

SOME PROBLEMS RESULTING FROM POWERING OF TURBINE ENGINES BY LIQUIFIED PETROLEUM GAS (LPG)

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Abstract

There has been observed for several years a number of attempts to introduce for everyday use small power units which utilize turbine engine as propulsion unit (the U.S., Japan, and Europe). Efficiency increase of such devices is achieved by improving of turbine engine design as well as utilizing of exhaust gas thermal energy to heat the compressed air supplied to combustion chamber and, for example to heat usable water. Significant orientation of turbine engine improvements lead to the modernization of combustion processes by applying of gaseous fuels (such as compressed natural gas) or implementation of high-temperature catalytic combustion. The purpose of these changes reduction of hydrocarbons, carbon monoxide and nitrogen oxides emissions. In Propulsion Department of Aviation Institute a scientific project has been realized, in which the object of study was aircraft turbine engine powered by a liquid propane-butane mixture. The paper presents some results of engine tests carried out, especially concerning feeding system, special fuel system applied LPG pumping systems with the use of sliding-vane pump and by means of pressure reservoir and combustion process of LPG atomized with the use of original GTD-350 vortex injector, adapted for aviation kerosene Jet-A.

Keywords: power engineering, turbine engines, alternative fuels, liquified petroleum gas (LPG), feeding system

1. Introduction

Turbine engines have – in comparison with piston engines – some advantages that encourage among others to use them in stand-alone power units.

These advantages, in comparison to Diesel engine, can be presented as follows:

- greater willingness to work at low temperatures due to the rapid start-up possibilities,
- lower (about eight times) heat transfer through the engine oil and lack of liquid cooling system, which significantly reduces the number of vulnerable assemblies and essentially lowers power consumption of the cooling system (even twice),
- less labor demands of repairs (even twice), no seasonal maintenance is required,
- reduced time required for unit/module replacement (approximately five times),
- reduced amount of oils and lubricants required to operation (about three times),
- mild torque characteristic, without pulsation typical for piston engines,
- significantly lower weight and size of turbine engine compared to piston engine of similar power (see Tab. 1)

However, some features of gas turbine engines – mainly much higher specific fuel consumption – eliminated them yet from applications other than aircraft drives. Nevertheless many well-known companies were involved in modification of these engines and application them in hybrid electric power systems with the intention that economic entities and even households located far from the central energy system become independent of them. Projects quoted in [11] described plants of power between several kilowatts (Nissan) and several hundred kilowatts (Siemens Westinghouse Power Corporation, producer of systems from 100 to 1200 kW).

Tab. 1. Typical parameters of some selected engines

Model	Power [kW/KM]	at [rpm]	Dimensions			Mass [kg]	Power per unit weight [KM/kg]
			Lenght [mm]	Width [mm]	Height [mm]		
Caterpillar 3116 TA	257 / 350	2800	1498	813	864	680	0.515
Caterpillar 3306 BTA	257 / 350	2200	1956	940	1067	1120	0.312
Cummins NTA-855	265 / 360	2100	1550	787	1320	1300	0.277
Detroit Diesel 8V-71T	266 / 362	2100	1270	1016	1346	1063	0.340
Jumo 205	637 / 867	2800	1943	547	1320	595	1.457
GTD-350	294 / 400	5900	1350	522	680	139	2.878

Note:

- GTD-350 – turbine helicopter engine, until recently produced in Poland as power unit of Mi-2 helicopter,
- Jumo 205 – Diesel aircraft engine applied in Germany during the World War II,
- The rest of engines mentioned in the table are Diesel engines for industrial applications or as propulsion units of vessels.

2. Difficulties associated with forcing through of LPG

The way of storage and forcing through of liquid gas (LPG) is strongly influenced by properties of its main components: propane and butane. Significant change of vapor pressure of these two components (i.e. vapor pressure in equilibrium state with liquid in a closed container) depending on the temperature change is of fundamental sense. At 0°C the vapor pressure of butane is 0.005 bar and rises to 0.8 bar at a temperature of 15°C, while the vapor pressure of propane at the same temperature is higher and amounts adequately 4 and 6.5 bar.

