



ภาคผนวก ก

ข้อมูลการทดสอบการถ่ายเทความร้อนครีปเกล็ดที่อัตราส่วนระยะห่างระหว่างครีปต่อระยะห่างระหว่างเกล็ด และมุมเอียงต่างๆ

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เนื่องจากการทดสอบการถ่ายเทความร้อนของครีบกี้ดได้ทำการวัดผลโดยมีสมมติฐานว่าระบบอยู่ในภาวะคงที่ไม่เปลี่ยนแปลงตามเวลา โดยได้ทำการวัดค่าต่างๆทุก 5 นาทีเป็นเวลาติดต่อกันทั้งหมด 120 นาที จากนั้นจึงนำค่าที่ได้ไปหาค่าเฉลี่ยก่อนนำไปคำนวณหาผลการทดสอบซึ่งจะได้กล่าวถึงในหัวข้อถัดไป และเนื่องจากการวัดผลที่ได้ทำหลายๆครั้งจึงทำให้ข้อมูลจากการทดสอบมีปริมาณมากไม่สะดวกต่อการแสดงผลได้ทั้งหมด ดังนั้นในการแสดงข้อมูลที่ได้จากการทดสอบนี้จึงจะได้แสดงอยู่ในรูปของค่าเฉลี่ย ซึ่งในการคำนวณผลการทดสอบก็จะได้นำค่าเฉลี่ยนี้ไปคำนวณต่อไป

โดย

Position	= ตำแหน่งของครีบกี้ด
t mean	= อุณหภูมิผิวกี้ดเฉลี่ย ($^{\circ}\text{C}$)
w in	= อุณหภูมิน้ำเข้า ($^{\circ}\text{C}$)
w out	= อุณหภูมิน้ำออก ($^{\circ}\text{C}$)
a in	= อุณหภูมิอากาศเข้า ($^{\circ}\text{C}$)
a out	= อุณหภูมิอากาศออก ($^{\circ}\text{C}$)
free stream	= อุณหภูมิอากาศเฉลี่ยภายในชุดทดลอง ($^{\circ}\text{C}$)

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ตารางที่ ก 1 ข้อมูลการทดสอบครีบกี้ดที่มุมเอียงกี้ด 18 องศา $Re_{L_p} = 232.59$

$F_p/L_p = 1.5$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	39.36	28.02	28.27	28.02	28.33	40.25	34.00	32.90
2	37.61	27.95	28.02	27.95	28.01	41.60	34.10	32.60
3	36.81	28.32	28.43	28.32	28.34	40.96	34.20	33.20
4	35.75	28.15	28.26	28.15	28.16	41.23	34.50	33.60
5	35.02	29.04	29.12	29.04	29.11	42.36	34.50	33.25
6	34.65	27.38	27.44	27.38	27.41	41.86	34.60	34.15
7	34.75	28.68	28.75	28.68	28.48	41.89	34.40	32.40
8	33.21	30.23	30.27	30.23	30.31	42.08	35.00	33.60
9	33.05	30.21	30.28	30.21	30.32	41.94	34.60	33.70

$F_p/L_p = 1$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	39.25	29.75	30.09	29.75	29.93	40.62	33.60	34.86
2	38.65	30.11	30.15	30.11	30.17	42.36	33.50	35.24
3	37.23	30.14	30.16	30.14	30.15	41.96	33.60	35.21
4	36.82	30.25	30.26	30.25	30.22	42.58	33.60	34.88
5	35.90	30.20	30.21	30.20	30.18	43.45	33.50	35.41
6	34.27	30.17	30.18	30.17	30.13	42.64	33.40	36.02
7	33.59	30.25	30.25	30.25	30.22	43.23	33.20	35.95
8	32.98	30.24	30.24	30.24	30.27	41.97	33.20	34.97
9	32.40	30.13	30.13	30.13	30.18	42.81	33.10	35.23

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	39.80	30.55	30.79	30.55	30.66	40.60	30.20	32.90
2	38.50	30.35	30.37	30.35	30.41	41.30	30.50	32.60
3	37.20	30.48	30.50	30.48	30.52	39.40	30.10	33.20
4	35.45	30.40	30.42	30.40	30.41	41.82	30.50	33.60
5	34.68	30.60	30.61	30.60	30.61	39.75	30.10	33.25
6	33.25	30.61	30.62	30.61	30.61	39.84	30.50	34.15
7	33.10	30.23	30.23	30.23	30.24	41.25	30.50	32.40
8	32.60	30.63	30.64	30.63	30.63	40.65	30.50	33.60
9	31.60	30.58	30.60	30.58	30.59	39.47	30.50	33.70

ตารางที่ ก 2 ข้อมูลการทดสอบครีปเกล็ดที่มุมเอียงเกล็ด 23 องศา $Re_{L_p} = 232.59$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	39.85	29.32	29.82	29.32	29.97	42.16	34.30	34.86
2	38.22	29.54	29.71	29.54	29.65	41.75	34.40	35.24
3	37.36	29.85	29.99	29.85	29.95	42.49	34.30	35.21
4	35.98	29.64	29.71	29.64	29.69	42.81	34.30	34.88
5	35.01	29.61	29.65	29.61	29.64	41.65	34.60	35.41
6	34.56	29.86	29.88	29.86	29.89	40.29	34.10	36.02
7	33.68	30.25	30.27	30.25	30.35	40.71	34.20	35.95
8	32.47	30.45	30.49	30.45	30.48	40.86	34.50	34.97
9	32.05	30.15	30.24	30.15	30.28	40.49	34.50	35.23

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	40.68	28.65	28.75	28.64	28.93	42.25	33.60	37.30
2	39.98	28.74	28.77	27.83	27.88	41.60	33.40	35.80
3	38.56	28.63	28.67	27.92	27.95	40.96	33.60	35.60
4	37.62	27.96	27.97	27.48	27.51	41.23	33.30	35.60
5	36.13	28.75	28.76	29.03	29.04	42.36	33.50	35.50
6	35.75	26.94	26.95	28.67	28.67	41.86	33.30	36.30
7	34.83	28.41	28.41	27.95	27.96	41.89	33.20	35.30
8	33.56	27.82	27.84	27.73	27.75	42.08	33.20	35.60
9	32.05	27.65	27.66	27.69	27.71	41.94	33.60	35.80

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	38.75	27.45	27.62	27.45	27.63	39.00	31.70	32.50
2	36.98	27.63	27.68	27.63	27.65	39.10	31.60	32.80
3	36.21	27.85	27.86	27.85	27.89	39.40	31.50	32.80
4	35.45	27.12	27.15	27.12	27.15	39.20	31.50	32.30
5	34.85	26.86	26.88	26.86	26.89	39.00	31.70	32.30
6	34.03	27.95	27.96	27.95	27.96	39.20	32.30	32.50
7	33.21	27.84	27.85	27.84	27.84	39.80	32.30	32.50
8	32.45	26.98	26.99	26.98	26.98	40.60	32.30	33.10
9	31.20	26.58	26.59	26.58	26.58	41.00	31.80	32.60

ตารางที่ 3 ข้อมูลการทดสอบครีบเกล็ดที่มุมเอียงเกล็ด 30 องศา $Re_{L_p} = 232.59$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	40.86	29.41	29.88	29.41	29.78	42.68	34.70	32.50
2	38.85	28.95	29.08	28.95	29.12	40.98	34.60	32.80
3	37.74	29.48	29.57	29.48	29.54	42.35	34.80	32.80
4	36.06	29.57	29.61	29.57	29.60	42.80	34.56	32.30
5	35.79	29.62	29.67	29.62	29.68	42.30	34.74	32.30
6	33.98	28.95	28.99	28.95	28.98	41.25	33.98	32.50
7	33.02	28.36	28.38	28.36	28.38	42.60	34.21	32.50
8	32.15	28.48	28.52	28.48	28.53	42.60	34.85	33.10
9	31.25	28.64	28.75	28.64	28.71	42.30	34.76	32.60

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	41.78	27.65	27.95	27.65	27.98	44.90	32.85	33.90
2	40.69	27.85	27.94	27.85	27.96	45.10	32.65	33.60
3	38.76	26.96	27.04	26.96	27.02	44.80	32.74	33.50
4	37.14	27.84	27.89	27.84	27.87	44.90	32.69	33.60
5	36.58	27.64	27.69	27.64	27.68	45.20	32.68	33.50
6	35.48	27.53	27.55	27.53	27.56	45.10	32.49	33.50
7	34.86	27.73	27.75	27.73	27.74	45.10	32.78	33.50
8	32.75	27.99	28.01	27.99	28.03	45.10	33.20	36.05
9	32.02	27.81	27.86	27.81	27.83	45.20	32.90	35.84

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	39.93	29.80	29.94	29.80	30.01	40.20	31.40	32.50
2	38.90	30.10	30.15	30.10	30.17	40.30	31.40	32.60
3	37.10	29.75	29.80	29.75	29.77	40.30	31.40	32.80
4	35.83	30.30	30.34	30.30	30.32	40.60	31.30	32.10
5	34.28	29.80	29.81	29.80	29.83	40.30	31.30	32.30
6	33.23	29.70	29.70	29.70	29.71	40.00	31.30	32.50
7	32.90	30.10	30.11	30.10	30.11	41.26	31.40	31.57
8	32.04	29.71	29.72	29.71	29.71	39.10	31.40	32.80
9	31.82	30.10	30.11	30.10	30.11	39.00	31.50	32.80

ตารางที่ ก 4 ข้อมูลการทดสอบครีบอกที่มุมเอียงเกิด 35 องศา $Re_{L_p} = 232.59$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	40.28	30.80	31.23	30.80	31.25	41.51	34.70	35.20
2	38.56	30.70	30.80	30.70	30.85	41.45	34.70	35.30
3	37.56	30.70	30.86	30.70	30.75	41.58	34.50	35.40
4	36.45	30.60	30.68	30.60	30.67	41.80	34.40	35.50
5	35.20	30.80	30.84	30.80	30.85	41.94	34.50	35.60
6	34.15	30.80	30.81	30.80	30.81	41.76	34.40	35.98
7	33.52	31.00	31.05	31.00	31.00	42.05	34.50	35.60
8	32.45	30.80	30.85	30.80	30.84	41.48	35.10	35.80
9	30.46	31.00	31.10	31.00	31.09	41.36	34.90	35.80

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	42.52	29.60	30.12	29.60	29.71	44.10	32.80	34.90
2	41.28	29.60	29.67	29.60	29.69	44.05	32.80	35.00
3	39.51	29.60	29.65	29.60	29.64	44.20	32.80	35.50
4	37.85	29.60	29.60	29.60	29.63	44.18	32.90	36.30
5	35.95	29.60	29.61	29.60	29.61	44.15	32.90	36.54
6	34.26	29.70	29.71	29.70	29.72	44.65	32.90	35.30
7	33.45	29.60	29.61	29.60	29.62	44.65	32.90	35.00
8	32.76	29.60	29.62	29.60	29.63	45.68	32.90	34.90
9	31.56	29.75	29.77	29.75	29.78	44.43	32.90	34.80

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	39.26	27.30	27.56	27.30	27.43	40.88	31.70	33.10
2	38.15	27.10	27.16	27.10	27.15	40.94	31.60	32.80
3	36.95	27.10	27.11	27.10	27.16	41.03	31.70	32.50
4	35.42	26.90	26.92	26.90	26.93	40.68	31.80	32.80
5	33.74	26.80	26.81	26.80	26.82	40.96	31.70	32.30
6	32.76	28.00	28.00	28.00	28.01	40.91	31.80	33.50
7	31.45	27.90	27.91	27.90	27.92	41.16	31.80	33.40
8	30.58	27.70	27.71	27.70	27.72	41.28	31.70	32.86
9	30.12	27.30	27.31	27.30	27.31	41.18	31.50	32.10

ตารางที่ ก 5 ข้อมูลการทดสอบครีบเกล็ดที่มุมเอียงเกล็ด 40 องศา $Re_{L_p} = 232.59$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	41.56	28.30	28.73	28.30	28.77	43.10	34.60	35.20
2	39.27	28.40	28.51	28.40	28.51	43.20	34.20	35.30
3	37.85	28.40	28.52	28.40	28.46	43.10	34.60	35.40
4	36.25	28.50	28.55	28.50	28.54	43.40	35.00	35.50
5	35.68	28.60	28.62	28.60	28.63	43.55	34.30	35.60
6	34.75	28.60	28.62	28.60	28.61	43.45	34.10	35.98
7	33.78	28.60	28.68	28.60	28.62	43.33	34.10	35.60
8	32.95	28.60	28.65	28.60	28.68	43.35	34.00	35.80
9	30.01	28.70	28.82	28.70	28.74	43.40	34.30	35.80

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	40.05	30.10	30.37	30.10	30.39	40.20	32.50	35.20
2	38.85	30.30	30.38	30.30	30.35	42.60	32.30	35.30
3	37.36	30.30	30.38	30.30	30.36	39.30	32.50	35.40
4	36.14	30.30	30.35	30.30	30.32	40.20	32.30	35.50
5	35.95	30.30	30.32	30.30	30.32	41.10	32.40	35.60
6	35.00	30.50	30.51	30.50	30.51	40.40	32.40	35.98
7	34.25	30.60	30.62	30.60	30.61	41.50	32.40	35.60
8	32.15	30.70	30.72	30.70	30.74	39.40	32.30	35.80
9	30.99	30.70	30.75	30.70	30.74	40.35	32.30	35.80

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	39.85	27.70	27.87	27.70	27.90	41.70	31.50	32.60
2	37.68	27.40	27.45	27.40	27.41	42.30	31.70	32.60
3	36.41	27.40	27.43	27.40	27.42	41.90	31.60	32.30
4	34.00	27.30	27.32	27.30	27.31	41.60	31.70	32.40
5	33.12	27.10	27.11	27.10	27.10	41.10	31.80	32.50
6	32.85	27.00	27.00	27.00	27.01	42.00	31.70	32.05
7	31.85	28.90	28.91	28.90	28.91	42.10	31.80	32.86
8	31.02	28.60	28.62	28.60	28.61	41.40	31.80	32.50
9	30.47	28.20	28.22	28.20	28.21	41.40	31.70	32.50

ตารางที่ ก 6 ข้อมูลการทดสอบครีปเกล็ดที่มุมเอียงเกล็ด 18 องศา $Re_{L_p} = 493.47$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	62.10	29.75	30.53	29.75	30.43	65.21	53.10	55.10
2	60.84	29.43	29.58	29.43	29.69	64.44	51.50	54.60
3	58.97	29.14	29.30	29.14	29.31	65.00	52.30	54.50
4	56.29	28.98	29.08	28.98	28.99	65.05	53.50	54.60
5	55.74	28.85	28.86	28.85	28.87	65.03	56.00	55.30
6	54.02	29.41	29.44	29.41	29.45	65.15	52.80	55.20
7	52.85	28.73	28.79	28.74	28.77	65.23	54.20	54.80
8	51.63	28.69	28.72	28.69	28.70	66.01	53.50	54.90
9	49.42	28.56	28.68	28.56	28.63	66.64	54.00	55.40

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	52.45	28.48	28.60	28.48	28.62	55.50	48.00	50.40
2	51.57	28.75	28.77	28.75	28.76	56.20	47.80	51.10
3	49.85	28.62	28.63	28.62	28.63	57.10	47.60	49.45
4	47.68	28.39	28.41	28.39	28.41	57.30	48.20	49.10
5	46.12	28.56	28.64	28.56	28.63	56.30	48.60	49.70
6	45.08	28.54	28.58	28.54	28.64	56.20	48.60	50.10
7	43.49	28.71	28.78	28.71	28.80	56.30	48.10	49.50
8	42.34	27.98	28.05	27.98	28.08	55.20	48.10	49.20
9	40.65	28.14	28.22	28.14	28.20	55.60	48.20	47.80

