Preferential transport effects in premixed bluff-body stabilized CH₄/H₂ flames

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Abstract

Recent studies of bluff-body stabilized premixed CH₄/air flames, using line-imaged Raman/Rayleigh/LIF methods to measure temperature and major species, have revealed significant effects of preferential species transport on scalar structure across the flame and into the recirculation zone. The main observations were that the C/H atom ratio and the equivalence ratio increased going from reactants to products along a radial profile when the reactant flow velocity was sufficiently high to push the flame close to the boundary of the recirculation zone. This phenomenon was attributed to preferential diffusion of H₂ and H₂O toward the reactants followed by convective transport of the hydrogen-species enriched fluid downstream and beyond the recirculation zone, leaving elevated levels of CO₂ and the C/H and C/O atom ratios within the recirculation zone.

The present work continues the investigation of this preferential transport phenomenon by considering lean premixed methane flames, with varying levels of H₂ addition, stabilized on the same bluff body burner as in the previous study. Results show similar effects of preferential transport as in the methane flames, with the measured equivalence ratio within the recirculation zone higher than in the reactant stream. However, with increasing levels of H₂ addition in the fuel, H₂ diffuses from reactants toward products rather than the other way around. For the highest level of H₂ addition (40 percent mole fraction) the C/H atom ratio in the products decreases relative to that in the reactants, while the C/O atom ratio still increases. This indicates that there is still preferential transport of H₂O into the rapidly flowing reactant stream, causing a net loss of oxygen from products in the recirculation zone. However, differential diffusion of H₂ from the reactant stream into the flame more than compensates for this effect on the C/H atom balance.

Keywords: Premixed flames; preferential diffusion; preferential transport; bluff-body flames; hydrogen addition

1. Introduction

It is well documented in the combustion literature that differential diffusion of species and heat can have significant effects on the structure and propagation speed of turbulent premixed flames [1]. This is particularly true for lean premixed hydrogen-air flames where the Lewis number, Le , defined as the ratio of the thermal diffusivity of the mixture to the mass diffusivity of the deficient reactant, is much less than unity. Effects of low Lewis number on global flame topology and propagation speed have been shown to extend to high turbulence levels in both experimental and computational studies [1-8], including experimental work at turbulence intensities, u'/S_{LO} , up to 100 [8]. This challenges a common assumption that molecular transport effects should become unimportant with increasing turbulence intensity.

The concept of leading points [9], which has been reviewed by Lipatnikov & Chomiak [1], provides a simple physical picture that can help to explain the observed importance of molecular transport in highly turbulent premixed flames, as well as provide a framework for physically-based models [1,7,8], which have had good success in correlating flame speed measurements over a wide range of conditions. The argument begins with the assumption that turbulent flame propagation is controlled by the flame surface elements that extend farthest into the reactants and that properties of the rest of the flame brush are unimportant with respect to flame speed. These leading points are characterized by positive curvature and hence enhanced burning rate for low Lewis number mixtures. In these flamelet based modeling concepts it is still assumed that differential diffusion effects are local and do not alter the mean temperature and composition of combustion products behind the turbulent flame brush.

It has been shown recently that differential diffusion of species alone can lead to significant global changes in the scalar structure and burnt gas composition of turbulent premixed CH_4 /air flames ($Le \approx 1$) stabilized in the shear flow adjacent to a bluff-body recirculation zone [10,11]. Briefly, measurements of major species in the near field of bluff-body stabilized flames, using line-imaged Raman/Rayleigh/LIF diagnostics, revealed significant increases in the measured equivalence ratio and the C/H and C/O atom ratios, going from reactants to products along a radial profile. This phenomenon was attributed to a combination of preferential diffusion of H_2 and H_2O toward the reactants followed by convective transport of the resulting hydrogen-species enriched fluid downstream and beyond

the recirculation zone, leaving elevated levels of CO_2 within the recirculation zone. The magnitude of the effect was observed to increase with increasing reactant flow velocity until a limiting condition appeared to be reached [11]. In these limiting cases the bulk reactant velocity was as high as 50 times the laminar flame speed. A key consideration is that the flame is stabilized in a region of strong mean shear, such that there is a significant change in the component of velocity tangent to the flame across the thickness of the flame. The observation of a limiting condition, with significantly altered atom balances, at high reactant velocity again challenges the common assumption that molecular diffusion effects should become less important as the level of turbulence increases, and this result suggests that preferential diffusion effects in bluff-body-stabilized flames may extend to the high Reynolds number regime of practical combustors.