Tab. 2. The comparison of propane, butane, gasoline and air-kerosene physical properties

Characteristic	PROPANE	BUTANE	GASOLINE	JET-A1
Density at +15°C [kg/dm ³]	0.508	0.584	0.73-0.76	0.775-0.83
Vapor pressure at +37.8°C [bar]	12.1	2.6	0.5-0.9	0.65
Boiling temperature [°C]	-43	-0.5	30-225	100-250
Research octane number R.O.N.	111	103	96-98	
Motor octane numer M.O.N.	97.1	89	85-87	
Calorific value [MJ/kg]	46.1	45.46	43.8	44.6
Calorific value [MJ/dm ³]	23.4	26.5	32.2	34.3

Another important difference in physical properties of these two gases is temperature at which they transit from a liquid to a gaseous state (different boiling points). Propane remains in the liquid state at temperatures below -43°C while butane at 0°C. In cold environment (e.g. in winter) to facilitate a phase change of mixture from liquid to gas, increasing ratio of propane to butane in the LPG is required. In practice, there are a "winter" mixture – 60% propane and 40% butane – and a "summer" one of inverse proportions. The characteristic feature of LPG is very high coefficient of thermal expansion (in case of liquid phase), which amounts about 0.002-0.004 [1/K], when for water – this ratio is several times smaller (0.00021 [1/K]). As a result of this property – for safety reasons – completely filling of LPG tanks is not allowed. LPG, which at a temperature of +15°C occupies 80% of tank volume at +38°C will occupy 84-86%, whereas at 50°C – as much as 87-91% of volume. In addition to increase of liquid gas volume, pressure in the tank will also grow: from about 6.5 bar at 15°C to 16.8 bar at 50°C. To protect the container from blowing out safety valves are used, usually set up at the maximum pressure of 25 bar.

Forcing through of condensed mixture of gases using classical pumps (e.g. sliding vane pump, as shown in Fig. 1) can cause, in case of too low pressure at the suction side, local phase change (from liquid to gas) and aeration of pump which in consequence of them can result of strong pumping pressure drop.

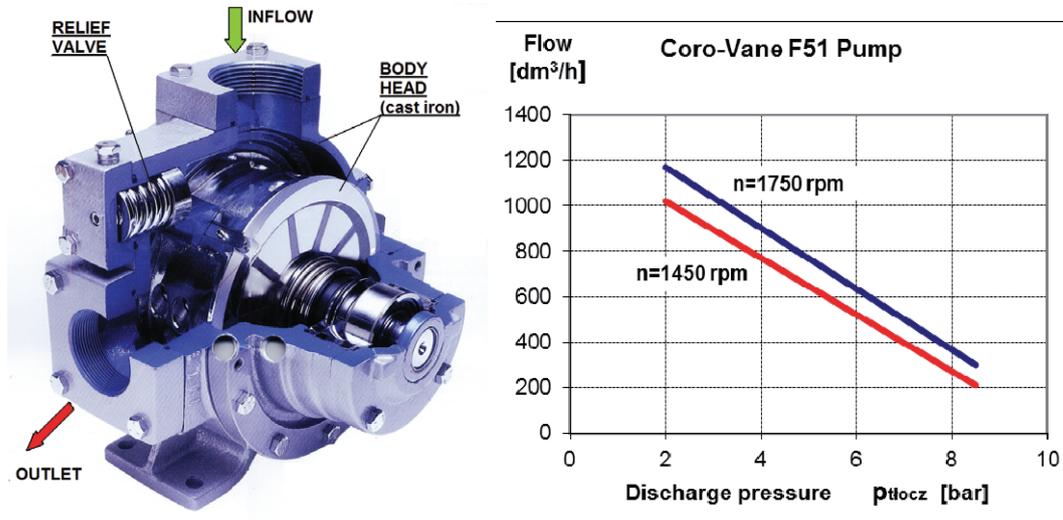


Fig. 1. Cross-section and operating characteristic of sliding-vane pump applied in LPG pumping systems

This can be avoided by using a different type of pump (e.g. a positive displacement), having more "flat" characteristic, which efficiency is less dependent on pumping pressure.

Another possible solution is the arrangement shown in Fig. 2b, where for pumping of LPG compressed nitrogen was used. Based on the previously determined flow characteristics of feeder line $Q_{LPG} = f(p_{N_2})$ nitrogen pressure is determined at value providing desired flow rate of LPG for the case of maximum engine demand (at the start phase). To control the flow at intermediate ranges a throttle valve (item 12 in Fig. 2b) is used.

3. Changes in the supply and control systems

Nearly all of the known control systems of turbine engines perform their functions by measuring the respective volumetric flow rate of fuel supplied to combustion chamber. Their principle of operation relies on modifying of cross-section of hole used to metering of flow. A special control system keeps pressure drop of fuel along this hole constant. If the fuel kind used has changed to one that has a lower calorific value per unit of volume – as it is in case of replacement of kerosene by LPG – to supply engine with comparable energy, the volume flow rate of fuel should be increased.

Control systems, which comprise rotor speed control, adapt to the changed conditions self-acting. This applies only to fixed operating conditions. Subsystems whose function is to limit the maximum fuel flow (or reduce the maximum torque on the shaft which connects turbine and compressor), limiting of the minimum fuel flow (securing flame in chamber against extinguish), leading start-up and acceleration will meter too small amount of fuel. This can result in: unsuccessful starting an engine (so-called "hovered revolutions"), long-term acceleration, and even inability to achieve maximum operating parameters and possible quenching of the combustion chamber due to excessive depletion of mixture ("flame blowing out").

