We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

6,900
Open access books available

186,000
International authors and editors

200M
Downloads

154
Countries delivered to

Our authors are among the

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

BOOK CITATION INDEX
CLARIVATE ANALYTICS
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Heat Transfer and Hydraulic Resistance in Rough Tubes Including with Twisted Tape Inserts

Stanislav Tarasevich and Anatoly Yakovlev
Kazan State Technical University,
Russia

1. Introduction

The spiral and cross-section wire insertions, knurls of a various configuration, microfinning, spherical, cylindrical, cone-shaped both other ledges and depressions, stamped surfaces etc. refer to the heat transfer intensifiers allowing considerably to augment a heat transfer at moderate or comparable growth of a pressure drop. The effect of a heat transfer intensification on rough surfaces is attained due to the additional vortex generation leading to raise of a turbulent diffusion in a conversion zone, to a turbulent kernel and due to lowering of stability and width of a viscous boundary layer with molecular thermal conduction at a surface. W. Nunner (1956) has determinated that in rough tubes at growth of ledge height of a roughness the heat transfer factors it is more to 3 times than value in smooth tubes. Intensifying agency of a roughness has been displayed in many subsequent papers (Dipprey & Sabersky, 1963; Isachenko et al., 1965; Kolar, 1965; Sheriff et al., 1964; Sheriff & Gumley, 1966; et al.).

Among artificially roughened surfaces there are surfaces with a continuous roughness (for example, in the form of a thread) and with a discrete roughness (the roughness ledges pitch considerably exceeds their absolute sizes). The discrete roughness is more often preferable for heat transfer enhancement. However the continuous roughness of the outer and inner surfaces of tubes also can be effective for raise of heat transfer, especially at boiling and condensation (Berenson, 1962; Buznik et al., 1969; Danilova & Belsky, 1965; Ivanov et al., 1988; Nishikawa et al., 1982; et al.).

The basic flow regularity in tubes with a continuous sand uniform granulous roughness has been determined in the first half of 20th century (Nikuradze, 1933; Schlichting, 1979; et al.). However the subsequent researches for tubes with a various uniform continuous "not sand" roughness (organized by the single-start and multiple-start cross threads with triangular, rectangular and rounded profiles, and also in the form of ring bores and spherical ledges with passage and chess arrangement) have displayed considerable divergences with an existing explanation of the action mechanism of a sand roughness and with theoretical models of a boundary layer on a rough surface (Ibragimov et al., 1978; Isachenko et al., 1965; et al.).

Thus intensity of a heat transfer and pressure drop in tubes with various aspects of roughnesses is rather individually and also is defined by not only a relative height of

elements of roughnesses, but their shape and disposing density on a surface. Therefore the universal calculation dependences reflecting link of hydrodynamic and thermal flow performances with geometrical parameters of a rough surface are absent while.

Along with rough surface intensifiers the one of effective ways of heat transfer enhancement (especially at boiling) is a flow twisting which promotes liquid phase rejection to a heat transfer surface. In this connection the hydrodynamics and heat transfer problems in channels with a flow twisting together with rough surfaces call a great interest. Now the combined affecting of a surface roughness and a flow twisting on a heat transfer is a little examined.

2. Results of experimental investigations of heat transfer and hydraulic resistance in rough tubes including those with twisted tape inserts

2.1 Heat transfer and hydraulic resistance in different rough tubes including those with twisted tape inserts at water flow

2.1.1 Heat transfer and hydraulic resistance in different rough tubes at water flow

The experimental investigation of heat transfer was carried out into steel tubes with continuous uniform roughness at water flow. Heat was supplied by passing electric current directly through the tube wall. Distribution of wall temperatures on a tube surface was defined by means of 28 thermocouples arranged on an outer surface of a tube.

The continuous transverse roughness of the tube was attained by threading with a different depth of the thread in a stainless steel tube with the inner diameter d = 10.2 mm and length L=500 mm, pitches of the thread t = 0.3…0.5 mm, and with the average height of the protrusions Δ= 0.09…0.12 mm (photographs in Fig. 1). All the considered roughnesses had deficient profile of thread and the shapes of ledges differed due to technological reasons (Fig. 2).
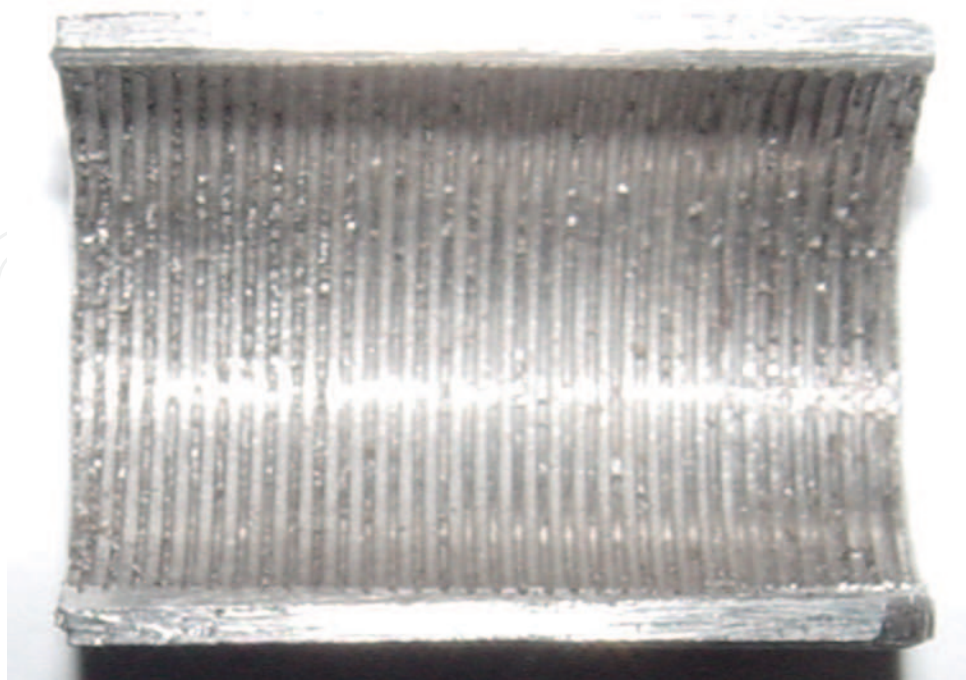

