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Introduction of a Steam Screw-Rotor Machine to Improve the Energy and Economic Efficiency of Chemical Enterprises

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Abstract. This article discusses how a steam screw-rotor machine (SSRM) can be introduced as an energy-saving measure at chemical plants. The difference between a SSRM and traditional blade steam turbine installations is also shown. It is proposed that SSRMs be introduced into the thermal circuits of the chemical plants in parallel with the existing pressure reduction and desuperheating station (PRDS) 30/16 and PRDS 15/8 to make it possible to use the potential energy of steam. Passing through the SSRM, the steam decreases its pressure to the required parameters and is then directed to the technological needs of the enterprise. This additionally generates electrical energy that can be used for the plant's own needs. Based on the calculation results, it is proposed that two SSRMs with a capacity of 1.4 and 1.6 MW be installed. This technical solution will make it possible to generate about 20 GW of electricity per year for the plant's own needs. The payback period of the project will be 5.5 years.

Keywords: Cogeneration; Energy saving; Expander; Pressure Reduction and Desuperheating Station (PRDS); Steam Screw-Rotor Machine (SSRM)

1. Introduction

The aim of this work is to increase the efficiency of chemical enterprises by introducing a screw-rotor machine (SSRM) into their heat-technological scheme; this will also generate additional electrical energy for their own needs. This topic is relevant since, in Russia, chemical enterprises use about 12% of the country's total energy consumption.

The energy intensity of the chemical industry is estimated at 15–17% on average. For a number of industries, such as the production of synthetic rubbers, the share of energy resources reaches 20–22% in the cost of production.

Chemical companies try to reduce the cost of heat and electricity by purchasing energy resources from external suppliers, buying energy sources from generating companies, or introducing their own generating capacity.

At the chemical plants under consideration, steam for their technological needs is generated and purchased at nearby thermal power plants. However, the parameters of this steam (temperature and pressure) are too large for the conditions required in the

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enterprises. To reduce the temperature and pressure of the initial steam, chemical enterprises are equipped with a number of pressure reduction and desuperheating stations (PRDSs).

However, when using a PRDS, steam loses its efficiency when throttled. The unused potential of the throttled steam can be realized in turbines (as a rule, these are bladed steam turbine units) when they are installed instead of a PRDS. At the same time, additional electrical energy will be generated for the company's own needs.

This article discusses the use of a steam screw-rotor machine (SSRM) instead of steam-turbine installations. The SSRM is essentially a new type of steam engine. More than 20 patents have been obtained in Russia and abroad for the design of SSRMs, their components and systems.

According to the principle of operation, a SSRM (Figure 1) is a volumetric machine; that is, the expansion of steam occurs in a closed, changing space of the working cavity. This cavity is formed by two helical cavities of the master and slave rotors, as well as the body, and is called a paired cavity (Berezin, 2010a; Ziviani et al., 2016; Rotach et al., 2019b).

High-pressure steam enters the SSRM through the intake window in the housing from one end of the rotors. After filling the groove with steam between the teeth, the steam is cut off and, with further rotation of the rotors in the groove (steam cavity), the volume expansion of the steam portion occurs. At the end of the expansion, the groove communicates with the exhaust windows in the housing at the other end of the rotors. The spent steam is supplied to the network for technological needs (Berezin, 2010b; Smith et al., 2011).

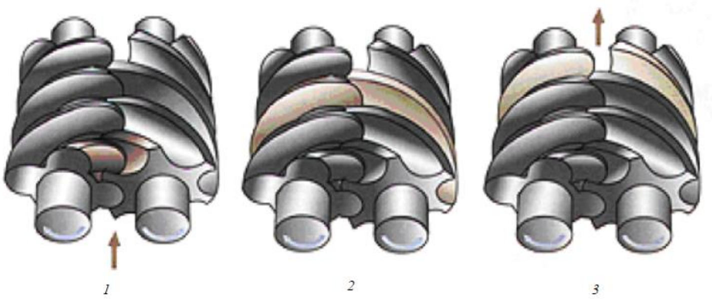

Figure 1 The principle of operation of the SSRM: (1) initial filling of the paired cavity; (2) the expansion of the steam; and (3) exhaust steam output

