The Results of Testing and Effectiveness of the Kr-Xe Mixture Application in SPT

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The paper presents preliminary results of testing of the SPT-100 and lab model SPT-140 working on industrially produced (production) krypton-xenon mixture as well as results of the analysis of effectiveness of this mixture utilization in electric propulsion systems (EPS). By using this mixture, for a number of modes of SPT operation, which are of practical interest, there is a success to obtain the same thrust efficiency of the thruster as that of the thruster working on pure krypton, and for some modes – the thrust efficiency close to that of thruster working on xenon. This allows to change from xenon – the main operating gas, which is now widely used in SPTs, – to a production Kr-Xe mixture. Since this mixture is about 15 times as cheaper as pure xenon, and 2-3 times as cheaper as pure krypton, then with such a change the cost of the operating gas filled in EPS as well as operating gas consumed during ground test and especially during long-term life test of the thruster is substantially reduced. All this allows to significantly reduce the cost of EPSs to be delivered for spacecraft (SC).

Introduction

This paper represents preliminary results of comparative studies of SPT-100 and lab model SPT-140 operation while using Xe and Kr-Xe mixture within its natural proportion (production mixture). There are an analysis of investigation outcomes and substantiation of Kr-Xe mixture application as SPT propellant.

Properties of propellants used in EPS

In the EPSs plasma generating matters with big atom weight and low ionization potential are traditionally used. Xenon, cesium and mercury are relative to the in the first place. Fluid metals have excellent physical characteristics, but their application is not desirable due to extraordinary insalubrity's and imminence of optics and solar batteries contamination as well as to payload on SC board.
Inert gases are more preferable among gaseous propellants. Actually xenon is largely used in SPTs, it has the greatest atom weight and low ionization potential. As for its physical properties and storage terms Xe surpasses all other gases. However, high quality xenon is considered one of the most expensive propellants. According to today costs 1 kg of xenon price is about \$1500. When the active operating period becomes larger and there is a need to solve transport problems fuel reserves increase considerably and the cost of supply rises correspondingly.
The world production of xenon is about 20 t per year. While developing large scale space programs, such as TELEDESIC, SKYBRIDGE, flights to Mars and others a sharp shortage of xenon can occur. Therefore a need arises to find alternative propellants.
Krypton is easier than xenon by 1,6 times, and so, it's inferior to in efficiency. When the power and discharge voltage become higher, SPT parameters obtained on Kr near to parameters on Xe. Although the pure Kr production is approximately ten times larger than Xe, their costs are comparable.
It is proposed to use Kr-Xe mixture within its natural proportion as an alternative propellant.

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Being seconadry product at liquid oxygen manufacturing such a gaseous mixture costs not less than $100 per kg and this is 15 times cheaper than high quality xenon. It makes krypton-xenon mixture attractive according to economic reasons, especially within the stage of SPT optimization and life testing.

The application of Kr-Xe mixture is expedient not only due to its cheapness, but to an opportunity of reaching required thrust specific impulses at reduced anode voltages and this will allow to increase a flow rate of the mixture and to create auspicious prerequisites for arranging effective operating process in SPT under insignificant increase of transport and manoeuvring activity period in space.

Objects of studies and test performing conditions

SPT-140 which is finishing to be qualified is optimized for fixed operating modes [1]. Its masse is minimized due to a selection of nominal sections of magnet system. For this reason in SPT-140 it's impossible to modify magnetic field within a large range. Therefore, to carry out studies using Kr-Xe mixture laboratory SPT models were developed ; as for efficiency these were inferior to serial thrusters, but allowed to increase magnetic induction by 1,5-2 times that reveals important facilities for optimization.

The lab model M140-15 had a discharge chamber external diameter of 140 mm and a discharge channel width of 15 mm. The magnet system elements had enlarged section and magnetic screens of the model were separated from magnetic circuit.

Studies of the laboratory model M140-15 was performed on the test bench of EDB Fakel having a vacuum chamber with diameter of 2,5 m and length of 4,5 m. This bench is possessed of powerful cryogenic pumping system. During the test a high quality Xe was supplied to the cathode, and Kr-Xe mixture - to the anode unit. To make a comparison test with the use of pure xenon at the same flow rates was carried out.