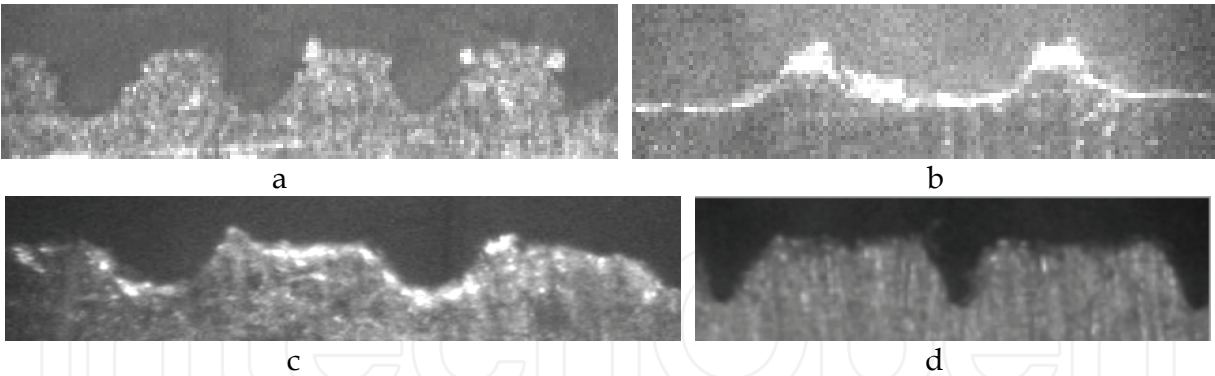Fig. 1. Photos of a tube with thread roughness (view in section)

a

b

c

d

Fig. 2. Photos of the profiles of thread roughness: a) Δ=0,11 mm, t=0,3 mm; b) Δ=0,12 mm, t=0,5 mm; c) Δ=0,09 mm, t=0,5 mm; d) Δ=0,17 mm, t=0,6 mm

On entry and exit of channel the rectilinear sections for flow stabilization have been installed with inner diameter equal d and with relative length L/d=100.

Dependence of a dimensionless heat transfer of tubes with a various continuous roughness on Reynolds number Re is presented on fig. 3 (Nu – Nusselt number, Pr_f and Pr_w - Prandtl numbers at average temperature of flow and wall accordingly). Diameter of an equal volume smooth tube was used as equivalent diameter d_e in similarity numbers. Experimental data have satisfactory qualitative conformity with experimental data of a tubes with the full triangular profile thread roughness in observed range Re (Isachenko, 1965).
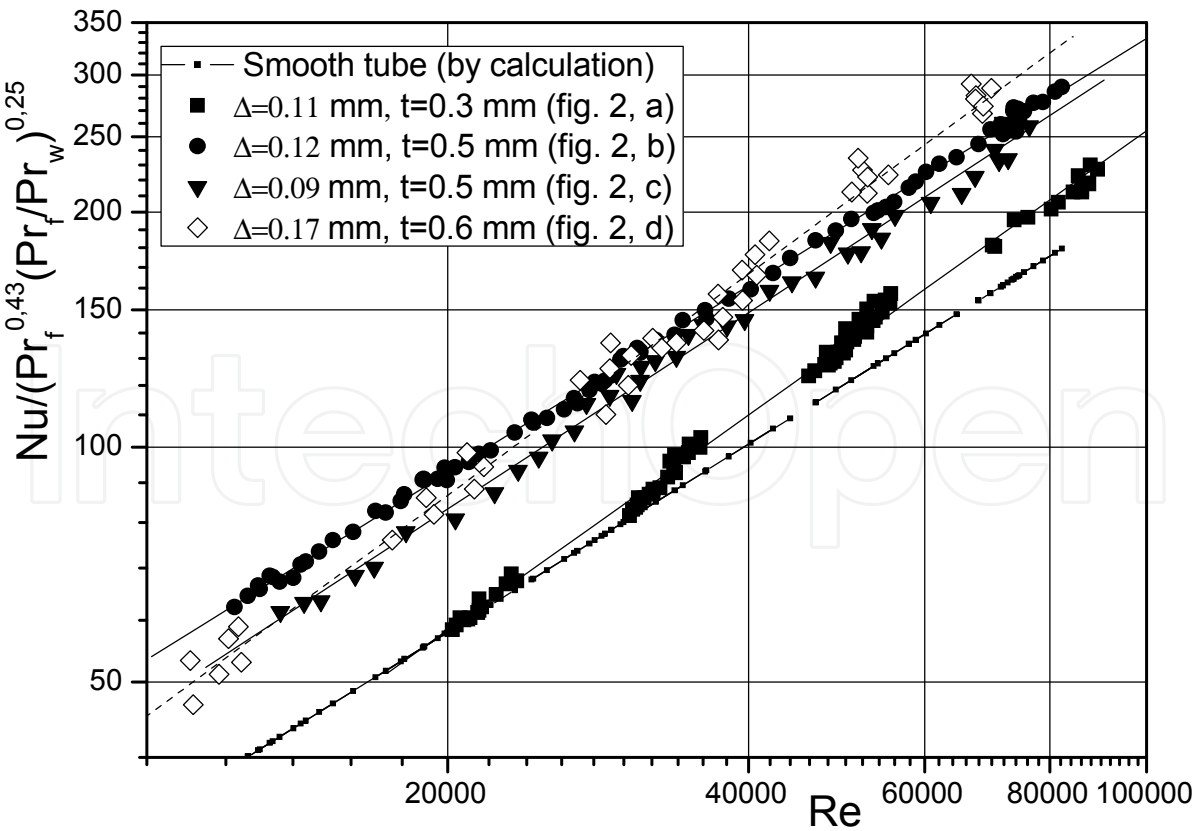
Fig. 3. Dependence of dimensionless heat transfer of rough tubes on Re

