

Optimization of geometric parameters of heat exchange pipes pin finning

K A Akulov, V V Golik, K S Voronin and A G Zakirzakov

Industrial University of Tyumen, 38 Volodarskogo St., Tyumen, 625000, Russia

E-mail: akukir@gmail.com

Abstract: The work is devoted to optimization of geometric parameters of the pin finning of heat-exchanging pipes. Pin fins were considered from the point of view of mechanics of a deformed solid body as overhang beams with a uniformly distributed load. It was found out under what geometric parameters of the nib (diameter and length); the stresses in it from the influence of the washer fluid will not exceed the yield strength of the material (aluminum). Optimal values of the geometric parameters of nibs were obtained for different velocities of the medium washed by them. As a flow medium, water and air were chosen, and the cross section of the nibs was round and square. Pin finning turned out to be more than 3 times more compact than circumferential finning, so its use makes it possible to increase the number of fins per meter of the heat-exchanging pipe. And it is well-known that this is the main method for increasing the heat transfer of a convective surface, giving them an indisputable advantage.

1. Introduction

One of the promising areas for improving heat exchangers is the use of pin finning of heat-exchange pipes [2] (Fig. 1). However, the use of this type of finning is constrained by its insufficient state of knowledge. One of the main issues facing engineers is the choice of geometric parameters of pin finning. This article is devoted to the answer to this question.

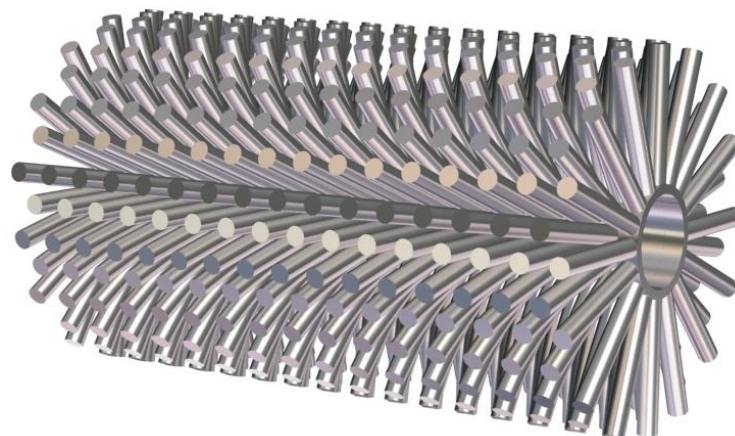


Figure 1. Pin-finned heat exchanger pipe.

2. Materials and methods

Pin-finned heat exchange pipes can be used in tubular heat exchangers - air cooling units and shell-and-tube heat exchangers. The flow of the washer fluid can move both parallel and perpendicular to the axis of the heat exchange pipe. In both cases, fin nibs located at an angle of 90° to the flow will have the maximum impact on them [1]. From the point of view of mechanics, the nib will be an overhang beam with length l with uniformly distributed load q (Fig. 2). It is known that maximum bending moment M from this load will be in the section of the rigid closing of the beam [11]. That is, the maximum stress in the beam will be observed at the base of the nib. This stress should not exceed the yield point for plastic materials (steel, aluminum, copper); otherwise deformation of the metal will be observed. It is necessary to find out at what geometric parameters of the nib (diameter and length), the stresses in it from the influence of the washer fluid will not exceed the yield strength of the material (aluminum). Let us solve this problem.

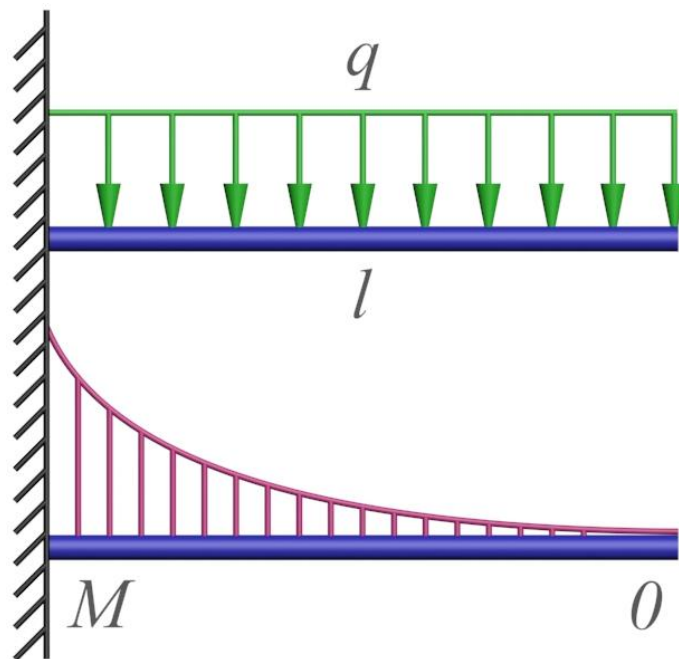


Figure 2. The design scheme of the nib as a cantilever beam with a uniformly distributed load and a bending moment diagram from this load

The maximum stress in the beam is given by formula [11]:

$$\sigma = \frac{M}{W}, Pa \quad (1)$$

where M – maximum bending moment, N/m; W – resistance moment, m^3 .

