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Appendix. A

EXPERIMENTAL DATA

RUN NUMBER ..1..

..Surface.. Temperature at current speed ..0.6... m/sec

32.50	32.50	32.50	32.50	32.50	32.50	32.50	32.50		32.80
	32.50	32.50	32.50	32.50	32.50	32.50			
33.10	33.23	33.33	33.35	32.50	32.50	32.50	32.50		32.55
	32.99	33.28	33.82	34.99	35.04	32.50			
32.65	32.65	33.89	34.00	35.09	34.94	35.67	34.50	33.96 ⊙	32.60
	33.23	34.00	34.04	35.50	35.77	36.40	36.50	35.92	32.50
33.21	33.79	34.57	35.01	35.28	34.94	34.82	32.84		32.77
	34.57	33.00	33.55	32.74	32.50	32.74			
32.99	32.99	32.72	32.67	32.77	32.50	32.67	32.50		32.96

Direction of flow ←

Nozzle Diameter ....3........ metre

Ambient Temperature ..32.50.... °C

Discharge Temperature 42.50....... °C

Date & Time ....27/5/77 00:45 P.M.

Scale

|←—— 100 m ——→|

RUN NUMBER .2...

...Surface Temperature at current speed ..0.6.. m/sec

32.10	32.10	32.10	32.10	32.10	32.10	32.10	32.10		32.10	
	32.56	32.59	32.64	32.51	32.01	32.10				
32.66	32.66	32.66	32.73	32.86	32.86	33.17	33.34		32.10	
	32.27	32.54	32.54	32.86	33.26	33.00	33.69	33.86	32.10	Direction of flow
32.42	32.44	32.64	33.56	33.64	33.69	33.95	34.30	⊙	35.10	←
	32.54	32.54	32.54	32.86	33.28	33.27	34.10	34.30	32.10	
32.69	32.71	32.83	33.00	32.91	32.86	33.34	33.59		32.17	
	32.54	32.17	32.29	32.22	32.20	32.20				
32.22	32.25	32.34	32.22	32.22	32.10	32.10	32.10		32.34	

Nozzle Diameter ....4....... metre

Ambient Temperature ..32.10...... °C

Discharge Temperature 42.10.......... °C

Date & Time ..27/5/77 11:00 A.M.

Scale

|←—— 100 m ——→|

RUN NUMBER ..3...

..Surface.. Temperature at current speed ..0.6.. m/sec

32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00
	32.59	32.59	32.95	32.78	32.00	32.00		
32.44	32.54	32.73	32.54	33.00	32.63	33.00	33.02	32.00
	32.34	32.46	32.16	32.73	33.03	33.00	32.68 34.00	32.00
32.39	32.39	32.56	33.49	33.49	33.84	34.00	34.20 ⊙	34.51
	32.49	32.66	33.33	33.73	33.26	33.37	33.90 34.00	32.00
32.41	32.88	32.88	33.10	33.46	33.12	33.05	32.63	32.10
	32.78	32.24	32.39	32.10	32.17	32.00		
32.20	32.27	32.27	32.24	32.27	32.00	32.12	32.12	32.27

Direction of flow ←

Nozzle Diameter ....5.... metre

Ambient Temperature 32.00 ..... °C

Discharge Temperature 42.00 ..... °C

Date & Time .. 26/5/77 10:30 A.M.

Scale

|← 100 m →|

RUN NUMBER .4....

..Surface.. Temperature at current speed .0.8.... m/sec

31.13	31.05	31.10	31.20	31.15	31.07	31.10	31.10	31.15
	31.25	31.15	31.15	31.15	31.15	31.17	31.15	
31.22	32.20	32.83	32.63	32.25	31.15	31.49	31.15	31.10
	31.56	32.63	33.15	33.20	33.27	31.76	31.15	
31.22	31.17	32.23	33.20.	33.20	33.22	33.39	34.00 ⊙	31.15
	31.51	31.39	32.10	33.17	33.59	33.00	32.07	
31.34	32.45	32.15	32.28	32.35	32.23	32.35	31.22	31.22
	31.71	31.81	31.15	32.00	31.24	31.22		
31.24	31.24	31.00	31.00	31.22	31.22	31.22	31.00	31.10

Direction of flow ←

Nozzle Diameter ....3.00.... metre

Ambient Temperature 31.15..... °C

Discharge Temperature 41.15..... °C

Date & Time ...2/4/77.......4:50 P.M.

Scale

100 m

RUN NUMBER ..5..

..Surface.. Temperature at current speed ..0.8.. m/sec

30.17	30.17	30.20	30.20	30.22	30.20	30.17	30.17	30.20	
	30.17	30.17	30.17	30.17	30.17				
30.66	31.00	30.88	31.08	30.98	30.95	31.30	30.27	30.27	
	30.20	30.17	31.42	30.94	31.19	31.28	31.28		Direction of flow
30.34	30.39	30.76	30.63	31.46	31.63	31.90	32.37 ⊙	33.22	←
	30.20	30.17	31.42	30.98	31.20	31.28	31.17		
30.34	30.81	30.83	30.90	31.05	30.95	31.38	30.66	30.37	
	30.42	30.27	30.42	30.46	30.49				
30.17	30.22	30.22	30.20	30.22	30.22	30.17	30.24	30.42	

Nozzle Diameter ...4.00..... metre

Ambient Temperature 30.17...... °C

Discharge Temperature 40.17...... °C

Date & Time ..5/4/77....11:30 A.M.

Scale

100 m

RUN NUMBER ..6..

..Surface.. Temperature at current speed ..0.8.. m/sec

31.17	31.20	31.20	31.24	31.24	31.24	31.00	31.00	31.00
	31.15	31.15	31.17	31.17	31.15			
31.81	31.85	32.00	32.00	32.00	31.95	32.05	31.05	31.02
	31.27	31.51	32.09	32.33	32.56	32.64	32.76	31.15
31.37	31.37	31.61	31.63	32.61	32.54	32.49	33.00 ⊙	33.81
	31.51	31.46	32.13	32.13	32.38	32.73	32.81	32.15
31.51	31.98	31.88	31.83	32.13	32.13	32.13	31.20	31.15
	31.15	31.63	31.15	31.15	31.12			
31.10	31.10	31.10	31.10	31.07	31.07	31.05	31.05	31.12

Direction of flow ←

Nozzle Diameter ...5.00... metre

Ambient Temperature ..31.10.... °C

Discharge Temperature 41.10..... °C

Date & Time ..7/4/77 ...11:00 A.M.