Studies of the serial SPT-100 was performed on the test bench having a vacuum chamber with diameter of 0,9 m and length of 3 m. The thrust measurement device of this equipment had an operating range of 0-150 mN, and devices to measure flow rate were calibrated using volumetric method (by means of buret) on Kr-Xe mixture. This mixture was supplied to the anode and cathode. To compare results this article was tested on the pure xenon. At every mode the optimization of magnetic field according to minimum discharge current was realized.

The purpose of investigation was to specify and to compare integral parameters and characteristics of lab models M140-15 and serial SPT-100 using Xe and Kr-Xe mixture.

Test results

Model M140-15

Relationship of the discharge current (Id), thrust (F), specific impulse (Isp) and efficiency (Ef) between anode flow rate (Ga) at discharge voltage of 300 V are shown in Fig.1. Similar performances at Ud=500 V are presented in Fig.2._Optimal currents in magnetizing coils on different propellants were comparable, so magnetic fields were approximately similar. Ionization factor on both propellants was close by the unity and this points at rather effective application of propellant.

At equal levels of flow rate to the anode and of discharge voltage the discharge current on Kr-Xe mixture was approximately by 1,5 times higher, so power, thrust and specific impulse were higher also. That's shown in Fig.1 where integral parameters of two propellants at Up=300 V are compared. At the increased anode flow rate and discharge voltage of 500 V the efficiency of the model on Kr-Xe mixture exceeded 50% and specific impulse exceeded 2600 s as it is presented in Fig.2.

SPT-100

The dependence of main integral parameters of the thruster on the anode flow at discharge voltage of 300 and 450 V are shown in Fig.3 and 4. The efficiency values of thruster on both propellants at anode flow more than 3 mg/s were close and specific impulse on Kr-Xe mixture is more high by 25% approximately.

During a few hours of operation the cathode functioned normally using Kr-Xe mixture. Additions presented in gas mixture were taken up by a getter built into cathode. However, its volume is limited, therefore in SPT operating on Kr-Xe mixture an additional getter subassembly should be foreseen to take up active gases and to maintain the serviceability of the emitter due to this.

Fig.5 and 6 demonstrate dependence of the same parameters on discharge current (and power which is proportional to current). On Kr-Xe mixture the anode flow was 1,5 times less, thrust was by 1,3 times reduced and efficiency was lower by 5%. At the discharged current higher than 4 A specific impulse on Kr-Xe mixture was by 18% higher than on xenon. Magnetic fields in thruster on both propellants were close and this allows to modernize it without important correcting. Because of the reduced thrust a duration of thruster operation should be increased by 30% to get an equal total impulse and this is considered an important limiting factor. For the purpose of transport the extension of the period for put into orbit can fully be recompensed due to the cutting of expenses for propellant.

Evident advantages of Kr-Xe mixture as for its specific impulse become visible at the increase of anode flow rate. If there is superfluous board power Kr-Xe mixture is capable to be competitive. For specifying an area of alternative application of propellant it is rational to carry out the mass and cost analysis of the propulsion unit taking into account the specific character of a task to be realized.

Conclusion

1. In the course of investigation the SPT serviceability using krypton-xenon mixture within its natural proportion was demonstrated. It was shown that at the increased flows effectiveness of the operating process is becoming higher.

2. There is a reserve for developing promising SPTs on krypton-xenon mixture. Their distinguishing property is low price of the propellant and more high specific impulse.

References

[1] R. Gnizdor, K. Kozubsky, N.Maslennikv, V.Murashko, S.Pridannikov, V.Kim. Performance and Qualification Status of Multimode Statinfry Plasma Thruster SPT-140. IEPC-99-090. *Proceedings of the 27th International Electric Propulsion Conference*. October 17-21, 1999.