The moment of resistance for a round-section beam [11]:

$$W = \frac{\pi d^3}{32}, m^3 \quad (2)$$

where d – diameter of a section of a circular beam, m.

The moment of resistance for beams of square section [11]:

$$W = \frac{a^3}{6}, m^3 \quad (3)$$

where a – cross-section side of a square beam, m.

Maximum bending moment for the cantilever beam [11]:

$$M = \frac{ql^2}{2}, \frac{N}{m} \quad (4)$$

where q – uniformly distributed load on the beam, N/m; l – length of beam, m.

Uniformly distributed load on a beam [12]:

$$q = S \cdot P \cdot c, \frac{N}{m} \quad (5)$$

where S – cross-sectional area of a beam, m^2 ; P – pressure on the beam, Pa; c - aerodynamic (hydrodynamic) factor ($c=1,2$ for round pipes, $c=2,1$ for square pipes [12]).

The cross-sectional area of a circular beam [11]:

$$S = \frac{\pi \cdot d \cdot l}{2}, m^2. \quad (6)$$

The cross-sectional area of a square beam [11]:

$$S = a \cdot l, m^2. \quad (7)$$

Pressure on the beam [11]:

$$P = \frac{\rho v^2}{2}, Pa \quad (8)$$

where ρ – density of the medium flowing around the beam, kg/m^3 ; v - velocity of the medium flowing around the beam, m/s .

Substituting (8) and (6) in (5), let us obtain a uniformly distributed load on the beam of circular section:

$$q = 0,3\pi \cdot d \cdot l \cdot \rho \cdot v^2, \frac{N}{m}. \quad (9)$$

Substituting (8) and (7) in (5), one obtains a uniformly distributed load on the beam of the square cross-section:

$$q = 1,05 \cdot a \cdot l \cdot \rho \cdot v^2, \frac{N}{m}. \quad (10)$$

Substituting (9), (4) and (2) in (1), let us obtain the maximum stress in the beam of circular cross-section:

$$\sigma = \frac{4,8\rho v^2 l^3}{d^2}, Pa. \quad (11)$$

Substituting (10), (4) and (3) in (1), one obtains the maximum stress in the beam of the square cross-section:

$$\sigma = \frac{3,15\rho v^2 l^3}{a^2}, Pa. \quad (12)$$

From equation (11), it is possible to express the velocity of the washing stream and the diameter, at which there will be maximum stresses in the beam of the circular cross-section:

$$v = \sqrt{\frac{\sigma d^2}{4,8\rho l^3}}, \frac{m}{s}; d = \sqrt{\frac{4,8\rho v^2 l^3}{\sigma}}, m. \quad (13)$$

From equation (12), it is possible to express the velocity of the washer flow and the side, at which there will be maximum stresses in the beam of the square cross-section:

$$v = \sqrt{\frac{\sigma a^2}{3,15\rho l^3}}, \frac{m}{s}; a = \sqrt{\frac{3,15\rho v^2 l^3}{\sigma}}, m. \quad (14)$$

Using equations (13) and (14), substituting the yield strength values of the main grades of aluminum alloys $\sigma_{0,2}$ in them (Table 1), let us obtain the optimal values of the geometric parameters of the nibs for different velocities of their washed medium. For aluminum grades №1 and №6 (Table 1), these values are shown in the graphs of Fig. 3-6. As a flow medium, water and air were chosen, and the cross section of the nibs was round and square. The optimal geometric parameters of the pin fins of heat-exchange pipes for different flow rates of heat carriers are recommended to be chosen taking into account the safety factor, which is usually 10-20%.

