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Fuel interchangeability: a comparative study of propane and methane in an industrial furnace burner

Intercambiabilidad de combustible: un estudio comparativo de propano y metano en un quemador de horno industrial

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Abstract
The need for studies on interchangeability prediction arose when street gas, generated from mineral coal, began to be replaced by natural gas or petroleum-derived gases. This need emerged mainly from the fact that burners have limited flexibility in responding to variations in the composition of their fuel. Subsequently, it was necessary to evaluate the performance of burners with different natural gas compositions. The current study assessed the feasibility of substituting fuel gas used in the furnace.

Keywords: Wobbe index, *Weaver index*, *gas interchangeability*.

Resumen
La necesidad de estudios de predicción de intercambiabilidad surgió cuando comenzó el reemplazo del gas de la calle, generado a partir de carbón mineral, por gas natural o gases derivados del petróleo. Esta necesidad provino principalmente del hecho de que los quemadores tienen una pequeña flexibilidad ante la variación de la composición de su combustible. Posteriormente, fue necesario evaluar el rendimiento de los quemadores con diferentes composiciones de gas natural. El estudio actual evaluó la viabilidad de sustituir el gas combustible utilizado en el horno.

Palabras clave: índice de Wobbe, *índice de Weaver*, *Intercambiabilidad de gas*.

Introduction

The concept of fuel interchangeability refers to the assessment of whether a gas or a mixture of combustible gases can be substituted with another without causing significant operational difficulties in the same burner or burner system [1, 2, 3]. Gases are considered interchangeable if they can be burned in each equipment without requiring mechanical modifications to the original burners, while maintaining operational safety and adequate energy performance. A thorough assessment of parameters that integrate the consequences of compositional deviations during combustion is imperative for this analysis [1,3].

Objective

The objective of this study was to demonstrate the occurrence of gas interchangeability in the case study, enabling a fuel gas substitution without requiring mechanical modifications to the combustion equipment (industrial furnace). Propane (C_3H_8) was used in this process, and due to strategic reasons, it was intended to replace this gas which had natural gas (CH_4). For stoichiometric calculations, propane and natural gas were both considered to be of high purity under standard temperature and pressure (STP) conditions.

Materials and methods

The academic research, grounded in classical literature, provided a technical foundation for application to contemporary needs through the comparison of established industry indices, specifically the Wobbe Index (WI) and, among the several Weaver indices, the Flame Front Speed Factor (SI) [3, 4, 5].
One of the main parameters of gas interchangeability is the WI, which depends on the volumetric Lower Heating Value (LHV) of the gas and its relative density, i.e., on the heating value and molecular weight characteristic of each gas assessed [1, 6, 7, 8, 9, 10].
This index is a parameter for verifying the thermal performance of different gases in each burner or pilot, and it expresses the ability of a given fuel to maintain a relationship between the amount of energy released and the pressure drop in the burner. This means that gases with similar WI values (5%) do not require adjustments to operating pressure nor physical alterations to the equipment in order to provide the same energy

release, as their resulting thermal performance curves are equivalent (Equation 1).

Wobbe Index (WI);

$$WI = \frac{LHV}{\sqrt{\rho}} \quad (1)$$

Being:
WI: Wobbe Index;
LHV: Lower Heating Value;
ρ: Relative density.

However, the Weaver Index (SI) is another crucial parameter to be considered, as it compares the flame propagation speeds of the gases being assessed. This index is calculated as a ratio of the combustible components in the gas, weighted by their respective characteristic flame speeds (using hydrogen (H_2) as a reference due to its high velocity), and the proportion of inert components (since a higher inert content results in lower flame speeds). The amount of air in the combustion (stoichiometric air-fuel ratio) also influences this calculation.
Higher SI values compared to the original ones indicate a faster flame propagation speed, meaning a greater tendency for the flame to lift off the burner or even flashback.
Conversely, a lower SI values suggest a slower flame propagation speed, potentially causing the flame to liftoff.
This method was developed by testing mixtures of methane, hydrogen, carbon monoxide, ethane, propane, butane, ethene, propene, acetylene, benzene, nitrogen, and carbon dioxide to simulate manufactured and natural gases (Equation 2).
Flame Propagation Speed Factor (SI);

$$SI = \frac{\sum xiFi}{A + 5Z - 18{,}8Q + 1} \quad (2)$$

Being:
SI = Weaver flame speed factor;
xi = Volumetric fraction of component i;
Fi = Weaver flame speed coefficient for component i;
A = Air required for stoichiometric combustion, vol. of air/ vol. of gas;
Z = Volumetric fraction of inert components (N_2, CO_2) in the mixture;
Q = Volumetric fraction of oxygen in the mixture;
Table 1 shows the Weaver flame speed coefficients for the evaluated gases [1].

Table 1 – Flame speed coefficient for some gases (%).