Scale

|← 100 m →|

RUN NUMBER ..7..

..Surface.. Temperature at current speed ..0.9.. m/sec

33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00
	33.00	33.00	33.00	33.00	33.00	33.00		
33.44	33.44	33.00	33.00	33.00	33.00	33.00	33.00	33.00
	33.56	33.49	34.46	34.71	34.00	33.00	33.00	33.00
33.15	33.49	35.15	34.73	34.00	35.00	35.76	34.34 34.44	33.05
	35.68	34.46	34.32	35.00	34.29	34.12	35.44	34.46
33.40	34.20	33.88	33.93	34.10	34.17	33.73	33.12	33.07
	33.00	33.00	33.07	33.00	33.39	33.00		
33.17	33.22	33.24	33.22	33.22	33.00	33.17	33.20	33.34

Direction of flow ←

Nozzle Diameter ....3.... metre

Ambient Temperature ..33.00.. °C

Discharge Temperature .43.00.... °C

Date & Time ..27/5/77 2:00 P.M.

Scale

100 m

RUN NUMBER 8

Surface Temperature at current speed 0.9 m/sec

33.00	33.00	33.00	33.00	33.00	33.00	33.20	33.20	33.20
	33.00	33.00	33.02	33.00	33.00	33.00		
33.37	33.27	33.49	33.50	33.73	33.56	33.56	33.00	33.00
	33.24	33.54	33.60	33.84	33.66	34.20	34.07	33.59
33.24	33.22	33.52	33.72	33.90	34.05	34.80	34.63 ⊙	35.42
	33.24	33.59	33.64	33.84	33.90	34.20	34.32	35.05
33.54	33.15	33.73	33.50	33.24	33.46	33.73	33.00	33.00
	33.00	33.02	33.00	33.00	33.17	33.05		
33.24	33.12	33.26	33.12	33.12	33.00	33.10	33.00	33.22

Direction of flow ←

Nozzle Diameter 4 metre

Ambient Temperature 33.00 °C

Discharge Temperature 43.00 °C

Date & Time 26/5/77 2:00 P.M.

Scale

100 m

RUN NUMBER ..9..

..Surface.. Temperature at current speed ..0.9.. m/sec

33.00	33.00	33.00	33.07	33.00	33.07	33.05	33.00	33.00	
	33.00	33.12	33.00	33.00	33.00	33.00			
33.46	33.56	33.73	33.71	33.90	33.90	33.73	33.00	33.00	
	33.24	33.70	33.72	33.76	33.85	33.49	33.00	33.48	Direction of flow
37.34	33.34	33.49	34.27	34.49	34.49	34.82	35.00⊙	35.27	←
	33.61	33.49	33.85	33.89	33.32	35.20	35.93	35.28	
33.71	33.37	33.90	33.73	33.81	33.49	33.42	33.07	33.07	
	33.05	33.00	33.15	33.12	33.32	33.24			
33.07	33.17	33.22	33.17	33.15	33.00	33.00	33.00	33.00	

Nozzle Diameter ......5...... metre

Ambient Temperature ..33.00.... °C

Discharge Temperature .43.00...... °C

Date & Time ..27/5/77 00:15 P.M.

Scale

|—— 100 m ——|

RUN NUMBER 10

Surface Temperature at current speed 1.0 m/sec

30.32	30.40	30.37	30.59	30.61	30.37	30.27	30.29	30.40
	30.46	30.37	30.54	31.05	30.46	30.46	30.46	
30.32	30.32	30.32	30.32	30.32	30.32	30.93	30.07	30.24
	30.88	31.83	32.13	31.88	31.39	30.32	31.17	
30.51	30.59	31.29	31.29	31.39	32.10	32.48	32.63 ⊙	30.12
	30.88	30.83	31.54	31.59	31.63	31.78	32.13	
30.59	30.59	30.49	31.12	31.12	31.12	31.15	30.40	30.24
	30.39	30.71	30.29	30.37	30.42	30.00	30.30	
30.44	30.44	30.22	30.34	30.34	30.34	30.32	30.32	30.46

Direction of flow ←

Nozzle Diameter 3.00 metre

Ambient Temperature 30.40 °C

Discharge Temperature 40.40 °C

Date & Time 2/4/77 3:00 P.M.

Scale

|← 100 m →|

RUN NUMBER ..H..

..Surface.. Temperature at current speed ..1.0.. m/sec

32.25	32.30	32.30	32.30	32.30	32.30	32.30	32.30	32.30
	32.20	32.23	32.28	32.28	32.33	32.33		
32.43	32.43	33.80	33.92	33.13	33.29	32.95	32.20	32.18
	32.65	32.85	33.05	32.98	33.27	33.73	33.76	
32.26	32.30	32.43	33.03	33.53	33.93	34.30	34.39 ⊙	34.81
	32.93	32.83	33.13	33.22	33.98	34.34	34.10	
32.26	32.75	32.85	33.03	33.07	33.20	32.98	32.12	32.12
	32.23	32.25	32.33	32.30	32.53	32.32		
32.12	32.12	32.12	32.12	32.10	32.02	32.02	32.12	32.12

Direction of flow ←

Nozzle Diameter ..4.00.. metre

Ambient Temperature ..32.12.. °C

Discharge Temperature ..42.12.. °C

Date & Time ..4/4/77 5:30 P.M...

Scale

100 m

RUN NUMBER 12

Surface Temperature at current speed 1.0 m/sec

32.38	32.40	32.45	32.50	32.53	32.58	32.23	32.23	32.15
	32.23	32.23	32.20	32.18	32.18	32.12	?	
32.53	32.60	32.85	32.83	32.78	32.25	32.10	32.13	32.10
	32.85	32.55	32.48	33.25	33.48	33.38	32.78	32.10
32.45	32.38	32.55	32.50	32.85	33.70	34.35	34.44 ⊙	34.54
	32.85	32.78	32.95	34.29	33.42	33.12	32.38	32.10
32.60	32.60	32.80	32.63	32.85	32.30	32.12	32.10	32.28
	32.38	32.48	32.38	32.38	32.49	32.12		
32.20	32.20	32.10	32.12	32.10	32.00	32.00	32.10	32.18

Direction of flow ←

Nozzle Diameter 5.0 metre

Ambient Temperature 32.12 °C

Discharge Temperature 42.12 °C

Date & Time 7/4/77 1:45 P.M.