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	45.86	27.65	27.68	27.45	27.68	47.85	33.70	42.80
2	44.06	27.84	27.87	27.86	27.87	47.83	33.10	42.80
3	43.47	27.41	27.42	27.53	27.54	47.99	34.40	42.90
4	41.89	27.63	27.67	27.63	27.61	48.03	33.40	43.20
5	40.56	27.98	28.02	27.86	27.88	48.30	33.40	42.80
6	39.24	27.63	27.73	27.72	27.71	48.19	33.30	42.80
7	38.43	28.04	28.08	28.15	28.16	48.23	33.00	42.70
8	36.78	27.28	27.36	28.31	28.34	48.19	33.10	42.80
9	35.62	27.43	27.45	27.51	27.61	47.99	32.60	42.90

ตารางที่ ก 7 ข้อมูลการทดสอบครีบกี้ดที่มุมเอียงกี้ด 23 องศา $Re_{L_p} = 493.47$

$F_p/L_p = 1.5$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	61.86	30.15	30.68	30.15	30.66	63.20	51.50	56.30
2	60.00	30.23	30.33	30.23	30.34	62.05	52.10	56.50
3	58.95	30.42	30.48	30.42	30.47	63.15	51.80	56.50
4	57.63	30.71	30.77	30.71	30.73	67.55	52.10	56.30
5	56.14	30.65	30.69	30.65	30.70	63.90	54.50	54.80
6	54.87	30.51	30.54	30.51	30.53	63.60	53.60	55.60
7	53.07	30.26	30.37	30.26	30.29	65.50	53.10	55.90
8	52.43	30.52	30.55	30.52	30.57	66.25	53.50	55.70
9	50.72	30.41	30.54	30.41	30.47	65.00	52.80	55.30

$F_p/L_p = 1$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	53.45	29.65	29.90	29.65	29.95	63.24	47.80	48.90
2	52.64	29.25	29.31	29.25	29.43	62.37	47.30	48.10
3	50.93	29.43	29.50	29.43	29.50	64.65	47.10	48.00
4	49.08	29.84	29.86	29.84	29.87	62.85	47.50	47.60
5	47.75	29.71	29.71	29.71	29.73	63.54	46.80	47.10
6	46.26	28.98	29.02	28.98	29.00	61.37	45.50	47.90
7	45.83	29.34	29.38	29.34	29.35	62.66	46.30	47.80
8	43.57	29.36	29.38	29.36	29.42	63.28	46.80	47.80
9	41.73	28.76	28.83	28.76	28.85	63.84	47.40	49.70

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	46.51	28.35	28.47	28.35	28.48	48.81	33.30	43.80
2	45.35	28.45	28.47	28.45	28.47	48.85	34.20	43.90
3	43.78	28.62	28.62	28.62	28.63	48.68	35.80	43.50
4	42.54	28.59	28.61	28.59	28.59	48.78	35.80	43.30
5	41.16	28.16	28.22	28.16	28.19	48.73	35.20	43.50
6	39.95	28.25	28.38	28.25	28.22	48.93	34.30	43.30
7	38.43	28.53	28.61	28.53	28.52	48.83	33.70	43.50
8	36.87	28.64	28.69	28.64	28.66	48.80	33.40	43.30
9	34.25	28.57	28.63	28.57	28.67	48.75	33.20	43.30

ตารางที่ ก 8 ข้อมูลการทดสอบครีบกี้ดที่มุมเอียงกี้ด 30 องศา $Re_{L_p} = 493.47$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	62.85	30.25	30.98	30.25	31.00	63.35	51.50	55.10
2	60.93	30.13	30.33	30.13	30.32	64.50	52.10	55.60
3	59.05	30.42	30.55	30.42	30.61	64.55	51.80	55.20
4	57.88	30.35	30.39	30.35	30.39	64.55	52.10	56.80
5	56.23	30.06	30.11	30.06	30.11	63.80	54.50	57.60
6	54.54	30.20	30.29	30.20	30.30	66.35	52.80	58.50
7	52.08	30.28	30.35	30.28	30.36	64.55	54.30	57.80
8	50.51	30.57	30.71	30.57	30.72	63.90	52.90	58.00
9	48.65	30.15	30.22	30.15	30.32	63.05	53.10	58.00

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	53.45	29.53	29.87	29.53	29.86	54.20	49.70	48.70
2	51.89	29.47	29.49	29.47	29.56	54.80	48.40	49.30
3	50.57	29.83	29.85	29.83	29.86	54.30	50.60	49.50
4	48.95	29.62	29.62	29.62	29.63	54.60	46.80	48.70
5	47.73	29.51	29.52	29.51	29.53	57.30	48.60	47.10
6	46.35	29.46	29.50	29.46	29.51	58.10	48.60	48.40
7	45.18	28.95	29.00	28.95	28.99	55.30	50.60	49.00
8	43.25	28.98	29.05	28.98	29.12	56.00	50.80	49.80
9	40.69	29.07	29.10	29.07	29.23	54.10	49.50	51.40

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	47.25	28.43	28.76	28.43	28.69	48.40	33.70	41.60
2	46.53	28.36	28.45	28.36	28.45	48.50	33.70	41.30
3	45.18	28.62	28.67	28.62	28.68	48.40	33.60	41.30
4	43.98	28.48	28.50	28.48	28.48	48.60	33.70	44.60
5	42.06	28.52	28.55	28.52	28.55	48.10	33.60	43.90
6	40.87	28.33	28.34	28.33	28.36	47.80	33.90	42.80
7	38.75	28.76	28.84	28.76	28.79	47.60	33.80	44.30
8	36.41	28.27	28.36	28.27	28.32	47.80	34.20	44.60
9	34.37	28.35	28.43	28.35	28.41	48.20	34.00	43.50

ตารางที่ ก 9 ข้อมูลการทดสอบครีบกี้ดที่มุมเอียงกี้ด 35 องศา $Re_{L_p} = 493.47$

$F_p/L_p = 1.5$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	63.23	30.12	30.88	30.12	30.88	64.30	54.50	55.70
2	62.18	30.42	30.66	30.42	30.65	64.40	54.30	55.40
3	60.85	30.25	30.44	30.25	30.40	64.25	54.60	55.10
4	58.76	30.51	30.66	30.51	30.67	63.35	54.60	53.80
5	57.45	30.50	30.58	30.50	30.59	64.40	53.80	54.80
6	55.68	30.34	30.36	30.34	30.37	65.00	54.50	56.65
7	53.27	30.22	30.25	30.22	30.27	65.10	53.20	55.10
8	50.97	30.53	30.61	30.53	30.58	65.85	54.10	54.60
9	48.77	30.55	30.63	30.55	30.66	65.05	54.60	54.60

$F_p/L_p = 1$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	54.84	29.36	29.72	29.31	29.69	56.20	48.30	49.80
2	52.56	29.65	29.68	29.66	29.74	57.10	48.50	50.30
3	51.28	29.58	29.59	29.57	29.61	57.30	48.30	50.10
4	48.65	29.45	29.47	29.45	29.47	56.30	48.60	49.50
5	46.98	29.74	29.82	29.74	29.82	56.20	48.90	50.10
6	45.05	29.44	29.52	29.44	29.51	56.30	48.60	49.40
7	44.23	29.35	29.48	29.35	29.45	55.20	48.70	50.60
8	41.35	29.68	29.73	29.68	29.76	55.60	49.30	49.80
9	39.45	29.18	29.20	29.18	29.23	54.30	49.50	49.70

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	47.83	28.23	28.42	28.23	28.40	48.10	33.40	44.50
2	46.56	28.41	28.46	28.41	28.47	48.20	33.70	43.30
3	45.25	28.32	28.35	28.32	28.38	48.90	33.60	42.20
4	43.78	28.43	28.44	28.43	28.43	48.80	33.40	43.30
5	41.96	28.25	28.26	28.25	28.26	48.60	33.40	42.50
6	39.51	28.10	28.12	28.10	28.11	48.60	33.30	41.60
7	38.45	28.15	28.17	28.15	28.21	48.10	33.40	42.00
8	36.45	28.56	28.63	28.56	28.64	49.00	33.30	43.60
9	34.24	28.26	28.31	28.26	28.35	48.10	33.50	43.00

ตารางที่ ก 10 ข้อมูลการทดสอบครีบอกที่มุมเอียงเกิด 40 องศา $Re_{L_p} = 493.47$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	64.25	30.25	31.04	30.25	31.00	65.70	55.10	56.70
2	62.41	30.41	30.65	30.41	30.57	63.75	54.50	56.80
3	60.60	30.33	30.41	30.33	30.41	65.90	54.80	57.60
4	58.77	30.24	30.30	30.24	30.32	64.70	54.60	56.50
5	56.35	30.65	30.69	30.65	30.66	65.10	54.30	57.02
6	55.26	30.84	30.87	30.84	30.90	63.70	54.60	56.90
7	53.10	30.26	30.33	30.26	30.37	63.15	55.20	56.90
8	50.29	30.15	30.25	30.15	30.27	62.95	56.10	57.30
9	48.75	30.40	30.56	30.40	30.55	63.05	55.60	59.10

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	53.25	29.53	29.81	29.53	29.72	54.68	45.50	50.00
2	52.48	29.41	29.48	29.41	29.47	54.55	47.10	50.10
3	50.65	29.23	29.25	29.23	29.26	54.95	50.80	49.60
4	48.23	29.56	29.61	29.56	29.59	55.33	45.50	50.10
5	46.03	29.71	29.80	29.71	29.81	55.59	43.70	50.50
6	44.58	29.52	29.61	29.52	29.63	56.04	46.50	49.70
7	42.15	29.51	29.62	29.51	29.60	56.48	47.30	49.80
8	41.00	29.33	29.41	29.33	29.44	56.58	47.60	49.40
9	38.74	29.45	29.51	29.45	29.50	56.89	47.10	49.50

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	48.13	27.53	27.85	27.53	27.79	49.50	32.60	42.50
2	46.65	27.45	27.54	27.45	27.49	49.20	32.90	42.60
3	44.97	27.14	27.18	27.14	27.16	48.00	33.10	42.60
4	42.75	27.36	27.36	27.36	27.36	47.30	33.20	42.50
5	40.68	27.58	27.62	27.58	27.61	47.10	33.20	43.10
6	38.85	27.62	27.65	27.62	27.67	48.30	33.30	43.00
7	37.15	27.80	27.86	27.80	27.87	47.80	33.30	43.30
8	35.45	27.45	27.57	27.45	27.53	47.50	33.50	43.00
9	34.06	27.36	27.43	27.36	27.41	47.00	33.50	43.20

ตารางที่ ก 11 ข้อมูลการทดสอบครีปเกล็ดที่มุมเอียงเกล็ด 18 องศา $Re_{Lp} = 659.20$

$F_p/L_p = 1.5$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	70.78	29.65	31.01	29.65	31.00	92.30	71.35	79.30
2	64.46	29.63	30.39	29.63	30.49	92.10	71.15	79.40
3	61.10	29.47	30.06	29.47	30.09	91.50	72.20	79.90
4	56.63	29.46	30.01	29.46	30.11	91.80	74.65	79.70
5	53.24	29.33	29.96	29.33	30.12	92.30	74.35	79.60
6	51.74	29.59	30.23	29.59	30.26	91.80	73.90	79.50
7	49.21	29.21	29.73	29.21	29.74	91.80	70.75	79.80
8	48.50	29.17	29.88	29.17	29.93	91.50	77.55	80.70
9	46.00	29.04	29.08	29.04	29.94	91.10	76.25	81.10

$F_p/L_p = 1$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	58.27	29.79	29.89	29.79	29.90	70.65	44.30	57.20
2	54.99	29.70	29.71	29.70	29.73	67.25	44.60	55.56
3	51.70	29.86	29.91	29.86	29.97	69.20	44.40	55.49
4	48.97	29.74	29.82	29.74	29.88	69.25	43.90	55.40
5	46.86	29.64	29.84	29.64	29.88	69.65	44.30	55.24
6	44.74	29.51	29.67	29.51	29.74	71.80	43.70	56.63
7	41.85	29.38	29.58	29.38	29.69	73.05	44.80	56.89
8	39.84	29.80	29.90	29.80	29.18	72.30	44.30	56.97
9	36.28	29.44	29.65	29.44	29.68	65.25	44.30	57.06

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	48.43	28.89	29.09	28.89	29.07	56.66	38.40	45.80
2	46.63	29.08	29.11	29.08	29.09	57.59	39.33	47.84
3	46.04	28.65	28.68	28.65	28.66	57.96	39.70	47.10
4	44.46	28.87	28.94	28.87	28.88	57.77	39.52	46.92
5	43.13	29.22	29.26	29.22	29.28	57.99	39.73	47.13
6	41.81	28.87	28.89	28.87	28.98	57.57	39.32	46.72
7	41.00	29.28	29.30	29.28	29.30	56.39	38.13	45.53
8	39.35	28.52	28.53	28.52	28.57	55.86	37.60	45.00
9	38.19	28.67	28.75	28.67	28.70	55.47	37.22	44.62

ตารางที่ ก 12 ข้อมูลการทดสอบครีบอกที่มุมเอียงเกล็ด 23 องศา $Re_{L_p} = 659.20$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	70.79	28.91	29.33	28.91	29.26	93.20	67.55	73.25
2	68.93	28.99	29.22	28.99	29.25	92.30	68.10	74.05
3	64.58	29.18	29.61	29.18	29.54	90.50	67.55	73.50
4	61.65	29.47	29.79	29.47	29.77	92.60	65.95	72.55
5	58.16	29.41	29.88	29.41	29.88	92.10	67.35	72.55
6	55.23	29.27	29.76	29.27	29.73	92.30	65.35	74.55
7	52.70	29.02	29.71	29.02	29.41	92.10	68.45	74.40
8	48.99	29.28	29.86	29.28	29.88	93.40	69.55	75.95
9	46.99	29.17	29.73	29.17	29.63	93.20	70.95	74.10

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	57.98	29.65	29.80	29.65	29.77	72.20	52.51	59.23
2	55.63	29.25	29.37	29.25	29.35	72.50	52.65	59.88
3	51.64	29.43	29.58	29.43	29.65	73.30	52.64	59.28
4	48.66	29.74	29.99	29.74	29.99	77.10	52.54	59.60
5	46.25	29.61	29.99	29.61	29.96	74.50	52.86	59.18
6	43.69	28.58	29.16	28.88	29.15	75.10	53.05	59.50
7	40.37	29.34	29.54	29.34	29.52	73.10	53.08	59.18
8	38.27	29.36	29.64	29.36	29.42	72.50	53.28	58.40
9	36.66	28.58	28.82	28.58	28.85	72.80	53.06	58.43

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	49.69	29.00	29.24	29.00	29.28	60.30	39.36	46.07
2	47.66	29.39	29.42	29.39	29.43	59.80	40.26	46.17
3	45.37	29.27	29.28	29.27	29.29	59.50	41.86	45.77
4	43.67	29.24	29.28	29.24	29.27	60.10	41.86	45.57
5	41.70	28.81	28.89	28.81	28.88	58.40	41.26	45.77
6	39.65	28.93	29.01	28.93	29.01	57.90	40.36	45.57
7	38.67	29.18	29.24	29.18	29.23	57.70	39.76	45.77
8	37.33	29.29	29.35	29.29	29.34	58.60	39.46	45.57
9	36.33	29.22	29.31	29.22	29.28	56.50	39.26	45.57