The main advantage of a SSRM compared with the steam turbine power plants available on the market is that steam turbine installations are designed for almost a single combination of flow and steam pressure at the entrance to the machine and at the exit from it (this combination of steam conditions determines the power of the machine). That is, there are only a certain number of capacities available for steam turbine installations. At the same time, the parameters of steam used by enterprises vary greatly, with the most common power range being 200–2000 kW. A SSRM does not have a certain number of capacities. With a single basic machine design, it is possible to produce a machine of the required power in the abovementioned range. Such variability significantly expands the range of SSRM applications (Berezin et al., 2009a; Guzairov and Akhmetshin, 2009; Rotach et al., 2019a).

In the power range of 200–2000 kW, SSRMs have a number of undoubted advantages over other types of expanders. These include their maneuverability, quick starting and stopping times, large range of power control (20–100%), high dynamics and controllability, frequent stops of the unit are allowed, there is a low load on the foundation (rotation of the rotors in opposite directions ensures balanced operation of the machine and minimizes vibration and force effects on the foundation), high resource (up to 100–150 thousand hours) due to the absence of mutual contact of the rotors and, accordingly, have better mechanical wear (Smith et al., 2001; Quoilin et al., 2010; Bianchi et al., 2018).

A special feature of the SSRM design is the presence of a guaranteed gap between the master and slave rotors. The consequence of this is the absence of mutual contact of the screws and friction between them (Berezin et al., 2009b; Sang-Yoon et al., 2010; Dumont et al., 2018).

An important advantage of the SSRM, which distinguishes it from a number of other machines, is its efficient operation on two-phase media; for example, on wet steam. The liquid phase in the gas during rotation is thrown to the periphery of the screw and flows into the gap between the body and the screws which reduces overflows, thereby contributing to an increase in efficiency (Berezin et al., 2009a; Xia et al., 2015; Dumont et al., 2017). Figure 2 shows the flow of the SSRM workflow in p-V coordinates.

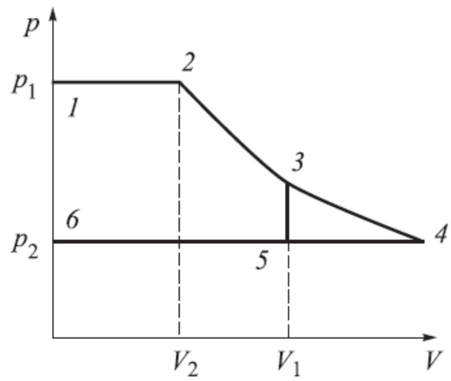

Figure 2 SSRM cycle (p – working fluid pressure; V – working fluid volume): (1)–(2) filling the steam cavity with steam through the inlet window; (2)–(3) volume expansion of steam; (3)–(4) outlet pipe pressure relief; (4)–(6) "squeezing" steam from the steam cavity

To date, SSRMs in the Russian Federation operate at the following facilities:

- Ufa CHPP-4. SSRM, with a capacity of 1.3 MW. The launch took place in 2007. To date, it has worked more than 70,000 hours. The introduction of the SSRM allowed 1600 tons of standard fuel to be saved annually.
- Municipal unitary enterprise "MKS" of the Yamalo-Nenets district. The 1 MW SSRM was launched in 2014.
- Boiler room in p. Krivodanovka, Novosibirsk region. There are two SSRMs with a capacity of 500 kW.
- Central heating point of the Moscow incineration plant no. 3. Three SSRMs with a capacity of 250 kW are used as drives for network pumps.
- Plant of concrete and ceramic products "Bekeron," Moscow (an SSRM with a capacity of 250 kW).
- In February–March 2021, a 1.25 MW steam engine is planned to launch at Ufa CHPP-3.

