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WORKING PLACES NOISE REDUCTION MEASURES FOR MILK PROCESSING INDUSTRY

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ABSTRACT

Noise levels are exceeded in the workplaces of the dairy industry. For noise reduction, an original insulation construction was developed. Its basis is a honeycomb panel covered with a plate with perforation in the form of triangular holes. A cellular elastic mesh of 2mm-isolon is fixed on the outer side of the perforated plate. The panel is hermetically covered with a thin 50 microns film. Evaluation of noise protection effectiveness measures was carried out according to the influence of increased noise on labor productivity. The annual economic effects of three workshops were estimated by comparing the economic result and the reduced costs of the preparation and implementation of the soundproof structure. With noise protection, working conditions improved, labor productivity increased, and the amount of insurance contributions to the pension fund decreased. The influence of noise on labor productivity was carried out taking into account the actual duration of technological processes with the participation of employees of the milk processing enterprise. The time of natural technological processes was excluded from the time of the work shift. Also, time for sanitary treatment was excluded too. The annual reduced costs included the costs of the preparation and installation of the noise insulation construction. The economic effect of the introduction of insulation construction in the form of a suspended ceiling in three workshops amounted to 1,171.59 thousand rubles with a 0.98-year payback period. This study allows us to recommend the developed sound-absorbing panels for use in similar enterprises.

Disciplinary: Industrial and Agricultural Process, Acoustics And Noise Control.

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1. INTRODUCTION

Increased noise has a detrimental effect on the entire human body. Conduct further engineering research to find new effective solutions for noise protection is an important socio-economic task. The assessment of social efficiency in terms of value is not always possible due to the lack of case studies results. The impact of increased industrial noise on workers' labor productivity seems possible since there are results of case studies on milk processing enterprises.

2. METHODS AND MATERIALS

The study discusses soundproofing measures at a milk processing enterprise. It is cellular sound-absorbing structures with sanitary-hygienic design solutions that meet regulatory requirements.

Research and methods:

- modeling the sound-resonant frequency of a noise insulation structure;
- a three-factor experiment conducted in a reverberation chamber and in a production environment;
- the methodology of the technical and economic evaluation of scientific developments.

3. RESEARCH RESULTS AND DISCUSSION

To reduce the noise level at the workplaces of the dairy processing enterprise, we have developed an original soundproofing construction (Pyatkina et al., 2013; Savel'yev, 2013; Tyurin, 2012), the basis of which is a cellular panel of a certain thickness. The faces of the hollow cells of the cellular panel have holes that ensure the distribution of inertial forces, elasticity, and friction of air masses in its internal space. On the bottom of the cellular panel, a solid plate is mounted, and a perforated plate is attached to the upper part also on a glue base. The geometric shape and area of perforation were determined as a result of theoretical and experimental studies to reduce noise in a given frequency range. An elastic mesh is attached to the outer side of the perforated plate. The prepared panel is hermetically covered with a thin film.

3.1 SOUND-ABSORBING STRUCTURE

The operation principle of the sound-absorbing structure is as follows.

The propagated direct and reflected sound waves in the room initially pass through a thin film of noise-absorbing structure. The resonant properties of the film and dissipative losses in the cells and air spaces provide maximum absorption of the sound wave energy. The air gap of sound-absorbing structures provide a decrease in sound pressure in the high-frequency range, and cellular cells operate as resonators in the low-frequency range. To ensure maximum sound absorption, the parameters of the noise protection structure were changed as follows. The film thickness (S_f) varied from 50 μm to 150 μm with an interval of 50 μm. The thickness of the isolon (S_i) was taken 2 and 4 mm. The type of perforation (B_p) was chosen in order to ensure the minimum perforation area (triangle) and the maximum one (circle).

With various combinations of sound-absorbing structure parameters, four versions of the design were made and investigated according to the plan of the full three-factor experiment.

The results of experimental studies of sound-absorbing structures (Enaleeva et al., 2017; Savel'yev, 2017a; 2017b; 2015; Tyurin, 2013) are given in Table 1 and Figures 1-4.

