Eng. & Tech. Journal, Vol.27, No.14, 2009

The Effect of Boundary Air Flow on Premixed Stationary Burning Velocity

Ali Rasool M. Al-Zubaidi*

Received on:14/4/2008
Accepted on:2/7/2009

Abstract

In this study the effect of boundary condition on premixed methane-air stationary Bunsen flames has been experimentally investigated. Laminar burning velocity is calculated by the concentrated cons method (CCM) and Schlieren photography technique, under the effect of laminar boundary horizontal stream air bulk with a range of air flow speeds. The experimental results have shown that the effect of these boundary conditions in general is small on calculated burning velocity if air flow speed is around between (0-50 cm/s). So, it is suggested that this effect be neglected. This effect so characterized increases at/around Stoichiometric ratio flames because of the increase of temperature difference between flame and boundary. The results of the experimental findings were compared with the latest published work and showed a good agreement with it, with a maximum discrepancy of (±2.5% at j =1.1).

Keywords: Bunsen flame, laminar, Burning velocity, boundary effect

تأثير جريان الهواء المحيط باللهب الساكن مسبق الخلط على سرعة الاحتراق

الخلاصة

تم في هذا البحث دراسة تأثير الظروف المحيطة بلهب بنسن الطباقي لخليط غاز الميثان مع الهواء مسبق الخلط. سرعة الاحتراق تم حسابها باستخدام طريقة المخروطين المتمركزين (CCM) وتقنية تصوير شليرن تحت تأثير ظرف جريان هواء طباقي لسرع هواء مختلفة. التجارب بينت وبشكل عام إن هذا التأثير على سرعة الاحتراق يكون صغيراً بحدود سرعة هواء (0-50 cm/s) واقترحت الدراسة إهمال هذا التأثير. لكن هذا التأثير يزداد عند/حول نسبة الخلط المثالية نتيجة زيادة الفرق بين درجة حرارة اللهب والمحيط. النتائج العملية لهذه الدراسة تم مقارنتها مع احدث الاعمال المنشورة واعطت توافق جيد معها. بنسبة خطأ اقصاها (±2.5% عند j =1.1).

Introduction

The Bunsen flame is one of the oldest known examples of stabilized premixed combustion, and it is most important of the simplest examples of multidimensional combustion field. As it have been used for decades to measure laminar flame speed (burning velocity S_u) [1, 2, 3, 4, 5 & 6]. So the previous studies showed that the burning velocity occurs approximately between (37- 43 cm/s) for methane-air mixtures (standard value) [7].

Assumptions have to be made about the velocity profiles of the

*Center of Training and Factoring, University of Technology / Baghdad

https://doi.org/10.30684/etj.27.14.7
2412-0758/University of Technology-Iraq, Baghdad, Iraq

gases released from the burner. The nature of flame shapes was already reviewed by [8]. The approximated shape calculation of Bunsen flame for LPG (liquefaction petroleum gas) is achieved by using concentrated cons method (CCM), suggested by [9].

$$S_u = 2U_{mix}\left(\frac{R_t}{R}\right)\Big/\left(C_1 + C_2\right) \ldots (1)$$

Where S_u burning velocity in cm/s, U_{mix} unburned speed of gas mixture, $\left(\frac{R_t}{R}\right)\Big/\left(C_1 + C_2\right)$ are geometrical dimension of flame surface and burner tube. Figure (1) illustrated these dimension.

Laminar burning velocity values and flame stability criteria such as flashback and blow-off ranges are generally affected by geometrical conditions or aerodynamic conditions [9,10,11,12 & 13] and physiochemical conditions such as temperature, pressure and chemical construction [8, 13, 15, 16, 17, 18 & 19]. But in Bunsen flames the geometrical conditions or aerodynamic conditions are considered important factors for flame speed, in addition to the physiochemical conditions, because the burning velocities are calculated from volumetric flow rates and the surface area of flames.

Influence of boundary conditions in large eddy simulation LES of premixed combustion instabilities is studies by [20], the electric field effect on gas temperature, and radiative heat flux and flame speed of premixed CH4/O2/N2 flames is investigated by [21]. Experiments were performed on laminar Bunsen flames (Re<2200) of lean to rich mixture composition

The present study is introducing external air affecting on burning velocity. This condition depends on boundary horizontal stream air bulk that has an effect on Bunsen flame shapes, or in other words (the effect of force convection as over all phenomena), that relies on the literature concerned.

