ACME IASI 2004: STRATEGY OF PHASING-OUT THE LEADED GASOLINE IN ISRAEL

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Abstract
In April 1994, the UN Commission on Sustainable Development called upon governments to eliminate lead from gasoline – worldwide. Each country has a definite phase-out schedule, but the approaches used vary from one country to another. This work presents the strategy proposed by the authors and approved by the Israeli Fuel Authority, to phase-out lead from gasoline in Israel. In the first stage of this work, a comprehensive literature review was carried out. Then, a statistical analysis of the old vehicles data was performed. The results showed that only about one third of the old vehicles fleet refueled with leaded gasoline, really needed this fuel. The first practical recommended measure within the proposed strategy was the immediate reduction of the lead content in the gasoline from 0.15 to 0.10 g/liter. The other measures proposed in this work were: to increase the efforts by the Israeli Refineries to supply the necessary quantity of unleaded gasoline, to improve public information and outreach campaign regarding the applicability of unleaded gasoline in older cars, by using lubricating additive based on phosphorus, potassium or sodium.

Key-words: *Leaded Gasoline phase-out, Leaded and Unleaded Gasoline, Valve Seat protection.*

Introduction

Since their discovery in the late 1920s, lead alkyls have been used in gasoline to improve octane quality. An additional benefit of lead is its good high-temperature lubrication properties, which effectively prevent wear of exhaust valves and seats. There are old vehicle engines specifically designed for operation using leaded gasoline. The engines of concern are those designed specifically to take advantage of the lubricating effects of lead oxide deposits formed in an engine, when leaded fuel is burned. [1-4]. These deposits have provided needed protection against exhaust valve seat wear. Without adequate lead (or lead substitute) content in the fuel, these engines are exposed to the risk of severe wear of exhaust valve seats, a phenomen known as "valve seat recession" (VSR), [3-6]. An illustration of exhaust valve seat recession is shown in Figure 1, [7].

Lead is well known as a hazardous, heavy metal that has a damaging impact on human health. It is regarded to be one of the most serious health problems facing human populations, particularly children. Common symptoms include IQ loss, reading and learning difficulties, hearing loss, difficulties in concentrations, adverse

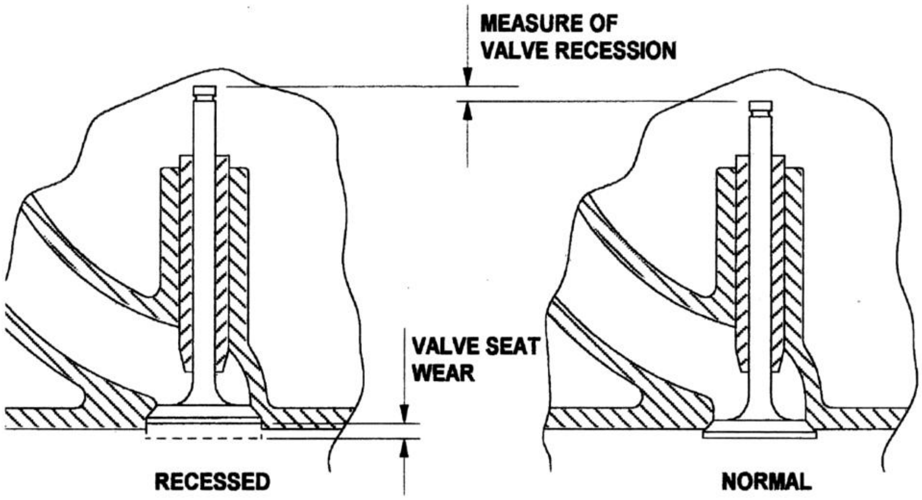

Fig. 1.: An illustration of exhaust valve recession [7].

effects on kidney function, blood chemistry, and the cardiovascular system as well as adverse reproductive effects for women [6]. Exposure is primarily caused by airborne lead. In congested urban areas, exhaust gases from vehicle using leaded gasoline typically account for some 90 percent of airborne lead pollution.
Since the early 1970s environmental pressures have lead to a reduction of lead levels and to introduction of unleaded gasoline, at first in the USA and Japan. Increasing environmental pressure in Europe however has led to some countries wishing to accelerate the phase out of leaded fuel. The first European countries which have phased-out the leaded gasoline were Austria (1993) and Sweden (1995).
In April 1994 , the UN Commission on Sustainable Development called upon governments to eliminate lead from gasoline worldwide. Each country has definite phase-out schedule, but the approaches used vary from one country to another.