ตารางที่ ก 13 ข้อมูลการทดสอบครีปเกล็ดที่มุมเอียงเกล็ด 30 องศา $Re_{Lp} = 659.20$

$F_p/L_p = 1.5$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	71.04	29.18	30.50	29.18	30.42	92.60	71.87	79.80
2	69.18	29.06	29.52	29.06	29.54	93.75	72.47	80.30
3	64.84	29.14	29.76	29.14	29.77	93.80	72.17	79.90
4	61.91	29.28	29.79	29.28	29.82	93.80	72.47	81.50
5	58.41	28.99	29.86	28.99	29.65	93.05	74.87	82.30
6	55.49	29.13	29.79	29.13	29.87	95.60	73.17	83.20
7	52.95	29.12	29.94	29.12	29.98	93.80	74.67	82.50
8	49.24	29.16	29.97	29.18	29.98	93.15	73.27	82.70
9	47.24	29.08	29.83	29.08	29.84	92.30	73.47	82.70

$F_p/L_p = 1$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	56.99	29.16	29.36	29.16	29.43	71.79	50.22	59.24
2	54.37	29.10	29.23	29.10	29.32	72.39	50.82	59.84
3	52.47	29.46	29.66	29.46	29.65	71.89	51.02	60.04
4	49.48	29.25	29.43	29.25	29.44	72.19	50.22	59.24
5	47.08	29.14	29.35	29.14	29.53	74.89	48.62	57.64
6	44.51	29.09	29.32	29.09	29.42	75.69	49.92	58.94
7	41.19	28.58	28.97	28.58	28.98	72.89	50.52	59.54
8	39.09	28.61	28.88	28.61	28.84	73.59	51.32	60.34
9	37.48	28.57	28.99	28.57	28.79	71.69	52.92	61.94

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	49.00	26.58	26.79	26.58	26.66	58.09	39.73	51.37
2	47.84	26.51	26.57	26.51	26.57	58.19	39.73	50.64
3	44.63	26.77	26.88	26.77	26.80	58.09	39.63	48.42
4	42.03	26.63	26.77	26.63	26.78	58.29	39.73	51.72
5	38.97	26.67	26.88	26.67	26.88	57.79	39.63	51.02
6	37.66	26.48	26.57	26.48	26.57	57.49	39.93	49.92
7	35.37	26.91	27.13	26.91	27.12	57.29	39.83	51.42
8	32.37	26.42	26.63	26.42	26.63	57.49	40.23	51.72
9	30.26	26.50	26.72	26.50	26.71	57.89	40.03	50.62

ตารางที่ ก 14 ข้อมูลการทดสอบครีบอกที่มุมเอียงเกล็ด 35 องศา $Re_{L_p} = 659.20$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	70.91	29.75	31.25	29.75	31.25	91.67	73.15	80.94
2	69.05	29.81	30.43	29.81	30.42	91.77	72.95	80.64
3	64.71	29.83	30.32	29.83	30.32	91.62	73.25	80.34
4	61.78	29.81	30.47	29.82	30.52	90.72	73.25	79.04
5	58.29	29.74	30.75	29.74	30.71	91.77	72.45	80.04
6	55.36	29.81	30.32	29.81	30.31	92.37	73.15	81.89
7	52.83	29.85	30.27	29.85	30.25	92.47	71.85	80.34
8	49.11	29.74	30.40	29.74	30.40	93.22	72.75	79.84
9	47.11	29.74	30.42	29.74	30.42	92.42	73.25	79.84

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	59.85	28.49	28.63	28.49	28.62	71.89	50.45	61.25
2	57.57	28.78	28.87	28.78	28.85	72.79	50.65	60.33
3	54.99	28.71	28.94	28.71	28.84	72.99	50.45	60.13
4	51.62	28.58	28.81	28.58	28.71	71.99	50.75	59.53
5	48.68	28.87	29.10	28.87	29.11	71.89	51.05	60.13
6	46.58	28.57	28.80	28.57	28.70	71.99	50.75	59.43
7	43.52	28.48	28.71	28.48	28.76	70.89	50.85	60.63
8	40.36	28.81	29.04	28.81	28.98	71.29	51.45	59.83
9	38.26	28.31	28.54	28.31	28.62	69.99	51.65	59.73

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	48.27	28.22	28.36	28.22	28.35	57.22	39.97	50.21
2	46.03	28.40	28.45	28.40	28.44	57.32	40.27	48.54
3	43.99	28.31	28.35	28.31	28.35	58.02	40.17	47.44
4	40.69	28.42	28.53	28.42	28.55	57.92	39.97	48.54
5	39.26	28.24	28.41	28.24	28.35	57.72	39.97	47.74
6	37.03	28.09	28.18	28.09	28.17	57.72	39.87	46.84
7	34.66	28.14	28.23	28.14	28.23	57.22	39.97	47.24
8	32.66	28.55	28.76	28.55	28.77	58.12	39.87	48.84
9	31.27	28.25	28.46	28.25	28.45	57.22	40.07	48.24

ตารางที่ ก 15 ข้อมูลการทดสอบครีปเกล็ดที่มุมเอียงเกล็ด 40 องศา $Re_{Lp} = 659.20$

$F_p/L_p = 1.5$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	71.37	29.21	30.36	29.21	30.43	93.83	73.11	79.66
2	68.53	29.37	29.98	29.37	29.87	91.88	72.51	79.76
3	65.27	29.29	29.97	29.29	29.97	94.03	72.81	80.56
4	62.66	29.20	29.69	29.20	29.72	92.83	72.61	79.46
5	59.36	29.26	29.98	29.26	29.99	93.23	72.31	79.98
6	55.63	29.36	30.18	29.37	30.19	91.83	72.61	79.86
7	51.37	29.22	29.95	29.22	29.84	91.28	73.21	79.86
8	48.37	29.11	29.83	29.11	29.83	91.08	74.11	80.26
9	45.37	29.36	29.79	29.36	29.76	91.18	73.61	82.06

$F_p/L_p = 1.5$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	58.12	29.28	29.46	29.28	29.42	72.93	51.83	59.86
2	55.70	29.16	29.25	29.16	29.27	72.80	53.43	59.96
3	52.37	28.98	29.11	28.98	29.09	73.20	57.13	59.46
4	49.63	29.31	29.56	29.31	29.46	73.58	51.83	59.96
5	46.26	29.46	29.76	29.46	29.78	73.84	50.03	60.36
6	43.69	29.27	29.62	29.27	29.58	74.29	52.83	59.56
7	41.69	29.26	29.56	29.26	29.48	74.73	53.63	59.66
8	38.99	29.08	29.43	29.08	29.46	74.83	53.93	59.26
9	36.25	29.20	29.55	29.20	29.72	75.14	53.43	59.36

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	48.69	28.57	28.68	28.57	28.65	58.65	39.59	50.24
2	45.70	28.49	28.59	28.49	28.47	58.35	39.89	49.18
3	42.70	28.18	28.28	28.18	28.32	57.15	40.09	49.18
4	40.70	28.40	28.46	28.40	28.59	56.45	40.19	49.08
5	38.63	28.62	28.80	28.62	28.81	56.25	40.19	49.68
6	35.70	28.66	28.87	28.66	28.85	57.45	40.29	49.58
7	33.37	28.84	28.99	28.84	29.03	56.95	40.29	49.88
8	31.70	28.49	28.79	28.49	28.68	56.65	40.49	49.58
9	30.70	28.40	28.58	28.40	28.59	56.15	40.49	49.78

ตารางที่ ก 16 ข้อมูลการทดสอบครีบอกที่มุมเอียงเกล็ด 18 องศา $Re_{L_p} = 832.90$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	70.48	29.76	33.80	29.84	34.30	100.40	70.30	90.84
2	66.88	31.30	32.40	31.30	32.80	102.55	74.60	92.65
3	66.75	32.40	33.40	32.40	33.70	97.55	73.30	94.36
4	62.60	31.70	32.40	31.70	32.80	100.20	74.30	92.15
5	60.70	31.60	32.40	31.60	32.60	99.28	69.90	90.98
6	58.70	29.50	30.80	29.50	31.20	98.80	64.80	90.87
7	55.40	31.60	32.70	31.60	32.60	100.90	73.85	90.74
8	54.60	31.30	32.90	31.30	32.90	100.30	71.50	90.56
9	53.50	29.60	30.30	28.60	30.00	99.30	68.75	90.17

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	64.69	30.50	32.10	30.50	32.30	87.25	64.10	77.37
2	57.40	30.80	31.80	30.80	31.20	87.55	63.20	79.40
3	55.95	31.20	31.60	31.20	31.70	87.10	62.40	77.80
4	54.19	32.00	32.50	32.00	32.90	87.45	62.50	75.60
5	53.23	32.40	32.60	32.40	33.33	87.45	63.70	78.30
6	50.91	30.00	30.70	30.00	30.80	87.80	62.75	79.50
7	49.90	31.40	32.10	31.40	32.10	87.90	56.65	78.20
8	49.38	31.30	31.80	31.30	31.90	86.85	54.40	76.67
9	48.33	31.30	31.90	31.30	32.10	87.20	50.85	75.70

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	57.48	30.10	32.10	30.10	32.34	79.30	58.20	79.07
2	55.50	32.60	32.50	31.70	32.60	81.20	60.15	82.00
3	53.35	29.70	30.70	29.70	30.30	81.10	57.80	77.40
4	50.91	30.00	30.20	30.00	30.50	80.70	56.30	77.37
5	51.80	30.10	30.30	31.50	31.80	81.00	56.85	77.37
6	50.06	31.80	32.30	31.80	32.30	81.10	57.55	78.23
7	49.55	31.90	32.90	31.90	32.80	79.00	57.25	77.23
8	48.78	31.30	31.50	30.50	31.50	81.80	57.70	79.65
9	43.33	30.80	31.30	30.80	31.40	81.55	57.10	74.35

ตารางที่ ก 17 ข้อมูลการทดสอบครีบเกล็ดที่มุมเอียงเกล็ด 23 องศา $Re_{L_p} = 832.90$

$F_p/L_p = 1.5$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	76.57	31.20	33.50	31.10	33.60	100.10	67.30	87.90
2	75.78	31.90	32.30	31.90	32.70	100.85	73.80	88.20
3	72.34	31.80	32.30	31.80	32.70	100.05	72.60	85.30
4	67.80	32.40	32.90	32.40	33.20	100.10	71.30	89.55
5	64.20	31.80	32.80	31.80	32.60	98.95	68.80	90.78
6	61.35	29.10	30.10	30.10	30.80	98.50	64.90	90.80
7	57.60	31.30	32.30	31.30	32.70	96.80	67.35	88.40
8	55.00	31.50	32.50	31.50	32.60	101.50	69.50	82.50
9	52.55	30.10	30.60	30.10	31.80	98.50	68.00	85.30

$F_p/L_p = 1$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	63.44	31.40	33.60	31.20	33.50	87.80	64.75	78.80
2	57.70	31.30	32.80	31.90	32.50	88.80	63.30	78.70
3	54.23	32.60	33.10	32.60	33.20	88.10	64.15	80.45
4	51.35	31.50	32.30	31.50	32.60	88.70	65.65	76.95
5	50.58	31.80	32.40	31.80	32.60	90.10	67.45	80.25
6	49.10	32.10	32.60	31.70	32.45	88.80	67.10	80.65
7	49.06	31.50	32.40	31.70	32.30	88.60	66.25	80.70
8	48.80	31.50	32.30	32.10	32.50	89.80	65.90	77.65
9	45.36	32.20	32.80	31.90	32.60	87.90	66.85	77.35

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	60.70	31.90	32.80	31.90	33.10	75.30	62.40	71.44
2	58.65	31.40	31.90	31.40	31.70	76.15	59.70	71.18
3	53.75	32.30	32.10	31.50	32.80	77.60	62.30	75.55
4	51.35	32.80	33.50	32.80	32.90	76.30	61.25	74.65
5	50.49	32.30	32.60	32.30	32.70	77.10	61.10	73.00
6	50.88	32.30	32.60	32.30	33.10	79.80	61.60	72.80
7	49.86	32.30	32.70	32.30	32.60	78.70	61.90	70.85
8	48.96	32.30	32.80	32.30	32.70	77.40	60.05	70.20
9	45.09	32.50	32.90	32.50	32.90	77.80	54.50	71.50

ตารางที่ ก 18 ข้อมูลการทดสอบครีบอกที่มุมเอียงเกิด 30 องศา $Re_{L_p} = 832.90$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	75.80	32.50	34.10	32.50	34.20	100.10	67.60	83.85
2	68.28	31.50	32.50	31.40	32.20	100.50	61.88	88.00
3	65.60	31.80	32.60	31.80	32.50	101.80	76.00	85.10
4	65.20	31.60	32.90	31.60	32.60	100.10	67.70	84.50
5	60.40	30.50	32.80	30.50	31.40	101.80	77.60	80.80
6	56.80	30.80	31.50	30.80	31.70	100.10	65.20	90.80
7	58.40	30.10	31.10	30.10	31.60	100.90	64.10	88.60
8	56.10	31.30	32.80	31.30	32.50	100.20	56.10	92.50
9	51.40	31.50	32.50	31.50	32.50	101.90	56.60	92.30

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	71.18	30.50	32.30	30.50	32.30	89.00	69.45	82.43
2	65.59	31.90	32.60	32.10	32.80	87.60	73.00	79.23
3	62.80	32.40	32.60	32.40	32.80	90.90	74.70	77.17
4	52.50	31.80	32.80	31.80	32.20	91.60	72.70	79.90
5	51.73	31.90	32.80	31.90	32.40	89.50	70.20	76.43
6	50.99	31.80	32.30	31.80	32.50	87.60	70.10	74.85
7	49.66	30.80	31.60	30.80	31.70	90.10	70.80	81.60
8	48.10	32.30	32.80	32.30	33.10	89.80	61.85	78.80
9	46.52	32.30	32.60	32.30	32.60	90.10	73.50	75.70

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	63.20	32.90	33.90	32.90	33.70	80.70	63.90	71.50
2	56.65	32.40	32.70	32.40	32.80	81.90	59.60	70.20
3	54.18	32.60	32.90	32.60	32.90	80.00	58.50	69.95
4	51.35	32.10	32.60	32.10	32.10	81.90	61.80	71.35
5	50.28	32.30	32.90	32.30	32.50	79.80	61.20	69.80
6	47.61	32.00	32.80	32.00	32.30	80.40	62.45	69.35
7	45.45	31.50	31.80	31.30	31.90	81.60	62.65	68.65
8	45.43	30.50	31.10	30.10	30.70	77.80	58.80	72.00
9	43.33	31.40	32.00	31.40	32.10	78.10	55.80	67.95

ตารางที่ ก 19 ข้อมูลการทดสอบครีปเกล็ดที่มุมเอียงเกล็ด 35 องศา $Re_{Lp} = 832.90$

$F_p/L_p = 1.5$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	76.53	31.70	34.40	31.30	33.90	100.30	68.20	89.60
2	67.18	32.30	33.40	32.30	33.50	100.80	62.90	89.60
3	67.50	31.80	32.20	31.80	32.70	100.80	67.50	84.20
4	59.60	31.60	33.40	31.80	32.90	98.00	62.10	85.50
5	56.78	30.30	32.60	30.50	31.60	99.80	73.30	90.00
6	53.63	30.50	32.60	30.50	31.45	100.50	64.60	86.20
7	52.50	30.10	31.60	30.10	31.10	98.50	64.90	90.80
8	49.25	31.50	33.50	31.50	32.40	100.08	55.20	86.00
9	43.45	31.90	32.50	31.90	32.60	100.20	69.03	88.80