Flame images are captured by using Schlieren photography technique. The advantages of this technique are illustrated in [9, 22, 22 & 24].

Experimental Set-up

The Bunsen burner designed here depends on the requirements of the burner design as described in [8]. The burner tube which is a copper tube with 100 cm length and 1.2 cm inside diameter has been used to obtain a wide range of equivalence ratio (f) and a range of flame stability with approximated zero external air speed. The details of the premixed chamber are illustrated in figure (2).

Fully developing air stream flow that is cutting across with the study phenomenon is achieved by designing of a fully developing channel [24], as illustrated in figure (3). Air flow is obtained by using 60×60×20 12V DC Flat Fan with a maximum airflow (23 CFM, 0.0283(m^3/m).

The fan selection and specification is depended on figure (4). The regulation of motor speed is achieved by using variable power supply dc source. Air bulk flow speed is measured by digital velocity-meter connected to the Pitot tube that is located near the study phenomenon [26] **. Fan setup and depended variables are show in table (1).

Another setup is achieved to obtained stable flame are show in tables (2 & 3)

Flow meters calibration formulas are

$$V_a = 3.9304 \times a_R + 7.7035 ...(m^3/s) \quad ... (2)$$

$$V_f = 0.51158 \times f_R + 2.2443 ....(m^3/s) \quad ... (3)$$

$$j = \frac{(m_f/m_a)}{(m_f/m_a)_{st}} = \frac{(V_f/V_a)}{(V_f/V_a)_{st}}$$

$$j = \frac{AFR_{st}}{AFR}$$

Calculationof *AFRst* (**st**oichiometric **A**ir to **F**uel **R**atio)

The stoichiometric quantity of oxidizer is just that amount that is necessary to completely burn a quantity of fuel. The stoichiometric AFR is calculated by balancing C, H, and O atoms in the combustion reaction. Complete combustion of a general hydrocarbon with atmospheric air is written as

$$C_x H_y + a(O_2 + \frac{0.79}{0.21} N_2) \rightarrow$$

$$\rightarrow xCO_2 + \frac{y}{2} H_2O + \frac{a0.79}{0.21} N2$$

By this chemical formula we obtained on table (3), and by floating metering we get the table (4).

Schlieren images of Bunsen flames are captured by commercial camera with 100 ISO Konica films with the camera being adjusted at (F/5.8 and 250 ASA). Schlieren images are saved as JPG extension files with 300 dpi resolution. The contrast and brightness of the images are treated by Adobe Photoshop and dimensions of Schlieren images are captured by AutoCAD to obtain more details. The sample of captured dimension and relation with j and U_a^{flame} are show in table (5), where reading dimension technique is

Actual dimension = measuring dimension × scale ratio (the scale ratio for Schlieren images is equal to 1.41361256) therefore,

$$H = 1.41361256.H_m ...(cm) ..... (4)$$

$$d = 1.41361256.d_m ...(cm) .... (5)$$

$$h_1 = 1.41361256.h_{1m} ...(cm) ..... (6)$$

Results and Conclusions

In this study that is not have a numerical relation between the effecter and burning velocity, but the act of the effecter are experiment as well as over all phenomenon under study. A number of experiments are made at room temperature $25C^{\circ}$ as details in sec.2. Calculated laminar burning velocity is achieved by eq.(1) and the results of these calculation are illustrated in Figures (5) in a wide range of equivalence ratio under variant effect of external air flow. The values of calculated burning velocity are shown that let at the standard value (37-43 cm/s). In otherwise the burning velocity are decreasing with the increase of air flow speed, this state occur duo to increase of the effect of flame quenching resulting from the heat transfer ratio being increased at the flame surface, with this being increased because of force convection – a best approximation of the above is the flow over cylinders, spheres, and other geometries [26]***).