As it has been noted the intensity of heat transfer and hydraulic resistance in tubes with various aspects of roughness is rather individual and is defined not only a relative height of roughness elements but their shape and disposing density on a surface. Therefore the tube with rather smaller height of a roughness (with a profile shown in fig. 2, c) has a higher heat transfer rate than a tube with higher roughness height (with the profile shown in fig. 2, a). In a tube with relatively narrow dints between ledges (a profile photo in fig. 2, a) the heat transfer growth in comparison with a smooth tube is manifested only at high Reynolds numbers (at Re=80000 an increase in the heat transfer rate as compared to smooth tube is 14 %). With increase of space between ledges the generation of vortexes is augmented in each element, the penetration of a main stream into the gap between ledges gain in strength as well as the interchanging of energy between vortexes and a main stream (Ibragimov et al., 1978). Stability of vortexes in a gap is also downgraded, the probability of their penetration into a flow kernel is augmented. At rather narrower and deep dint between the ledges the vortex is inside the dint, while in another case the votex structures leave a dint in a flow kernel, and the heat transfer is augmented. The heat transfer rate in rough tube with the almost same ledge height but with a larger gap between ledges (the profile photo in fig.2, b) is 1.7 times higher in comparison with a smooth tube in all observed range of Re.

The experimental data presented in fig.3 can be described by the next relationship:

$$\frac{Nu}{Pr_f^{0.43}\left(Pr_f\middle/Pr_w\right)^{0.25}} = C \times Re^n . \tag{1}$$

The gained factors C and n are presented in table 1.

Roughness	Δ , mm	t, mm	n	C
Fig.2, a	0.11	0.3	0.91	0.0067
Fig.2, b	0.12	0.5	0.8	0.035
Fig.2, c	0.09	0.5	0.84	0.021
Fig.2, d	0.17	0.6	0.94	0.0077

Table 1. Generalizing factors

Generalizing dependence has not been gained since the shapes of a roughness profile essentially differ.

In tubes with the relatively narrow dints (with a profile in fig. 2, a and in fig.2, d) the extent of agency of a Reynolds number (factor n) is more that is linked with various developing process of a roughness with increase in number Re: the agency of roughness ledges with narrow dints is poorly expressed at relatively small Reynolds number and augmented with growth of Re.

In a tube with the large pitch between ledges the factor of hydraulic resistance ξ ($\xi=2\Delta P/(\rho V^2)\cdot d_e/L$, where ΔP - pressure drop, ρ - mass flow density, V - average flow velocity, L/d_e - relative length of the channel) is also appreciable higher (fig.4).