Regarding application abroad, SSRMs can be found:

- after the heating furnace at Tianjin Tiangang United Co (Lu, 2013);
- in distributed solar power generation systems in Phoenix, Sacramento, Cape Town, Canberra, Lhasa, and Barcelona (Li et al., 2017);
- in the UK, in production by Heliexpower (Heliex Power Ltd);

- in Japan, in production by Kobelco Steel Group (KoCoLab); and at Novolipetsk Metallurgical Plant, where the option of installing a SSRM after the waste heat boilers is being considered.

In a SSRM, the main characteristics of water vapor used as a working fluid are (Berezin et al., 2009b; Giuffrida, 2017): steam pressure at the entrance to the SSRM P = 0.4...2.1 MPa; steam temperature at the entrance to the SSRM t = 145...350°C; consumption of steam passing through the SSRM 5 ... 50 t/h; and steam humidity is not regulated.

SSRMs are designed to work 100,000 hours, have a geometric degree of expansion of ε ≤ 5, and a rational power range of ~ 0.2...2.0 MW (Berezin et al., 2009a; Giuffrida, 2017). Installation of SSRMs is complex, consisting of a power unit and the following systems (Berezin, 2010a; Smith et al., 2011): steam inlet and outlet; a drainage system; a lubrication system; barrier water systems; a cooling system; automatic control, monitoring, and protection; and a generator, switch, control, and protection circuits.

There are three types of SSRMs for power plants: an autonomous mode, a parallel network mode, as well as one for driving actuators. When operating in parallel mode, the power plant operates on the electric network of the enterprise, covering part of its own electricity needs and thereby reducing its consumption from the external power grid (Berezin et al., 2009a; Rane et al., 2013). Thus, when using the potential energy of water vapor that would be lost when reducing steam in existing PRDSs, SSRM installation provides energy-saving measures that allow electrical energy to be generated without the cost of additional fuel (Orosz et al., 2013).

2. Methods

In this section, the calculations consider options for improving the energy efficiency of two petrochemical enterprises by introducing a SSRM into the technological cycle. At the enterprises under consideration (Figure 3), the initial steam of high parameters passes through a number of reduction and cooling units to reduce the initial parameters. Further, the reduced steam is sent to the technological needs of the enterprise. When reducing, the steam loses its potential energy without performing work.

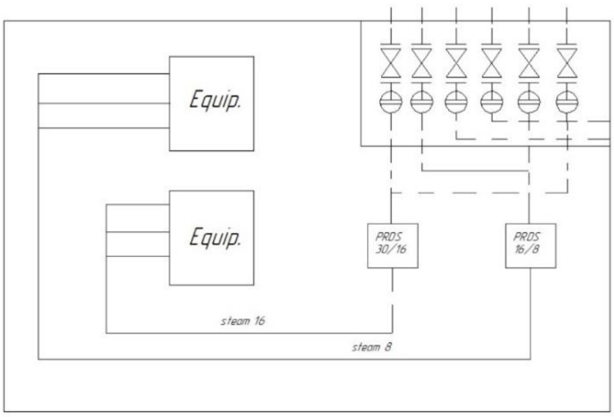

Figure 3 Initial thermal scheme

In order to usefully use the potential energy of the steam, it is proposed that SSRMs be installed parallel to the existing PRDS and steam be passed through them (Figure 4). The electricity generated by the generator will be distributed to the company's electric buses (Kovacevic and Rane, 2013).