Scale

|←— 100 m —→|

RUN NUMBER ..13.

..Surface.. Temperature at current speed ..1.2.. m/sec

30.54	30.66	30.54	30.78	30.66	30.81	30.49	30.51		30.68
	30.66	30.54	30.73	30.51	30.27				
30.66	30.66	30.66	30.66	30.66	30.27	30.42	30.54		30.76
	30.78	31.00	31.10	31.49	31.44	32.02	33.76		
30.63	30.66	31.61	31.61	31.71	32.15	33.22	33.29	⊙	30.63
	30.90	30.93	31.00	31.39	31.60	32.07	35.17		
30.63	30.85	30.85	30.85	30.68	30.61	30.44	30.44		30.44
	30.66	30.66	30.56	30.66	30.41	30.44			
30.66	30.66	30.59	30.56	30.66	30.30	30.46	30.59		30.66

Direction of flow ←

Nozzle Diameter ....3.0.... metre

Ambient Temperature 30.66..... °C

Discharge Temperature 40.66........ °C

Date & Time ....4/4/77 1:30 P.M.

Scale

|←—— 100 m ——→|

RUN NUMBER 14

Surface Temperature at current speed 1.2 m/sec

32.03	32.03	32.03	32.03	32.03	32.03	32.03	32.03	32.03
	32.00	32.00	32.00	32.00	32.00	32.00		
32.28	32.33	32.33	32.65	32.45	32.20	32.00	32.00	32.00
	32.00	32.00	32.00	32.50	32.93	33.66	34.17	
32.20	32.00	32.13	32.80	33.00	33.15	33.35	33.66 ⊙	32.00
	32.05	32.00	32.08	32.48	32.93	33.73	33.95	32.88
32.35	32.45	32.45	32.58	32.48	32.45	32.00	32.00	32.00
	32.00	32.00	32.00	32.00	32.00	32.00		
32.03	32.03	32.03	32.03	32.03	32.03	32.03	32.03	32.03

Direction of flow ←

Nozzle Diameter 4.0 metre

Ambient Temperature 32.00 °C

Discharge Temperature 42.00 °C

Date & Time 4/4/77 4:00 P.M.

Scale

|←— 100 m —→|

RUN NUMBER ..15..

..Surface.. Temperature at current speed ..1.2.. m/sec

33.37	33.37	33.37	33.37	33.37	33.37	33.37	33.37	33.37
	33.37	33.37	33.37	33.37	33.37			
33.46	33.46	33.71	33.71	33.83	33.37	33.37	33.37	33.37
	33.46	33.76	34.06	34.18	34.31	34.51	35.27	33.54
33.61	33.49	33.99	34.49	34.56	34.81	35.01	35.56 ⊙	33.37
	33.83	33.71	34.00	34.10	34.29	34.56	35.71	33.51
33.51	33.49	33.46	33.37	33.37	33.37	33.37	33.37	33.37
	33.37	33.37	33.37	33.37	33.49	33.56		
33.37	33.37	33.34	33.32	33.32	33.37	33.37	33.31	33.51

Direction of flow ←

Nozzle Diameter ..5.0.. metre

Ambient Temperature 33.37.. °C

Discharge Temperature 43.37.. °C

Date & Time ..7/4/77 4:00 P.M..

Scale

|← 100 m →|

Appendix. B

SAMPLE OF CALCULATION

1. Prototype

1.1 Heat being dissipated to sea.

Power output from power plant	=	600 MW
Efficiency	=	30 %
$\frac{\text{Power output}}{\text{Power input}}$	=	0.3
Power input ($\dot{q}_i$)	=	600/0.3
	=	2000 MW
Heat being dissipated to sea	=	2000 - 600
	=	1400 MW

1.2 Mass flow rate of cooling water.

Temperature at the discharge is approximately 10 °C above ambient.

$$\Delta T = 10\ ^\circ C$$

From

$$\dot{q}_o = \dot{m}\, C_p\, \Delta T$$

$$1400 \times 10^6 = \dot{m} \times 3.93 \times 10^3 \times 10$$

$$\dot{m} = 35.6 \times 10^3 \quad \text{Kg/sec}$$

1.3 Velocity of cooling water.

From

$$Q = (\pi d^2 U)/4$$

$$= (35.6 \times 1000)/(1.02 \times 1000)$$

$$= 34.9 \quad m^3/sec$$

$$U = 4Q/\pi d^2$$

$$= (4 \times 34.9)/d^2$$

$$= 44.4/d^2$$

If $d = 3$ m.

$$U = 44.4/3^2$$

$$= 4.93 \quad m/sec$$

1.4 Reynolds Number.

$$Re = \rho Ud/\mu$$

$$= (1.02 \times 10^3 \; U \; d)/(.8 \times 10^{-3})$$

$$= 1.275 \times 10^6 \; U \; d$$

$d = 3$ m. , $U = 4.93$ m/sec

$$Re = 1.275 \times 10^6 \times 3 \times 4.93$$

$$= 1885 \times 10^4$$

1.5 Tide discharge.

Tide discharge = cross section area x velocity

= depth x width x velocity

= 8 x 200 x 1

= 1600 m^3/sec

2. Model

2.1 Size of basin.

From section 2.2.1 $L_r = 1/100$

Size of prototype = 400 m. by 200 m.

Size of model = 400/100 m. by 200/100 m.

= 4 m. by 2 m.

Area of model = 4 x 2

= 8 m^3.

2.2 Tide velocity.

From section 2.2.2 $V_m/V_p = L_r^{\frac{1}{2}}$

velocity in prototype = 1 m/sec

$V_m = 1 \times (1/100)^{\frac{1}{2}}$

= 0.10 m/sec

2.3 Tide discharge.

Tide discharge = depth x width x velocity

= 0.08 x 2 x 0.10

= 0.016 m^3/sec

2.4 Velocity of cooling water

Nozzle diameter in prototype = 3 m.

Nozzle diameter in model = 3/100 m.