In this case, a comparable increase in the heat transfer rate and hydraulic resistance as against a smooth tube (Nu_0 and ξ_0) is observed at Re=10000…20000. With the further increase of Re the hydraulic resistance grows livelier (fig. 5).
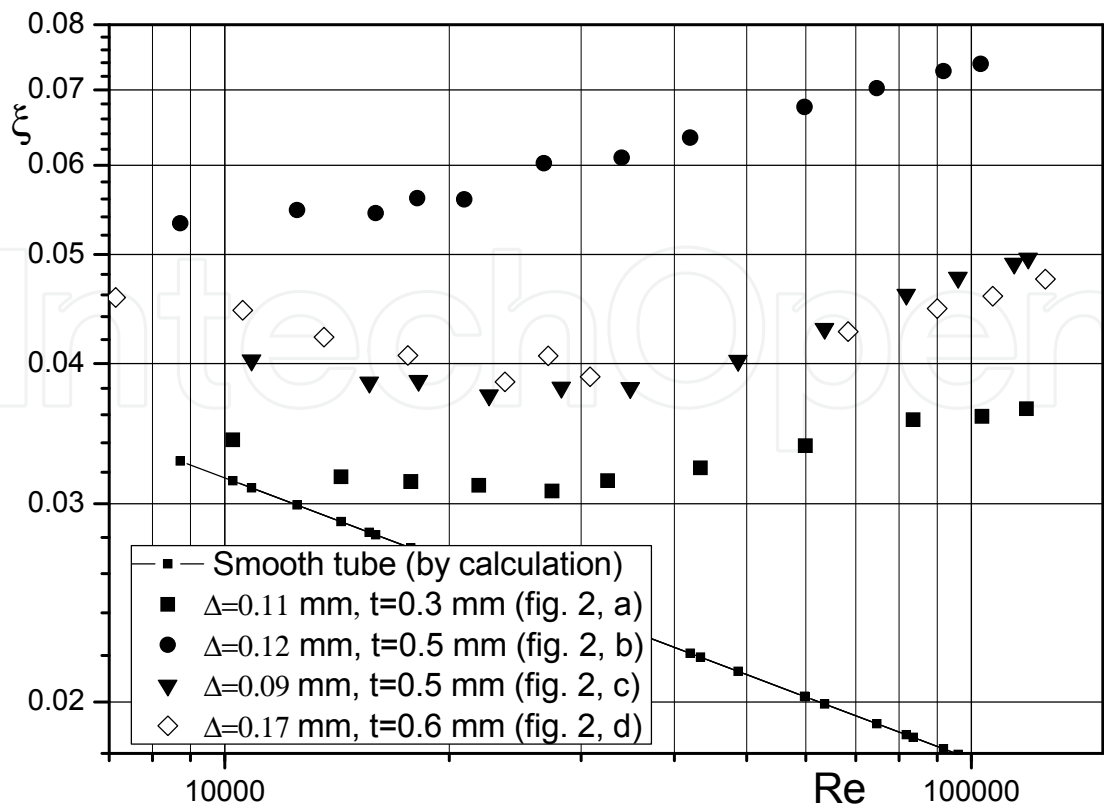
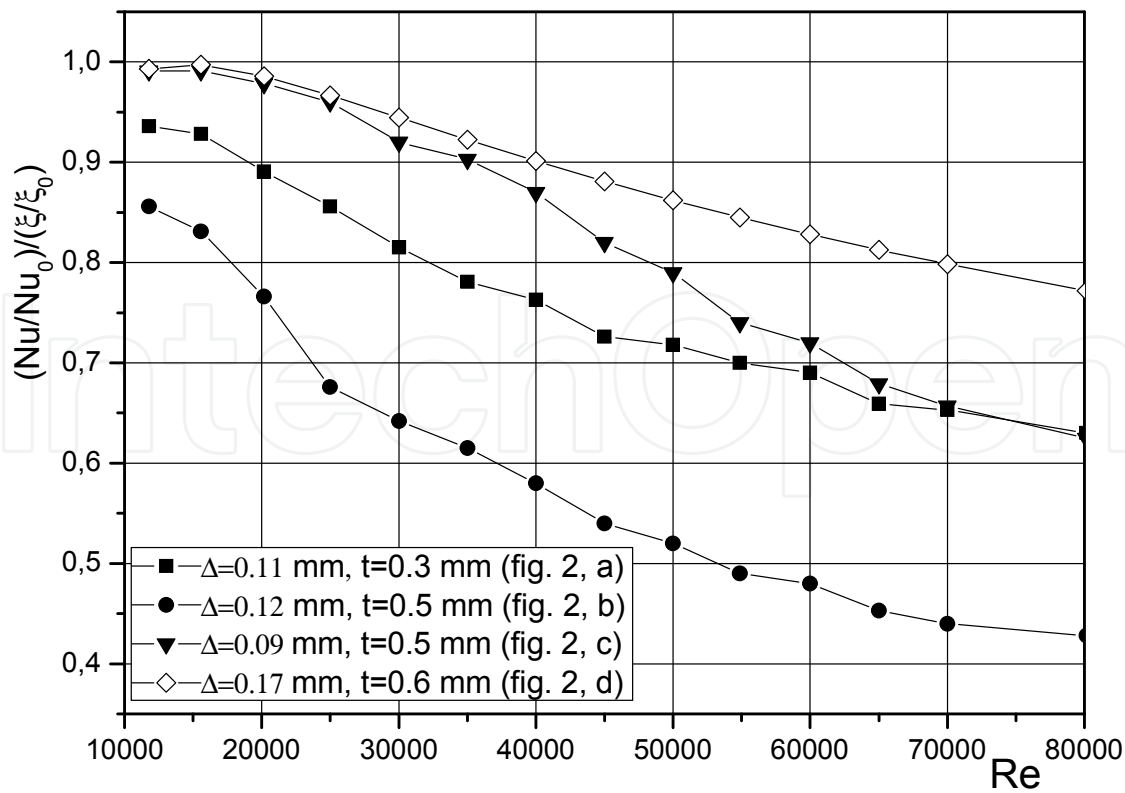Fig. 4. Dependence of hydraulic resistance factor of rough tubes on Re

Fig. 5. Thermohydraulic efficiency of rough tubes

2.1.2 Heat transfer and hydraulic resistance in different rough tubes with twisted tape inserts at water flow

For a flow twisting in rough tubes with roughness profiles shown in fig. 2 the twisted tape (width is 0.7 mm) was inserted into tube. The tapes have been covered by a high-temperature varnish for creation of electric isolation with a channel wall. Relative pitches of a tape twisting at turn on 180^0 was S/d=2.5 … 6 (a photo shown in fig. 6). Hereinafter at machining of experimental data the similarity numbers paid off using equivalent diameter of the equal volume smooth tube taking into account a tape insert (in a tube cross-section).
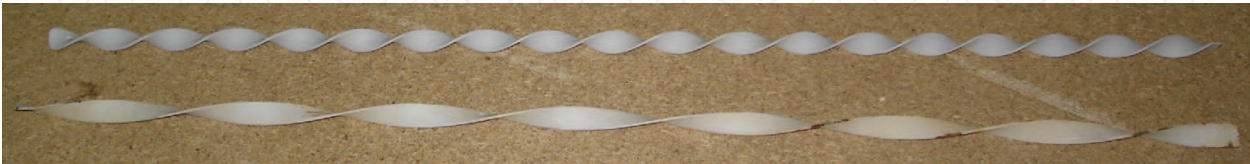
Fig. 6. Tapes with a minimum (*S/d* = 2.5) and maximum (S/d = 6) relative pitches of twisting

