Problems of aviation leaded gasoline application on aircraft

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Abstract. Special aviation gasoline with specified operational properties is used for aircraft piston engines. The level of operational properties indicators is specified by the special additives introduction. One of these additives is an antiknock additive – tetraethyl lead. The influence of tetraethyl lead contained in aviation gasoline on the oil systems of aircraft piston engines operation are shown in the article. The insignificant content of TEL decomposition products in aviation oils sharply worsens their pumpability and leads to complete fine oil filters clogging in a few minutes of engine operation, which is negative from the point of view of flight safety.

1. Introduction

Modern trends in the development of civil aviation (CA) show a stable increase in the small aircraft fleet. These aircrafts are equipped with piston engines operated on aviation gasoline, which has raised standards. The main aviation gasoline brands for CA at the moment are the Russian B-91/115 and American 100LL. A number of additives are added to these gasolines to set the required operational properties. As an anti-knock additive, lead-containing additives are used: mainly this is tetraethyl lead (TEL).

Tetraethyl lead (Pb(C₂H₅)₄) used in the form of ethyl liquid is a mortal danger poison with a pronounced cumulative effect, causes disorders of the Central nervous system, has an allergic effect, belongs to the 1st class of danger. TEL penetrates into the body even through the skin. The maximum permissible concentration of TEL vapors is 0.005 mg/m³ [1-3]. TEL is extremely unsafe for the environment, and therefore its use in motor gasoline in most countries of the world is prohibited.

However, in aviation, this additive is a necessary component for a number of reasons. First, it is an effective anti-knock additive that provides the necessary level of gasoline rating on a rich mixture. Secondly, the oxides of lead formed during the combustion of gasoline have a positive effect on the anti-wear properties of fuels (in relation to the parts of the piston-cylinder-unit).

The influence of TEL on the gasoline stability is ambiguous: in some cases, TEL is a catalyst for the oxidation of hydrocarbons, and in others is an inhibitor [4].

TEL has the negative impact on carbon forming properties, TEL oxidation products with air oxygen form insoluble precipitates in gasoline, which can cause clogging of fuel filters, combustion products of TEL have a negative impact on catalytic converters, etc. [5].

The content of TEL in aviation gasoline is shown in Table 1 [1, 2].

For an objective comparison of the Table 1 data, it’s necessary to reduce to the TEL concentration values. Taking the aviation fuel 100LL density at 750 kg/m³ with 20 °C, we obtain gPb/kg = 0,75.
Table 1. The content of TEL in aviation gasoline.

| TEL concentration | 100LL | B-91/115 |
|-------------------|-------|---------|
| mlTEL/dm³, no more | 0,53  | -       |
| gPb/dm³, no more  | 0,56  | -       |
| gPb/kg, no more   | -     | 2,5     |

The letters in the marking of aviation gasoline 100LL means low lead (low lead content), in some sense, it corresponds true (the difference of content of TEL compared to the petrol B-91/115 is more than 3 times), but we can talk that the negative impact of these gasoline brands on the environment as a result of the TEL toxicity, and the aircraft engines operation are practically identical (as we’ll see later).

As is known, the peculiarity of piston engines is the following: the parts of the cylinder-piston group (CPG) work in conditions of high irregular thermal stresses and shock loads, while the piston lower part works in the liquid friction conditions, and the upper part works in the boundary friction conditions. During operation the piston is deformed and at certain moments takes the ellipse form, elongated along the axis of the piston pin. It conditions a guaranteed (and often increased) clearance between the piston and the cylinder. Thus, the used gasoline and its combustion products can get into the oil, especially in the case of increased CPG parts wear [6, 7]. Accordingly, the TEL gets in the oil, as well as the products of its decomposition after aviation gasoline combustion in the combustion chamber.

2. Method

To assess the composition of metallic impurities in aviation oils of piston engines, an x-ray fluorescence spectral analysis method was used, implemented at the Prisma ADC installation (Figure 1). ADC Prizma allows to conduct quantitative and qualitative analysis of oil samples for the metal presence in them with high reliability and is characterized by sample preparation simplicity.