The effect of air flow has been found to be very strong in the range (0.8-1.4) of equivalence ratio as show in shadow reign; this is due to the difference between flame temperature and air flow temperature being larger than the difference at far lean and rich sides. Also it has been shown that if the effect of air flow speed is between (0-50 cm/s), it can be neglected due to the fact that the burning velocity values of methane-air mixtures being in the range specified above in (section 1).

The figure (6) is given comparison between present work and published work depended on ref. [7] to rechecking the present work. And this comparison is illustrating good agreement with published work.

In the future studies we suggested increasing the strong of this effect by using multistage of fans to increasing CFM of system.

References

[1] Zhou, M. and Garner, C. P., "Direct measurements of Burning Velocity of Propane-Air Using Particle Image Velocimetry". *Combustion and Flame*, 106: 363-367 (1996).

[2] Colin R. Ferguson, "Bunsen Flame Hydrodynamics", *Combustion and Flame*, 51: 267-272 (1985).

[3] Rallis, C. J. and Garforth, A. M., "The Determination of Laminar Burning Velocity", *Progress in Energy and Combustion Science*, 6: 303-329 (1980).

[4] Conan, H. R. and Linnet, J. W., "Burning velocity Determinations, *part V.- the use of Schlieren photography in determining burning velocities by the burner method*", *Trans. Faraday Soc.*, 47: 981-988 (1951).

[5] Andersen, J. W. and Fein, R. S., "Measurement of Normal Velocities and Flame Temperatures of Bunsen Flames", *The Journal of Chemical physics*, Vol. 17, No. 12: 1268-1274 (1950).

[6] Andersen, J. W. and Fein, R. S., "Measurement of Normal Velocities of Propane-Air Flames from Shadow photographs", *The Journal of Chemical physics*, Vol. 18, No. 4: 441-444 (1950).

[7] Heavi, H. M., Azarinfar, A., Bowen, P. J. and Syred, N., "Determination of Laminar Flame Thickness and Burning Velocity of Methane-Air Mixture", *Third European Combustion Meeting ECM*, p 1-6, (2007).

[8] Andrews, G. E. and Bradley, D., "Determination of Burning Velocity: A Critical Review", *Combustion and Flame*, 18: 133-153 (1972).

[9] Al-Zubaidi, Ali R. M., "Using Schlieren Photography Method for Studying Flame Propagation of Gas-air Mixture", MSc. thesis, Mechanical Engineering Dep., University of Technology-Baghdad, 69-93 (2000).

[10] Bourehla, A. and Baillot, F., "Appearance and Stability of a Laminar Conical Premixed Flame Subjected to an Acoustic Perturbation", *Combustion and flame*, 144: 303-318 (1998).

[11] Cha, J. M. and Sohrab, S. H., "Stabilization of Premixed Flames on Rotating Bunsen Burners", *Combustion and flame*, 106: 467-477 (1996).

[12] Sheu, W. J., Sohrab, S. H. and Sivashinsky, G. I., "Effect of Rotation on Bunsen Flame" *Combustion and flame*, 79: 190-198 (1990).

[13] Joulin, Guy, "On the Radiation-induced Curvature Effect on Particle-Laden Premixed Flames", *Combustion Sci. and Technology*, 54: 117-132 (1987).

[14] Mizomoto, M. and Yosheda, H., "Effect of Lewis Number on the Burning Intensity of Flames", *Combustion and flame*, 70: 47-60(1987).

[15] Law, C. K., Ishizuka, S. and Cho, P., "On the Opening of Premixed Bunsen Flame Tips", *Combustion Sci. and Technology*, 28: 89-90 (1982).

[16] Putnam, A. A., Ball, D. A. and Levy, A., "Effect of Fuel Composition on Relation of Burning Velocity to product of Quenching Distance and Flashback Velocity Gradient", *Combustion and flame*, 37: 193-196 (1980).

[17] Rallis, C. J. and Garforth, A. M., "Laminar Burning Velocity of Stoichiometric Methane-Air: Pressure and Temperature Dependence", *Combustion and flame*, 21: 53-68 (1972).

[18] Rosser, W. A., Inami, Jr. S. H. and Wise, H., "The Quenching of Premixed Flames by

Volatile Inhibiters", *Combustion and flame*, 10: 287-294 (1966).