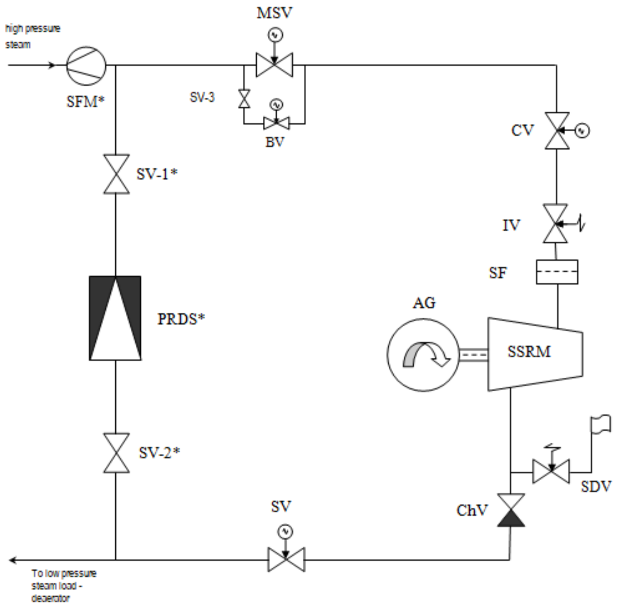

Figure 4 Thermal circuit of the SSRM. SSRM – steam screw-rotor machine; AG – electrical generator; CV – control valve; MSV – main steam valve; BV – bypass steam valve; SV – steam valve; IV – emergency isolation valve; ChV – check valve; SDV – steam dump valve; SF – steam filter; SFM – steam flow meter; PRDS – pressure reducing and desuperheating station

2.1. Enterprise 1: Modernization of the Thermal Circuit by Installing the SSRM Parallel to the PRDS 15/8

To assess the efficiency of the *SSRM* installation, an exergetic calculation of the *PRDS* 15/8 was performed. The equation of exergy balance for the PRDS is:

$$e_{p1} + e_k = e_{p2} + e_{con} \tag{1}$$

where e_{p1} is the specific exergy of steam at the entrance to the PRDS (kJ/kg), e_{p2} is the specific exergy of steam at the outlet of the PRDS (kJ/kg), e_k is the specific exergy of condensate (kJ/kg), and e_{con} is the specific exergy losses from the irreversibility of the throttling process (kJ/kg).

$$e_{con} = \frac{h_{p1} - h_0 \cdot (S_{p1} - S_0) \cdot G_p + h_k - h_0 - T_0 \cdot (S_k - S_0) \cdot G_k - (h_{p2} - h_{0-} T_0 \cdot (S_{p2} - S_0)) \cdot (G_p + G_k)}{(G_p + G_k)} \tag{2}$$

where S_{p1} and S_{p2} are the entropy of the pair before and after the PRDS (kJ/K; S_{p1} = 6.7 kJ/K, S_{o2} = 2.04 kJ/kg), h_{p1} and h_{p2} are the enthalpy of steam before and after the PRDS (kJ/kg; Table 1), S_k and h_k are the entropy and enthalpy of steam of condensate injected into the PRDS (kJ/kg; S_k = 0.95 kJ/K, h_k = 295.48 kJ/kg), T_0 and S_0 are the temperature and the entropy of the environment (T_0 = 293K, S_0 = 0.29 kJ/K), G_p is the steam flow through the PRDS (Table 1), and G_k is the condensate flow injected into the PRDS (Gk = 0.25 kg/s).

Substituting all the values in Equation 2, we determine the exergy losses in the PRDS:

$$e_{con} = 48.97 \text{ kJ/kg}$$

When installing a SSRM, exergy losses will occur due to the irreversibility of the steam-expansion process. We calculate the specific exergy from the irreversibility of the steam-expansion process in the SSRM.

$$e_u = h_{p3'} - h_{p3} - T_0 \cdot (S_{p3'} - S_{p3}) \tag{3}$$

where $h_{p3'}$ and $S_{p3'}$ are the enthalpy and entropy of steam after a SSRM ($h_{p3'}$=2768 kJ/kg, $S_{p3'}$ =2.04 kJ/K), and h_{p3} and S_{p3} are the enthalpy and entropy of steam in the theoretical process of steam expansion in the SSRM (h_{p3}=2743 kJ/kg, S_{p3}=2.01 kJ/K).

