

**POSSIBILITIES FOR ADMIXING GASIFICATION GASES: COMBUSTION
ASPECTS IN DOMESTIC NATURAL GAS APPLIANCES IN THE
NETHERLANDS**

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1. ABSTRACT

Arising from the desire to increase the proportion of sustainable fuels in the energy infrastructure, there is an increasing interest to introduce gases produced from biomass or coal gasification into the natural gas infrastructure. These gases mainly consist of carbon monoxide CO and hydrogen H₂, but may have been converted to synthetic natural gas SNG. Hydrogen-containing gases, with or without CO, increase the burning velocity in gas/air mixtures, possibly causing light-back and overheating of the burnerdeck. In this study adequate analytical methods for comparing the combustion performance of gases (interchangeability methods) are developed and applied as an alternative for large-scale testing of domestic appliances. Fundamental combustion properties of gases are calculated and compared while incorporating the changes that occur in the appliance primary air ratio when just changing gas quality. In this way the resulting gas interchangeability limitations are founded on the physics and chemistry of gas utilization, and not on the performance of individual appliances.

In this study, limits of acceptability are derived for mixtures of a number of these gases from gasified solid fuels with natural gas compositions. The conditions were constrained such that all mixtures must be within the existing Dutch Wobbe distribution band {43,46 – 44,41 MJ/m³(n) (25 °C, 0 °C)}, and that there be no increase in the chances of light-back and burner overheating as compared to the "traditional" natural gases.

In determining the light-back limitgas for the interchangeability analysis for this narrow-band situation the starting point has been that the installed appliance conditions are generally unknown. A reasonable assumption is that the installed appliance population can accept the range of gases currently being distributed. Within this range the lowest Wobbe number represents the highest light-back propensity, in other words the limit of acceptability in this respect. For burners for hot-water heaters, bar burners for central heating boilers and radiant surface burners overheating of the burner is a relevant issue. With respect to this combustion aspect the maximum acceptable burnerdeck temperature increase is assumed to be equal to the maximum increase when changing from a natural gas at the upper Wobbe limit to a natural gas at the lower Wobbe limit. In the interchangeability context of the present study this maximum 50K increase is taken as the limit of acceptability with respect to burner overheating, considering a burnerdeck material with an emission coefficient $\varepsilon = 0.7$.

Higher CO content increases the burnerdeck temperature, often to an overheating status. Materials with lower values of the emission coefficient yield higher burnerdeck temperatures.

Except for the SNG's the maximum new gas contents in mixtures with upper Wobbe limit natural gas are limited. Note that mixing with a natural gas with a Wobbe index < 44.41 MJ/m³(n) will yield still smaller values for the maximum new gas contents. In spite of that still considerable flows of gasification gases might be allowed, depending on the natural gas flow at the mixing point. With lower Wobbe limit natural gas possibilities for non-methanized gasification gases would be absent because of the Wobbe limitation. Possibilities for introducing gasification gases in this narrow distribution band probably can be maximized by methanization to SNG's with a Wobbe index within the distribution band.

It should be stressed that the methods used here can be extended and applied in a straightforward way to any natural gas distribution situation.

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2. INTRODUCTION

There is increased pressure to limit fossil fuel utilization because of concerns regarding greenhouse emissions. Given its intrinsic advantages natural gas is the ideal transition fuel for bridging the gap to sustainability and balancing the increasing demand for energy. For instance, gas-fired power generation can quickly respond to a sudden reversion of wind or solar power. In another way, the natural gas infrastructure can be used to facilitate the introduction of sustainable energy by transporting and distributing sustainable "biogases", the supply of which is increasing. In this fashion the same high-efficiency technology developed for natural gas can be utilized using biofuels. But these new gases do show non-traditional component concentrations as compared to natural gases, which poses a significant challenge to the natural gas industry. The efficiency, safety and fitness-for-purpose of the end-use equipment may not noticeably deteriorate when supplied with biogases: an increase in the tendency for blow-off, light-back, incomplete combustion, soot formation, burner overheating and engine knock is clearly unacceptable. The combustion behavior of biogases (CH_4/CO_2 fermentation mixtures or CO/H_2 mixtures from thermal gasification) is substantially different from that of natural gas, and these "new" gases cannot be added to natural gas in arbitrary quantities without leading to unacceptable behavior in end-use equipment. The acceptable limits for these mixtures in the installed population of gas-utilization equipment are in general unknown, as sufficiently detailed insight in equipment conditions (construction, installation, maintenance) for the overall population is lacking.

In this paper the introduction of gasification gases in the Dutch natural gas system is considered. More specifically, the consequences for domestic appliances are studied. Thermal gasification becoming mature, the supply of gasification gases is expected to increase, where biomass is gasified in itself or added to a coal gasification process. These gases mainly consist of carbon monoxide CO and hydrogen H_2 , but may have been converted to synthetic natural gas (SNG: predominantly methane, with significant fractions of hydrogen, nitrogen, and carbon dioxide). Hydrogen-containing gases, with or without CO , increase the burning velocity in gas/air mixtures, possibly causing the flame to propagate upstream into the burner ("light-back") which in turn might result in damage to the appliance and/or extinction of the flame releasing a flammable mixture. An increased burning velocity also can cause overheating of the burnerdeck. This overheating can cause damage to the deck possibly resulting in lower appliance efficiency, incomplete combustion and release of flammable gas/air mixture, as well as in a shorter life span of the appliance.

