SHORT COMMUNICATION

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Gas removal efficiency from a well

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Abstract. The set of equipment for evacuation of wells by pumping gas out from the annulus of the well was developed to study the effect of gas on the characteristics of pumps, increase the pump's feed rate, to reduce gas ingress into the pump and reduce wear of rod screw pumps. The influence of vacuum and pressure increase in the annulus on the dynamic level of the well was studied. The necessity of gas removal from the annular space and bottomhole well zone was substantiated.

Keywords: set of equipment for evacuating of wells, cavity pump installation, wear of elastomer

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During the operation of wells, a fluid along with gas comes out of a formation, the fluid gets degassed, consequently the part of the gas enters the pump, and the other part, separated from the fluid, enters the annulus. The liberation of gas proceeds due to the bottomhole pressure depletion when wells are operated under the saturation pressure. Bottomhole pressure depletion leads to an increase in differential pressure and the inflow of oil from the formation into the well. When a well is operated under a reservoir pressure (P_f) above the saturation pressure (P_{sat}), the gas in the formation will remain in a dissolved state, which facilitates reduction of oil viscosity and increase in mobility of well production within the reservoir (Isaev, 2017).

During oil production, reservoir energy is expended to overcome the hydraulic resistance, adhesive, capillary and other forces. In the reservoir, the fluid flows in capillaries of variable cross-section, the drops of oil or gas surrounded by water get deformed in a narrowing capillary , wherein the radii of curvature of front and rear parts are different, the latter is very wide compared with the tapered front part. In this case, the capillary pressure becomes infinitely large, and this phenomenon is called the Jamin effect. The Jamin effect is the occurrence of additional back pressure in a porous medium due to the fact that the pore channel is a structure of capillaries of variable radii and shapes (Gimatudinov, 1971). The influence of the Jamin effect is widely considered by drillers during completion of producing formations when it is necessary, using the Jamin effect, to take into account such an indicator as drilling mud spurt loss and its clogging properties; it is important to prevent uncontrolled negative impact on the bottomhole formation zone (Andaeva et al., 2013).

Due to vacuuming, the Jamin effect is reduced. Fig. 1 shows the direct Jamin effect, where in the well 1 with the oil reservoir 2, occurs the release of dissolved gas from oil, wherein the movement of fluids in porous media becomes easier.

Experience with operation of wells in the presence of gas in the annulus of wells shows a degradation of the dynamometer chart completeness, a decrease in the delivery rate and operating efficiency of the pumps, a decrease in flow rates and a dynamic level.

As it has been noted, the creation of a vacuum allows the gas to be removed from the fluid in the annulus. Research has established that during evacuation, the chemical analysis of oil changes: it is determined by measuring the gas factor, the values of which were thus zero; thereby, it is possible to completely abandon the gas anchors, since no gas enters the pump during evacuation. Before evacuation the average gas factor values were 24 m^3/t. Measurements of free and dissolved gas were performed using the UZGF unit (gas factor measurement unit), developed by employees of the Department for Innovations and Examination of the Sheshmaoil Management Company. The unit is certified, the method for measuring the gas factor has been agreed and approved by Nefteavtomatika JSC.