Substituting the entire value in Equation 3, we get the value of the specific exergy loss from the irreversibility of the steam-expansion process in the SSRM.

$$e_u=16.21 \text{ kJ/kg}$$

Thus, installation of a SSRM instead of the PRDS 15/8 reduces the loss of exergy by three times.

Table 1 The source data for calculating the parameters of the SSRM

Measurements	Value
Steam consumption	D = 12.7 kg/s
Steam pressure at the PRDS inlet	P_1 = 1.5 MPa
Steam temperature at the PRDS inlet	t_1 = 249 °C
Enthalpy of steam at the PRDS inlet	h_1 = 2921 kJ/kg
Specific volume of steam at the PRDS inlet	v_1 = 0.151 m³/kg
Steam pressure at the PRDS outlet	P_2 = 0.8 MPa
Steam temperature at the PRDS outlet	t_2 = 170 °C
Enthalpy of steam at the PRDS outlet	h_2 = 2768 kJ/kg
Specific volume of steam at the PRDS outlet	v_2 = 0.24 m³/kg

The screw profile is SRM. According to the method of profiling the intake and exhaust windows, the geometric degree of expansion is ε = 1.8. The relative length of the screws is L/D=1.35. For this steam flow rate for a standard-sized row of screws, we accept the diameter of the screws as D = 500 mm, and the length of the screws as L = 675 mm.

The maximum volume of one steam cavity for the SSRM is:

$$V_h = 0.1144 \cdot D^2 \cdot L = 0.1144 \cdot 0.25 \cdot 0.675 = 0.0193 \quad (4)$$

The theoretical steam flow through the SSRM (that is, the maximum throughput of the SSRM) is:

$$G_t = \frac{4 \cdot V_h \cdot n}{\varepsilon \cdot 60 \cdot v_1} = \frac{4 \cdot 0.019 \cdot 3000}{1.8 \cdot 0.151 \cdot 60} = 13.9 kg/s \quad (5)$$

where n is the frequency of rotation of the generator shaft.

The internal SSRM power is:

$$N_i = G_t \cdot (h_1 - h_2) - Q_t = 13.9 \cdot (2921 - 2768) - 600 = 1526 kW \quad (6)$$

where Q_t is the heat taken into the cooling system.

The power of mechanical losses is:

$$N_m = N_i \cdot \left(\frac{1}{\eta_m} - 1\right) = 1526 \cdot \left(\frac{1}{0.95} - 1\right) = 79 kW \quad (7)$$

where Nm is the mechanical efficiency of the SSRM.

Power loss in the generator is:

$$N_m = N_i \cdot \left(\frac{1}{\eta_m} - 1\right) = 1526 \cdot \left(\frac{1}{0.95} - 1\right) = 79 kW \quad (8)$$

where η_g is the efficiency of the SSRM generator.

The SSRM's electrical power (power on the generator shaft) is:

$$N_e = N_i - N_m - N_g = 1526 - 79 - 72 = 1375 \ kW$$

Power generation for the plant's own needs when operating the SSRM n_h = 7000 hours per year is:

$$N = N_e \cdot n_h = 1375 \cdot 7000 = 9625 MWh \quad (9)$$

The savings for the year will be:

$$E = N \cdot C = 9625 \cdot 41.16 = 396165 USD \quad (10)$$

where N is the SSRM's electricity generation per year (thousand kWh), C is the price of electricity for the plant's own needs (USD/thousand kWh), and C =41.16 USD/MW·h.

$$P = E - O = 396165 - 5190 = 390975 USD \quad (11)$$

where O is the equipment repair costs (5190 USD/year).

2.2. Enterprise 2: Modernization of the Thermal Circuit by Installing the SSRM Parallel to the PRDS 30/16

To assess the efficiency of the SSRM installation, an exergetic calculation of the PRDS 30/16 was performed (Martin et al., 2016; Ulum et al., 2017; Nasruddin et al., 2018). Using Equation 2, we determined the specific exergy losses from the irreversibility of the econ-throttling process

$$e_{con}=56.8 \text{ kJ/kg}$$

Using Equation 3, we determined the specific exergy from the irreversibility of the steam-expansion process in the SSRM:

$$e_u=21.28 \text{ kJ/kg}$$

Thus, the installation of a SSRM instead of the PRDS 30/16 reduces exergy losses by 2.5 times.