To guarantee the end-user not to be faced with unacceptable consequences of the introduction of the new gases in the natural gas system, in principle every domestic appliance should be checked, meaning a very costly and time-consuming operation. In similar cases usually an interchangeability analysis is applied, comparing the new *gases with gases* that are stated to guarantee the safety concerning the overall appliance population. In this study KEMA-developed analytical interchangeability methods are applied. Fundamental combustion properties of gases are calculated and compared while incorporating the changes that occur in the general operation of domestic appliances when just changing gas quality, specifically changes in primary air ratio. In this way the resulting gas interchangeability limitations are founded on the physics and chemistry of gas utilization, and not on the performance of individual appliances. In this study, limits of acceptability are derived for mixtures of a number of these gases from gasified solid fuels with natural gas compositions, when specifically considering domestic appliances in the Dutch market as an example. The conditions in the study were constrained such that all mixtures must be within the existing Dutch Wobbe distribution band $\{43,46 - 44,41 \text{ MJ/m}^3(\text{n}) (25^\circ\text{C}, 0^\circ\text{C})\}$, and that there be no increase in the chances of light-back and burner overheating as compared to the "traditional" natural gases. Note that these limits of acceptability are purely to be understood here in the context of the interchangeability considerations.

It should be stressed that the methods used here can be extended and applied to any natural gas distribution situation. For example, as a part of the EDGaR program (see Acknowledgements) a different Dutch distribution situation is under study with an extended Wobbe range.

3. NEW GAS COMPOSITION: CHANCE OF LIGHT-BACK

As in this work the impact of added H_2/CO mixtures is assessed on the performance characteristics of installed natural gas appliances, it is basic to consider the question of what is meant by "natural gas" in this context. From the international standard ISO 13686 (1) it follows that in a dry natural gas the concentrations of H_2 and CO are $< 0.1\%$ (weight/weight basis). The presumption here is that the amounts of CO and H_2 in the natural gas under consideration are negligible.

The laminar burning velocity (S_L) of H_2 at stoichiometric conditions is 5.6 times that of methane. To a good approximation the flow of gas/air mixtures from burner ports in domestic appliances can be considered to be laminar. Considering these facts, light-back is a relevant issue in the present context. As is well known S_L not only depends on the fuel composition but also very much on the (primary) gas/air equivalence ratio ϕ , defined as the actual gas/air ratio divided by the stoichiometric gas/air ratio.

A well-known aspect of appliance behavior is that at a given pressure drop across a fuel nozzle, the air flow is constant, regardless of the gas composition (2). This is true for both naturally aspirated appliances and for fan-assisted appliances (3). For these conditions it was shown that for natural gases to a good approximation $\phi_2/\phi_1 = W_2/W_1$ upon changing from gas 1 to gas 2: changes in Wobbe index lead directly to changes in equivalence ratio (4), often called the " ϕ -shift". With "new" components being present another ϕ -shift formula might become necessary, as was shown for H_2 (5).

As compared to natural gases H_2 shows large differences in combustion properties (3). Its gross calorific value is about three times less. Its relative density is about eight times less as compared to methane. Upon H_2 addition the gross calorific value (numerator of the Wobbe index) as well as the relative density (square of the Wobbe index denominator) decrease as already mentioned. Up to about 70% admixture, the decrease of the calorific value prevails, causing the mixture Wobbe index to decrease. The gross calorific value of CO is very similar to that of H_2 . However, the relative density of CO is 2.2 times that of CH_4 and 17.6 times that of H_2 . As a result of these facts adding CO to natural gas causes a considerably steeper decline of the Wobbe index as compared to the H_2 addition. In any case, admixing CO/H_2 mixtures to natural gas causes the Wobbe index to decrease, and therefore a ϕ -shift towards a lower value. As a consequence, for fuel-lean appliances ($\phi \leq 1$), like many modern central heating boilers, S_L will decrease, or remain about constant when the influence of H_2 prevails. In the latter case the ϕ -shift effect compensates the S_L increasing effect of H_2 itself (3). Thus, for fuel-lean appliances the chance of light-back is not expected to increase by the addition of CO/H_2 mixtures; therefore these appliances are further left out of consideration. On the other hand, for fuel-rich appliances ($\phi > 1$), like cooking burners, hot-water heaters and fuel-rich central heating boilers, S_L will increase as now the ϕ -shift effect will even amplify the S_L increasing effect of H_2 itself (3). The paper therefore focuses on just this kind of appliances.

Burning velocities are computed using the PREMIX code from the CHEMKIN suite (6). The GRI-Mech 3.0 (7) chemical mechanism is used, since burning velocities are used as targets in the optimization method, and the uncertainties in its performance are known. Because of the presence of H_2 the Soret effect (thermal diffusion) is taken into account.