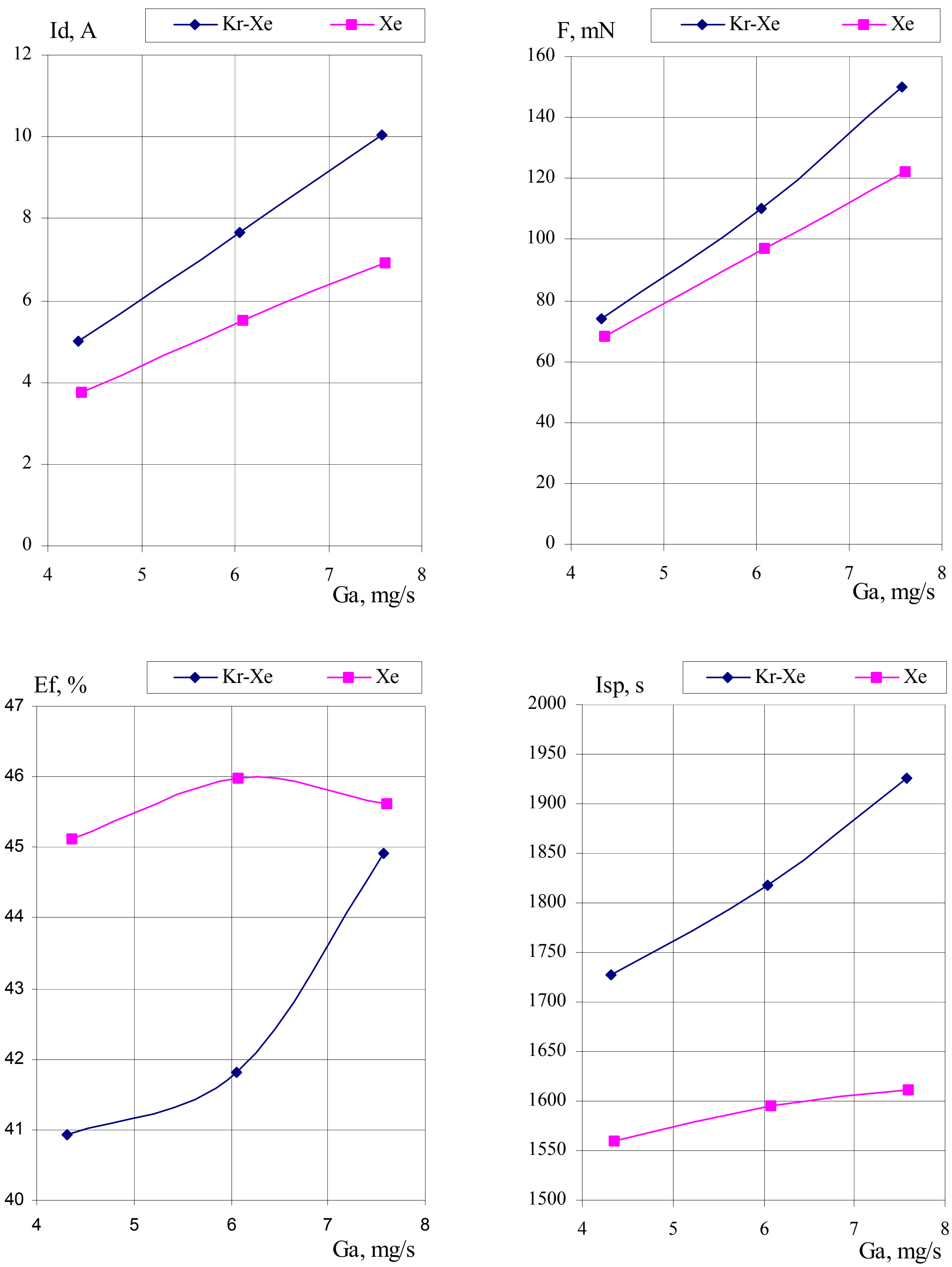


Fig.1. M140-15. Dependence of main parameters on the anode flow rate at Ud=300 V
a)- discharge current; b) - thrust, c) - efficiency without taking into consideration cathode flow, d) - specific impulse without taking into consideration cathode flow