1. Objectives

The main goal of this work was to develop the strategy to phase out of leaded gasoline in Israel. To rich this goal the present work gives the answers on the following questions:
- What is a percentage of VSR-sensitive engines in Israeli car fleet?
- What is the minimum gasoline lead content to prevent VSR in the sensitive vehicles engines under the Israeli driving conditions?
- What alternative additives are available to provide protection equivalent to lead, under all conditions?
- What are the technical and administrative measures which have to carried-out to make possible the phase out of leaded gasoline in Israel?

2. Strategy of leaded gasoline phasing-out:

Statistical data concerning the Israeli VSR – sensitive engines and gasoline consumption.

Statistical data for the passenger cars (with or without catalyst), like year of production and manufacturer [8] were analyzed concerning the needed type of gasoline according to Esso Unleaded Guide [9]. The results of this analysis are summarized in Table 1.

With catalyst	**Without catalyst**						**Grand Total**
1994-2000	Up 1983	1984-1987	1988-1993	Total	Unleaded	Leaded	
676254	101021	135946	403544	640511	442312	198199	1316765

Table 1 : Passenger cars in Israel at the end of 1999 according to production year [10].

Figure 2 shows the total of gasoline passenger cars in Israel at the end of 1999 according the needed fuel for correct refueling.

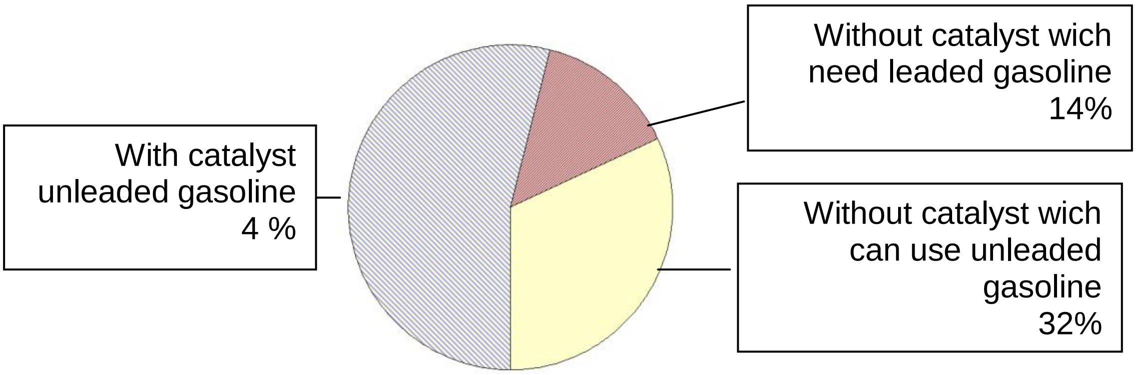

Fig. 2: Distribution of gasoline demand by passenger cars at the end of 1999 in case of correct refueling [10].

The total of gasoline motor vehicles at the end of year 1999 according to the type of vehicle and the recommended fuel is presented in Table 2 , [10].

Type of vehicles	**Total vehicles**	**Vehicles according the recommended fuel**			
		Leaded gasoline		**Unleaded gasoline**	
		Total	**%**	**Total**	**Percent**
Passenger cars	1316765	198199	15.05	1118566	84.95
Trucks up 4t	140455	28957	20.62	111498	79.38
Motorcycles	75643	9070	11.99	66573	88.01
Special vehicles	895	895	100	0	0
Taxies	235	0	0	235	100
Buses	4	4	100	0	0

Table 2: Total of gasoline motor vehicles at the end of 1999 according to the type of vehicle and the recommended fuel [10].

Fig. 3 and 4 show the real and correct (according to the recommendations [10]) total leaded and unleaded gasoline consumption for the year 1999.