[19] Gibbs, G. j. and Calcote, H. F., "Effect of Molecular Structure on Burning Velocity", *Journal of Chemical and Engineering Data*, Vol. 4, No. 3: 226-237 (1959).

[20] Schonfeld T. and Ppoinsot T., "Influence of boundary conditions in LES of premixed combustion instabilities", *Center for Turbulence Research Annual Research Briefs* 73-83, (1999).

[21] Eugene V. Vega and Yong Lee Ki, "An experimental study on laminar CH4/O2/N2 premixed flames under an electric field", Journal *of Mechanical Science and Technology* 22 312~319,(2008).

[22] Albers, Burt W. and Agrawal, Ajay K., "Schlieren Analysis of Oscillating Gas-jet Diffusion Flame", *Combustion and flame*, 119: 84-94 (1999).

[23] Dunn-Rankin, Derek and Weinberge, Felix, "Location 'of the Schlieren Image in Premixed Flames: Axially Symmetrical Refractive Index Fields", *Combustion and flame*, 113: 303-311 (1998).

[24] Settles, G. S., "Colour-Coding Schlieren Techniques for the Optical Study of Heat and fluid Flow", *Int. J. Heat and Fluid Flow*, Vol. 6, No. 1: 3-14 (1985).

[25] Wallis, R. Allin, *Axial Flow Fans and Ducts*, John Wiley & Sons, Inc., (1983), ch.4: 61-82.

[26] Frank Kreith, "Engineering Thermodynamics", *the CRC Handbook of Thermal Engineering*, Boca Raton: CRC Press LLC, (2000).

Notes:

****section 4-606, ref [26]**

***** Section 3-2 to 3-26, ref [26]**

Flo over a flat plate and wedges were classified as laminar or turbulent, depending on the Reynolds number, and correlations for the local and average convective heat transfer coefficients were developed. But flows over cylinders (perpendicular to the axis) and spheres are more complex. In general, the flow over cylinders and spheres may have a laminar boundary layer followed by a turbulent boundary layer

$$q'' = h\left(T_s - T_{aw}\right) \qquad \mathrm{Re}_d = \frac{\rho U_{max} d}{\mu} \qquad \mathrm{Nu} = \frac{h_c L}{k} = \frac{qL}{A_s \Delta T k} \qquad \Delta T = T_s - T_\infty$$

$$\mathrm{Re}_d < 10{,}000: \qquad \mathrm{Nu}_d = 0.3 + \frac{0.62\,\mathrm{Re}_d^{1/2}\,\mathrm{Pr}^{1/3}}{\left[1 + \left(0.4/\mathrm{Pr}\right)^{2/3}\right]^{1/4}}$$

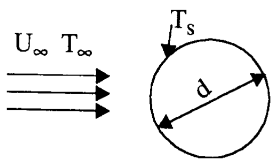


Table (1) Air bulk flow speed depended on ($60mm \times 60mm$) cores section channel

volt	External air flow rate		Air velocity	
	ft^3/m	cm^3/s	U_a^{fan} cm/s	U_a^{flame} cm/s
6.00	12.34	20566.67	571.30	155.493
4.00	6.32	10533.33	292.59	101.9406
2.00	3.05	5083.33	141.20	49.53184
Where *volt* (voltage regulator), U_a^{fan} (at the fan), U_a^{flame} (at the flame)				

Table (2) General data of mixing

a_R	f_R	$T_a(C^o)$	C_n	H_n
22	10	298	1	4
22	11	298	1	4
22	12	298	1	4
22	13	298	1	4
22	14	298	1	4
22	15	298	1	4
22	17	298	1	4
22	19	298	1	4

22	21	298	1	4
22	23	298	1	4
22	25	298	1	4

Where a_R (air mixed reading), f_R (fuel mixed reading), $T_a(C^{\circ})$ (air temperature), C_n (number of carbon atoms in fuel), H_n (number of hydrogen atoms in fuel)