- ability to determine 74 the elements from Ca to Am;
- measured concentrations range: from 0,1 to 250 g/t;
- concentration measurements relative error limits: from 5 to 20 % subject to the concentration.

Figure 1. General view of ADC Prisma and its main parameters.

3. Results and discussion

X-ray fluorescence spectral analyses of aviation oil samples from piston engines showed a significant content of lead in them (Table 2). Source of lead in the oil is a TEL of aviation gasoline. At the same time, there is no significant difference in this parameter depending on the used aviation gasoline brand.

Table 1 shows that the presence of lead in the samples can be significant even when the engine is running on fresh oil. This can be explained by the fact that the engine is not washed when changing
the oil. Any dependence of Pb presence in samples of working oil depending on oil operating time is also not found.

The presence of a small amount of lead in the oil samples impairs the pumpability of the oil and its filterability. In the presence of lead, the oil blackens and forms clots.

Oil fine filters of piston engines which meshes size is from 10 to 25 microns depending on a type of the applied filter are clogged up at work on such oil almost instantly (Figure 2,3), and contaminated oil continues to be supplied to the engine through the bypass valves bypassing the filters, that negatively affects the flight safety.

It is also worth noting that TEL in the form of ethyl fluid dissolved in the fuel, does not cause problems with the fuel pumpability through the fuel filters, the cell size which is from 10 to 25 µm depending on the applied filter, and especially not to cause their clogging. Clogging of filters is caused only by TEL oxidation or decomposition products after its combustion. In this case, these are decomposition products-lead dioxide (PbO₂) as part of other combustion products and oxidation of aviation gasoline, which is inevitable when using aviation gasoline with TEL.

### Table 2. Lead content in oil samples from piston engines with different oil operating time.

| Sample № | Engine operating time ASH-62IR on mineral oil MS-20, hour | Fe, g/t | Pb, g/t | Cu, g/t | Zn, g/t | Cr, g/t | Ag, g/t | Zr, g/t |
|----------|--------------------------------------------------------|--------|---------|---------|---------|---------|---------|---------|
| 1        | 1,5                                                   | 1,76   | 8,19    | 1,7     | 0,31    | -       | -       | -       |
| 2        | 100                                                   | 1,29   | 8,81    | 0,67    | -       | 0,21    | 2,62    | -       |
| 3        | 2                                                     | 1,24   | 1,91    | 0,82    | -       | -       | -       | -       |
| 4        | 2                                                     | 2,02   | 3,09    | 0,72    | -       | -       | -       | 0,67    |
| 5        | 100                                                   | 1,73   | 2,67    | 0,81    | 0,23    | 0,25    | -       | -       |

In the design of PD oil systems, multi-stage oil scavenging can be used, which consists in the fact that the oil before entering the fine filter is pre-cleaned in a centrifuge. The oil centrifugation before the filter in these circumstances, obviously, has some positive effect, because a significant amount of fairly large particles (from 50 microns) for a certain period of time settles on the walls of the centrifuge. However, practice shows that centrifugation does not prevent oil clogging, and when they are clogged, it cannot be an effective system for cleaning oil from contamination instead of fine oil filters.

These facts also point to the oil toxicity used in aircraft piston engines, respectively, to its disposal and to safety should be applied the appropriate requirements.

The ways to solve this problem can be different, including:
1. Replacement of anti-knock additive to aviation gasoline.
2. Changing the regulations for oil change, fine filters replacement (cleaning) and centrifuge cleaning (if available), washing of the piston engine.
3. Changing the design of filter elements or oil filtration system.

Any of these ways will require significant time-labor and economic costs, but is necessary to ensure the flight safety of aircrafts equipped with piston engines, and environmental friendliness of these engines.
Figure 2. The filter MFM-25 after 1.5 hours of engine operation.

Figure 3. Centrifuge TCM-25 after 100 hours of engine operation.

References

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