One of the methods for improving circumferential-finned heat-exchange pipes is to increase the length and decrease the thickness of the fins. To date, these values have reached 16 mm and 0.3 mm. In the air-cooling apparatus, the airspeed reaches 13 m/s [8]. As calculations have shown, the geometric parameters of the pin finning will be much smaller than of the circumferential finning. Moreover, transverse fins are made only out of their alloys of the first group (Table 1), since the material is forced to stretch during the formation of the fin, and the pins can be made from the strongest aluminum alloy of the sixth group [4] (Table 1). If one sets the height of the pin fins and the airspeed similar to the pin-finned heat exchangers (height -16 mm, speed -13 m/s), then their thickness will be 0.09 mm for round nibs and 0.07 mm for square nibs. Reducing the thickness of the nib more

than 3 times allows one to increase the number of fins per one meter of the heat exchange pipe by the same amount. And as it is known, this is the main method for increasing the heat transfer of the convective surface. Thus, the optimal size of the pin fins is much smaller than the optimal size of the circumferential fins, which gives them an indisputable advantage.

Table 1. Guaranteed level of mechanical properties of Russian and American aluminum alloys

№	Alloys						Standard samples		
	System	Russia GOST 4784	USA ASTM B221	Russia	USA	Heat treatment	Mechanical properties		
							Strength limit σ_s , MPa	Yield strength $\sigma_{0.2}$, MPa	Relative extension ψ , %
1	Al>99%	A5, A6, AD, AD0, AD1	1050, 1060, 1070, 1100	AD1	1060	F	60	15	25
2	Al-Mn	MM, AMn, D12	3003, 3004, 3005, 3010, 3104	D12	3004	0	160	60	20
3	Al-Mg	AMG1, AMG2, AMG3, AMG4, AMG5, AMG6	5005, 5052, 5154, 5086, 5182, 5654	AMG4	5083	0	270	110	14
4	Al-Mg-Si	AD31, AD33, AD35, AB	6063, 6262	AD31	6063	T6	205	170	10
5	Al-Cu-Mg	D1, D16, 1161, 1163, 1201	2024, 2117, 2219, 2419	D16	2024	T3511	450	315	9
6	Al-Zn-Cu-Mg	B93, B95, B96, 1915, 1935 1955	7050, 7075, 7070, 7108, 7004, 7475	B95	7075	T6511	560	490	6

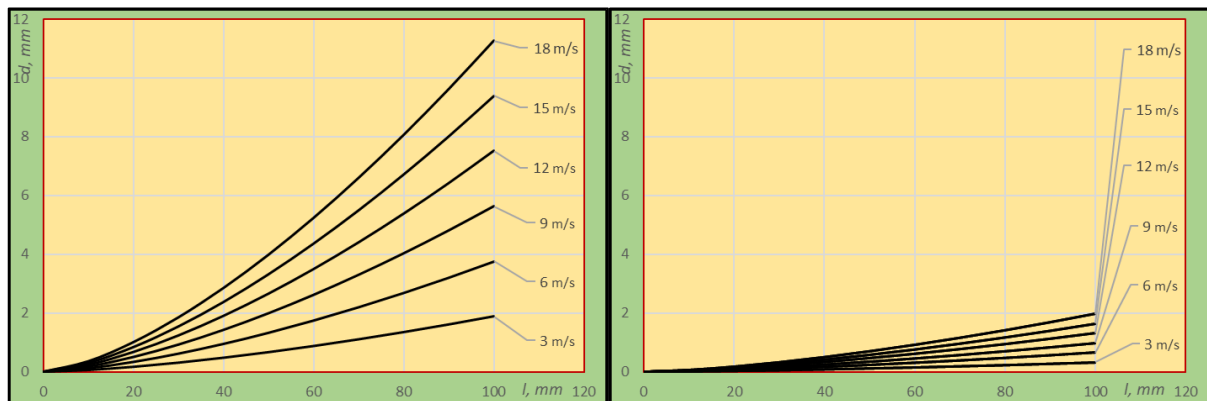


Figure 3. Optimal geometric parameters of round nibs at different speeds of the air being washed. On the left, there are alloys №1 from Table 1; on the right, there are alloys № 6 from Table 1.

