices (Suction Type)**

1. air or inert gas inlet (through drier)
2. cylinder type test piece holder
3. U-shaped manometer
4. flow meter (a) 0 to 200 cm/min   (b) 200 to 1,500 cm/min
5. Wolff safety bottle
6. adjusting valve
7. pump

1.2 Drying Apparatus.

The drying apparatus shall be an electric thermostatic heater which can automatically control the temperature from 105º to 120º .

1.3 Length Meter.

The length meter shall be one that can measure up to 0.5 mm.

2. Test Piece.

2.1 Cut off a cylinder (round pole) 50 mm in diameter and 50 mm in height from a sample fire brick to serve as a test piece.
The dimension allowances shall be ± 1.0 mm for the diameter and ± 1.0 mm for the height.
2.2 To prepare a test piece, first discard a layer at least 4 mm in thickness from the natural surface of a sample fire brick as a rule, and proceed to splity the underlayer in parallel or vertical to the sample firebrick.
2.3 Dry the test piece in the drier until it has attained constant mass[1] at 105 to 120 ºC, and cool it down to room temperature.
Note (1): When the measured weights show no discrepancy 0.1 g or greater, a constant mass may be considered attained.

3. Operation.

3.1 Put the test piece in the holder, and ensure air tightness by covering the smooth sections with nonpermeable materials or by other methods.
3.2 Send air or inert gas and conduct at least 3 measurements under different constant pressures for each test piece.

4. Calculation.

The permeability K of a test piece shall be calculate from the following formula, and the result shall be rounded off two effective figures in accordance with JIS Z 8401.

$$\frac{V}{t} = K \; \frac{1}{\mu} \; \frac{S}{L} \; (P_1 - P_2) \; \frac{(P_1 \pm P_2)}{2P} \qquad \text{(A1-6)}$$

where:

P	:	absolute pressure (N/mm^2) kg/mm^2
t	:	testing time (s)
V	:	volume of gas (mm^3) passing through within time t under absolute pressure P
S	:	sectional area (mm^2) of test piece passed through by gas
L	:	thickness of sectional area of object (mm)
P_1	:	absolute pressure (N/mm^2) kg/mm^2 at time of gas intrusion
P_2	:	abolute pressure when gas is set free (N/mm^2) kg/mm^2
μ	:	viscosity of gas in testing temperature (Pa.s)
K	:	permeability of test piece of object (m^{2}s Pa)

Remarks: (1)   P   means the pressure of the flowing gas when its volume is being measured.

P   = P_1; when functioning as active pressure

P   = P_2; when functioning as passive pressure

(2)   Correction factor $\frac{P_1 \pm P_2}{2P}$ is as a rule about equal to 1.

In case the pressure difference $(P_1 - P_2)$ is not more than 100 mm water column. This may be neglected. The equation accords with the rule of Darcy.

(3)   The permeability is the factor K in the above equation. The equation expresses the volume of gas which passes through the object within a given time.

(4)   It should be noted that permeability is a characteristic which, unlike density or porosity, has a directional nature similar to vector. Hence, permeability varies not only depending on the measuring direction, but also, as the case may be, depending on the flowing direction of gas.

(5)   The kinematic viscosity of air shall be as specified in table A1-1.

Table A1-1   Viscosity of Air

Air temperature [°C]	16	18	20	22	24	26	28
Viscosity [Pa.s]	17.88	17.98	18.08	18.18	18.28	18.38	18.47

5. Report.

The report shall carry the average value calculated from the results of three measurements and rounded off to the second decimal place in accordance with JIS Z 8401. In addition, the testing conditions (the sectionally cut direction, the pressure or the suction strength, and the temperature of the sample fire bricks) shall also be noted in the report.

Testing Method for Slag Corrosion of Refractories Using Crucibles.

This Japanese Industrial Standard specifies the testing methods for slag corrosion of refractories using crucibles.

1. Apparatus.

1.1 Drying Apparatus.

An electric constant temperature apparatus attached with automatic thermostat capable of keeping at 105 to 120°C in temperature shall be used.

1.2 Heating Furnace.

An electric furnace of silicon-carbide heating element shall be used. The furnace shall be capable of raising temperature from 1,000°C up to 1,500°C at a heating speed of 5°C (5 K) per min, and have performance capable of keeping the sample put into the furnace within the specified test temperature $\pm$ 5°C ($\pm$ 5 K).

1.3 Pyrometer.

A thermocouple thermometer shall be used.

1.4 Mass Gauge.

A mass gauge capable of measuring to the unit of 0.1 gram shall be used.

1.5 Length Gauge.

A length gauge capable of measuring to the unit of 0.05 mm shall be used.

2. Slag.

The slag crushed to powder of not more than 710 μm and dried until becoming constant quantity[1] at 105 to 120°C shall be used.

Note (1): If the measured mass has no difference of 0.1 g or more, it is taken as constant quantity.

3. Sample.

Cut out a size of approximately 70 mm x 70 mm x 65 mm from the specimen refractory, drill the central part of 70 mm x 70 mm surface to make a crucible having a hole 30 mm in diameter, and 35 mm in depth, dry it until becoming constant quantity[2] at 105 to 120°C and take it as the sample. Provided that the wall surface and bottom surface of crucible shall be finished as flat and smooth as far as possible. Further, the surface to be drilled shall be the surface of raw brick.

Note (2): If the measured mass has no difference of 1 gram or more, it is taken as constant quantity.

4. Testing Method.

4.1 Put the slag micropowder of 25 gram which is dried until becoming constant quantity and cooled in a desiccator into a crucible dried and cooled similarly, and make the upper surface of slag flat.

4.2 Place the crucible containing the slag into the equal

temperature zone of furnace capable of keeping within $\pm$ 5ºC ($\pm$ 5 K) at test temperature and heat uniformly.

As to the supporting stand of this crucible use the substance having quality not to react with the crucible, and in the case of testing two or more samples at the same time, make necessarily the sample mutual distance 10 mm or more, and make the interval between the sample and the furnace wall 30 mm or more.

4.3 Measure the temperature according to a thermocouple, and necessarily so set that the top end part is positioned just above the middle part of the sample by 10 mm.

4.4 Carry out the heating under the atmosphere, and take 5ºC (5K) per min as the standard in heating speed from 1,000ºC up to 1,500ºC.

4.5 As to test temperature, after keeping at 1,500 $\pm$ 5ºC for 2 hours, cut the power source of an electric furnace and cool naturally.

