Charcoal Gasifier Nozzle Sizing Calculations - A Comparison

DRAFT, 5/29/23, subject to revision or correction

by Martin B. Payne

(Koen van Looken v. Eddy Ramos v. Kaupp/Goss)

Method 1 - From Kaupp/Goss, *Small Scale Gas Producer-Engine Systems* (1984):

Step 1 – Calculate Total Gas Flow Rate (through engine)

(note: this Gas Flow Rate calculation is not from Kaupp, but from Maxgasman)

Engine Displacement and RPM: 4.9 L, 2000 RPM (50 MPH in 4^{th}, 65 MPH in 5^{th})

Maxgasman's volumetric flow equation, total gas flow rate through engine (from charcoalgas Yahoogroup, 2012):

Displacement (l) x RPM (1000's) x 3 ("combined stationary factors"(1))

4.9 x 2 x 3 = 29.4 l/s (or 62.5 ft3/min (CFM))

29.4 l/s = 106 m3/h = 0.029 m3/s

(1)Note: I am not aware of the origin or derivation of Maxgasman's "combined stationary factors" – simply using his equation here based on observed/apparent confidence in his computational abilities …

Step 2 – Calculate Total Air Flow Rate (into gasifier)

From Kaupp/Goss, *Small Scale Gas Producer-Engine Systems* (1984):

Table 3, page 74 shows various Useful Range Air Rates and the corresponding Useful Range Gas Rates, and averaging same finds that the Useful Air Rate tends to be about 77 % of the Useful Gas Rate.

So, 0.029 m3/sec x 0.77 = 0.022 m3/s or 80.4 m3/h air flow rate into gasifier

<u>Step 3 – Determine recommended nozzle size, based on air flow rate and/or velocity</u>

First, a few notes, on Kaupp/Goss:

1.)Figure 67, page 73 is a graph of CO conversion efficiency versus air rate in m3/h, for various nozzle sizes – but only up to a 25.4 mm, or 1" nozzle diameter. In other words, they are showing how much "good stuff"/fuel (CO) is produced compared to the total of both fuel (CO) and inert (CO2).

This graph is very useful, and indicates that there are threshold air flow rates (read: velocities) for each nozzle diameter where a small increase in air flow yields a large increase in conversion efficiency (aka gas quality). Then there are "diminishing returns" flowrates where further increases in air flow rates no longer make significant improvements in conversion efficiency/gas quality.

They do make what I believe to be a misleading conclusion, in their analysis of the graph, namely that "at air rates higher than 30 m3/h, the tuyere diameter does not influence the conversion ratio…" – this appears to be the case for up to a 25.4mm nozzle, but the graph only includes up to that size. It is likely, that if say a 1.5 " nozzle were needed, the gas quality would continue to increase above 30 m3/h, etc.

Their second conclusion, in the same sentence says "and higher air velocities produce better gas."* This, I believe, is a very important conclusion, and has to do with the size of the Partial Combustion/Reduction areas, or lack thereof, whereupon the generated CO can be re-combusted. This likely speaks to what might result in mediocre or poor quality gas which might come from a “bottom sucker with a randomly large hole size”, or multiple nozzle holes of miscellaneous flowrates and diameters. In other words, the shape and size of the Partial Combustion area is created by the velocity/flow rate, and is critical to making good gas (CO-wise).

(* subject to the diminishing returns referenced above – in other words, above a certain flow rate for a certain nozzle size, there is little improvement in gas quality.)