Table 1: Experimental dependencies of the sound absorption coefficient of the noise protection structure

Structure option	Frequency Hz														
	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000
№ 1	0.05	0.12	0.13	0.18	0.24	0.30	0.35	0.49	0.71	0.55	0.47	0.51	0.29	0.15	0.13
№ 2	0.05	0.11	0.12	0.15	0.23	0.33	0.42	0.46	0.51	0.40	0.45	0.34	0.19	0.11	0.10
№ 3	0.06	0.25	0.24	0.25	0.26	0.20	0.25	0.31	0.72	0.92	0.77	0.50	0.35	0.20	0.18
№ 4	0.05	0.19	0.20	0.16	0.21	0.15	0.23	0.30	0.42	0.47	0.59	0.39	0.22	0.20	0.18

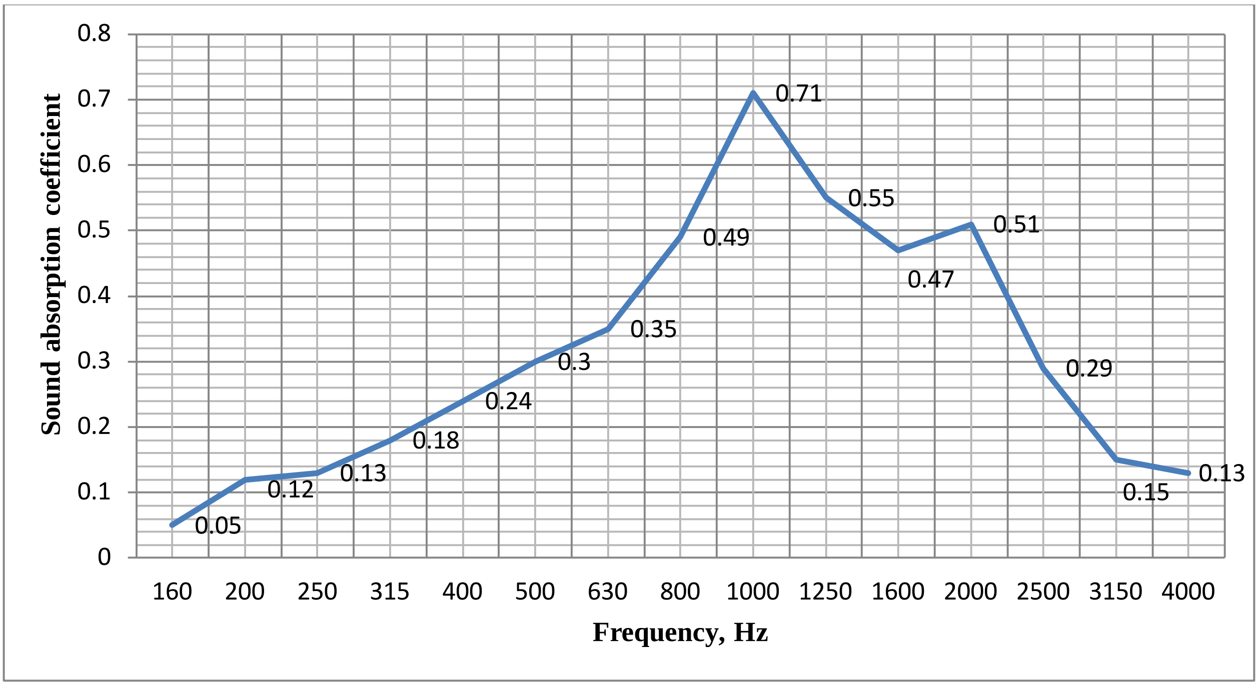

Figure 1: Dependence of the sound absorption coefficient of the cellular noise-protection panel on the sound wave frequency (sound-absorbing structure No 1 – S_f =150 μm, S_i = 4 mm, B_p - Δ-shape)

