Liquefied Natural Gas in Railways

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Liquefied natural gas (LNG) can used as an alternative to diesel fuel in railway traction. At present, there is a common effort to reduce the environmental effect of energy consumption. With this objective, the transportation sector seeks to improve emissions in all its modes. In particular, the rail transport industry is analysing various alternatives for non-electrified lines. These services are mainly carried out with diesel units.

Keywords: alternative fuel ; liquefied natural gas ; energy consumption ; emissions ; railways

1. Introduction

The transport sector is responsible for a significant share of greenhouse gas emissions. In Europe, in particular, this value amounts to a quarter of all emissions [1]. This is why there is great concern to reduce these emissions. Railway companies are no stranger to this awareness. The transport sector is engaged in a process of reducing its carbon footprint through more efficient technologies [2].

However, the carbon footprint is not the only problem associated with transport emissions. The transport sector is one of the main sources of air pollutants that can cause a variety of health impacts, especially in urban and suburban areas. Nitrogen oxides (NO_x), particulate matter (PM), sulphur oxides, and carbon monoxide are all emitted from the exhausts of combustion engines. Exposure to these pollutants has both acute and chronic effects on human health, affecting different organs and systems, and is associated with increased mortality [3][4]. So-called nitrogen oxides include both nitrogen monoxide (NO) and nitrogen dioxide (NO_2) and have a wide range of effects on human health (inflammation of the respiratory tract, disorders of organs such as the liver or spleen, or of systems such as the circulatory or immune system, which in turn lead to lung infections and respiratory failure) and on the environment (acidification and eutrophication of ecosystems, metabolic disorders, limitation of plant growth). Acidification processes can also affect buildings [5]. In addition, NO_x contributes secondarily to the formation of inorganic particulate matter (as precursors of nitric acid, HNO_3, and thus nitrate, NO_3- in particulate matter) and also acts as a precursor for the formation of ozone (O_3) and other photochemical pollutants, which can aggravate health and environmental impacts and lead to climatic effects. Sulphur dioxide (SO_2) causes eye irritation, coughing, mucous secretion, asthma, and bronchitis [6]. Exposure to high levels of PM is associated with increased mortality and hospital admissions for respiratory and cardiovascular diseases worldwide [7].

Rail transport is undergoing renewal with improvements in both rolling stock and infrastructure [8]. Therefore, investment in new technologies is essential in order to reduce GHG emissions and other air pollutants [9]. Emissions from the rail industry can be loosely grouped into the following major categories: energy consumption of the vehicles; occupancy levels and service frequency; electricity production; rolling stock technologies; the manufacture, construction, and use of infrastructure; and modal shift and factoring in demand generation [10].

In recent decades, the railroad has been powered by electric or diesel locomotives. In society, there is an idea, accepted as an axiom, that electric traction is more environmentally friendly than diesel. Nevertheless, if the whole supply chain is considered, some studies deny this assertion [2][11]. These results hold if well-to-wheel surveys are performed [12]. Eco-efficiency studies have also been used in the evaluation of diesel traction in railroads [13].

Over the past two decades, the rail industry has increasingly investigated the field of alternative fuels, with the aim of finding substitutes for diesel. This work is aimed at both reducing emissions and minimizing operating costs. [14]. For example, the Clean European Rail-Diesel project analyses the various traction alternatives for railways [15].

Alternatives to existing fuels include biodiesel [16], thorium [17], natural gas [18], and hydrogen [19]. Of these, natural gas is the most promising [20]; it can be used in both gaseous (compressed natural gas, CNG) and liquid form (liquefied natural gas, LNG). Emissions from engines using natural gas have been the subject of numerous studies including [21][22][23][24][25][26][27].

In the recent literature there are a variety of studies on the use of LNG in rail traction only in heavy-duty locomotives. For instance, in Russia [28][29][30][31], Canada [32][33], and the USA [34][35][36][37][38][39].

The different studies reveal that natural gas is a technically viable alternative to diesel fuel. In addition, it has been shown to significantly reduce pollutant emissions, such as particulate matter and NO_x. Given that these emissions have a significant impact on health when they occur in urban environments, the application of this type of fuel in diesel commuter trains is being considered.

The previous experiences have been with freight locomotives; therefore, in the present study, the use of LNG in diesel multiple units was considered for the first time. In order to evaluate the impact that the application of this fuel would have on the current network, the methodology described in this paper was proposed.

This methodology was applied in Spain, where in 2017 the Spanish operator RENFE began pilot tests of a self-propelled passenger train powered with liquefied natural gas (LNG). The tests took place on a narrow-gauge network. An engine powered by LNG replaced one of the two diesel engines used on the two-coach train, with the second diesel engine used to compare the results of operation (emissions and consumption) with diesel and LNG traction [40]. The first step was to analyse the rolling resistance of the railway composition [41]. In addition, pilot tests made it possible to obtain the traction performance of the various powertrains [42]. This allowed accurate monitoring of the tested rail network [43] by means of vehicle instrumentation [44] to analyse driving conditions and emissions with the same techniques as used for other types of land vehicles [45].

2. Artificial Intelligence Applied to Evaluate Emissions and Energy Consumption in Commuter Railways: Comparison of Liquefied Natural Gas as an Alternative Fuel to Diesel

To explore the possibility of replacing diesel as the fuel for rail vehicles, the use of LNG was considered. Within the framework of a public-private consortium, the Spanish operator RENFE conducted a pilot test of a self-propelled passenger train powered by LNG. The tests have allowed the fitting and validation of a smart predictive model to evaluate and compare the operation with traditional fuel (diesel) and with LNG. This model was applied to a study section of track, over which both consumption and emissions were analysed under real conditions of commercial operation. The following conclusions were drawn:

Instantaneous consumption: The LNG engine has a lower instantaneous consumption (measured in kg/s). CO_2 emissions were precisely measured, and the instantaneous emissions of both engines were similar. As the emission factors were close to each other (2.79 kg CO_2 per litre of diesel, versus 2.75 kg CO_2 per kg of LNG) the measurement data for CO_2 emissions support the previous conclusion that fuel consumptions are lower in LNG engines.

Instantaneous greenhouse gas emissions: CO_2 emissions are lower in the LNG engine. The methane emissions from the LNG engine are lower than the hydrocarbon emissions from the diesel engine. Methane emissions from the LNG engine do not constitute a significant emission of greenhouse gases. Venting was not taken into account in this analysis, since the operation of refuelling and maintenance of the vehicle has yet to be defined.

Instantaneous emissions of pollutants: Diesel engine NO, NO_2, and particulate matter emissions (soots) are higher than the corresponding LNG engine emissions in all operating scenarios, and by several orders of magnitude. In fact, the emissions of nitrogen oxides and particles from the LNG engine were negligible. The CO emissions from the Diesel engine were lower than the emissions from the LNG engine.

The conclusions that can be drawn coincide with those expressed for the instantaneous data: (1) CO_2 (greenhouse gas) emissions are lower in LNG engines than in diesel powertrains, in the absence of methane venting considerations, (2) CO emissions are lower in the diesel engine, and (3) emissions of pollutants (nitrogen oxide and particles) are higher in the diesel engine by several orders of magnitude.

We investigated the effect of fuel replacement on a non-electrified rail network. Pilot tests carried out on a train powered by both a diesel and an LNG engine were used to fit a predictive model of consumption and emissions. A methodology was proposed and implemented for the comparative evaluation of consumption and emissions with diesel or LNG powertrains. The effect under commercial operating conditions can be inferred. The use of LNG as a fuel leads to improvement in some indicators, while other values do not show significant improvements.

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