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Contamination effects study in the centrifugal compressor flow stage by means numerical simulation methods.

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Abstract. At the moment there is no effective way to clean the flow of the turbine unit, which is justified from an economic point of view. It is important to understand how deposits affect compressor performance and the need to clean contaminants. In the available literature, such studies are not described. The computational the model stage domain for the study includes the following elements: inlet pipe, impeller, bladeless diffuser, swivel elbow, backward guide apparatus, outlet pipe. For calculations, the computational fluid dynamics methods in the Ansys software package were used. A numerical experiment was carried out in six mass flow rate variants, two impeller revolutions variants, and three different sediment thicknesses in the flow part variants. Based on the numerical experiment the results, the calculated machine operating modes characteristics are constructed. The analysis revealed that the studied deposits cause a drop in the stage characteristics by 1.5-2%. Losses in the stage increase in proportion the thickness deposits in the compressor flow part.

Introduction

Centrifugal compressors have found the widest application in power engineering. In modern gas-transport networks, centrifugal compressors are the main equipment for gas compression. Despite the filtering equipment presence at an inlet to the compressor, its flow-through part is contaminated with aerosols present in the environment, as well as various contaminants (oil, soot, drip, etc.) allocated by various nodes of the unit itself. In the literature available, such studies are not described. It is very important to understand exactly how deposits affect compressor characteristics, and the need for cleaning the contaminants. At the moment there is no effective cleaning method, which would justify itself from an economic view point [1]. One of the simplest methods is mechanical

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compressor flow part cleaning. This method is quite effective, but requires complete unit stoppage and partial disassembly. This involves some difficulties, the gas transport shutdown since causes economic loss, as well as a reverse assembly of the machine, in which , for example, it is possible to improperly perform balancing, which will lead to other problems. The second method is special pumping composition through a turbine unit flowing part. This method does not require stopping the machine, but does not guarantee a flow section complete cleaning, since if the composition is excessively aggressive, the compressor working part may be a subject to destruction.

The objectives of this work:

1. Sediments effects investigation in a centrifugal compressor flow part and the rationale for cleaning from an economic point of view.

Methods

The study was carried out on a real prototype stage centrifugal compressor, using the software package ANSYS. The calculation involved the detailed spatial computer model use with a grid of discretization [2-11] necessary for solving this problem, and real gas parameters [12] were used as working fluid, which directly leads to the increase in the results obtained accuracy. The gas composition is shown in Table 1. Viscous gas flow numerical simulation was carried out with six different mass flow options, from 28 kg / s to 33 kg / s, and also with two rotor speeds, at nominal speed of 10600 rpm and at 10000 rpm. The depositions were taken with a thickness δ = 2 mm and 3 mm, and their scheme is shown in Fig. 1.The deposits position was taken based on the using compressors practice. In the simulation, the SST turbulence model was used [13-20], and the grid elements total number exceeded 1 million. In the results processing, pressure and useful-action coefficient were calculated by the formulas:

$$\psi_n = \frac{h_p}{U_2^2} \quad (1).$$

$$\eta_p = \frac{h_\Pi}{h_i - h_d} \quad (2).$$

Where, h_p – is the polytrophic head, J/kg; h_i – is the internal head, J/kg; h_d – is the dynamic head, J/kg, pressure J/kg, in the above expressions are determined by the following formulas:

$$h_p = \frac{n}{n-1} R T_0 \left[\left(\frac{p_i}{p_0} \right)^{\frac{n-1}{n}} - 1 \right] \quad (3).$$

The exponent n/(n - 1) is determined by the formula:

$$\frac{n}{n-1} = \log \frac{p_i}{p_0} / \log \frac{T_i}{T_0} \quad (4).$$

The dynamic head h_d, J/kg, is determined by the formula:

$$h_d = \frac{c_i^2 - c_0^2}{2} \quad (5).$$

Where, c_i and c_o – are the velocities in the corresponding sections, m/s;

$$h_i = h_T + h_{df} + h_l \quad (6).$$

here h_t is the theoretical head, J/kg; h_{df} – disk friction pressure, J/kg; h_l – leakage pressure, J/kg. These characteristics determine compressor efficiency and pressure, the zone of its stable operation.

Table 1. - The gas mixture's composition.

