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OEM Versus After Market

Heat cannot be patented or copy written

Design can be patented or copy written

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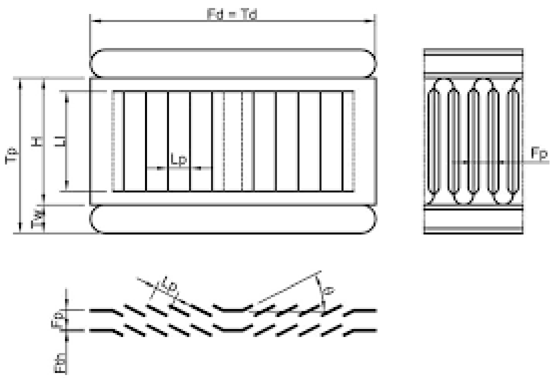
Various Radiator Designs and principal of heat transfer for each type:

Tubes

- Round fins and their characteristics- 3 stages of heat transfer, water forced convection, metal heat transfer, air forced convection
- Flat tubes and their characteristics
- Finned tubes and their characteristics

Fins:

- Louvered Fins
- Dimpled fins
- Formed fins



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Painted Radiators

Used Radiators

Microchannel Heat Exchangers

Various flow characteristics:

- Single Pass and Multiple Pass Characteristics
- Single row and multiple raw characteristics.
- Water only versus Glycol mix Radiator characteristics.

Relationship between Heat and Pressure Drop

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Wind Tunnel Testing

Description of various wind tunnel test facilities:

- Fan and Radiator Simulating car situations, forward and backward fans – Disadvantages
- Streamlined wind tunnel with suction fan type. Scientific type.
- Wind tunnel testing instrumentation- Electronic versus physical instrumentation, Principle of Pitot Tube- Temperature distribution across the air flow surface (after the radiator), etc.
- Wind tunnel testing procedure, obtaining heat versus air speed, head loss versus air speed, “j” and “f” Factors

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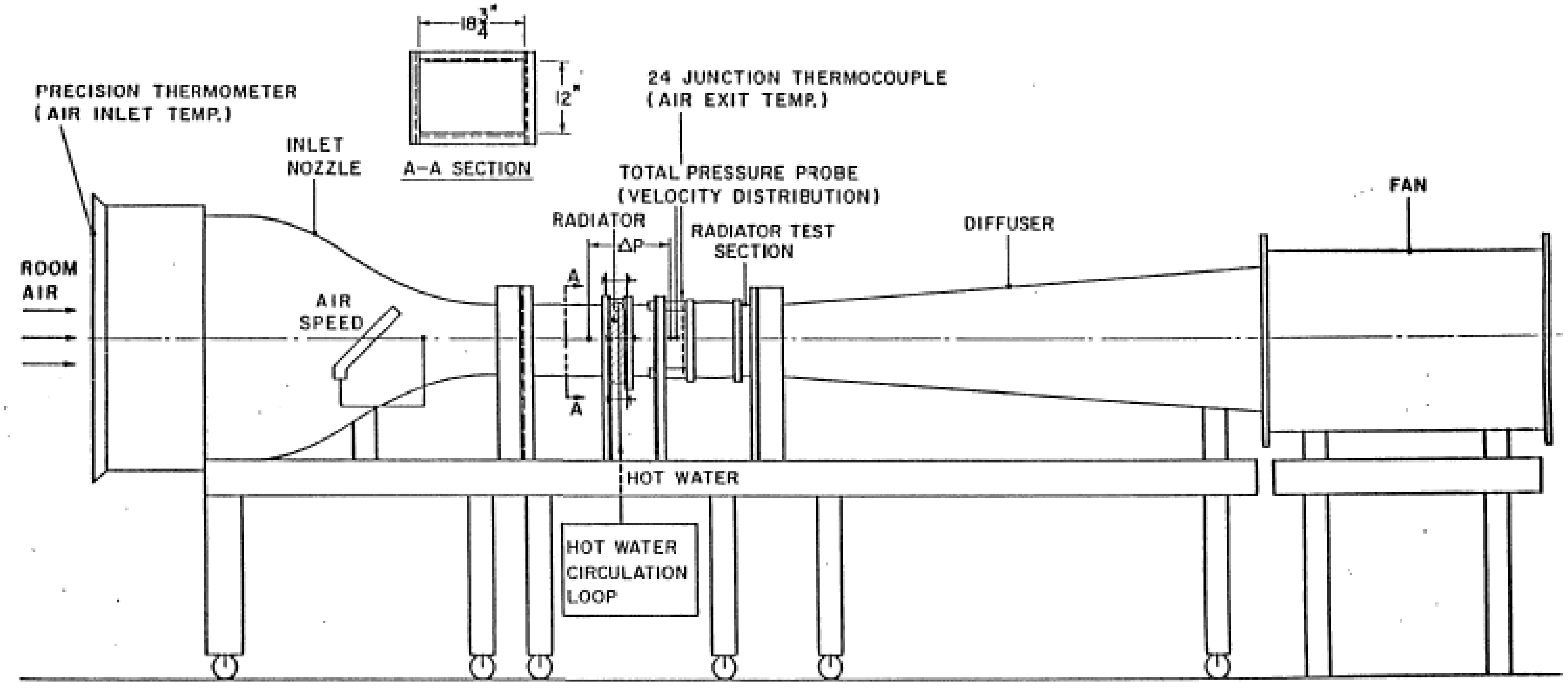