From section 2.2.2 $U_m/U_p = L_r^{\frac{1}{2}}$

$$U_m = 4.93\sqrt{1/100}$$

$$= 0.49 \quad m/sec$$

2.5 Mass rate of cooling water.

$$\dot{m} = \text{density x area of nozzle x velocity}$$

$$= 10^3 \times 0.49 \times \pi(0.03)^2/4$$

$$= 0.349 \quad Kg/sec$$

2.6 Rate of heating required for the model.

$$\dot{P}_m = \dot{m}\, C_p\, \Delta T$$

$$= 0.349 \times 1000 \times 1 \times 10$$

$$= 3490 \quad cal/sec$$

$$= 3490 \times (3600/252) \quad Btu/hr$$

$$= 49857/3412 \quad kw$$

$$= 14.6 \quad kw$$

Appendix. C

DERIVATION OF THE PREDICTION EQUATION

The prediction equation has the form:

$$\frac{\partial \alpha}{\partial t} = - \frac{Q}{A} \cdot \frac{\partial \alpha}{\partial x} + E \frac{\partial^2 \alpha}{\partial x^2} + S_c \qquad (A)$$

where :

α = concentration of water quality characteristic

t = time

Q = total flow

A = cross-sectional area

E = dispersion coefficient

S_c = source or sink

x = coordinates measured in the direction of the current

Armstrong derived this equation as follow :

He assumed that $E = 0$

The equation is reduced to

$$\frac{\partial \alpha}{\partial t} = - \frac{Q}{A} \cdot \frac{\partial \alpha}{\partial x} + S_c \qquad (B)$$

The concentration of heat, H, may be represented as :

$$H = \gamma C_p (T - T_R)$$

where :

γ = water density

C_p = specific heat of water

T = water temperature at any point

T_R= arbitrary base temperature

Substituting the value of H into equation (B) gives :

$$\frac{\partial[\gamma C_p(T-T_R)]}{\partial t} = -\frac{Q}{A}\cdot\frac{\partial[\gamma C_p(T-T_R)]}{\partial x} + S_c$$

Considering T_R , γ , and C_p to be constant, then dividing by γC_p

$$\frac{\partial T}{\partial t} = -\frac{Q}{A}\cdot\frac{\partial T}{\partial x} + \frac{1}{\gamma C_p} S_c \qquad (C)$$

It may be shown that

$$S_c = H_n/D$$

where :

H_n= interfacial heat transfer rate and is the function of solar and atmospheric radiation, back radiation, evaporation, and conduction.

D = hydraulic depth

and $$H_n = \lambda(T_a - T)$$

where :

λ = heat exchange coefficient

T_a = ambient temperature

then $$S_c = \lambda(T_a - T)/D$$

Substituting the value of S_c into equation (C)

$$\frac{\partial T}{\partial t} = -\frac{Q}{A}\frac{\partial T}{\partial x} + \frac{\lambda(T_a - T)}{\gamma C_p D}$$

at steady state $\frac{\partial T}{\partial t} = 0$

then, the equation becomes

$$\frac{\partial T}{\partial x} = \frac{A \lambda \ (T_a - T)}{Q \gamma C_p D} \qquad (D)$$

The solution of the equation (D) is

$$T = (T_R - T_a)\, e^{-kx/U} + T_a \qquad (E)$$

where :

$k = \lambda \gamma C_p D$

U = velocity of ambient current

T_R= base temperature along the centre-line of the nozzle

Appendix. D

Selection of the materials to make the sea bed.

Materials	Roughness coefficient of materials	Depth (cm.)	Velocity measured (cm/sec)
Mortar	0.013	8	15.4
Sand	0.018	8	11.0
gravel	0.020	8	10.0

It may be observed from the Table that the desired depth and velocity could be obtained using either the sand or gravel as the bedding materials. In the present work, gravel was chosen because of its good resistance against deformation by the current.

Appendix. E

Experimental results plotted in dimensionless form.