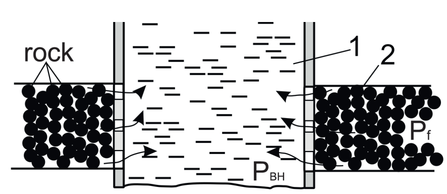

Fig. 1. Gas flow from the oil formation to the well

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Due to the operation of a well with intake pressure (P_{in}) below the saturation pressure, the elastomer material of the screw pump is saturated with aggressive gases. This caused 44.6% of all the repairs with screw pump units (PCP units) at Sheshmaoil Management Company (Isaev, 2016). The analysis of the PCP units' sucker rod partings showed that during the operation under $P_{sat}>P_{in}$, 77% of the rod breaks occurred (Isaev, Arkhipov, 2015). Reducing the dynamic level lower than H_{sus}-$H_{dyn}<100$ m. leads to wear of the elastomer, the pump starts to work in conditions of dry friction, thereby not providing the necessary cooling and lubrication of the pump, which leads to overheating of the elastomer, resulting in an elastomer increasing in size and rupturing. Such facts were recorded on 202 implemented PCP units at Sheshmaoil Management Company LLC (66.8% of the total). As can be seen, the operation of the PCP units is strongly influenced by the value of the fluid level above the screw pump and the saturation pressure. Therefore, it is necessary to strive for increase of the level in the annulus, which is made possible by removing the gas from above the fluid level.

Evacuation will eliminate the saturation pressure, because gas in the «reservoir-bottomhole-pump intake» system is absent, especially at low levels of fluids in the well, and the removal of gas from the reservoir, under certain conditions, will allow increasing the mobility of the reservoir production due to the release by the gas of its occupied space.

Various devices are used to reduce the gas pressure in the annulus of wells: wellhead backpressure valves; bypass valves installed on tubing; compressors installed on conventional pumping unit or wellhead fittings (Sevastyanov et al., 2014; Technology of Gas Withdrawal..., 2012; Molchanova, Topolnikov, 2007; Mak-Koi, 2004). Such devices depend on the gas pressure in the annulus and the pressure in the manifold line.

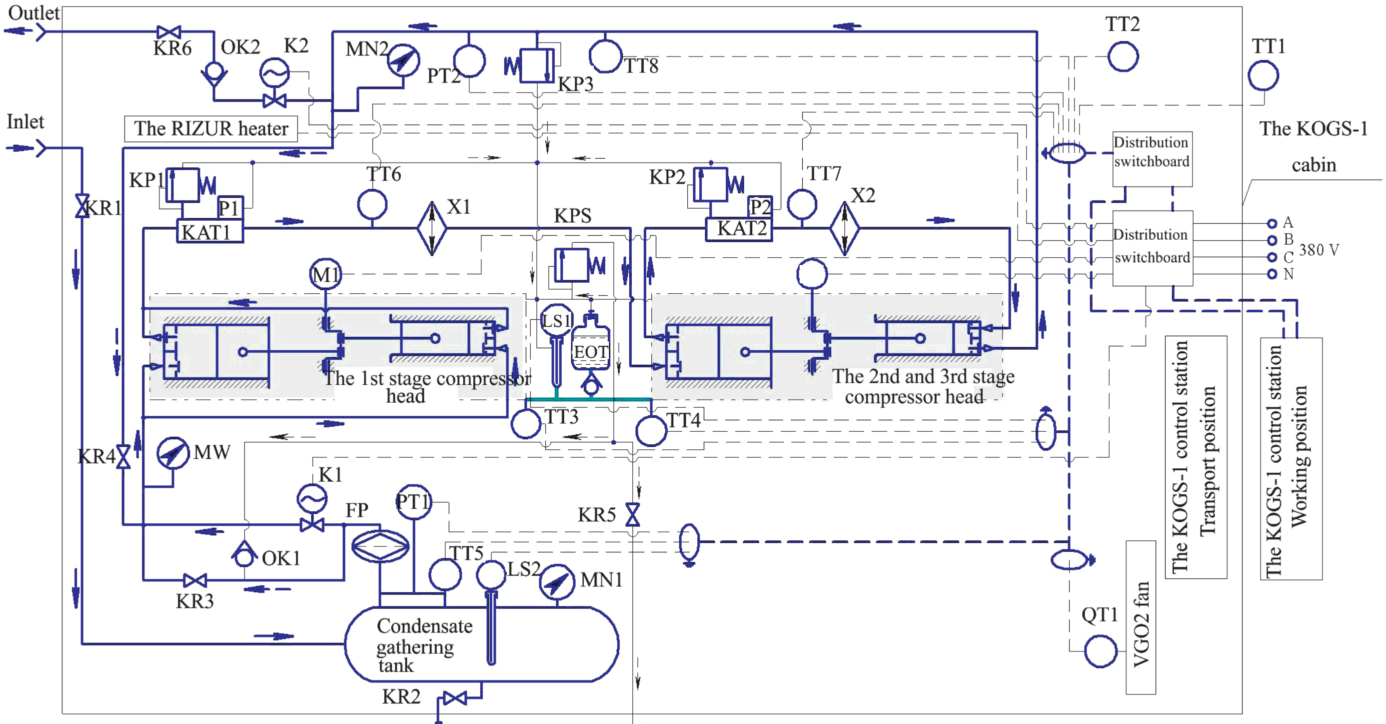
The primary objective was to develop a device that allows to pump the gas out, regardless of the pressure in the annulus, this can be achieved by pumping gas out with a compressor of a certain capacity. The second objective was to pump the gas to a pressure line with a pressure at the outlet of the compressors not lower than the wellhead pressure. The most suitable device for pumping the gas out and pumping it over was a piston compressor. When pumping gas out the compressor allows to create a vacuum, that is, negative pressure. The complex for pumping gas from the annulus of the well and pumping it into the product gathering system (KOGS), shown in Fig. 2 was developed, certified and patented in the Department for Innovations and Examination of the Sheshmaoil Management Company. The technology of creating a vacuum in the annulus of the well, providing a negative pressure of up to 0.085 MPa, has been used in 6 fields of Sheshmaoil Management Company. The maximum capacity of the KOGS compressor is 0.95 Nm^3/min., the maximum operating pressure at the outlet is 2.5 MPa. The KOGS dimensions are small – 4.2 m^2.