Table 2 The source data for calculating the parameters of the SSRM

Measurements	Value
Steam consumption	D = 15 kg/s
Steam pressure at the PRDS inlet	P_1 = 3 MPa
Steam temperature at the PRDS inlet	t_1 = 280 °C
Enthalpy of steam at the PRDS inlet	h_1 = 2942 kJ/kg
Specific volume of steam at the PRDS inlet	v_1 = 0.077 m^3/kg
Steam pressure at the PRDS outlet	P_2 = 1.6 MPa
Steam temperature at the PRDS outlet	t_2 = 201 °C
Enthalpy of steam at the PRDS outlet	h_2 = 2792 kJ/kg
Specific volume of steam at the PRDS outlet	v_2 = 0.123 m^3/kg

Due to the high initial steam parameters, we suggest installing a pressure-reducing valve in front of the SSRM, reducing the steam pressure in it from 3 MPa to 2.2 MPa. The reduced steam parameters will be: P_1 = 2.2 MPa, t_1 = 268°C, h_1 = 2942 kJ/kg, and v_1 = 0.105 m^3/kg.

The screw profile is SRM. The geometric degree of expansion is ε = 2.2. The relative length of the screws is L/D = 1.35. For this steam flow rate for a standard-sized row of screws, we accept the diameter of the screws as D = 500 mm, and the length of the screws as L = 675 mm.

The maximum volume of one steam cavity is:

$$V_h = 0.1144 \cdot D^2 \cdot L = 0.1144 \cdot 0.25 \cdot 0.675 = 0.0193 m^3 \quad (12)$$

The theoretical steam flow through the SSRM is:

$$G_t = \frac{4 \cdot V_h \cdot n}{\varepsilon \cdot 60 \cdot v_1} = \frac{4 \cdot 0.019 \cdot 3000}{1.8 \cdot 0.105 \cdot 60} = 16.4 kg/s \tag{13}$$

The internal SSRM power is:

$$N_i = G_t \cdot (h_1 - h_2) - Q_t = 16.4 \cdot (2942 - 2792) - 700 = 1760 kW \tag{14}$$

where Q_t is the heat taken into the cooling system.

The power of mechanical losses is:

$$N_m = N_i \cdot \left(\frac{1}{\eta_m} - 1\right) = 1760 \cdot \left(\frac{1}{0.95} - 1\right) = 93 kW \tag{15}$$

where Nm is the mechanical efficiency of the SSRM.

The power loss in the generator is:

$$N_g = (N_i - N_m) \cdot \left(\frac{1}{\eta_g} - 1\right) = (1760 - 93) \cdot \left(\frac{1}{0.95} - 1\right) = 88 kW \tag{16}$$

where η_g is the efficiency of the SSRM generator.

The SSRM's electrical power is:

$$N_e = N_i - N_m - N_g = 1760 - 93 - 88 = 1579\ Kw$$

Power generation for the plant's own needs when operating the SSRM n_h = 7000 hours per year is:

$$N = N_e \cdot n_h = 1579 \cdot 7000 = 11053 MWh \tag{17}$$

The savings for the year will be:

$$E = N \cdot C = 11053 \cdot 41.16 = 454941 USD \tag{18}$$

where N is the SSRM's electricity generation per year (thousand kWh), C is the price of electricity for the plant's own needs (USD/thousand kWh), and C =41.16 USD/MW·h.

$$P = E - O = 454941 - 5190 = 449751 USD \tag{19}$$

where O is the equipment repair costs (5190 USD/year).

3. Results and Discussion

3.1. Results of Calculations for Enterprise 1

An estimated calculation of the economic efficiency of implementing a SSRM at enterprise 1 is given in Tables 3–5, as well as in Figure 5.