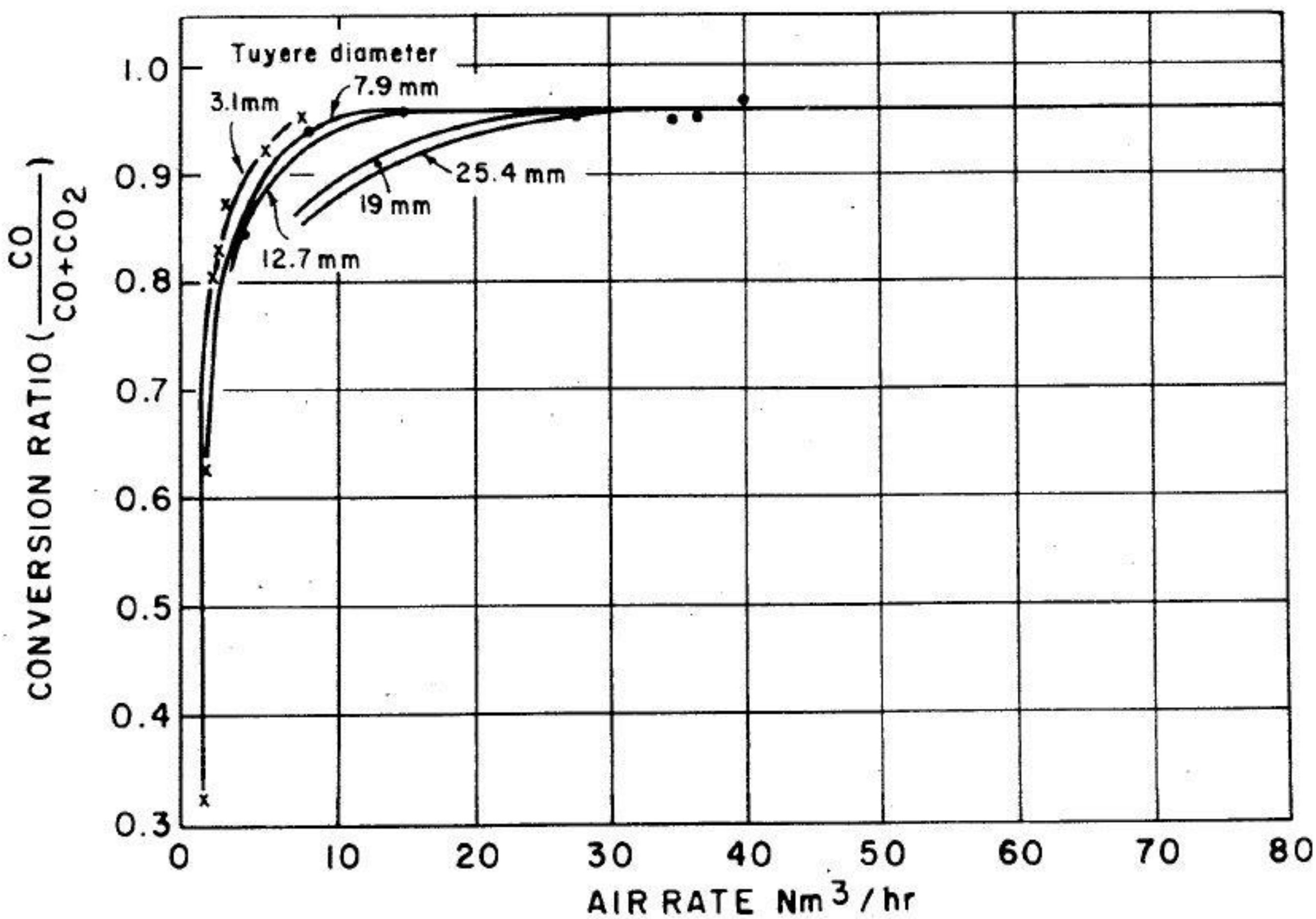


Figure 67. Conversion Ratio Versus Air Rate for Various Tuyere Diameters (16).

Our “mental models” of the chemical reactions/thermodynamics going on with the Partial Oxidation/Reduction areas - are no doubt imperfect.

(Kaupp/Goss references same, on page 75) Mathematical models/simulations – likely the same. So, that is why empirical results like in Figure 67 are so valuable. Namely, testing, and measurement of results (gas quality) – is necessary to see what works best.

Table 2, which shows Gas Composition for various Air Blast Velocities – appears very useful. And it is, however this data was only generated for a … 3.2 mm nozzle! Tiny! So, the velocities shown here, in order to generate good CO and H2, would not be applicable for larger nozzles. However, the concept is useful: namely, "higher velocities generate much better gas" and, there is a sweet spot where most of the gas quality can be realized without having to go to higher and higher velocities and their accompanying, more difficult temps!

Table 2. Gas Composition Versus Air Blast Velocity at Tuyere (16).