Presence of the twisted tape insert in a tube with a uniform continuous roughness leads to a heat transfer intensification (fig. 7, 8). In a tube with relatively large pitch between ledges the twisting effect decreases with growth of Reynolds number Re (fig. 8), i.e. the twisting a little suppresses the turbulent perturbations which oscillate by roughness ledges.
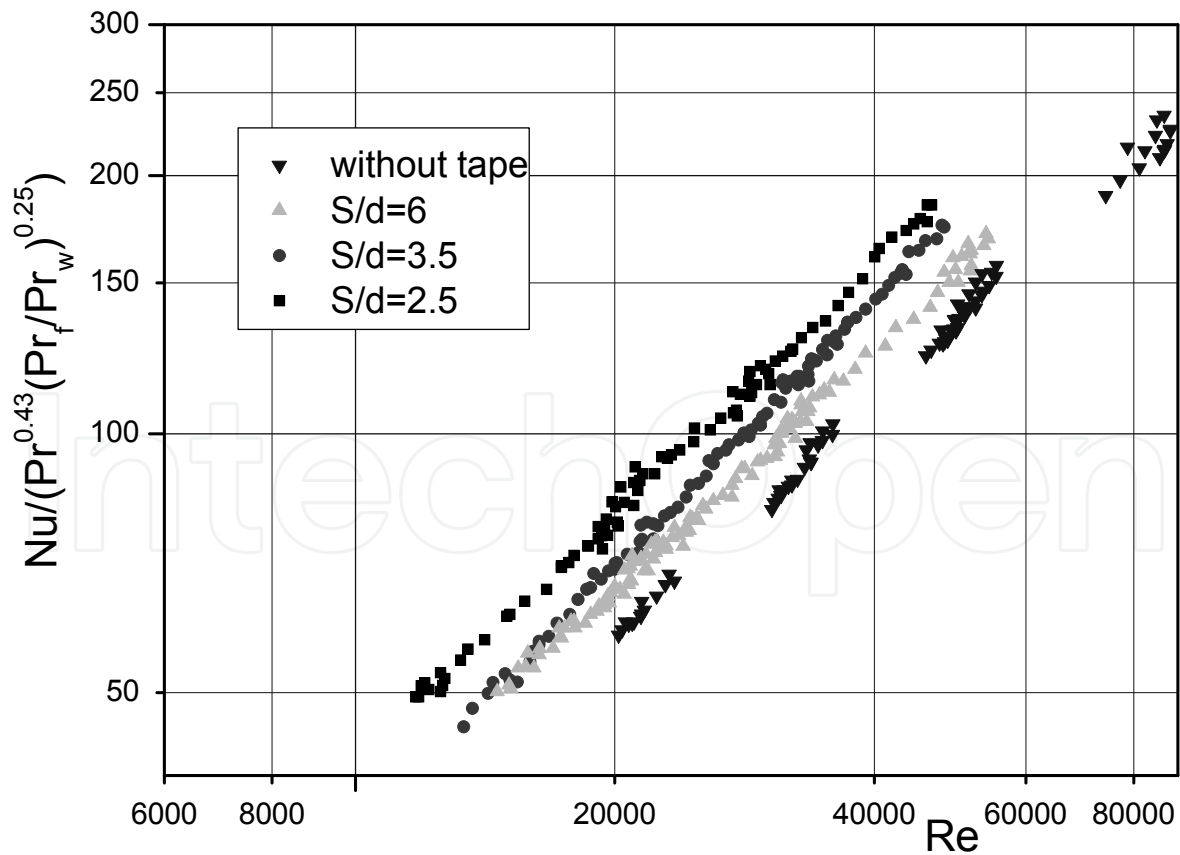
Fig. 7. Heat transfer in a tube with uniform continuous roughness (Δ=0.11 mm, *t*=0.3 mm, shown in fig. 2,a) and twisted tape inserts
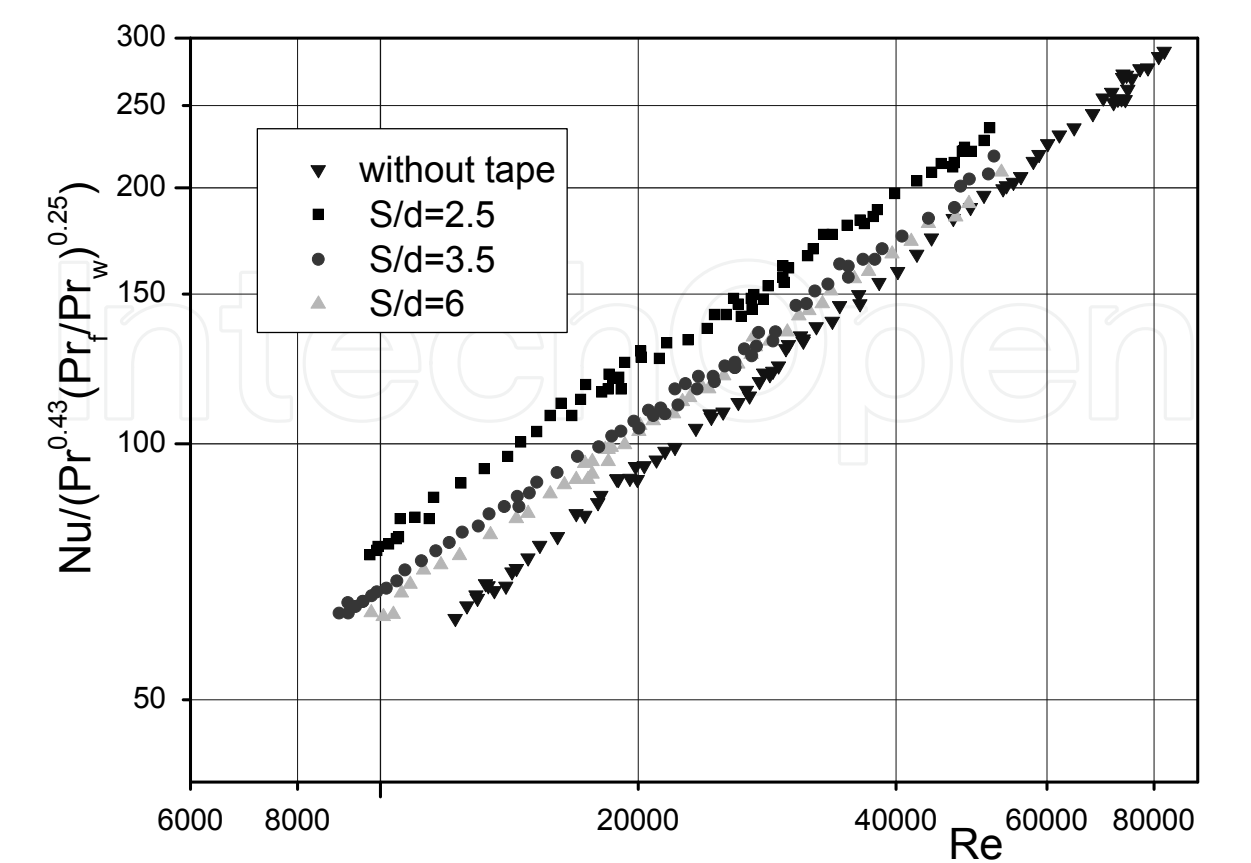
Fig. 8. Heat transfer in a tube with uniform continuous roughness (Δ=0.12 mm, t=0.5 mm, shown in fig. 2, b) and twisted tape inserts