Table 3 An estimated calculation of the economic efficiency of implementing a SSRM at enterprise 1 for the period 2021–2027

Year	2021	2022	2023	2024	2025	2026	2027
Electricity generation, thousand kWh/year	9625	9625	9625	9625	9625	9625	9625
The price of kWh subject to indexation, USD/kWh	0.041	0.043	0.044	0.046	0.047	0.049	0.051
Savings on own needs, thousand USD/year	396.25	411.31	425.29	440.18	455.58	471.53	488.03
Average indexation coefficient for the cost of electricity	1.038	1.034	1.035	1.035	1.035	1.035	1.035
Average annual repair costs, thousand USD	5.19	5.39	5.58	5.77	5.97	6.18	6.40
Growth rate of the construction price index (repair)	1.038	1.034	1.035	1.035	1.035	1.035	1.035
Total savings, thousand USD/year	391.06	405.92	419.72	434.41	449.61	465.35	481.63

Table 4 Estimated calculation of the economic efficiency of SSRM implementation at enterprise 1 for the period 2028–2030

Year	2028	2029	2030
Electricity generation, thousand kWh/year	9625	9625	9625
The price of kWh subject to indexation, USD/kWh	0.016	0.016	0.017
Savings on own needs, thousand USD/year	505.11	522.79	541.09
Average indexation coefficient for the cost of electricity	1.035	1.035	1.035
Average annual repair costs, thousand USD	6.62	6.85	7.09
Growth rate of the construction price index (repair)	1.035	1.035	1.035
Total savings, thousand USD/year	498.49	515.94	534.00

3.2. Calculation of Economic Indicators

The net discounted income (NPV) can be calculated by:

$$NPV = -C_0 + \sum_{i=1}^{t} \frac{C_i}{(1+r)^i} \tag{20}$$

where C_0 is the initial cash investment (C_0 = 770,271 USD), C_i is the income from the implementation of the SSRM in each period (USD), i is the number of periods (i = 10), and r is the discount rate (r = 10%). The internal rate of return (IRR) is calculated from the following equation:

$$NPV = \sum_{i=1}^{t} \frac{C_i}{(1+IRR)^i} = 0 \tag{21}$$

The profitability index can be calculated by:

$$PI = \frac{\sum_{i=1}^{t} \frac{C_i}{(1+r)^i}}{C_0} \tag{22}$$

where C_0 is the initial cash investment (C_0 = 770,271 USD), and r is the discount rate (r = 10%). The payback period can be calculated by:

$$PB = \frac{C_0}{E} \tag{23}$$

where E is the average net profit for the year (USD).

Due to cumbersome formulas, the calculations are not given in this article. The results of the calculations are presented in Table 5.

Table 5 Payback period for the SSRM at enterprise 1

No	Indicator	Value
1	Net discounted income (NPV), thousand USD	59.80
2	Internal rate of return (IRR), %	11.75
3	Profitability index (PI)	1.08
4	Payback period (PBP), years	2.50

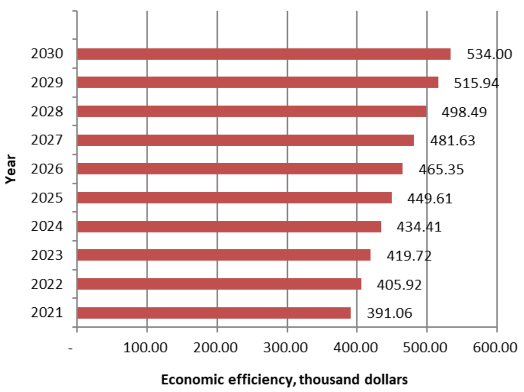

Figure 5 The economic effect of the introduction of a SSRM parallel to the PRDS 15/8

