Parameters	Uncertainty
D_i , D_o , a , b	±0.5 mm
A	±0.5 mm
A_{Burner}	±2.084%
ν	±0.09%
ρ_{air}	±0.201%
$\overline{T}$	±0.5 ℃
P_0	±1 torr
$\dot{V}_0$	±2.2%
Q_{fuel}	±1%
U_{in}	±2.54%
V_w	±2.31%
Re	±3.04%
T_t	±0.2%
P_{sat}	±3.01%

Table 3.1 Summary of uncertainty analysis

methane to nitrogen ratio	Envelope flame transition limits velocity (1st measured) (m/s)	Envelope flame transition limits velocity (2nd measured) (m/s)	Envelope flame transition limits velocity (3rd measured) (m/s)	Average value of three times (m/s)	Error (%)
40 %	0.7	0.68	0.72	0.7	5.71
50 %	0.98	1	0.98	0.986	2.02
60 %	1.06	1.04	1.08	1.06	3.77
70 %	1.09	1.14	1.12	1.117	4.27
80 %	1.14	1.19	1.16	1.163	4.29
90 %	1.21	1.24	1.21	1.22	2.46
100 %	1.26	1.29	1.26	1.27	2.36

Table 3.2 Table of envelope flame transition limits experimental repeatability

methane to nitrogen ratio	wake flame transition limits velocity (1st measured) (m/s)	wake flame transition limits velocity (2nd measured) (m/s)	wake flame transition limits velocity (3rd measured) (m/s)	Average value of three times (m/s)	Error (%)
70 %	1.32	1.34	1.29	1.316	3.79
80 %	1.48	1.42	1.46	1.453	4.12
90 %	1.51	1.53	1.48	1.506	3.31
100 %	1.56	1.58	1.53	1.556	3.21

Table 3.3 Table of wake flame transition limits experimental repeatability

	α						
	100%	90%	80%	70%	60%	50%	40%
U_{in} (m/sec)	2.63	2.63	2.63	2.63	2.63	2.63	2.63
	2.35	2.35	2.35	2.35	2.35	2.35	2.35
	2.25	2.25	2.25	2.25	2.25	2.25	2.25
	2.16	2.16	2.16	2.16	2.16	2.16	2.16
	2.06	2.06	2.06	2.06	2.06	2.06	2.06
	1.96	1.96	1.96	1.96	1.96	1.96	1.96
	1.87	1.87	1.87	1.87	1.87	1.87	1.87
	1.77	1.77	1.77	1.77	1.77	1.77	1.77
	1.72	1.72	1.72	1.72	1.72	1.72	1.72
	1.67	1.67	1.67	1.67	1.67	1.67	1.67
	1.63	1.63	1.63	1.63	1.63	1.63	1.63
	1.58	1.58	1.58	1.58	1.58	1.58	1.58
	1.56						
	1.53	1.53	1.53	1.53	1.53	1.53	1.53
		1.51					
	1.48	1.48	1.48	1.48	1.48	1.48	1.48
			1.46				
	1.42	1.42	1.42	1.42	1.42	1.42	1.42

Table 4.1 the three measured data and made an averaged value

error bar is ± 0.02m/sec

	α						
	100%	90%	80%	70%	60%	50%	40%
U_{in} (m/sec)	1.38	1.38	1.38	1.38	1.38	1.38	1.38
	1.34	1.34	13.4	1.34	1.34	1.34	1.34
				1.32			
	1.29	1.29	1.29	1.29	1.29	1.29	1.29
	1.26						
	1.24	1.24	1.24	1.24	1.24	1.24	1.24
		1.21					
	1.19	1.19	1.19	1.19	1.19	1.19	1.19
			1.16				
			1.14	1.14			
				1.12			
	1.09	1.09	1.09	1.09	1.09	1.09	1.09
					1.06		
					1.04		
	1	1	1	1	1	1	1
						0.98	
						0.95	
	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	0.62	0.62	0.62	0.62	0.62	0.62	0.68
	0.51	0.51	0.51	0.51	0.51	0.51	0.51

Continued Table 4.1 the three measured data and made an averaged value

U_{in} (m/s)	100% Flame thickness (mm)	90% Flame thickness (mm)	80% Flame thickness (mm)	70% Flame thickness (mm)
0.41	2.4	2.4	2	2
0.51	**2.4**	**2.4**	**2**	**1.7**
0.62	**2.4**	**2**	**1.7**	**1.7**
0.68				
0.70	**2**	**2**	**1.7**	**1.7**
0.80	**2**	**1.7**	**1.3**	**1.3**
0.90	**2**	**1.7**	**1.3**	**1.3**
0.95				
1.00	**1.7**	**1.3**	**1.3**	**1.3**
1.04				
1.09	**1.7**	**1.3**	**1.3**	**1.3 (critical U_{in})**
1.14			**1.3 (critical U_{in})**	
1.19	**1.3**	**1.3 (critical U_{in})**		
1.24	**1.3 (critical U_{in})**			

Table 4.2 the envelope flame thickness

U_{in} (m/s)	60% Flame thickness (mm)	50% Flame thickness (mm)	40% Flame thickness (mm)
0.41	1.7	1.7	1.3
0.51	**1.7**	**1.3**	**1.3**
0.62	**1.7**	**1.3**	**1.3**
0.68			**1 (critical U_{in})**
0.70	**1.7**	**1.3**	
0.80	**1.3**	**1.3**	
0.90	**1.3**	**1**	
0.95		**1 (critical U_{in})**	
1.00	**1.3**		
1.04	**1 (critical U_{in})**		

Continued Table 4.2 the envelope flame thickness

U_{in} (m/s)	100% Stand off distance (mm)	90% Stand off distance (mm)	80% Stand off distance (mm)	70% Stand off distance (mm)
0.41	1.7	1.7	1.7	1.7
0.51	**1.2**	**1.2**	**1.2**	**1.2**
0.62	**1.2**	**1.2**	**1.2**	**1.2**
0.68				
0.70	**1**	**1**	**1**	**1**
0.80	**1**	**1**	**1**	**1**
0.90	**1**	**1**	**1**	**1**
0.95				
1.00	**1**	**1**	**1**	**1**
1.04				
1.09	**1**	**1**	**1**	**1** (critical U_{in})
1.14			**1** (critical U_{in})	
1.19	**1**	**1** (critical U_{in})		
1.24	**1** (critical U_{in})			

Table 4.3 the envelope flame stand off distance

U_{in} (m/s)	60% Stand off distance (mm)	50% Stand off distance (mm)	40% Stand off distance (mm)
0.41	1.7	1.7	1.7
0.51	**1.2**	**1.2**	**1.2**
0.62	**1.2**	**1.2**	**1.2**
0.68			**1 (critical U_{in})**
0.70	**1**	**1**	
0.80	**1**	**1**	
0.90	**1**	**1**	
0.95		**1 (critical U_{in})**	
1.00	**1**		
1.04	**1 (critical U_{in})**		

Continued Table 4.3 the envelope flame stand off distance

U_{in} (m/s)	100% Flame attached angle	90% Flame attached angle	80% Flame attached angle	70% Flame attached angle
1.32				149 (critical U_{in})
1.46			149 (critical U_{in})	
1.48			143	145
1.51		1.48 (critical U_{in})		
1.56	154 (critical U_{in})			
1.58	150	141	141	143
1.67	144	139	139	141
1.77	141	138	138	138
1.87	136	138	136	137
1.96	135	135	134	135
2.06	134	135	134	133
2.35	133	130	131	130
2.63	131	125	125	125

Table 4.4 the wake flame attached angle

U_{in} (m/s)	60% Flame attached angle	50% Flame attached angle	40% Flame attached angle
0.70			151 (critical U_{in})
0.80			150
0.90			149
0.98		151 (critical U_{in})	
1.06	152 (critical U_{in})		
1.09	150	146	146
1.19	146	142	146
1.29	145	138	145
1.38	143	134	143
1.48	142	133	142
1.58	139	133	140
1.67	136	130	138
1.77	135	128	136
1.87	134	128	134
1.96	132	127	133
2.06	130	127	131
2.35	127	125	126
2.63	123	122	122

Continued Table 4.4 the wake flame attached angle

The envelope flame thickness				
Uin (m/s)	100% Flame thickness (mm)	90% Flame thickness (mm)	80% Flame thickness (mm)	70% Flame thickness (mm)
0.6	2.46	2.36	2.14	2.1
0.7	2.25	2.25	2.1	2.1
0.8	2.25	2.1	2.1	2.1
0.9	2.25	2.1	2.04	2.04
1.0	2.25	2.1	2.04	2.04
1.01				2.01 (blow-off limit)
1.075			2.04 (blow-off limit)	
1.1	2.1	2.1 (blow-off limit)		
1.15	2.1 (blow-off limit)			

Table 4.5 the Chen's numerical simulation results of the envelope flame thickness

The envelope flame thickness			
Uin (m/s)	60% Flame stand-off distance (mm)	50% Flame stand-off distance (mm)	40% Flame stand-off distance (mm)
0.6	2.1	2.1	1.71
0.7	2.1	2.04	1.65
0.75			1.5 (blow-off limit)
0.8	2.04	1.93	
0.85		1.93 (blow-off limit)	
0.9	2.04		
0.94	2.04 (blow-off limit)		

Continued Table 4.5 the Chen's numerical simulation results of the envelope flame thickness

The stand-off distance of envelope flame				
Uin (m/s)	100% Flame stand-off distance (mm)	90% Flame stand-off distance (mm)	80% Flame stand-off distance (mm)	70% Flame stand-off distance (mm)
0.6	4.7	4.7	4.5	4.5
0.7	4.2	4.2	4.2	4.16
0.8	3.2	3.2	3.1	2.6
0.9	2.8	2.6	2.36	2.14
1.0	2.36	2.36	2.25	2.1
1.01				2.1 (blow-off limit)
1.075			2.1 (blow-off limit)	
1.1	2.1	2.1 (blow-off limit)		
1.15	2.1 (blow-off limit)			

Table 4.6 the Chen's numerical simulation results of the stand off distance

The stand-off distance of envelope flame			
Uin (m/s)	60% Flame stand-off distance (mm)	50% Flame stand-off distance (mm)	40% Flame stand-off distance (mm)
0.6	4.5	4.07	3.86
0.7	4.05	3.21	2.36
0.75			2.1 (blow-off limit)
0.8	2.55	2.25	
0.85		2.1 (blow-off limit)	
0.9	2.36		
0.94	2.1 (blow-off limit)		

Continued Table 4.6 the Chen's numerical simulation results of the stand off distance

The wake flame attached angle				
Uin (m/s)	100% Flame attached angle	90% Flame attached angle	80% Flame attached angle	70% Flame attached angle
1.07				128 (flame transition limit)
1.1				132
1.2			135 (flame transition limit)	128
1.25			132.5	122
1.3		134 (flame transition limit)	130	
1.325		130		
1.35	138 (flame transition limit)	129	129	120
1.36	132			
1.37	130			
1.375	127	128	126	
1.4	124.5	127	125	119
1.425	121	122	120	120

Table 4.7 the Chen's numerical simulation results of the wake flame attached angle

The attached angle of stable wake flame for lower concentration			
Uin (m/s)	60% Flame stand-off distance (mm)	50% Flame stand-off distance (mm)	40% Flame stand-off distance (mm)
0.76			124 (flame transition limit)
0.8			121.5
0.85		130 (flame transition limit)	
0.9		121	125
0.95	121 (flame transition limit)		
1.0	119	123	123
1.1	124	124	124
1.2	120	120	122
1.3	120	120	120
1.4	119	119	119

Continued Table 4.7 the Chen's numerical simulation results of the wake flame attached angle