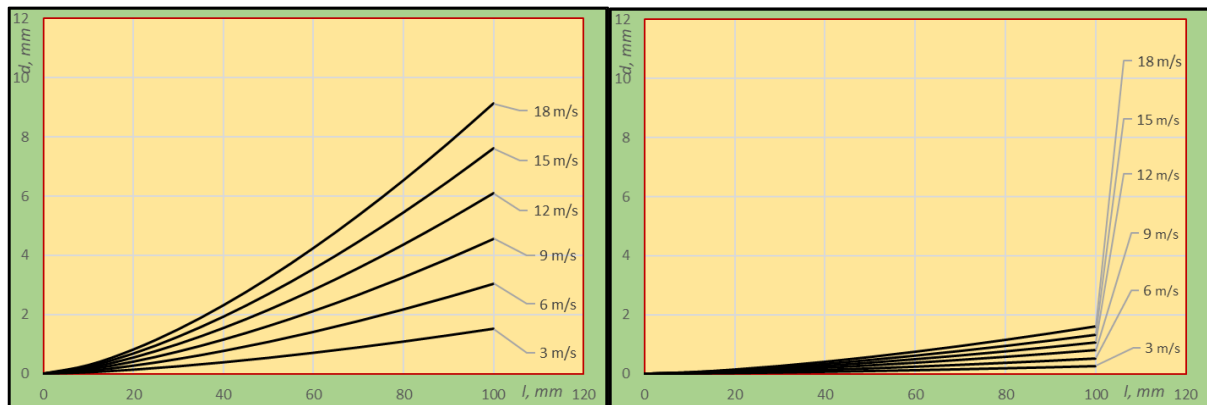


Figure 4. Optimal geometric parameters of square nibs at different speeds of the air being washed. On the left, there are alloys №1 from Table 1; on the right, there are alloys № 6 from Table 1.

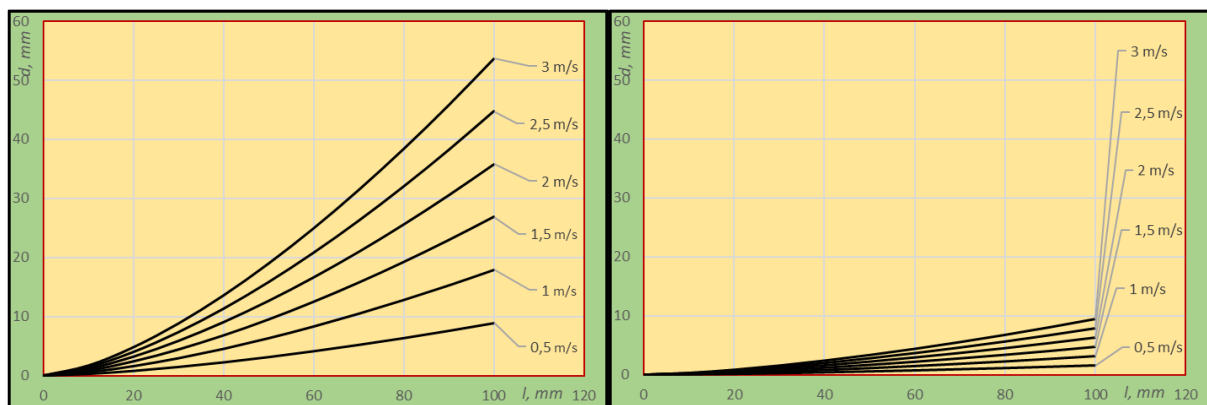


Figure 5. Optimal geometric parameters of round nibs at different speeds of the air being washed. On the left, there are alloys №1 from Table 1; on the right, there are alloys № 6 from Table 1.

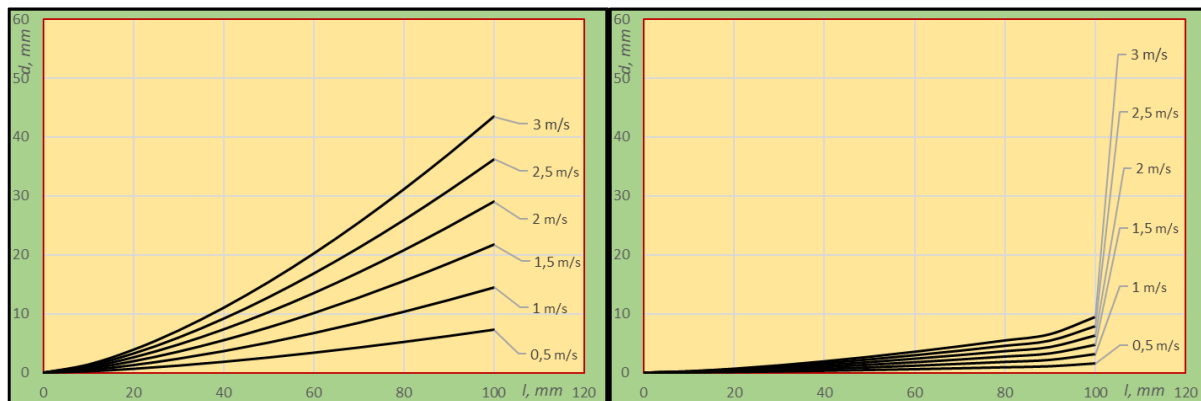


Figure 6. Optimal geometric parameters of square nibs at different speeds of the air being washed. On the left, there are alloys №1 from Table 1; on the right, there are alloys № 6 from Table 1.