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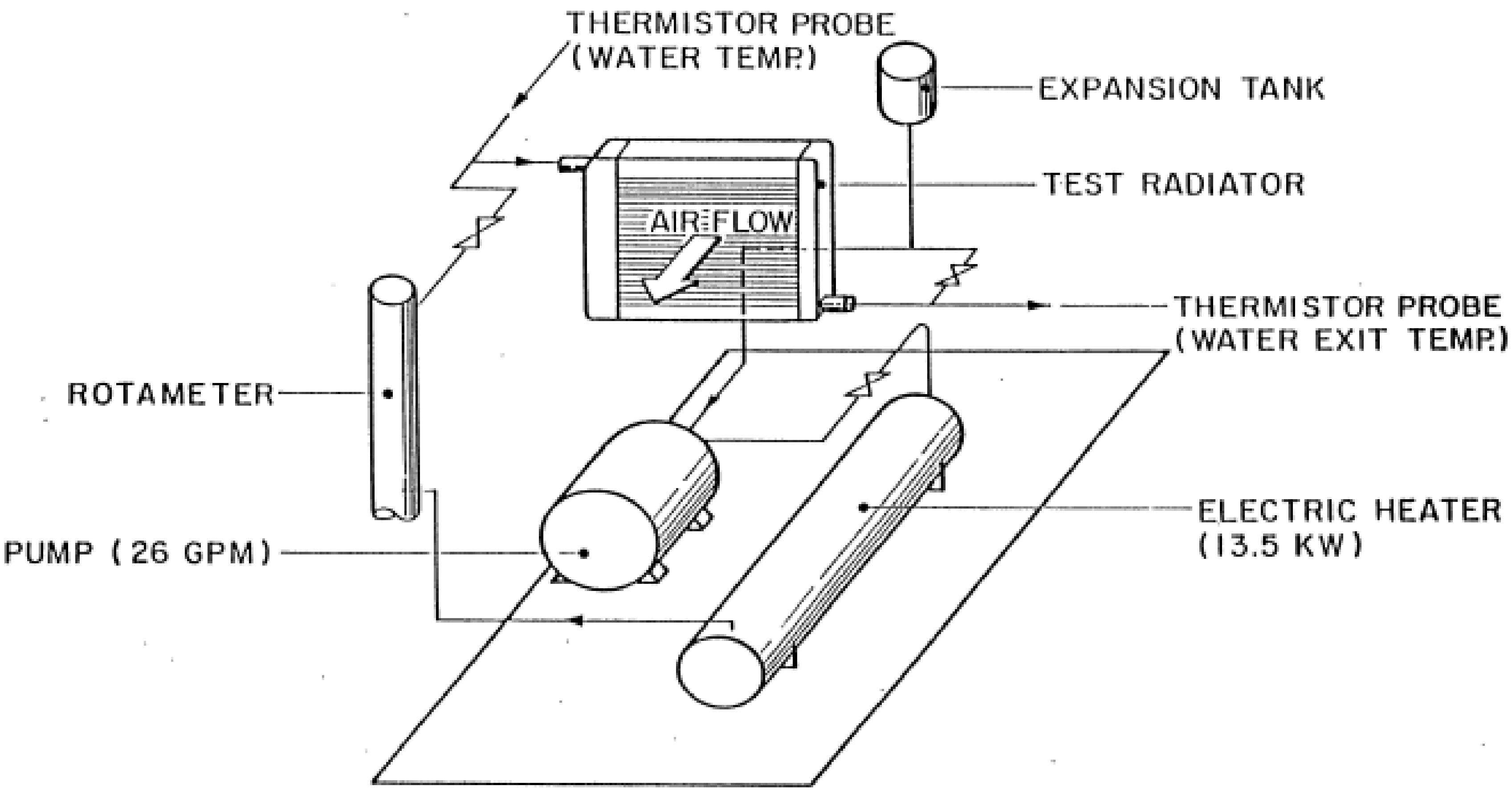

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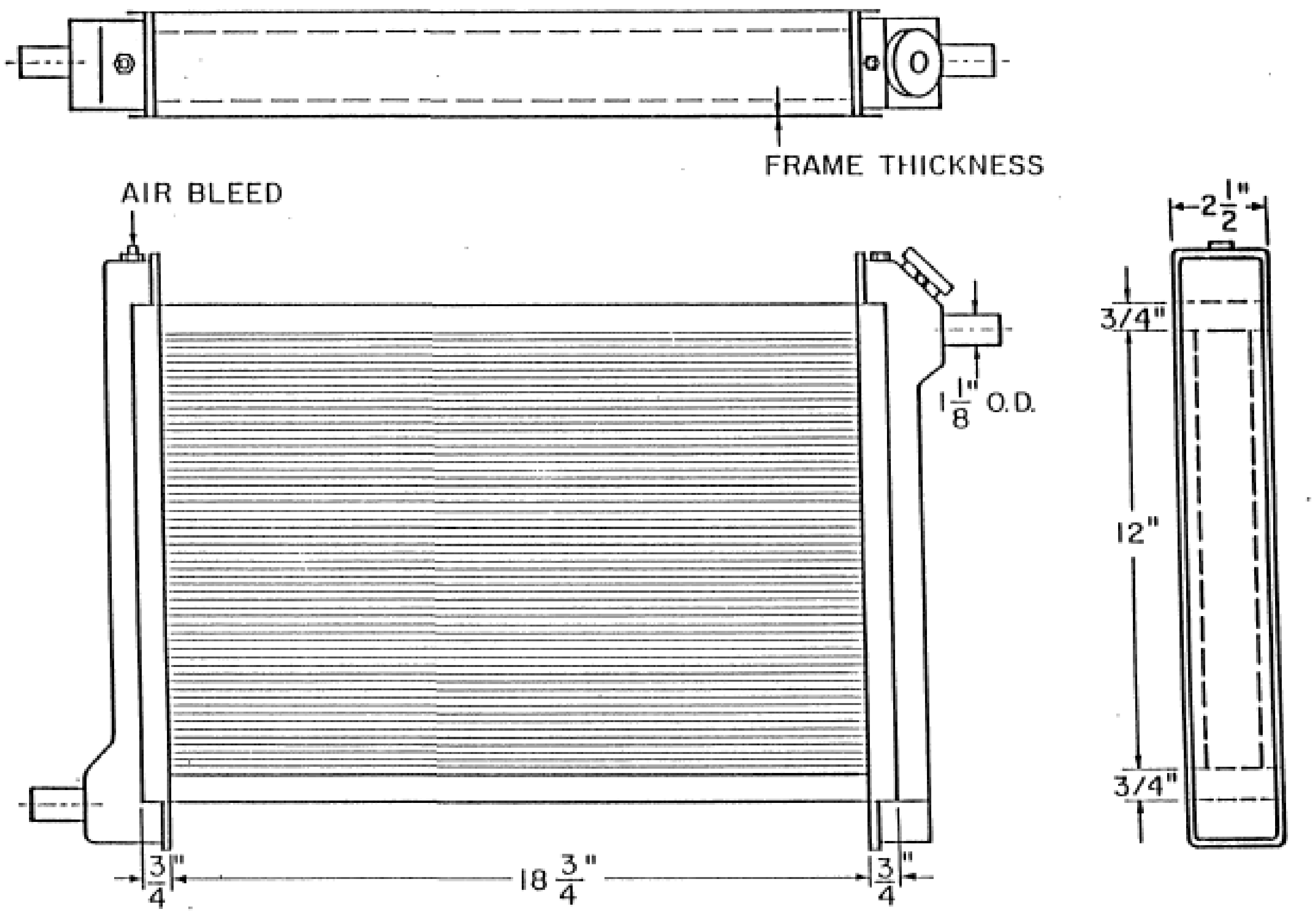