$F_p/L_p = 1$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	70.50	30.80	33.20	31.00	32.10	91.40	67.55	82.30
2	61.20	31.80	32.50	31.80	32.30	91.05	63.05	84.85
3	56.03	31.30	32.30	31.30	31.70	90.35	63.35	82.37
4	53.53	31.80	32.90	32.10	32.50	89.20	65.50	81.70
5	51.04	31.70	32.40	31.70	32.80	91.15	69.45	83.40
6	49.56	30.60	31.80	30.60	31.30	89.80	58.50	82.57
7	47.59	30.20	30.50	30.20	31.30	91.20	67.55	83.77
8	46.21	31.80	32.50	31.80	32.50	91.50	63.85	83.03
9	44.33	31.40	32.10	31.40	32.40	91.80	63.50	81.17

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	63.43	31.60	33.60	32.60	32.60	75.40	64.50	71.90
2	59.70	32.20	32.70	32.20	32.80	77.20	65.00	74.30
3	56.00	32.30	32.90	32.30	32.60	75.85	61.60	77.35
4	51.35	32.10	32.80	32.10	32.50	79.95	62.55	74.65
5	49.50	32.30	32.90	32.30	32.30	82.70	60.55	72.20
6	46.94	32.80	33.20	32.80	33.20	80.00	62.10	72.70
7	46.11	32.10	32.40	32.00	32.80	78.80	59.70	72.30
8	45.44	32.20	32.50	32.30	32.70	77.80	62.80	72.00
9	43.90	31.40	32.30	31.20	31.60	80.10	53.00	75.30

ตารางที่ ก 20 ข้อมูลการทดสอบครีบอกที่มุมเอียงเกล็ด 40 องศา $Re_{L_p} = 832.90$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	78.90	31.70	33.40	31.30	33.40	100.80	66.30	87.65
2	68.90	32.50	33.80	31.40	33.10	100.60	63.00	88.50
3	62.28	31.60	32.30	31.60	32.60	100.00	62.28	87.00
4	58.23	30.50	32.80	30.50	31.40	101.80	77.60	80.80
5	52.68	30.50	32.60	30.50	31.60	99.10	67.80	86.80
6	51.50	31.70	32.90	31.70	32.80	99.70	65.70	86.40
7	49.70	32.10	32.50	32.10	32.60	101.80	66.80	88.70
8	47.00	32.10	32.40	32.10	32.90	100.70	65.40	89.00
9	44.70	31.60	32.90	31.90	32.80	100.30	65.70	87.30

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	64.60	32.20	33.10	32.10	32.80	88.30	66.85	76.65
2	62.61	31.90	32.80	32.40	32.60	91.80	63.80	86.10
3	57.50	33.10	33.20	33.10	33.60	88.40	63.80	74.90
4	53.10	32.40	32.80	32.10	32.60	89.80	59.40	72.80
5	52.80	32.40	32.80	32.40	32.80	88.90	60.20	76.03
6	49.70	32.10	32.50	32.10	32.60	91.90	61.55	73.20
7	47.60	32.20	32.60	32.20	32.80	90.20	56.85	72.75
8	45.90	33.10	33.30	33.10	33.10	95.35	63.25	73.25
9	45.20	32.50	32.60	32.50	32.70	91.80	62.10	73.03

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	64.10	31.00	32.30	32.40	32.90	81.80	65.00	73.60
2	61.90	30.80	31.60	32.30	32.30	80.80	61.50	77.60
3	58.00	31.80	32.10	31.90	32.60	79.70	59.10	76.80
4	52.40	32.40	32.70	31.60	32.10	81.80	61.25	73.25
5	48.64	32.30	32.90	32.30	32.50	78.70	60.40	72.20
6	46.30	32.60	32.70	32.60	32.90	83.10	60.75	73.45
7	46.83	32.10	32.80	32.10	32.30	79.90	61.85	72.50
8	44.50	32.20	32.80	32.60	32.70	79.60	64.90	69.90
9	43.60	31.90	32.10	32.30	32.40	80.60	64.00	70.60

ตารางที่ ก 21 ข้อมูลการทดสอบครีปเกล็ดที่มุมเอียงเกล็ด 18 องศา $Re_{L_p} = 1023.67$

$F_p/L_p = 1.5$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	87.68	29.35	31.56	29.35	31.98	112.00	86.80	95.10
2	81.54	29.41	30.61	29.41	30.57	110.50	85.80	94.30
3	76.25	29.23	29.84	29.23	30.04	111.36	85.80	94.30
4	72.98	29.42	29.96	29.42	29.98	110.75	85.10	94.50
5	70.56	29.65	30.46	29.65	30.32	110.36	85.80	94.10
6	68.45	29.53	29.85	29.53	29.99	111.52	85.70	94.30
7	66.58	29.50	30.28	29.50	30.07	110.35	86.70	94.30
8	64.38	29.37	30.11	29.37	30.16	109.98	86.50	95.10
9	62.74	29.31	30.30	29.31	30.08	110.88	86.70	95.30

$F_p/L_p = 1$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	71.25	30.12	32.04	30.12	32.11	96.90	75.80	82.85
2	67.56	30.10	30.58	30.10	30.59	94.60	76.10	83.65
3	65.45	30.07	30.56	30.07	30.51	96.10	77.30	85.35
4	63.14	30.16	30.65	30.16	30.62	96.30	78.10	84.80
5	59.76	30.09	30.47	30.09	30.46	97.30	77.80	84.85
6	56.53	30.02	30.48	30.02	30.51	97.90	76.60	84.60
7	52.47	30.13	30.54	30.13	30.49	97.80	78.00	85.65
8	50.74	30.11	30.62	30.11	30.65	96.80	79.50	83.15
9	49.65	30.04	30.57	30.04	30.52	96.60	77.60	85.50

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	62.54	29.41	29.99	29.41	30.04	79.60	53.70	67.25
2	59.41	29.56	29.78	29.56	29.71	76.30	53.60	65.60
3	57.03	29.52	29.61	29.52	29.57	77.80	54.80	65.80
4	55.65	29.61	29.72	29.61	29.73	79.30	53.90	64.90
5	52.98	29.64	29.84	29.64	29.83	79.25	55.70	66.95
6	50.15	29.55	29.73	29.55	29.65	77.30	54.80	64.40
7	49.55	29.52	29.71	29.52	29.60	80.80	54.60	64.10
8	48.67	29.43	29.57	29.43	29.56	79.70	54.30	62.80
9	45.76	29.51	29.72	29.51	29.63	79.10	52.60	61.60

ตารางที่ ก 22 ข้อมูลการทดสอบครีบอกที่มุมเอียงเกิด 23 องศา $Re_{L_p} = 1023.67$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	86.87	30.11	32.05	30.11	32.08	110.00	82.80	93.80
2	84.65	30.05	30.75	30.05	30.87	106.60	82.60	93.60
3	81.88	30.14	30.69	30.14	30.68	107.40	82.80	93.50
4	77.51	30.03	30.50	30.03	30.51	108.50	82.20	93.50
5	75.32	30.08	30.76	30.08	30.76	110.70	75.50	93.60
6	71.93	30.09	30.66	30.09	30.64	109.60	80.50	93.50
7	67.74	30.13	30.65	30.13	30.66	105.80	80.80	93.50
8	65.11	30.08	30.68	30.08	30.70	105.30	81.10	94.30
9	61.86	30.15	30.62	30.15	30.61	111.00	81.10	92.90

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	72.56	29.52	31.31	29.52	31.36	97.60	72.55	85.08
2	68.50	29.61	30.58	29.61	30.41	94.60	72.55	83.58
3	66.75	29.23	29.79	29.23	29.82	96.10	74.55	85.33
4	63.98	29.56	29.88	29.56	29.85	96.80	74.40	85.60
5	61.55	29.47	29.89	29.47	29.88	98.00	75.95	86.98
6	58.36	29.61	29.83	29.51	29.79	96.20	74.10	85.15
7	55.12	29.46	29.86	29.46	29.84	99.10	73.55	86.33
8	52.88	29.49	29.79	29.49	29.74	99.00	72.95	85.98
9	49.87	29.55	29.86	29.55	29.77	98.20	72.30	81.84

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	61.25	29.12	29.87	29.12	29.96	76.30	55.50	67.80
2	58.56	29.20	29.50	29.20	29.46	77.80	55.10	68.30
3	56.74	29.11	29.24	29.11	29.24	79.30	56.20	67.50
4	54.22	29.05	29.32	29.05	29.28	75.60	57.60	68.50
5	52.36	29.04	29.25	29.04	29.23	77.30	55.20	66.80
6	50.14	29.10	29.23	29.10	29.28	80.80	56.50	68.40
7	48.25	29.06	29.24	29.06	29.27	79.70	56.30	67.70
8	46.89	29.08	29.23	29.08	29.32	79.10	55.20	69.10
9	45.55	29.16	29.34	29.16	29.35	77.80	58.30	69.10

ตารางที่ ก 23 ข้อมูลการทดสอบครีปเกล็ดที่มุมเอียงเกล็ด 30 องศา $Re_{L_p} = 1023.67$

$F_p/L_p = 1.5$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	86.35	30.25	32.25	30.25	32.04	110.60	82.45	93.30
2	82.86	30.14	31.00	30.14	30.99	107.10	81.75	93.80
3	79.67	30.20	30.86	30.20	30.74	106.20	83.00	93.80
4	77.41	30.16	30.72	30.16	30.63	107.90	82.10	93.60
5	75.69	30.12	30.76	30.12	30.79	104.60	82.30	92.70
6	72.06	30.18	30.77	30.18	30.76	105.90	82.90	93.60
7	69.85	30.12	30.65	30.12	30.66	106.80	82.65	93.20
8	67.35	30.15	30.79	30.15	30.75	109.70	80.95	94.10
9	64.23	30.13	30.65	30.13	30.72	106.10	81.94	95.80

$F_p/L_p = 1$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	73.56	30.04	31.86	30.04	31.78	96.40	74.10	84.30
2	69.75	30.02	30.68	30.02	30.66	97.10	73.55	84.80
3	66.84	30.05	30.56	30.05	30.64	96.60	72.95	84.80
4	64.23	30.01	30.38	30.01	30.42	96.30	72.30	83.70
5	62.14	30.00	30.42	30.00	30.39	96.80	73.65	84.50
6	59.36	30.03	30.44	30.03	30.41	95.80	75.00	85.90
7	56.85	30.12	30.52	30.12	30.51	95.80	74.20	82.20
8	53.24	30.08	30.47	30.08	30.45	95.20	74.15	82.30
9	49.78	30.10	30.40	30.10	30.42	96.40	74.00	85.70

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	62.15	29.25	29.85	29.25	29.92	77.40	58.65	68.54
2	58.26	29.24	29.52	29.24	29.51	77.30	58.63	66.70
3	56.41	29.18	29.37	29.18	29.32	78.70	58.18	65.70
4	53.69	29.22	29.39	29.22	29.35	78.70	57.28	66.60
5	51.05	29.11	29.40	29.11	29.38	77.80	56.70	68.30
6	48.63	29.17	29.43	29.17	29.41	77.40	56.65	67.80
7	46.25	29.24	29.40	29.24	29.48	81.40	56.25	67.10
8	44.35	29.19	29.39	29.19	29.44	80.80	56.13	69.50
9	42.47	29.20	29.35	29.20	29.40	78.10	56.00	70.30

ตารางที่ ก 24 ข้อมูลการทดสอบครีบอกเก็ตที่มุมเอียงเก้ด 35 องศา $Re_{L_p} = 1023.67$

$$F_p/L_p = 1.5$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	87.68	30.56	32.88	30.56	32.88	108.50	83.70	96.30
2	84.95	30.47	31.41	30.47	31.42	112.80	82.30	95.80
3	81.25	30.25	30.86	30.25	30.86	113.60	83.50	94.50
4	76.84	30.22	30.77	30.22	30.76	114.10	81.90	94.10
5	74.93	30.15	30.86	30.15	30.87	113.00	87.30	94.50
6	72.03	30.25	30.90	30.25	30.88	110.10	80.80	94.10
7	69.17	30.23	30.83	30.23	30.88	107.80	85.60	96.80
8	66.82	30.28	30.81	30.28	30.69	113.50	81.10	96.20
9	61.57	30.14	30.64	30.14	30.72	109.80	82.20	95.20

$$F_p/L_p = 1$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	74.26	29.54	30.75	29.54	30.68	96.50	72.30	82.20
2	71.34	29.45	29.99	29.45	29.97	96.60	73.10	82.30
3	68.46	29.48	29.85	29.48	29.87	95.40	72.50	85.70
4	66.19	29.65	29.93	29.65	29.96	95.50	73.30	83.80
5	63.95	29.48	29.89	29.48	29.88	95.40	73.60	83.70
6	60.57	29.53	29.94	29.53	29.87	94.60	73.10	85.10
7	57.23	29.55	30.50	29.55	29.89	94.60	73.40	85.10
8	54.65	29.61	29.90	29.61	29.86	94.40	72.30	85.10
9	50.24	29.45	29.82	29.45	29.79	93.80	72.80	83.10

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	64.25	29.54	30.12	29.54	30.15	81.10	56.80	70.30
2	60.57	29.65	29.84	29.65	29.88	79.60	57.90	68.60
3	56.59	29.35	29.68	29.35	29.67	76.30	58.00	70.80
4	54.66	29.57	29.69	29.57	29.64	77.80	56.50	71.10
5	52.37	29.53	29.78	29.53	29.79	79.30	56.80	68.80
6	49.87	29.48	29.76	29.48	29.62	75.60	58.80	68.20
7	46.96	29.52	29.70	29.52	29.65	80.60	56.20	69.10
8	44.69	29.39	29.69	29.39	29.68	78.80	56.80	67.70
9	41.90	29.47	29.67	29.47	29.70	78.80	57.40	68.30

ตารางที่ ก 25 ข้อมูลการทดสอบครีปเกล็ดที่มุมเอียงเกล็ด 40 องศา $Re_{L_p} = 1023.67$

$F_p/L_p = 1.5$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	88.65	30.25	31.99	30.25	31.98	110.40	83.70	95.10
2	84.37	30.21	30.99	30.21	30.95	110.30	84.50	95.30
3	81.87	30.25	30.88	30.25	30.87	111.40	85.90	95.60
4	77.48	30.35	30.84	30.35	30.84	110.40	82.20	95.50
5	74.70	30.24	30.93	30.25	30.97	109.10	82.30	95.20
6	71.99	30.21	30.87	30.21	30.79	110.60	85.70	95.30
7	67.99	30.27	30.87	30.27	30.85	112.50	83.80	95.60
8	65.55	30.27	30.89	30.27	30.87	109.80	83.70	96.40
9	60.66	30.25	30.82	30.25	30.82	111.80	85.10	95.20