Simple comparison of calorific values of Jet-A and LPG (propane to butane composition 1:1) shows that at similar operating conditions the control system should provide (volumetric) 37.5% more LPG than kerosene Jet-A before. In reality, this amount is slightly smaller. This is brought about better conditions of formation and combustion of mixture in case of liquid gas.

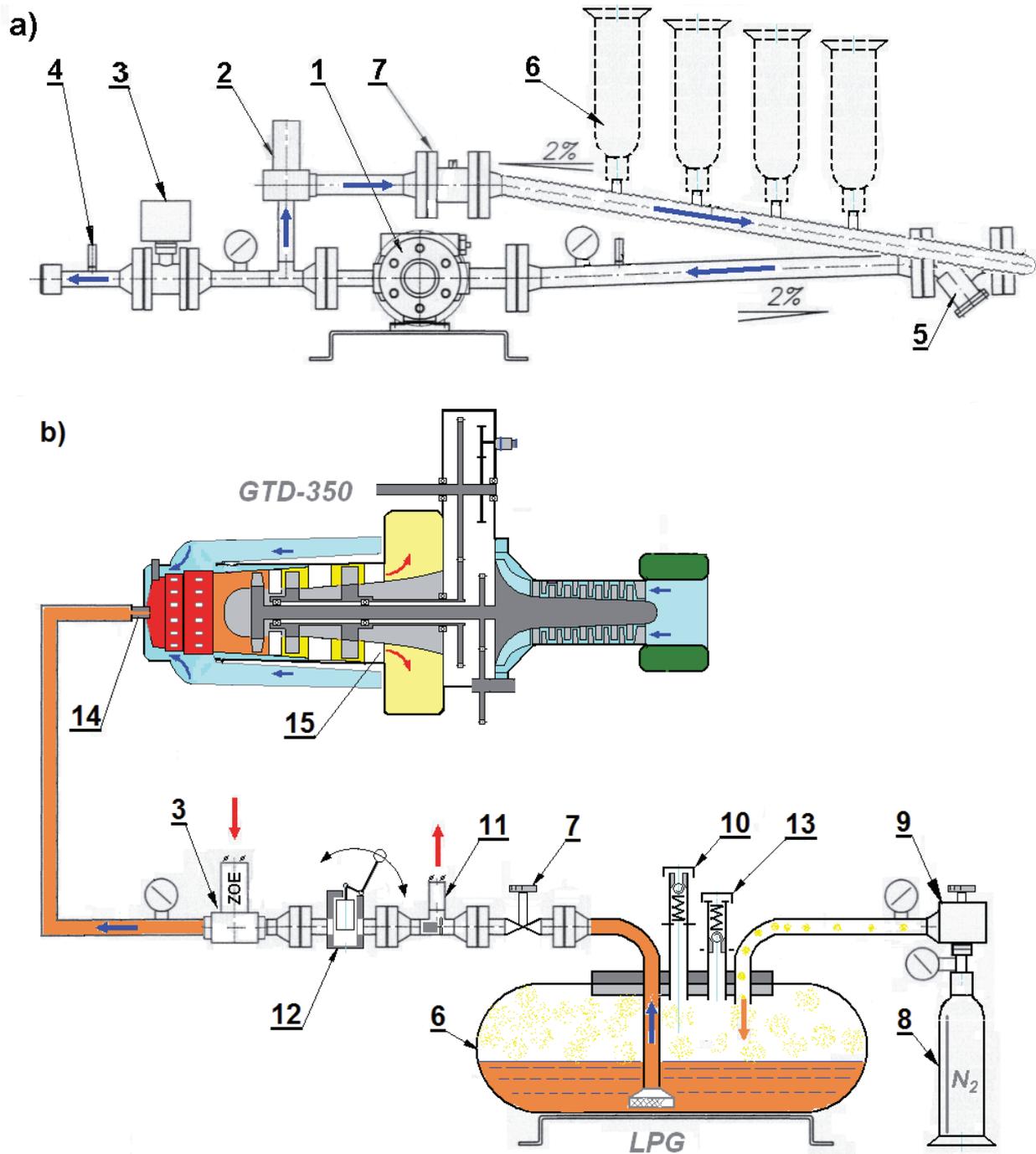


Fig. 2. Schematic diagrams of applied LPG pumping systems: a) with the use of sliding-vane pump, b) by means of pressure reservoir, 1 – sliding-vane pump driven by three-phase motor, 2 – overflow valve, 3 – solenoid cutting-off valve, 4 – hydrostat, 5 – filter, 6 – the gas cylinder / LPG tank, 7 – cutting off valve, 8 – compressed nitrogen cylinder, 9 – reducing valve, 10 – valve to refueling of tank, 11 – turbine flowmeter, 12 – hand-operated throttle valve, 13 – safety-valve, 14 – injector located in combustion chamber, 15 – engine under test

The above-mentioned adjustments in the control system can be made using the appropriate screws or by changing the characteristics and settings in FADEC memory. In some cases – where the large range of adjustment is not intended – replacement of all components may be necessary, i.e. needles for flow metering, sleeves equipped with control windows, etc.