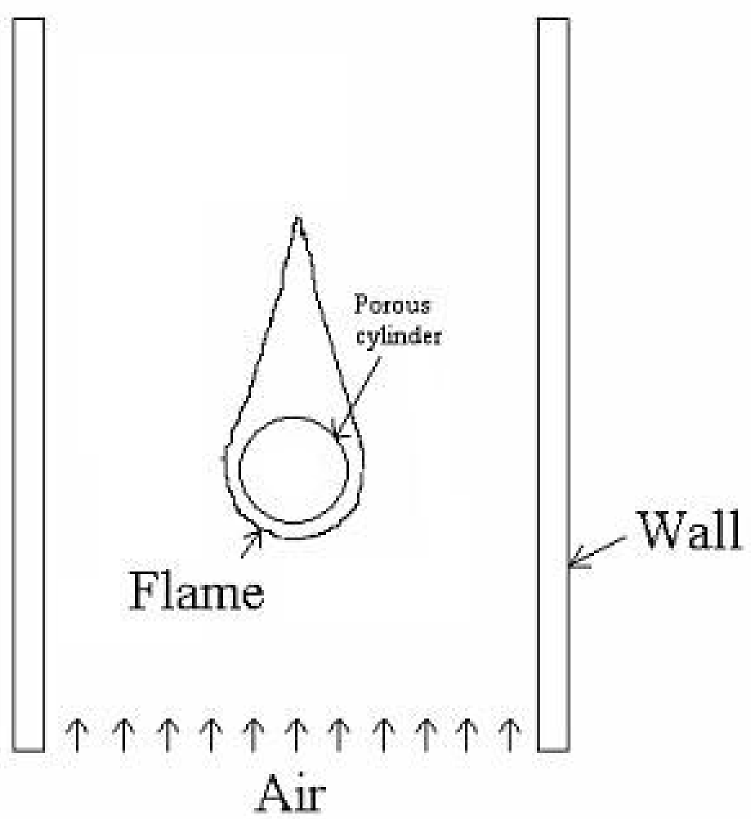


Fig 1.1 Schematic configuration of the physical problem

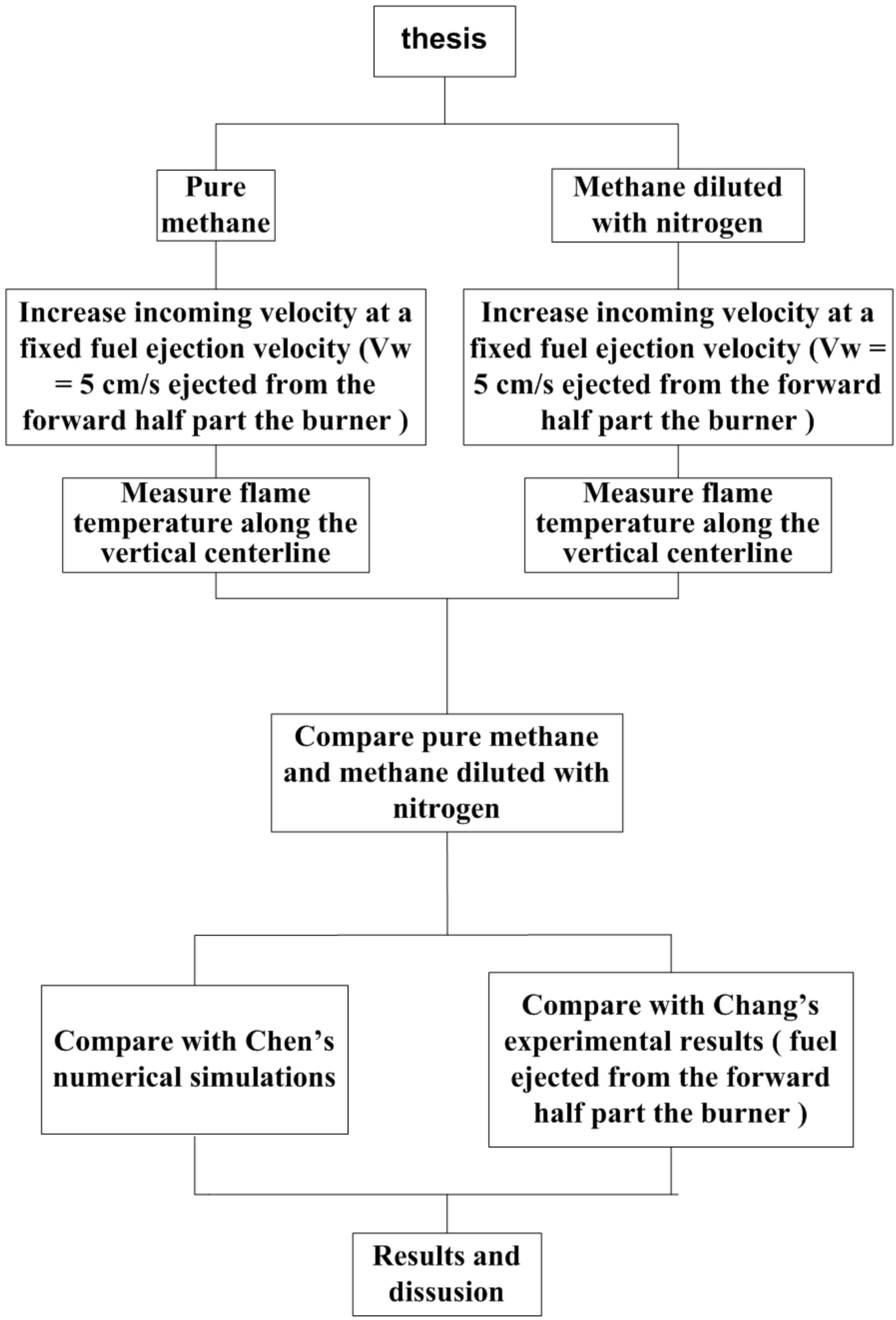


Fig 1.2 Scheme diagram

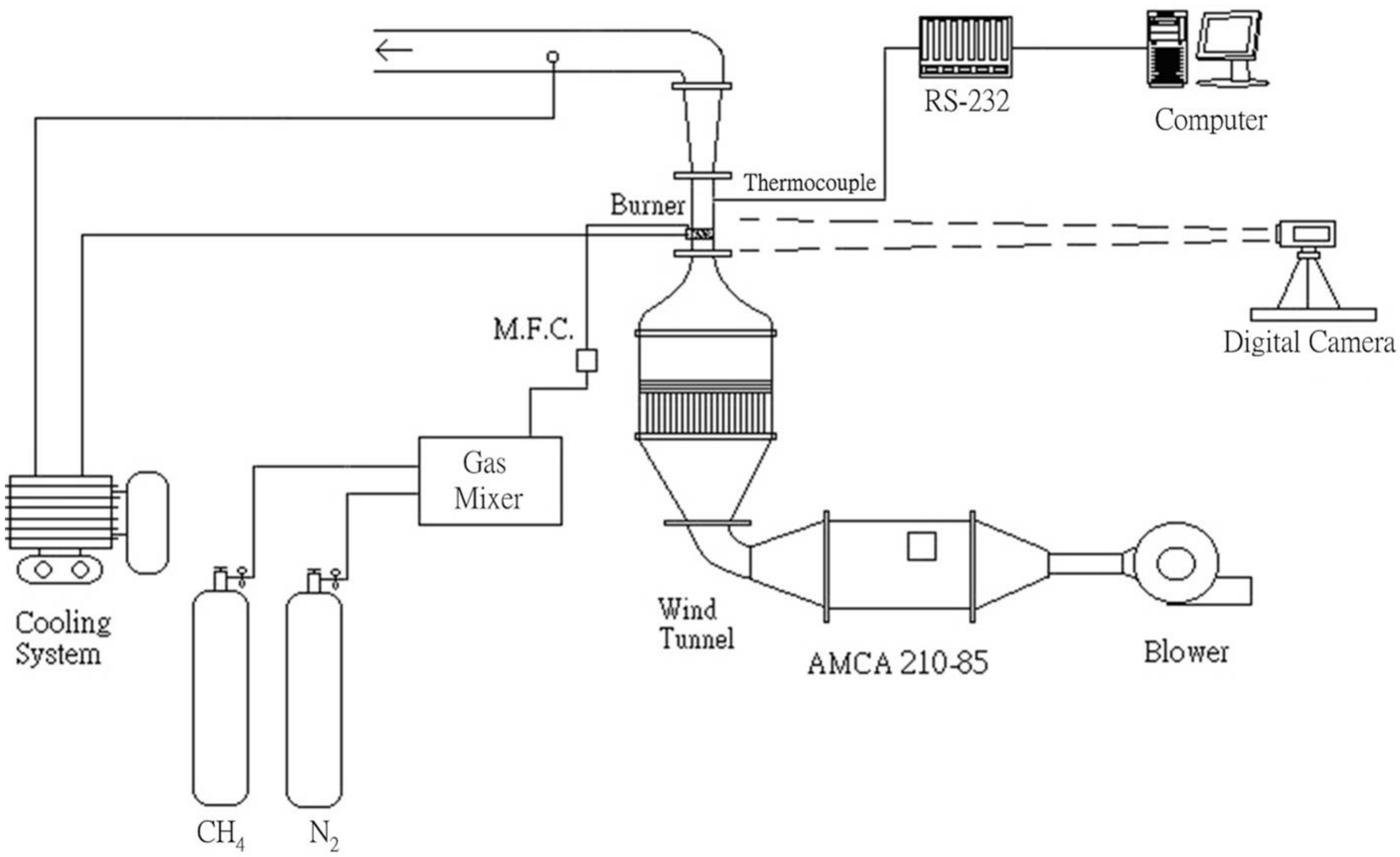


Fig. 2.1 Schematic drawing of overall experimental system

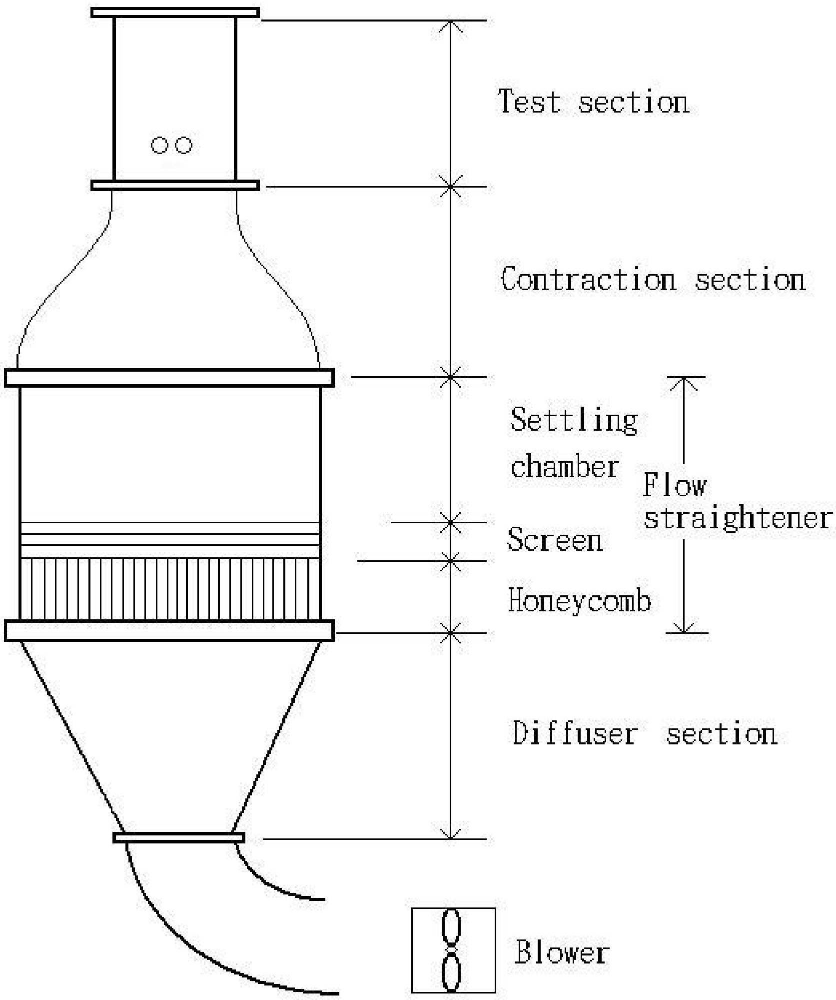


Fig. 2.2 Schema of the wind tunnel

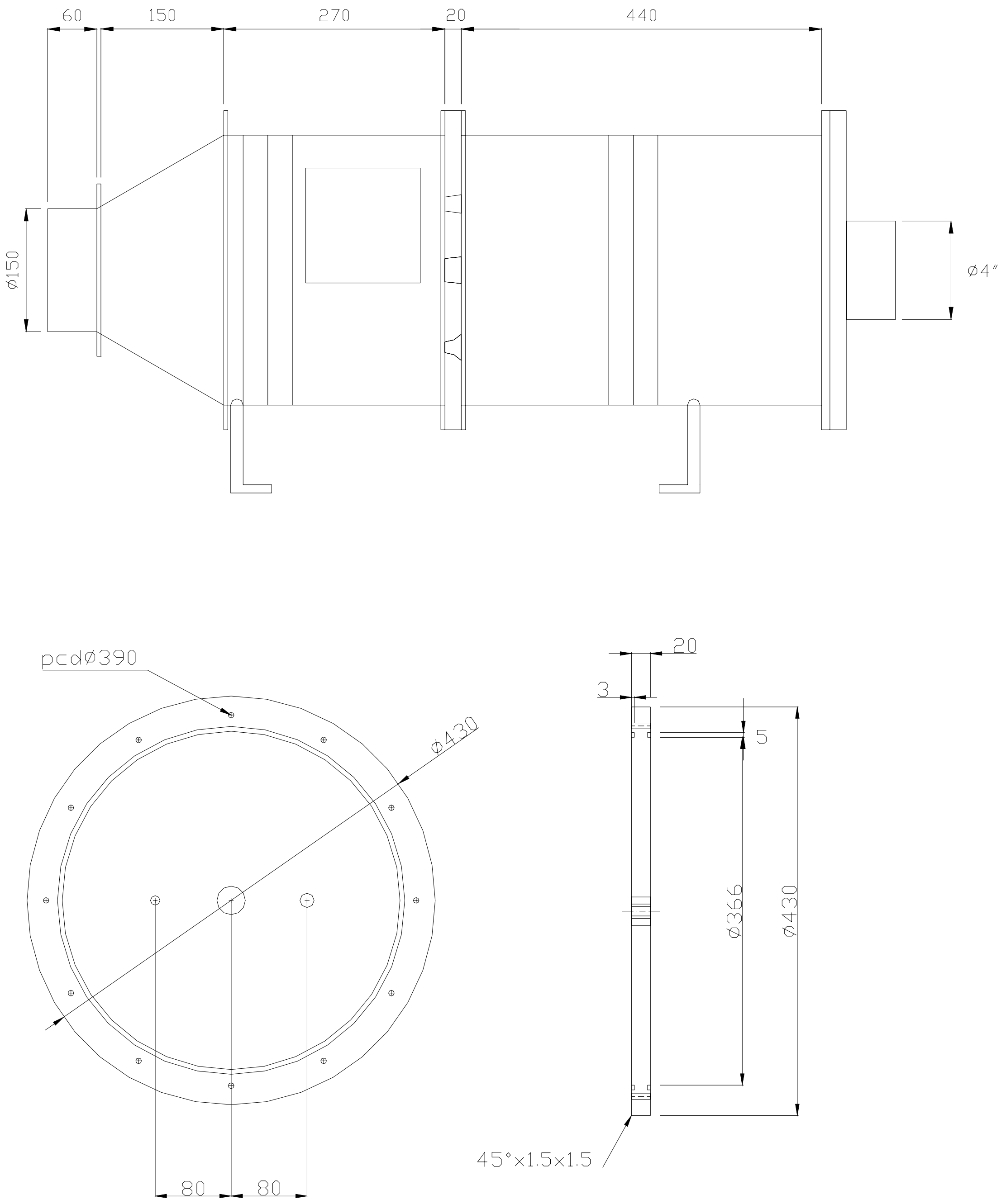


Fig. 2.3 The design of AMCA 210-85 standard

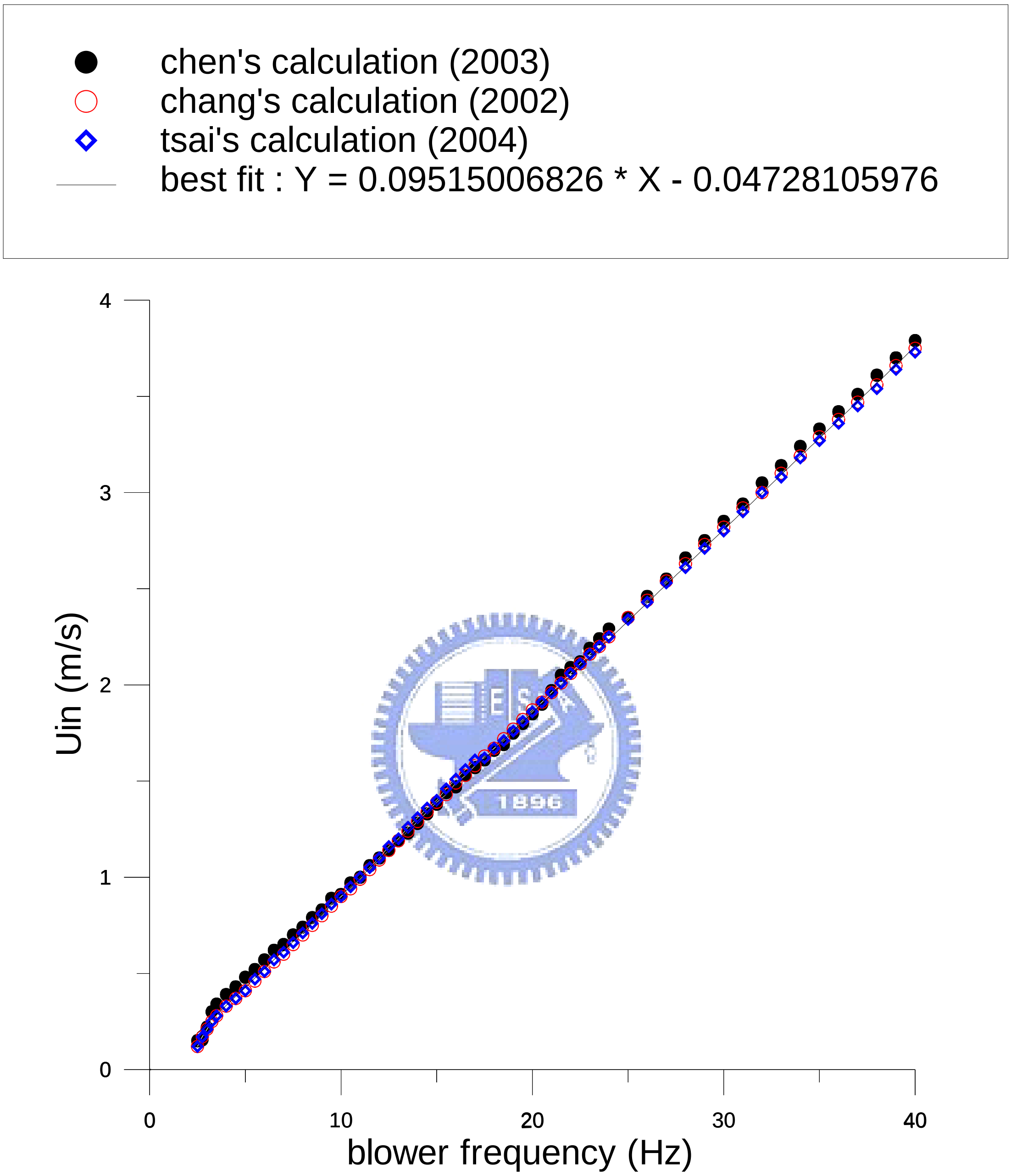


Fig. 2.4 The relation figure of blower frequency and airflow velocity

Fig. 2.5 The connecting of blower and tunnel