$F_p/L_p = 1$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	75.65	28.20	29.24	28.20	29.22	95.50	73.45	82.50
2	71.74	27.90	28.45	27.90	28.26	95.70	74.30	84.00
3	68.25	29.10	29.37	29.10	29.37	95.60	75.50	82.60
4	64.99	28.40	28.69	28.40	28.72	96.50	76.10	83.90
5	61.60	28.40	28.88	28.40	28.81	95.80	75.85	85.50
6	57.37	28.10	28.70	28.10	28.74	95.80	73.90	84.20
7	55.03	28.20	28.76	28.20	28.56	96.10	74.90	83.10
8	52.37	29.10	29.65	29.10	29.54	95.60	72.55	82.50
9	49.60	28.50	28.83	28.50	28.73	95.50	75.55	82.50

$$F_p/L_p = 0.75$$

position	t mean	w in	w out	w in	w out	a in	a out	free stream
1	65.24	29.45	30.11	29.45	30.11	78.80	59.65	71.75
2	62.59	29.15	29.43	29.15	29.43	79.80	59.60	71.25
3	58.99	29.34	29.48	29.34	29.45	79.50	59.50	73.00
4	56.48	29.65	29.83	29.65	29.84	81.10	59.18	72.80
5	52.02	29.47	29.81	29.47	29.92	79.60	59.10	72.80
6	49.99	29.35	29.74	29.35	29.63	76.30	59.05	73.00
7	47.52	29.45	29.63	29.45	29.60	77.80	59.00	72.40
8	44.99	29.56	29.72	29.56	29.75	79.30	58.85	72.55
9	41.69	29.48	29.81	29.48	29.81	75.60	58.85	73.40

ตารางที่ ก 26 ข้อมูลการคำนวณประสิทธิภาพการไหลที่มุมเอียงเกล็ดต่างๆ

$$F_p/L_p = 1.5$$

Re _{Lp}	18	23	30	35	40
232.59	0.39427	0.424356	0.459567	0.481318	0.500991
439.47	0.505319	0.543879	0.589007	0.616885	0.642099
659.20	0.591889	0.637055	0.689913	0.722568	0.752101
832.90	0.648417	0.697897	0.755804	0.791577	0.823931
1023.67	0.702725	0.756349	0.819106	0.857876	0.892939

$$F_p/L_p = 1$$

Re_{L_p}	18	23	30	35	40
232.59	0.470241	0.506125	0.54812	0.574063	0.597526
439.47	0.602688	0.648678	0.702502	0.735752	0.765824
659.20	0.705939	0.759808	0.822852	0.861799	0.897023
832.90	0.773360	0.832373	0.901439	0.944105	0.982693
1023.67	0.838133	0.902089	0.976939	1.023179	1.064999

$$F_p/L_p = 0.75$$

Re_{L_p}	18	23	30	35	40
232.59	0.533109	0.573789	0.621399	0.65081	0.67741
439.47	0.683262	0.735401	0.796420	0.834115	0.868208
659.20	0.800317	0.861387	0.932860	0.977013	1.016946
832.90	0.876751	0.943654	1.021953	1.070323	1.114070
1023.67	0.950184	1.022690	1.107547	1.159968	1.207379

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ภาคผนวก ข

ตัวอย่างการคำนวณค่า j โคเบิร์น แฟกเตอร์, ค่าประสิทธิภาพการไหล, สมดุลความร้อน
และสมการความสัมพันธ์ของตัวแปรต่างๆ ของครีบบแบบเกล็ด

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่

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ตัวอย่างการคำนวณค่า j Colburn factor ของครีบกี้ด

คุณสมบัติของอากาศร้อนที่อุณหภูมิเฉลี่ย 353.85 K

ค่าความจุความร้อนของอากาศ (C_p)	=	1.009	kJ/kg.K
ค่าพรีนัมเบอร์ (Pr)	=	0.700	
ความหนืดสัมบูรณ์ (μ)	=	234.45×10^{-7}	N.s/m ²
พื้นที่ปล่อง	=	0.12	m ²
พื้นที่ที่ไหลอิสระในช่องว่างที่ตั้งฉากกับการไหล (A_{ff})	=	0.012	m ²
พื้นที่ผิวเกล็ดทั้งหมด	=	0.016	m ²
ระยะห่างระหว่างเกล็ด	=	0.02	m
ผลต่างของอุณหภูมิน้ำเข้าและออกสายที่ 1	=	1	C
ผลต่างของอุณหภูมิน้ำเข้าและออกสายที่ 2	=	0.5	C
$\dot{m}_a = \rho A_p v = 0.97 \times 0.4 \times 0.3 \times 1$	=	0.116	kg/s
อัตราการไหลของน้ำ (m ³)	=	0.025	kg/s
อุณหภูมิผิวเกล็ด (T_s)	=	85	C
อุณหภูมิฟรีสตรีม	=	65	C

การคำนวณเริ่มจากการหาค่า G กรณีความเร็วอากาศเข้าเท่ากับ 1 ($Re_{Lp} = 853.06$)

$$G = \frac{\rho V A_{fr}}{A_{ff}} = \frac{\dot{m}}{A_{ff}}$$

$$= \frac{0.116}{0.012}$$

$$= 9.7 \frac{\text{kg}}{\text{m}^2 \text{s}}$$

$$Q = h A \Delta T$$

$$h = \frac{Q}{A \Delta T} = \frac{\dot{m} c_p (\Delta T_1 + \Delta T_2)}{A_s (T_s - T_{ref})}$$

$$h = \frac{0.025 \times 4180 \times (1 + 0.5)}{0.4 \times 0.04 \times (85 - 60)}$$

$$h = \frac{156.75}{0.4} = 391.875 \text{ W/m}^2 \text{ K}$$

$$j = \frac{391.875 \times 0.7^{2/3}}{9.7 \times 1009} = 0.03156$$

ส่วนเรย์โนลด์ส้นัมเบอร์หาจาก

$$Re = \frac{\rho v L_p}{\mu} = \frac{v L_p}{\nu} = \frac{1 \times 2 \times 10^{-2}}{23.445 \times 10^{-6}} = 853.06$$

ตัวอย่างการคำนวณประสิทธิภาพการไหล

ในการคำนวณใช้ค่าตัวแปรต่างๆ ดังนี้

มุมเอียงเอียงเกล็ด	(θ)	=	30	องศา
ระยะห่างระหว่างเกล็ด	(L_p)	=	3	cm
ระยะห่างระหว่างครีป	(F_p)	=	3	cm

เริ่มต้นจากการหาค่า Re_{L_p} จาก

$$Re_{L_p} = \frac{\rho v L_p}{\mu} = \frac{v L_p}{\nu} = \frac{1 \times 2 \times 10^{-2}}{23.445 \times 10^{-6}} = 853.06$$

และหาค่า Re^* จาก

$$Re^* = 828 \left(\frac{\theta}{90} \right)^{-0.34} = 828 \left(\frac{30}{90} \right)^{-0.34} = 1202.96$$

ดังนั้นจะเห็นได้ว่า Re^* มากกว่า Re_{L_p} ดังนั้นจะใช้สมการประสิทธิภาพการไหลเป็นดังนี้

$$\eta = 0.091 (Re_{L_p})^{0.39} \left(\frac{L_p}{F_p} \right)^{0.44} \left(\frac{\theta}{90} \right)^{0.3} \quad \text{กรณี } Re_{L_p} < Re^*$$

แทนค่าต่างๆ จากที่กำหนดข้างต้นจะได้

$$\eta = 0.091 (853.06)^{0.39} \left(\frac{1}{1} \right)^{0.44} \left(\frac{30}{90} \right)^{0.3}$$

$$\eta = 0.91$$

$$\eta = 91\%$$

MUTIPLE LINEAR REGRESSION

$$Sr = \sum_{i=1}^n (y_i - a_0 - a_1 x_{1i} - a_2 x_{2i})^2$$

Differentiating แต่ละตัวแปรที่ไม่ทราบค่า

$$\frac{\partial Sr}{\partial a_0} = -2 \sum (y_i - a_0 - a_1 x_{1i} - a_2 x_{2i})$$

$$\frac{\partial Sr}{\partial a_1} = -2 \sum x_{1i} (y_i - a_0 - a_1 x_{1i} - a_2 x_{2i})$$

$$\frac{\partial Sr}{\partial a_2} = -2 \sum x_{2i} (y_i - a_0 - a_1 x_{1i} - a_2 x_{2i})$$

หาค่าตัวแปรที่ไม่ทราบค่าจาก Matrix form

$$\begin{bmatrix} n & \sum x_{1i} & \sum x_{2i} \\ \sum x_{1i} & \sum x_{1i}^2 & \sum x_{1i} x_{2i} \\ \sum x_{2i} & \sum x_{1i} x_{2i} & \sum x_{2i}^2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum x_{1i} y_i \\ \sum x_{2i} y_i \end{bmatrix}$$

ตรวจสอบความผิดพลาดจากสมการ

$$S = \left(\frac{Sr}{n - (m+1)} \right)^{\frac{1}{2}}$$

ตัวอย่างการคำนวณ

ใช้วิธี Multiple Linear Regression และใช้ matrix แก้สมการ

โดยมีสมการเริ่มต้นคือ

$$j = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + e$$

โดยเมื่อนำข้อมูลทั้งหมดจัดให้อยู่ในรูปของ Regressions แล้วจะได้

n	x1	x2	x3		y
75.000	55.329	81.250	2190.000	a0	3.78
x1	x1^2	x1x2	x1x3		yx1
55.329	48.884	59.940	1615.619	a1	2.33
x2	x1x2	x2^2	x2x3		yx2
81.250	59.940	95.313	2372.500	a2	4.09
x3	x1x3	x2x3	x3^2		yx3
2190.000	1615.619	2372.500	68670.000	a3	111.63

แก้สมการหาค่าตัวแปรต่างๆ แล้วจะได้ความสัมพันธ์เป็นดังสมการ

$$j = 0.0853 + 0.0054 \frac{\theta^*}{90} - 0.0568 (Gr \times 10^{-7}) - 0.0007 \frac{F_p}{L_p}$$

$$\text{โดย } \theta^* = \frac{\theta \times 90}{90}$$

ตัวอย่างข้อมูลจากการคำนวณ

y	x1	x2	x3		
j	Gr x 10 ⁻⁷	Fp/Lp	angle	Regression	error %
0.09010	0.21	1.00	30.00	0.08164	9.39
0.07120	0.54	1.00	30.00	0.06269	11.95
0.04950	0.82	1.00	30.00	0.04714	4.77
0.03736	0.98	1.00	30.00	0.03766	0.79
0.02730	1.13	1.00	30.00	0.02935	7.49

โดยมีค่าความคลาดเคลื่อนมากที่สุด 27.39 % เกิดขึ้นที่มุมเอียงเกล็ด 40 องศา Fp/Lp 0.75 และที่ Gr เท่ากับ 1.13 x 10⁷

สมดุลความร้อน

จากการทดลองสามารถหาสมดุลความร้อนได้จาก

ความร้อนที่ให้ = ความร้อนที่ถ่ายเทจากครีบเกล็ดสู่น้ำ + ความร้อนสูญเสีย

$$(\dot{m} c_p \Delta T)_{air} = (\dot{m} c_p \Delta T)_{water} + q_{loss}$$

ΔT_{air} คือ ผลต่างอุณหภูมิเฉลี่ยของอากาศขาเข้าและออกของอากาศร้อน

$$\Delta T_{air} = (T_{mi} - T_{mo})$$

โดย T_{mi} และ T_{mo} คือ Mixing-cup temperature ของอากาศขาเข้าและออก ตามลำดับ

ซึ่ง T_m สามารถหาได้จาก

$$T_m = \frac{1}{A} \int_A \frac{\rho}{\rho_{av}} \frac{C_p}{C_{pav}} T dA$$

จากผลการทดลองสามารถหาสมมูลความร้อนได้ดังตาราง

ตัวอย่างข้อมูลจากการทดลอง

ตารางที่ ค1 ความร้อนขาเข้า

Gr	210.51	544.12	817.99	984.86	1131.15
T_{mi}	42.00	64.83	91.97	100.17	111.29
T_{mo}	27.00	52.30	69.23	74.73	84.70
m'	0.01	0.05	0.07	0.09	0.14
Q	177.99	594.68	1618.50	2414.30	3785.68

ตารางที่ ค2 ความร้อนที่ถ่ายเทให้น้ำที่ Gr = 210.51 อัตราส่วนระยะห่างครีบท่อต่อระยะห่างระหว่างเกล็ดเท่ากับ 1

position	มุมเอียงเกล็ด				
	18.00	23.00	30.00	35.00	40.00
1	26.479	57.998	62.078	60.515	49.232
2	2.436	24.616	31.627	11.522	13.198
3	1.814	14.456	4.913	5.238	4.400
4	4.581	4.766	1.063	3.897	7.982
5	15.431	2.709	2.933	12.645	20.374
6	14.665	6.055	9.427	15.712	20.519
7	16.760	5.342	8.904	24.092	12.620
8	17.807	8.799	11.998	13.618	19.798
9	15.388	17.409	12.903	7.333	12.004
รวม	115.362	142.150	145.845	154.571	160.127

ตารางที่ ค3 ความร้อนสูญเสีย

มุมเอียงเกล็ด	18.00	23.00	30.00	35.00	40.00
$Q_{loss} \%$	35.19	20.13	18.06	13.16	10.03

จากตารางจะเห็นได้ชัดว่าที่ความร้อนสูญเสียจะลดลงเมื่อเพิ่มมุมเอียงเกล็ด



ภาคผนวก ค
การวิเคราะห์ตัวแปรไร้มิติและค่า Uncertainty

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การวิเคราะห์มิติของตัวแปรต่างๆของ ค่า j โคนเบิร์น แฟกเตอร์

อัตราการไหลภายในอาจจะขึ้นอยู่กับตัวแปรดังต่อไปนี้คือ $L, k, \rho, \mu, D, w, h, c_p, g, \Delta T, \beta$

โดยที่มีมิติพื้นฐานของตัวแปรแต่ละตัวในหน่วยของ $MLT\Theta$ มีดังต่อไปนี้

	ตัวแปร	หน่วย	มิติพื้นฐาน
\dot{m}	อัตราการไหลเชิงมวล	kg/s	MT^{-1}
v	ความเร็วอากาศ	m/s	LT^{-1}
F_p	ระยะห่างระหว่างครีป	L	L
L_p	ระยะห่างระหว่างเกล็ด	L	L
ρ	ความหนาแน่นของของไหล	kg/m ³	ML^{-3}
k	สภาพการนำความร้อน	W/m ² K	$MLT^{-3}\Theta^{-1}$
μ	ความหนืดสัมบูรณ์	kg/m-s	$ML^{-1}T^{-1}$
h	สัมประสิทธิ์การพาความร้อน	W/m ² K	$MT^{-3}\Theta^{-1}$
c_p	ความจุความร้อนจำเพาะ,	kJ/kg-K	$L^2T^{-2}\Theta^{-1}$
g	ความเร่งเนื่องจากแรงโน้มถ่วงของโลก	m/s ²	LT^{-2}
ΔT	ผลต่างของอุณหภูมิ	K	Θ
β	สัมประสิทธิ์การขยายตัวของความร้อน	1/K	Θ^{-1}