Combustion chamber of the GTD-350 engine is supplied with fuel through a single, two-stage spin injector. Such injector, designed especially to operate with Jet-A fuel, atomizes liquid gas

improperly (see Fig. 3). This is probably due to the low injection pressure [3, 4]. During the injection process a few centimeters long stream behind it was created and the flame was moved far into the chamber. In this case a damage of turbine or rear bearing may exist. In the course of research activity a different injector design was developed, free from these disadvantages. This injector operated at higher pressure than original and sprayed better LPG on a much shorter path. One should however remember that the change of injector must be investigated to determine the droplet size distribution of the fuel spray, for example, using the analyzer uses the Doppler effect [2], demands additional research to "equalize" temperature field behind chamber by changing of flame tube design to modificate for instance diameter and position of holes which deliver secondary air.

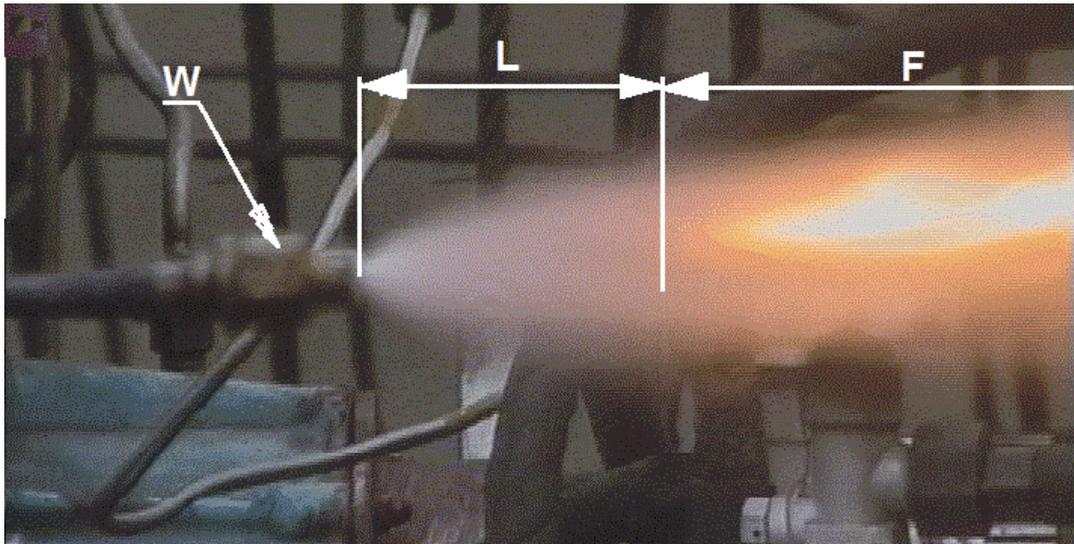


Fig. 3. Combustion process of LPG atomized with the use of original GTD-350 vortex injector, adapted for aviation kerosene Jet-A: W – injector; L – length of the fuel vaporization zone; F – combustion zone

During flow tests the phenomenon of precipitation on the injectors of solid, jelly-like substance was observed, which sublimated in open air. One was afraid of injector's holes plugging and disturbing of LPG – spray field. Perhaps it might be propylene layer, which is a kind of pollution most difficult to remove. Its content in liquid propane-butane mixture is usually about 3-5%.

4. Summary

The aim of the project was to examine possibility of turbine engine feeding by mixture of liquid propane-butane gas. This fuel is twice cheaper than aviation kerosene and could be used in stationary power units. It is generally available and used in home heating systems as well. An additional advantage of this fuel is reduction of harmful agents emission (exhaust emission results measured on test bed are to be found in the paper "GTD-350 engine powered by LPG – research work", by: P. Kalina, B. Niedziałek, W. Gryglewski, A. Irzycki, K. Snopkiewicz).

Composition analysis of turbine engine exhaust gas is hindered by the fact that the total excess air number λ is at the level of 3 to 6 [7], unlike spark ignition engine's one, which amounts about 1. Exhaust gases are namely "diluted" by additional secondary air. Thus, measurement range of applied instruments, adapted for piston engines ranges, do not match those of turbine engine and may cause measurement errors.

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