This is also confirmed by investigations of heat transfer in a tube with a discrete (by knurling) roughness (the photo shown in Fig. 9) and with an inserted twisted tape (Fig. 10). A negative effect of flow twisting on heat transfer in a discretely rough tube is noted. The macro vortexes appearing in the channel with twistig suppress the mechanism of flow turbulization in a discretely rough channel. It leads to a decrease in the heat-transfer rate. Thus, the use of twisting to intensify heat transfer can be inadvisable at relatively high ledges of roughness which considerably turbulize the flow area near the wall.
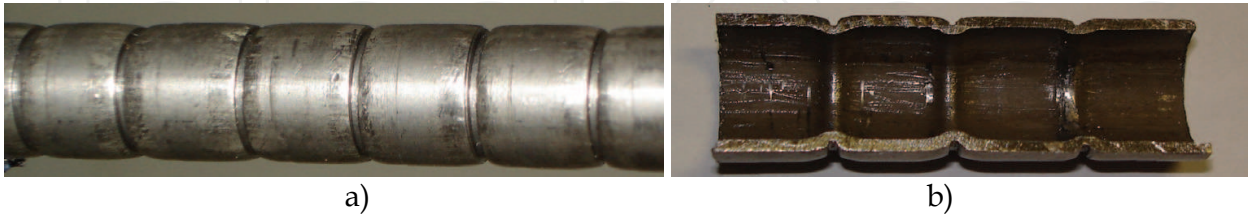
Fig. 9. Photos of a discretely rough tube: a) outside view; b) sectional view

From the results of comparing the rate of heat transfer from rough and smooth tubes with an identical twisted tape insert (fig. 11) the same specific features were noted as in tubes without a tape (fig. 3): in a tube with a relatively large pitch between the ledges a considerable increase in the heat transfer rate is observed in the entire range of Re; in a tube with a small pitch an increase in the heat transfer rate is insignificant and manifests itself only at high Re.
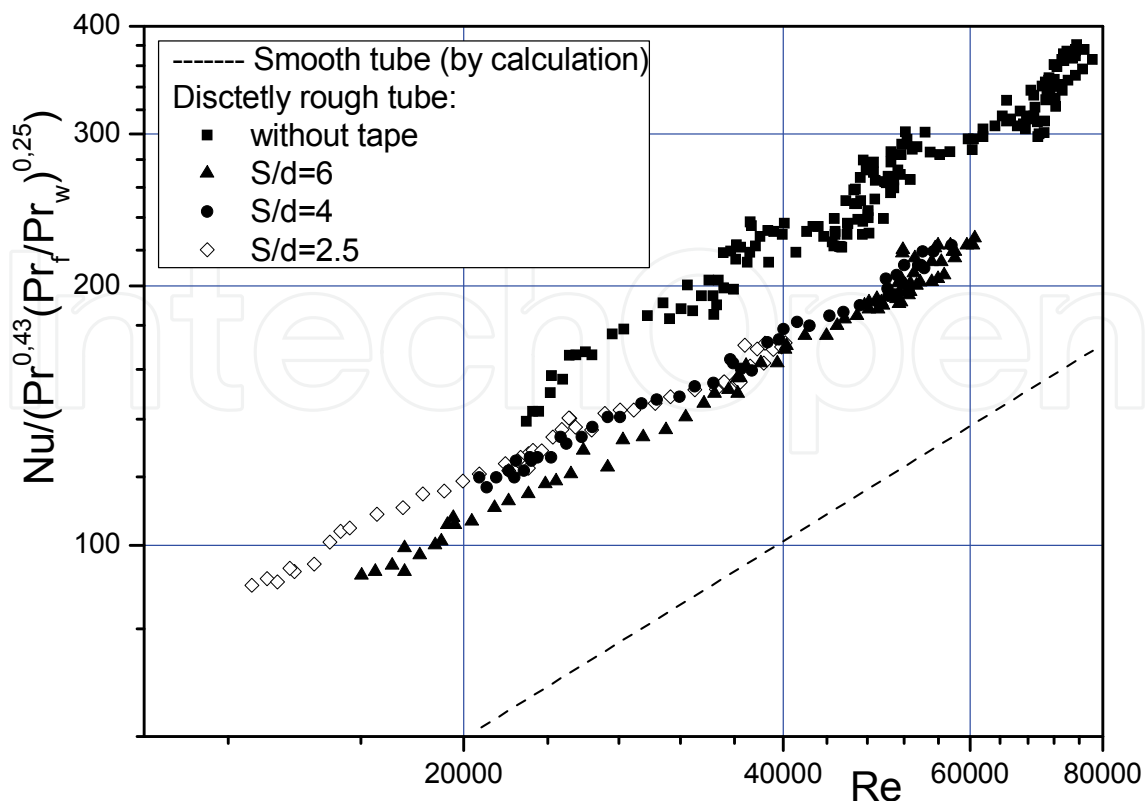
Fig. 10. Heat transfer in discretely rough tube with twisted tape insert