Component name	Share, %Mol.
Helium,%	0.00565
Hydrogen,%	0.00155
Oxygen,%	less 0.005
Carbondioxide,%	0.34750
Nitrogen,%	0.41900
Methane,%	94.78500
Ethane,%	1.5000
Propane,%	1.23500
i-Butane,%	0.42900
n-Butane,%	0.45850
neo-Pentane,%	0.00750
i-Pentane,%	0.14200
n-Pentane,%	0.10200
Hexanes,%	0.07550
Heptanes,%	0.02990
Octanes,%	0.00875
Densityat kg/m3 0.725	

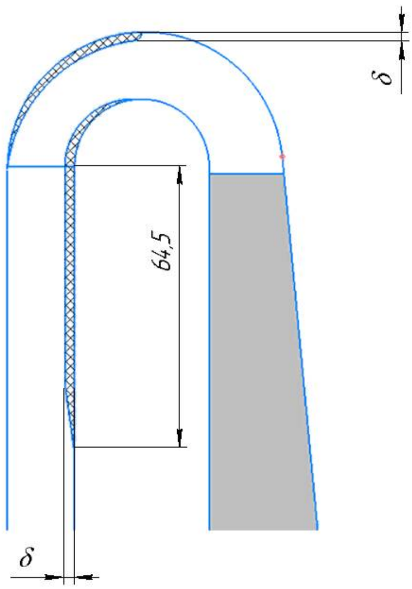

Fig.1. Deposits scheme in a centrifugal compressor stage flow part.

Results

Table 2 presents the calculating results the gas-dynamical parameters a centrifugal compressor stage at n = 10600 without contamination in the flow section, as well as the processing results these data.

Table 2 Three-dimensional viscous ANSYS calculation at n = 10600 with thickness deposits δ = 0 mm

$\bar{m}$	ΔT	P_k	Π	Π_k	η_p	ψ_i	$\zeta_{2\text{-}4}$	$\zeta_{4\text{-}5}$	$\zeta_{5\text{-}k}$	$\zeta_{2\text{-}k}$
28	23.72	240384	1.352	1.2375	0.9094	0.7199	0.11171	0.08410	0.2692	0.4276
29	23.46	239398	1.347	1.2354	0.9095	0.7127	0.10893	0.08176	0.2639	0.4141
30	23.19	238362	1.343	1.2332	0.9091	0.7055	0.10653	0.07962	0.2600	0.4027
31	22.91	237282	1.338	1.2309	0.9083	0.6982	0.10419	0.07789	0.2568	0.3924
32	22.63	236159	1.333	1.2285	0.9072	0.6909	0.10143	0.07624	0.2541	0.3822
33	22.33	234992	1.328	1.2259	0.9057	0.6836	0.09887	0.07485	0.2524	0.3732

Table 3 presents the calculating results the gas-dynamical parameters a centrifugal compressor stage at n = 10600 with contamination in the flowing part 2 mm thick, as well as the processing results these data.

Table 3 Three-dimensional viscous ANSYS calculation at n = 10600 with thickness deposits δ = 2 mm

$\bar{m}$	ΔT	P_k	Π	Π_k	η_p	ψ_i	$\zeta_{2\text{-}4}$	$\zeta_{4\text{-}5}$	$\zeta_{5\text{-}k}$	$\zeta_{2\text{-}k}$
28	23.71	240118	1.35	1.2372	0.9062	0.7199	0.1168	0.0872	0.2678	0.4446

29	23.45	239127	1.346	1.2352	0.9061	0.7127	0.1140	0.0851	0.2630	0.4320
30	23.17	238084	1.341	1.2330	0.9056	0.7055	0.1113	0.0835	0.2592	0.420
31	22.89	236994	1.336	1.2307	0.9046	0.6983	0.1089	0.0817	0.2561	0.4103
32	22.61	23585	1.331	1.2283	0.9033	0.691	0.1063	0.0801	0.2538	0.4005
33	22.32	234678	1.326	1.2257	0.9016	0.6836	0.1040	0.0784	0.2527	0.3922

Table 4 presents the calculating results the gas-dynamical parameters a centrifugal compressor stage at n = 10600 with contamination in the flowing part 3 mm thick, as well as the processing results these data.