It was reported in [10] that a pilot stabilized annular flame did not show measureable effects of preferential transport on internal flame structure or product composition, and the authors concluded that the effect must be amplified (or accumulated over a long residence time) by a recirculation zone in order to reach an observable level. Similarly, measurable effects of preferential transport on atom balances were not observed in strongly swirling bluff body flames that had a large, open, conical recirculation zone [12], so it appears that a compact, enclosed recirculation zone is needed in addition to strong shear across the flame brush in order to produce large changes in atom balances going across the flame.

Simulations by Katta & Roquemore [13] of a laminar premixed flame with the same bluff body geometry showed similar effects of preferential transport on the C/H atom balance, with the greatest effect on C/H ratio occurring in the low-velocity products adjacent to the high-shear region near the corner of the bluff body. Nambully et al [14,15] have developed a LES subgrid model for differential diffusion of mixture fraction, and simulations match well the measured increase of equivalence ratio within the recirculation zone of premixed and stratified methane-air bluff-body flames reported by Sweeney et al. [16]. Further development and validation of such models may be important for accurate prediction of this class of turbulent flames.

It is common in practical combustion systems to stabilize flames by establishing recirculation zones of hot combustion products, using bluff bodies, swirling flows, or a combination of the two. Therefore, it is important from both fundamental and practical

perspectives to better understand this preferential transport phenomenon and the parameters that control it. Fuel composition is one such parameter. In the present study we consider the effects of hydrogen addition to the methane fuel, using the same annular bluff body burner as in [10,11]. Hydrogen addition is of interest from a fundamental perspective because it alters the boundary conditions for differential species diffusion. In lean premixed methane flames (and other hydrocarbon flames) H_2 is produced as an intermediate within the reaction zone, and it diffuses in both directions, toward reactants and toward products. In the bluff-body methane flames of [10,11,13] H_2 diffuses preferentially toward reactants and is then convected downstream. With H_2 already present in the premixed reactant stream it is possible for the net transport of H_2 to be toward the products rather than the other way around. Hydrogen addition is also of interest in the context of a variety of fuel blends that have been considered for power generation, including syngas, bio-derived gas, and hydrogen-augmented methane or natural gas [8,17-21]. Here we report a parametric study on the effects of hydrogen addition on the scalar structure of lean methane-air flames stabilized on an annular bluff body burner.

2. Experimental Methods

The burner shown in Fig. 1 is the same as used in the parametric study of premixed methane flames [11]. It has a 12.7 mm diameter stainless steel centerbody and an annular gap of 5.0 mm. A perforated plate was mounted in the annular passage 35 mm upstream of the exit plane to promote symmetry and to act as a turbulence generator for the higher velocity flows. In order to document the effects of hydrogen addition on the scalar structure, four series of flames were measured, with the hydrogen mole fraction in the fuel being varied — $X_{H_2}/(X_{CH_4} + X_{H_2}) = 0.0, 0.1, 0.2, 0.4$ — while holding a constant equivalence ratio of $\phi = 0.77$. Each flame series covered a range in reactant flow rate, starting from a laminar condition and increasing to turbulent values. The bulk velocity, U_b , ratio of bulk velocity to laminar flame speed, U_b/S_L , and Reynolds number based on hydraulic diameter and cold flow properties, Re_{Dh} , are listed in Table 1 for each flame series. Note that the entries in Table 1 correspond to the plotted lines in figures, which were selected for visual clarity. In most cases the measurements included higher velocities than are listed in Table 1, but those results are not presented because the higher velocities did not produce significant further changes in scalar

structure. The case with 0% H₂ was reported previously in [11] and is included here to facilitate comparisons. Laminar flame speeds for CH₄/H₂/air mixtures are from [22]. All measurements were performed 10 mm above the burner exit with the laser probe oriented in the radial direction and centered on the flame brush for each flow condition. This height corresponds roughly to the middle of the recirculation zone for high velocity flows, based on velocity measurements [16,23] in similar bluff-body-stabilized flames.