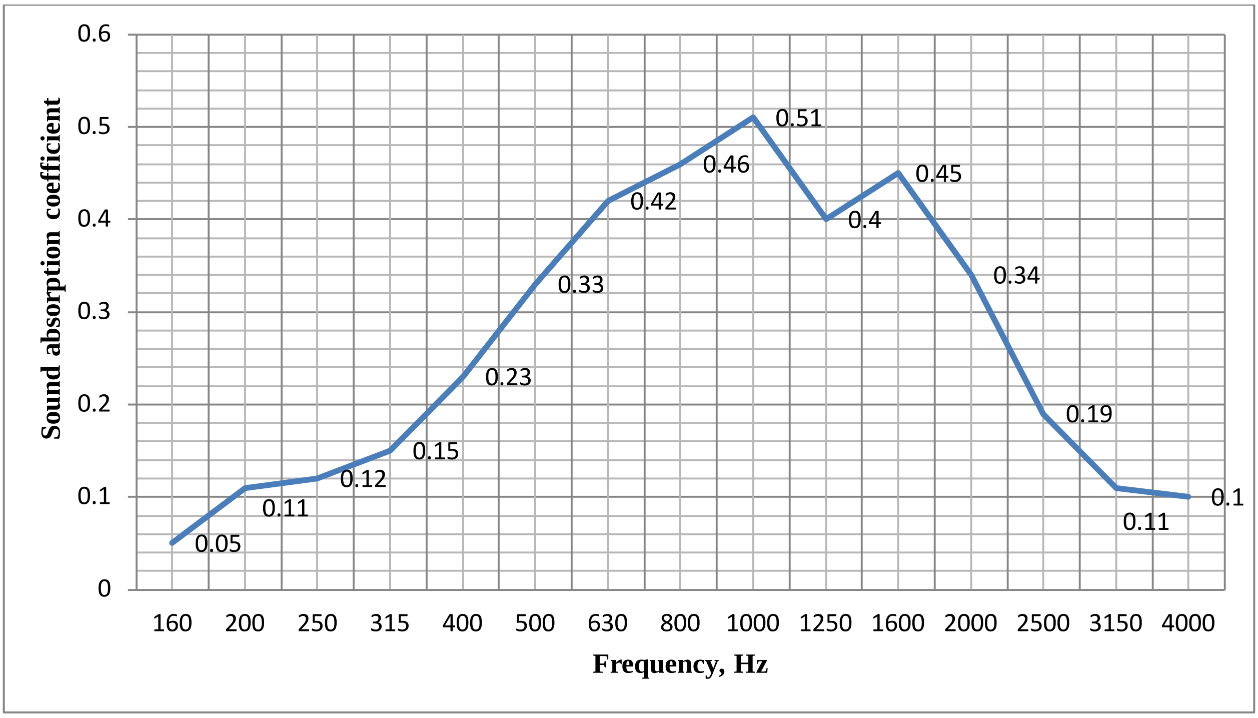

Figure 2: Dependence of the sound absorption coefficient of the cellular noise-protective panel on the sound wave frequency (sound-absorbing structure No 2 – S_f =150 μm, S_i = 4 mm, B_p – o-shape).