The burning velocities for individual gases, accounting for ϕ -shifts, are compared to a "limit" gas to assess whether a given new gas is interchangeable with the gases traditionally distributed, without appliance adjustments being necessary. Thus the choice of the light-back limitgas is essential for the outcomes; it is only partially a technical issue, and will often depend on the local history of gas distribution (8, 9). The results of these analyses concern the overall domestic appliance population, and do not mean anything considering the limitations of a specific appliance. The light-back propensity of an individual appliance depends on the detailed appliance (burner) conditions (construction, installation, maintenance). These conditions for all appliances in the overall Dutch population are unknown. Once having chosen the limitgas the only result that counts is whether for a new gas the burning velocity exceeds that of the limitgas, or not.

Domestic appliances installed in The Netherlands need to have a CE-marking according to the legal framework of the European Union (Gas Appliances Directive, GAD) (10). Within this framework groups of gases have been defined with concomitant reference gases and limit testgases (10, 11) to be used in typetesting new types of appliances. The limit testgases are meant to be representative for extreme variations in the characteristics (light-back for example) of the gases for which the appliance is designed. In this work the GAD "limit testgases" are expressly distinguished from the "limitgases" as considered in the interchangeability analyses.

Fuel-rich premixed domestic appliances in this study are assumed to be adjusted with the EN437 L-band reference gas G25 (86 vol% CH₄ , 14 vol% N₂) (11) at $\phi = 1.2$. According to EN437, G25 is also defined as the limit testgas for light-back for the L-band. Given the fact that an EN437 limit testgas is meant to guarantee a sufficient safety margin at "normal use", as a function of the combustion aspect under consideration (light-back in this case) it should be outside the gas quality range normally distributed. Therefore, it is remarkable that considering light-back propensity G25 is situated well within the Dutch distribution band, obviously implying a reconsideration of the EN437 limit testgas for light-back.

Now the light-back limitgas has to be determined as a basis for the interchangeability analyses. As the appliance conditions are generally unknown the only reasonable assumption is that the appliance population can accept the range of gases currently being distributed: Wobbe band 43,46 – 44,41 MJ/m³(n) (3). Within this range, considering light-back in fuel-rich premixed flames, the lowest Wobbe number causes a ϕ -value closest to stoichiometric, implying the highest burning velocity and therefore the highest light-back propensity, in other words the limit of acceptability in this respect. The composition "LOW" was taken as the light-back limitgas: 0.9 mol% CO₂, 81.0 mol% CH₄, 3.4 mol% higher C_xH_y and 14.7 mol% N₂.

4. NEW GAS COMPOSITION: CHANCE OF BURNER OVERHEATING

Burners with Bunsen-like flames, for instance cooking burners, are more prone to light-back as compared to overheating. Some degree of burner heating can occur in this case implying some degree of preheating of the premixed gas/air mixture. Under (un)favorable conditions light-back might result. Overheating however is deemed possible only in extreme situations for this type of burner.

Burners for hot-water heaters and bar burners for central heating boilers, for example, have patterns of holes and slots designed to prevent light-back. On this kind of burner flames often burn close to the surface and discoloration of the surface can be observed. For such burners as well as for radiant surface burners, burner overheating is a relevant issue.

Considering burner overheating implies the calculation of burnerdeck temperatures. We performed these calculations based on the work of Sepman et al (12), applicable to situations with flames close to the burnerdeck where a 1-D (one-dimensional) approximation holds. Starting from enthalpy conservation in the flame-burner system and considering the radiation from the burner as the only heat-loss process, the following equation can be derived (12):

$$\rho_0 v (I(300K) - I(T_f)) = \varepsilon \sigma T_b^4 \quad (1)$$

where ρ_0 is the density (kg/m³) and v the linear velocity of the (cold) mixture (m/s), $I(300 K)$ is the specific enthalpy of the cold mixture (J/g), $I(T_f)$ is the specific enthalpy of the hot combustion gases at flame temperature T_f (K) (J/g), ε is the emission coefficient, σ is the Stefan-Boltzmann constant (Wm⁻²K⁻⁴) and T_b is the temperature of the burnerdeck (K). The temperature of the surroundings is assumed to be low enough to be neglected in this equation. The equation was experimentally confirmed (12). Thus the burner radiates (right-hand side) the heat lost from the flame (left-hand side). In the case of a free flame ($S_L < v$) no heat is transferred to the burner. For increasing S_L relative to v the flame will stabilize closer to the burner, heat will be transferred to the burner and the flame temperature will decrease (a well-known NO_x reduction strategy). Simultaneously the burner temperature T_b will increase. Upon admixing H₂/CO

mixtures to natural gas for fuel-lean appliances ($\varphi \leq 1$) S_L will decrease, or remain about constant when the influence of H_2 prevails as already noted in the previous section. For fuel-lean appliances the chance of burner overheating is therefore not expected to increase by the addition of CO/H_2 mixtures and these appliances are further left out of consideration in this respect.