The facility for multiscalar measurements [16, 24] combined line imaging of spontaneous Raman scattering, Rayleigh scattering, and two-photon LIF of CO to obtain single-shot profiles of temperature and the mass fractions of major species (CO₂, O₂, CO, N₂, CH₄, H₂O, and H₂) along a 6-mm segment. The beams from four frequency-doubled Nd:YAG lasers were used for Raman and Rayleigh line imaging (~1.8 J/pulse; ~0.22 mm diameter, 1/e²). CO was excited at 230.1 nm, with the UV laser beam aligned on the same axis as the Nd:YAG laser beams.

Three CCD cameras for line-imaged Raman/Rayleigh/CO-LIF were mounted onto a single detection unit. A pair of 150-mm diameter achromats imaged a portion of the laser beam into this detection unit. The projected spacing of binned superpixels along the laser axis was 0.103 mm, 0.020 mm, and 0.101 mm, for the Raman, Rayleigh, and CO-LIF measurements, respectively. The optical resolution of 0.04-0.06 mm across most of the detection region was limited primarily by the pair of achromatic lenses at the front end of the collection system. Data processing was performed using methods described in [25]. Calibrations were based on cold flows and flat CH₄/air flames.

The accuracy and precision of the diagnostic system was documented in [10,11] by comparing measurements in laminar premixed methane-air flames with calculated results for freely propagating flames, using Chemkin with GRI Mech 3.0 and multi-component transport with the Soret effect included. Similarly, in the present study, laminar flame measurements are compared with Chemkin calculations for a case with equivalence ratio $\phi = 0.63$ and 20% added hydrogen. This laminar flame was a rod-stabilized V-flame, with the burner tilted to align one side of the V-flame to be nearly vertical and normal to the laser beam, as described in [10]. The equivalence ratio from the experiments and from Chemkin was calculated from the fuel/oxygen atom balance, using only the measured species (CH₄, O₂, CO₂, H₂O, CO, and H₂), according to the formula:

$$\phi = \frac{[(X_{H_2} + X_{H_2O})/2] + X_{CO_2} + X_{CO} + 2X_{CH_4}}{X_{O_2} + 2X_{CO_2} + [(X_{H_2O} + X_{CO})/2]} \quad (1)$$

where X_i are the mole fractions of the measured major species. Atom ratios were also calculated from the same seven species.

Figure 2 shows good agreement between measured and calculated species mass fractions. The measured H_2 mass fraction is slightly high for temperatures above 1500 K, but corresponding mole fractions are very low and this bias error results from imperfect corrections for background luminosity, light scatter within the Raman spectrograph, and temperature dependent crosstalk from H_2O , which is not accounted for in the theoretical Raman spectral libraries. Conditional mean values of equivalence ratio and the C/H and C/O atom ratios are also slightly high for temperatures above 1000 K. However, these differences are small compared to the effects of preferential transport in the bluff body flames, and they do not influence the main results or conclusions of this study. Uncertainties at representative conditions, based on the standard deviations (precision) and estimated accuracy of averaged measurements, are tabulated in [10] and are not duplicated here.

3. Results and Discussion

We examine the effects on scalar structure of varying the level of H_2 addition at a constant equivalence ratio by comparing results from the four flame series listed in Table 1, with $\phi = 0.77$ and hydrogen levels of 0, 10, 20 and 40 percent in the fuel. Results are presented in Figs. 3-6, respectively. Conditional mean mass fractions of CH_4 , O_2 , CO_2 , H_2O , CO , and H_2 , along with equivalence ratio and the C/H and C/O atom ratios calculated from measured species mole fractions, are plotted versus temperature. Each plot includes corresponding results from freely propagating laminar flame calculations, using Chemkin with GRI Mech 3.0, multi-component transport, and the Soret effect included. Results in Fig. 3 for the flame series with no hydrogen addition were also reported in [11] and are included here to facilitate a brief review of the effects and physical mechanisms of preferential transport in premixed, bluff-body-stabilized methane flames, as well as to serve as the baseline for understanding the effects of hydrogen addition.

In the 0% H₂ series (Fig. 3) the lowest velocity flame has scalar structure close to that of the Chemkin laminar flame calculation. As with the laminar V-flame results in Fig. 2, there is an apparent bias in the measurements of equivalence ratio, C/H-atom ratio, and C/O-atom ratio in the lowest velocity flame, which is expected to have scalar structure close to that of a freely propagating one-dimensional flame. This bias is relatively small compared to the overall changes in these scalar quantities through the flame series, and it does not influence conclusions regarding effects of preferential transport on scalar structure.