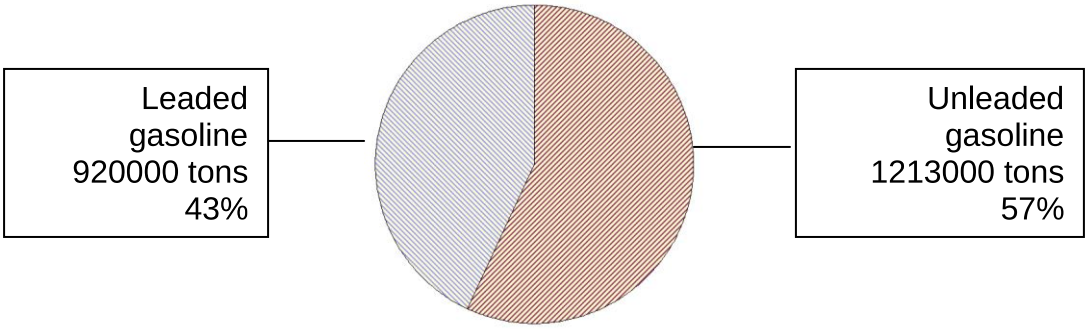

Fig. 3: Riel unleaded gasoline consumption for the year 1999.

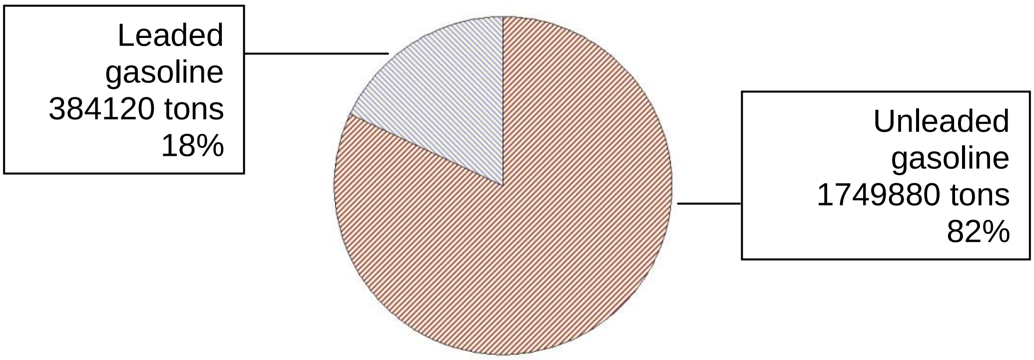

Fig. 4: Correct gasoline consumption for the year 1999 .

From Figures 3 and 4 results that the real leaded gasoline consumption for the year 1999 was 920000 tons (43%) and not 384000 tons (18%) that could be possible in case of a correct vehicles refueling. Therefore, for a correct vehicle refueling in 1999 was possible to reduce the lead consumption from 184 tons to only 77 tons.

The minimum gasoline lead content to prevent VSR in the sensitive engines under the Israeli driving conditions

From the technical literature results that the most valve-seats produced in the 1960s and early 1970s use a form of either grey or nodular cast iron, with Brinell Hardness values in the range 150-220 HB. Since then the majority of "soft" valve seats comprise forms of cast iron or inserts in aluminium heads, with hardness values roughly in the range 250-350 HB. Typical "hard" valve seats current comprise induction – hardened iron with hardness grater than 400 HB. Although the words "soft" and "hard" are used regularly to describe exhaust valves and valve-seats [4] .
The mechanism of valve-seat wear starts with localized welding of the valve to the seat, followed by separation (tearing out) of a small particle of metal from the seat. These metal particles become oxidized, leading to formation of "warts" of hard iron

oxides on the valve face. Repeated impact of these warts on the seat causes further cracking flaking and abrasive wear of the seat. As it was shown in the introduction, the lead compounds formed from the combustion of lead alkyls prevent VSR by forming thin layers of lead oxides and sulphates on the valve and seats faces. These layers prevent metal-to-metal contact and hence localized welding, and are in the state of equilibrium, being continuously worn away but simultaneously replenished from the fuel. Higher engine speeds and temperatures increase the rate of wear and hence attrition of such coatings so a higher lead content is required under these conditions to prevent VSR [4].

In order to recommend a minimal required lead content, it is necessary to define a critical level of VSR which constitutes engine failure. The work [4] has defined this as less than 0.2 mm (0.008 in) wear within 20000 km, which corresponds to 1 micrometer/h at an average speed of 100 km/h. The effect of lead content was studied by a number of US authors [4]. The results are plotted in Figure 5 in a common format as micrometers/hour vs lead content in gPb/l. This work was carried out on older V8 test bed engines manufactured in U.S.A., run at a variety of speed/load conditions.