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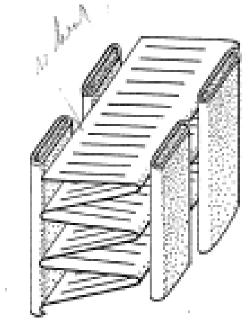
- Principal of heat transfer from water to air.
- Water side forced convection (turbulent and streamlined, dimpled tubes)
- Heat transfer through tubes and the effect of various material- negligible.
- Air side forced convection.
- Heat Transfer formulas
- "j" and "f" factor Formulas
- How to apply them
- Various Software

$$j_H = \frac{f}{2} = \frac{h}{\rho C_p V} \mathrm{Pr}^{2/3}$$



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$$Q_a = \rho u_{fr} A_{fr} c_{p,a}(T_{aout} - T_{a,in})$$

$$Q_w = m_w c_{p,w}(T_{w,in} - T_{w,out})$$

The fin efficiency (ηf) for cores using "flat-oval" tubes is given by

$$\eta_f = \tanh(ml)/ml, \text{ where } m = (2h_o/k_f t_f)^{1/2}$$

The surface efficiency is given by

$$\eta = 1 - (1 - \eta_f)A_f/A_o$$

From the above UA formula, h_o is determined, and

$$j = h_o Pr^{2/3}/\rho \cdot u_c c_p$$

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NOMENCLATURE

σ	Air-side contraction ratio ($=A_c/A_{fr}$)
ΔP	Air pressure drop
ϵ	Core effectiveness
μ	Air viscosity
ρ	Air mass density
A_c	Contracted air-side air flow area
A_f	Fin surface area
A_{fr}	Core frontal area
A_i	Water-side heat transfer area
A_o	Air-side surface area
C	Capacity rate ($=mc_p$)
C_{max}	Maximum heat capacity rate
C_{min}	Minimum heat capacity rate
c_p	Constant pressure specific heat
c_{pa}	Constant pressure specific heat of the air
c_{pw}	Constant pressure specific heat of the water

C_r	Ratio of minimum to maximum heat capacity rate
D_h	Hydraulic diameter
f	Air-side friction factor
g_c	Physical constant that expresses the proportionality between force and momentum change
h_i	Water-side heat transfer coefficient
h_o	Air-side heat transfer coefficient
HB	Heat balance
ITD	Difference between inlet water temperature and inlet air temperature
j	Air-side Colburn j-factor
k	Thermal conductivity
m	Mass flow rate
m_w	Water mass flow rate
η	Surface efficiency
η_f	Fin efficiency
NTU	Number of transfer units

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Pr	Prandtl number of the air
Q_a	Air heat transfer rate
Q_{ave}	Average heat transfer rate of the air and water
Q_w	Water heat transfer rate
Re_i	Water-side Reynolds number based on the hydraulic diameter
Re_o	Air-side Reynolds number based on the hydraulic diameter
R_w	Thermal resistance of the tube wall
$T_{a,in}$	Inlet air temperature
$T_{a,out}$	Exit air temperature
T_D	Tube depth
T_w	Tube width
$T_{w,in}$	Inlet water temperature
$T_{w,out}$	Exit water temperature
UA	Product of the overall heat transfer coefficient and the total heat transfer area
u_c	Air velocity through the contracted flow area
u_{fr}	Air frontal velocity

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Heat Transfer Thermal Resistance

$R_t = R_{cool} + R_{wall} + R_{air}$

$R_{cool} = 1/(h_{cool} A_{cool})$

R_{wall} = negligible

$R_{air} = 1/(h_{air} \cdot \eta \cdot A_{air})$

A_{cool} = coolant-side heat transfer surface area

A_{air} = air-side heat transfer surface area

η = fin efficiency

* Q is proportional to $A \cdot \Delta T$, h is the constant of proportionality
i.e. $Q \sim A \cdot \Delta T$ ---> $Q = h \cdot A \cdot \Delta T$

h_{cool} = coolant side heat transfer coefficient

h_{air} = air side thermal heat transfer coefficient

j = dimensionless heat transfer coefficient

$= [\, h/(\rho \cdot C_p \cdot V) \,] \cdot Pr^{2/3}$

where:

h = heat transfer coefficient

ρ = fluid density

C_p = specific heat

V = fluid velocity

$Pr = \nu/\alpha$

ν = kinematic viscosity of the fluid

α = thermal diffusivity of the fluid

$h = j \cdot \rho \cdot C_p \cdot V \cdot Pr^{-2/3}$

h then is used in the expression for the overall heat transfer coefficient, U

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f = dimensionless pressure drop

$= \Delta p/[(L/D)\cdot(\rho \cdot V^2 \cdot 0.5)]$

where

Δp = air-side pressur

L = depth of radiator

D = hydraulic diamet

ρ = fluid density

V = fluid velocity

$$\Delta p = f\cdot(L/D)\cdot(0.5\cdot\rho\cdot V^2)$$

f is determined from correlations or test data and then the pressure drop is calculated from the above expression

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JFCURV PROGRAM OUTPUT

RADIATOR SPECIFICATIONS:

HEADER WIDTH (in) = 12.00
NUMBER OF TUBE ROWS = 1.0

CORE HEIGHT (in) = 18.75

TUBE DEPTH (in) = .740
TUBE PITCH (in) = .440

TUBE WIDTH (in) = .080
TUBE WALL THICKNESS (in) = .0060

FINS PER INCH = 16.00
FIN THICKNESS = .0025

FIN DEPTH (in) = .810

OPERATING CONDITIONS:

- HEAT TRANSFER TEST DATA

Ufr (ft/s)	Tai (F)	Twi (F)	UA/Afr (Btu/h*ft2*F)	Q/(Afr*ITD) (Btu/h*ft2*F)	GAMMA (lbm/h*in)
8.2	93.0	172.3	716.7	388.0	1272.4
13.9	95.1	152.2	899.5	555.5	1295.6
18.9	96.2	144.1	946.9	638.0	1284.0
26.7	95.9	136.2	1029.5	745.1	1309.2
34.5	95.5	131.9	1152.7	857.2	1310.8
50.5	96.4	126.8	1292.9	1003.3	1320.0

** GAMMA = MASS FLOW RATE PER UNIT CORE WIDTH

j	RED	G/MU (1/ft)
.0387	474.7	56459.5
.0300	834.1	99206.1
.0237	1146.6	136363.2
.0186	1646.7	195848.1
.0166	2138.1	254288.4
.0132	3150.4	374681.8

j = B * [(G/MU) ** A]
where: A = -.5801 B = 22.5878 (RMS ERROR = 2.66 %)

- PRESSURE DROP TEST DATA

AVERAGE TEST AIR TEMPERATURE = 80.0 F

Ufr (ft/s)	DPair (in H2O)	f	ReD	G/MU (1/ft)
6.82	.0711	.1215	442.3	52598.4
14.40	.2150	.0803	933.8	111058.1
22.34	.4234	.0645	1448.7	172294.3
31.26	.6980	.0533	2027.1	241088.7
39.51	1.0114	.0477	2562.1	304715.7
47.84	1.3852	.0441	3102.3	368959.7
56.89	1.8550	.0414	3689.2	438756.7

f = B * [(G/MU) ** A]
where: A = -.5130 B = 31.4702 (RMS ERROR = 1.84 %)