Table (3) *x*-mole of fuel construction of CH_4

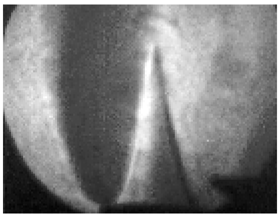
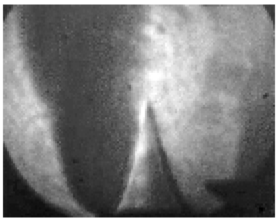
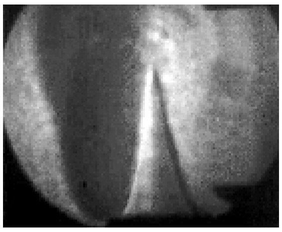
xCO_2	xH_2O	xN_2	xO_2	xCO	
0.07274	0.14548	0.73246	0.04932	0	
0.0774	0.15481	0.72877	0.03902	0	
0.08202	0.16404	0.72513	0.02881	0	
0.08659	0.17319	0.72151	0.01871	0	
0.09112	**0.18224**	**0.71794**	**0.0087**	**0**	Stoichiometric
0.09309	0.19097	0.71355	0	0.00239	
0.06169	0.20463	0.69305	0	0.04062	
0.03207	0.21752	0.67371	0	0.07669	
0.00406	0.22971	0.65543	0	0.1108	
-0.02247	0.24126	0.63811	0	0.1431	
-0.04763	0.25221	0.62168	0	0.17374	

Table (4) Unburned mixture parameters

f %	AFR	$U_{mix}(cm/s)$	j
4.1525	23.082	88.224	0.7468
4.4283	21.582	88.59	0.7987
4.7026	20.265	88.957	0.85061
4.9753	19.099	89.323	0.90252
5.2464	18.061	89.69	0.95443
5.516	17.129	90.057	1.0063
6.0506	15.527	90.792	1.1102
6.5792	14.199	91.529	1.214
7.1019	13.081	92.266	1.3178
7.6188	12.125	93.004	1.4216
8.1299	11.3	93.744	1.5254

Where f %(fuel present), f/a (air to fuel ratio), $U_{mix}(cm/s)$ (fully develop mixture velocity, j (equivalence ratio)

Table (5) Finishing experimental setup

j = 0.7468 or 4.1525% fuel					
Reading dimensions	Boundary air velocity effect U_a^{flame} cm/s				
	0.0	49.53184	101.9406	155.493	
$H_m(cm)$	1.7	1.75	1.8	1.8	
$d_m(cm)$	0.82	0.82	0.82	0.820.	
$h_{1m}(cm)$	0.13	0.13	0.13	0.14	
j = 1.0063 or 5.516%fuel					
Reading dimensions	Boundary air velocity effect (external effect) cm/s				
	0.0	49.53184	101.9406	155.493	
$H_m(cm)$	1.12	1.12	1.13	1.13	
$d_m(cm)$	0.74	0.74	0.74	0.74	
$h_{1m}(cm)$	0.12	0.12	0.12	0.13	
j = 1.5254 or 8.1299%fuel					
Reading dimensions	Boundary air velocity effect (external effect) cm/s				
	0.0	49.53184	101.9406	155.493	
$H_m(cm)$	2.32	2.33	2.33	2.35	
$d_m(cm)$	0.84	0.74	0.74	0.74	
$h_{1m}(cm)$	0.16	0.16	0.16	0.17	