Fig. 2.6 The picture of cooling system

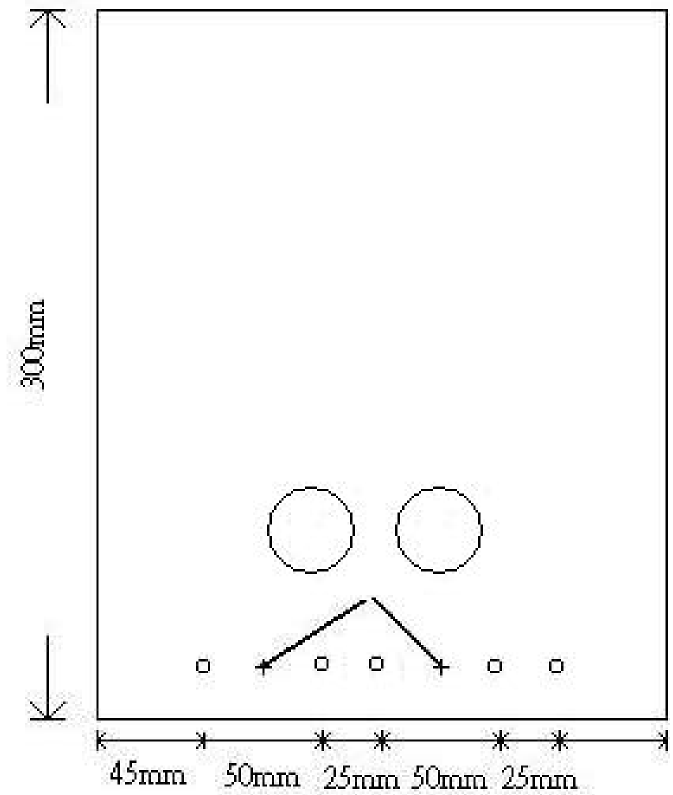


Fig. 2.7 The picture of four pitot tube and a fixed static pressure holes

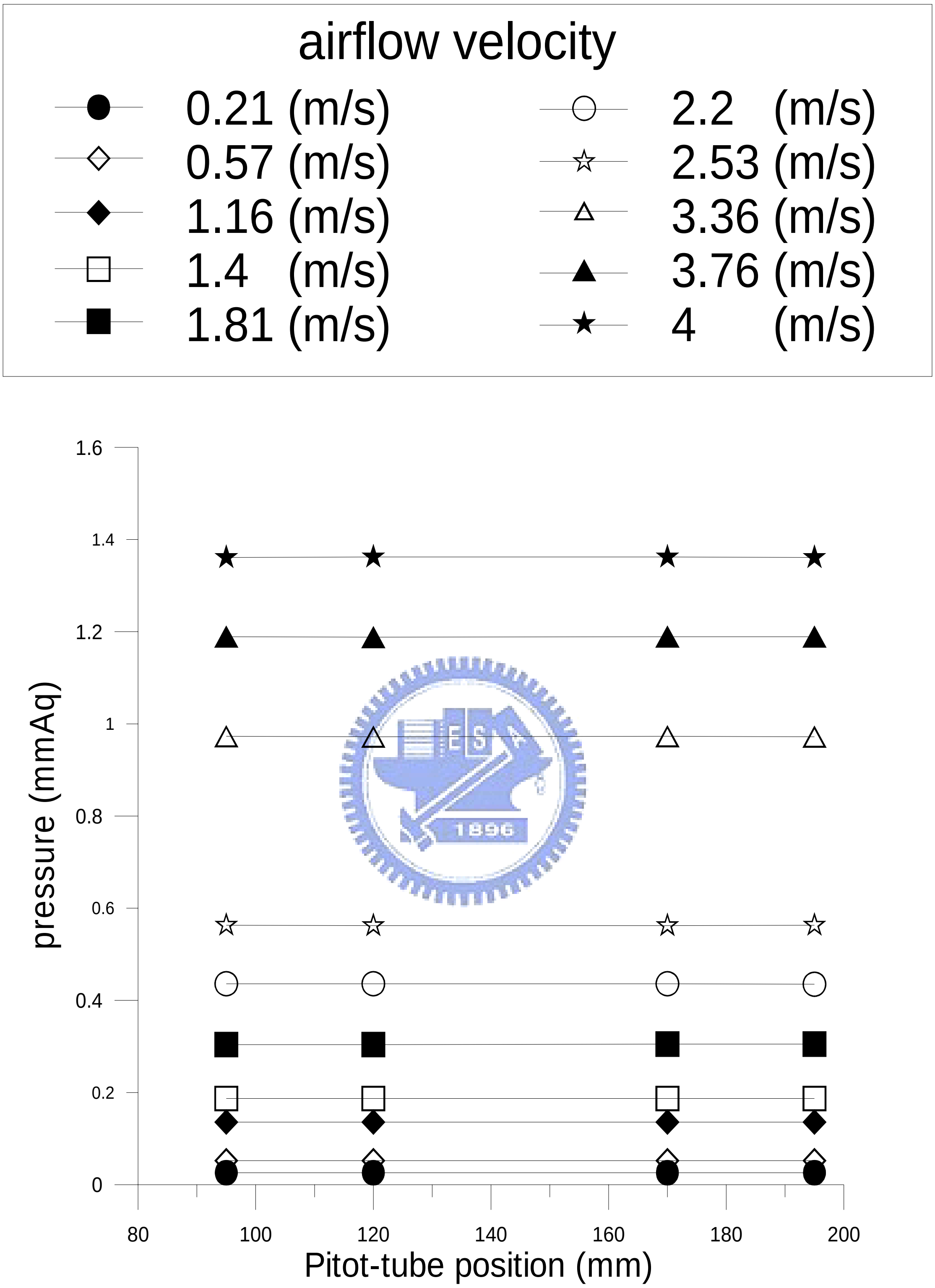


Fig. 2.8 Inflow velocity at each position in the test section

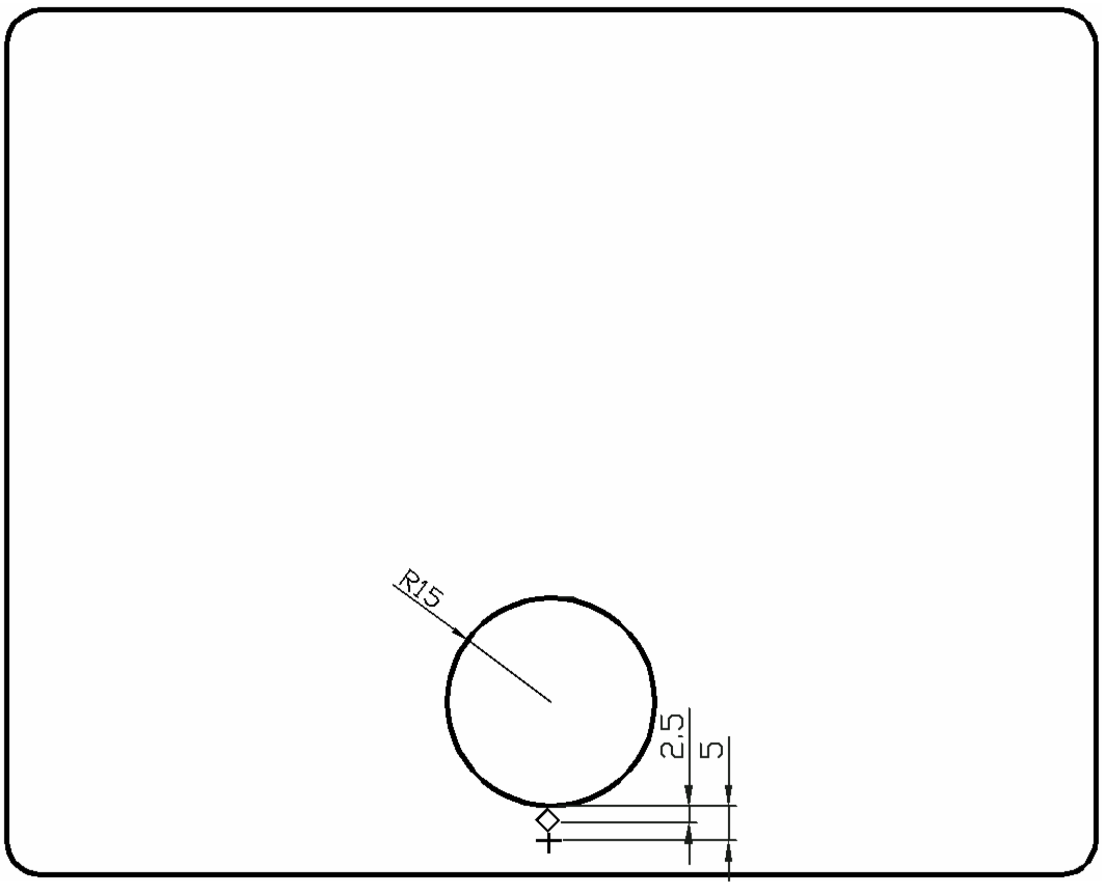


Fig. 2.9 The measuring position in the front of the cylinder burner

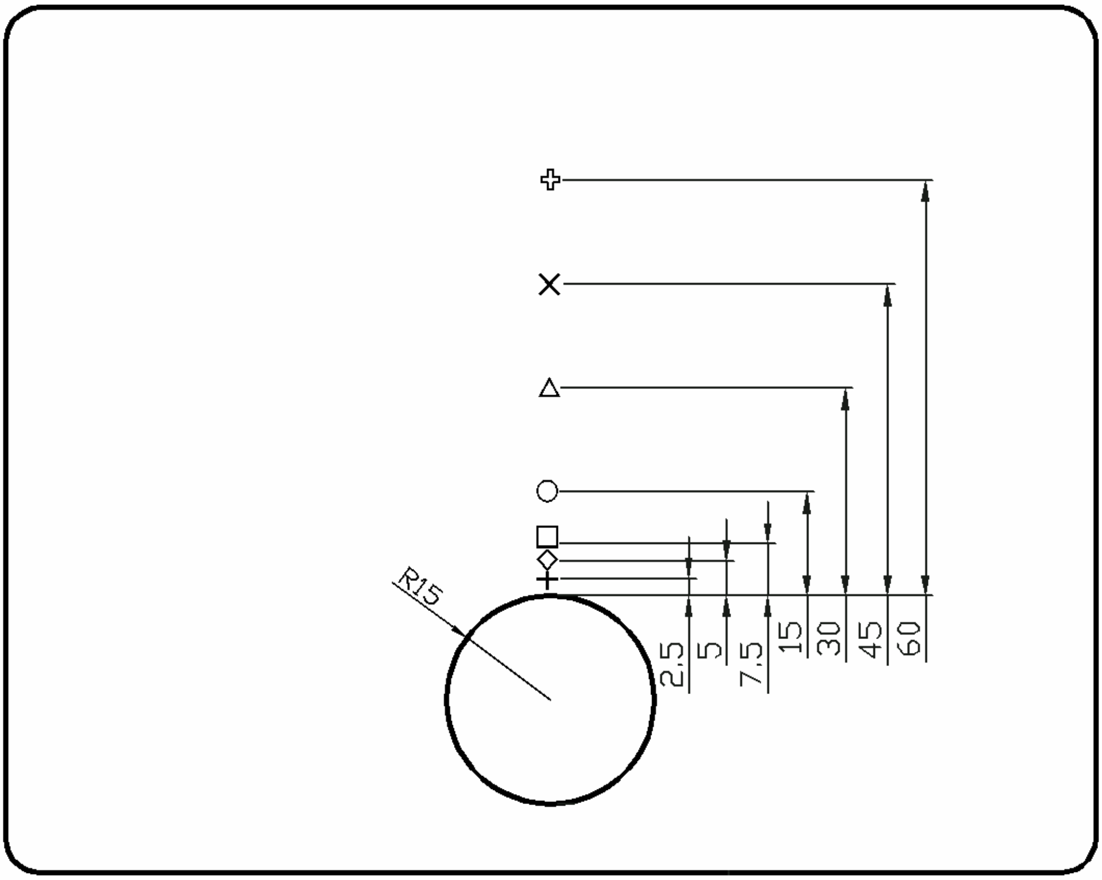


Fig. 2.10 The measuring position in the rear of the cylinder burner

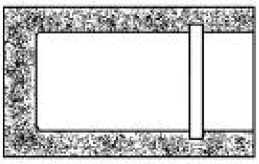


Fig. 2.11 Porous sintered stainless steel cylinder