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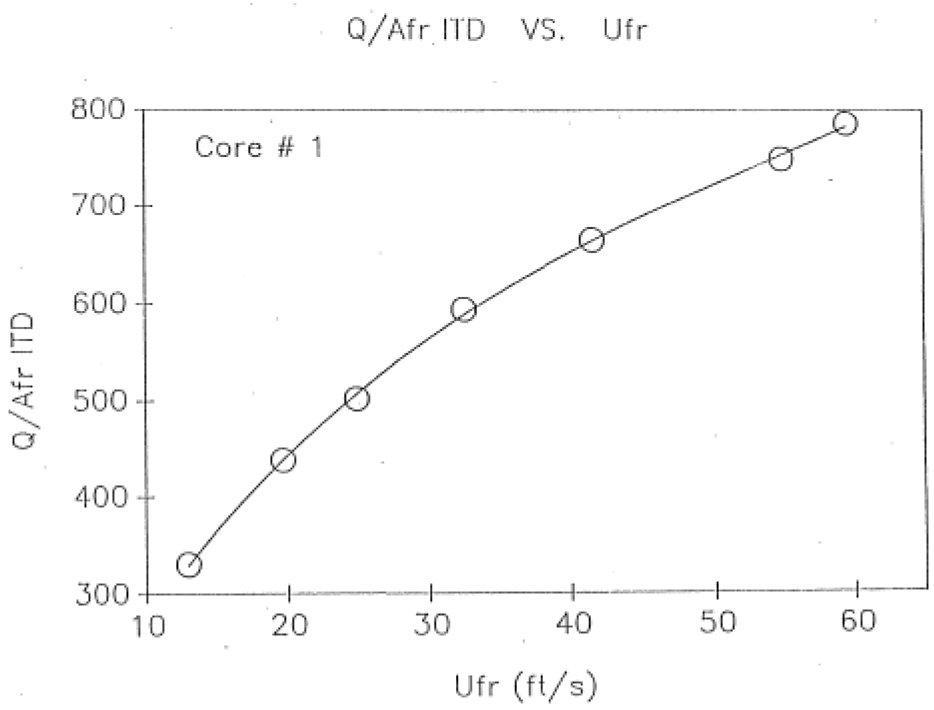