4.6 After the completion of test, take out gently the naturally cooled crucible from the furnace, and so cut it into two parts that the drilled axis is on the cut surface and passes through the center of crucible (refer to figure A1-4).
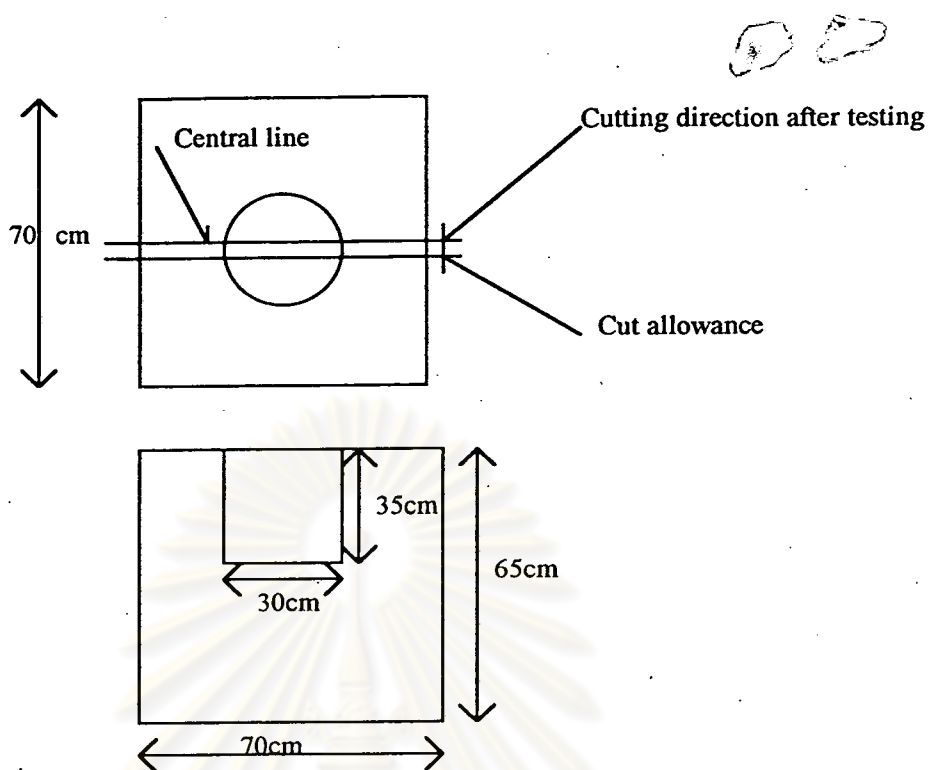
**Figure A1-4 Dimensions of Crucible and Cutting Method of Sample
After Testing**

4.7 Measure the area of the part corroded and dissolved at
the cut surface, obtain in the unit of cm^2 to the first place of decimal and
cut away the rest.

Further, observe and note the existence of softening,
deformation, and foaming, condition and degree of soakage, general
conditions and smoothness of corroded surface, etc. of sample.

In this case, if required, sketch or photograph the cut surface
(refer to figure A1-5).
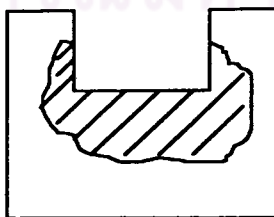
Figure A1-5 Example of Marking of Result after Testing

5. Report.

The corrosion area (cm^2) of one piece crucible shall be reported. In this case, the existence of softening, deformation, foaming, condition and degree of soakage, and general conditions and smoothness, etc. of sample shall be described.

Further, if required, append the sketch or photograph of cut section including in the report the chemical composition of the slag tested.

Thermal Shock Resistance.

Thermal shock resistance was evaluated by two methods. For the first method, a specimen measuring 30 mm x 40 mm x 155 mm was heated abruptly in an electric furnace maintaining at 1,773 K for 30 minute and cooled forcibly by a fan to room temperature. Two points of time such as first appearance of crack and separation of specimen were referred to for evaluation.

The second method involves, measuring the stress strain curve at 1,773 K in order to evaluate the fracture energy. The measuring stress-strain curve is as follows: The relation between stress T [Pa] and strain e [-] is defined by equation (A1-7):

$$T = Ee \qquad\qquad (A1\text{-}7)$$

where : E (Pa) is modulus of elasticity.

Equation (A1-8) shows the relation between bending load P (N) and modulus of elasticity E (Pa).

$$E = \frac{PL^3}{4\Delta bt^3} \qquad\qquad (A1\text{-}8)$$

where: L = span length [m]
        b = specimen width [m]
        t = specimen thickness [m]
        Δ . = displacement of bending [m]

Bending stress is expressed by equation (A1-9)

$$T = \frac{3PL}{2bt^2} \qquad (A1\text{-}9)$$

Combining equations (A1-7), (A1-8) and (A1-9) yields:

$$e = \frac{6\,\Delta\,t}{L^2} \qquad (A1\text{-}10)$$

Therefore, the stress-strain curve can be given by equations (A1-9) and (A1-10) by measuring P and Δ. The experiment was carried out at 1,773 K in an electric furnace.

Test Method for Mean Pore Size.

The Pore Sizer 9320 is a 30,000 psia (207 MPa) mercury porosimeter covering the pore diameter range from approximately 360 to 0.006 μm. The unit has two built-in low pressure ports and one high pressure chamber. Data collection, data reduction, and data display are processed by the optional control module. All aspects of the high pressure analysis are also managed by the control module.
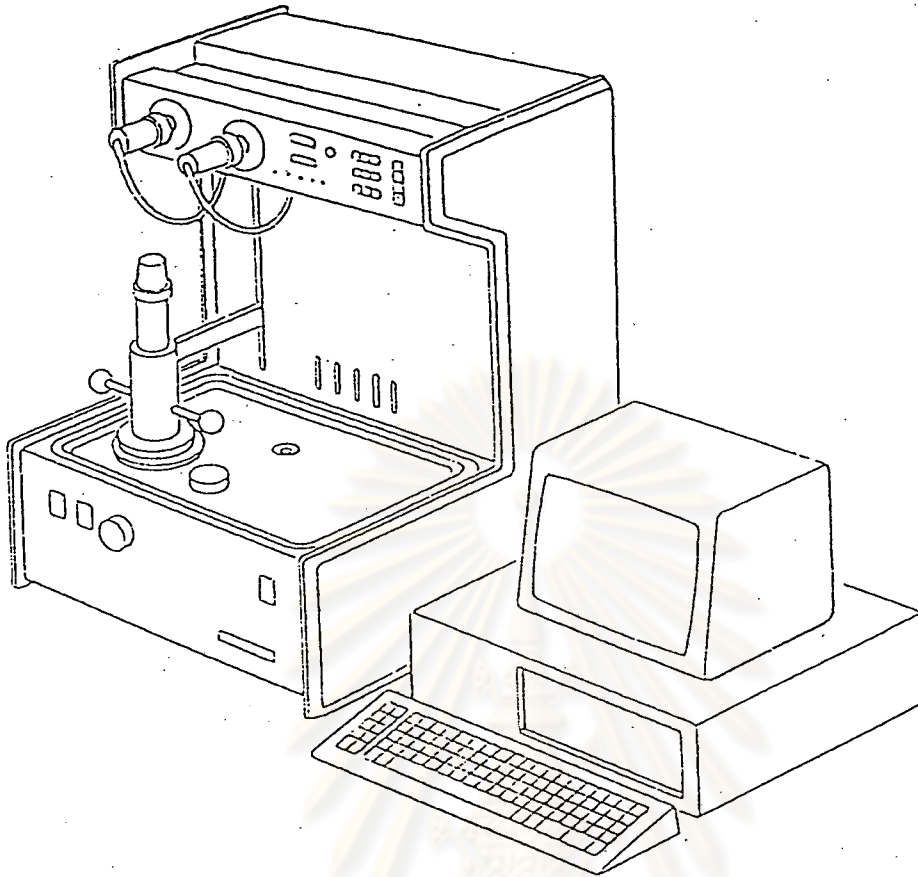
Figure A1-6   Pore Sizer 9320 System