Fig. 2. Set of equipment for gas extraction from wells (KOGS)

The schematic diagram of the KOGS unit is shown in Fig. 3. A three-stage compressor consists of a 1st stage compressor head, which operates in a single-stage compressor mode with pistons of different diameters, performs a 1st gas compression stage, and a 2nd and 3rd stage compressor head, which is a two-stage compressor with pistons of different diameter which performs 2nd and 3rd compression stages. Both heads and two electric motors are mounted to them on plates welded to the condensate-gathering tank (CGT). The unit is equipped with an external oil tank (EOT) with an oil level sensor (LS1) to monitor the critically low oil level, to visually monitor the oil level in the lubrication systems of the compressor heads. The condensate-gathering tank (CGT) is a steel vessel with convex elliptical bottoms and four holders. A condensate level sensor (LS2) and a condensate drain valve (KR2) are provided to control the level and drain of condensate from the tank (CGT). The heating system, which includes the RIZUR heater, provides cabin heating with the doors closed and at an external temperature below +10^{0}C in addition to the compressor heads, refrigerators (X1, X2). The ventilation system, which includes the VGO2 fan, provides, if necessary, forced ventilation of the unit's cabin.

The KOGS unit is equipped with electrically driven ball valves (K1 and K2), respectively, at the inlet and outlet of the unit, a back pressure valve (OK1) at the outlet of the unit, safety relief valves (KP1, KP2, KP3), respectively, on the compressor stage and its outlet, a back pressure valve (OK2), safety relief valve of KPS type and ball valve (KR5) in the off- gas gathering system, ball valves (KR1and KR6), respectively, at the inlet and outlet of the unit, gas valves (KR3, KR4) in gas pipelines, for activation bypass line at the beginning of the compressor start-up.