The ratio of reactant bulk velocity to laminar flame speed, U_b/S_L , increases by a factor of 10 in this flame series from 5.2 to 52. At the lowest velocities the flame stabilizes at the edge of the bluff body and burns in a cone, analogous to a V-flame, so that there is a buffer of products between the flame and the recirculation zone at the 10 mm measurement location above the bluff body surface. With increasing U_b/S_L the flame angle becomes more vertical, such that the composition within the recirculation zone becomes closely coupled with the convection, reaction, and diffusion processes of the three dimensional flame. Concurrently, the measured values of equivalence ratio, C/H atom ratio, and C/O atom ratio increase progressively in the products and throughout the flame structure. As discussed in [10,11] these results indicate that H₂ and H₂O are preferentially transported through the preheat zone toward the reactant stream and are then carried downstream by the sheared flow, leaving an elevated mass fraction of CO₂ within the recirculation zone and across the whole flame profile. Also, as discussed in [11], these effects of preferential transport on conditional scalar profiles appear to saturate, such that the curves corresponding to the highest velocities, $U_b/S_L = 41$ and 52 m/s, fall on top of each other. In Fig. 3 the curves for Y_{CO2} move up with increasing U_b/S_L , while the curves for Y_{O2} move down. Y_{H2O} shows no significant change through this series of flames. Both Y_{CO} and Y_{H2} decrease with increasing U_b/S_L in spite of the increase in equivalence ratio, and these trends may be associated with progressively increasing strain.

Now consider corresponding plots in Figs. 3-6 and compare trends in each measured scalar as the level of H₂ addition is increased. In all four of these flame series the measured equivalence ratio increases going from reactants to products as U_b/S_L increases. The C/O ratio also increases in the products with increasing U_b/S_L in each flame series, and Y_{O2} decreases. Considering Y_{CO2}, the significant increase observed in the 0% H₂ flame (Fig. 3) is

progressively moderated with increasing H_2 addition, such that there little change in Y_{CO_2} within the 40% H_2 series (Fig. 6). Conversely, while Y_{H_2O} is insensitive to U_b/S_L in the 0% H_2 series, it becomes increasingly affected as the level of H_2 addition to the fuel increases. In the 40% H_2 series Y_{H_2O} at the highest temperatures increases by nearly 20% as U_b/S_L increased from 6.6 to 27 m/s. Y_{CO} decreases significantly with increasing U_b/S_L in the 0% H_2 series but becomes less affected as more hydrogen is added, and Y_{CO} becomes insensitive to U_b/S_L in the 40% H_2 series.

Whereas Y_{H_2} decreases with increasing U_b/S_L in the 0% H_2 flames, the effect is much reduced in the 10% H_2 series (Fig. 4), and Y_{H_2} increases with increasing U_b/S_L in the 20% and 40% H_2 series. Note also that the initial trajectory of Y_{H_2} with increasing temperature is vertically upward in the 0% H_2 flames but downward in all three flames with H_2 addition. The net effect of these changes in conditional mass fractions of H_2O , CO_2 , CO , and H_2 is displayed in the C/H atom ratio, which increases significantly with U_b/S_L in the 0% H_2 series, less so in the 10% H_2 series, is nearly independent of reactant velocity in the 20% H_2 series, and decreases with increasing U_b/S_L in the 40% H_2 series.

These trends are interpreted as follows. In the premixed CH_4 flame with no added hydrogen, H_2 is formed in the reaction zone and diffuses preferentially toward reactants. With increasing H_2 addition to the fuel stream the diffusive flux of H_2 is reversed, such that H_2 preferentially diffuses into the flame, as revealed by the initially negative trajectories in the curves of Y_{H_2} vs. temperature in Figs.4-6. The C/O atom ratio increases with increasing U_b/S_L , so there is still preferential transport of H_2O toward the reactants and then downstream beyond the recirculation zone, causing a net loss of oxygen from the products in the recirculation zone. In the 10% H_2 series the C/H ratio still increases with increasing U_b/S_L , demonstrating that the diffusion of H_2 from reactants into the flame is not sufficient to compensate for the loss of hydrogen due to preferential transport of H_2O into the sheared reactant flow. In the 20% H_2 flames the loss of H_2O is roughly balanced by the gain of H_2 , so the C/H ratio is nearly independent of reactant velocity and follows a curve similar to that of the laminar V-flame measurement in Fig. 2. In the 40% H_2 series, transport of H_2 from the reactant stream into the flame more than compensates for the loss of H_2O by preferential transport ahead of CO_2 and CO , causing the C/H ratio to decrease with increasing U_b/S_L .