Moreover, a rough tube with the profile shown in Fig. 2, c which without a tape has a smaller heat transfer rate (fig. 3) than the tube with a profile form fig. 2, b in the presence of a tape (especially at high Re and tight twisting S/d = 2.5) has a noticeably higher heat transfer rate. This is due to the reasons indicated above: the twisting suppresses vortex formation between the ledges with a large pitch between them. Thus it's possible to obtain an optimum combination of the parameters of twisting and surface roughness.

In rough tubes with twisted tape insert the increase in the hydraulic resistance (Fig, 12), as against the increase in the heat-transfer rate, is commensurable with an analogous relation for rough tubes without a tape.

2.1.3 Features of water boiling in rough tubes

The results of heat transfer in developed bubble boiling in rough tubes with a twisted tape insert are presented in Figs. 13 and 14. They allow one to draw the conclusions analogous to those made for heat transfer in convection. It is seen that with a decrease in the flow velocity V and an increase in the heat flux q the heat transfer data approach the heat transfer lines for pool boiling. The lines of pool boiling on rough surfaces are much higher than the lines of pool boiling on a smooth surface. The heat transfer rate in boiling in a rough tube with roughness profile shown in fig.2, a is higher by 15-20% than in boiling on a smooth surface (fig. 13), and with roughness profile shown in fig.2, b is higher already by 70% (fig. 14). This is attributable to different specific areas of heat-transfer surfaces and to the conditions of the heat flux distribution on the surface of boiling caused by the geometry of the tube wall. Moreover, the boiling heat transfer rate in a rough channel with a relatively large pitch is notably higher due to the higher convective component of heat transfer.
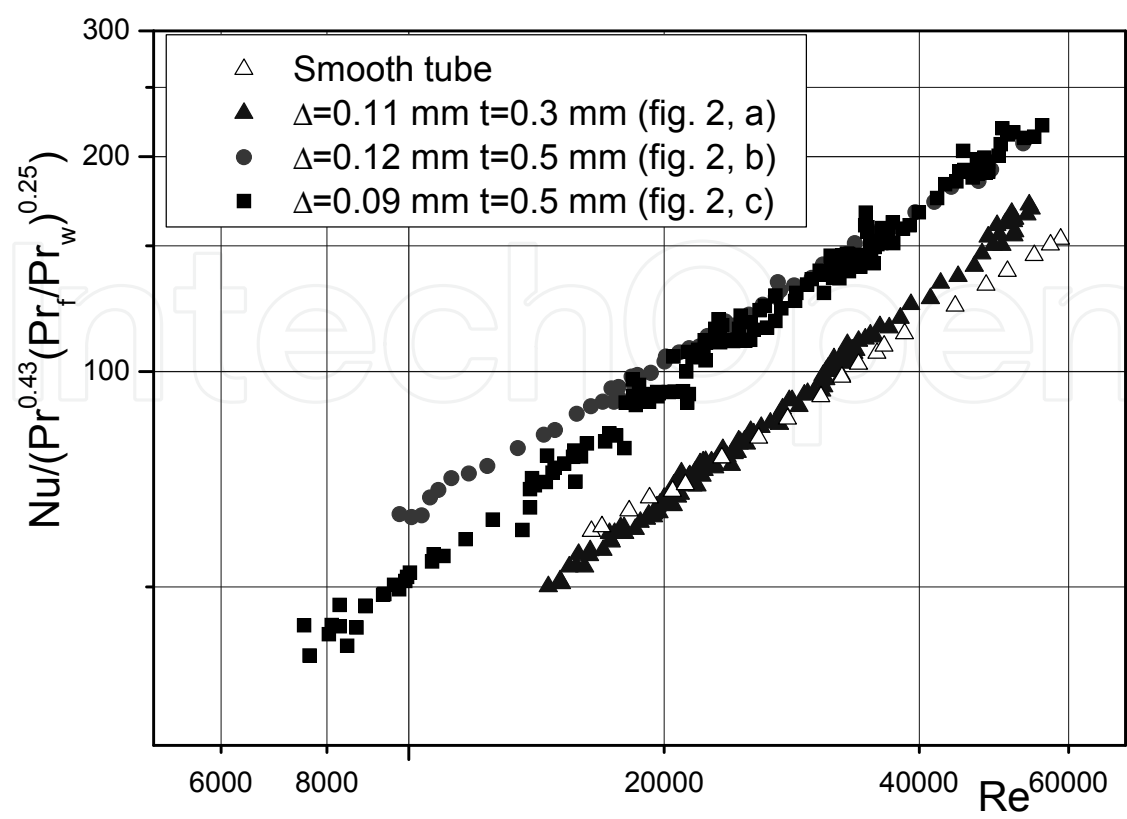
a)
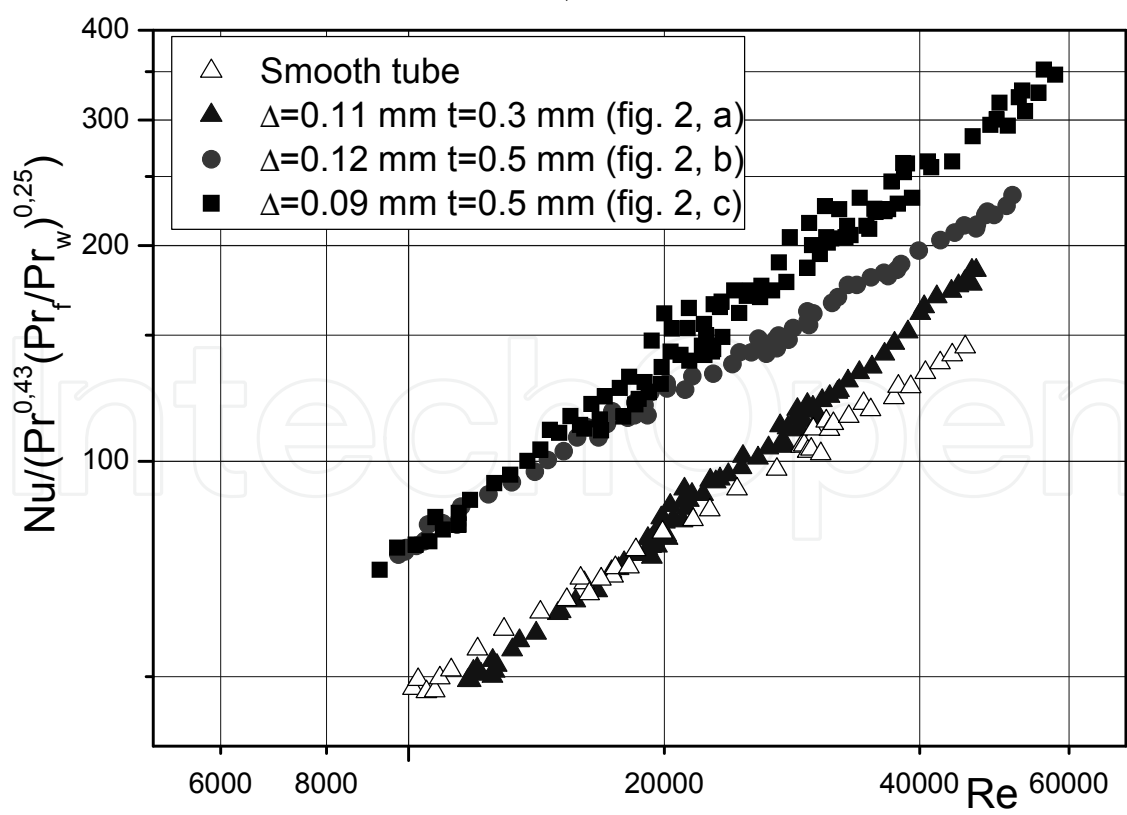
b)