Gas	Chemical formula	*Fi*
Propane	C_3H_8	398
Methane	CH_4	148

Source: Garcia, R. (2013)

Results and Discussion

Stoichiometric calculations were first performed to determine the air required for combustion, according to equations 3 and 4.

$C_3H_8 + 5O_2 \rightarrow 3\ CO_2 + 4H_2O$ (3)
O_{2Est} = 5 mol
O_{2Fuel} = 0
O_{2Teo} = 5 mol
O_{2Rea} = 5 mol
N_2 = 5 × 79/21 = 18,8
Air = 23,8 mol
Air = 23,8 × (22,4 L/mol) = 533,1 L
C_3H_8 (fuel) = 5 mol × (22,4 L/mol) = 112,0 L
Air/ fuel ratio = 533,1 L/112,0 L = 4,76 L

$CH_4 + 2\ O_2 \rightarrow CO_2 + 2H_2O$ (4)
O_{2Est} = 2 mol
O_{2Fuel} = 0
O_{2Teo} = 2 mol
O_{2Rea} = 2 mol
N_2 = 2 × 79/21 = 7,5
Air = 9,5 mol
Air = 9,5 × (22,4 L/mol) = 212,8 L
CH_4 (Fuel) = 2 × (22,4 L/mol) = 44,8 L
Air/ fuel ratio = 212,8L/44,8L = 4,7 L

Subsequently, both the Wobbe Index (WI) and the Weaver Index (SI) were calculated and graphically represented on a scatter plot (see Figure 1), where each evaluated gas was plotted relative to the original gas. In the literature, gases with WI varying up to ±5% and SI varying up to ±10% are considered equivalent. From equations 1, 2, 3, and 4, the results expressed in equations 5, 6, 7, and 8 were obtained.

$$WI_{\ (C_3H_8)} = \frac{22389}{\sqrt{1{,}55}} = 17983\ \frac{kcal}{m^3} \quad (5)$$

$$WI_{(CH_4)} = \frac{9430}{\sqrt{0{,}60}} = 7300\ \frac{kcal}{m^3} \quad (6)$$

$$SI_{(C_3H_8)} = \frac{3 \times 398}{4{,}76 + 0 - 0 + 1} = 207{,}29 \quad (7)$$

$$SI_{(CH_4)} = \frac{1 \times 148}{4{,}76 + 0 - 0 + 1} = 25{,}96 \quad (8)$$

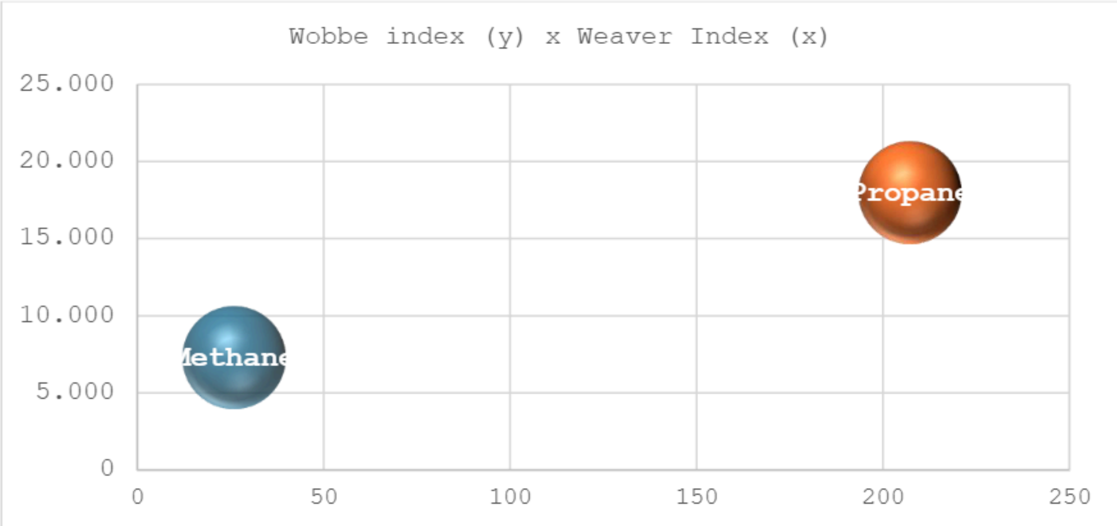

Figure 1 – Gas interchangeability map.

The abscissa (x-axis) was scaled in %mol, while the ordinate (y-axis) was scaled in kcal/m³ at standard temperature and pressure (STP).

Conclusions

This evaluation aimed to verify the feasibility of using Methane gas as an alternative to Propane gas in a specific industrial furnace. To this end, potential effects, such as flame lift-off and flashback in the burners, were analysed. The findings revealed that the gases are not interchangeable, and the existing equipment cannot operate safely with the new fuel without mechanical adjustments.

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