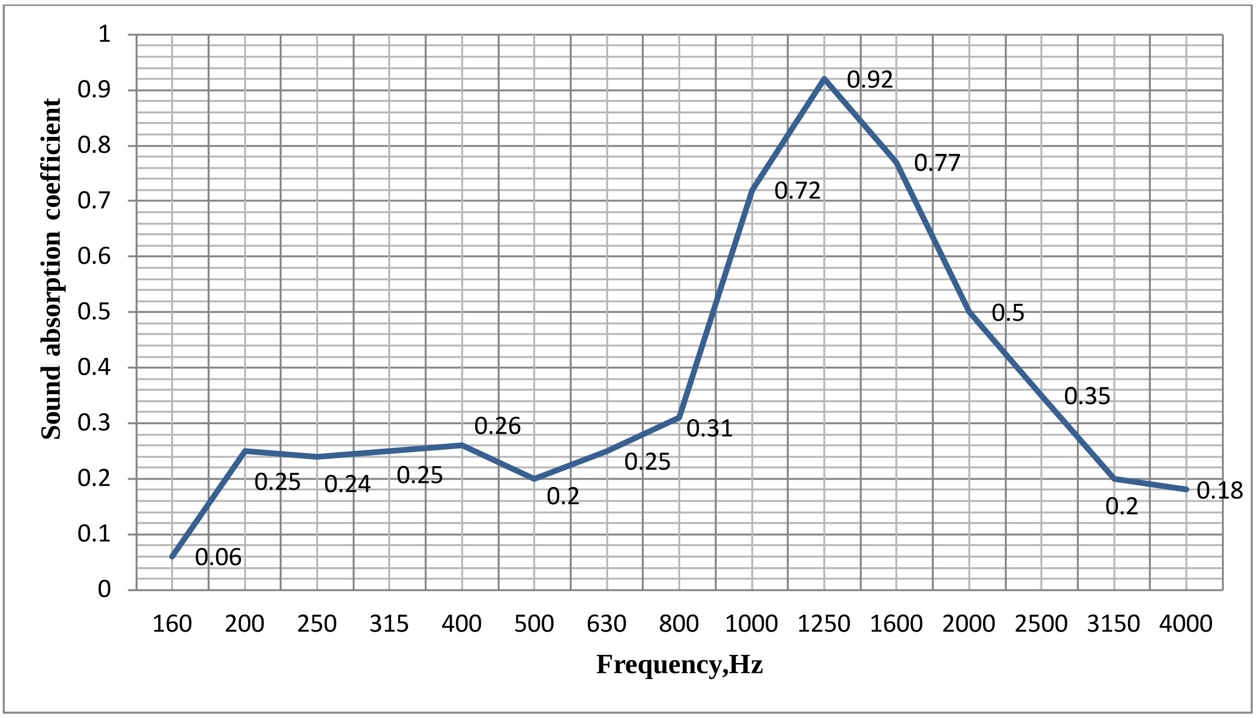

Figure 3: Dependence of the sound absorption coefficient of the cellular noise-protection panel on the sound wave frequency (sound-absorbing structure No 3, S_f =50 μm, S_i = 2 mm, B_p - Δ-shape)

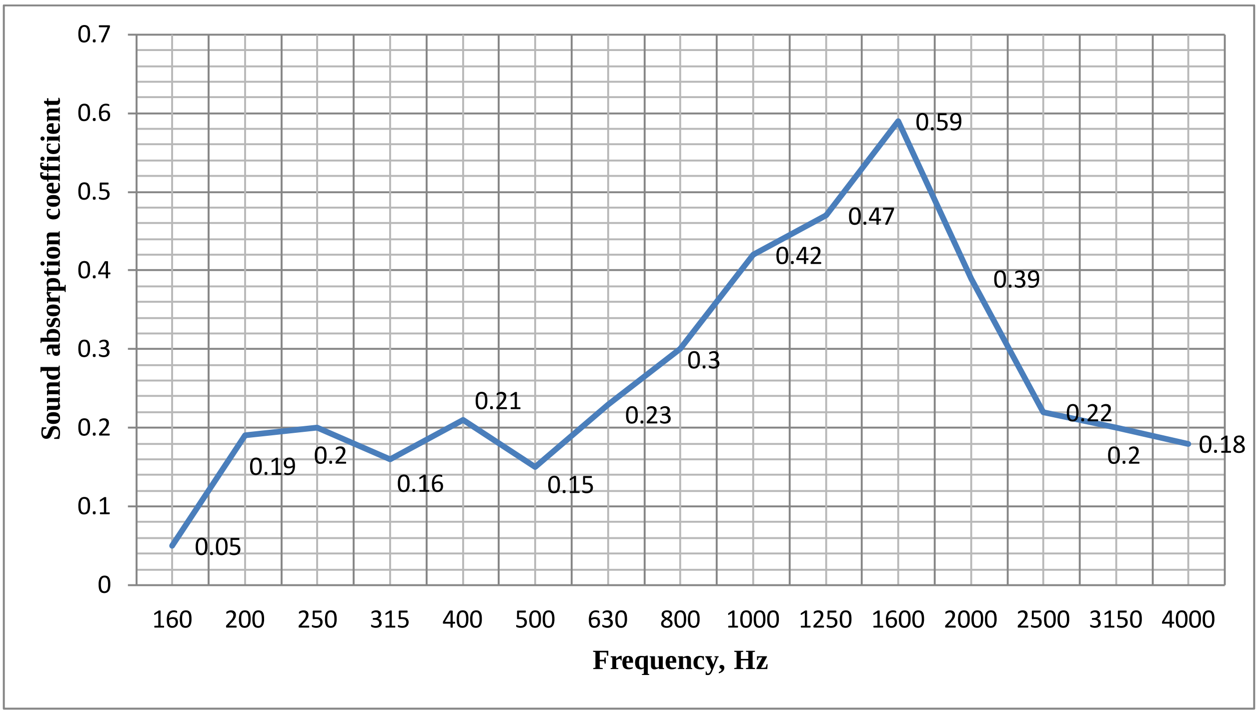

Figure 4: Dependence of the sound absorption coefficient of the cellular noise-protection panel on the sound wave frequency (sound-absorbing structure No 4 – S_f =50 μm, S_i = 2mm, B_p - o-shape)

The maximum sound absorption of the noise protection structure is observed in sample No. 3, which has a minimum perforation area in the form of triangular holes. The thickness of the isolon was 2 mm, and the film 50 microns. The sound absorption coefficient of the noise protection structure was in averaged 0.81 in the frequency range from 1000-1600 Hz. The use of a sound-absorbing structure allowed to reduce the sound pressure level from 7.85 dB to 8.20 dB depending on the workshop and improve the working conditions from a harmful class to an acceptable one.