The unit is equipped with pressure gauges (MN1 and MN2) and pressure sensors (PT1 and PT2) to control



EOT – External oil tank
K1, K2 – Electrically driven ball valves
KAT1, KAT2 – Gas accumulation tank
KP1, KP2 – Safety relief valve
KP3 – Safety relief valve
KPS – Safety relief valve of KPS type
KR1, KR2 – Ball valve
KR3, KR4 – Gas valves
KR5, KR6 – Ball valve
LS1 – Oil level sensor

LS2 – Condensate level sensor
M1, M2 – Actuator
MN1, MN2 – Pressure gauge
MW – Vacuum pressure meter
OK1, OK2 – Back pressure valve
P1, P2 – Pressure release assembly
PT1– Intake line pressure sensor
PT2 – Pressure sensor before gate valve of the discharge line
PT3 – Pressure sensor after gate valve of the discharge line
TT1 – Ambient temperature sensor
TT2 – Temperature sensor inside KOGS-1

TT3 – Temperature sensor of oil in the crankcase of the 1st stage compressor head
TT4 – Temperature sensor of oil in the crankcase of the 2nd and 3rd stage compressor head
TT5 – Inlet gas temperature sensor
TT6 – Gas temperature sensor after compressor (1st stage)
TT7 – Gas temperature sensor after compressor (2nd stage)
TT8 – Gas temperature sensor after compressor (3rd stage)
X1, X2 – Refrigerator
FP – Filter in the pressure case
QT1 – Gas content sensor

Fig. 3. Schematic diagram of the KOGS unit

the pressure at the inlet and outlet of the unit, a vacuum pressure meter (MW) to control the magnitude of the vacuum at the intake of the unit, temperature sensors (TT1 and TT2) to monitor the temperature outside and inside the unit's cabin, temperature sensors (TT3 and TT4) to monitor the temperature of the oil in the crankcase of the compressor head of the 1st stage, as well as of the 2nd and 3rd stages, temperature sensors (TT5, TT6, TT7 and TT8) to control the inlet gas temperature after the 1st, 2nd and 3rd stages of the compressor, respectively. A gas content sensor (QT1) is installed in the unit's cabin to control the gas content .

The pipelines interconnect the elements of the unit and have an entrance to the annulus of the well and an exit to the production gathering system of a well. A filter is installed in the pressure case (FN) at the outlet of the condensate-gathering tank.

The control station, which is located in the cabin of the unit in the transport position , and in the working position extends to a safe distance, consists of components that allow to carry out safe unit operation in automatic mode.

The KOGS unit works as follows (Fig. 3). The unit is started by simultaneous starting of electric motors of both compressor heads. Gas from the annulus of the well through the unit's entrance enters the condensate-gathering tank (CGT) and, after passing through the filter in the pressure case (FP), enters the cylinders of the first compression stage, where it is pre-compressed, then via the pipeline and through the refrigerator it enters the second stage, and finally reaches the third stage of compression. The compressed gas is supplied to the product gathering system through the unit's outlet via the pressure line and further through the injection to the line and gas injection control nodes (Fig. 4). KOGS units work 45 minutes on average, then gas is accumulated for 161 minutes.

The use of KOGS increases the production of gas, which is used to heat the oil during its treatment at the oil gathering and treatment facilities. According to the gas meter readings at the DNS-6a and UPSV-567 facilities

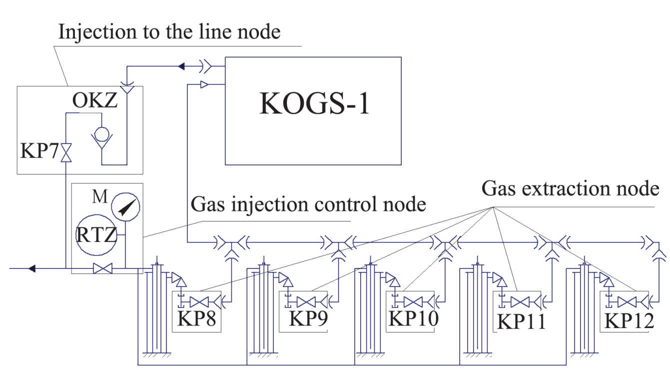


Fig. 4. Layout of a KOGS unit connection in a well cluster: KP7, KP8, KP9, KP10, KP11, KP12 – ball valve, OKZ – check valve, PTZ – pressure sensor, M – pressure gauge

of Sheshmaoil, the volume of additional gas production averages 120 m^3/day for one KOGS unit. An important advantage of KOGS units is the elimination of emissions of harmful substances (gas) into the atmosphere.