In order to calculate T_b at first the flame temperature T_f is determined by simulating the flame (CHEMKIN) for a relevant value of the massflux $\rho_0 v$. Then the flame heat-loss (left-hand side of equation (1)) can be calculated. Next a value of the emission coefficient ε is needed, which depends on the burnerdeck material. To limit the amount of calculations, ε is varied from 0.95 (experimental low- NO_x burner) to 0.02 (polished silver). For practical purposes specific results for $\varepsilon = 0.7$ (ceramic burnerdeck) will be shown.

For individual appliances the burner overheating propensity is determined by the burner conditions (construction, installation, maintenance). One would have to assess this combustion aspect for every single burner, a very expensive and time-consuming exercise. In this work an interchangeability analysis is applied instead, where acceptable burner temperatures are based on considering the Wobbe distribution limits. The maximum acceptable burnerdeck temperature increase is stated to be equal to the maximum burnerdeck temperature increase when changing from a natural gas at the upper limit 44.41 MJ/m³(n) to a natural gas at the lower limit 43.46 MJ/m³(n). The lower limit composition is taken to be the "LOW" composition. For the upper limit the composition "HIGH" is taken: 1.0 mol% CO_2 , 74.3 mol% CH_4 , 8.7 mol% higher C_xH_y and 16.0 mol% N_2 . The burner of fuel-rich appliances considered here is assumed to be adjusted with the "HIGH" gas. Next, the burner is thought to be fueled with the "LOW" gas, *without any burner readjustment*. This fuel change implies an increased burning velocity because of the φ -shift and thus an increased light-back propensity as well as an increased chance of burner overheating. Actually, a maximum burnerdeck temperature increase would be obtained with a "HIGH" gas with a minimal burning velocity with respect to gas composition distributed and a "LOW" gas with a maximal burning velocity with respect to gas composition distributed. In this respect the LOW and HIGH compositions used here merely do have a illustrative character.

Burnerdeck temperatures have been calculated, burning HIGH and LOW gas, for a ceramic burnerdeck ($\varepsilon = 0.7$), as a function of the so-called relative flow velocity, which is defined as the linear

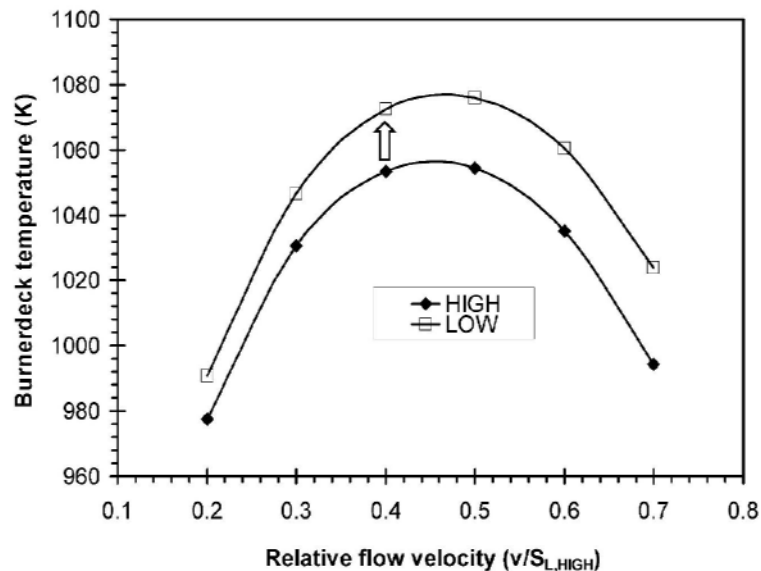


Fig. 1. Calculated burnerdeck ($\varepsilon = 0.7$) temperatures. The arrow indicates the temperature increase keeping the burner adjustments unchanged.

velocity of the cold gas/air mixture v divided by its value at free flame conditions with HIGH. At free flame conditions $v_{\text{free}} = S_{L, \text{HIGH}}$. As the densities ρ of the gas mixtures considered in this context remains constant to a good approximation, burnerdeck temperatures can be calculated as a function of v (equation (1)). The result is shown in Fig. 1. The relative flow velocity varies from 0 (no flame) to 1 (free flame for HIGH, burnerdeck temperature equals room temperature). Keeping the burner adjustments unchanged implies a vertical change in Fig. 1 (arrow) when changing to a different gas. The burnerdeck temperature increases upon going from HIGH to LOW gas, as expected. This temperature difference $\Delta T = T_{\text{LOW}} - T_{\text{HIGH}}$ increases with increasing relative flow velocity; this behavior is made more explicit in Fig. 2.