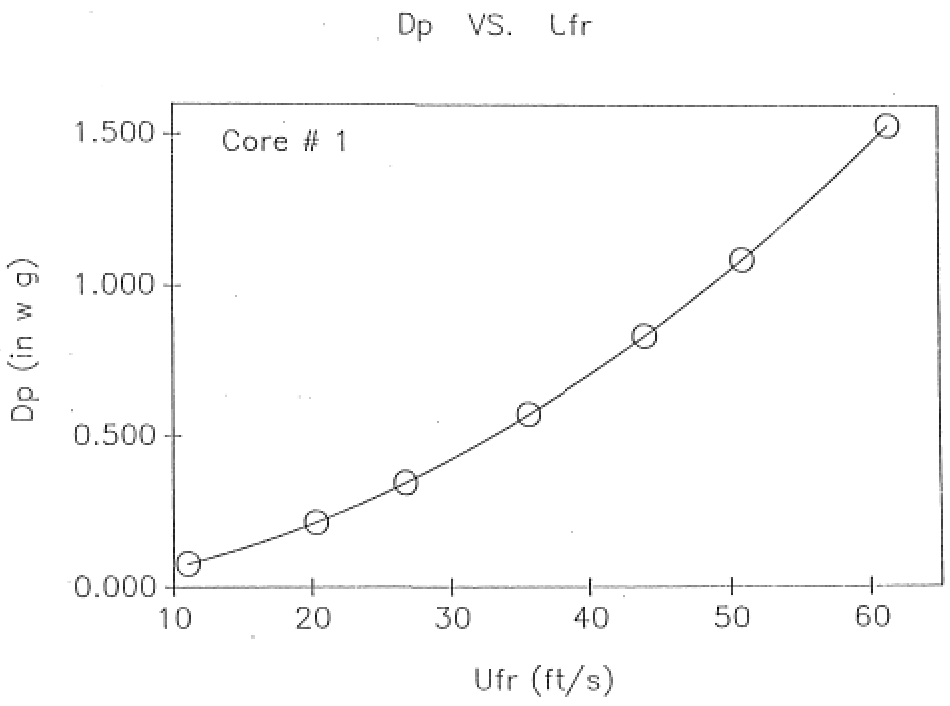

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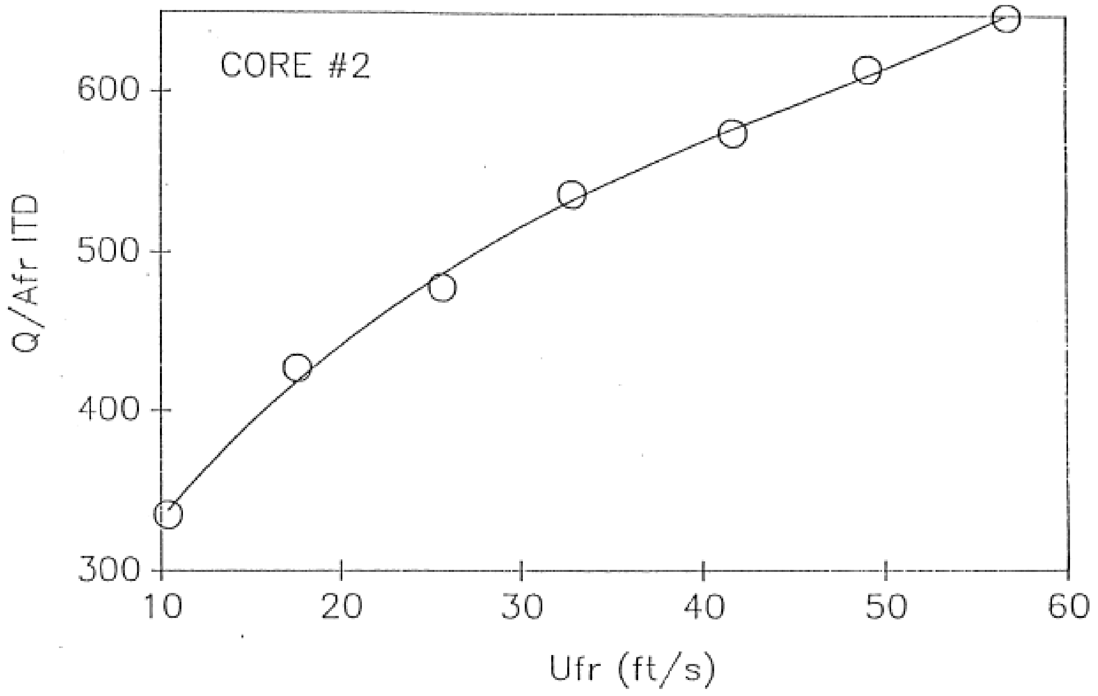
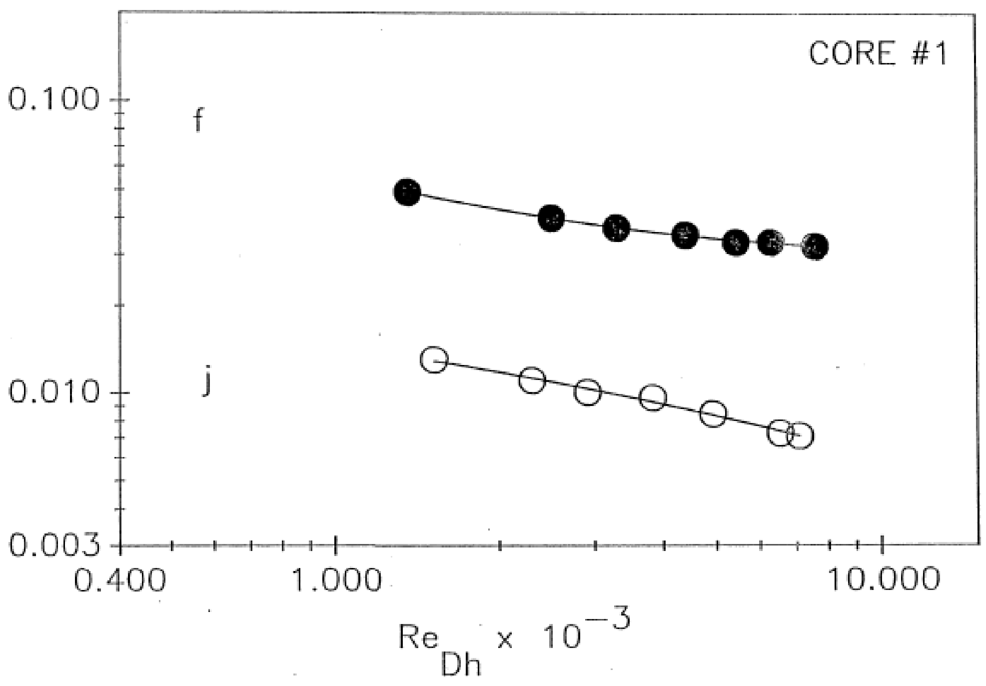
Q/Afr ITD vs. Ufr



J AND F VS. Re_{Dh}



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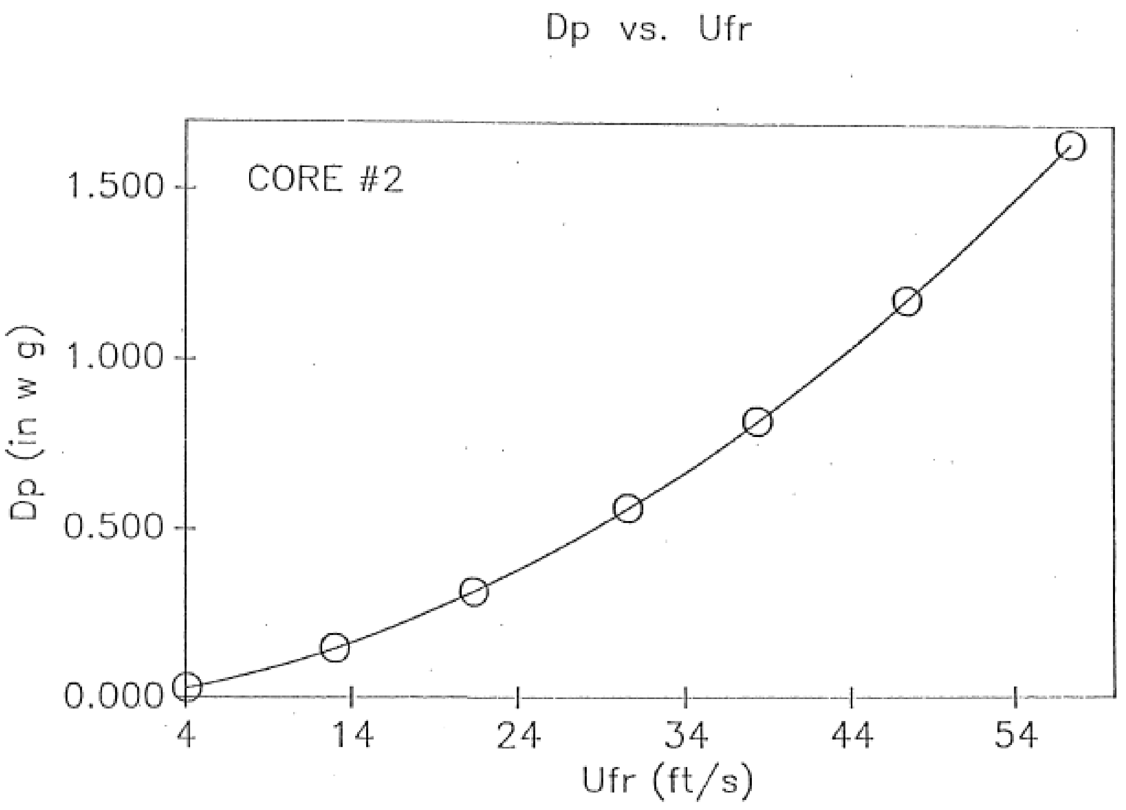