The positive side of KOGS unit application was the reduction of wear of the screw pump's elastomer. Under favorable conditions of wells operation by PCP units ($P_{sat}<P_{in}$) the average value of wear degree of the elastomer is 29.5%, i.e. natural wear of the screw pump's elastomer takes place. The degree of wear of the elastomer was determined by the following method: screw pump bench test reports were analyzed before and after the tripping out, then the flow rates at a pressure head of 1000 m have been compared (Isaev, 2018).

The degree of the elastomer wear during the operation of the screw pump up to 21 million rotations and $P_{sat}>P_{in}$ corresponds to the wear degree of the elastomer under favorable conditions. A further increase in the number of rotor rotations in conjunction with the condition $P_{sat}>P_{in}$ leads to even greater wear of the elastomer, thus it is necessary to maintain a dynamic level above the screw pump: one of the solutions is to pump the gas from the annulus of the well (Isaev, 2018). Field experiments with evacuation of annular gas were carried out at 16 wells with the PCP units at the Dachny, Krasnooktyabrsk, Severny and Letny fields (the Republic of Tatarstan). After repair works on these wells and pumps removal, bench tests of screw pumps were carried out to determine the degree of wear of the screw pumps. The wear rate of the elastomer during operation of screw pump with KOGS unit was 24% (Fig. 5), thereby gas evacuation from the annulus of the well allows reduction of pump wear and increases the exploratory work of PCP units (Fig. 6).

The greatest effect of using KOGS units can be achieved under maximum pressure in the annulus (P_{an}) and minimum difference between formation and the bottomhole pressures (P_f-P_{BH}) (Tronov, 2002; Isaev, 2017). According to the efficiency criterion K_{eff}, 3/4 of the wells, which are subject to evacuation, have a flow rate above 2 m^3/day. Regardless of the flow rate, the criterion K_{eff} does not exceed 35% (Isaev, 2018).

The introduction of KOGS units on wells leads to an increase in the dynamic level with a subsequent increase in the flow efficiency of the pump and oil production. Wide experience in the effective operation of KOGS, in

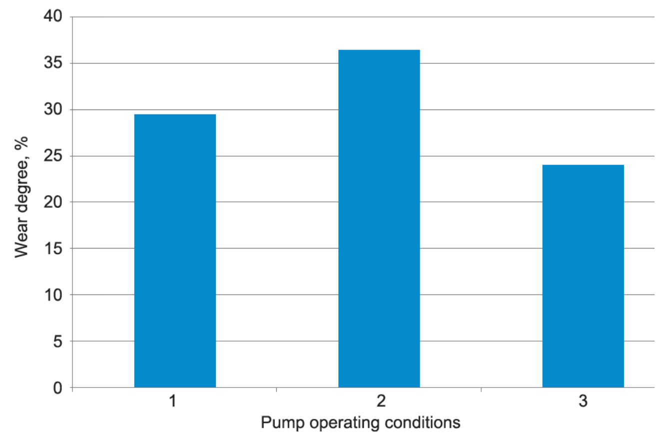


Fig. 5. The wear degree of PCP unit depending on the operating conditions: 1 – favorable, 2 – at $P_{sat}>P_{in}$, 3 – with use of KOGS