Table 4 Three-dimensional viscous ANSYS calculation at n = 10600 with thickness deposits δ = 3 mm

$\bar{m}$	ΔT	P_k	Π	Π_k	η_p	ψ_i	$\zeta_{2\text{-}4}$	$\zeta_{4\text{-}5}$	$\zeta_{5\text{-}k}$	$\zeta_{2\text{-}k}$
28	23.7	239928	1.349	1.2374	0.9041	0.7199	0.1198	0.0917	0.2693	0.4581
29	23.43	238928	1.345	1.2353	0.9038	0.7127	0.1169	0.0899	0.2643	0.4457
30	23.16	237875	1.34	1.2331	0.9031	0.7055	0.1144	0.0882	0.2603	0.4348
31	22.88	236774	1.335	1.2308	0.9020	0.6983	0.1121	0.0866	0.2570	0.4249
32	22.6	235627	1.33	1.2284	0.9005	0.6909	0.1096	0.0850	0.2548	0.4158
33	22.3	234435	1.325	1.2258	0.8986	0.6836	0.1075	0.0834	0.2541	0.4080

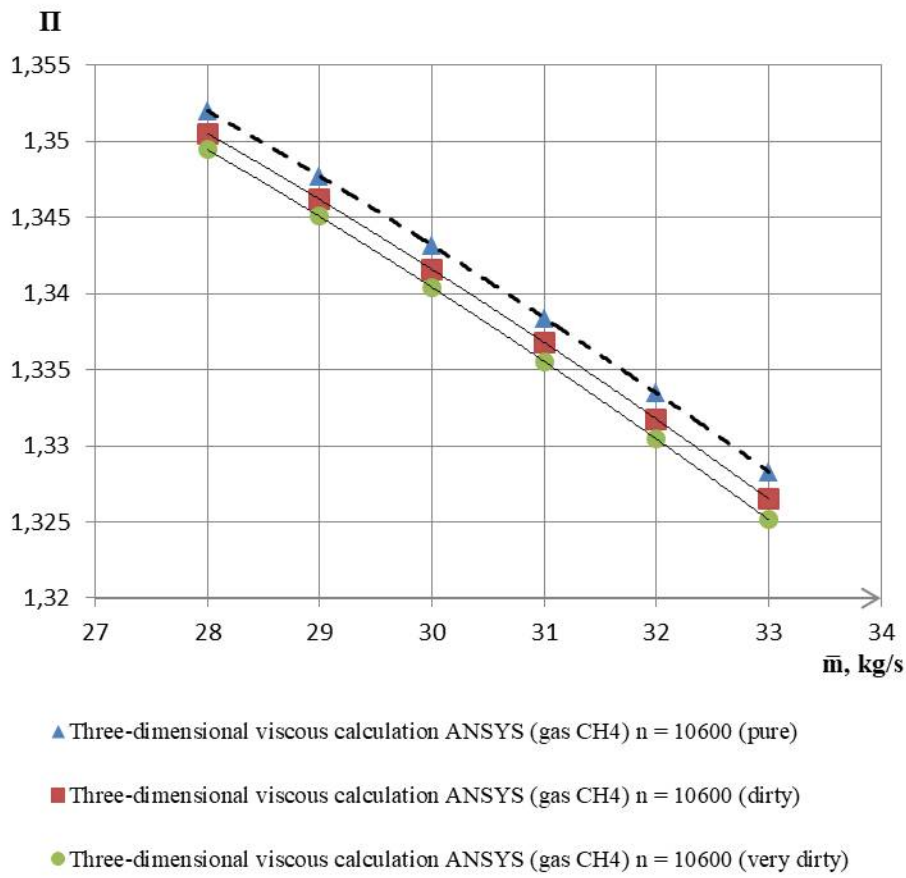

Fig. 2 Deposits effect on a compressor stage efficiency at n = 10600

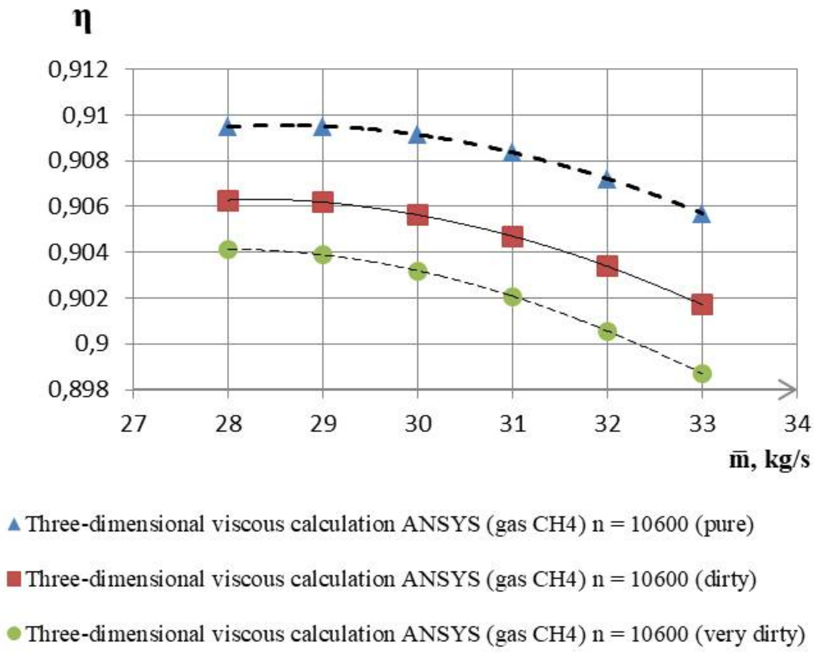

Fig. 3. Deposits effect on a compressor stage efficiency at n = 10600

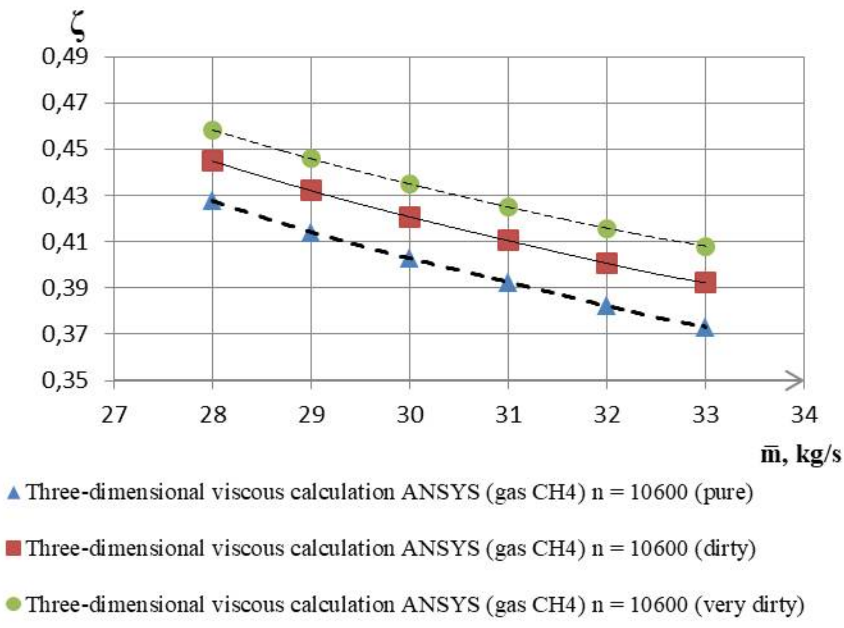

Fig. 4 Deposits effect on a compressor stage efficiency at n = 10600