ทำการวิเคราะห์มิติโดยวิธี Buckingham Pi theorem

กำหนดตัวแปรซ้ำดังต่อไปนี้คือ ρ, μ, L_p, k

มีจำนวนตัวแปรทั้งสิ้น 12 ตัว จะได้จำนวนกลุ่มตัวแปรไร้มิติคือ $n - m$ คือ $12 - 4 = 8$ กลุ่ม

$$\Pi_1 = L^a p^b k^c \mu^d \dot{m} = (L)^a \left(\frac{ML}{T^3\Theta}\right)^b \left(\frac{M}{L^3}\right)^c \left(\frac{M}{LT}\right)^d \left(\frac{M}{T}\right)$$

$$M; \quad b \quad +c \quad +d \quad +1 \quad = 0 \quad , a = -1$$

$$L; \quad a \quad +b \quad -3c \quad -d \quad = 0 \quad , b = 0$$

$$T; \quad -3b \quad -d \quad -1 \quad = 0 \quad , c = 0$$

$$\Theta; \quad -b \quad = 0 \quad , d = -1$$

จะได้ $\Pi_1 = \frac{\dot{m}}{L_p \mu}$

$$\Pi_2 = L_p^a k^b \rho^c \mu^d F_p = (L)^a \left(\frac{ML}{T^3 \Theta}\right)^b \left(\frac{M}{L^3}\right)^c \left(\frac{M}{LT}\right)^d (L)$$

$$\begin{array}{l} M; \quad \quad \quad b \quad +c \quad +d \quad = 0 \quad , a = -1 \\ L; \quad a \quad +b \quad -3c \quad -d \quad +1 = 0 \quad , b = 0 \\ T; \quad \quad \quad -3b \quad \quad -d \quad = 0 \quad , c = 0 \\ \Theta; \quad \quad \quad -b \quad \quad \quad \quad = 0 \quad , d = 0 \end{array}$$

จะได้ $\Pi_2 = \frac{F_p}{L_p}$

$$\Pi_3 = L_p^a k^b \rho^c \mu^d A_{ff} = (L)^a \left(\frac{ML}{T^3 \Theta}\right)^b \left(\frac{M}{L^3}\right)^c \left(\frac{M}{LT}\right)^d (L)^2$$

$$\begin{array}{l} M; \quad \quad \quad b \quad +c \quad +d \quad = 0 \quad , a = -2 \\ L; \quad a \quad +b \quad -3c \quad -d \quad +2 = 0 \quad , b = 0 \\ T; \quad \quad \quad -3b \quad \quad -d \quad = 0 \quad , c = 0 \\ \Theta; \quad \quad \quad -b \quad \quad \quad \quad = 0 \quad , d = 0 \end{array}$$

จะได้ $\Pi_3 = \frac{A_{ff}}{L_p^2}$

$$\Pi_4 = L_p^a k^b \rho^c \mu^d h = (L)^a \left(\frac{ML}{T^3 \Theta}\right)^b \left(\frac{M}{L^3}\right)^c \left(\frac{M}{LT}\right)^d \left(\frac{M}{T^{-3} \Theta^{-1}}\right)$$

$$\begin{array}{l} M; \quad \quad \quad b \quad +c \quad +d \quad +1 \quad = 0 \quad , a = 1 \\ L; \quad a \quad +b \quad -3c \quad -d \quad \quad \quad = 0 \quad , b = -1 \\ T; \quad \quad \quad -3b \quad \quad -d \quad -3 \quad = 0 \quad , c = 0 \end{array}$$

$$\Theta ; \quad -b \quad -1 \quad = 0 \quad , d = 0$$

จะได้ $\Pi_4 = \frac{hLp}{k}$

$$\Pi_5 = L^a k^b \rho^c \mu^d c_p = (L)^a \left(\frac{ML}{T^3\Theta}\right)^b \left(\frac{M}{L^3}\right)^c \left(\frac{M}{LT}\right)^d \left(\frac{L}{T^2}\right)$$

$$\begin{array}{l} M ; \quad b \quad +c \quad +d \quad = 0 \quad , a = 0 \\ L ; \quad a \quad +b \quad -3c \quad -d \quad +2 \quad = 0 \quad , b = -1 \\ T ; \quad -3b \quad -d \quad -2 \quad = 0 \quad , c = 0 \\ \Theta ; \quad -b \quad -1 \quad = 0 \quad , d = 1 \end{array}$$

จะได้ $\Pi_5 = \frac{c p \mu}{k}$

$$\Pi_6 = L^a k^b \rho^c \mu^d g = (L)^a \left(\frac{ML}{T^3\Theta}\right)^b \left(\frac{M}{L^3}\right)^c \left(\frac{M}{LT}\right)^d \left(\frac{L}{T^2}\right)$$

$$\begin{array}{l} M ; \quad b \quad +c \quad +d \quad = 0 \quad , a = 3 \\ L ; \quad a \quad +b \quad -3c \quad -d \quad +1 \quad = 0 \quad , b = 0 \\ T ; \quad -3b \quad -d \quad -2 \quad = 0 \quad , c = 2 \\ \Theta ; \quad -b \quad = 0 \quad , d = -2 \end{array}$$

จะได้ $\Pi_6 = \frac{L^3 \rho^2 g}{\mu^2}$

$$\Pi_7 = L^a k^b \rho^c \mu^d \Delta T = (L)^a \left(\frac{ML}{T^3\Theta}\right)^b \left(\frac{M}{L^3}\right)^c \left(\frac{M}{LT}\right)^d (\Theta)$$

$$\begin{array}{l} M ; \quad b \quad +c \quad +d \quad = 0 \quad , a = 2 \\ L ; \quad a \quad +b \quad -3c \quad -d \quad = 0 \quad , b = 1 \end{array}$$

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$$\begin{array}{rcll}
 T ; & -3b & -d & = 0, c = 2 \\
 \theta ; & -b & +1 & = 0, d = -3
 \end{array}$$

จะได้ $\Pi_7 = \frac{L^2 k \rho^2 \Delta T}{\mu^3}$

$$\Pi_8 = L_p^a k^b \rho^c \mu^d \beta = (L)^a \left(\frac{ML}{T^3 \Theta} \right)^b \left(\frac{M}{L^3} \right)^c \left(\frac{M}{LT} \right)^d \left(\frac{1}{\Theta} \right)$$

$$\begin{array}{rcll}
 M ; & b & +c & +d & = 0, a = -2 \\
 L ; & a & +b & -3c & -d & = 0, b = -1 \\
 T ; & -3b & & -d & = 0, c = -2 \\
 \theta ; & -b & & & -1 & = 0, d = 3
 \end{array}$$

จะได้ $\Pi_8 = \frac{\mu^3 \beta}{L^2 k \rho^2}$

$$\Pi_9 = L_p^a k^b \rho^c \mu^d v = (L)^a \left(\frac{ML}{T^3 \Theta} \right)^b \left(\frac{M}{L^3} \right)^c \left(\frac{M}{LT} \right)^d \left(\frac{L}{T} \right)$$

$$\begin{array}{rcll}
 M ; & b & +c & +d & +1 & = 0, a = 1 \\
 L ; & a & +b & -3c & -d & = 0, b = 0 \\
 T ; & -3b & & -d & -1 & = 0, c = 1 \\
 \theta ; & -b & & & & = 0, d = -1
 \end{array}$$

จะได้ $\Pi_9 = \frac{\rho v L_p}{\mu}$

จะได้ความสัมพันธ์ในรูปของกลุ่มตัวแปรไร้มิติได้ดังต่อไปนี้

$$j = f(\Pi_1, \Pi_2, \Pi_3, \Pi_4, \Pi_5, \Pi_6, \Pi_7, \Pi_8, \Pi_9)$$

หรือ

$$\frac{\dot{m}}{L\mu} = f\left(\frac{F_p}{L_p}, \frac{A_{ff}}{L_p^2}, \frac{hL_p}{k}, \frac{c_p\mu}{k}, \frac{L_p^3\rho^2g}{\mu^2}, \frac{L_p^2k\rho^2\Delta T}{\mu^3}, \frac{\mu^3\beta}{L_p^2k\rho^2}\right)$$

นำ Π_6, Π_7, Π_8 คูณกันแล้วจะได้ $\frac{gL^3\beta\Delta T}{v^2} = \text{Grashof number, Gr}$

$$\frac{c_p\mu}{k} = \text{Prandtl number, Pr}$$

และนำ Π_4 หารด้วย Π_5 และ Π_1 หารด้วย Π_3 จะได้

$$\frac{hL_p}{\mu c_p} = \Pi_{10}, \frac{\dot{m}L_p}{A_{ff}\mu} = \Pi_{11}$$

กำหนดให้

$$\frac{\dot{m}}{A_{ff}} = G \text{ จะได้}$$

Π_{10} หารด้วย Π_{11}

$$\frac{h}{Gc_p}$$

เพราะฉะนั้นเราสามารถเขียนความสัมพันธ์ให้อยู่ในรูปที่เราศึกษานั้นคือ

$$\frac{h}{Gc_p} = f\left(\frac{F_p}{L_p}, Re_{L_p}, Gr, \frac{\theta}{90}, Pr\right)$$

Uncertainty analysis

จากสมการการหาค่า j Colburn factor

$$j = \frac{hPr^{2/3}}{Gc_p}$$

$$\dot{m}c_{pw}(\Delta T_1) + \dot{m}c_{pw}(\Delta T_2)$$

$$h = \frac{\dot{q}}{T_s - T_{ref}} = \frac{A_s}{T_s - T_{ref}}$$

$$G = \frac{\dot{m}_a}{A_{ff}} = \frac{\rho A_p v}{A_{ff}}$$

$$j = \frac{\dot{m}c_{pw}(\Delta T_1 + \Delta T_2) Pr^{2/3}}{A_s(T_s - T_{ref})} = \frac{\dot{m}c_{pw}(\Delta T_1 + \Delta T_2) Pr^{2/3} A_{ff}}{A_s(T_s - T_{ref}) \rho A_p v c_{pa}}$$

$$\Delta T_1 = T_{wo1} - T_{wi1}$$

$$\Delta T_2 = T_{wo2} - T_{wi2}$$

$$\therefore j = \frac{\dot{m}c_{pw}(T_{wo1} - T_{wi1} + T_{wo2} - T_{wi2}) Pr^{2/3} A_{ff}}{A_s(T_s - T_{ref})} \frac{Pr^{2/3} A_{ff}}{\rho A_p v c_{pa}}$$

จากสมการการหาค่า Uncertainty

$$w_R = [(\frac{\partial R}{\partial x_1} w_1)^2 + (\frac{\partial R}{\partial x_2} w_2)^2 + \dots + (\frac{\partial R}{\partial x_n} w_n)^2]^{1/2}$$

แทนค่าจากสมการ j โดยเทียบกับตัวแปรต่างๆ จะได้

$$\frac{\partial j}{\partial \dot{m}} = \frac{c_{pw}(T_{wo1} - T_{wi1} + T_{wo2} - T_{wi2}) Pr^{2/3} A_{ff}}{A_s(T_s - T_{ref})} \frac{Pr^{2/3} A_{ff}}{\rho A_p v c_{pa}} = 2.58$$

$$\frac{\partial j}{\partial A_{ff}} = \frac{\dot{m}c_{pw}(T_{wo1} - T_{wi1} + T_{wo2} - T_{wi2}) Pr^{2/3}}{A_s(T_s - T_{ref})} \frac{Pr^{2/3}}{\rho A_p v c_{pa}} = 5.37$$

$$\frac{\partial j}{\partial T_{wo1}} = \frac{\dot{m}c_{pw}}{A_s(T_s - T_{ref})} \frac{Pr^{2/3} A_{ff}}{\rho A_p v c_{pa}} = 0.021$$

$$\frac{\partial j}{\partial T_{wo2}} = \frac{\dot{m}c_{pw}}{A_s(T_s - T_{ref})} \frac{Pr^{2/3} A_{ff}}{\rho A_p v c_{pa}} = 0.021$$

$$\frac{\partial j}{\partial T_{wi1}} = -\frac{\dot{m}c_{pw}}{A_s(T_s - T_{ref})} \frac{Pr^{2/3} A_{ff}}{\rho A_p v c_{pa}} = -0.021$$

$$\frac{\partial j}{\partial T_{wi2}} = -\frac{\dot{m}c_{pw}}{A_s(T_s - T_{ref})} \frac{Pr^{2/3} A_{ff}}{\rho A_p v c_{pa}} = -0.021$$

$$\frac{\partial j}{\partial A_s} = -\frac{\dot{m}c_{pw}(T_{wo1} - T_{wi1} + T_{wo2} - T_{wi2}) Pr^{2/3} A_{ff}}{A_s^2(T_s - T_{ref})} \frac{Pr^{2/3} A_{ff}}{\rho A_p v c_{pa}} = 4.02$$

$$\frac{\partial j}{\partial A_p} = -\frac{\dot{m}c_{pw}(T_{wo1} - T_{wi1} + T_{wo2} - T_{wi2}) Pr^{2/3} A_{ff}}{A_s(T_s - T_{ref})} \frac{Pr^{2/3} A_{ff}}{\rho A_p^2 v c_{pa}} = 10.89$$

$$\frac{\partial j}{\partial v} = -\frac{\dot{m}c_{pw}(T_{wo1} - T_{wi1} + T_{wo2} - T_{wi2}) Pr^{2/3} A_{ff}}{A_s(T_s - T_{ref})} \frac{Pr^{2/3} A_{ff}}{\rho A_p v^2 c_{pa}} = 0.054$$

$$\frac{\partial j}{\partial T_s} = -\frac{\dot{m}c_{pw}(T_{wo1} - T_{wi1} + T_{wo2} - T_{wi2}) Pr^{2/3} A_{ff}}{A_s(T_s - T_{ref})^2} \frac{Pr^{2/3} A_{ff}}{\rho A_p v c_{pa}} = 2.02 \times 10^{-4}$$

$$\frac{\partial j}{\partial T_{ref}} = \frac{\dot{m}c_{pw}(T_{wo1} - T_{wi1} + T_{wo2} - T_{wi2}) Pr^{2/3} A_{ff}}{A_s(T_s - T_{ref})^2} \frac{Pr^{2/3} A_{ff}}{\rho A_p v c_{pa}} = -3.6 \times 10^{-4}$$