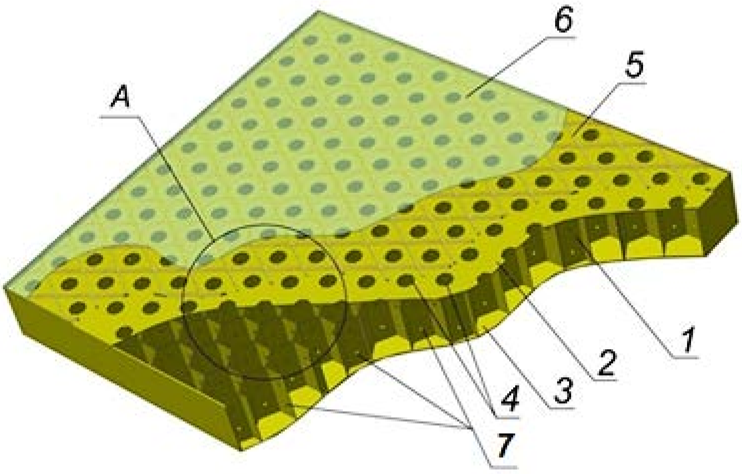

Figure 5: Noise protection panel. General view with a slit:
1 - honeycomb panel; 2 - perforated plate; 3 - a solid plate; 4 - plate holes;
5 - wire mesh; 6 - thin membrane; 7 - holes in the faces of the hollow cells.

According to several indicators that evaluate the effectiveness of investments, we have assessed the effectiveness of noise protection measures at the dairy processing enterprise of average capacity in the Mordovia Republic (192 workers) due to annual economic efficiency. Economic indicators in the calculations were taken in thousand rubles and in thousand rubles/year.

The annual economic effect $Э_a$ of introducing sound absorbing structure was determined by the formula (Minakov et al., 2004; Vodyannikov et al., 2015).

$$Э_a = \mathrm{P}_r - \mathrm{C}_{arc}, \qquad (1),$$

where P_r – is the annual economic result from introducing sound absorbing structure;

C_{arc} is an annual reduced cost for the preparation and implementation of sound-absorbing structures.

3.2 ANNUAL ECONOMIC RESULT

When calculating the annual economic result, we proceeded from the actually obtained annual economic result for the three studied shops of the enterprise P_{aw}.

Increasing the annual economic result is possible after the introduction of sound-absorbing structures by increasing the workers' labor productivity by reducing noise exposure.

Due to the specifics of production (naturally occurring technological processes), the time for performing technological operations with the participation of workers takes up only part of the work shift.

In this regard, we used the coefficient to increase the actual annual economic result K_{lpi}, which takes into account the increase in labor productivity while reducing noise during the execution of technological operations involving workers.

Also, with improved working conditions, the amount of insurance contributions to the Russian pension fund decrease, which is proposed to be taken into account through the component C_{rpf}

Taking into account the above, the expression for determining the annual economic result from the implementation of sound-absorbing structures can be written in the form

$$P_r = К_{lpi} P_{aw} + C_{rpf}, \qquad (2),$$

where $К_{lpi}$ – is the coefficient of labor productivity increase in the function of the noise level and the execution time of a technological operation involving an employee;

P_{aw} – is an actual annual economic result of a separate workshop of an enterprise;

C_{rpf} – is savings in the payment of insurance premiums to the Pension fund of Russia.

The annual reduced costs for the implementation and operation of sound-absorbing structures C_{arc} is determined by (Minakov et al., 2004; Vodyannikov et al., 2015)

$$C_{arc} = C_{shs} + E_s К_{ke} \qquad (3),$$

where C_{shs} – is an annual operating cost for sanitary and hygienic maintenance of sound-absorbing structures;

E_s – is regulatory investment ratio;

$К_{ke}$ – is capital costs for the manufacture and implementation of sound-absorbing structures.

The economic efficiency of investment in the development and implementation of a sound-absorbing structure was determined by the payback period by (Minakov et al., 2004; Vodyannikov et al., 2015)

$$T = {}^{К_{ke}}/_{(P_r - C_{shs})} \qquad (4).$$

The actual annual economic result for the three workshops of the dairy plant for 2016 is as follows:

- sour dairy products workshop - 19270;
- butter workshop - 68442;
- workshop for fat cheese production - 913.