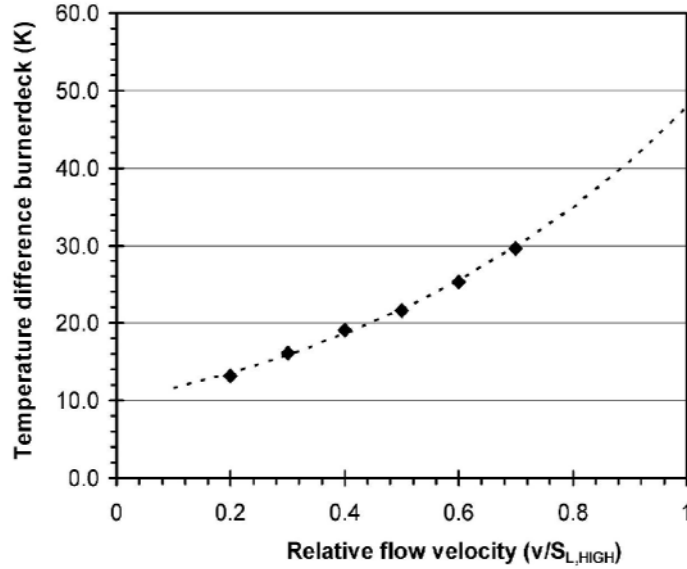


Fig. 2. $\Delta T = T_{\text{LOW}} - T_{\text{HIGH}}$ vs. relative flow velocity. The points individually marked have been obtained from the Fig. 1 data. The dotted curve indicates the fit by equation (2).

The temperature difference ΔT has been calculated for six values of the relative flow velocity, up to 0.7. Because of the time consumption of the flame simulations for values > 0.7 , the ΔT behavior for relative flow velocities 0.7 – 1 has been extrapolated applying the function:

$$\Delta T_b = A \cdot \text{Exp} \left[B \left(\frac{v}{S_L} \right) \right] \quad (2)$$

where ΔT_b is the burnerdeck temperature increase starting from T_{HIGH} , A and B are fit parameters (in this case for changing from HIGH to LOW gas), and v/S_L is the relative flow velocity.

Upon increasing the relative flow velocity the flame – burner distance increases causing less heat transfer to the burner surface. HIGH with $v/S_{L, \text{HIGH}} = 1$ represents the onset of a free flame situation: no heat transfer, leaving the burnerdeck at the ambient temperature. In the present study this is considered to be the "basic" situation in this context. For a different gas (LOW in the present case) the independent variable in Fig. 1 is still $v/S_{L, \text{HIGH}}$; in the situation where $v_{\text{LOW}}/S_{L, \text{HIGH}} = 1$ the flame is not free as $S_{L, \text{LOW}} > S_{L, \text{HIGH}}$. In this latter situation the burnerdeck temperature increase is at its maximum (50K for $\varepsilon = 0.7$, Fig. 2) within the current distribution band, which can be regarded as a worst case for burner overheating.

In practice appliance adjustments will deviate from the HIGH gas free flame condition $v_{\text{HIGH}}/S_{L, \text{HIGH}} = 1$. For the burner types under consideration here in most cases the HIGH gas relative flow

velocity will be < 1 . Fig.1 shows that the temperature increase for relative velocities < 1 ranges from $\sim 20\text{K}$ to 40K when switching from HIGH to LOW gas. In this regard, the maximum temperature increase of 50K at $v_{\text{LOW}}/S_{\text{L, HIGH}} = 1$ is within the same range as the temperature increase under practical conditions. Therefore in the interchangeability context of the present study the 50K increase situation is taken as the limit of acceptability with respect to burner overheating. Experimental verification of this limit is recommended.

Different outcomes are obtained with different burnerdeck materials, as illustrated in Fig. 3.

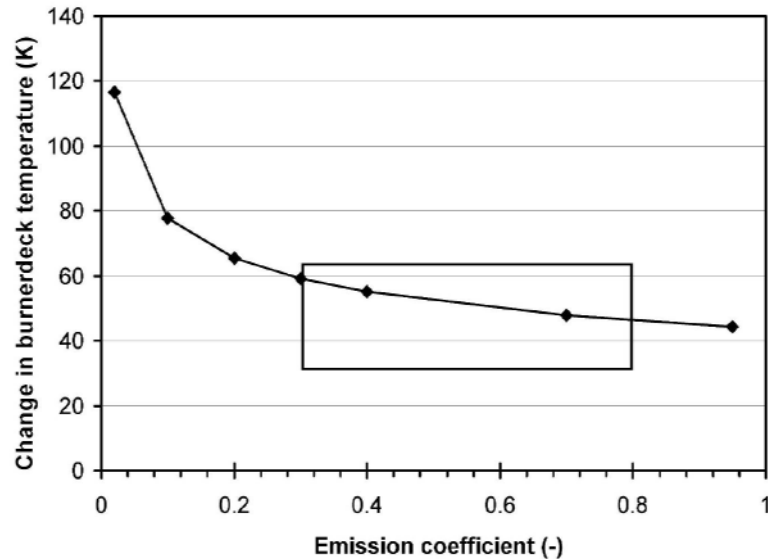


Fig. 3. $\Delta T = T_{\text{LOW}} - T_{\text{HIGH}}$ vs. emission coefficient. The region of common burnerdeck materials is indicated with a rectangle.

ΔT varies from 41K ($\varepsilon = 0.95$) to almost 120K for polished silver ($\varepsilon = 0.02$). Common burnerdeck materials have emission coefficients between 0.3 and 0.8 (Table 1) corresponding to ΔT -values between 50K and 60K .