The Pore Sizer measures the volume distribution of pores in materials by mercury intrusion or extrusion. Mercury has a high surface tension and is non-wetting to all materials with the exception of a few noble metals. These properties cause a mercury surface in contact with a solid to assume the minimum surface area and largest radius of curvature possible at a given pressure. An increase in pressure on the mercury shifts the balance between surface tension and surface area causing the radius of curvature of the mercury contacting the solid to become smaller. When the radius is equal to that of a pore entrance, mercury fills the volume within the pore. A thorough discussion of the theory of porosimetery is given in the following:

The Mercury porosimetry is based on the capillary law governing liquid penetration into small pores. This law, in the case of a non-wetting liquid like mercury and cylindrical pores, is expressed by the Washburn equation:

$$d = -(1/P)4\, \gamma \cos \theta \qquad\qquad (A1-11)$$

The true pressure is found when the mercury head correction is added to the pressure reading. Calculating the pore diameter intruded by mercury at each pressure requires solving the basic equation.

$$d = \frac{-4\, \gamma \cos \theta}{P} \qquad\qquad (A1-12)$$

where:

d = the diameter

γ = the surface tension

θ = the contact angle

P = the pressure

Presently, the generally accepted value for γ is 485 dynes/cm. The contact angle generally varies around 130 degrees for which the cosine is -0.6428. The true angle depends on the material being examined, and this true value should be employed. For purposes of illustration, 130 degrees will assumed here. Pore diameters are usually desired in units of micrometers (μm), and here pressures are measured in pounds per square inch. This use of a variety of units requires inclusion of conversion factors.

The final result is that diameters are calculated by:

$$d\,\mu m = \frac{-4 \times 485 \text{ dynes/ cm } \times 104 \text{ } \mu m/cm \times -0.6428}{P \text{ psia} \times 6.8948 \times 104 \text{ dyne/cm}} \quad (A1-13)$$

which, in this illustration using a contact angle of 130 degrees, reduces to:

$$d\,\mu m = \frac{180 \text{ } \mu m \text{ psia}}{P \text{ psia}} \qquad\qquad (A1-14)$$

Plotting calculated cumulative pore volumes vs. calculated pore diameters gives the convenient form of data presentation illustrated by figure A1-7.

[x] Diameter [Å]   [y] Intrusion Volume [c.c/g]
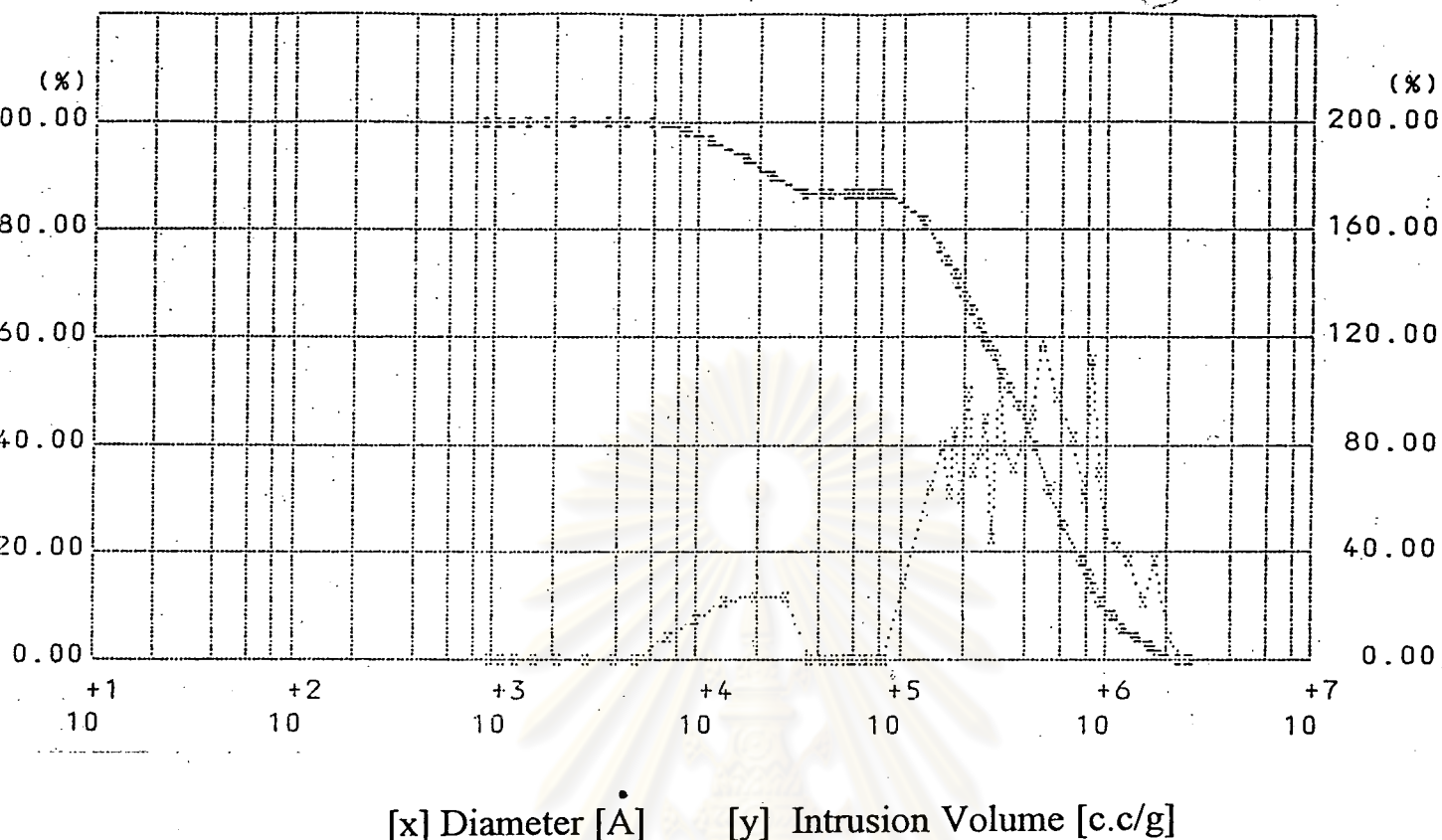
Figure A.1-7 Cummulative Pore Volumes vs. Calculated Pore Diameters

Often it is desired to present mercury intrusion data in a differential form as an alternative to a cumulative. There are several choices for obtaining a derivative plot, or differentiating the cumulative curve: dV/d(d) ($\Delta V \div \Delta d$), dV/d log d (ΔV - Δ log d), or just   the incremental volume different (dV or ΔV) plotted vs. mean pore diameter (d). dV is easy to obtain by differences between adjacent cumulative volume points on the tabulation.

Mean pore diameter is the diameter value halfway between the two points, and is obtained by adding them together and dividing by two, for example, $(d_1 + d_2)/2$, etc.

The volume of mercury V penetrating the pores is measured directly as a function of applied pressure. This P-V information serves as a unique characterization of pore structure.