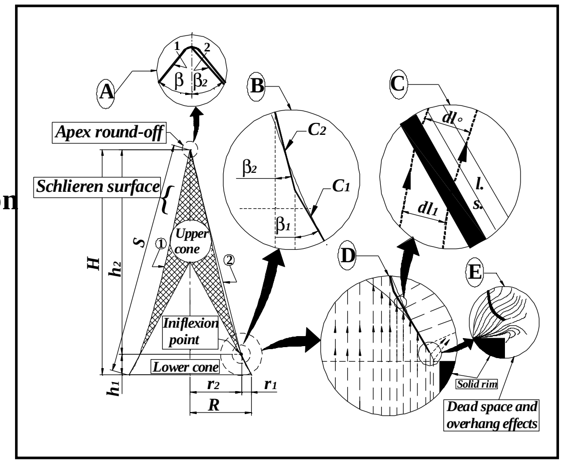


Figure (1) geometrical description of Benson flame surface

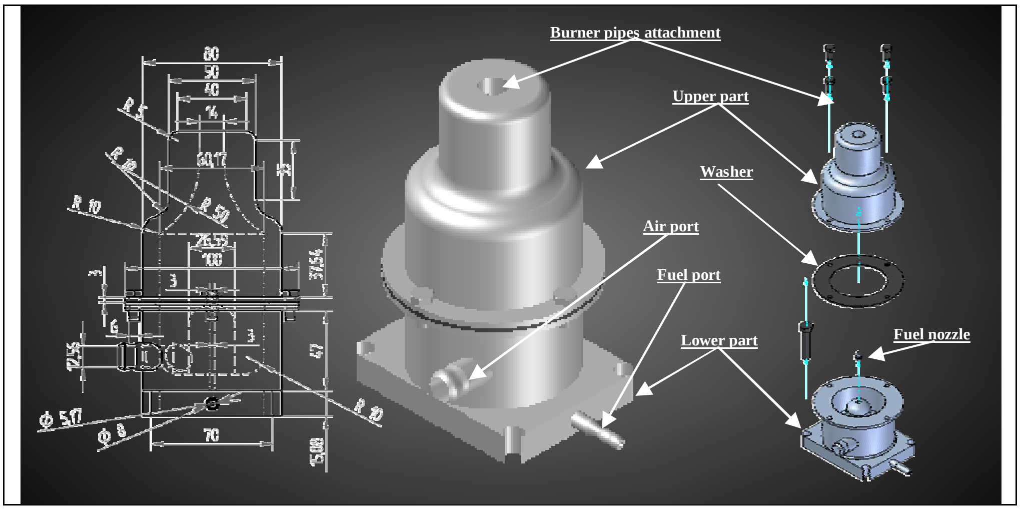


Figure (2) Benson premixed fuel chamber detail

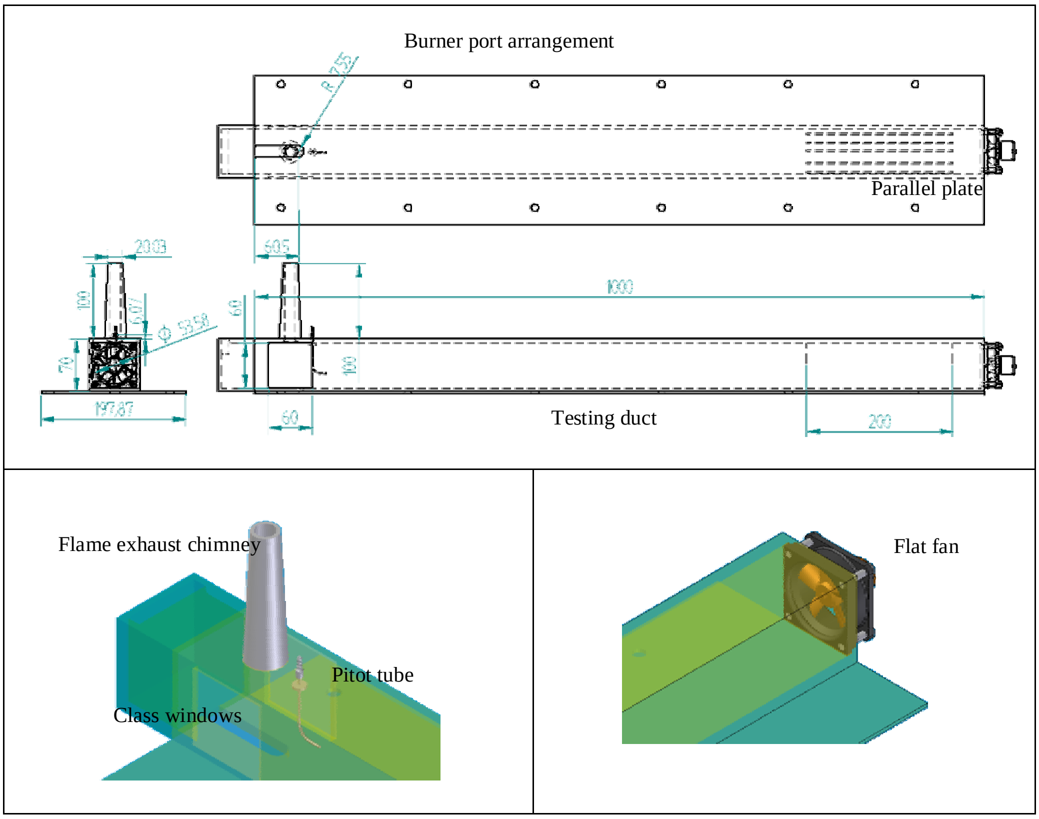
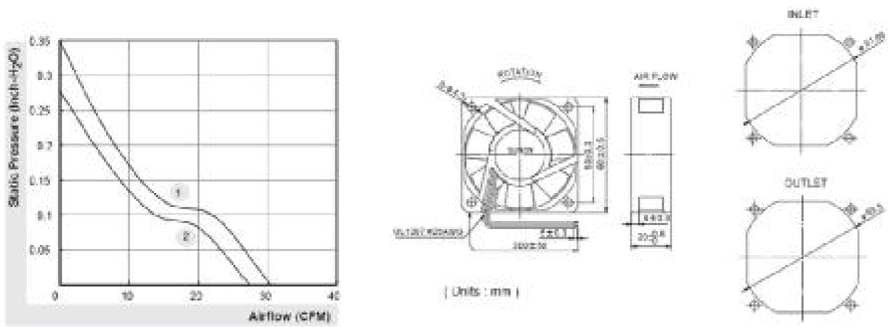