To determine the quantitative characteristics of the increase coefficient of the actual annual economic result $К_{ILP}$ in the enterprise, the following source data were used.

The results of studies on the dependence of workers' labor productivity on level noise in milk processing enterprises are given in Table 2. (Katsnelson, 1986).

Table 2: Dependence of workers' labor productivity of milk processing enterprises on level noise at workplaces.

Noise level, dB	75	80	85	90	95
Workers' labor productivity of milk processing enterprises	100	96	90	80	70

The interpolation method made it possible to determine the productivity level for the equivalent level in the three workshops before and after the implementation of sound-absorbing structures.

The equivalent sound level (dB) before and after implementation soundproofing structures was 86.9 and 78.7 respectively in the butter workshop. The figures were 84.6 were 78.1 for sour dairy products shop, and 86.4 and 78.3 respectively for fat cheese production shop.

The productivity level of dairy processing workers (in %) before and after the introduction of sound-absorbing structures was 86.2 and 96.0 in the butter workshop, 89.6 and 96.0 in sour dairy products workshop, and 86.0 and 96.0 respectively in the workshop for fat cheese production.

The coefficient of increase in workers' labor productivity of dairy processing enterprise $К_{ILP}$ for a full work shift could be 9.80% in butter workshop, 6.44% in sour dairy products workshop, and 9.96% in fat cheese production shop workshop.

The time during which natural technological processes are carried out was determined according to the standards of technological operations and is indicated by T_{np}.

The actual labor productivity coefficient of employees of a dairy processing enterprise K_{LPDW} was determined by

$$K_{LPDW} = K_{ILP}\frac{T_{ap}}{T_{swh}} \quad (5),$$

where T_{ap} – is the actual duration of the technological operations involving workers, h;

T_{swh} – is standard working hours, h.

The actual duration of the technological operations with the participation of workers of dairy processing enterprise was determined by

$$T_a = T_{swh} - T_{np} - T_{shs} \quad (6),$$

where T_{np} – is the duration of the working day coming to the natural technological processes;

T_{shs} – is the total time for sanitary and hygienic processing in terms of the duration of the working day, h.

The analysis of the technological operations standards and the results of timing made it possible to determine the time for natural technological processes T_{np} and sanitary-hygienic processing.

Per the approved regulations for the studied company, sanitary and hygienic processing was carried out for one hour daily and three times a month (general cleaning) for three hours with production stopped. Thus, the time for sanitary-hygienic processing amounted to 1.3 hours per working day.

Table 3: The value of the coefficient of productivity K_{lpi} for workshops and its components.

workshop	T_{np}, h	T_{shs},h	T_{ap},h	$\frac{T_{ap}}{T_{swh}}$	K_{lpi} ,%	K_{LPDW}
butter workshop	2.0	1.3	8.2	0.68	9.80	6.67
sour dairy products workshop	2.5	1.3	7.7	0.64	6.44	4.12
workshop for fat cheese production	3.0	1.3	7.2	0.60	9.96	5.98

The development and implementation of sound-absorbing structures in the form of a false ceiling gave the following annual economic result P_r:

- sour dairy products workshop - 1241;
- workshop for fat cheese production - 55.

The annual economic result in two workshops amounted to 1,296 thousand rubles/year. Due to the increase in purchase prices for milk, the butter workshop worked with losses and it was not taken into account.

The annual economic result from the introduction of sound-absorbing structures is the sum of the annual economic result in two workshops was 1,296 thousand rubles/year and savings of the enterprise on the payment of insurance contributions to the Pension fund of Russia was 86.4 thousand rubles, which is total 1382.4 thousand rubles.

The operating costs of maintaining sound-absorbing false structures represent the sum of the costs of carrying out sanitary-hygienic processing and the cost of the means used C_{cro}.

The actual costs for sanitary-hygienic processing at the dairy processing plant in 2016 were

- sour dairy products workshop – 9.5 thousand rubles;
- butter workshop – 24.5 thousand rubles;
- workshop for fat cheese production – 0.6 thousand rubles.

After false ceiling (sound-absorbing structures) installing, the area of sanitary-hygienic treatment increased by 30%, and costs increased by 40%.