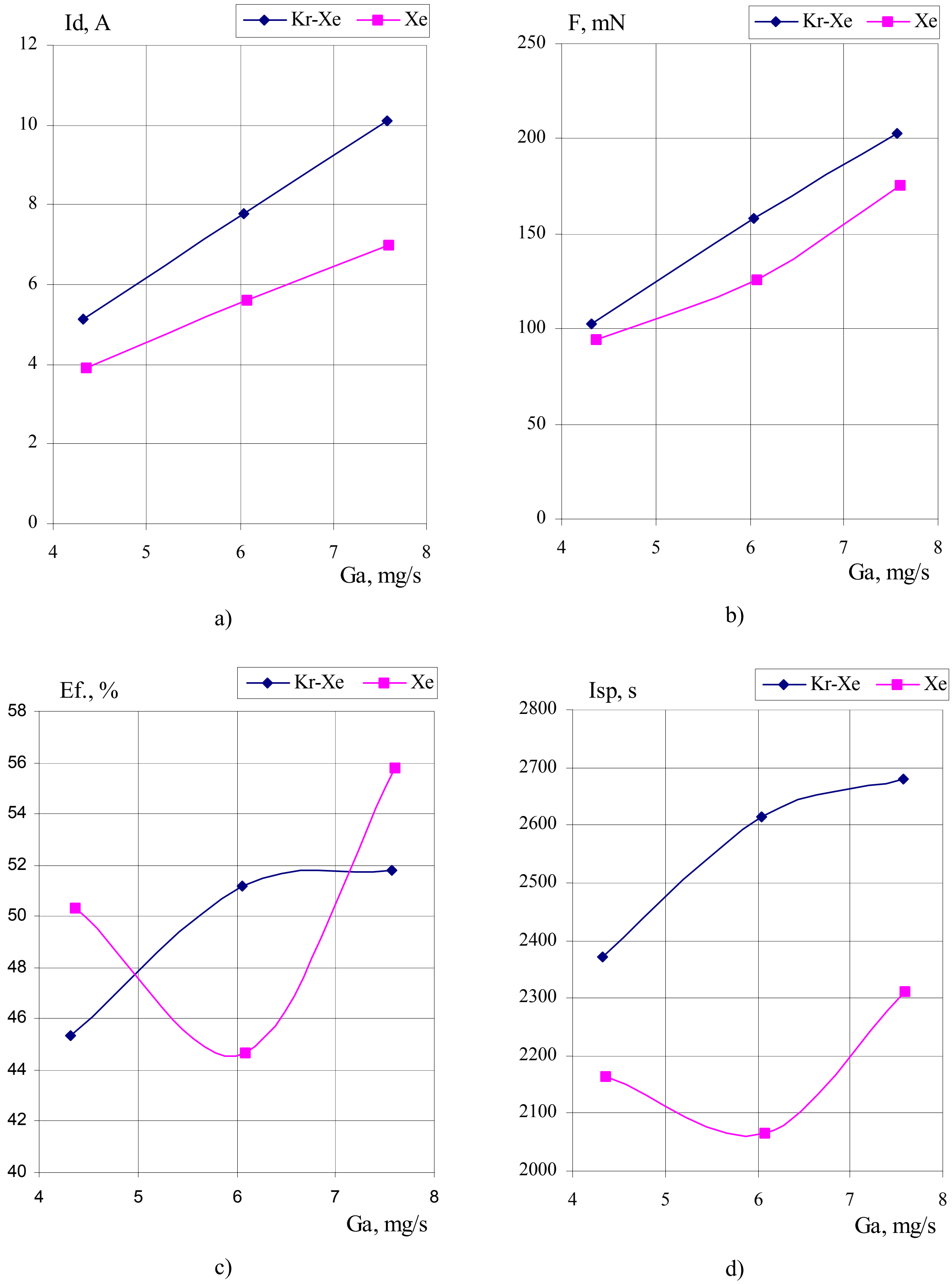


Fig.2. M140-15. Dependence of main parameters on the anode flow rate at Ud=500 V
a)- discharge current; b) - thrust, c) - efficiency without taking into consideration cathode flow,
d) - specific impulse without taking into consideration cathode flow