Pores   are   rarely   cylindrical, hence   the   above   equation constitutes a special model. Such a model may not best represent pores in actual materials, but its use is generally accepted as the practical means for treating what, otherwise, would be a most complex problem. The surface

tension of mercury varies with purity. Its usually accepted value and the value recommended here is 485 dynes/cm. The contact angle between mercury and the solid containing the pores varies somewhat with solid composition. A value of 130 degrees is recommended in the absence of specific information to the contrary.

Mercury extruding from pores upon the reduction of pressure is in general accord with the above equation, but indicated pore diameters are always offset toward larger diameters. This results from equivalent volumes of mercury extruding at pressures lower than those at which the pores were intruded. It is also commonly observed that actual pores always trap mercury. The first phenomena is usually attributed to receding contact angles being less than advancing ones. The second is likely due to pore irregularities giving rise to enlarged chambers and "ink-well" structures. These phenomena give rise to hysteresis phenomena, i.e., distinct intrusion and extrusion P-V curves.

APPENDIX 2

Example of Calculation

Calculation of Calculated Pressure Drop per Unit Length, $\Delta P_c/m$

$$Q = \frac{1}{RT} \Delta \frac{P_c}{L} \left(\frac{\bar{P} r^4}{8u} + \frac{8}{3} r^3 \sqrt{(\pi RT)/2M} \ E \right) \qquad \text{(A2-1)}$$

$$E = \frac{1 + (2/\mu)\sqrt{M/RT} \ r \bar{P}}{1 + (2.47/\mu) \sqrt{M/RT} \ r \bar{P}} \qquad \text{(A2-2)}$$

$\bar{P}$ = $(P_1 + P_2)/2$ = average pressure, Pa
P_1 = upstream absolute pressure, Pa
P_2 = downstream absolute pressure, Pa
E = empirical factor
μ = viscosity of air, Pa.s
r = pore radius, m
R = gas constant
L = specimen thickness
M = air molecular weight, kg/mole
ΔP_c = calculated pressure drop across specimen

An example of calculation is shown in table A2-1.

Table A2-1 Example of Calculation of Calculated Pressure Drop per Unit Length for Specimen A

A	B	C	D	E	F
Patm mmHg (City record)	Wet-gas meter Liter/min	Puv cm Hg Mercury mano.	Pua mm Hg A-(C*10)	abs Pu.Pa = P1 1.3329*100*D	DP cm, Ca Castor oil mano.
766.53	1.132	74.9	17.53	2336.5737	31.8686625
766.53	1.132	74.8	18.53	2469.8637	30.9029454
766.53	1.132	74.7	19.53	2603.1537	29.4543699
766.53	1.132	74.5	21.53	2869.7337	27.0400773
766.53	1.132	73.8	28.53	3802.7637	19.1211975
766.53	1.132	72.6	40.53	5402.2437	12.5543216
766.53	1.132	71.6	50.53	6735.1437	9.65717045
766.53	1.132	69	76.53	10200.6837	5.79430227
766.53	0.740	75.4	12.53	1670.1237	32.8343795
766.53	0.740	75.3	13.53	1803.4137	30.9029454
766.53	0.740	75.2	14.53	1936.7037	28.0057943
766.53	0.740	74.9	17.53	2336.5737	21.245775
766.53	0.740	74.5	21.53	2869.7337	16.4171898
766.53	0.740	74.1	25.53	3402.8937	13.0371801
766.53	0.740	73.1	35.53	4735.7937	9.17431193
766.53	0.740	70.5	61.53	8201.3337	4.82858522
766.53	0.740	66.8	98.53	13133.0637	2.89715113
766.53	0.740	54.5	221.53	29527.7337	1.25543216
766.53	0.740	76	6.53	870.3837	28.0057943
766.53	0.364	75.9	7.53	1003.6737	22.6943506
766.53	0.364	75.7	9.53	1270.2537	17.3829068
766.53	0.364	74.6	20.53	2736.4437	7.72573636
766.53	0.364	73.2	34.53	4602.5037	4.82858522
766.53	0.364	71.4	52.53	7001.7237	3.18686625
766.53	0.212	76	6.53	870.3837	12.5543216
766.53	0.212	75.6	10.53	1403.5437	7.72573636
766.53	0.212	74.9	17.53	2336.5737	4.82858522
766.53	0.212	74.6	20.53	2736.4437	4.3457267
766.53	0.212	72.9	37.53	5002.3737	2.41429261
766.53	0.212	71.1	55.53	7401.5937	1.64171898
766.53	0.212	66.5	101.53	13532.9337	0.86914534
766.53	0.068	76	6.53	870.3837	4.3457267
766.53	0.068	75.6	10.53	1403.5437	2.41429261
766.53	0.068	75	16.53	2203.2837	1.54514727
766.53	0.068	74.8	18.53	2469.8637	1.30371801
766.53	0.068	74	26.53	3536.1837	0.86914534
766.53	0.068	73.5	31.53	4202.6337	0.67600193
766.53	0.017	76	6.53	870.3837	1.06228875
766.53	0.017	75.6	10.53	1403.5437	0.57943023
766.53	0.017	75	16.53	2203.2837	0.33800097

Table A2-1 Example of Calculation of Calculated Pressure Drop per Unit Length for Specimen A [Continue]

G	H	I	J	K	L
DP Pa	Qm kg/min	Pd Pa = P2	Pav , Pa	pore (r) , m	mu, Pa.s
0.95*9.81*F*10	B*1.27895*10-3	E-G	(E+I)/2	Phy. prop.	Vis. of air
2970	0.00144051	-633.4263	851.5737	0.0000673	0.0000181
2880	0.00144051	-410.1363	1029.8637	0.0000673	0.0000181
2745	0.00144051	-141.8463	1230.6537	0.0000673	0.0000181
2520	0.00144051	349.7337	1609.7337	0.0000673	0.0000181
1782	0.00144051	2020.7637	2911.7637	0.0000673	0.0000181
1170	0.00144051	4232.2437	4817.2437	0.0000673	0.0000181
900	0.00144051	5835.1437	6285.1437	0.0000673	0.0000181
540	0.00144051	9660.6837	9930.6837	0.0000673	0.0000181
3060	0.00094168	-1389.8763	140.1237	0.0000673	0.0000181
2880	0.00094168	-1076.5863	363.4137	0.0000673	0.0000181
2610	0.00094168	-673.2963	631.7037	0.0000673	0.0000181
1980	0.00094168	356.5737	1346.5737	0.0000673	0.0000181
1530	0.00094168	1339.7337	2104.7337	0.0000673	0.0000181
1215	0.00094168	2187.8937	2795.3937	0.0000673	0.0000181
855	0.00094168	3880.7937	4308.2937	0.0000673	0.0000181
450	0.00094168	7751.3337	7976.3337	0.0000673	0.0000181
270	0.00094168	12863.0637	12998.0637	0.0000673	0.0000181
117	0.00094168	29410.7337	29469.2337	0.0000673	0.0000181
2610	0.0004632	-1739.6163	-434.6163	0.0000673	0.0000181
2115	0.0004632	-1111.3263	-53.8263	0.0000673	0.0000181
1620	0.0004632	-349.7463	460.2537	0.0000673	0.0000181
720	0.0004632	2016.4437	2376.4437	0.0000673	0.0000181
450	0.0004632	4152.5037	4377.5037	0.0000673	0.0000181
297	0.0004632	6704.7237	6853.2237	0.0000673	0.0000181
1170	0.00026978	-299.6163	285.3837	0.0000673	0.0000181
720	0.00026978	683.5437	1043.5437	0.0000673	0.0000181
450	0.00026978	1886.5737	2111.5737	0.0000673	0.0000181
405	0.00026978	2331.4437	2533.9437	0.0000673	0.0000181
225	0.00026978	4777.3737	4889.8737	0.0000673	0.0000181
153	0.00026978	7248.5937	7325.0937	0.0000673	0.0000181
81	0.00026978	13451.9337	13492.4337	0.0000673	0.0000181
405	8.6533E-05	465.3837	667.8837	0.0000673	0.0000181
225	8.6533E-05	1178.5437	1291.0437	0.0000673	0.0000181
144	8.6533E-05	2059.2837	2131.2837	0.0000673	0.0000181
121.5	8.6533E-05	2348.3637	2409.1137	0.0000673	0.0000181
81	8.6533E-05	3455.1837	3495.6837	0.0000673	0.0000181
63	8.6533E-05	4139.6337	4171.1337	0.0000673	0.0000181
99	2.1633E-05	771.3837	820.8837	0.0000673	0.0000181
54	2.1633E-05	1349.5437	1376.5437	0.0000673	0.0000181
31.5	2.1633E-05	2171.7837	2187.5337	0.0000673	0.0000181