Operating expenses for the maintenance of sound-absorbing structures C_{shs} were:

- sour dairy products workshop – C_{shs} =9.80;
- butter workshop – C_{shs} = 3.80;
- workshop for fat cheese production – C_{shs} = 0.24.

Operating costs for the maintenance of sound-absorbing ceilings for the three workshops amounted to $C_{shs\Sigma}$ = 13.84 thousand rubles/year.

The local estimates for the device of noise-reducing ceilings are made according to the same methodology of the construction industry, which includes territorial estimated standards provided for use in the territory of the Mordovia Republic under the order of the Ministry of Construction of Russia (Table 4).

Table 4: Estimated false sound-absorbing ceilings installation cost at dairy processing plant.

Code, standard number, resource code	Activities and expenses, equipment characteristics, weight	Unit of measurement	Amount		Cost at basic prices (Rubles)		Estimated cost at current prices (Rubles)	
		Number of machine operators	Per unit	According to project data	Per unit	Total	Per unit	Total
	Section 1. Butter workshop							
E15-01-053-01	False sound proof ceilings mounting	100 sq.м^2		1	47 169.28	47 169	170 920.47	170 920
31-1037	Construction worker of avg grade 3.7	man-hours	84.98	84.98	8.710	740	164.650	13 992
31000-0001	Labor costs of machine operators		0.04	0.04	12.840	1	242..640	10
X03-0954	Elevators with a loading capacity up to 500 kg single-mast, lifting height 45 m	Machine hours	0.04	0.04	30.13	1	288.00	12
		1			12.84	1	242.64	10
X13-4041	Screwdriver	Machine hours	1.56	1.56	2.98	5	10.85	17
X33-0206	Electricdrills		0.42	0.42	2.08	1	7.66	3
C101-3149	Plastic dowels with screws 8x40 mm	10 pcs	74,1	74,1	2,61	193	14,69	1 089
C101-4830	Acoustic Ceiling Panels, Ecophon Focus E T15 type, 600 * 600 * size, 20 mm	sq.м^2	103	103	300,03	30 903	1 200,00	123 600
C201-0840	Still support Connect, 48 mm length	pcs.	70	70	7,28	510	23,42	1 639
C201-8260	U-profile Connect	м	263	263	46,01	12 101	82,37	21 663
C201-8261	Shadow line trim Connect, white colour		107	107	25,38	2 716	83.23	8 906
	Overhead costs				95%	704	80%	11 202
	Estimated profit				47%	348	37%	5 181
	Total including Overhead costs & Estimated profit					48 221		187 302
Total for section 1 with VAT						47 169		170 920
Cost of construction works						47 169		170 920
Overhead costs (80%)						704		11 202
Estimated profit (37%)						348		5 181
Total cost of construction works						48 221		187 303
Total for section 1						48 221		187 303
Total overhead costs						704		11 202
Total Estimated profit						348		5 181
Estimated Wages						741		14 002
Regulatory complexity						85.02		85.02
Unforeseen work and costs					2	964	2	3 746
Total unforeseen						49 185		191 049
VAT					18	8 853	18	34 389
Total for section 1 with VAT						58 038		225 438

Similarly, the calculation of estimates for the installation of the sound-absorbing ceiling for sour dairy products workshop and cheese production workshop with an estimated cost of 757.46 thousand rubles and 360.70 thousand rubles respectively has been done.

Capital expenditures for the implementation of sound-absorbing structures consist of the cost of mounting elements of false ceiling and the cost of fabricated sound-absorbing panels, the cost of which is three times higher than the cost of the base cellular ones.

The cost of the base cellular panel was 0.20 thousand rubles/m^2

The cost of capital expenditures K for sound-absorbing ceilings, taking into account their area (S), was:

- in butter workshop (S = 100 m^2) - 225.44 thousand rubles;
- sour dairy products workshop (S = 336 m^2) - 757.46 thousand rubles;
- workshop for fat cheese production (S = 160 m^2) - 360.70 thousand rubles.

Capital expenditures for the three workshops amounted to 1343.60 thousand rubles.

The standard efficiency ratio of capital investments E_n is assumed to be equal to the bank rate E_n = 0.1466.

3.3 EFFICIENCY ESTIMATION AND PAYBACK PERIODS

To calculate the annual economic effect, the following indicators were obtained:

Annual economic result P = 1382.40 thousand rubles/year;

Operating costs for sound-absorbing ceiling C = 13.84 thousand rubles/year.