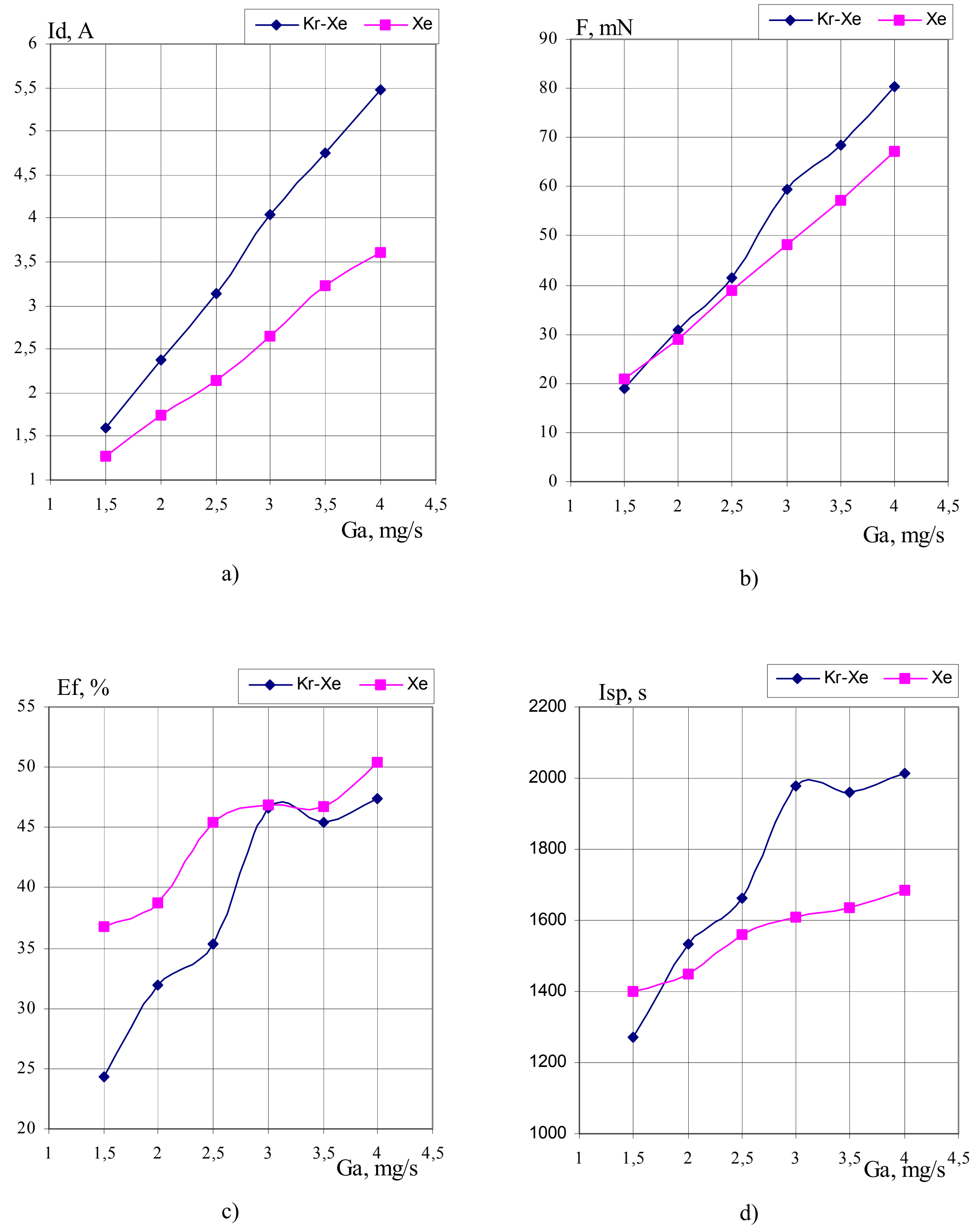


Fig.3. SPT-100. Dependence of main parameters on the anode flow rate at Ud=300 V

a)- discharge current; b) - thrust, c) - efficiency without taking into consideration cathode flow, d) - specific impulse without taking into consideration cathode flow