Figure (3) Fully developing channel with burner and fan locations

19~25.5 CFM

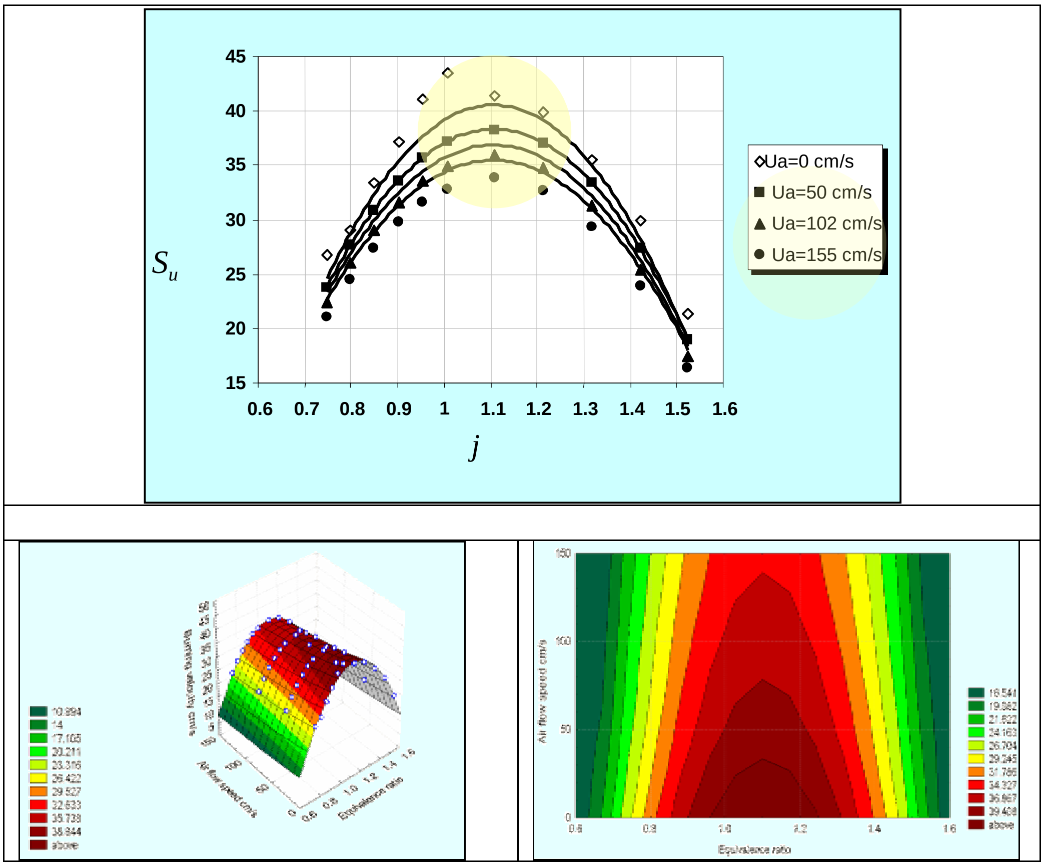
	P/N	Bearing ■ Vapo	Rating Voltage (VDC)	Power Current (AMP)	Power Consumption (WATTS)	Speed (RPM)	Air Flow (CFM)	Static Pressure (inch-H₂O)	Noise (dBA)	Weight (g)	Curve
KDE1206PKV1	MS.A.GN	■	12	0.15	1.8	4500	23.0	0.18	33.5	52	1
KDE1206PKV2	MS.A.GN	■	12	0.07	0.8	3700	19.0	0.14	28.0	52	2
KDE2406PKV1	MS.A.GN	■	24	0.075	1.8	4500	23.0	0.18	33.5	52	1
KDE2406PKV2	MS.A.GN	■	24	0.047	1.1	3700	19.0	0.14	28.0	52	2