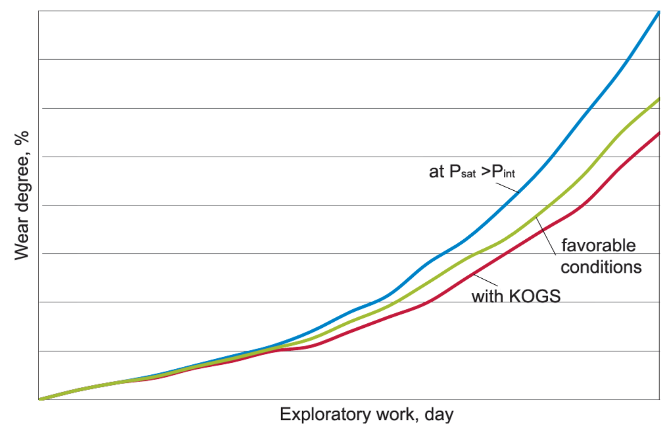
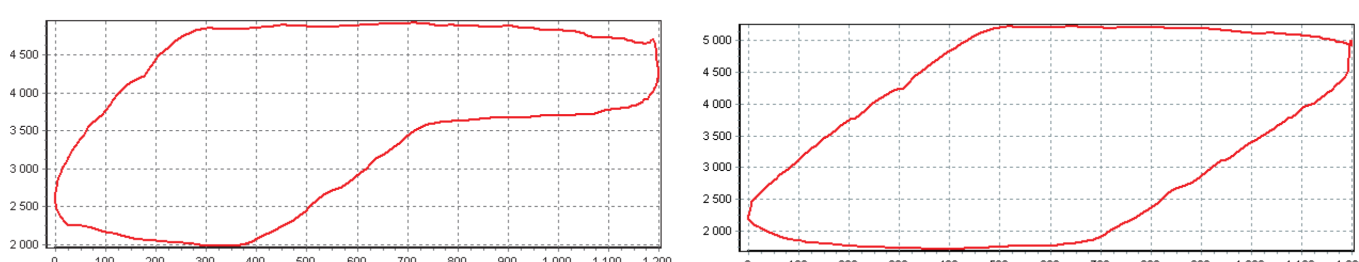


Fig. 6. The dependence of the wear degree on the exploratory work and operating conditions of PCP units

the selection of wells has been accumulated for 8 years of pilot field operation щa KOGS units on 424 wells at Sheshmaoil Management Company. The creation of a vacuum can lead to the absence of gas in the pumped-out fluid and its zero metering by the flowmeters, therefore the minimum pressure for starting the KOGS was taken 0.05-0.1 MPa on these wells. A significant increase in oil viscosity was not detected during vacuuming; only 5 wells recorded an increase in viscosity from 120 to 180 MPa·s on average. The increase in completion of a dynamometer chart when evacuating equals 40% on average (Fig. 7).

The following comparative experiment with measurements of dynamic level and unit's flow rate was conducted on wells 9708 and 9302 of the



a) b)

Fig. 7. Dynamometer chart for well no. 3737 before (a) and after (b) evacuation

Krasnooktyabrsky field (Table 1). At first, the annular space was evacuated by the KOGS units in continuous mode with pressure from minus 0.05 MPa to 0 MPa, and in periodic mode. Periodic vacuuming mode includes first creating a vacuum up to minus 0.05 MPa, then opening the casing valve to equalize the pressure in the annulus with the atmospheric one, followed by an increase in pressure to 0.2 MPa. This process was repeated 4 times. The subsequent analysis showed that the increase in the dynamic level during the described periodic pressure in comparison with the constant vacuum is 2.4%, the fluid flow rate increases by an additional 6-7%. It is planned to conduct additional comparative field experiments with constant and periodic evacuation on wells with different physical and chemical properties of production and geological operating conditions.