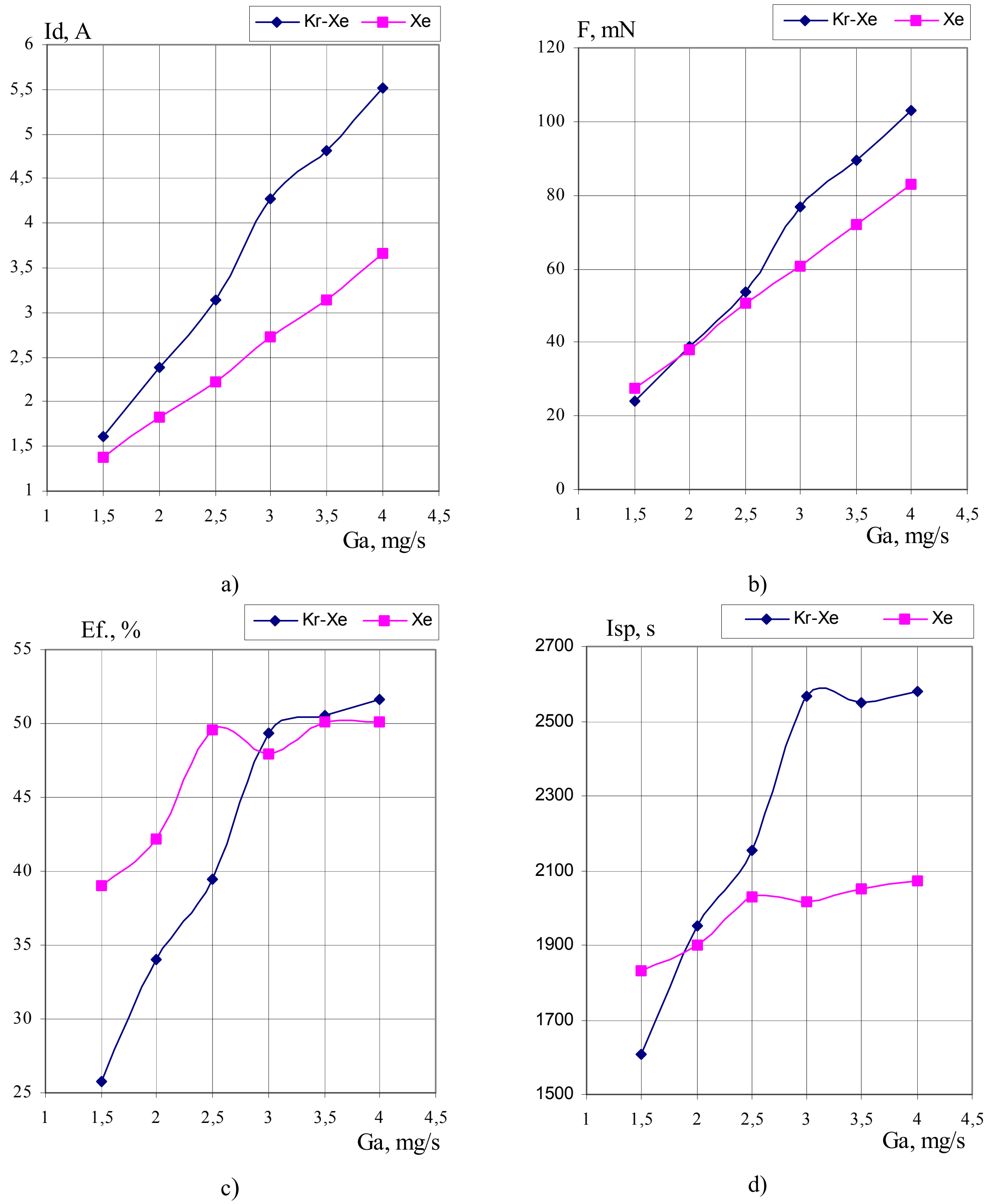


Fig.4. SPT-100. Dependence of main parameters on the anode flow rate at Ud=450 V
a)- discharge current; b) - thrust, c) - efficiency without taking into consideration cathode flow,
d) - specific impulse without taking into consideration cathode flow