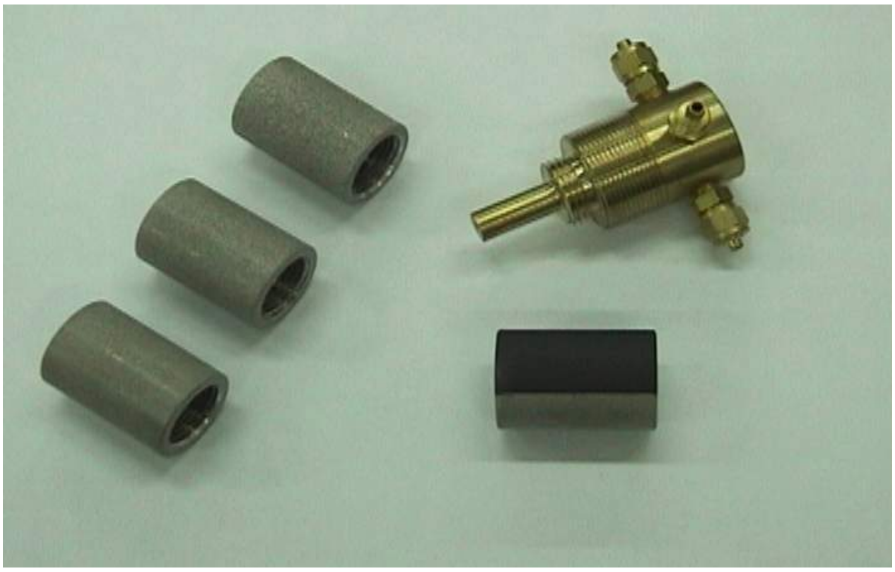


Fig. 2.12 The picture of burner

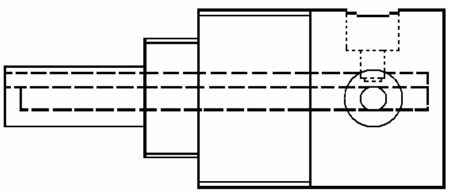


Fig. 2.13 Cylindrical brass rod

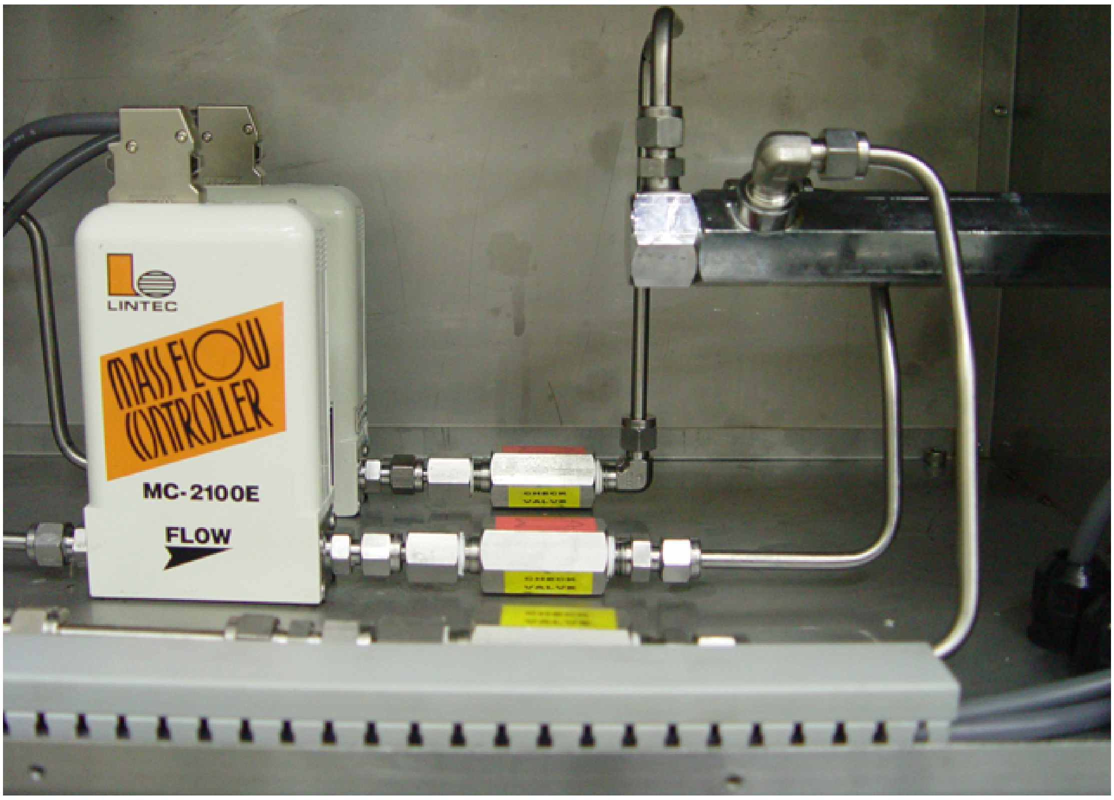


Fig. 2.14 The picture of mass flow controller,
check valve and spiral mix tube

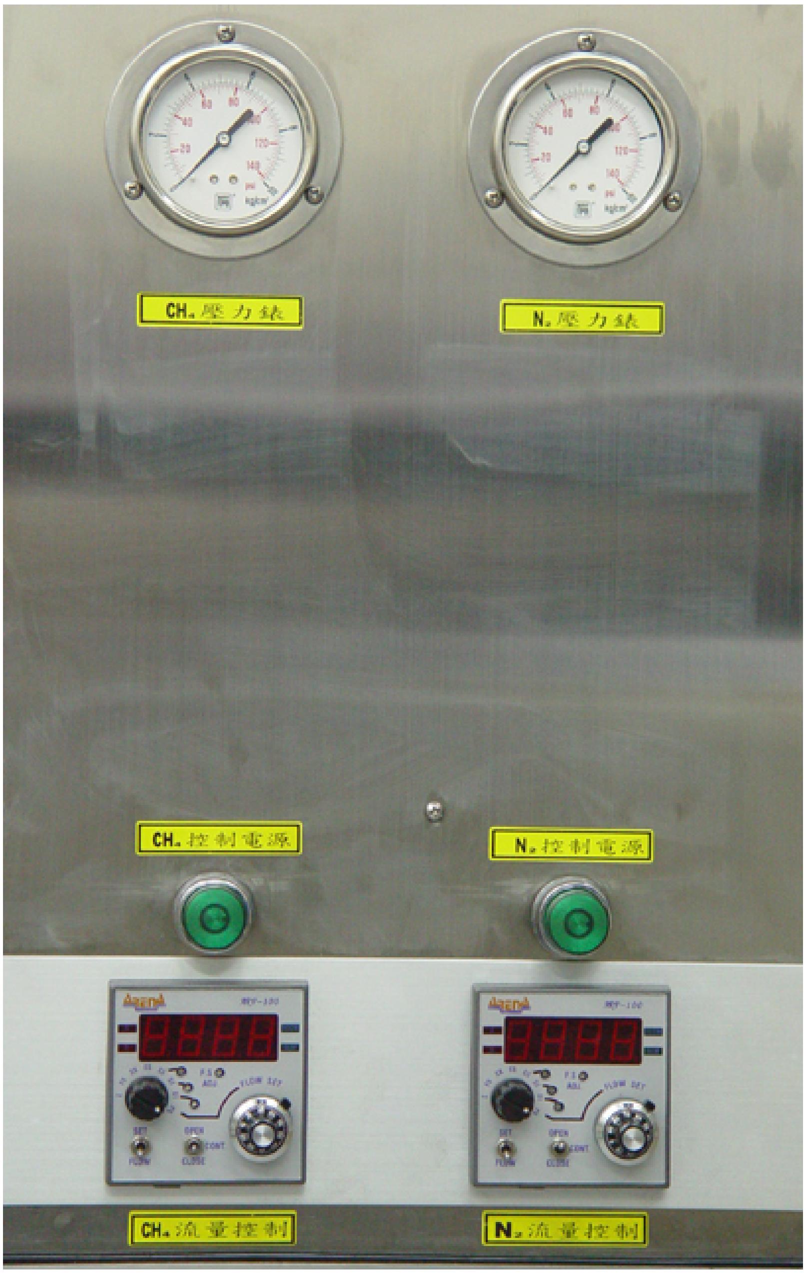


Fig. 2.15 The picture of pressure gauge, power supply and control unit

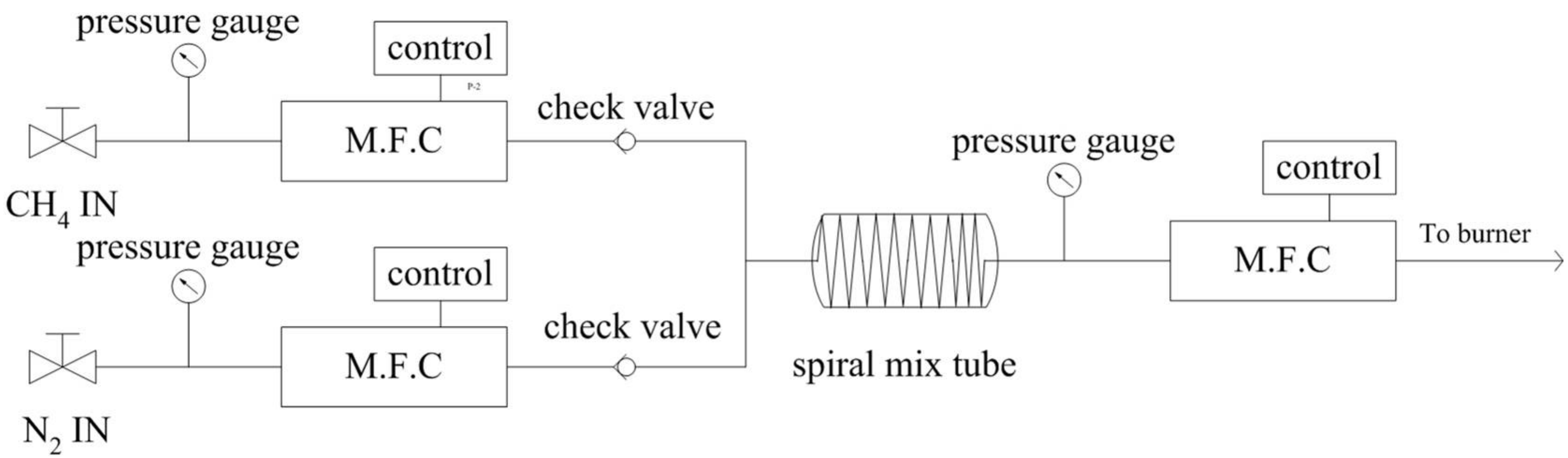


Fig. 2.16 schematic configuration of gas mixer

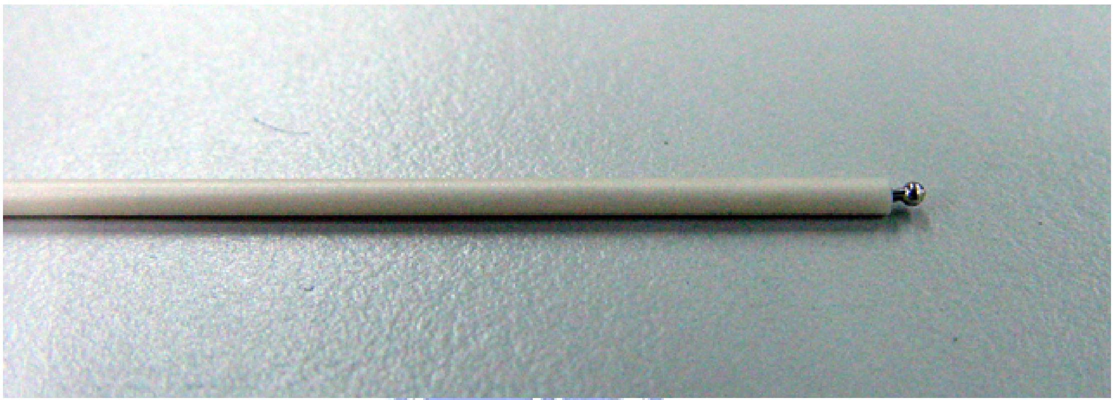
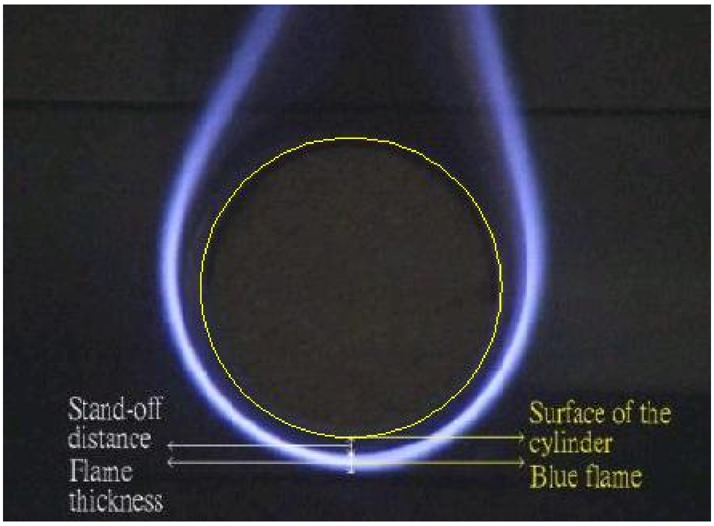
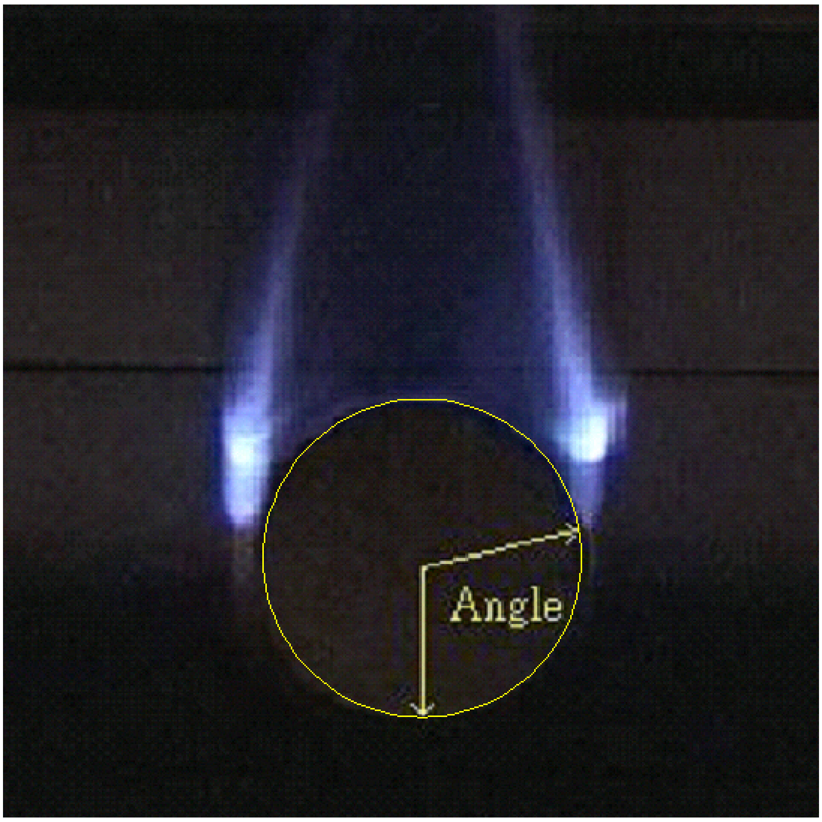