Material	Emission coefficient (-)
Ceramic foam burner	0.7
Metal fibres	0.6
Stainless Steel 316	0.3 – 0.6
Stainless Steel 310 (high temperature)	0.6 – 0.8

Table 1. Burner deck material emission coefficients (12, 13).

5. MIXING DUTCH "G-GAS" WITH CO/H_2

As explained in section 3, admixing CO/H_2 mixtures to natural gas causes the Wobbe index to decrease. So within the Wobbe distribution band considered the maximum amount of new gas admixture will be possible in a natural gas with a Wobbe index at the top of the band. As such, in this work the

composition of HIGH (see previous section) has been taken. In gasification gases CO concentrations can be as high as 70%. Here four gasification compositions have been considered: 100 mol% H₂, 100 mol% CO, and the two CO/H₂ 30/70 and 70/30 mol%/mol% mixtures.

From the point of view of the Wobbe index the maximum amount of new gas admixture to HIGH is obtained when the lower limit 43.46 MJ/m³(n) is reached. For the four gasification compositions just mentioned, this amounts to 10.3 mol%, 2.5 mol%, 5.2 mol% and 3.2 mol% respectively, of the new gas in the overall mixture. As mentioned in section 3, adding CO causes the steeper decline of the Wobbe index.

The composition LOW is already indicated to represent the limit of acceptability with respect to light-back. Burning velocities have been calculated for mixtures of the four gasification compositions with HIGH, and compared with the limitgas value. $S_{L, HIGH} < S_{L, LOW}$ as explained above. Adding these new gases causes the mixture burning velocity to increase. Upon adding H₂ the ϕ -shift effect amplifies the increase in mixture burning velocity due to the high S_L of pure H₂. In contrast, the increase in mixture S_L when adding CO is only caused by the large ϕ -shift effect due to the steeper decline of the Wobbe index. The maximum amount of new gas admixture to HIGH is obtained when the mixture burning velocity equals $S_{L, LOW}$. For the four gasification compositions just mentioned, this amounts to 2.1 mol%, 1.2 mol%, 1.7 mol% and 1.3 mol% respectively, of the new gas in the overall mixture.

Thus, as compared to remaining within the Wobbe band, light-back is limiting the possibilities for admixing these new compositions even more.

$\Delta T = 50K$ ($v/S_{L, HIGH} = 1$, $\varepsilon = 0.7$) has been stated to represent the limit of acceptability with respect to burner overheating. ΔT has been calculated for the four light-back limited mixtures. For the two new compositions containing predominantly CO $\Delta T > 50K$ is obtained. For pure H₂ and CO the three limitative effects are illustrated in Fig. 4.

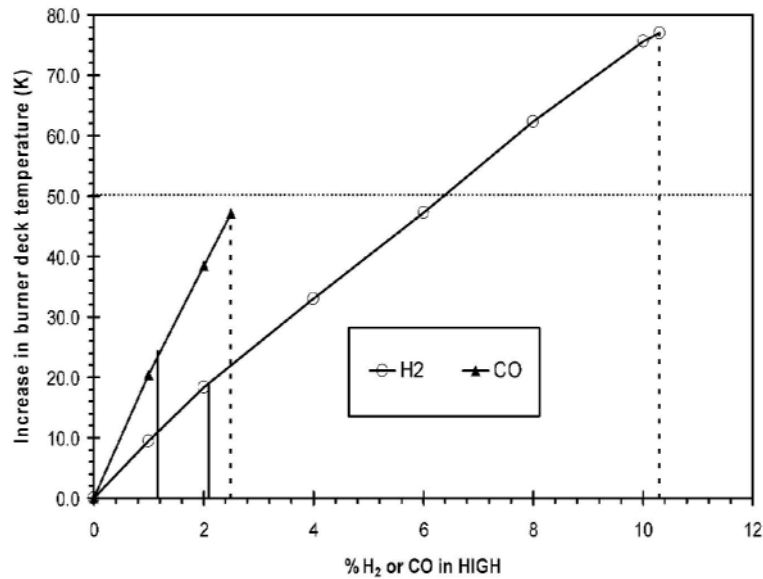


Fig. 4. ΔT vs. H₂ or CO admixture in HIGH. The verticals indicate the new gas contents as limited by the Wobbe band (dotted) or by light-back (solid). The limit value for overheating is $\Delta T = 50K$.

It should be noted that individual burners in the field can exist, having ΔT ($v_{LOW}/S_{L, HIGH} = 1$, $\varepsilon = 0.7$) smaller or greater than 50K. The outcomes of the interchangeability analysis have no meaning for an individual appliance. In this analysis gas-to-gas comparisons are made, concerning the overall population in the country of the appliance types under consideration.

Further note that the increased upstream heat transfer causing increased burnerdeck temperatures as shown for the new CO-containing gases in principle implies decreased flame temperatures, and therefore decreased NO_x emissions.