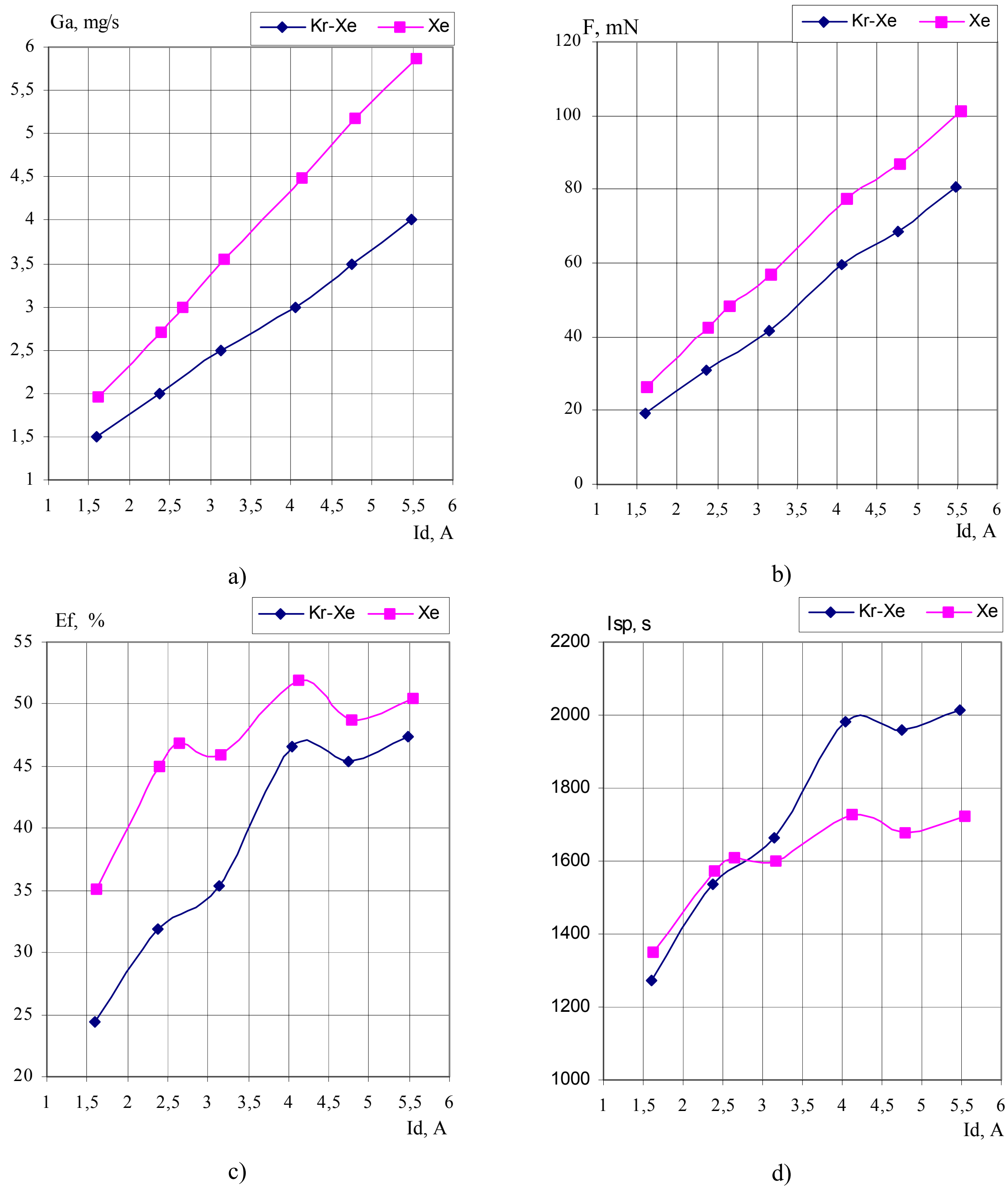
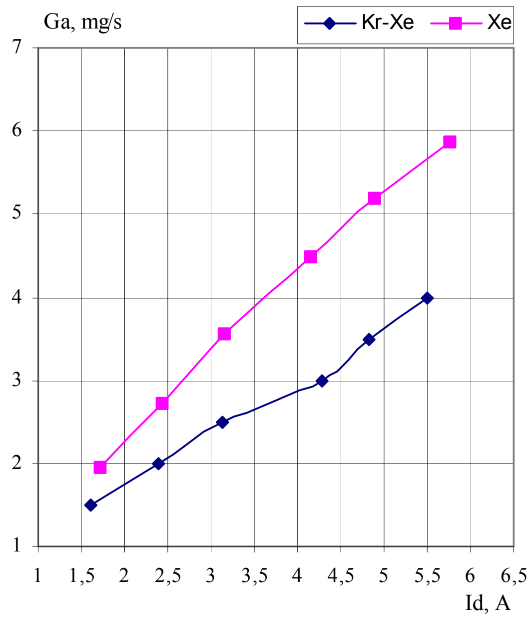
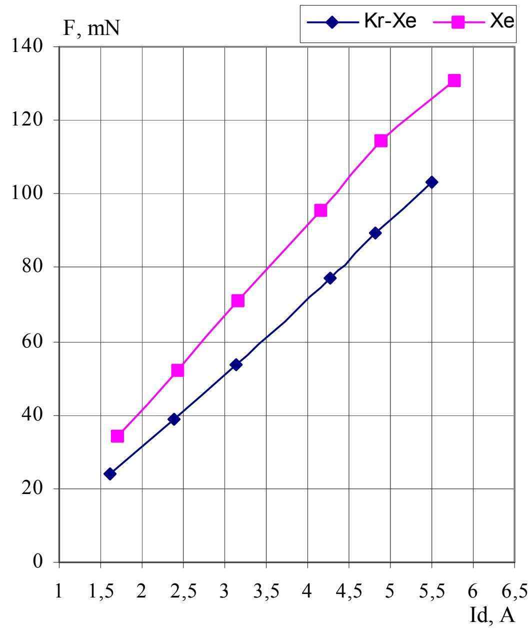