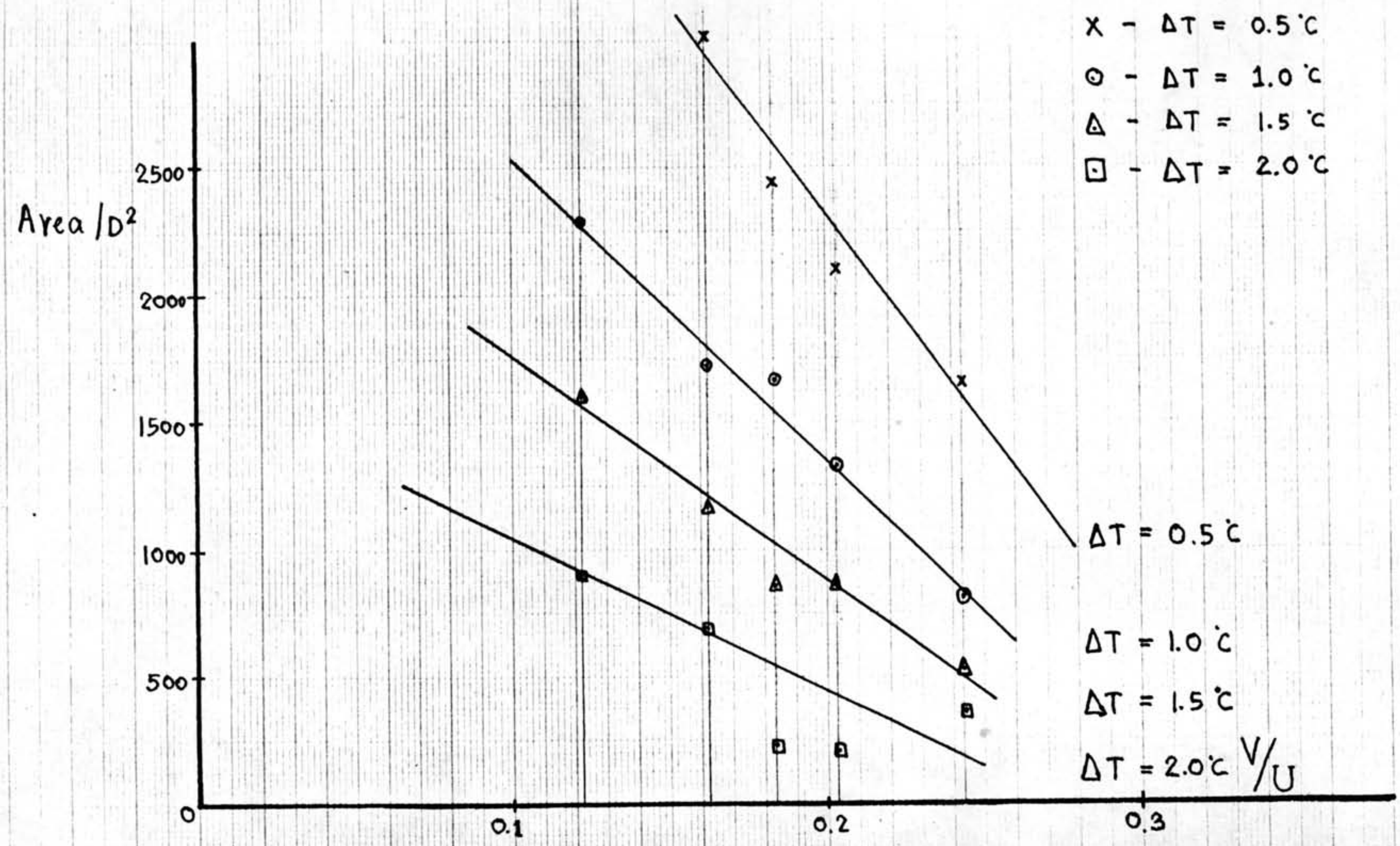

Figure 5.21 Relation between the area of the mixing zone and current speed.

(3 m. nozzle diameter)

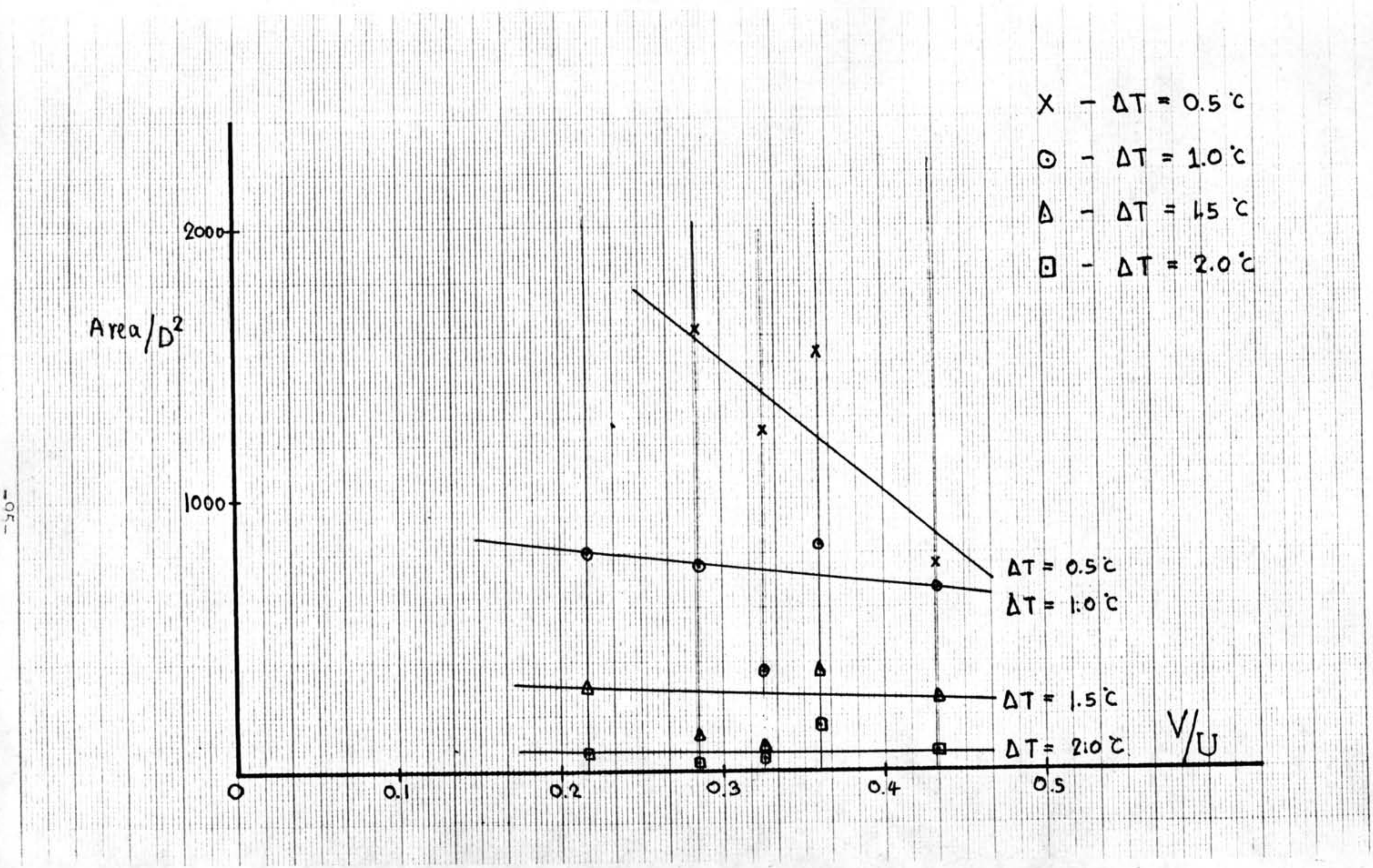

Figure 5.22 Relation between the area of the mixing zone and current speed.

(4 m. nozzle diameter)