Model	P/N	● 2Ball ○ Sleeve	(VDC)	(AMP)	(WATTS)	(RPM)	(CFM)	(inch-H₂O)	(dBA)	(g)	Curve
KD1206PKB1	(2).GN	●	12	0.154	1.8	4500	23.0	0.18	34.5	52	1
KD1206PKB2	(2).GN	●	12	0.088	1.1	3700	19.0	0.14	29.0	52	2
KD1206PKS1	GN	○	12	0.154	1.8	4500	23.0	0.18	33.5	52	1
KD1206PKS2	GN	○	12	0.09	1.1	3700	19.0	0.14	28.0	52	2



*All model could be customized. Please contact with Sunon Sales.
*Specifications subject to change without notice. Please visit SUNON web-site at http://www.sunon.com for update information.

Figure (4) Impeller Flat fan specification (www.sunon.com)



3D illustration | contour illustration

Figure (5) Relation between burning velocity and effected external air bulk

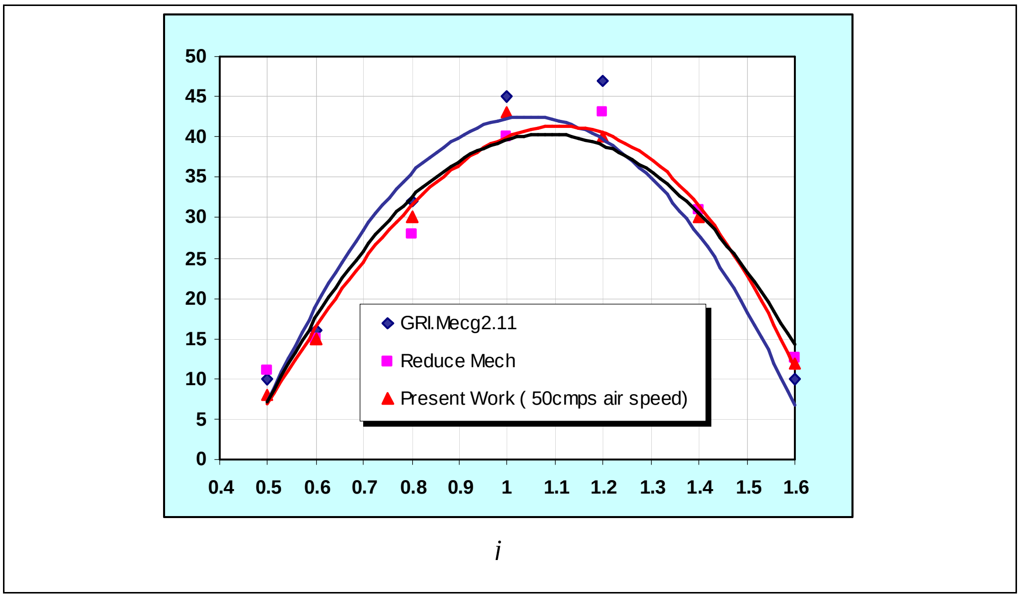


Figure (6) Comparison between present work and published work depended on ref [7]