Table 5 presents the calculating results the gasdynamic parameters a centrifugal compressor stage n = 10000 without contamination in the flowing part, as well as the processing results these data.

Table 5. Three-dimensional viscous ANSYS calculation at n = 10000 with thickness deposits δ = 0mm

$\bar{m}$	ΔT	P_k	Π	Π_k	η_p	ψ_i	$\zeta_{2\text{-}4}$	$\zeta_{4\text{-}5}$	$\zeta_{5\text{-}k}$	$\zeta_{2\text{-}k}$
28	20.58	231113	1.299	1.204655	0.9082	0.7047	0.1042	0.0803	0.2614	0.399
29	20.31	230101	1.295	1.202417	0.9073	0.696	0.1021	0.0780	0.2577	0.3888
30	20.04	229040	1.29	1.200043	0.9060	0.6891	0.100	0.0760	0.2547	0.3796
31	19.76	227942	1.285	1.197581	0.9043	0.6812	0.0989	0.0745	0.2526	0.3717
32	19.48	226805	1.28	1.195004	0.9022	0.6733	0.0973	0.0729	0.2523	0.3653
33	19.17	225626	1.275	1.192304	0.8997	0.6653	0.0958	0.0709	0.2541	0.3598

Table 6 presents the calculating results the gas-dynamical parameters a centrifugal compressor stage at n = 10000 with contamination in the flowing part 2 mm thick, as well as the processing results these data.