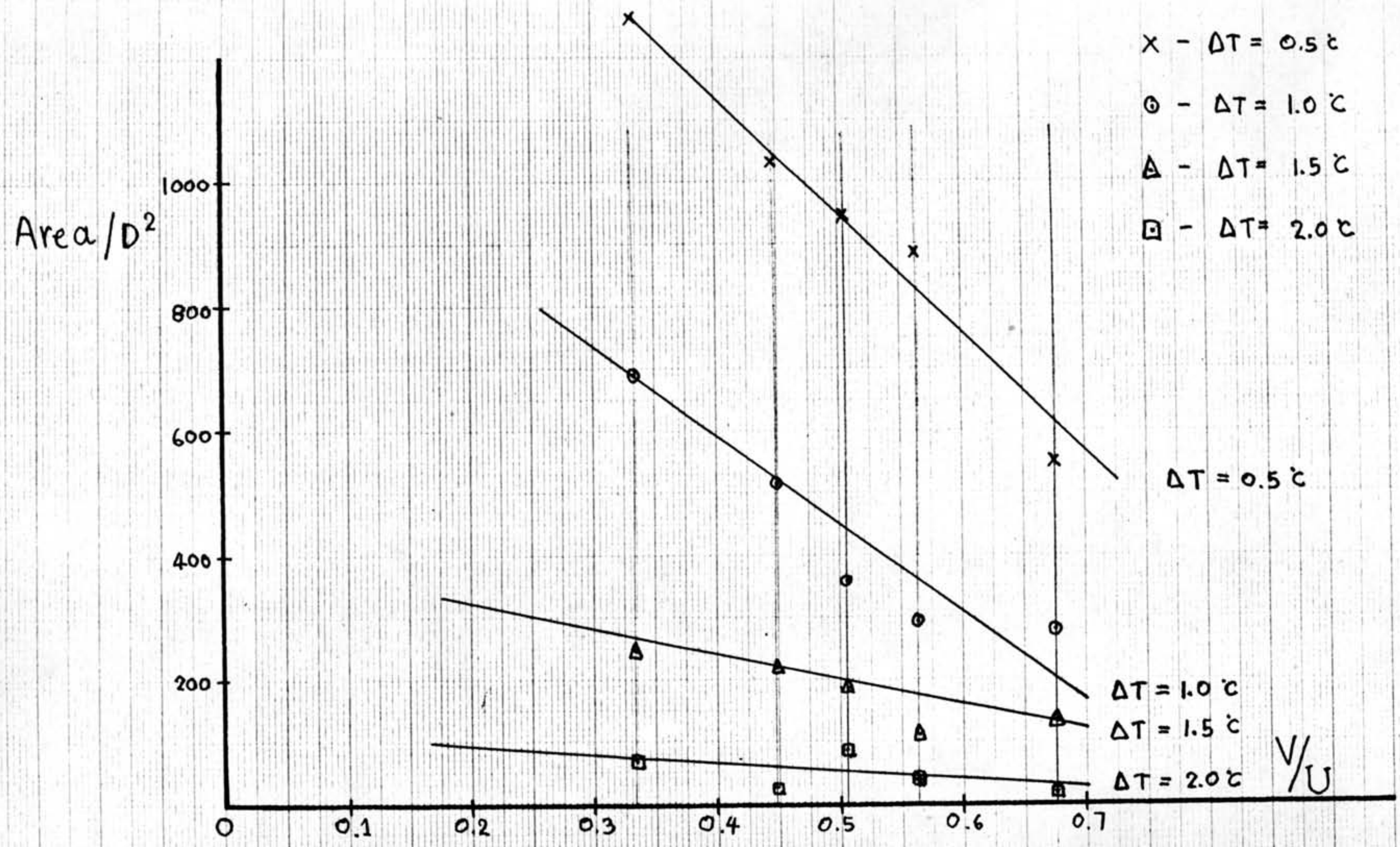

Figure 5.23 Relation between the area of the mixing zone and current speed.

(5 m. nozzle diameter)

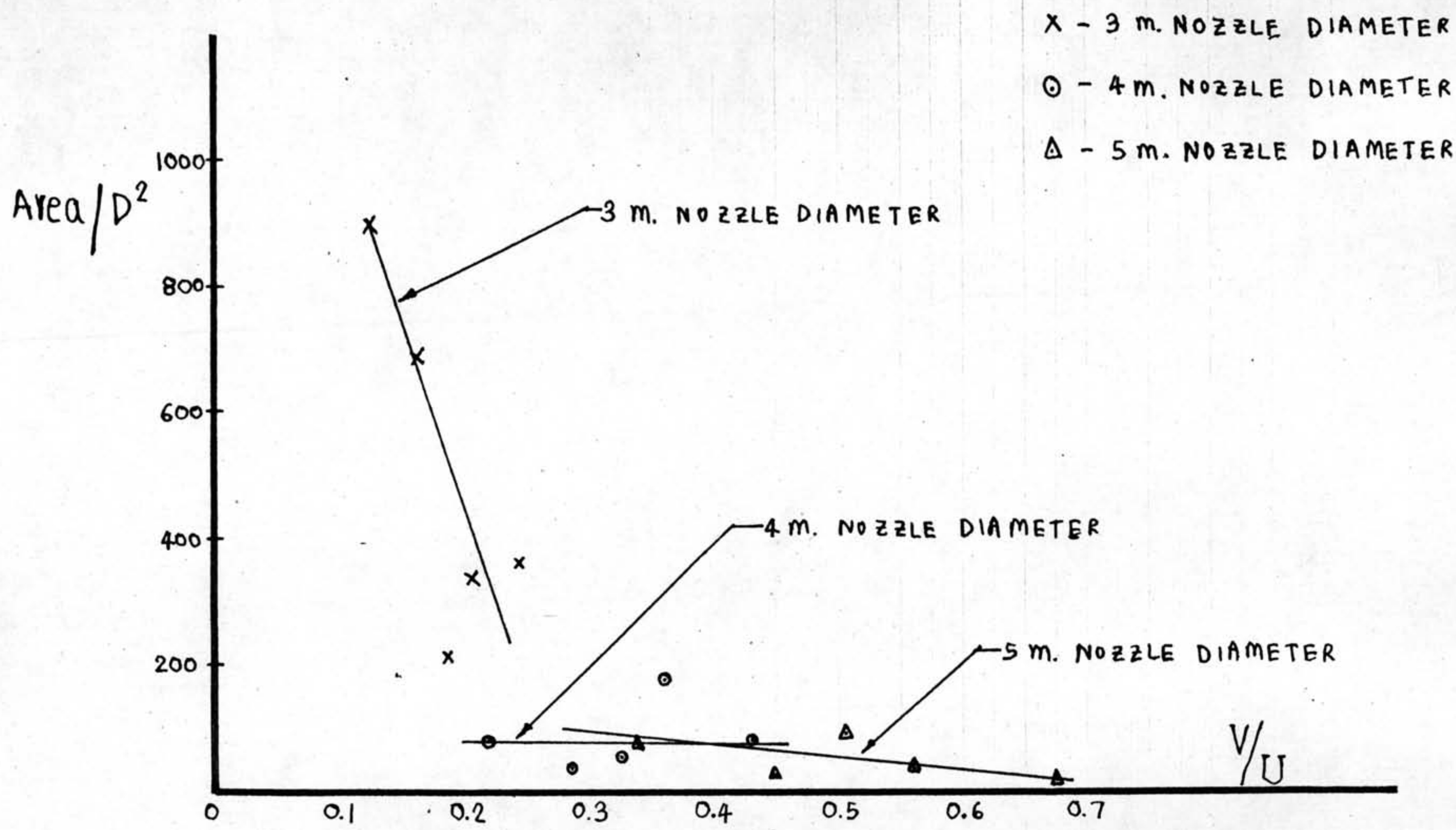

Figure 5.24 Relation between the area within 2.0°C isothermal line and the current velocity for various nozzle diameters.