For predominantly H₂ containing new gases probably no burner overheating will take place with burner materials having $\varepsilon > 0.8 - 0.9$. The CO content is an important factor in this respect. The lower the CO content, the smaller the ε -value will be below which overheating will be the case, in other words the larger the ε -range will be without overheating taking place. The light-back limited mixture with the pure CO does show overheating for all burnerdeck materials.

6. MIXING DUTCH "G-GAS" WITH CO/H₂ CONTAINING GASIFICATION GASES

Except CO and H₂, in practice gasification gases do contain different components like CO₂ and N₂ as well. In this study three realistic gasification compositions have been considered (Table 2).

	component concentrations (mol%)		
component	Syngas 1	Biogas 2	Biogas 3
CO	2	43	21
H ₂	85	22	17
CH ₄	0	16	3
C ₂ H ₆	0	5	1
CO ₂	2	13	11
N ₂	11	0	44
H ₂ O	0	1	3
TOTAL	100	100	100
Wobbe {MJ/m ³ (n) (25 °C, 0 °C)}	23.91	20.57	7.33

Table 2. Gasification gases to be admixed.

These new gases have been theoretically mixed into HIGH gas. Just considering the Wobbe index the maximum amounts of admixture obtained for Syngas 1, Biogas 2 and Biogas 3 are 5.9, 3.7 and 2.3 mol% of the new gas in the overall mixture, respectively. Biogas 3 has the lowest value as it contains the highest amount of inerts (58 mol%). Syngas 1 allows the highest amount of admixing because of its high H₂ content.

From the point of view of light-back the maximum amounts of admixture obtained for Syngas 1, Biogas 2 and Biogas 3 are 2.0, 1.8 and 1.5 mol% of the new gas in the overall mixture with HIGH, respectively. As in the previous section, as compared to remaining within the Wobbe band, light-back is limiting the possibilities for admixing these new gases even more.

ΔT ($v/S_{L, HIGH} = 1$, $\varepsilon = 0.7$) has been calculated for the light-back limited mixtures with Syngas 1 and Biogas 3. For the mixture with Syngas 1 the burnerdeck temperature increase ΔT is found to be acceptable. For the Biogas 3 mixture, however, this is not the case: $\Delta T = 56K$. For this latter mixture overheating is shown to take place ($\Delta T > 50K$) over the complete range of ε -values. The Syngas 1 mixture ΔT -value is shown to be unacceptable when $\varepsilon < 0.7$. The difference in CO content probably accounts for the different ΔT behavior of the Syngas 1 and Biogas 3 mixtures.

7. SNG INTO THE GRID: PURE OR WITH N₂ ADDED

The previous sections show (very) limited possibilities for admixing gasification gases within the current natural gas distribution band for domestic connections in The Netherlands. The question arises whether possibilities for applying gasification gases can be extended by conversion (methanization) into SNG. As an example, the practical SNG composition of Table 3 has been studied.

component	concentration (mol%)
CO	0
H ₂	3
CH ₄	86
C ₂ H ₆	0
CO ₂	2
N ₂	9
H ₂ O	0
TOTAL	100
Wobbe {MJ/m ³ (n) (25 °C, 0 °C)}	44.82

Table 3. SNG composition considered.

As the Wobbe index of this SNG is just above the distribution maximum, only a small amount of N₂ addition is sufficient to obtain acceptability from the Wobbe point of view. This is shown in Fig. 5.

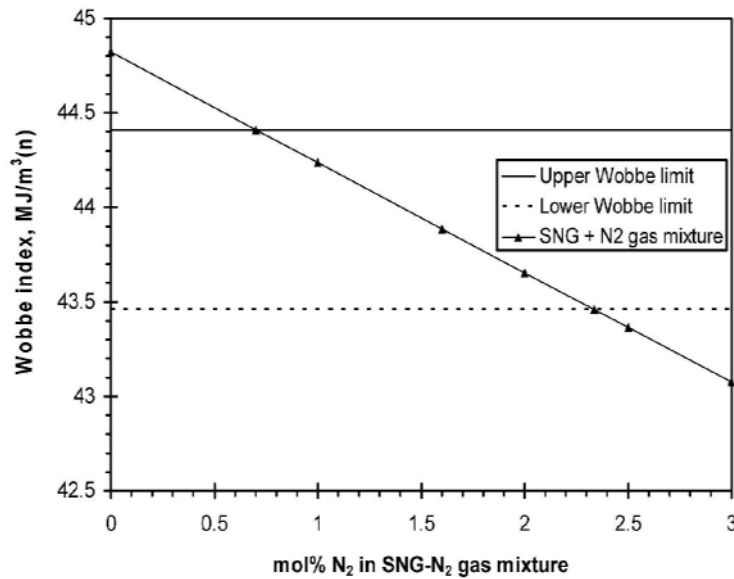


Fig. 5. SNG Wobbe index as a function of N₂ dilution.

Between 0.7 and 2.34 mol% N₂ dilution the SNG-N₂ mixture Wobbe index is within the distribution band. From the point of view of light-back, the 2.34 mol% mixture is not acceptable. Considering light-back the mixture range 0.7 – 1.6 mol% N₂ dilution the SNG-N₂ mixture is acceptable.