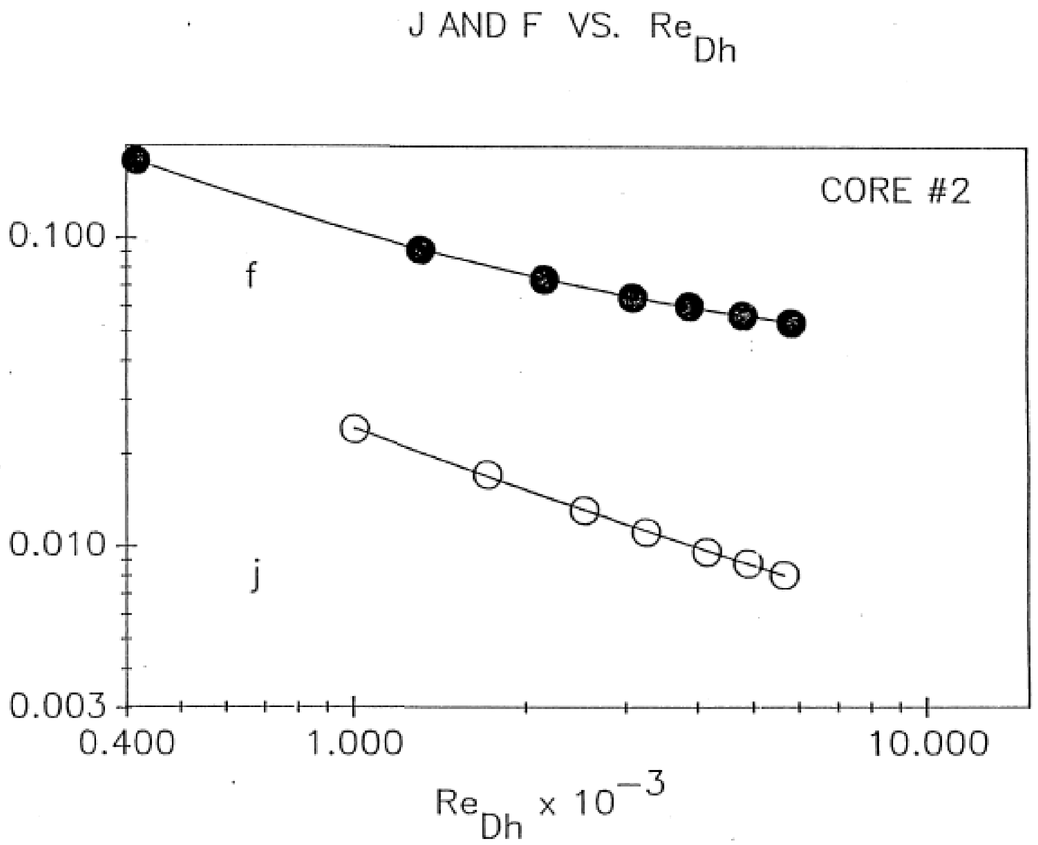

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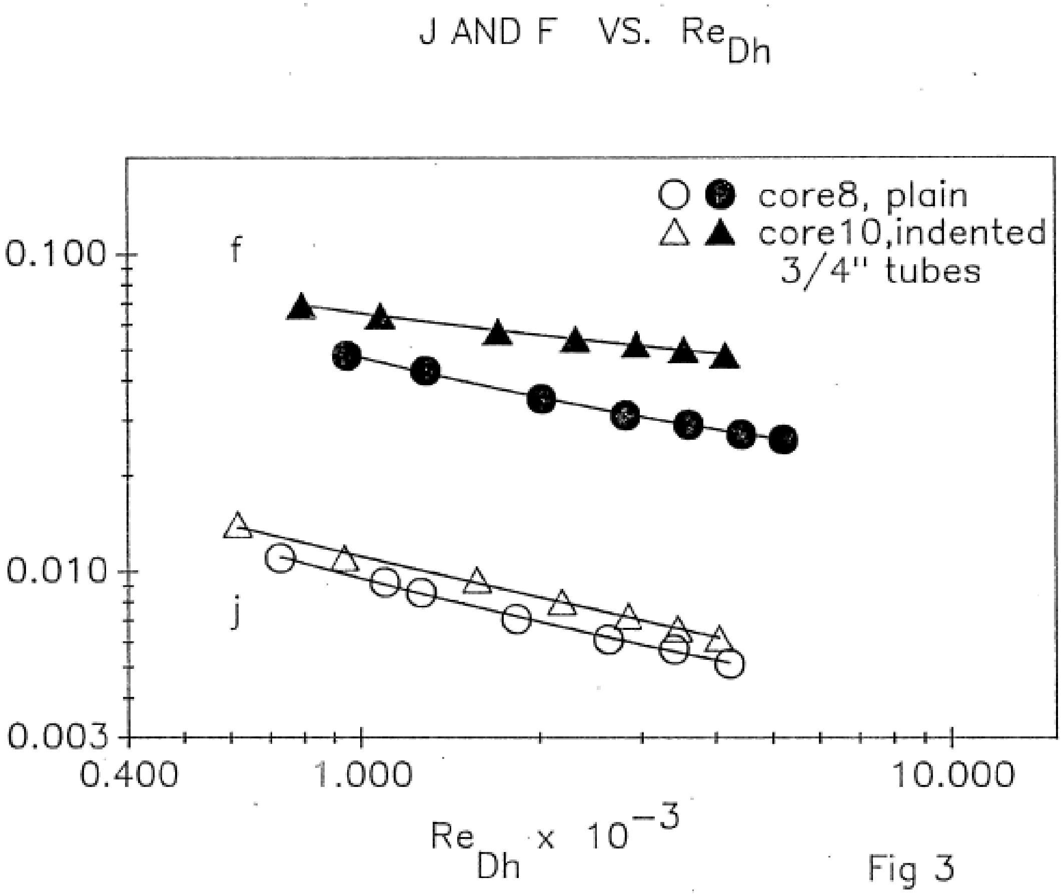