Table A2-1 Example of Calculation of Calculated Pressure Drop per Unit Length for Specimen A [Continue]

M	N	O	P	Q
r/mu K/L	T, atm K Room temp.	R, gas const. Pa m3/mole K	r3/L K*K*K/0.009	Pai r Pavg/8 mu 3.1415*J*M/8
3.71823204	292.15	8.3144	3.3869E-11	1243.38552
3.71823204	292.15	8.3144	3.3869E-11	1503.70733
3.71823204	292.15	8.3144	3.3869E-11	1796.88146
3.71823204	292.15	8.3144	3.3869E-11	2350.3774
3.71823204	292.15	8.3144	3.3869E-11	4251.47563
3.71823204	292.15	8.3144	3.3869E-11	7033.67316
3.71823204	292.15	8.3144	3.3869E-11	9176.95872
3.71823204	292.15	8.3144	3.3869E-11	14499.8235
3.71823204	292.15	8.3144	3.3869E-11	204.595069
3.71823204	292.15	8.3144	3.3869E-11	530.621523
3.71823204	292.15	8.3144	3.3869E-11	922.352623
3.71823204	292.15	8.3144	3.3869E-11	1966.13663
3.71823204	292.15	8.3144	3.3869E-11	3073.12851
3.71823204	292.15	8.3144	3.3869E-11	4081.56341
3.71823204	292.15	8.3144	3.3869E-11	6290.55362
3.71823204	292.15	8.3144	3.3869E-11	11646.2707
3.71823204	292.15	8.3144	3.3869E-11	18978.515
3.71823204	292.15	8.3144	3.3869E-11	43028.1238
3.71823204	292.15	8.3144	3.3869E-11	-634.58467
3.71823204	292.15	8.3144	3.3869E-11	-78.591955
3.71823204	292.15	8.3144	3.3869E-11	672.017921
3.71823204	292.15	8.3144	3.3869E-11	3469.85316
3.71823204	292.15	8.3144	3.3869E-11	6391.60736
3.71823204	292.15	8.3144	3.3869E-11	10006.4142
3.71823204	292.15	8.3144	3.3869E-11	416.689667
3.71823204	292.15	8.3144	3.3869E-11	1523.68154
3.71823204	292.15	8.3144	3.3869E-11	3083.11561
3.71823204	292.15	8.3144	3.3869E-11	3699.81942
3.71823204	292.15	8.3144	3.3869E-11	7139.72046
3.71823204	292.15	8.3144	3.3869E-11	10695.3931
3.71823204	292.15	8.3144	3.3869E-11	19700.3462
3.71823204	292.15	8.3144	3.3869E-11	975.179158
3.71823204	292.15	8.3144	3.3869E-11	1885.0571
3.71823204	292.15	8.3144	3.3869E-11	3111.89425
3.71823204	292.15	8.3144	3.3869E-11	3517.55473
3.71823204	292.15	8.3144	3.3869E-11	5104.05912
3.71823204	292.15	8.3144	3.3869E-11	6090.28585
3.71823204	292.15	8.3144	3.3869E-11	1198.57495
3.71823204	292.15	8.3144	3.3869E-11	2009.89592
3.71823204	292.15	8.3144	3.3869E-11	3194.02506

Table A2-1 Example of Calculation of Calculated Pressure Drop per Unit Length for Specimen A [Continue]

R	S	T	U
sq(RT) B/3*SQRT(N*O*3.1415/0.05794)	epthiron1 M*SQRT(0.02897/O/N)*J	epthiron2 (1+2*S)/(1+2.47*S)	Q, m3Pa/s P*(Q+R*T)*G
967.757223	10.9348939	0.81651021	0.00020456
967.757223	13.2242815	0.81536903	0.00022364
967.757223	15.8025872	0.81446984	0.00024034
967.757223	20.6702805	0.81337199	0.00026779
967.757223	37.3893971	0.81175495	0.00030401
967.757223	61.8572989	0.81095391	0.00030982
967.757223	80.7063202	0.81066638	0.00030365
967.757223	127.517997	0.81031882	0.00027953
967.757223	1.79930145	0.8446677	0.00010592
967.757223	4.66652535	0.82490729	0.00012963
967.757223	8.11158559	0.81876237	0.00015158
967.757223	17.2910936	0.81407001	0.00018468
967.757223	27.0264802	0.81252499	0.0002
967.757223	35.8951123	0.81183885	0.00020029
967.757223	55.3219699	0.81109902	0.00020489
967.757223	102.422565	0.81046579	0.00018946
967.757223	166.905633	0.81017705	0.00018072
967.757223	378.408756	0.80991997	0.00017361
967.757223	-5.5808242	0.79483284	1.19E-05
967.757223	-0.6911732	0.54064983	3.185E-05
967.757223	5.91002915	0.821916	8.0515E-05
967.757223	30.515456	0.81220809	0.00010378
967.757223	56.2106822	0.81107732	0.00010938
967.757223	88.0009261	0.81058801	0.00010855
967.757223	3.66455715	0.82864753	4.829E-05
967.757223	13.3999437	0.81529711	5.6397E-05
967.757223	27.1143113	0.81251602	5.8974E-05
967.757223	32.5378832	0.81205514	6.153E-05
967.757223	62.7899268	0.81093565	6.0389E-05
967.757223	94.0601179	0.81053212	5.9488E-05
967.757223	173.253743	0.81016022	5.6197E-05
967.757223	8.57616601	0.81829444	2.4239E-05
967.757223	16.5780436	0.8142528	2.037E-05
967.757223	27.3674037	0.81249051	1.9012E-05
967.757223	30.9349652	0.81217474	1.7709E-05
967.757223	44.8874014	0.8114175	1.6157E-05
967.757223	53.5607248	0.81114414	1.467E-05
967.757223	10.5408095	0.8167548	6.6692E-06
967.757223	17.6759326	0.81397735	5.1167E-06
967.757223	28.0896991	0.8124202	4.2464E-06