Air Blast Velocity m/s	Tuyere Fire Temperature °C	Gas Composition*				Conversion Ratio
		CO_2	CO	H_2	CH_4	
22.6	980	17.7	8.5	1.3	0.9	0.325
44.8	1300	9.1	20.3	4.2	1.1	0.693
72.3	1420	6.0	24.9	4.2	1.1	0.807
90.0	1400	5.6	27.5	4.3	1.2	0.832
115.0	1420	4.2	28.4	5.6	1.3	0.877
218.6	1520	2.6	30.1	6.5	1.3	0.922

*N_2 = 100 (% CO_2 + % CO + % H_2 + % CH_4)

OK, so now to calculate some velocities based on various trial nozzle sizes (note, Kaupp/Goss only goes up to 1”, in terms of recommendations for air flow rates and velocities):

First, calculate nozzle cross-sectional areas:

1” nozzle = 0.785 in2 = 0.000506 m2

1.25” nozzle = 1.23 in2 = 0.000794 m2

1.5’’ nozzle = 1.77 in2 = 0.00114 m2

Given our above calculated air flow rate, and the areas calculated above, calculate air velocities for the above nozzles:

Vair1” = 0.02233 m3/s / 0.000506 m2 = 44.1 m/s

Vair1.25” = 0.02233m3/s / 0.000794 m2 = 28.1 m/s

Vair1.5” = 0.02233 m3/s / 0.00114 m2 = 19.6 m/s

Kaupp/Goss, Figure 67, indicates that for a 1” nozzle, only about 25 m3/h is required to get 94 % conversion efficiency (good gas). Our engine air flowrate is about 80 m3/h – at the right hand end of the graph - and much higher than needed/desired for a 1” nozzle.

Also based on volume, Table 3, page 74 shows that for a 1” nozzle, a “Useful Air Range” of 13.9 to 64.6 m3/h is suggested. (of course, their max HP listed in this range is 32 HP) So, our Air Flow Rate is 80 m3/h, or a bit above their 64.6 m3/h max for the 1” nozzle.

Table 3. Tuyere Diameter Versus Useful Range of Air Rate, Gas Rate and Engine Power (16).

Tuyere Diameter mm	7.9	12.7	19	25.4
Useful Range Air Rate m^3/h	6.3-11.9	7.6-27.2	12.4-47.6	13.9-64.6
Useful Range Gas Rate m^3/h	8.1-15.6	9.9-35.7	16.1-61.2	17.5-85
Useful Range, Engine Power hp	2.5-6	4-14	5-22	6-32

Likewise, Table 4, page 75 indicates that for a 1" nozzle a minimum required Air Velocity of 7.5 m/s is all that is needed. Our Vair1" is 44.1 m/s, which is much, much higher. (note that Koen's spreadsheet references a "desired airspeed at nozzles" of 25 m/s. I have no idea of the origin of this number, but have also seen it elsewhere, I believe)

Finally, Table 4 shows the recommended minimum air velocity, air rate and gas rate for various tuyere diameters, to obtain a good conversion ratio of 0.9.

Table 4. Recommended Minimum Air Velocities, Gas and Air Rates, for Various Tuyere Diameters (16).

Tuyere Diameter mm	3.2	7.9	12.7	19	25.4
Air Blast Velocity m/s	146.0	35.0	17.0	12.0	7.5
Air Rate m^3/h	4.2	6.3	7.7	12.4	14.0
Gas Rate m^3/h	5.3	8.2	10.0	16.2	17.5

So, based on the above, it appears that Kaupp/Goss would suggest that a 1" nozzle might be a bit too small for this application.

Kaupp/Goss' Table 3, Tuyere Diameter Versus Useful Range of Air Rate, Gas Rate and Engine Power, only covers up to 25.4 mm (1") nozzle size. So, by graphing the Useful Air Range minimum and maximum, for each of those nozzle sizes, we can fit a curve and obtain an equation for same:

<u>Useful Air Flow Rate (m3/h) Maximum:</u>

= 3.0302(nozzle diameter in mm) -11.415

<u>Useful Air Flow Rate (m3/h) Minimum:</u>

= 0.4706(nozzle diameter in mm) + 2.4028

Let’s try a 1.25 in (31.75 mm) nozzle:

Useful Air Flow Rate Maximum(for 31.75mm) = 3.0302(31.75) -11.415 = 84.8 m3/h

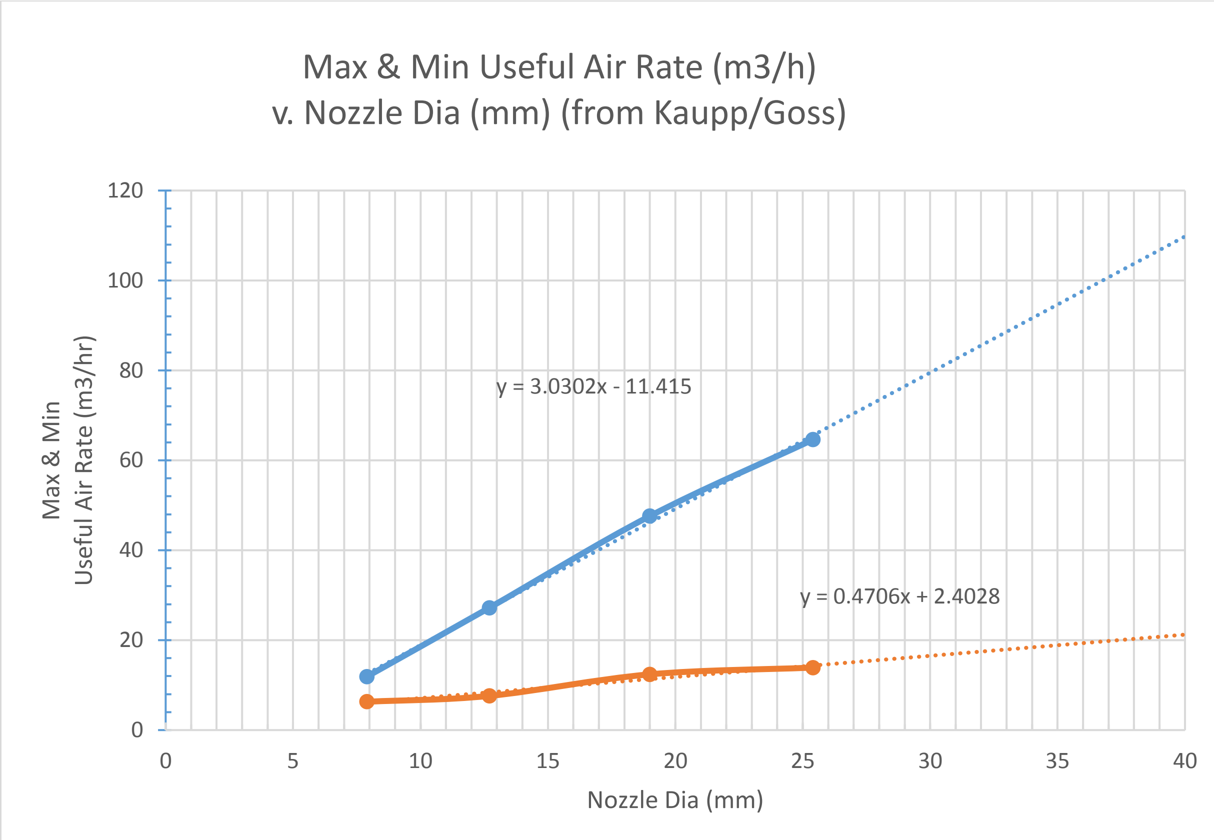
Useful Air Flow Rate Minimum(for 31.75mm) = 0.4706(31.75) + 2.4028 = 17.3 m3/h

So, our 4.9L at 2000 RPM pulls 80m3/hr and it is within this range, suggesting a 1.25 in nozzle might be appropriate.

Shown below is a portion of Table 3 from Kaupp/Goss, and the graphs and equations derived from same:

Useful Air Rates (m3/h), from Table 3:

Useful Range Air Rate(m3/h) (from Kaupp/Goss)				
Tuyere Diameter (in)	0.324	0.520	0.779	1.041
Tuyere Diameter (mm)	7.9	12.7	19	25.4
Min	6.3	7.6	12.4	13.9
Max	11.9	27.2	47.6	64.6



Making velocity calculations from Kaupp/Goss' Table 3 is a matter of applying the cross-sectional area of each of the nozzle sizes to the Air Rate. Then, in similar manner, this Useful Air VELOCITY, minimum and maximum, for each of the given nozzle sizes can be plotted, and we can fit a curve and obtain an equation for same:

Useful Air Velocity (m/s) Maximum:

= -1.858(nozzle dia in mm) + 82.477

Useful Air Velocity (m/s) Minimum:

= 469.39(nozzle dia in mm)^^-1.269

Let's try a 1.25 in (31.75 mm) nozzle:

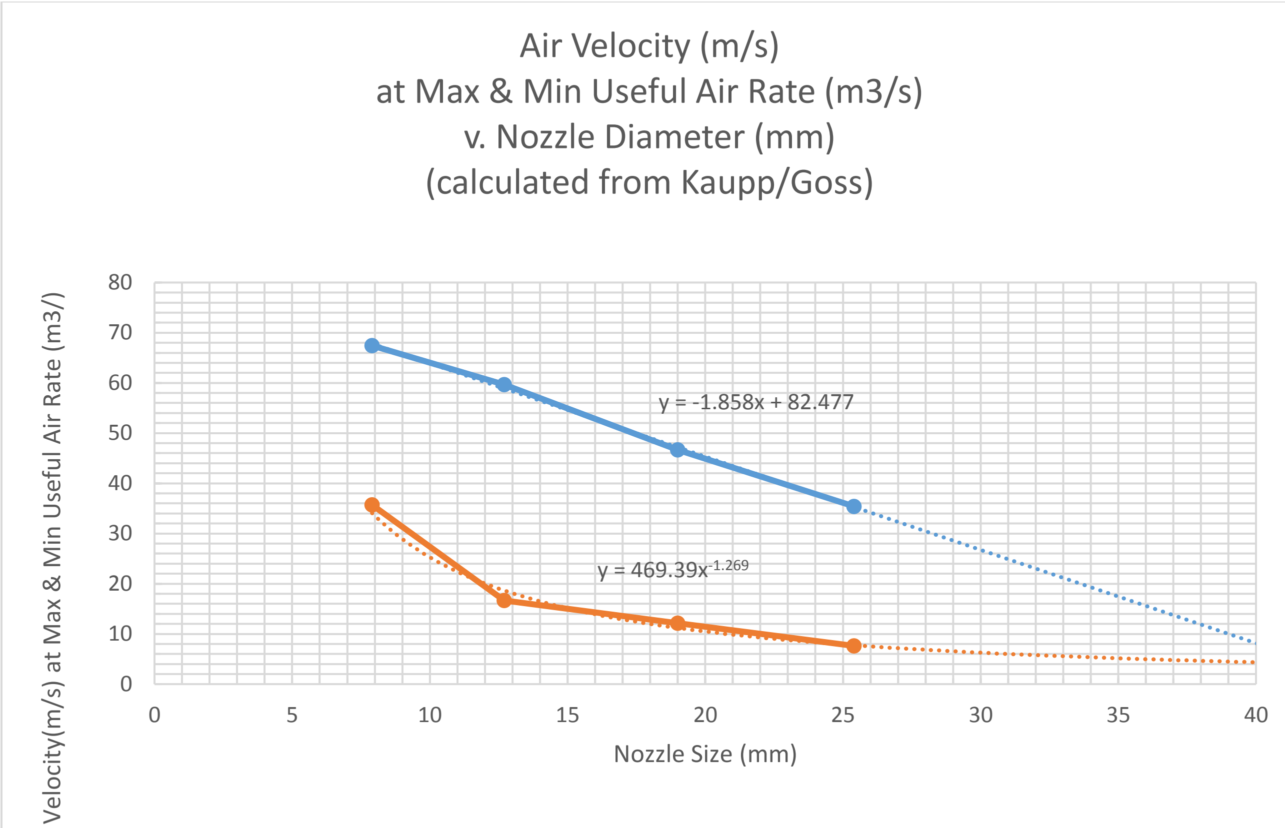
Useful Air Velocity Maximum(for 31.75mm) = -1.858(31.75) + 82.477 = 23.5 m/s

Useful Air Velocity Minimum(for 31.75mm) = 469.39(31.75)^^-1.269 = 5.83 m/s

So, our 4.9L at 2000 RPM pulls 80 m3/h, or 28.0 m/s across a 1.25 in nozzle, and that is close to the above range, suggesting a 1.25 in nozzle, or just slightly larger, might be appropriate.