All KOGS units are equipped with a BS-21-UVS-2 control station, designed for automatic (based on pressure) and local control of the KOGS units. Under the automatic control mode, the station provides operation of the KOGS unit using signals from pressure sensors installed on the intake and discharge lines. Under the local control mode, the unit is turned on and off with control buttons located on the front side of the station. The unit's data is transmitted to the dispatcher's automated workstation (AWS) in real time mode regardless of the the control station's operation mode. In automatic mode, the station provides the ability to start / stop the unit from the dispatcher's automated workplace. The control station provides remote control and change in the basic working conditions of KOGS unit. In addition to the control station, the automation complex for KOGS includes two non-direct-acting electromagnetic flange valves, one check valve, one DTS125L air temperature sensor, one Metran-75 pressure sensor and two Metran-55-Ex pressure sensors. Table 2 shows the technical characteristics of the BS-21-UVS-2 control station.

When KOGS is operated, the power of the electric motors (compressors (12 kW*h), heater (1.5 kW*h), air fan (0.3 kW*h), heating of the suction and pressure hoses (5 kW*h), electric drive of two valves (0.2 kW*h)) adds up to 19 kW*h. In the warm season, the heating and the furnace are turned off. Given the average KOGS load of 31.7%, the energy consumption of electric motors will be 91 kW*h/day.

During the implementation of KOGS a total of 12,702 tons of oil were additionally produced (Fig. 8). As of 01.09.2018 45 KOGS units are in operation (24 in Sheshmaoil LLC, 17 in Ideloil LLC and Geotech LLC operates 4 units) connected to 194 oil wells. After optimization of all wells, the predicted additional oil production for 2018 is 18,000 tons.

With a discounted payback period of 1.09 years, the profitability index of the discounted costs is 1.35.

Summary

1. Studies of the well's annular space evacuation revealed an improvement in the condition of oil inflow to the well; an increase in operating efficiency and delivery rate of pump; additional production of petroleum gas and oil; decrease in wear of screw pumps and increase in an exploratory work of PCP units; and the elimination of harmful emissions into the atmosphere.

2. Evacuation allows to reset the gas factor, because gas does not flow into the pump during the evacuation.

3. A set of equipment for evacuation of wells has been developed to create vacuum in the annulus of the well and subsequent gas transfer into the manifold.

	Well number	Operational date of KOGS	Pump-setting depth, m	Perforation interval, m	H_{dyn}/P_{annul} before evacuation	H_{dyn} with constant vacuum	H_{dyn} with periodic vacuum
1	9708	11.08.2017	837	839-842	807/7,4	719	701
2	9302	27.07.2017	970	978-982, 989-994	876/3,3	823	804

Table 1. The main properties of wells no. 9708 and 9302

	Technical properties	Value
1	Common power of the station, V	3x380 ±38
2	Nominal frequency, hz	50±1
3	Station power, no more than, kW	20
4	Capacity, no more than, mm	800x600x250
5	Weight, no more than, kg	40
6	Protection level	IP54

Table 2. Technical properties of the Control Station BS-21-UVS-2

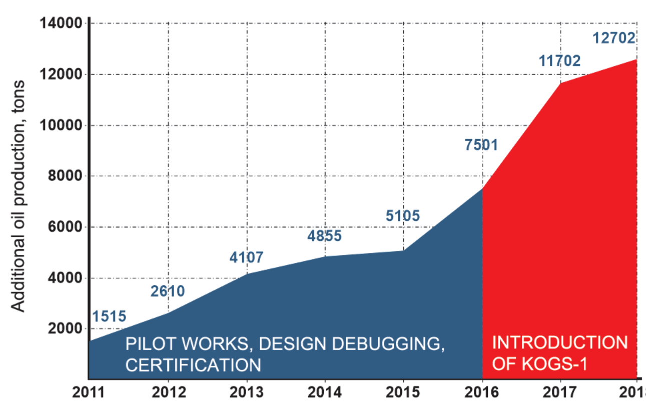


Fig. 8. Additional production from the introduction of KOGS (as of 01.04.2018)

4. Additional oil production during the implementation of KOGS since 2010 amounted to 12,702 tons.

5. The pay-back period of the KOGS introduction on wells is 1.09 years.

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