It can be seen that generally only lead contents above 0.05 g/l give wear rates below the above mentioned critical wear rate of 1 micrometer/hour. A few of the lower speed studies howerer do show acceptable wear rates at lead levels around 0.026 g/l (0.1 g/US gal).

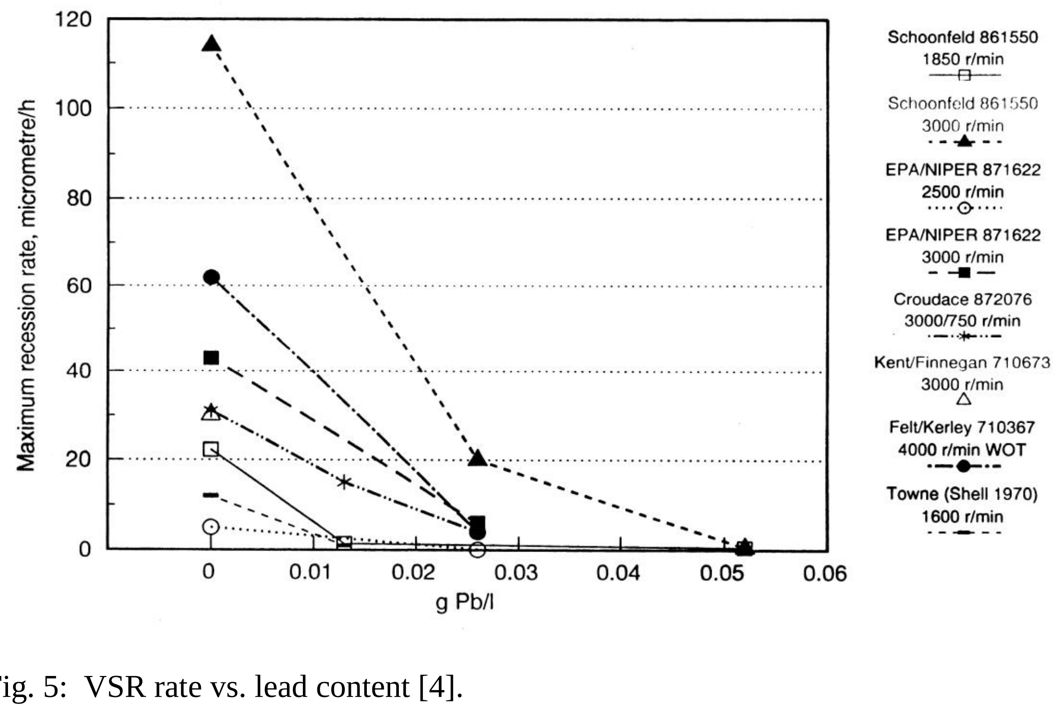

Fig. 5: VSR rate vs. lead content [4].

Our recommendation was to reduce, as a first stage of this work, the lead content in gasoline from 0.15 g/l to a maximum content of 0.10 g/l.

The considerations for this recommendation are:

- The test results from fig. 5 and from other works [3,5].
- The received answer from Shell Company with the recommendation of a 0.075 g/l lead content based on its experience in Europe;
- The existence in Israel of many roads with high gradients that contribute to severe driving conditions.

Selection of an alternative additive instead of lead to prevent VSR

The effectiveness of phosphorus, compounds based on alkali metals, specifically sodium and potassium, and mangan (methylcyclopentadienyl manganese – MMT) , has been known for many years.
Shell found that phosphorus was significantly more effective in the prevention of VSR than alkali metals, leading to the use of phosphorus based additives in unleaded gasoline in the USA in the early 1970s. However, because of its adverse effects on catalysts, use of it in bulk gasoline effectively ceased in America with the introduction of vehicles fitted with exhaust catalysts in 1975. Phosphorus based additive has had many years of successful use, also in New Zealand, United Kingdom, Australia and elsewhere since the global phase out of leaded gasoline began. In many European countries like Austria, Sweden, Finland, Germany, Denmark were used additives based on Sodium or Potassium. A mixture of sodium and potassium was used in Germany. According to Shell research work, potassium additive levels could lead to a number of problems, especially a tendency towards inlet valve sticking in critical vehicles under cold start conditions. Another problem that has been reported in Europe has been mainly regarding water sensitivity of the additivated fuels, overtreatment of additives based on alkali metals (by mistake) by some companies creating filter blocking. For this reason some additive companies have stipulated a limit of maximum 200 ppm (weight) content of water in gasoline. Hot corrosion damages from sodium based additives were registered for the engine turbocharger. Potassium-based additives perform significantly better than sodium in this respect but some damage has been reported with this metal. Phosphorus based additives have shown no adverse corrosive effects with turbochargers.
In the draft of the British Standard BS DC 99/120286 the limits for the recommended lead replacement additive (see Table 3) are given.