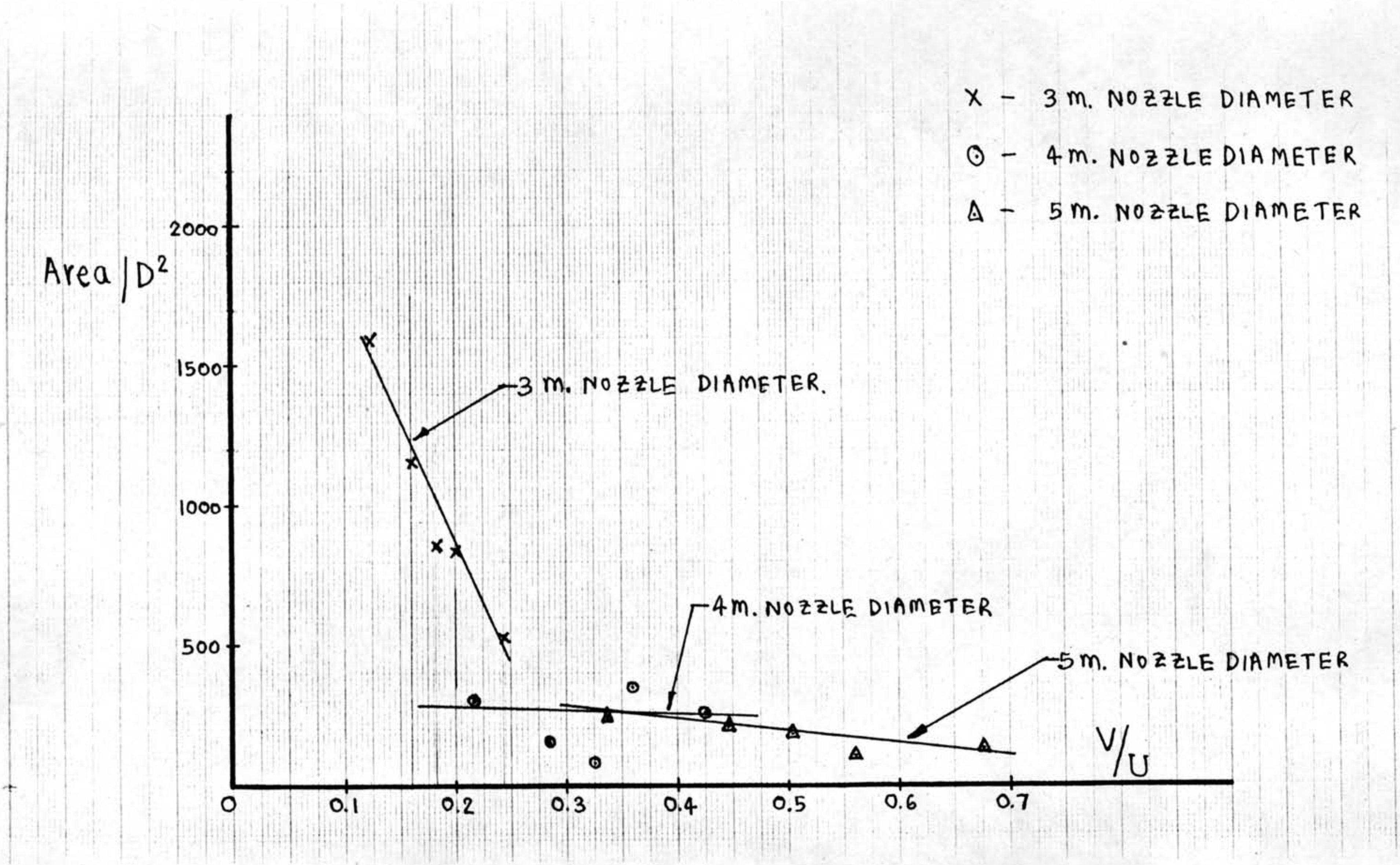

Figure 5.24-b Relation between the area within 1.5°C isothermal line and the current velocity for various nozzle diameters.