Table 6. Three-dimensional viscous ANSYS calculation at n = 10000 with thickness deposits δ = 2 mm

$\bar{m}$	ΔT	P_k	Π	Π_k	η_p	ψ_i	$\zeta_{2\text{-}4}$	$\zeta_{4\text{-}5}$	$\zeta_{5\text{-}k}$	$\zeta_{2\text{-}k}$
28	20.57	230871	1.298	1.204463	0.9047	0.7047	0.1097	0.0832	0.260	0.4174
29	20.3	229847	1.293	1.202236	0.9036	0.697	0.1076	0.0812	0.2571	0.4071
30	20.03	228781	1.289	1.199896	0.9022	0.689	0.1056	0.0798	0.2543	0.3983
31	19.74	227671	1.284	1.197434	0.9002	0.681	0.103	0.0786	0.252	0.3908
32	19.46	226519	1.279	1.194856	0.8979	0.6734	0.1024	0.0768	0.2531	0.3846
33	19.15	225325	1.273	1.19215	0.8952	0.6654	0.1011	0.0746	0.2555	0.380

Table 7 presents the calculating results the gas-dynamical parameters a centrifugal compressor stage at n = 10000 with contamination in the flowing part 3 mm thick, as well as the processing results these data.

Table 7. Three-dimensional viscous ANSYS calculation at n = 10000 with thickness deposits δ = 3 mm

$\bar{m}$	ΔT	P_k	Π	Π_k	η_p	ψ_i	$\zeta_{2\text{-}4}$	$\zeta_{4\text{-}5}$	$\zeta_{5\text{-}k}$
28	20.56	230686	1.297	1.204554	0.90221	0.7047	0.1130	0.0875	0.2618
29	20.29	229651	1.292	1.202322	0.900945	0.6969	0.1108	0.0861	0.2583
30	20.01	228574	1.288	1.199982	0.899247	0.6891	0.1088	0.0850	0.2552

31	19.73	227454	1.282	1.19752	0.897154	0.6812	0.1072	0.0839	0.2534
32	19.44	226293	1.277	1.194943	0.894605	0.6733	0.1060	0.0818	0.2545
33	19.14	225088	1.272	1.192236	0.891648	0.6653	0.1047	0.0800	0.2566

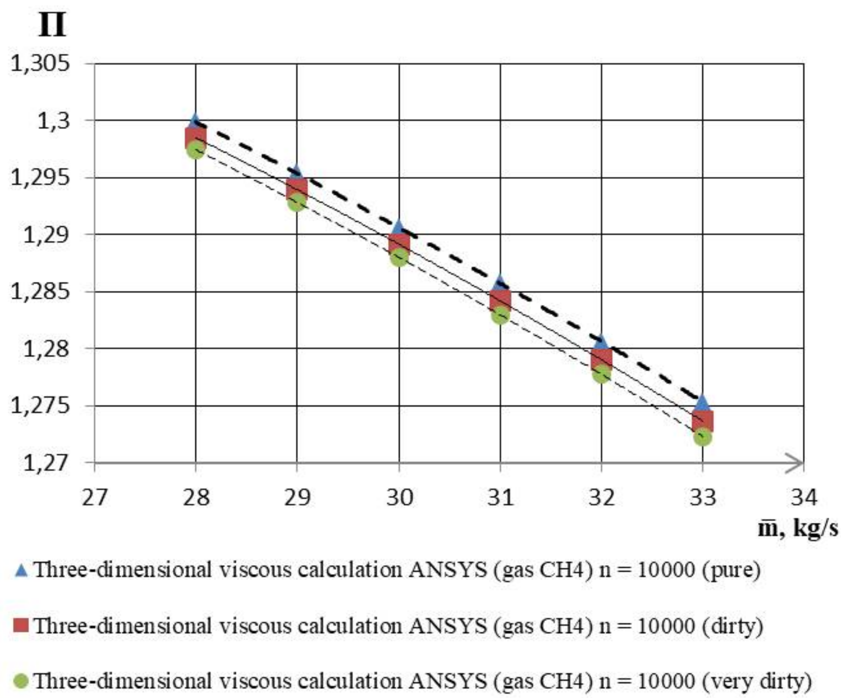

Fig. 5. Deposits effect on a increase pressure degree of the compressor stage at n = 10000