Fig 3

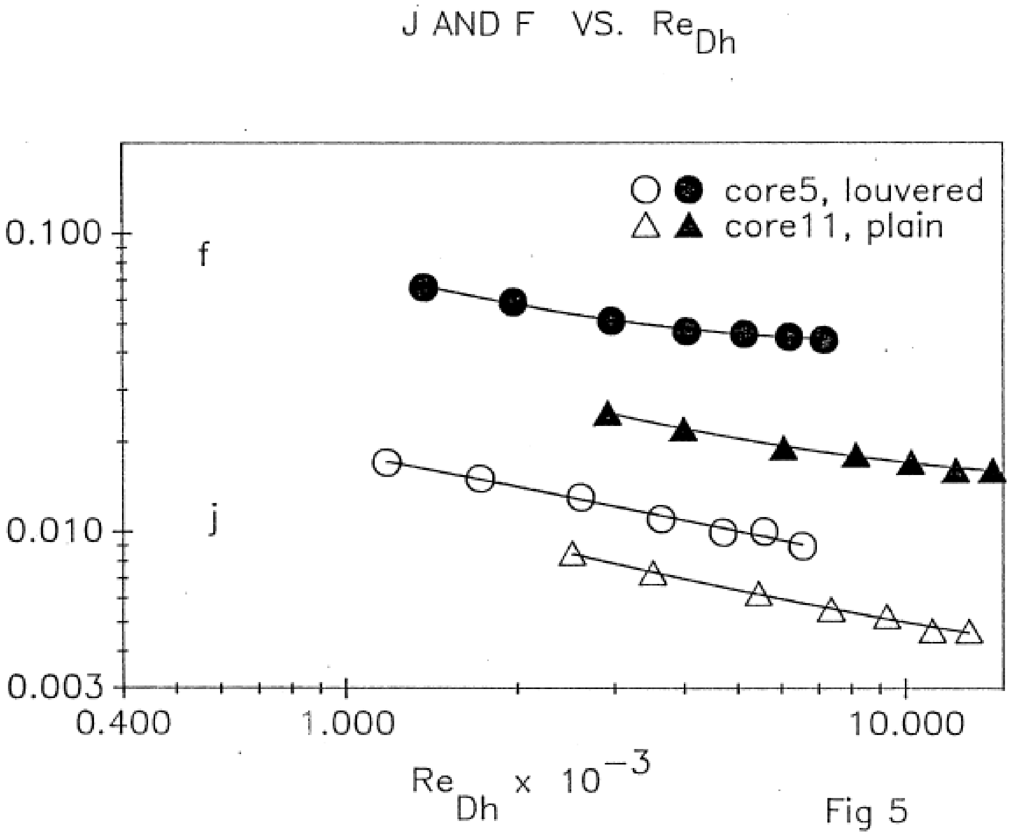

Fig 5

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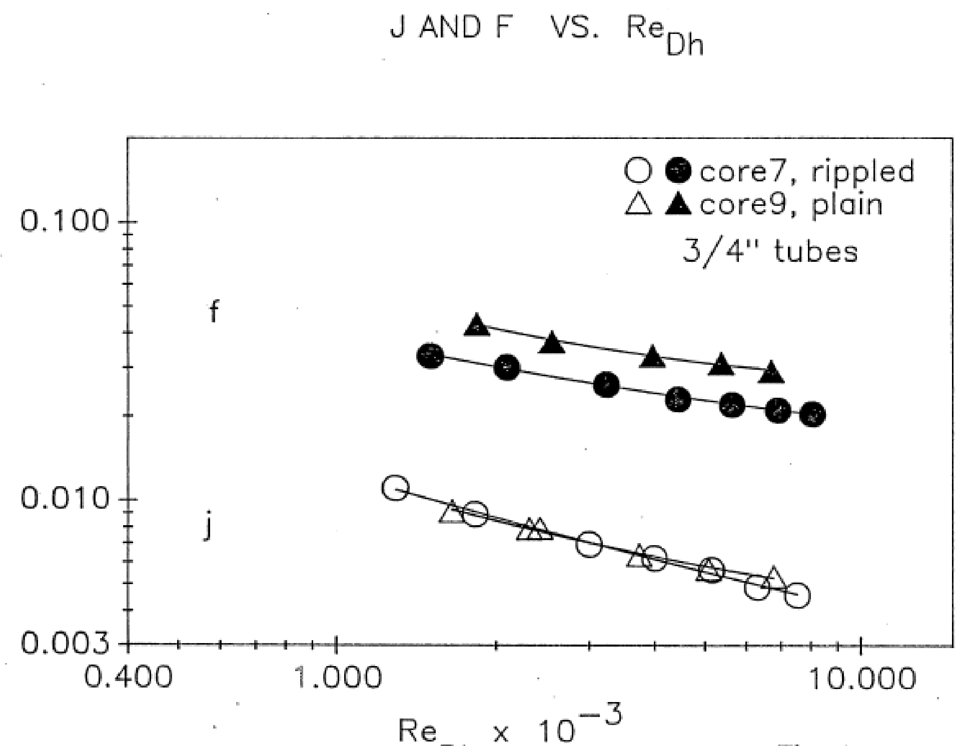