Fig.5. SPT-100. Dependence of main parameters on the discharge current at Ud=300 V
a) - anode flow rate; b) - thrust, c) - efficiency without taking into consideration cathode flow, d) - specific impulse without taking into consideration cathode flow



a)



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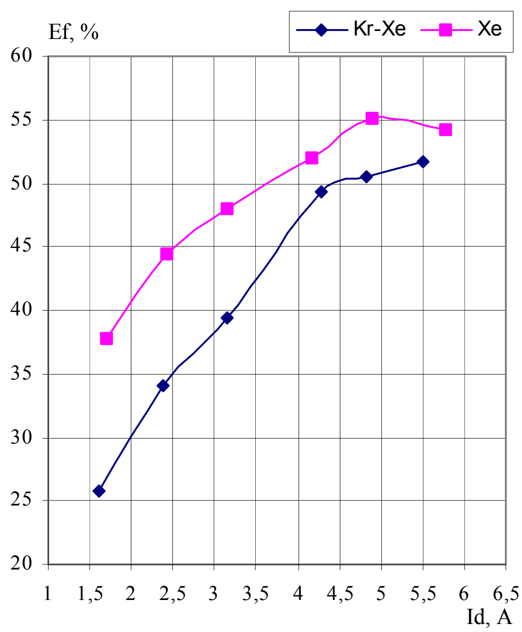

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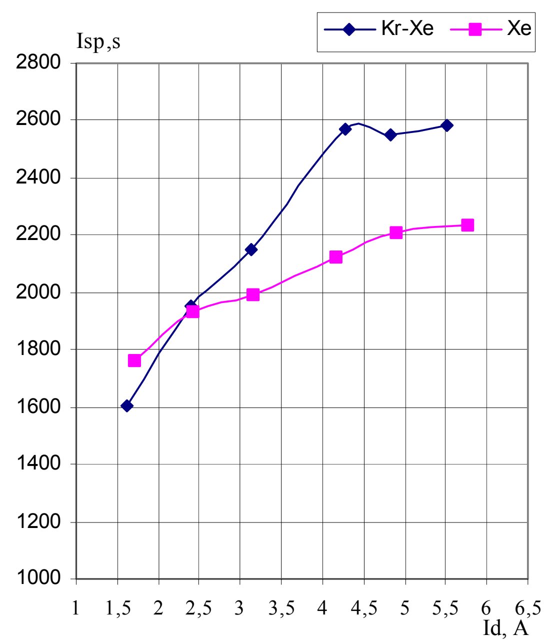

d)

Fig.6. SPT-100. Dependence of main parameters on the discharge current at Ud=450 V
a) - anode flow; b) - thrust, c) - efficiency without taking into consideration cathode flow,
d) - specific impulse without taking into consideration cathode flow