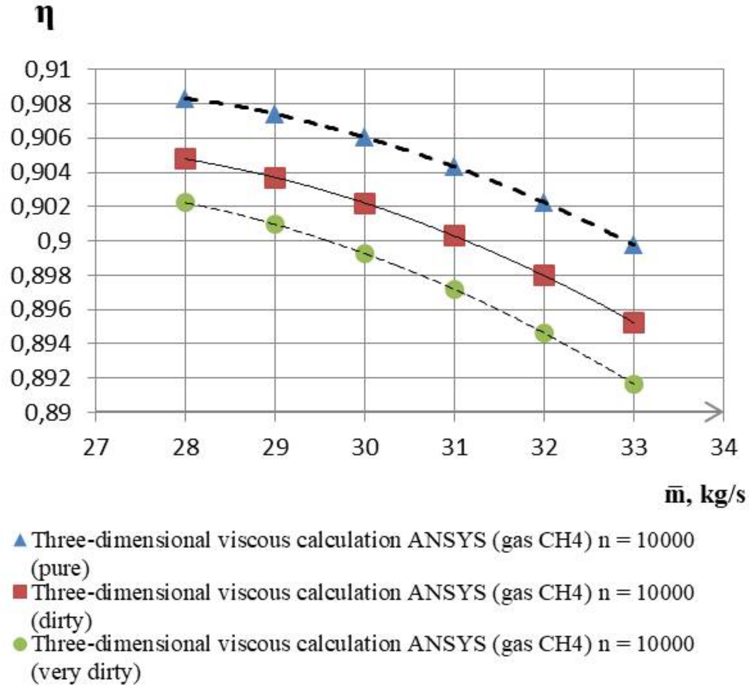

Fig. 6 Deposits effect on total loss in the compressor stage with n = 10000

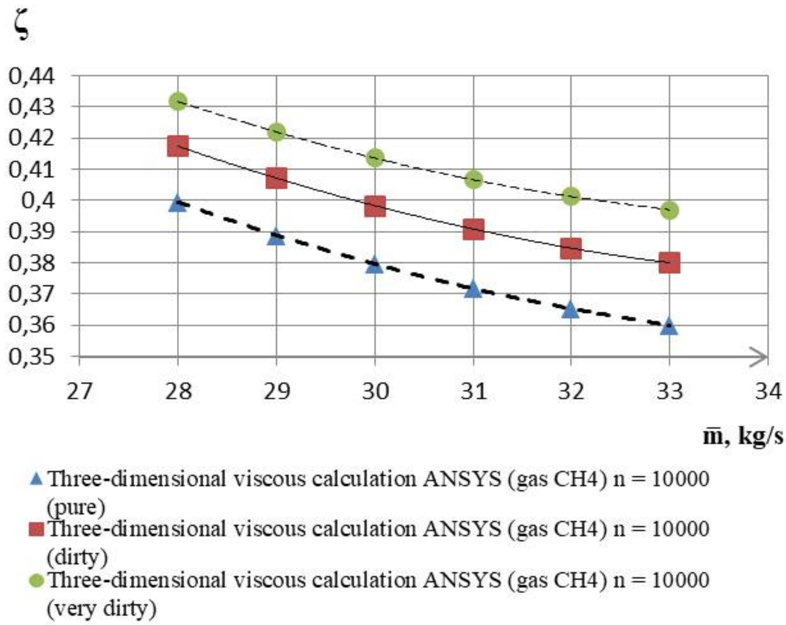

Fig. 7 Deposits effect on total loss in the compressor stage with n = 10000

As it can be seen from the graphs, the deposits presence in the compressor flowing part causes a drop in the compressor characteristics output, the drop lies within 1-2%. The loss in the compressor stages increase in proportion to the deposits thickness in the flow part. The deposits thickness can't be more than certain; the flow velocity in the flowing part will not allow to detain the forming elements, and in the deposits presence, the velocity will only increase. However, the deposits presence in the flowing part not only affects the characteristics of the machine, but also is a particles source that is detached from the deposits under the flow influence. The dense particles presence in the flow can lead to damage surface of the blade, for example, the protective layer destruction, which will lead to corrosion, and, accordingly, to the working part replacement.

Conclusions

As a result of the numerical study carried out in CFD for the this type stage and modes of operation, it has been shown that, in addition to the deposits effect on characteristics, other factors that may have a greater effect on the change in compressor performance during operation are to be considered.

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