Fig 4

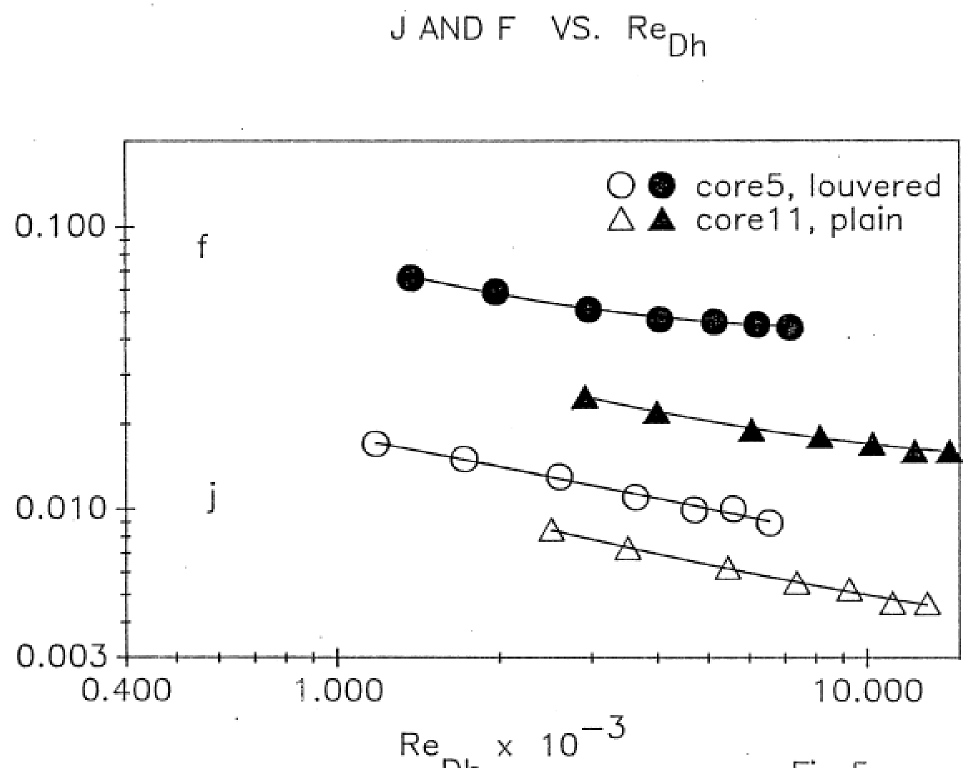

Fig 5

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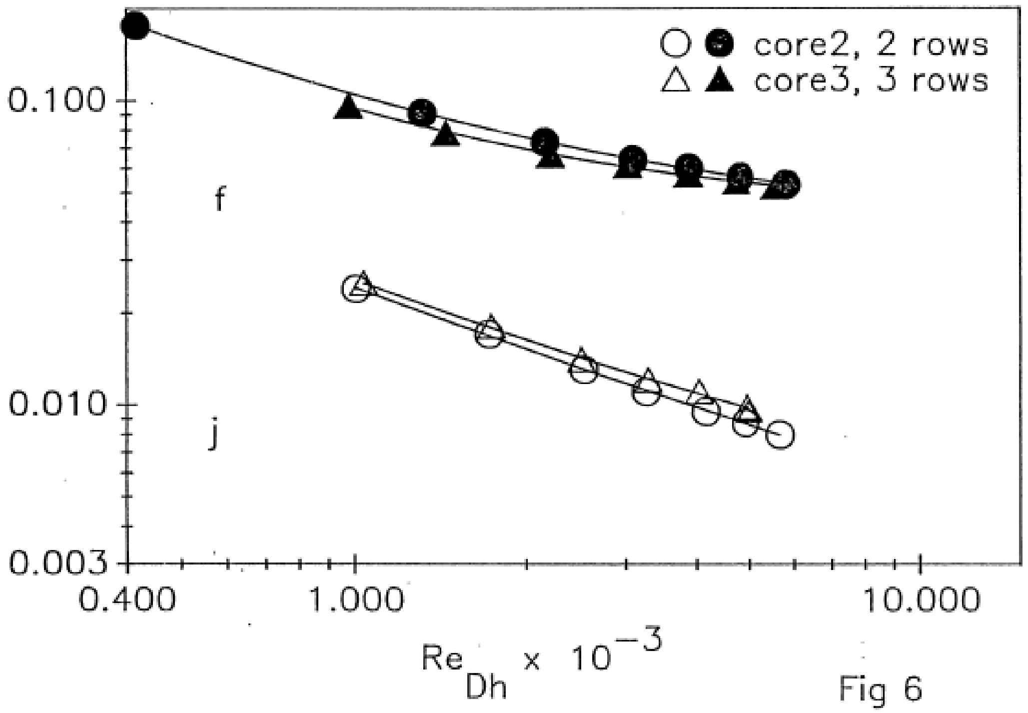

Fig 6

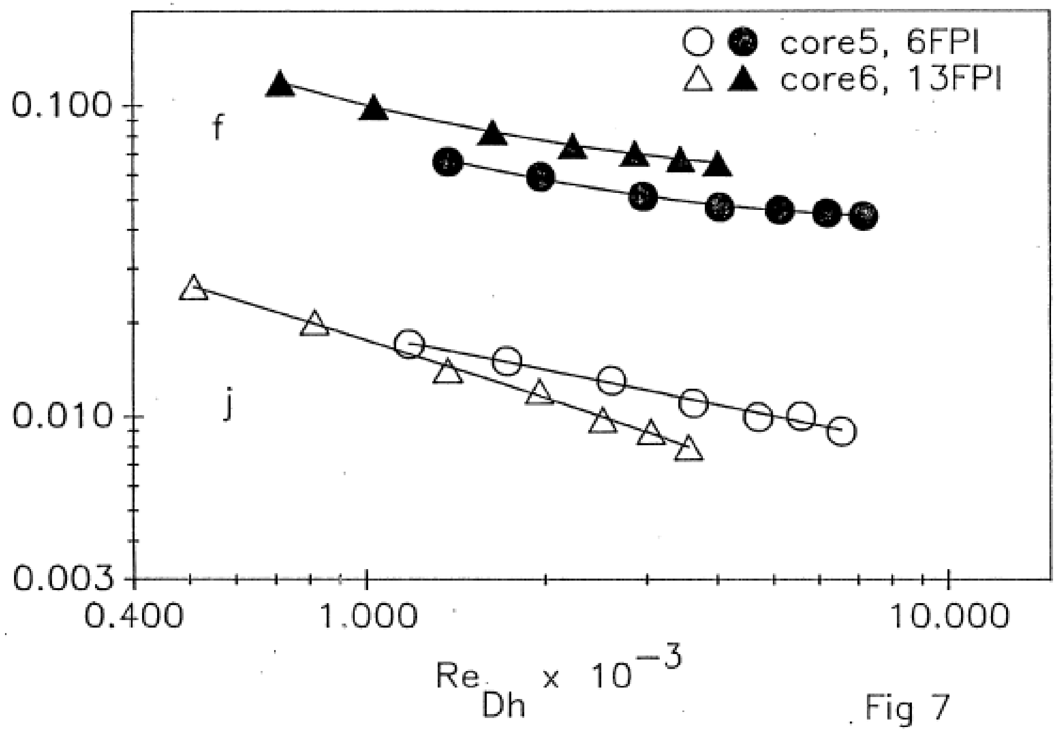

Fig 7

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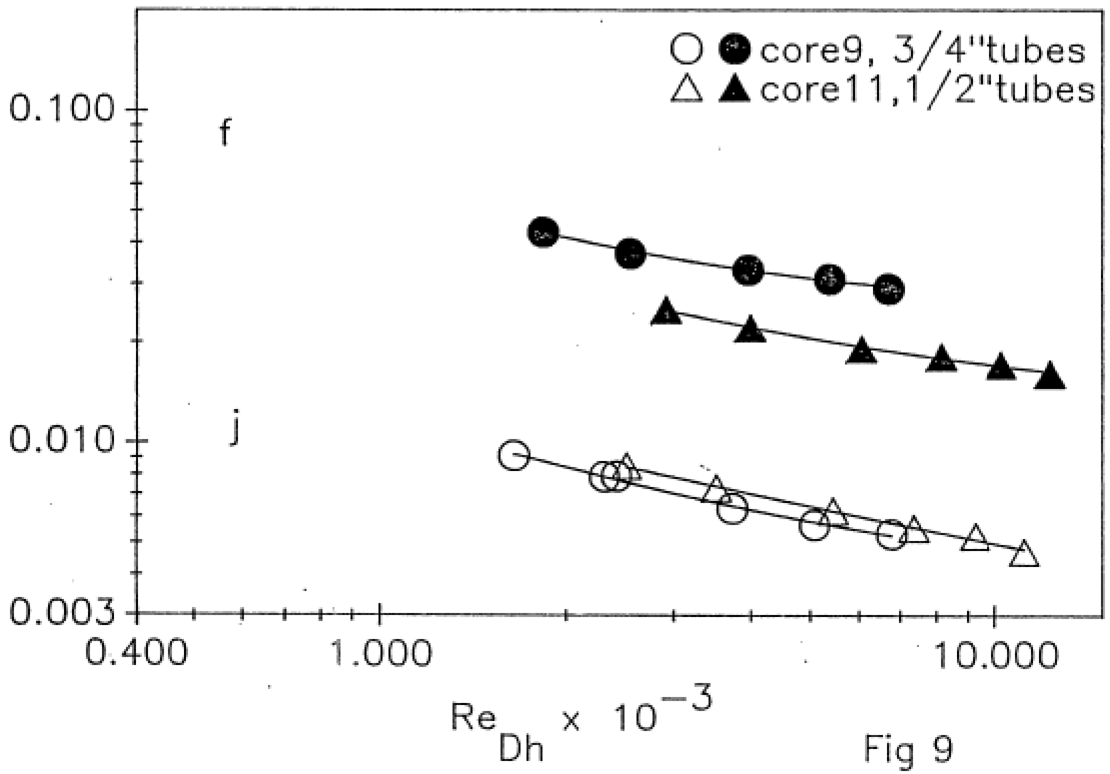

Fig 9

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- Temperature Cycling
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