นำค่าจากการทดลองแทนค่าในสมการข้างต้นแล้วแทนค่าในสมการ Uncertainty จะได้

$$w_j = [(\frac{\partial j}{\partial \dot{m}} w_{\dot{m}})^2 + (\frac{\partial j}{\partial A_{ff}} w_{A_{ff}})^2 + (\frac{\partial j}{\partial T_{wo1}} w_{T_{wo1}})^2 + (\frac{\partial j}{\partial T_{wo2}} w_{T_{wo2}})^2 + (\frac{\partial j}{\partial T_{wi1}} w_{T_{wi1}})^2 + (\frac{\partial j}{\partial T_{wi2}} w_{T_{wi2}})^2 + (\frac{\partial j}{\partial A_s} w_A)^2 + (\frac{\partial j}{\partial A_p} w_A)^2 + (\frac{\partial j}{\partial v} w_v)^2 + (\frac{\partial j}{\partial T_s} w_{T_s})^2 + (\frac{\partial j}{\partial T_{ref}} w_{T_{ref}})^2]^{1/2}$$

$$w_j = [(2.58)^2(1.67 \times 10^{-3})^2 + (5.37)^2(2.5 \times 10^{-7})^2 + (0.021)^2(0.062)^2 + (0.021)^2(0.125)^2 + (0.021)^2(0.135)^2 + (0.021)^2(0.146)^2 + (4.02)^2(2.5 \times 10^{-7})^2 + (10.89)^2(2.5 \times 10^{-7})^2 + (0.054)^2(0.02)^2 + (0.021)^2(0.36)^2 + (0.021)^2(0.64)^2]^{1/2} = 0.016$$

$$j = \frac{h Pr^{2/3}}{Gc_p} = 0.086$$

ได้ Uncertainty ของการทดลองเป็น 18.53%

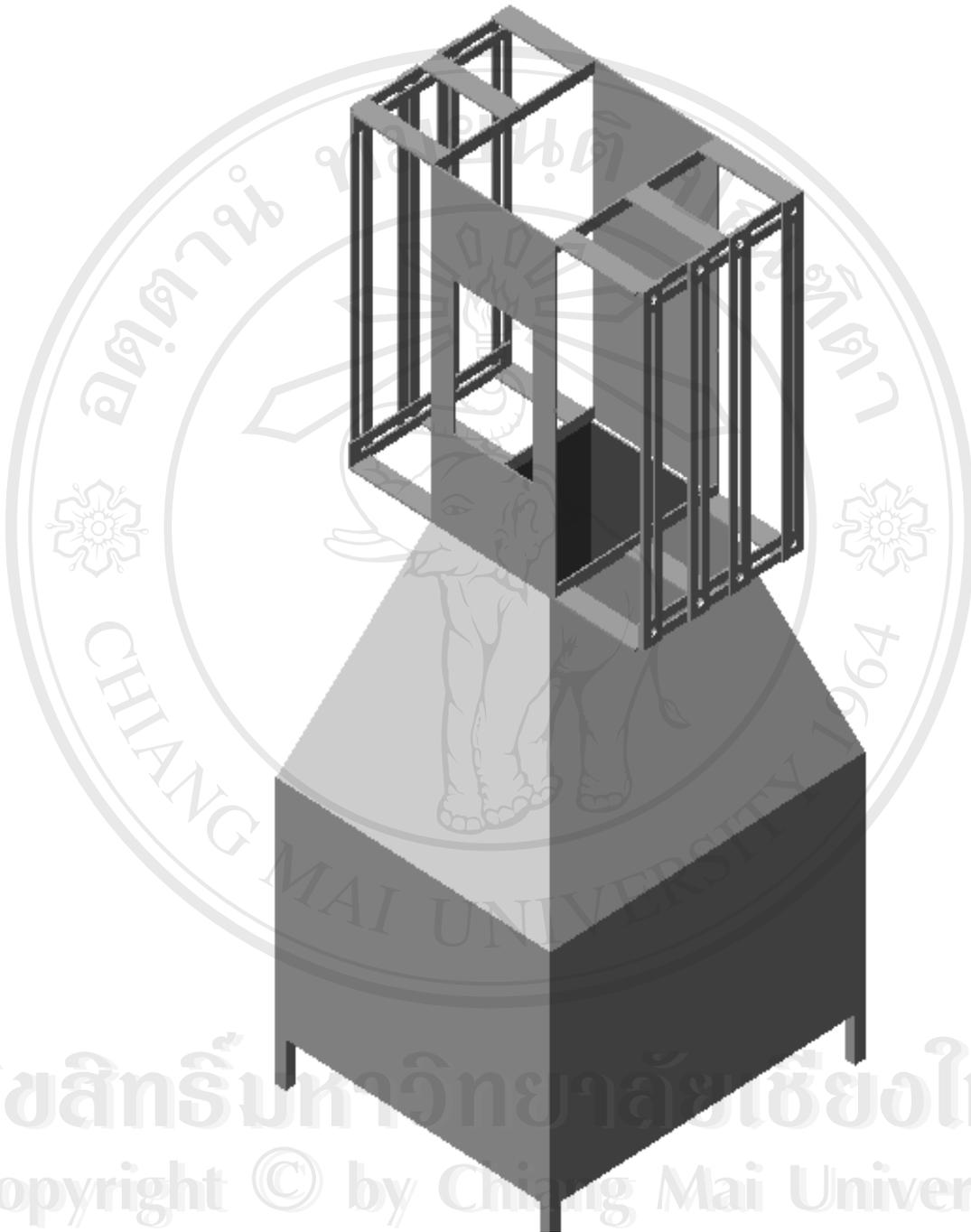
ดังนั้นในการทดลองนี้มีค่าความถูกต้อง 81.47 %



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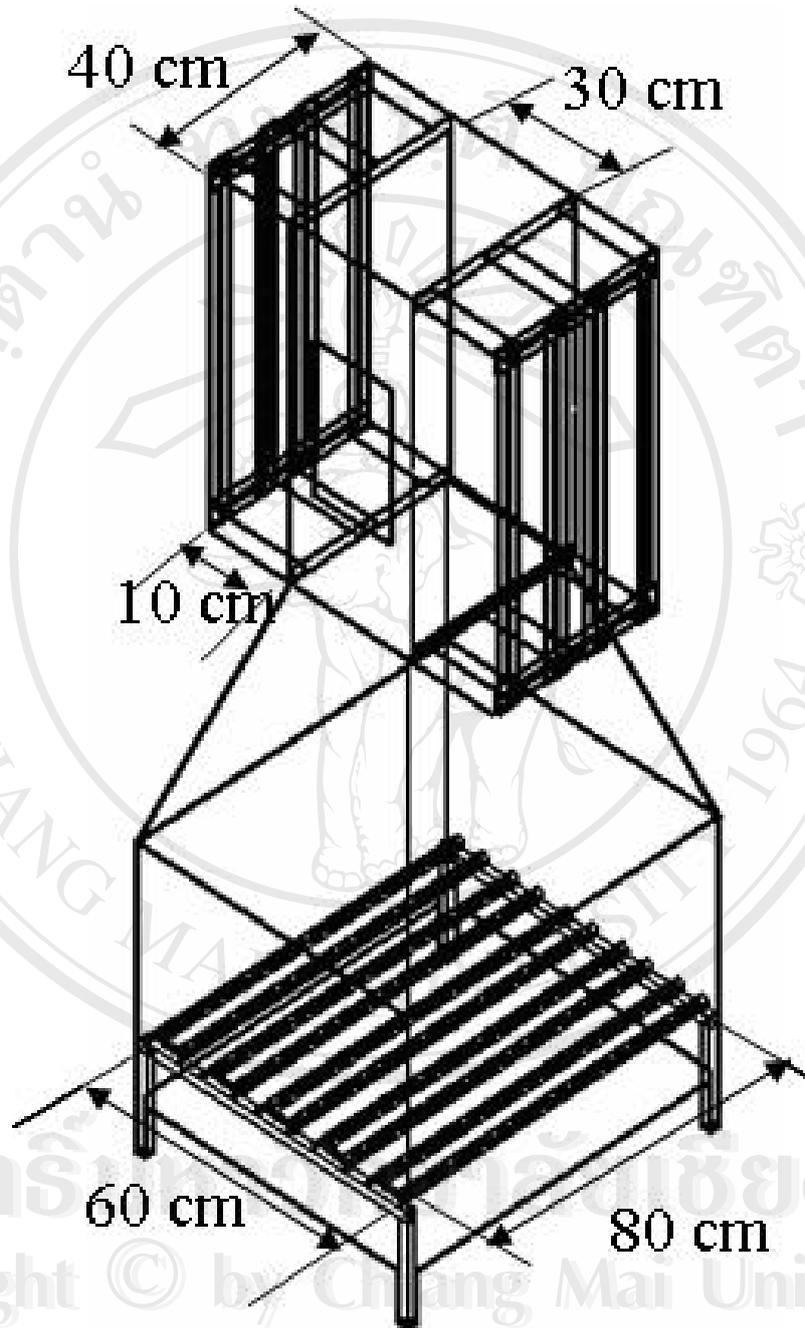


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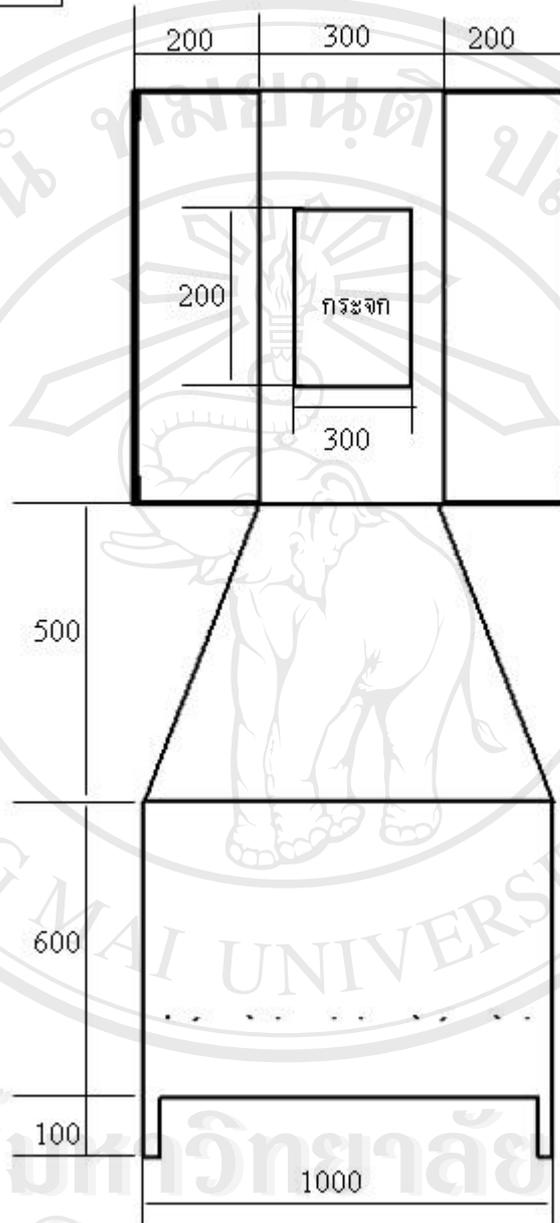
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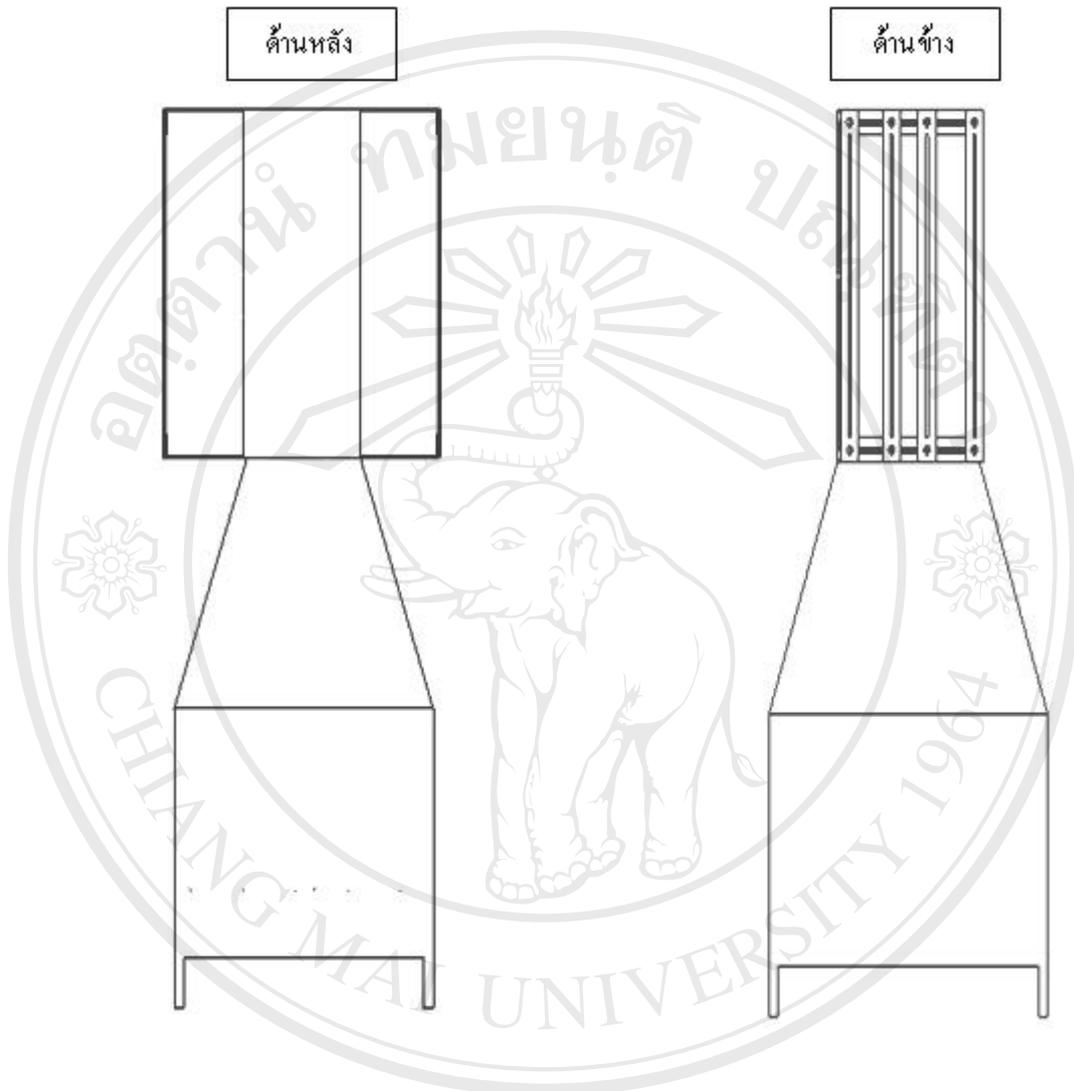
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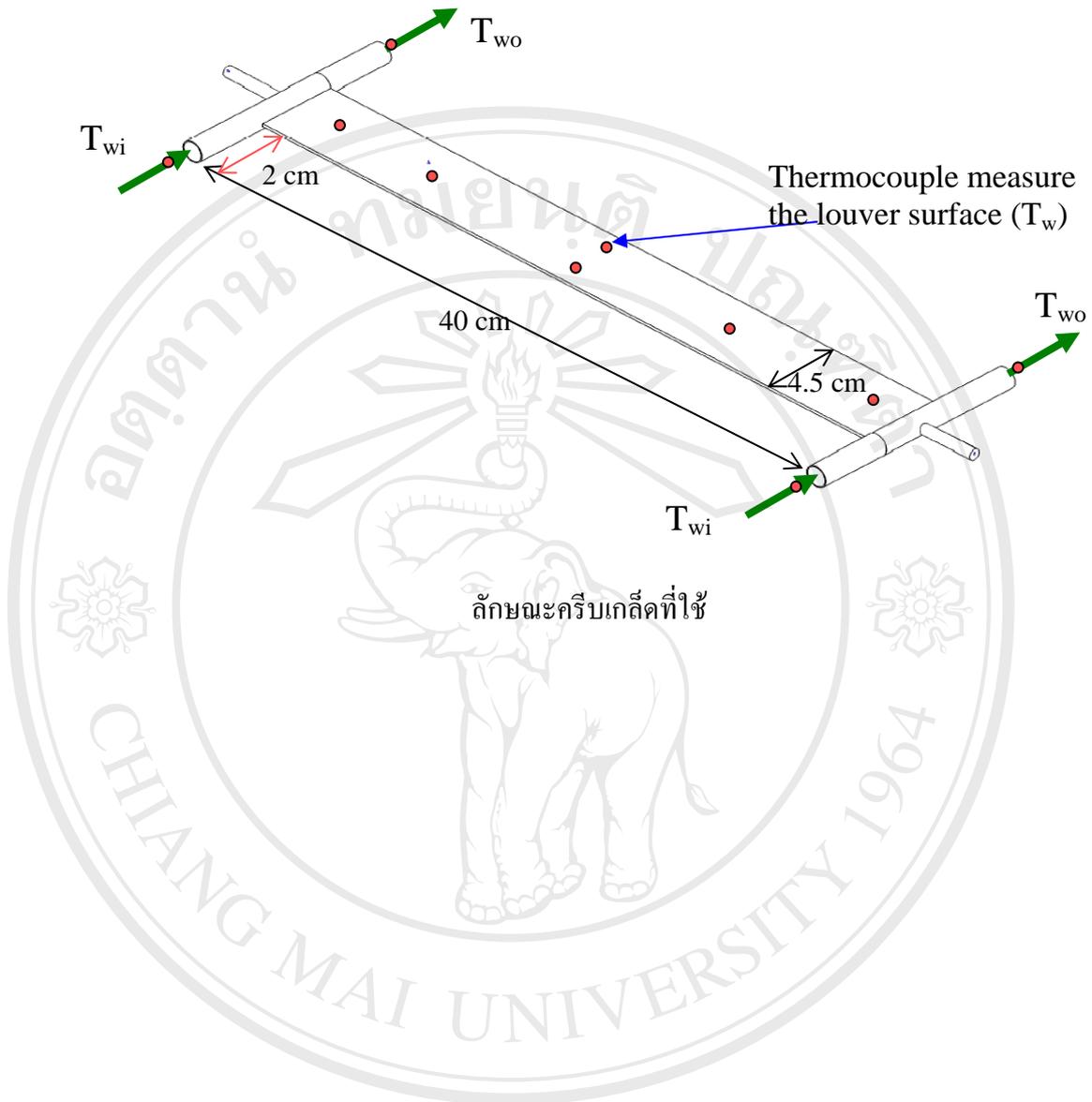
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ภาคผนวก จ

บทความเข้าร่วมประชุมวิชาการ

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THERMAL CHARACTERISTICS OF LOUVERED FINS AT LOW REYNOLDS NUMBER FLOW

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ABSTRACT Design parametric studies of a louvered-fin compact heat exchanger are carried out where fin pitch relative to the louver pitch and the angle of the louvers are investigated under the heat transmission from the hot buoyant plume of which the Reynolds number based on louver pitch is considered to be low. Experiments were conducted on the 15:1 scaled-up louver fin models. It is found that the highest j Colburn factor for such low Reynolds number flow emerges when the louver pitch ratio is 1 and louver angle is 30, respectively.