Table A2-1 Example of Calculation of Calculated Pressure Drop per Unit Length for Specimen A [Continue]

V	W	X	Y	Z
c , mole/s U/N/O	Qc kg/min V*0.02897*60	Total area, m2 (3.1415*0.025*0.025)/4	1 Pore area, m2 3.1415*54.1*54.1*10 −12	Total Pore, m2 X*0.241
8.4213E-08	1.4638E-07	0.00049086	1.4229E-08	0.0001183
9.2071E-08	1.6004E-07	0.00049086	1.4229E-08	0.0001183
9.8943E-08	1.7198E-07	0.00049086	1.4229E-08	0.0001183
1.1024E-07	1.9163E-07	0.00049086	1.4229E-08	0.0001183
1.2516E-07	2.1755E-07	0.00049086	1.4229E-08	0.0001183
1.2755E-07	2.217E-07	0.00049086	1.4229E-08	0.0001183
1.2501E-07	2.1729E-07	0.00049086	1.4229E-08	0.0001183
1.1508E-07	2.0003E-07	0.00049086	1.4229E-08	0.0001183
4.3606E-08	7.5797E-08	0.00049086	1.4229E-08	0.0001183
5.3366E-08	9.276E-08	0.00049086	1.4229E-08	0.0001183
6.2402E-08	1.0847E-07	0.00049086	1.4229E-08	0.0001183
7.6031E-08	1.3216E-07	0.00049086	1.4229E-08	0.0001183
8.2335E-08	1.4311E-07	0.00049086	1.4229E-08	0.0001183
8.2456E-08	1.4333E-07	0.00049086	1.4229E-08	0.0001183
8.4351E-08	1.4662E-07	0.00049086	1.4229E-08	0.0001183
7.7996E-08	1.3557E-07	0.00049086	1.4229E-08	0.0001183
7.44E-08	1.2932E-07	0.00049086	1.4229E-08	0.0001183
7.1473E-08	1.2423E-07	0.00049086	1.4229E-08	0.0001183
4.8991E-09	8.5156E-09	0.00049086	1.4229E-08	0.0001183
1.3112E-08	2.2791E-08	0.00049086	1.4229E-08	0.0001183
3.3147E-08	5.7615E-08	0.00049086	1.4229E-08	0.0001183
4.2725E-08	7.4265E-08	0.00049086	1.4229E-08	0.0001183
4.5029E-08	7.827E-08	0.00049086	1.4229E-08	0.0001183
4.4687E-08	7.7674E-08	0.00049086	1.4229E-08	0.0001183
1.988E-08	3.4556E-08	0.00049086	1.4229E-08	0.0001183
2.3218E-08	4.0357E-08	0.00049086	1.4229E-08	0.0001183
2.4279E-08	4.2201E-08	0.00049086	1.4229E-08	0.0001183
2.5331E-08	4.403E-08	0.00049086	1.4229E-08	0.0001183
2.4861E-08	4.3214E-08	0.00049086	1.4229E-08	0.0001183
2.449E-08	4.2569E-08	0.00049086	1.4229E-08	0.0001183
2.3135E-08	4.0214E-08	0.00049086	1.4229E-08	0.0001183
9.9788E-09	1.7345E-08	0.00049086	1.4229E-08	0.0001183
8.386E-09	1.4577E-08	0.00049086	1.4229E-08	0.0001183
7.8269E-09	1.3605E-08	0.00049086	1.4229E-08	0.0001183
7.2907E-09	1.2673E-08	0.00049086	1.4229E-08	0.0001183
6.6514E-09	1.1562E-08	0.00049086	1.4229E-08	0.0001183
6.0394E-09	1.0498E-08	0.00049086	1.4229E-08	0.0001183
2.7456E-09	4.7724E-09	0.00049086	1.4229E-08	0.0001183
2.1064E-09	3.6614E-09	0.00049086	1.4229E-08	0.0001183
1.7482E-09	3.0387E-09	0.00049086	1.4229E-08	0.0001183

Table A2-1 Example of Calculation of Calculated Pressure Drop per Unit Length for Specimen A [Continue]

AA	AB	AC	AD	AE
No. of Pore Z/Y	Tot.Q Kg/min AA*W	Qm*RT H*O*N	R.H.S Term 0.02897*60*AA*Pavg*(Q+R*T)	DPc/m AC/AD/0.009
8313.94104	0.00121699	3.499073639	0.00098949	330000.000
8313.94104	0.00133054	3.499073639	0.00111562	320000.000
8313.94104	0.00142985	3.499073639	0.00125785	305000.000
8313.94104	0.00159316	3.499073639	0.00152665	280000.000
8313.94104	0.00180866	3.499073639	0.00245093	198000.000
8313.94104	0.00184324	3.499073639	0.00380431	130000.000
8313.94104	0.00180651	3.499073639	0.00484705	100000.000
8313.94104	0.00166304	3.499073639	0.00743688	60000.000
8313.94104	0.00063017	2.28738965	0.0004973	340000.000
8313.94104	0.0007712	2.28738965	0.00064663	320000.000
8313.94104	0.00090179	2.28738965	0.00083434	290000.000
8313.94104	0.00109874	2.28738965	0.00134002	220000.000
8313.94104	0.00118984	2.28738965	0.00187793	170000.000
8313.94104	0.0011916	2.28738965	0.00236829	135000.000
8313.94104	0.00121898	2.28738965	0.00344279	95000.000
8313.94104	0.00112714	2.28738965	0.00604847	50000.000
8313.94104	0.00107518	2.28738965	0.00961605	30000.000
8313.94104	0.00103288	2.28738965	0.02131796	13000.000
8313.94104	7.0799E-05	1.125136868	6.5504E-05	290000.000
8313.94104	0.00018949	1.125136868	0.00021635	235000.000
8313.94104	0.00047901	1.125136868	0.00071402	180000.000
8313.94104	0.00061744	1.125136868	0.00207082	80000.000
8313.94104	0.00065073	1.125136868	0.00349195	50000.000
8313.94104	0.00064578	1.125136868	0.00525061	33000.000
8313.94104	0.00028729	0.655309638	0.00059295	130000.000
8313.94104	0.00033552	0.655309638	0.00112531	80000.000
8313.94104	0.00035086	0.655309638	0.00188279	50000.000
8313.94104	0.00036606	0.655309638	0.00218264	45000.000
8313.94104	0.00035928	0.655309638	0.0038559	25000.000
8313.94104	0.00035391	0.655309638	0.00558583	17000.000
8313.94104	0.00033433	0.655309638	0.00996727	9000.000
8313.94104	0.00014421	0.210193153	0.00085983	45000.000
8313.94104	0.00012119	0.210193153	0.00130065	25000.000
8313.94104	0.00011311	0.210193153	0.00189678	16000.000
8313.94104	0.00010536	0.210193153	0.00209401	13500.000
8313.94104	9.6122E-05	0.210193153	0.00286562	9000.000
8313.94104	8.7278E-05	0.210193153	0.00334537	7000.000
8313.94104	3.9677E-05	0.052547681	0.0009678	11000.000
8313.94104	3.0441E-05	0.052547681	0.00136127	6000.000
8313.94104	2.5264E-05	0.052547681	0.00193671	3500.000