ΔT ($v/S_{L, \text{HIGH}} = 1$, $\varepsilon = 0.7$) has been calculated for the light-back limited 0.7 and 1.6 mol% N₂ dilution mixtures. For the 0.7 mol% mixture ΔT is even negative: the SNG does not contain $C_{x>1}H_y$, therefore the 0.7 mol% mixture has a lower S_L value as compared to HIGH, resulting in an increased burner-flame distance and less heating of the burnerdeck. With increasing relative flow velocity ΔT becomes even more negative. For the 1.6 mol% mixture ΔT is positive again, thanks to the φ -shift effect; here ΔT ($v/S_{L, \text{HIGH}} = 1$, $\varepsilon = 0.7$) remains $< 50\text{K}$. In this case overheating only results when $\varepsilon < 0.3$. For the 0.7 mol% mixture ΔT remains negative for all values of ε . Simultaneously this implies a higher flame temperature, promoting NO_x formation. This is illustrated by flame simulations (0.7 mol% mixture, $\varepsilon = 0.7$) where the increased flame temperature results in an up to 6% increased NO generation.

8. CONCLUSIONS

In this study the possibilities have been assessed for the introduction of gasification gases in the current natural gas distribution system for domestic connections in The Netherlands. Concerning domestic appliances and applying interchangeability considerations the limits of acceptability of "new" gas mixtures have been studied with respect to the Wobbe index, the chance of light-back and the chance of burner overheating.

Within the European Gas Appliances Directive GAD (10), according to the Harmonised Standard EN437 (11) G25 not only is defined as the L-band reference gas but also as the limit testgas for light-back. Given the fact that this testgas is meant to guarantee a sufficient safety margin at "normal use", as a function of the light-back combustion aspect, it should be outside the gas quality range normally distributed. Therefore, it is remarkable that considering light-back propensity G25 is situated well within the Dutch distribution band, obviously implying a reconsideration of the EN437 limit testgas for light-back.

In determining the light-back limitgas for the interchangeability analysis for this narrow-band situation the starting point has been that as the appliance conditions are generally unknown the only

reasonable assumption is that the appliance population can accept the range of gases currently being distributed: Wobbe band 43,46 – 44,41 MJ/m³(n) (3). Within this range the lowest Wobbe number represents the highest light-back propensity, in other words the limit of acceptability in this respect.

For burners for hot-water heaters, bar burners for central heating boilers and radiant surface burners overheating of the burner is a relevant issue. With respect to this combustion aspect the maximum acceptable burnerdeck temperature increase is stated to be equal to the maximum burnerdeck temperature increase when changing from a natural gas at the upper limit 44.41 MJ/m³(n) to a natural gas at the lower limit 43.46 MJ/m³(n). In the interchangeability context of the present study this maximum 50K increase is taken as the limit of acceptability with respect to burner overheating, considering a burnerdeck material with an emission coefficient $\varepsilon = 0.7$.

For the gasification gases considered an overview of the results is given in Table 4.

Gasification gas	Max. new gas content in overall mixture (mol%)		$\Delta T (v/S_{L, HIGH} = 1, \varepsilon = 0.7) \text{ (K)}$
	Light-back limitation	Wobbe limitation	
H ₂	2.1	10.3	48
CO	1.2	2.5	56
H ₂ /CO 30/70	1.3	3.2	52
H ₂ /CO 70/30	1.7	5.2	49
Syngas 1	2.0	5.9	49
Biogas 2	1.8	3.7	53
Biogas 3	1.5	2.3	57
SNG-0.7mol%N ₂	100	100	-17
SNG-1.6mol%N ₂	100	100	41

Table 4. Maximum new gas contents in overall mixtures with HIGH gas. In addition the burnerdeck temperature increase is given for the light-back limited mixtures (actually, SNG-0.7mol%N₂ is a Wobbe limited mixture).

Except for the SNG's the maximum new gas contents in mixtures with HIGH are limited. Note that mixing with a natural gas with a Wobbe index < 44.41 MJ/m³(n) will yield still smaller values for the maximum new gas contents. In spite of that still considerable flows of gasification gases might be allowed, depending on the natural gas flow at the mixing point. With 43.46 MJ/m³(n) natural gas possibilities for non-methanized gasification gases would be absent because of the Wobbe limitation.

Higher CO content increases the burnerdeck temperature, often to an overheating status. Materials with lower values of the emission coefficient yield higher burnerdeck temperatures.

Possibilities for introducing gasification gases in the narrow natural gas distribution band considered probably can be maximized by methanization to SNG's with a Wobbe index within the distribution band. These SNG's can be used as such in the domestic appliance population, provided the chances of light-back and burner overheating have been considered. Also SNG production capacities and processing costs will play a part.

It should be stressed that the methods used here can be extended and applied in a straightforward way to any natural gas distribution situation. For example, as a part of the EDGaR program (see Acknowledgements) a different Dutch distribution situation is under study with an extended Wobbe range.

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