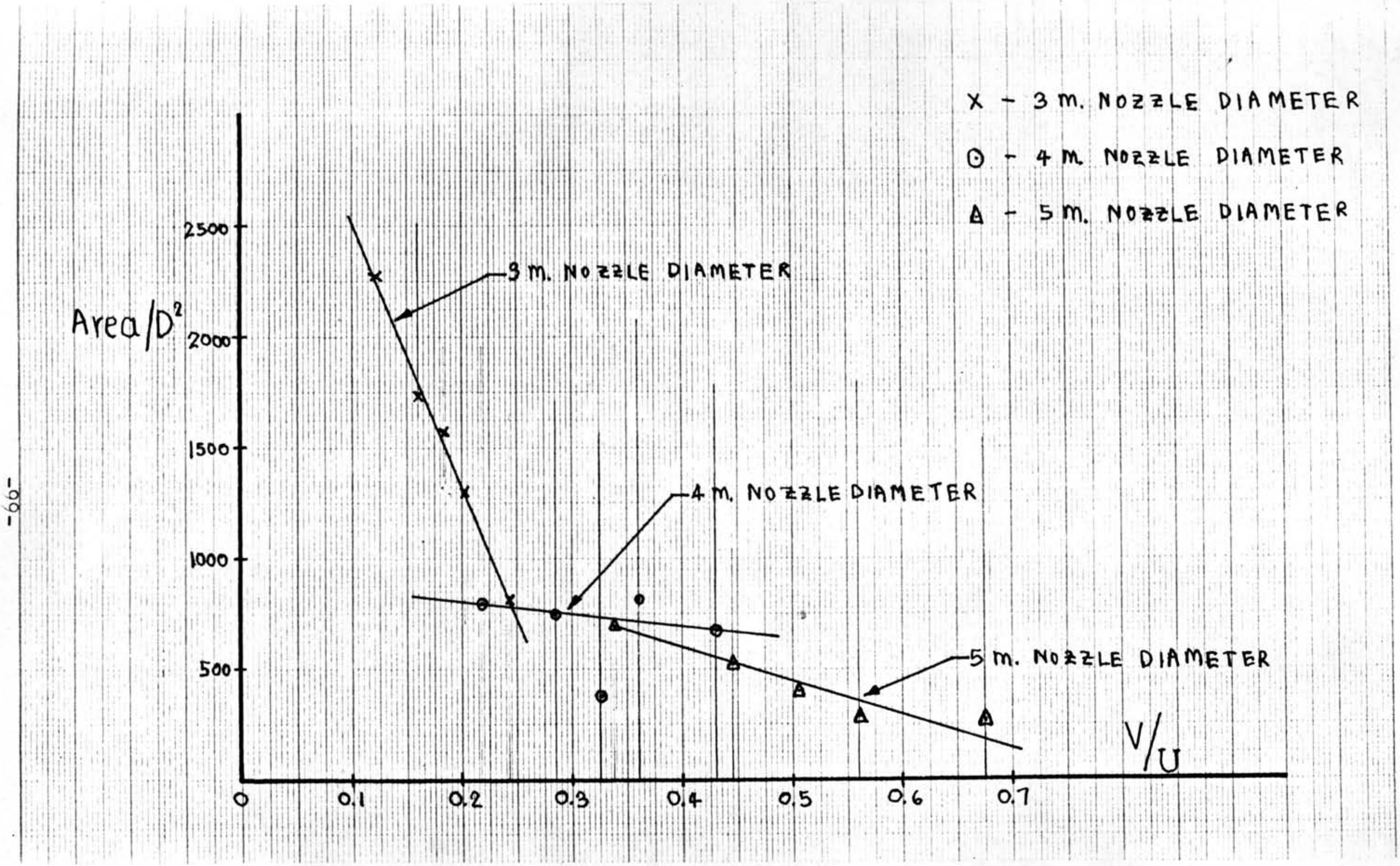

Figure 5.24-c Relation between the area within 1.0°C isothermal line and the current velocity for various nozzle diameters.

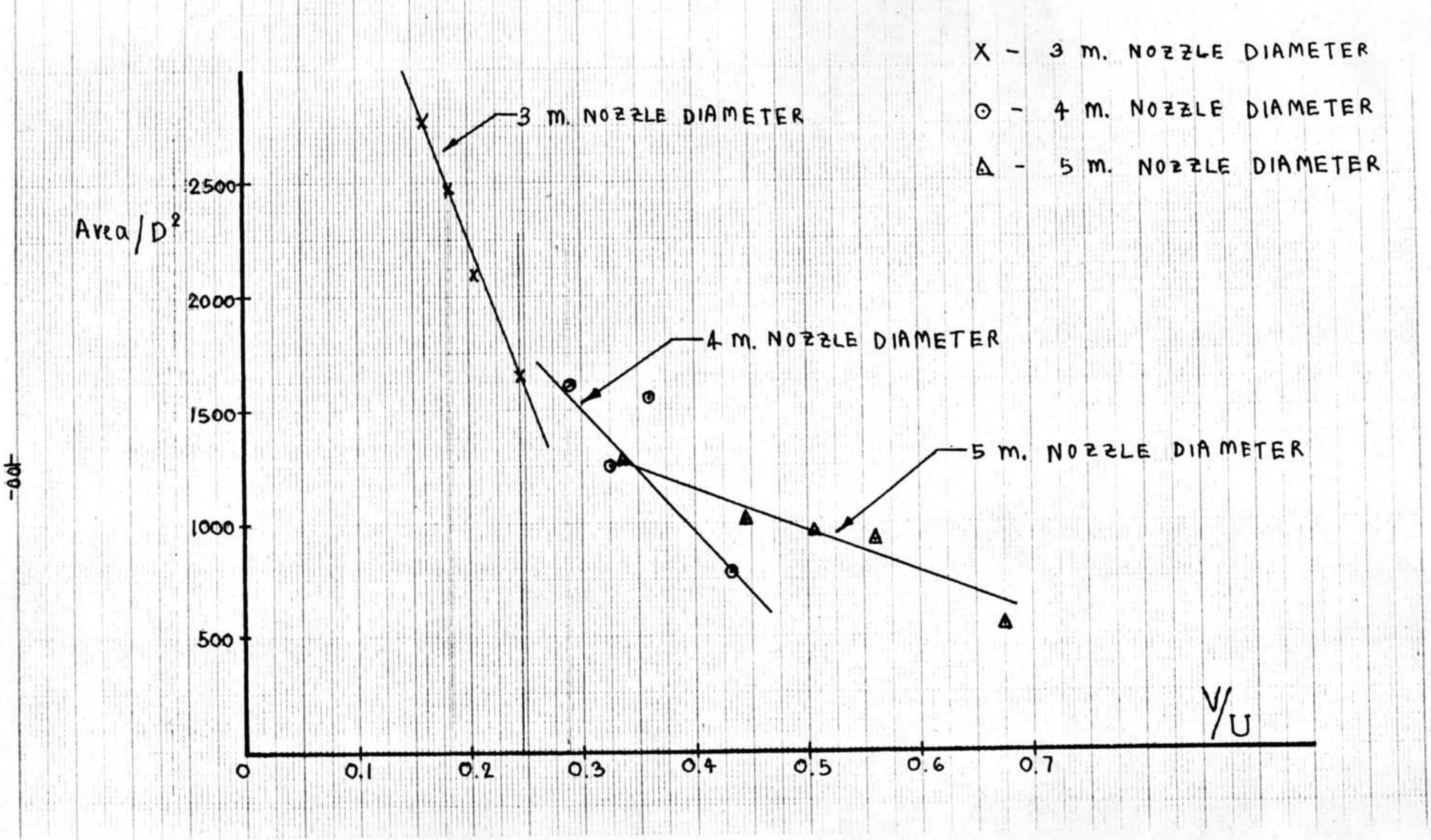

Figure 5.24-d Relation between the area within 0.5°C isothermal line and the current velocity for various nozzle diameters.

VITA

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