Fig. 2.17 The picture of R-type thermocouple



(a) Stand off distance and flame thickness



(b) Flame attached angle

Fig. 2.18 Definitions of stand off distance, flame thickness and flame attached

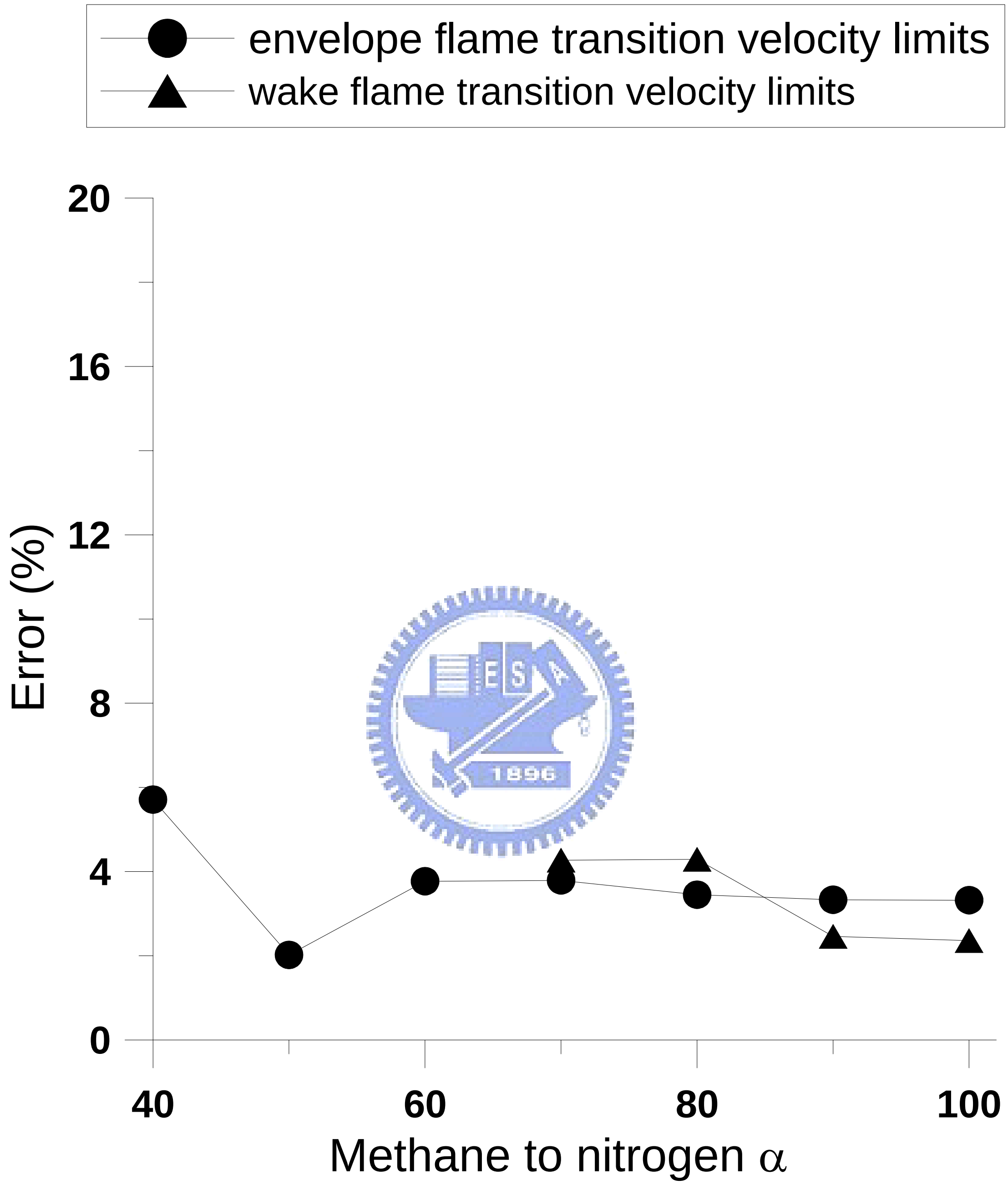


Fig. 3.1 The errors of experimental repeatability

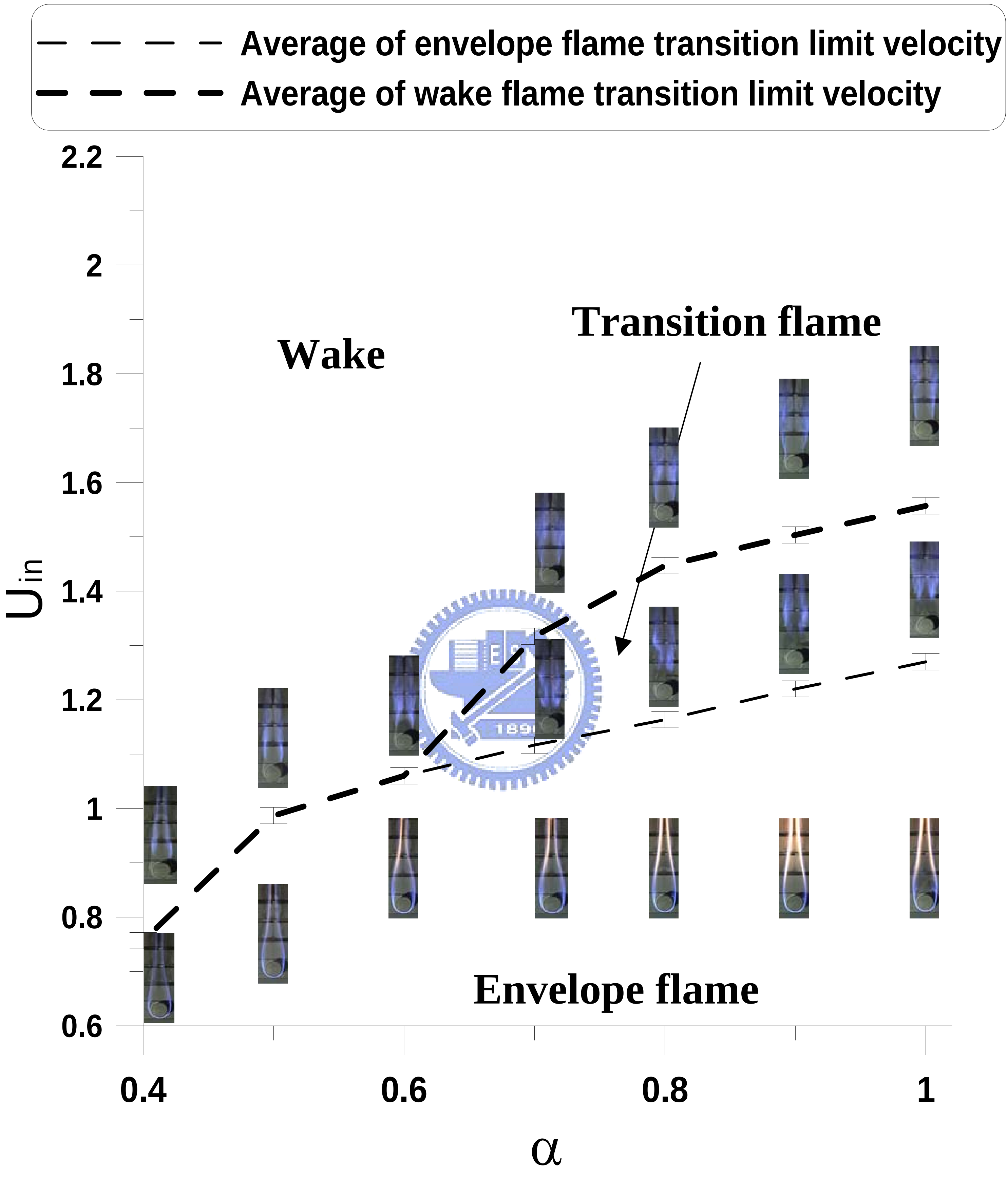
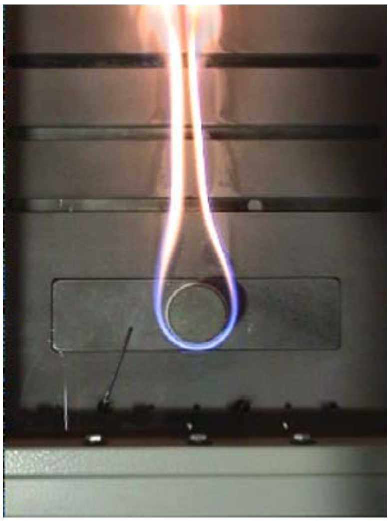


Fig. 4.1 the flame transition limit velocity under different α and U_{in}

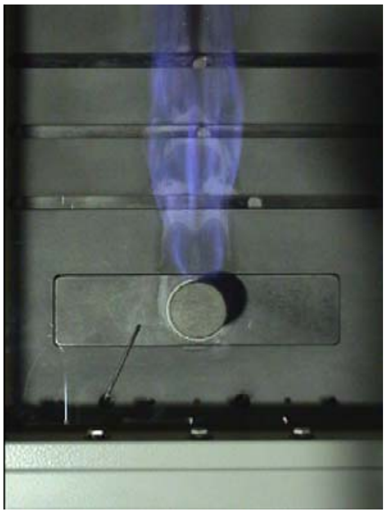


(a) U_{in} = 0.41m/sec

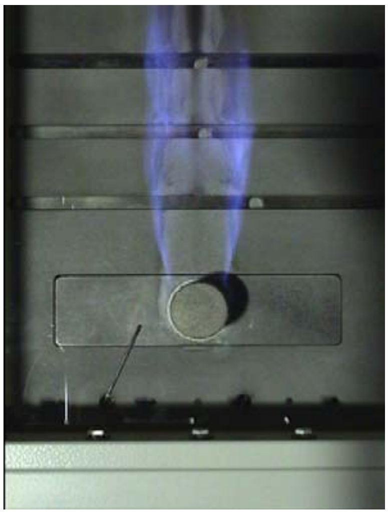
(b) U_{in} = 1.24m/sec

(c) U_{in} = 1.26m/sec

(d) U_{in} = 1.53m/sec



(e) U_{in} = 1.56m/sec



(f) U_{in} = 2.63m/sec

Fig. 4.2 Series of the pure methane flame configurations as function of inflow velocity from high to low.

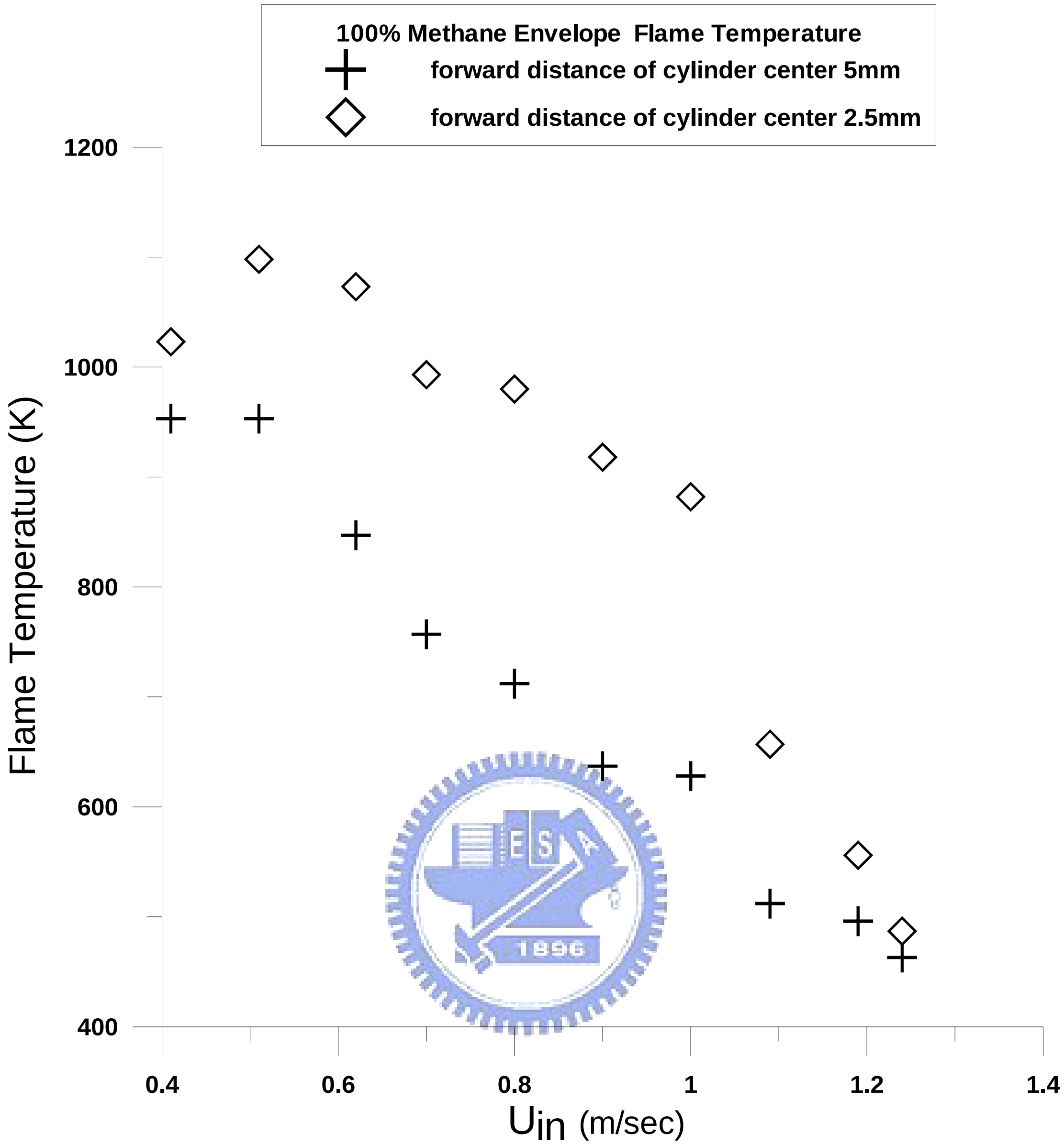


Fig. 4.3 the 100% methane vertical centerline envelope flame temperature in the cylinder burner forward