Taking into account expressions (1) and (3), the annual economic effect was

$$E=1382.40 – 210.81=1171.59 \text{ thousand rubles.}$$

Taking into account the expression (4), the economic efficiency of capital investments for sound-absorbing ceilings implementation in the three workshops amounted to

$$T = 1343.60/(1382.40–13.84)=0.98 \text{ years.}$$

The economic effect from the introduction of noise-absorbing structures in the form of a false ceiling in three workshops amounted to 1,171.59 thousand rubles with a payback period of 0.98 years. The obtained indicators on the effectiveness of noise protection measures at the workplaces of a dairy processing enterprise allow us to recommend developed sound-absorbing panels for use in similar enterprises.

Our rationale for the effectiveness of noise protection measures at a dairy processing plant of average capacity, as noted above, was developed not for the most favorable conditions. Noise protection measures were required for only three workshops, which allowed to improved working conditions for 58 employees (taking into account shift work and auxiliary workers). This accounted for 30% of the total number of employees. With the stabilization of prices for dairy processing products and an increase in the number of employees, needed in working conditions improvement, the effectiveness of noise protection measures is higher.

4. CONCLUSION

The rationale for the effectiveness of noise protection measures in the form of suspended ceilings is given by the example of a medium-capacity milk processing enterprise. The protection was implemented by a noise insulation construction in the form of a honeycomb panel covered with a perforated plate in the form of triangular holes. A cellular elastic mesh of 2mm-isolon is fixed on the outer side of the perforated plate. The panel is hermetically covered with a thin 50 microns film. The decrease in sound pressure level was from 7.85-8.20 dB, depending on the workshop. Working conditions improved from harmful levels to an acceptable one. The economic effect amounted to 1171.59 thousand rubles with a 0.98-year payback period.

5. DATA AND MATERIAL AVAILABILITY

Information regarding this study is available by contacting the corresponding author.

6. REFERENCES

Enaleeva S. A., Savel'yev, A. P., Shkrabak, V. S. (2017). The sound absorption evaluation by biresonance construction with improved sanitary and hygienic properties. News of the International Academy of Agrarian Education. 33, 31–34.

Katsnelson M. U., Seliverstov, B. A., Tsukernikov, I. E. (1986). Reducing the noise of food processing machines. Agropromizdat, 256p.

Minakov I.A., Kulikov N.I., Sokolov O.V. et al. (2004). Economics of the branches of the agroindustrial complex /, ed. by I. A. Minakov. - M.: KolosS, - 464 p. (Textbooks and study guides for students of higher education institutions.)

Pyatkina S. A., et al. (2013). Noise protection panel. Patent 2478762 Russian Federation, IPC E04B, B32B, G10K

Savel'yev A. P. (2012). Development of a biresonance construction with improved sanitary and hygienic properties and evaluation of its sound absorption. Theoretical and Practical Journal "Kishovarz" (Farmer), № 4, 45 - 48.

Savel'yev A. P. (2015). Engineering solutions to protect workers from increased noise / A. P. Savel'yev, S. A. Enaleeva. Protection and Labor Economics, Scientific and Professional Journal, 3(20), 27-31.

Savel'yev A.P., et al. (2017a). Workers' noise protection in processing industry of agro-industrial complex with cellular structures. Bulletin of Mordovia University, 27(2), 215–223.

Savel'yev, A.P. (2017b). Sound protection structures with acceptable sanitary and hygienic properties for workers of agro-industrial complex: Improving ways to prevent production risks, dynamically reducing and eliminating injuries and morbidity of workers in agro-industrial complex. Collection of scientific papers of the International Scientific-practical Conf, 106-116.

Tyurin, A.P., Pyatkina, S.A. (2012). Influence of sound sparsity on the sound insulation of vacuumized cellurar structure. Vacuum equipment and technology, 22(4), 235-240.

Tyurin, A.P. et al. (2013). Theoretical foundations of noise-protection construction calculation with improved sanitary and hygienic properties. Protection against increased noise and vibration:

Collection of report of All-Russia scientific-practical conference. Ed. by N.I. Ivanov, The Baltic State Technical University "Voenmech", 623-630.

Vodyannikov, V. T. et al. (2015). Agricultural Economics. 543 p.

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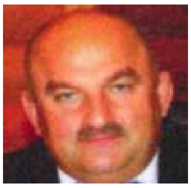

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