3. Conclusion

Optimal values of the geometric parameters of nibs were obtained for different velocities of the medium washed by them. As a flow medium, water and air were chosen, and the cross section of the nibs was round and square. Pin finning turned out to be more than 3 times more compact than circumferential finning, so its use makes it possible to increase the number of fins per meter of heat-exchanging pipe. And it is well-known that this is the main method for increasing the heat transfer of a convective surface, giving them an indisputable advantage.

References:

- [1] Akulov K A, Golik V V, Ponomareva T G 2015 Purification of units for air cooling of gas *Fundamental research* **12-3** 453-456
- [2] Akulov K, Golik V, Chekardovsky M, Serebrennikov A 2016 Research of Spined Heat-Exchanging Pipes *MATEC Web of Conferences* **73**
- [3] Akulov K A, Petryakov V A, Mostovaya N A 2017 The Use of Foamed Concrete for Oil Spill Treatment and Carbon Capture *IOP Conference Series: Earth and Environmental Science* **50**
- [4] ASTM B221M-13 *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes* (Metric)
- [5] Brand A E, Chekardovskiy S M, Akulov K A 2017 The Analysis of the Development Dynamics and Structural Balance of Solar Energy in the World *IOP Conference Series: Earth and Environmental Science* **50**
- [6] GOST 13726-97 *Tapes of aluminum and aluminum alloys*
- [7] Kulikov A M 2016 On Choosing Multicomponent Multiphase System Separation Progress Optimization Criteria V *IOP Conference Series: Materials Science and Engineering* **154**
- [8] Kuntyshev V B, Sukhotsky A B 2013 To the problem of calculating the vibrational reliability of beams from bimetallic finned tubes of air cooling apparatuses *Bulletin of the International Academy of Refrigeration* **2** 46-50
- [9] Pirogov S P, Cherentsov D A 2016 Theoretical foundations of the design of vibration-resistant manometers. *Measurement Techniques* 1-5
- [10] Pirogov S P, Cherentsov D A, Chuba A Y 2016 Study of elastic sensing elements for vibration-resistant pressure gauges *IOP Conference Series: Materials Science and Engineering "International Scientific-Practical Conference of Students, Graduate Students and Young Scientists "Transport and Storage of Hydrocarbons"*
- [11] Aleksandrov A V, Potapov V D, Derzhavin B P, Alexandrov A V 2003 *Resistance of materials* (Textbook for universities M.)
- [12] SNiP 2.01.07-85 Loads and effects

- [13] Zemenkov Y D, Shalay V V, Zemenkova M Y 2015 Immediate analyses and calculation of saturated steam pressure of gas condensates for transportation conditions. *Source: Oil and Gas Engineering* **113** 254-258
- [14] Dudin S M, Zemenkov Y D, Shabarov A B, 2016 Modeling the Phase Composition of Gas Condensate in Pipelines *IOP Conference Series: Materials Science and Engineering* **154**
- [15] Gusev A I, Kozyrev N A, Osetkovskiy I V, Kozyreva O A, Valuev D V 2017 Quality of metal deposited flux cored wire with the system Fe-C-Si-Mn-Cr-Mo-Ni-V-Co *Key Engineering Materials* **736** 23-28
- [16] Valuev D V, Malushin N N, Valueva A V, Dariev R S, Mamadaliev R A 2016 Manufacturing component parts of mining equipment with application of hardening technologies *IOP Conf. Series: Materials Science and Engineering* **127**
- [17] Gizatulin R A, Valuev D V, Trifonov V A, Valueva A V, Serikbol A 2015 Oxidation processes in blowing steel with inert gas into the ladle *IOP Conference Series: Materials Science and Engineering* **91** 1-7
- [18] Saprykina N A, Saprykin A A, Matrunchik M S 2014 Formation of Surface Layer of Cobalt Chrome Molybdenum Powder Products with Differentiation of Laser Sintering Modes *Applied Mechanics and Materials* **682** 294-297
- [19] Gizatulin R A, Kozyrev N A, Valuev D V, Valueva A V, Serikbol A 2016 research on operational characteristics of imported rails under conditions of east siberian railway *IOP Conf. Series: Materials Science and Engineering* **127**
- [20] Malushin N N, Kovalev A P, Valuev D V, Shats E A, Borovikov I F 2016 Development and study of hard-facing materials on the base of heat-resisting high-hardness steels for plasma-jet hard-facing in shielding-doping nitrogen atmosphere *IOP Conference Series: Materials Science and Engineering* **142**