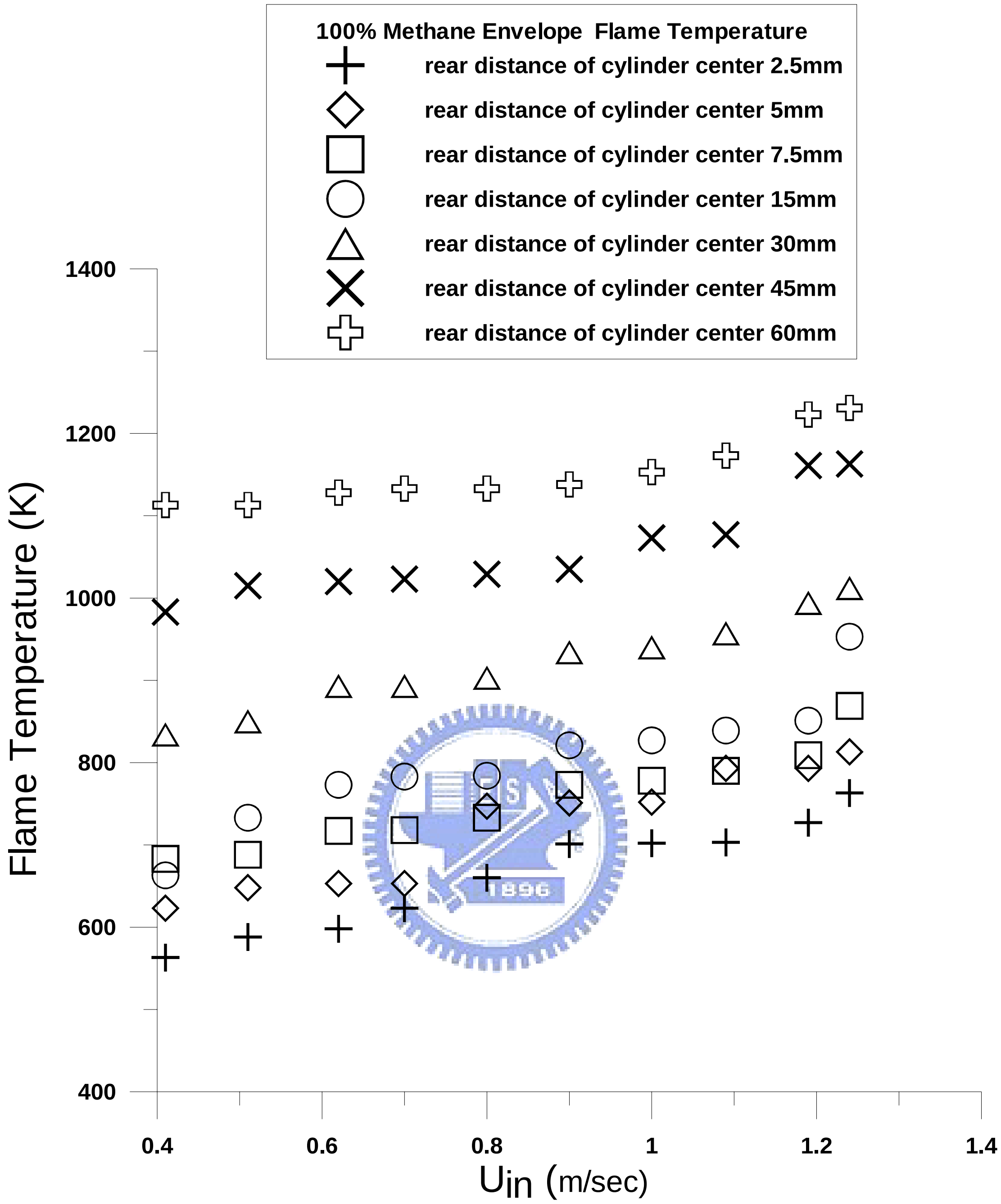
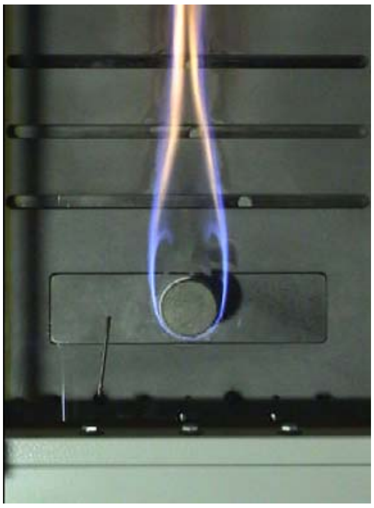


Fig. 4.4 the 100% methane vertical centerline envelope flame temperature in the cvlinder burner rearward



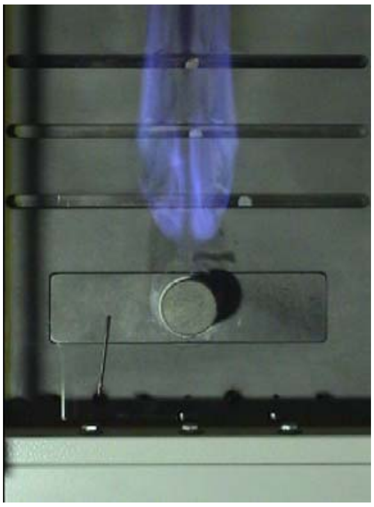
（a） 6.33 sec

（b） 6.36 sec

（c） 6.39 sec

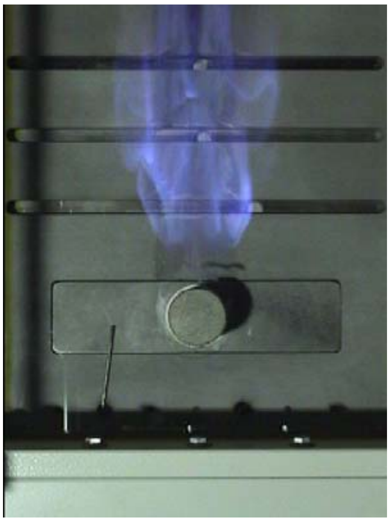
（d） 6.42 sec

（e） 8.99 sec



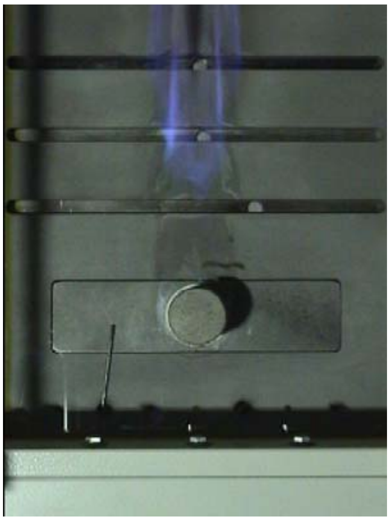
（f） 10.48 sec

Fig. 4.5 Series of flame transition as fixed incoming airflow velocity 1.26 m/s



（g）12.69 sec

（h）12.72 sec



（i）12.75 sec

Continued Fig. 4.5 Series of flame transition as fixed incoming airflow velocity 1.26 m/s

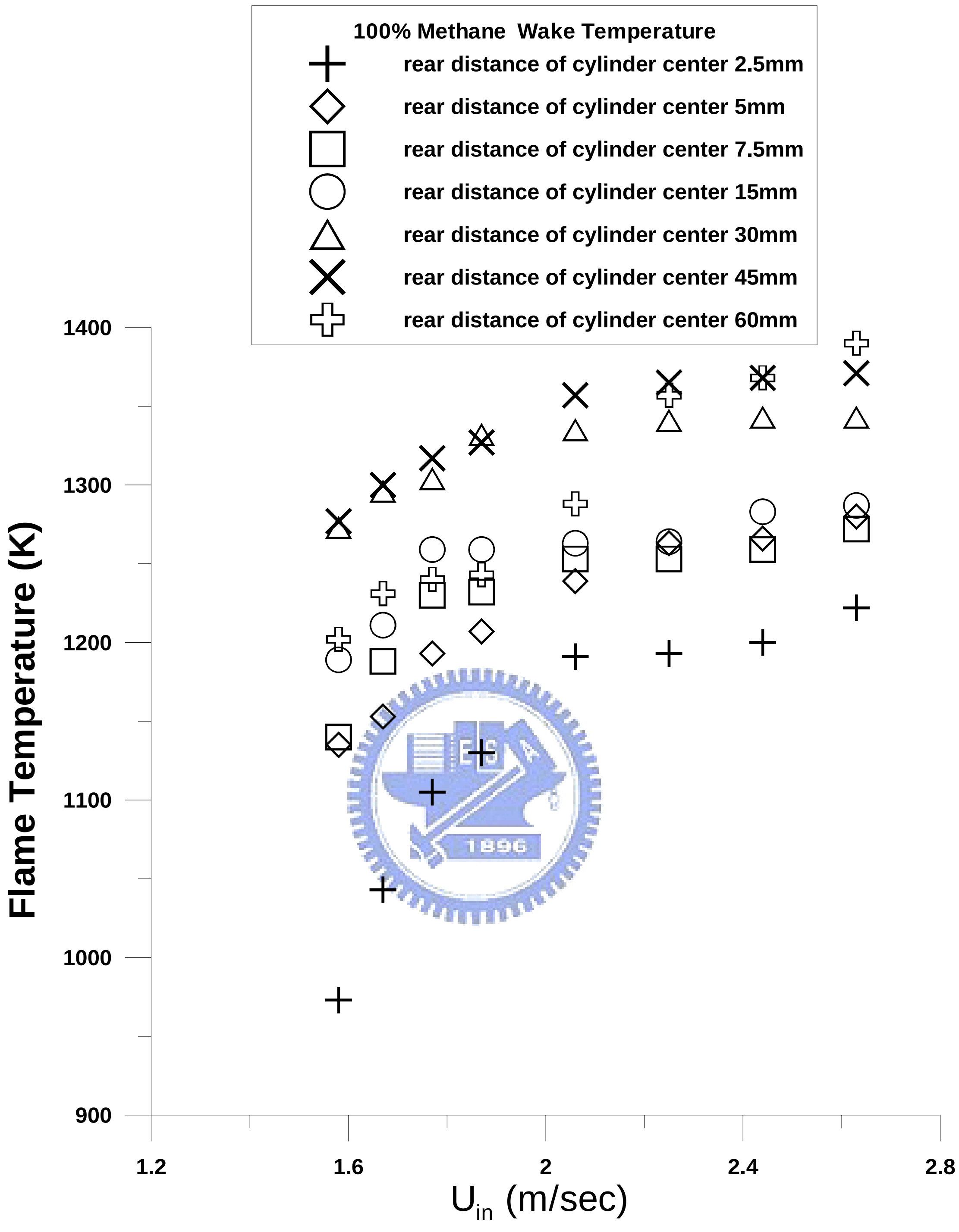
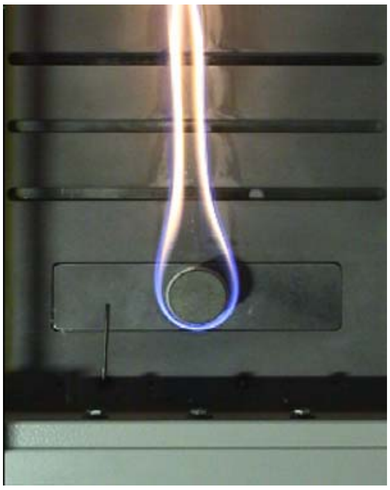
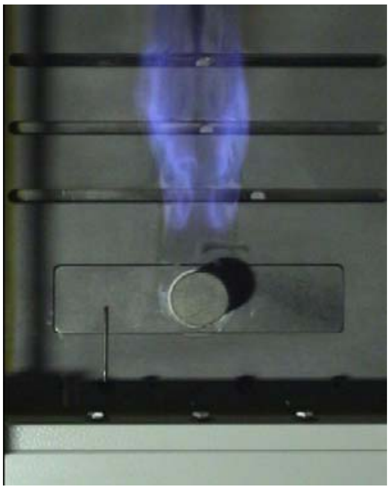


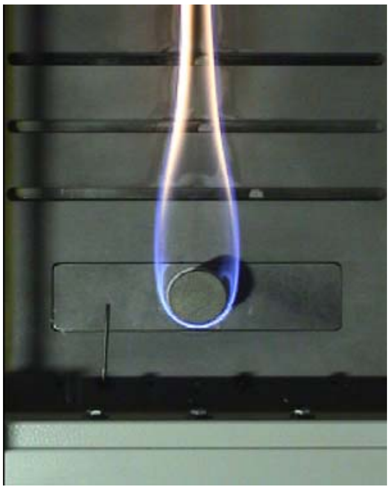
Fig. 4.6 the 100% methane vertical centerline wake flame temperature in the cvlinder burner rearward