Insight regarding the physical mechanisms at play and the influence of hydrogen addition on preferential transport effects in these bluff body stabilized flames may be gained from consideration of laminar flame calculations. Figure 7 shows spatial profiles of selected scalars from Chemkin calculations of freely propagating methane flames with 0, 10, 20, and 40% hydrogen addition. The origin for the spatial coordinate is the location of maximum heat release in each flame. Key observations are as follows. First, the profile of H_2O mole fraction leads those of CO and CO_2 by 0.2 mm to 0.25 mm. Second, as a consequence of this spatial separation of these species profiles, the mole fraction ratio, $X_{\text{H}_2\text{O}}/(X_{\text{CO}_2} + X_{\text{CO}})$, increases rapidly, starting near the location of maximum heat release in each flame and moving toward the reactants. Third, rapid diffusion of H_2 relative to the other scalars creates gradients in H_2 mole fraction that extend well into the reactant flow. As mentioned already in the context of the Figs. 3-6, these gradients are such that H_2 diffuses preferentially out of the flame and into reactants in the methane flame with no H_2 addition. However, with all of the levels of H_2 addition considered here there is diffusive transport of H_2 from reactants into the preheat zone of each flame, such that the X_{H_2} decreases significantly before the temperature begins to increase.

Figure 8 shows the spatial profiles of relative net production rates of H_2O and CO_2 calculated for the laminar flame with no hydrogen addition. The peak in H_2O production occurs at the location of maximum heat release (origin of the spatial scale), while production of CO_2 is shifted toward higher temperatures on the product side of the flame. This offset between the production regions of H_2O and CO_2 contributes significantly to the offset between mole fraction curves in Fig. 7 and the behavior of the mole fraction ratio $X_{\text{H}_2\text{O}}/(X_{\text{CO}_2} + X_{\text{CO}})$ through the preheat zone. The fact that the C/H ratio increases in the flame series with 10% H_2 addition indicates that production and transport of H_2O is of primary importance in the pure methane flame.

In the bluff body flames with reactant velocity much higher than the laminar flame speed, the flame is stabilized in a region of high shear, such that fluid in the outer part of the preheat zone is rapidly carried downstream, removing water preferentially from the local species balance until the measured steady state condition is reached. The present measurements are limited to relatively low Reynolds number. However, for two reasons we speculate that the effects of preferential species transport observed in the present experiments will also be

present in bluff body flames at high Reynolds number and possibly in other combustion geometries where flames are stabilized in regions of high shear. First, as previously reported in [11] and again observed in methane flames with hydrogen addition, the measured effects of preferential transport increase with increasing velocity and appear to reach a saturation condition instead of becoming less important as turbulence levels increase. Second, because production of H_2O extends to lower temperatures than production of CO_2 (Fig. 8) one can expect the physical mechanism of preferential convective transport to be qualitatively similar in flame regimes where there is significant turbulence within the preheat zone.

4. Conclusions

Measurements of temperature and major species have been obtained in lean premixed, bluff body stabilized flames of methane with varying levels of H_2 addition in order to further study effects of preferential species transport on scalar structure in this important class of flames. Four series of flames were investigated, having 0, 10, 20, and 40% hydrogen addition, all with equivalence ratio $\phi = 0.77$. Measurements were obtained at a distance of 10 mm above the bluff body surface, corresponding roughly to the middle of the recirculation zone. In each flame series, the measured equivalence ratio and C/O atom ratio in the products within the recirculation zone increased with increasing reactant flow velocity. This was attributed to preferential transport of H_2O toward the reactants and then downstream beyond the recirculation zone. An important consideration in this context is the fact that H_2O production is shifted toward lower temperature relative to CO_2 production, based on laminar flame calculations. This facilitates the loss of H_2O by convective transport. This effect of preferential species transport becomes more significant as the ratio of reactant flow velocity to laminar flame speed, U_b/S_L , increases because the flame becomes more vertical and more closely coupled with the composition of the recirculation zone. The C/H ratio in the 0% H_2 flame series also increased with increasing reactant velocity. However, as the level of H_2 addition was increased, the trend in C/H ratio was moderated and then reversed, as diffusion of H_2 from the reactant stream into the flame progressively compensated for the loss of H_2O . These observations have potential significance for modeling of laminar and turbulent flames of hydrogen enriched fuels that are stabilized in shear flows adjacent to compact, enclosed recirculation zones.