Calculation of Specific Surface Area of Particles, S_v

$$\frac{Q.L}{\Delta P.A} = \frac{F_1 \bar{P}}{5 S^2_v \mu RT} + \frac{4 z F_2 \bar{v}}{3 S_v RT} \qquad (A2-3)$$

$$
\begin{aligned}
\bar{P} &= (P_1 + P_2)/2 \\
\Delta P &= P_1 - P_2 \\
Z &= 0.47 \\
\varepsilon &= \text{porosity obtained from table (4.5) in chapter 4} \\
F_1 &= \varepsilon^3/(1-\varepsilon)^2 \\
F_2 &= \varepsilon^2/(1-\varepsilon) \\
Q &= \text{wet gas meter reading} \\
\mu &= \text{viscosity of gas}
\end{aligned}
$$

$\bar{P}, \Delta P$ are obtained from experimental measurement and S_v can be calculated as shown in table A2-2

Calculation of Mean Free Path, λ

$$\lambda = 2.295279 \times 10^{-5} \times T/\bar{P} \qquad (A2-4)$$

Absolute temperature and absolute pressure are obtained from experimental measurement, while calculation of λ is as presented in table A2-3.

Table A2-2 Example of of Calculation of Specific Surface Area of Particles for Specimen A

DP Pa	Pavg, Pa	mu, Pa.s	Tatm, K	R, gas const.	Q, mole/s
2970	851.5737	0.0000181	292.15	8.3144	8.4213E-08
2880	1029.8637	0.0000181	292.15	8.3144	9.2071E-08
2745	1230.6537	0.0000181	292.15	8.3144	9.8943E-08
2520	1609.7337	0.0000181	292.15	8.3144	1.1024E-07
1782	2911.7637	0.0000181	292.15	8.3144	1.2516E-07
1170	4817.2437	0.0000181	292.15	8.3144	1.2755E-07
900	6285.1437	0.0000181	292.15	8.3144	1.2501E-07
540	9930.6837	0.0000181	292.15	8.3144	1.1508E-07
3060	140.1237	0.0000181	292.15	8.3144	4.3606E-08
2880	363.4137	0.0000181	292.15	8.3144	5.3366E-08
2610	631.7037	0.0000181	292.15	8.3144	6.2402E-08
1980	1346.5737	0.0000181	292.15	8.3144	7.6031E-08
1530	2104.7337	0.0000181	292.15	8.3144	8.2335E-08
1215	2795.3937	0.0000181	292.15	8.3144	8.2456E-08
855	4308.2937	0.0000181	292.15	8.3144	8.4351E-08
450	7976.3337	0.0000181	292.15	8.3144	7.7996E-08
270	12998.0637	0.0000181	292.15	8.3144	7.44E-08
117	29469.2337	0.0000181	292.15	8.3144	7.1473E-08
2610	-434.6163	0.0000181	292.15	8.3144	4.8991E-09
2115	-53.8263	0.0000181	292.15	8.3144	1.3112E-08
1620	460.2537	0.0000181	292.15	8.3144	3.3147E-08
720	2376.4437	0.0000181	292.15	8.3144	4.2725E-08
450	4377.5037	0.0000181	292.15	8.3144	4.5029E-08
297	6853.2237	0.0000181	292.15	8.3144	4.4687E-08
1170	285.3837	0.0000181	292.15	8.3144	1.988E-08
720	1043.5437	0.0000181	292.15	8.3144	2.3218E-08
450	2111.5737	0.0000181	292.15	8.3144	2.4279E-08
405	2533.9437	0.0000181	292.15	8.3144	2.5331E-08
225	4889.8737	0.0000181	292.15	8.3144	2.4861E-08
153	7325.0937	0.0000181	292.15	8.3144	2.449E-08
81	13492.4337	0.0000181	292.15	8.3144	2.3135E-08
405	667.8837	0.0000181	292.15	8.3144	9.9788E-09
225	1291.0437	0.0000181	292.15	8.3144	8.386E-09
144	2131.2837	0.0000181	292.15	8.3144	7.8269E-09
121.5	2409.1137	0.0000181	292.15	8.3144	7.2907E-09
81	3495.6837	0.0000181	292.15	8.3144	6.6514E-09
63	4171.1337	0.0000181	292.15	8.3144	6.0394E-09
99	820.8837	0.0000181	292.15	8.3144	2.7456E-09
54	1376.5437	0.0000181	292.15	8.3144	2.1064E-09
31.5	2187.5337	0.0000181	292.15	8.3144	1.7482E-09

Table A2-2 Example of of Calculation of Specific Surface Area of Particles for Specimen A [Continue]

Total Surface Area, m2 (3.1415*0.025*0.025)/4	1 Pore area, m2 3.1415*54.1*54.1*10 -12	No. of Pore Total area/Pore area	Porosity ,e
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241
0.00049086	1.4229E-08	8313.94104	0.241

Table A2-2 Example of of Calculation of Specific Surface Area of Particles for Specimen A [Continue]

F1 e3/(1-e)2	F2 e2/(1-e)	Z Constant	v, m/s SQRT(8*RT/(3.1415*M))	[A] (Q*L)/(DP*A)
0.00090083	0.00072927	0.47	462.083665	4.3223E-06
0.00092709	0.00074958	0.47	462.083665	4.8733E-06
0.00094907	0.00076656	0.47	462.083665	5.4946E-06
0.00097764	0.0007886	0.47	462.083665	6.6688E-06
0.00102374	0.00082409	0.47	462.083665	1.0706E-05
0.00104863	0.00084321	0.47	462.083665	1.6618E-05
0.00105794	0.00085036	0.47	462.083665	2.1173E-05
0.00106947	0.0008592	0.47	462.083665	3.2486E-05
0.00053161	0.00043973	0.47	462.083665	2.1723E-06
0.00074831	0.00061059	0.47	462.083665	2.8246E-06
0.00085365	0.00069268	0.47	462.083665	3.6446E-06
0.00095924	0.00077441	0.47	462.083665	5.8535E-06
0.00100114	0.0008067	0.47	462.083665	8.2032E-06
0.00102122	0.00082215	0.47	462.083665	1.0345E-05
0.00104401	0.00083966	0.47	462.083665	1.5039E-05
0.00106456	0.00085543	0.47	462.083665	2.6421E-05
0.00107426	0.00086288	0.47	462.083665	4.2005E-05
0.0010831	0.00086965	0.47	462.083665	9.3122E-05
19.4561449	-37.32404	0.47	462.083665	2.8613E-07
0.0496995	0.02988095	0.47	462.083665	9.4505E-07
0.00079597	0.0006478	0.47	462.083665	3.119E-06
0.00101029	0.00081375	0.47	462.083665	9.0458E-06
0.0010447	0.00084019	0.47	462.083665	1.5254E-05
0.00106051	0.00085233	0.47	462.083665	2.2936E-05
0.00069615	0.00056972	0.47	462.083665	2.5902E-06
0.0009288	0.0007509	0.47	462.083665	4.9156E-06
0.0010014	0.0008069	0.47	462.083665	8.2244E-06
0.00101479	0.0008172	0.47	462.083665	9.5343E-06
0.00104922	0.00084366	0.47	462.083665	1.6843E-05
0.00106236	0.00085374	0.47	462.083665	2.44E-05
0.00107484	0.00086332	0.47	462.083665	4.3539E-05
0.000863	0.00069994	0.47	462.083665	3.7559E-06
0.00095456	0.0007708	0.47	462.083665	5.6815E-06
0.00100213	0.00080746	0.47	462.083665	8.2855E-06
0.00101127	0.0008145	0.47	462.083665	9.1471E-06
0.00103405	0.00083201	0.47	462.083665	1.2518E-05
0.00104259	0.00083857	0.47	462.083665	1.4613E-05
0.00089543	0.00072508	0.47	462.083665	4.2276E-06
0.00096164	0.00077626	0.47	462.083665	5.9463E-06
0.00100415	0.00080902	0.47	462.083665	8.46E-06