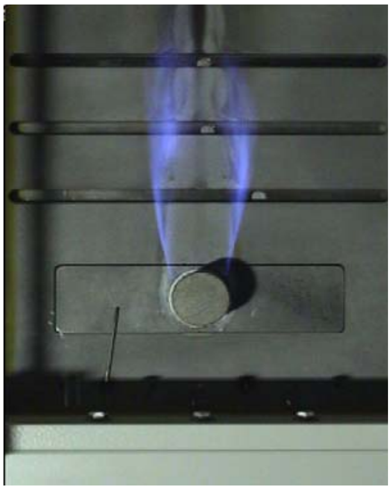
（a）U_{in} = 0.41 m/sec



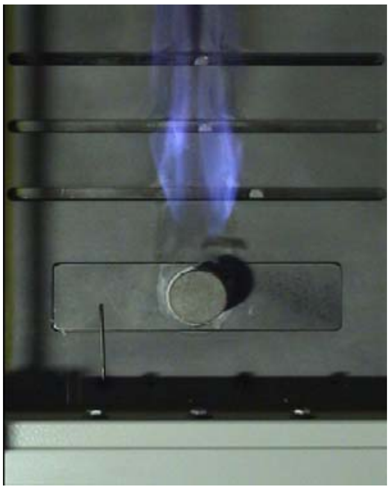
（d）U_{in} = 1.42/sec



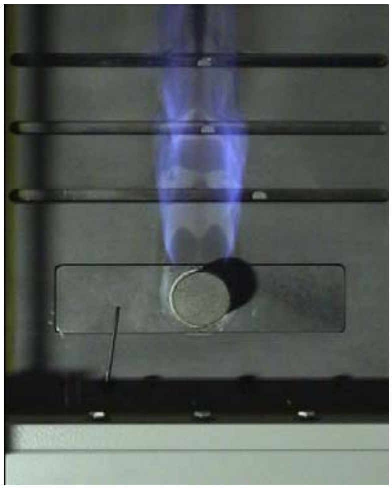
b）U_{in} = 1.14m/sec



（e）U_{in} = 2.63 m/sec



（c）U_{in} = 1.16 m/sec



（f）U_{in} = 2.63 m/sec

Fig. 4.7 Series of flame transition in the higher methane mass fraction ($\alpha = 0.8$)

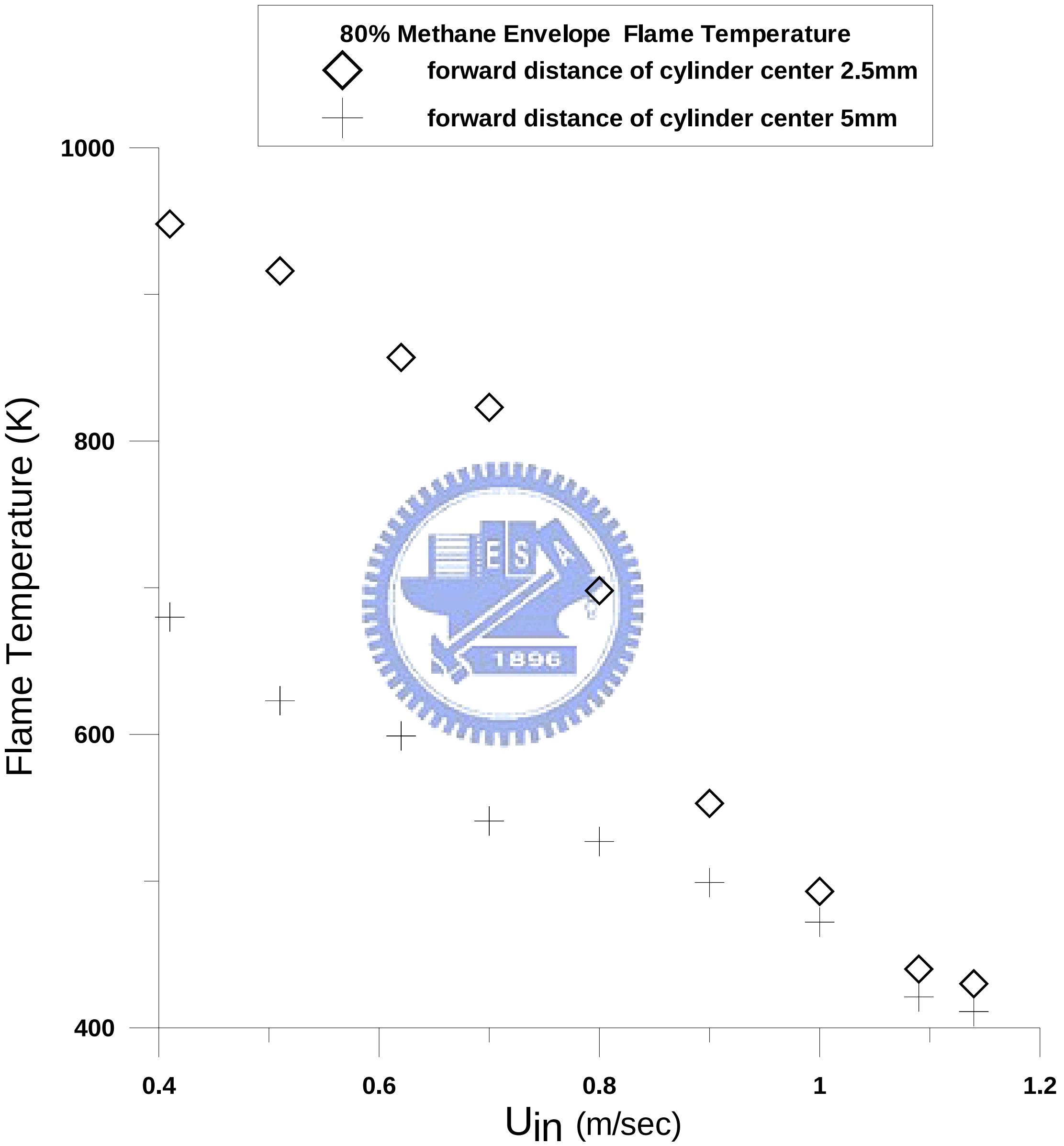


Fig. 4.8 the 80% methane vertical centerline envelope flame temperature in the cvlinder burner forward

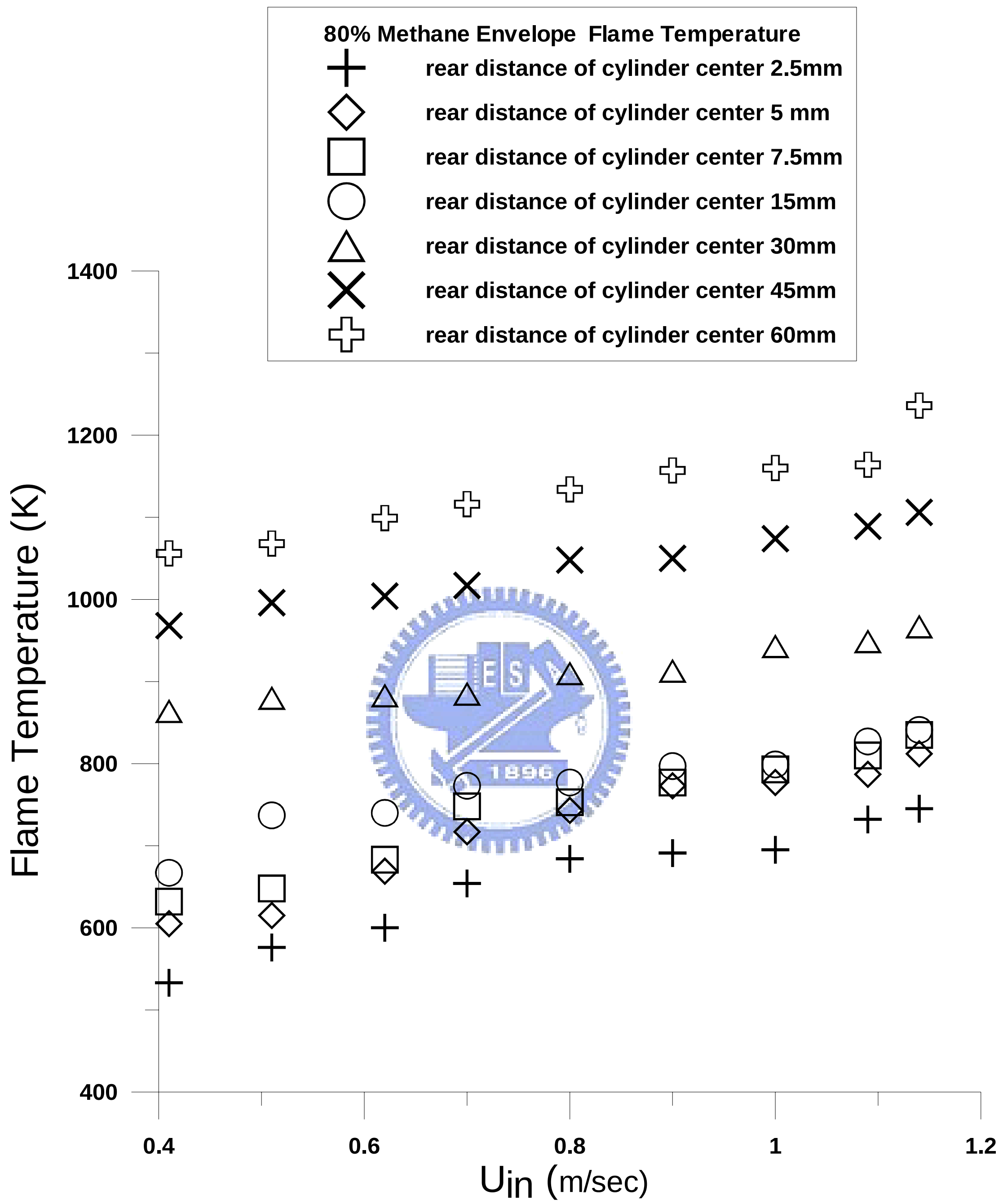
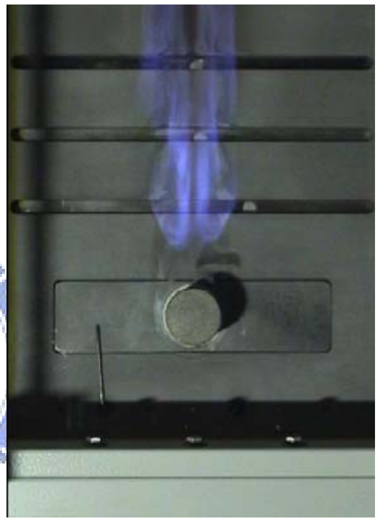


Fig. 4.9 the 80% methane vertical centerline envelope flame temperature in the cvlinder burner rearward

（a） 6.12 sec

（e） 6.27 sec

（b） 6.15 sec



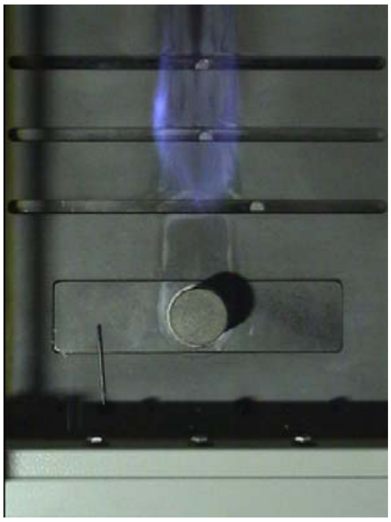
（f） 6.54 sec

（c） 6.18 sec

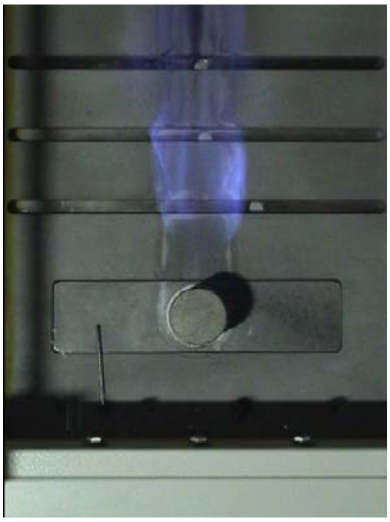
（g） 8.84 sec

Fig. 4.10 Series of flame transition as fixed incoming airflow velocity 1.24 m/s under α = 80%

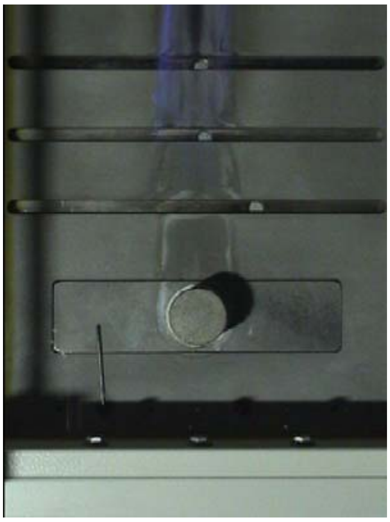
（h）9.75 sec



（j）12.57sec



（i）12.54 sec



（k）12.6 sec

Continued Fig. 4.10 Series of flame transition as fixed incoming airflow velocity 1.24 m/s under α = 80%