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Figure captions

Figure 1. Premixed bluff body burner photo and illustration.

Figure 2. Comparison of measured (solid blue line, error bars) and calculated (dashed red line) results for species mass fractions, equivalence ratio, and selected atom ratios plotted vs. temperature in a laminar premixed $\text{CH}_4/\text{H}_2/\text{air}$ flame (20% H_2 addition) at $\phi = 0.63$. The error bars around the conditional mean curves represent conditional fluctuations ($\pm\sigma$).

Figure 3. Measured conditional mean scalars in the bluff body flame series with $\phi = 0.77$, 0% H_2 for $U_b/S_L = 5.2, 10, 15, 21, 26, 31, 41, 52$. Arrows indicate increasing U_b/S_L . Chemkin laminar unstrained flame (dashed red line).

Figure 4. Measured conditional mean scalars in the bluff body flame series with $\phi = 0.77$, 10% H_2 for $U_b/S_L = 7.9, 12, 16, 20, 24$. Arrows indicate increasing U_b/S_L . Chemkin laminar unstrained flame (dashed red line).

Figure 5. Measured conditional mean scalars in the bluff body flame series with $\phi = 0.77$, 20% H_2 for $U_b/S_L = 5.9, 12, 18, 24, 30, 36$. Arrows indicate increasing U_b/S_L . Chemkin laminar unstrained flame (dashed red line).

Figure 6. Measured conditional mean scalars in the bluff body flame series with $\phi = 0.77$, 40% H_2 for $U_b/S_L = 6.6, 13, 20, 27$. Arrows indicate increasing U_b/S_L . Chemkin laminar unstrained flame (dashed red line).

Figure 7. Spatial profiles of mole fractions of H_2 , H_2O , CO_2 , and CO (left column) and their mole fraction ratios (right column) for freely propagating one-dimensional flames with 0, 10, 20, and 40% H_2 addition, calculated using Chemkin with GRI Mech 3.0, multi-component transport, and the Soret effect. The spatial origin is the location of maximum heat release. Temperature is also plotted in each frame.

Figure 8. Spatial profiles of the relative net production rates of H_2O and CO_2 for the freely propagating laminar methane flame with no hydrogen addition. The spatial origin is the location of maximum heat release.

Table 1. Bluff body flame conditions: measured equivalence ratio; percent H_2 in the fuel; bulk velocity in m/s, U_b ; ratio of bulk velocity to laminar flame speed, U_b/S_L [22]; and Reynolds number based on hydraulic diameter of the annular premixed flow.

$\phi = 0.77; 0\% \text{ H}_2,$ $S_L = 0.25 \text{ m/s}$			$\phi = 0.77; 10\% \text{ H}_2,$ $S_L = 0.33 \text{ m/s}$			$\phi = 0.77; 20\% \text{ H}_2,$ $S_L = 0.44 \text{ m/s}$			$\phi = 0.77; 40\% \text{ H}_2,$ $S_L = 0.60 \text{ m/s}$		
U_b	U_b/S_L	Re_{Dh}	U_b	U_b/S_L	Re_{Dh}	U_b	U_b/S_L	Re_{Dh}	U_b	U_b/S_L	Re_{Dh}
1.29	5.2	840	2.60	7.9	1690	2.61	5.9	1700	4.0	6.6	2600
2.58	10	1680	3.9	12	2530	5.2	12	3400	8.0	13	5200
3.9	15	2520	5.2	16	3380	7.8	18	5100	12.0	20	7790
5.2	21	3360	6.5	20	4220	10.4	24	6800	15.9	27	10400
6.4	26	4200	7.8	24	5070	13.0	30	8500			
7.7	31	5040				15.7	36	10200			
9.0	36	5880									
10.3	41	6720									
12.9	52	8400									

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