Shown below are the minimum and maximum air velocities derived from Table 3 from Kaupp/Goss, and the graphs and equations derived from same:

Useful Range Air Velocity(m/s) (calculated from Kaupp/Goss Useful Air Rates)				
Tuyere Diameter (mm)	7.9	12.7	19	25.4
Min	36	17	12	8
Max	67	60	47	35


Air Velocity (m/s)
at Max & Min Useful Air Rate (m3/s)
v. Nozzle Diameter (mm)
(calculated from Kaupp/Goss)
y = -1.858x + 82.477
y = 469.39x-1.269
Nozzle Size (mm)
Velocity(m/s) at Max & Min Useful Air Rate (m3/)
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30
35
40

Method 2 – Mr. Koen Van Looken's Spreadsheet

Mr. Van Looken's spreadsheet has been utilized by several folks on DOW, and he provided a link for me to use same.

The only entries made were:

> Displacement in liters: 4.9
>
> Engine Rated RPM: 2000
>
> Nozzle Size diameter in mm: (tried 1" (25.4 mm), 1.25" (31.75 mm) and 1.5" (38.1 mm)
>
> Desired velocity: 25 m/s

(I am only interested in one nozzle, for this application, but I went ahead and entered "3" as a multi-nozzle option, anyway.)

So, based on the desired 25 m/s velocity, Koen's spreadsheet is suggesting that a 35.2 mm (1.39") nozzle might be about right for this application.

Comparison-wise, the calculations in Method 1 indicate a velocity of 28.0 m/s, if using a 1.25" nozzle, whereas Koen's simple spreadsheet derives a velocity of 30.7 m/s, with this nozzle size. Pretty close to agreement, the two methods!

Spreadsheet screenshots, attached below:

Engine displacement in Liters		4.9
Engine rated Rpm		2000
Engine displacement efficiency		0.7
Stoichiometric ratio combustion (gas to air)		0.5
Air to gas ratio gasifier		0.85
Nozzle capacity Liter/sec		24.295833
Nozzle size diameter in mm		38.1
Airspeed at Nozzle m/sec		21.3
Desired Airspeed m/sec		25
recomended nozzle size diameter in mm for 1 nozzle		35.2
Multi nozzle	Number of nozzles	3
recomended nozzle size diameter in mm		20.3

Engine displacement in Liters		4.9
Engine rated Rpm		2000
Engine displacement efficiency		0.7
Stoichiometric ratio combustion (gas to air)		0.5
Air to gas ratio gasifier		0.85
Nozzle capacity Liter/sec		24.295833
Nozzle size diameter in mm		25.4
Airspeed at Nozzle m/sec		48.0
Desired Airspeed m/sec		25
recomended nozzle size diameter in mm for 1 nozzle		35.2
Multi nozzle	Number of nozzles	3
recomended nozzle size diameter in mm		20.3

Engine displacement in Liters		4.9
Engine rated Rpm		2000
Engine displacement efficiency		0.7
Stoichiometric ratio combustion (gas to air)		0.5
Air to gas ratio gasifier		0.85
Nozzle capacity Liter/sec		24.29583333
Nozzle size diameter in mm		31.75
Airspeed at Nozzle m/sec		30.7
Desired Airspeed m/sec		25
recomended nozzle size diameter in mm for 1 nozzle		35.2
Multi nozzle	Number of nozzles	3
recomended nozzle size diameter in mm		20.3

Method 3 – Mr. Eddy Ramos' equation

From Mr. Ramos' excellent publication, "DRIVE ON WASTE – A guide for driving a vehicle on chargas & water, page 7, Mr. Ramos lists the following equation:

Desired nozzle size = RPM x 0.0046 x SQR RT(Engine Displacement in liters)

So, 2000 x 0.0046 x SQR RT(4.9) =20.4 mm, or about 0.80 in

Mr. Ramos says that the optimum nozzle size can be 10 percent more, or less, than this calculated amount.

So, 0.80 x 90 percent = 0.72", or say ¾"

And, 0.80 x 110 percent = 0.88", or say 7/8"

These nozzle sizes are obviously smaller than what was calculated from the previous methods. However, note that Mr. Ramos is using a bottom nozzle entry, updraft gasifier, versus a side entry updraft – which is the most likely type anticipated by Kaupp/Goss, or Van Looken. So, the fire shape/partial combustion/reduction areas of a bottom entry updraft MAY perform better at higher velocities. Certainly Mr. Ramos has a long record of successful usage with his gasifier designed as such.