Additive	**Treat level limits, mg/kg**	
	Min	**Max**
Manganese	10	50
Potassium	8	20
Phosphorous	8	30

Table 3. Treat level limits for additives to prevent VSR.

Our recommendation was to use a phosphorus based additive because it is significantly more effective in the prevention of VSR than alkali metals. The second option of our recommendation was to use an additive based on alkali metals.
Concerning the mode of the additive introduction it was proposed, to use the bulk treatment of unleaded gasoline sold through wide neck refueling nozzle and after 2-3 years to use the sale of aftermarket additives for application to unleaded gasoline during refueling.

Technical and administrative measures

In order to announce a clear lead phase out schedule and deadlines, of the refineries, regarding the time needed to increase the production of high octane blendstocks by

increasing utilization and, if necessary, expanding or modernizing existing process units, have to be received.
Implementing lead phase-out programs requires a broad consensus among the main stakeholders, and the understanding and acceptance of the program by the public.
One of the most important elements in this strategy program is fiscal incentives to create a price structure favor unleaded gasoline. Incentives policies could play a key role in smoothing the transition period during the phase-out of lead by influencing gasoline supply and demand according to the experience accumulated by some European countries, as is shown in Table 4. Our recommendation was to increase the price of the leaded gasoline by 5-10%, [2].

Country	**Price Difference between Leaded and Unleaded Gasoline, 1990-93* (percent)**	**Market Share of Unleaded Gasoline, 1993 (percent)**
Belgium	6.5 - 11.2	57
Denmark	8.7 - 15.6**	76
Finland	8.4 - 15.5	70
France	2.4 - 6.5	41
Germany	8.2 - 13.3	89
Greece	6.0 - 9.7	23
Ireland	3.1 - 4.8	38
Italy	0 - 5.6	24
Luxembourg	4.5 - 16.5	69
Netherlands	4.5 - 9.2	75
Norway	7.9 - 10.9	50
Portugal	4.4 - 7.3	21
Spain	2.1 - 3.1	14
Switzerland	7.6 - 8.3	65
U.K.	6.9 - 9.5	53

* Expressed in percentage of leaded gasoline price, based on retail prices of 95 RON gasoline prices.
** Based on 92 RON gasoline prices.
Source: EDE, 1994; IEA, 1994. Octel, 1994.

Table 4: Price difference between leaded and unleaded gasoline in some European countries [2].

Other recommended steps were as follows:
- Public information about the kind of gasoline (leaded or unleaded) needed for each type of vehicle for a correct refueling.

- Public information with regard to the health benefits and some positive effects in terms of engine maintenance which may, in fact, be gained by switching from leaded to unleaded gasoline.
- Control of the fuel tanks bottom in the public fuel stations, which have to be performed by the fuel companies, to assure the inexistence of water, prior to the start of the distribution of gasoline containing the selected lead substitute additive.

3. Conclusions

1. The analysis of the gasoline vehicles data for the year 1999 shown that by correct refueling it was possible to reduce the leaded gasoline consumption with 58% and to reduce the lead consumption from 184 tons to only 77 tons.
2. The first practical recommended measure within the proposed strategy was the immediate reduction of the lead content in the gasoline from 0.15 to 0.10 g/liter.
3. Through the other measures proposed in this work can be mentiond:
- To increase the efforts by the Israeli refineries to supply the necessary quantity of unleaded gasoline;
- To use a non lead lubricating additive based on phosphorus, potassium or sodium;
- To increase the price of the leaded gasoline by 5-10% , 2-3 months before the start of it phase-out;
- Public information about the kind of gasoline (leaded or unleaded) needed, for each type of vehicles, for a correct refueling.

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