1. INTRODUCTION

Louvered fin compact heat exchangers (Fig.1) are used in a variety of applications including heat rejection system in automobiles, residential air-conditionings, oil coolers, and radiators. One of the most important objectives in the investigations regarding to these compact heat exchangers has been focusing on developing high performance heat exchangers without sacrificing the lightness and small volume. Achaichia and Cowell [1] were the first to experimentally verify that it is relatively important to design louvered fins in a way such that the flow is louver directed rather than duct directed (Fig.2a and b). Their study indicated an increase in heat transfer coefficients as the flow transitioned from being duct direct to being louver directed. Zhang et al [2] studied the effect of Reynolds number, fin pitch, louver thickness and louver angle on flow efficiency in multi-louvered fins. Results showed that flow efficiency was strongly dependent on geometrical parameter, especially at low Reynolds Number. Flow efficiency increases with Reynolds number and louver angle but it decreases with fin pitch and thickness ratio. Ralph and Webb [3] used a dye injection technique with 10:1 models in their work. The geometrical parameters, louver pitch, louver angle and fin pitch were varied to determine their effect on the flow structure. Tests covered Re of 400-4000 based on louver pitch. It was found that when louver angle and louver pitch increased the flow efficiency was increased, representing the louvered-directed flow where heat transfer is increased but if the fin pitch increased the flow efficiency was decrease.

Lyman et al [4] presented a method for evaluating the spatially resolved louver heat transfer coefficients using various reference temperatures, such as the bulk flow temperature and adiabatic wall temperature, to define the convective heat transfer coefficients. It was found that larger fin pitches and higher louver angles were better performance at the lower Reynolds numbers. At high Reynolds numbers, the performance is highly influenced by how many louvers downstream the heated wakes

influence. Louver geometries in which the louvers are nearly aligned do not provide a good design from heat transfer perspective, particularly for high Reynolds numbers. The heat transfer coefficients based on the bulk flow temperature for a particular louver did correlate closely with its local thermal field indicating the dominant importance of the thermal field approaching a particular louver. The objectives of previous literature were to design the heat exchanger so that high-performance and low pressure drop are achieved in which the forced convection heat transfer dominates. In contrast, this research work used 15:1 scaled-up model of louver fins to study the effects of the geometry in corresponding to the low Reynolds number flow of hot buoyant air plume which has never been investigated before.

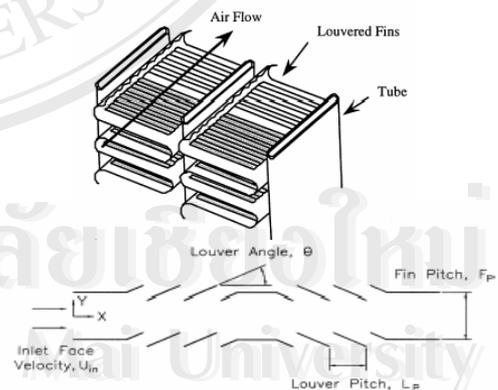


Fig.1 Illustration of the louvered plate fin heat exchanger and parameters of louvered fins geometry (Springer and Thole)

The objective of this study is to study the effect of the geometrical parameters including the fin pitch (F_p), louver pitch (L_p) and louver angle (θ) of the louver fins to clarify the better design parameters for the louvered compact heat exchanger to be used the heat recovery

system from hot buoyant air plume which is normally rejected in food industries.

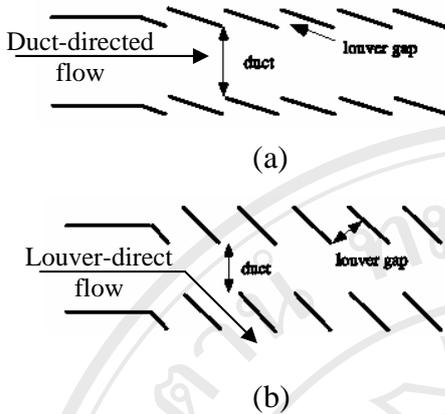


Fig.2 a) Duct-directed flow b) Louver directed-flow through a typical louver array (Springer)

2. THEORY AND PRINCIPLE

From the Newton's law of cooling, the predictive equation for the convective heat flux q [W/m^2] is suggested as

$$q = \frac{Q}{A} = h(T_w - T_{ref}) \quad (1)$$

where h is heat transfer coefficient

A is the louver surface area

T_w is louver wall temperature

T_{ref} is the free stream temperature used as the reference temperature

For the low speed external flow application, the free stream temperature is taken as the reference temperature, and for internal flow applications the bulk flow temperature is taken as the reference temperature (Lyman et al.)

Q in equation (1) can also be solved by

$$Q = m' c_p (\Delta T_1 + \Delta T_2) \quad (2)$$

where ΔT_1 and ΔT_2 are the water inlet and outlet temperature differences.

Additionally, the convection heat transfer coefficient of air on the side can be represented in a form of Colburn factor (j) as

$$j = \frac{hPr^{2/3}}{Gc_p} \quad (3)$$

where G is the maximum mass velocity can written as

$$G = \frac{m'_a}{A_{ff}} = \frac{\rho A_p v}{A_{ff}} \quad (4)$$

A_{ff} is the minimum cross sectional free flow area

A_p is the test section cross area

3. EXPERIMENTAL APPARATUS

In this investigation, the experiment set up as seen in Fig. 3a) in the investigation consisted of 1000-watt heater as the heat sources to naturally induce hot air with low speed to rise upward through louvers fin situated far above. The louver pitch, fin pitch and louver angle can be varied.

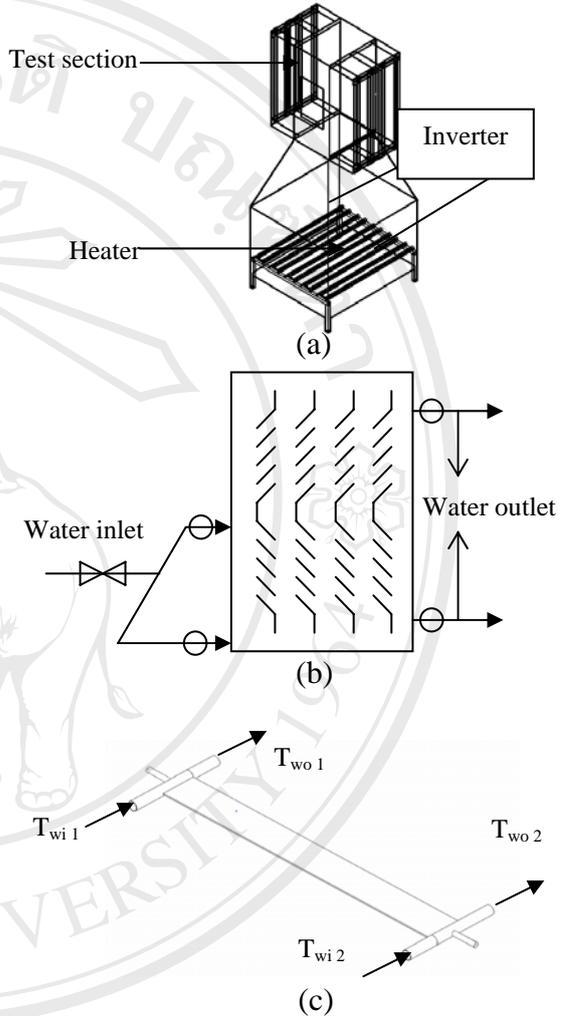


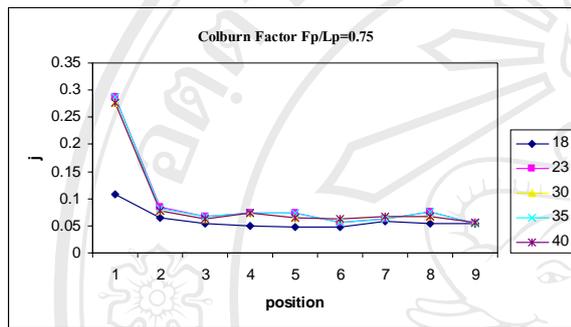
Fig. 3 a) Experimental test set up b) the test section c) louver fin design with scale up 15:1 louver models

The power of the heater can varied as the voltage input is altered. Air plume's velocity is measured using anemometer and pitot tube. The natural convective heat transfer is then achieved by circulating the cooling water to both sides of each louver blade by using a $\frac{1}{2}$ hp centrifugal pump as seen in Fig. 3b). Its flow rate is measured by the flow meter and Rota meter. The water inlet and outlet separate in two ducts as shown in Fig 3c).

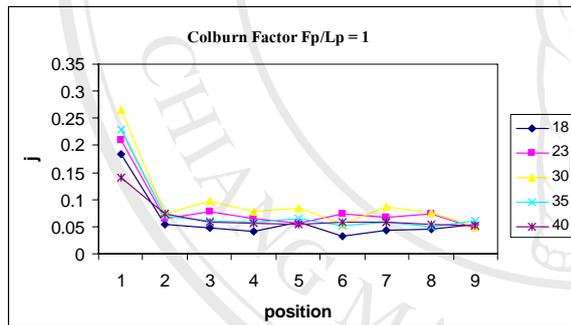
In the experiment all of the louver surfaces were attached with thermocouples where surface temperatures were recorded under the steady-state condition to determine the average louver surface temperature.

4. RESULT

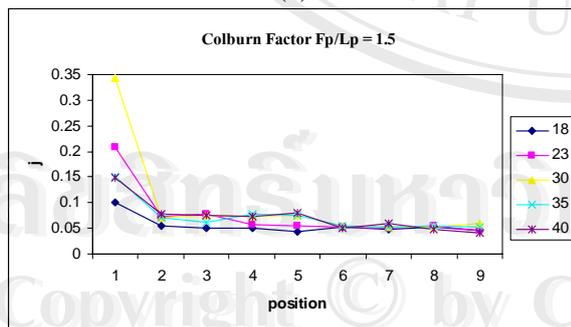
The data were taken for three values of fin-to-louver pitch ratio ($F_p/L_p = 0.75, 1, \text{ and } 1.5$) and five louver angles ($\theta = 18^\circ, 23^\circ, 30^\circ, 35^\circ, \text{ and } 40^\circ$). Fig. 4 shows the Colburn factor for each louver position for all louver angle. In Fig.4a, for small ratio of F_p/L_p , the Colburn factor of 23, 30, 35 and 40 of louver fin angle there are close. The Colburn factor at the first of louver position are larger than other positions along the louver length showing the high value of convective heat transfer coefficient after which the flow gains heat and the heat coefficient is lower as one might expected. The Colburn factor, henceforth, becomes uniform throughout the louver length.



(a)



(b)



(c)

Fig.4 Colburn factor for each position of all louver angle
a) $F_p/L_p = 0.75$ b) $F_p/L_p = 1$ c) $F_p/L_p = 1.5$

4.1 Effect of fin to louver pitch ratio

The flow must choose whether it will follow the louver direction, the duct direction, or some intermediate angle between the two directions. Which direction it goes will depend on the hydraulic resistance (the duct between the louvers in Fig.2) of the flow path in the louver direction relative to that in the duct direction. As F_p/L_p

increased (with L_p is fixed and the fin spacing increases), it appears that this wider fin spacing reduces the hydraulic resistance in the duct direction relative to that in the louver direction. This reduced hydraulic resistance results in a greater fraction of the flow passing in the duct direction. As F_p/L_p is decreased the duct direction hydraulic resistance increases, forcing more of the flow in the louver direction. At the smallest fin spacing the hydraulic resistance in the louver direction is much smaller than in the duct direction, so all of the flow will go in the louver direction. If the flow is louver direct flow the Colburn factor will increase as shown in Fig.5 the highest average Colburn factor occur at $F_p/L_p = 1$.

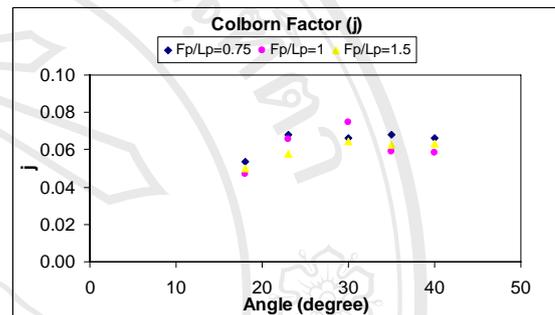


Fig. 5 Averaged Colburn factor for all F_p/L_p and θ

4.2 Effect of louver angle

Fig.5 shows a relatively clear comparison among the effects of the louver angles ranging between 18° to 30° for all included F_p/L_p where the corresponding Colburn factor increases. It also shows that when the louver is tilted to 30° and 40° , the Colburn factor is adversely decreased. The results quite suggested and agree well with the past studied in which the flow is regarded as the louver-directed flow at small louver angle. For the louver direct flow the louvers have more area to exchange the hot air more than duct direct flow. The highest Colburn factor is 7.5×10^{-2} occurring at $F_p/L_p = 1$ and 30° of louver angle. And the lowest Colburn factor occur at $F_p/L_p = 1$ and $\theta = 18^\circ$ where the flow is possibly duct-directed flow which agrees quite well with the past studies.

5. CONCLUSION

The optimized geometrical parameter of the louver fins to obtain the most effective heat transfer with the low speed hot air is investigated in this work. Heat transfer characteristic of the louver fins in terms of j Colburn factor is investigated. Experiments were conducted in 15:1 scaled-up louver model with varied fin pitch, louver pitch, and louver angle. The Colburn factor has a strong dependent on geometrical parameter such as, louver pitch, fin pitch, and louver angle especially at low Reynolds number flow. The highest Colburn factor is 7.5×10^{-2} occur at $F_p/L_p = 1$ and 30° of louver angle.

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"Give yourself one major goal a day, then achieve it, whatever else you may have to drop"

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