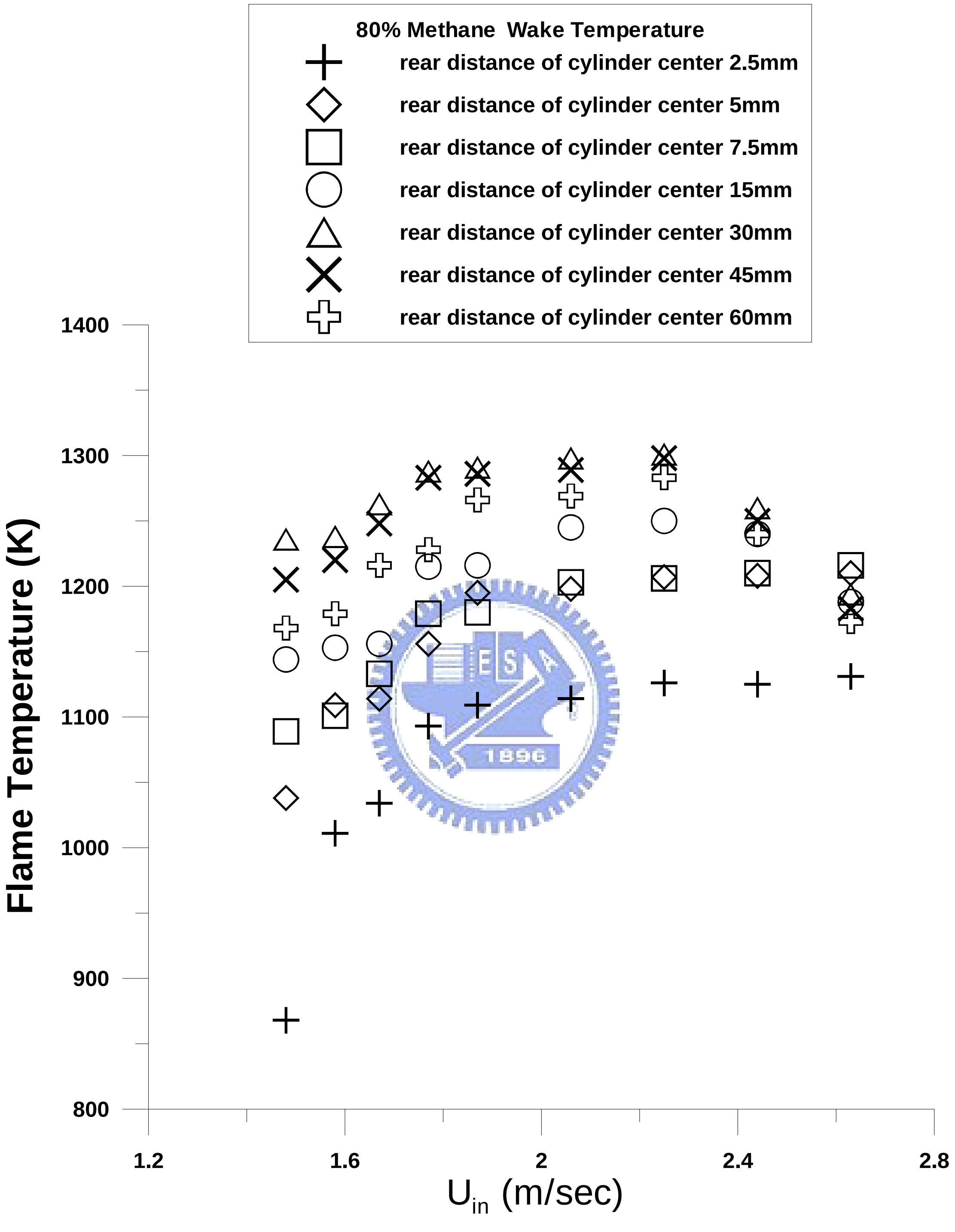
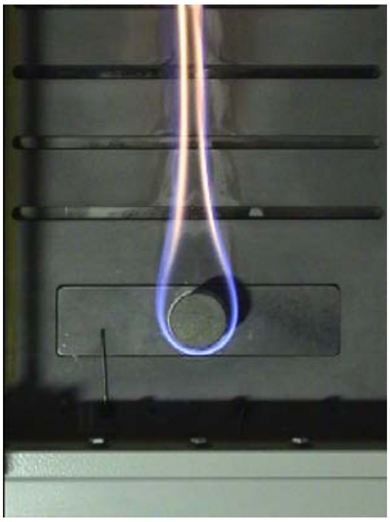
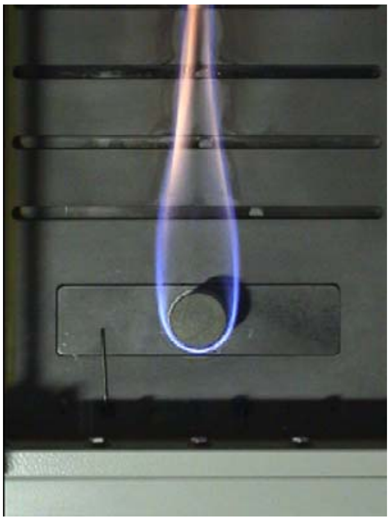


Fig. 4.11 the 80% methane vertical centerline wake flame temperature in the cylinder burner rearward



(a) U_{in} = 0.41 m/sec

(c) U_{in} = 1.06 m/sec



(b) U_{in} = 1.04 m/sec

(d) U_{in} = 2.63 m/sec

Fig. 4.12 Series of flame transition in the lower methane mass fraction ($\alpha = 0.6$)

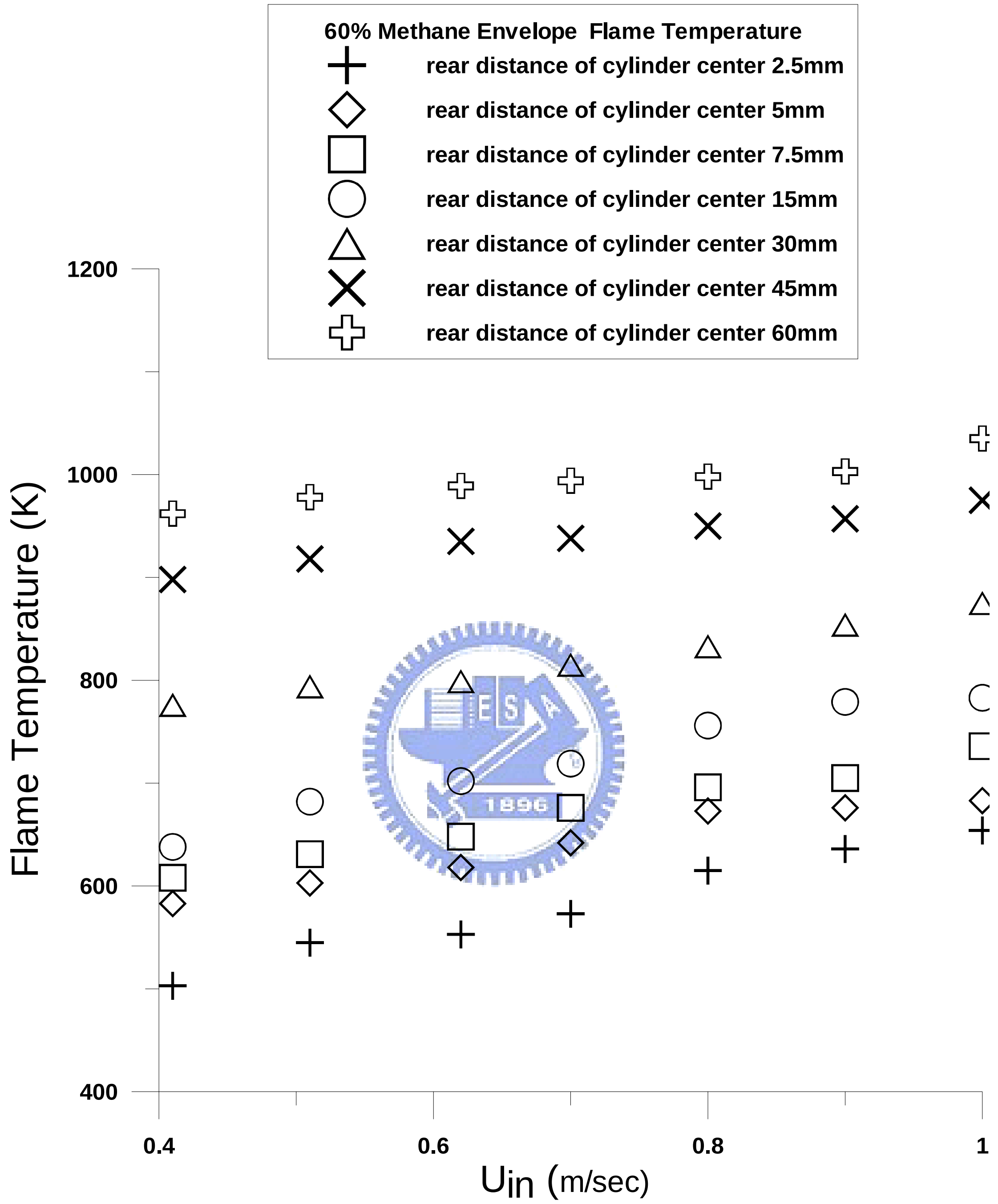


Fig. 4.13 the 60% methane vertical centerline envelope flame temperature in the cvlinder burner rearward

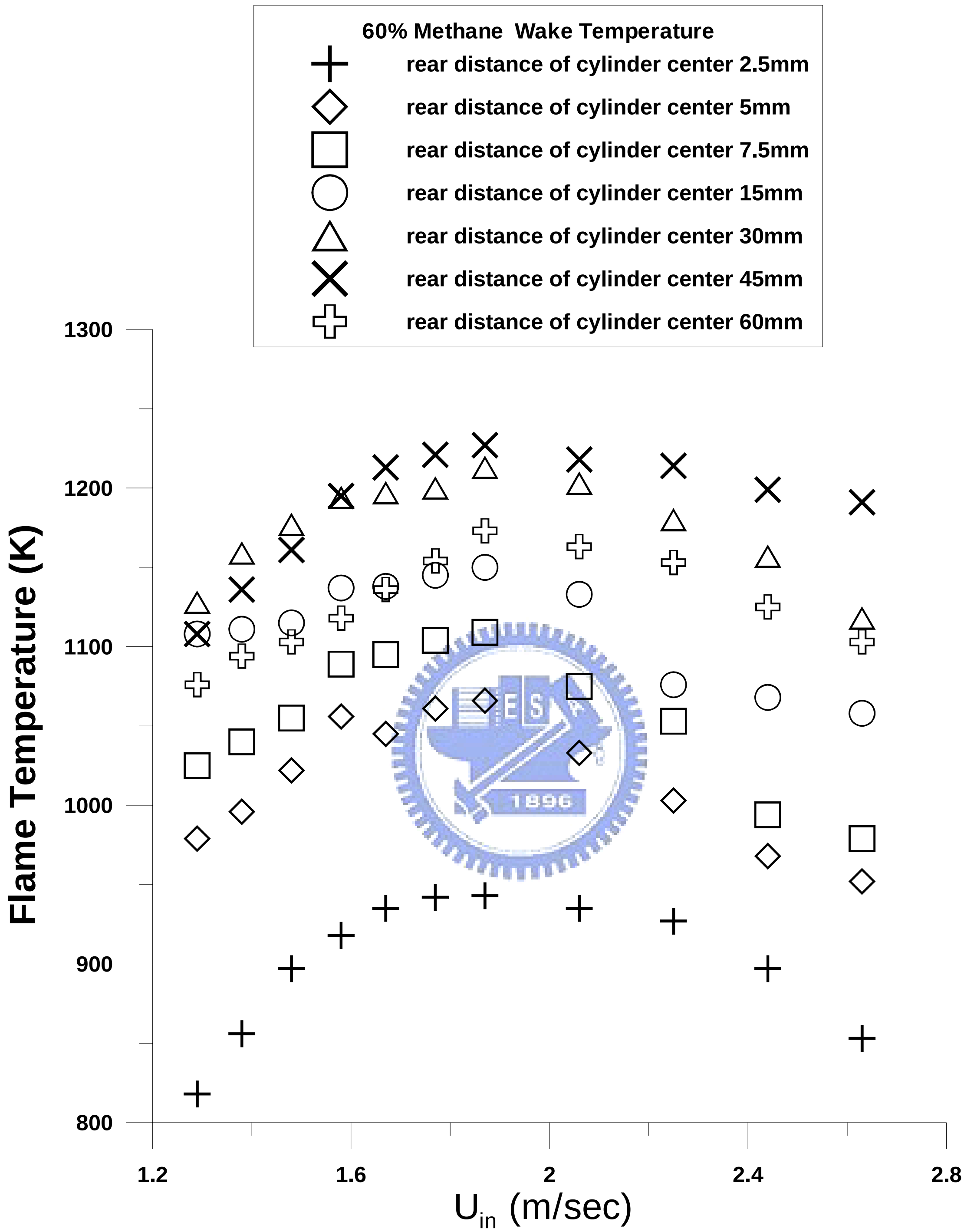


Fig. 4.14 the 60% methane vertical centerline wake flame temperature in the cvlinder burner rearward

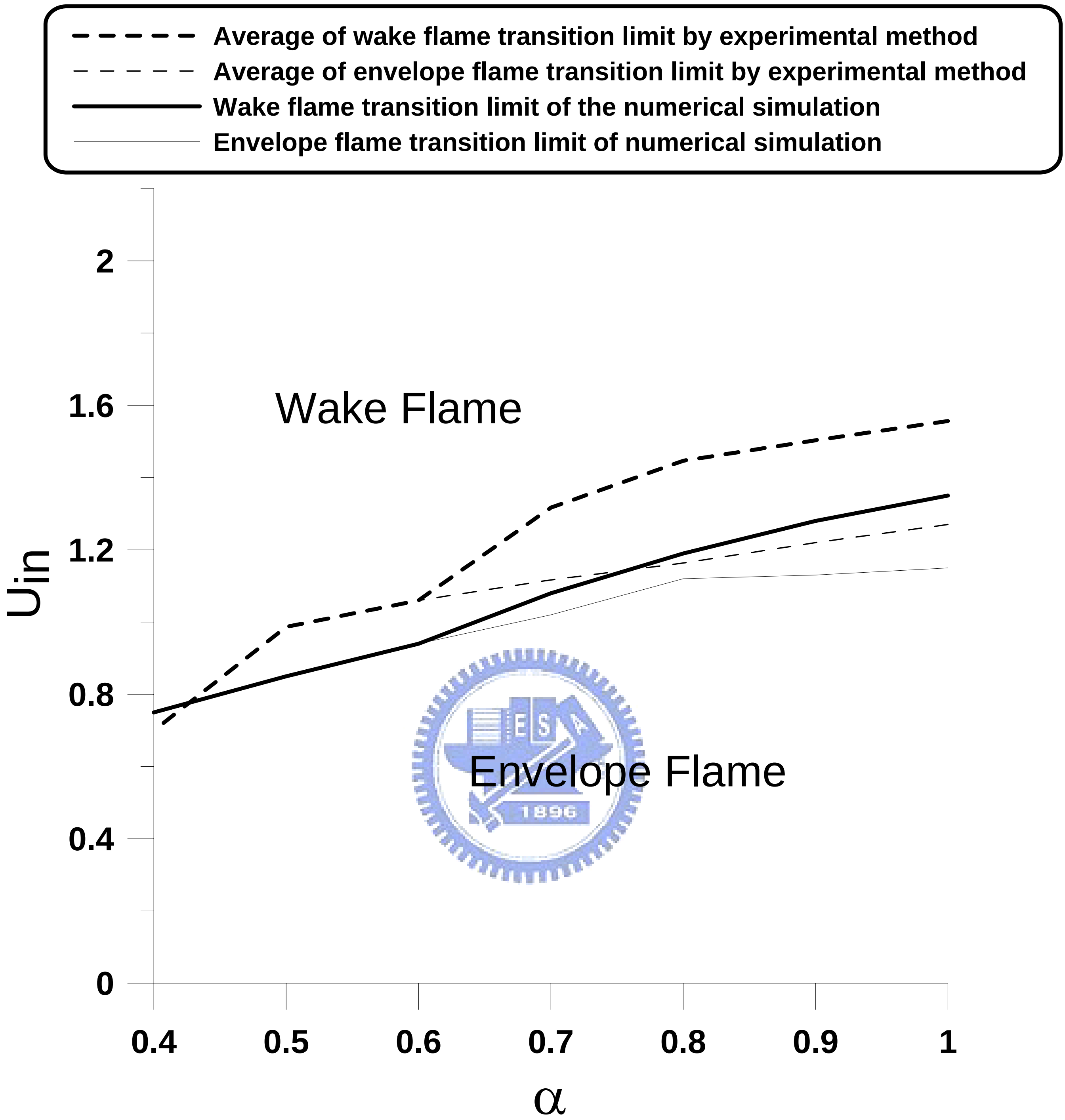


Fig. 4.15 Comparison with Chen's numerical simulation results of the flame transition limit