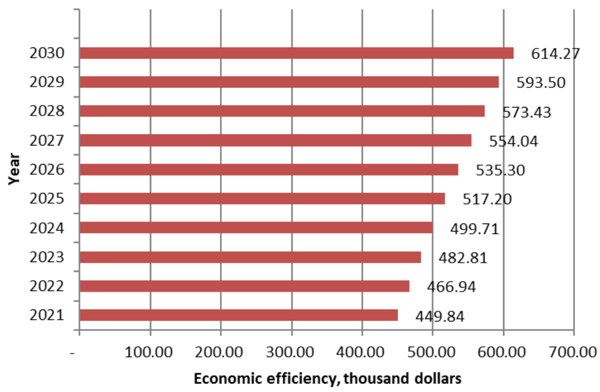

Figure 6 The economic effect of the introduction of a SSRM parallel to the PRDS 30/16

3.3. Results of Calculations for Enterprise 2

An estimated calculation of the economic efficiency of implementing a SSRM at enterprise 2 is given in Tables 6–8, as well as in Figure 6.

Table 6 An estimated calculation of the economic efficiency of implementing a SSRM at enterprise 2 for the period 2021–2027

Year	2021	2022	2023	2024	2025	2026	2027
Electricity generation, thousand kWh/year	11053	11053	11053	11053	11053	11053	11053
The price of kWh subject to indexation, USD/kWh	0.04	0.04	0.04	0.05	0.05	0.05	0.05
Savings on own needs, thousand USD/year	455.04	472.33	488.39	505.48	523.18	541.49	560.44
Average indexation coefficient for the cost of electricity	1.038	1.034	1.035	1.035	1.035	1.035	1.035
Average annual repair costs, thousand USD	5.19	5.39	5.58	5.77	5.97	6.18	6.40
Growth rate of the construction price index (repair)	1.038	1.034	1.035	1.035	1.035	1.035	1.035
Total savings, thousand USD/year	449.84	466.94	482.81	499.71	517.20	535.30	554.04

Table 7 Estimated calculation of the economic efficiency of SSRM implementation at enterprise 2 for the period 2028–2030

Year	2028	2029	2030
Electricity generation, thousand kWh/year	11053	11053	11053
The price of kWh subject to indexation, USD/kWh	0.05	0.05	0.06
Savings on own needs, thousand USD/year	580.05	600.36	621.37
Average indexation coefficient for the cost of electricity	1.035	1.035	1.035
Average annual repair costs, thousand USD	6.62	6.85	7.09
Growth rate of the construction price index (repair)	1.035	1.035	1.035
Total savings, thousand USD/year	573.43	593.50	614.27

Economic indicators were calculated using formulas 20–23 and are summarized in Table 8.

Table 8 Payback period for the SSRM at enterprise 2

No	Indicator	Value
1	Net discounted income (NPV), thousand USD	170.90
2	Internal rate of return (IRR), %	14.75
3	Profitability index (PI)	1.22
4	Payback period (PBP), years	2.00

4. Conclusions

The introduction of a SSRM in the technological scheme of a chemical enterprise will allow the company to obtain steam of the necessary parameters for its technological needs, namely 1.6 and 0.8 MPa, and at the same time will allow additional electricity to be generated by eliminating steam throttling through the PRDS 15/8 and PRDS 30/16. The result of this implementation will be the annual generation of more than 20 GW of electricity for the company's own needs.

The calculations show that, on average, the payback period of the project will be 2.5 years. And with the introduction of a SSRM in parallel with the PRDS 15/8 and PRDS 30/16, the company will be able to save 840,900 USD in 2021. Due to the annual cost indexation for equipment and materials, the savings will only grow.

Installation of a SSRM instead of the PRDS leads to a reduction of the exergy losses of the system. Joint production of electricity does not disrupt the operation of the main production of the chemical enterprise. The steam used in the SSRM has thermodynamic parameters sufficient for use for the main purpose and is sent to the plant's technological needs and its heat exchangers. In addition, the introduction of a SSRM has a positive environmental aspect. Since no organic fuel is used to generate electricity, no pollutants are emitted.

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