Table A2-2 Example of of Calculation of Specific Surface Area of Particles for Specimen A [Continue]

[B] (4*F2*v)/(3*R*RT)	[C] (F1*P)/(5*u*R*T)	Sv, m3/m2
1.4887E-08	1.0233E-07	5839.63077
1.5252E-08	1.2653E-07	5858.79947
1.5556E-08	1.5396E-07	5874.47128
1.5949E-08	2.0605E-07	5894.35727
1.658E-08	3.8622E-07	5925.35462
1.6918E-08	6.5093E-07	5941.56454
1.7044E-08	8.551E-07	5947.53586
1.7201E-08	1.3624E-06	5954.86765
9.537E-09	1.1216E-08	5496.56483
1.2732E-08	3.7849E-08	5717.05152
1.4228E-08	7.2824E-08	5803.87116
1.5696E-08	1.6986E-07	5881.61355
1.6271E-08	2.744E-07	5910.32219
1.6545E-08	3.7008E-07	5923.69127
1.6856E-08	5.8018E-07	5938.58248
1.7134E-08	1.0904E-06	5951.75171
1.7265E-08	1.7894E-06	5957.89525
1.7385E-08	4.0828E-06	5963.44153
-0.0001764	-6.044E-05	25226.6527
3.9803E-07	-1.519E-07	8949.5082
1.3413E-08	5.0272E-08	5757.62423
1.6396E-08	3.1201E-07	5916.44613
1.6865E-08	5.898E-07	5939.02713
1.7079E-08	9.3414E-07	5949.17802
1.1979E-08	2.8112E-08	5669.86705
1.5276E-08	1.2839E-07	5860.0339
1.6275E-08	2.7535E-07	5910.49424
1.6458E-08	3.3383E-07	5919.43289
1.6926E-08	6.6103E-07	5941.94128
1.7104E-08	9.998E-07	5950.35313
1.7273E-08	1.8583E-06	5958.25615
1.4359E-08	7.7644E-08	5811.09395
1.5632E-08	1.6224E-07	5878.33458
1.6285E-08	2.7807E-07	5910.98431
1.641E-08	3.1653E-07	5917.09562
1.672E-08	4.6727E-07	5932.10904
1.6836E-08	5.6111E-07	5937.65949
1.4812E-08	9.8186E-08	5835.6197
1.5729E-08	1.7397E-07	5883.2848
1.6312E-08	2.8586E-07	5912.33784

Table A2-3 Example of Calculation of Mean Free Path of Specimen A

A	B	C	D	E	F	G
tm mmHg (ty record)	Wet-gas meter Liter/min	Puv cm Hg Mercury mano.	Pua mm Hg A-(C*10)	Pu abs. Pa = P1 1.3329*100*D	T, atm K Room temp.	Mean Free Path 2.295279*10-5*F/E
766.53	1.132	74.9	17.53	2336.5737	292.15	2.87e-6
766.53	1.132	74.8	18.53	2469.8637	292.15	2.71e-6
766.53	1.132	74.7	19.53	2603.1537	292.15	2.58e-6
766.53	1.132	74.5	21.53	2869.7337	292.15	2.34e-6
766.53	1.132	73.8	28.53	3802.7637	292.15	1.76e-6
766.53	1.132	72.6	40.53	5402.2437	292.15	1.24e-6
766.53	1.132	71.6	50.53	6735.1437	292.15	9.96e-7
766.53	1.132	69	76.53	10200.6837	292.15	6.57e-7
766.53	0.740	75.4	12.53	1670.1237	292.15	4.02e-6
766.53	0.740	75.3	13.53	1803.4137	292.15	3.72e-6
766.53	0.740	75.2	14.53	1936.7037	292.15	3.46e-6
766.53	0.740	74.9	17.53	2336.5737	292.15	2.87e-6
766.53	0.740	74.5	21.53	2869.7337	292.15	2.34e-6
766.53	0.740	74.1	25.53	3402.8937	292.15	1.97e-6
766.53	0.740	73.1	35.53	4735.7937	292.15	1.42e-6
766.53	0.740	70.5	61.53	8201.3337	292.15	8.18e-7
766.53	0.740	66.8	98.53	13133.0637	292.15	5.11e-7
766.53	0.740	54.5	221.53	29527.7337	292.15	2.27e-7
766.53	0.740	76	6.53	870.3837	292.15	7.70e-6
766.53	0.364	75.9	7.53	1003.6737	292.15	6.68e-6
766.53	0.364	75.7	9.53	1270.2537	292.15	5.28e-6
766.53	0.364	74.6	20.53	2736.4437	292.15	2.45e-6
766.53	0.364	73.2	34.53	4602.5037	292.15	1.46e-6
766.53	0.364	71.4	52.53	7001.7237	292.15	9.58e-7
766.53	0.212	76	6.53	870.3837	292.15	7.70e-6
766.53	0.212	75.6	10.53	1403.5437	292.15	4.78e-6
766.53	0.212	74.9	17.53	2336.5737	292.15	2.87e-6
766.53	0.212	74.6	20.53	2736.4437	292.15	2.45e-6
766.53	0.212	72.9	37.53	5002.3737	292.15	1.34e-6
766.53	0.212	71.1	55.53	7401.5937	292.15	9.06e-7
766.53	0.212	66.5	101.53	13532.9337	292.15	4.96e-7
766.53	0.068	76	6.53	870.3837	292.15	7.70e-6
766.53	0.068	75.6	10.53	1403.5437	292.15	4.78e-6
766.53	0.068	75	16.53	2203.2837	292.15	3.04e-6
766.53	0.068	74.8	18.53	2469.8637	292.15	2.71e-6
766.53	0.068	74	26.53	3536.1837	292.15	1.90e-6
766.53	0.068	73.5	31.53	4202.6337	292.15	1.60e-6
766.53	0.017	76	6.53	870.3837	292.15	7.70e-6
766.53	0.017	75.6	10.53	1403.5437	292.15	4.78e-6
766.53	0.017	75	16.53	2203.2837	292.15	3.04e-6

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