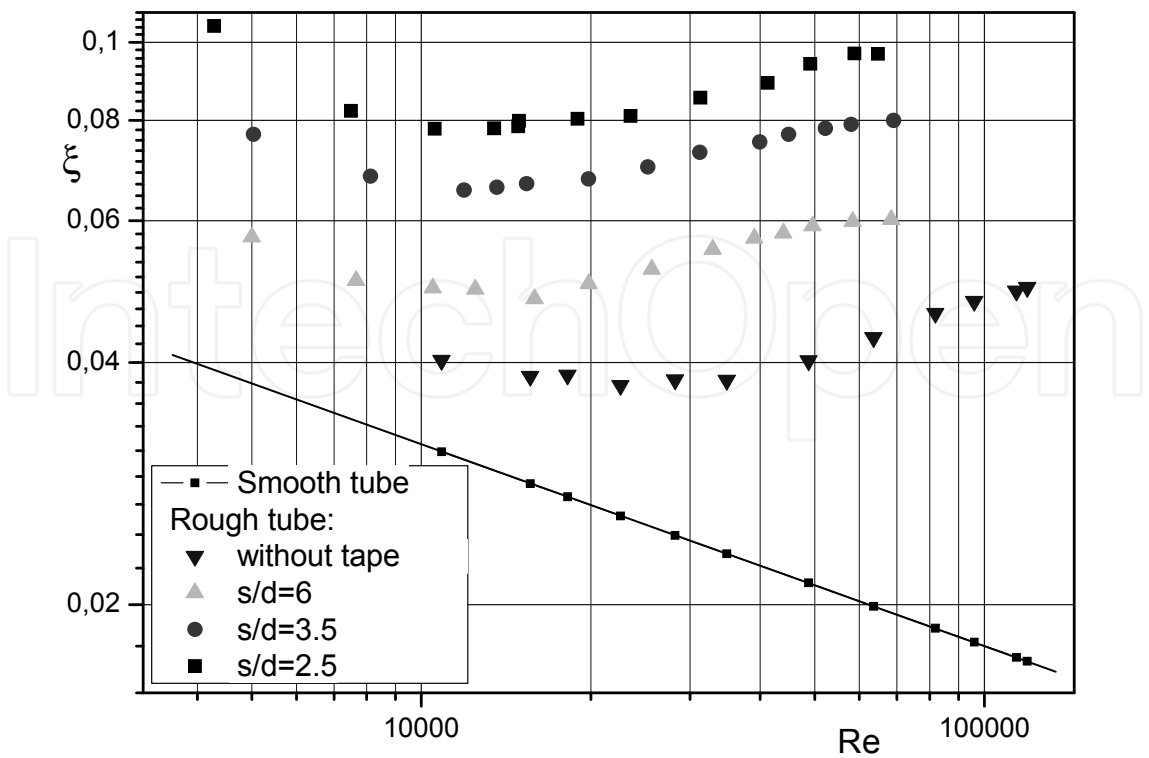Fig. 11. Heat transfer of rough tubes with twisted tape insert: a) S/d=6, б) S/d=2.5

Fig. 12. Hydraulic resistance of tubes with a uniform continuous roughness (with profile shown in fig.2, c) and with an inserted twisted tape
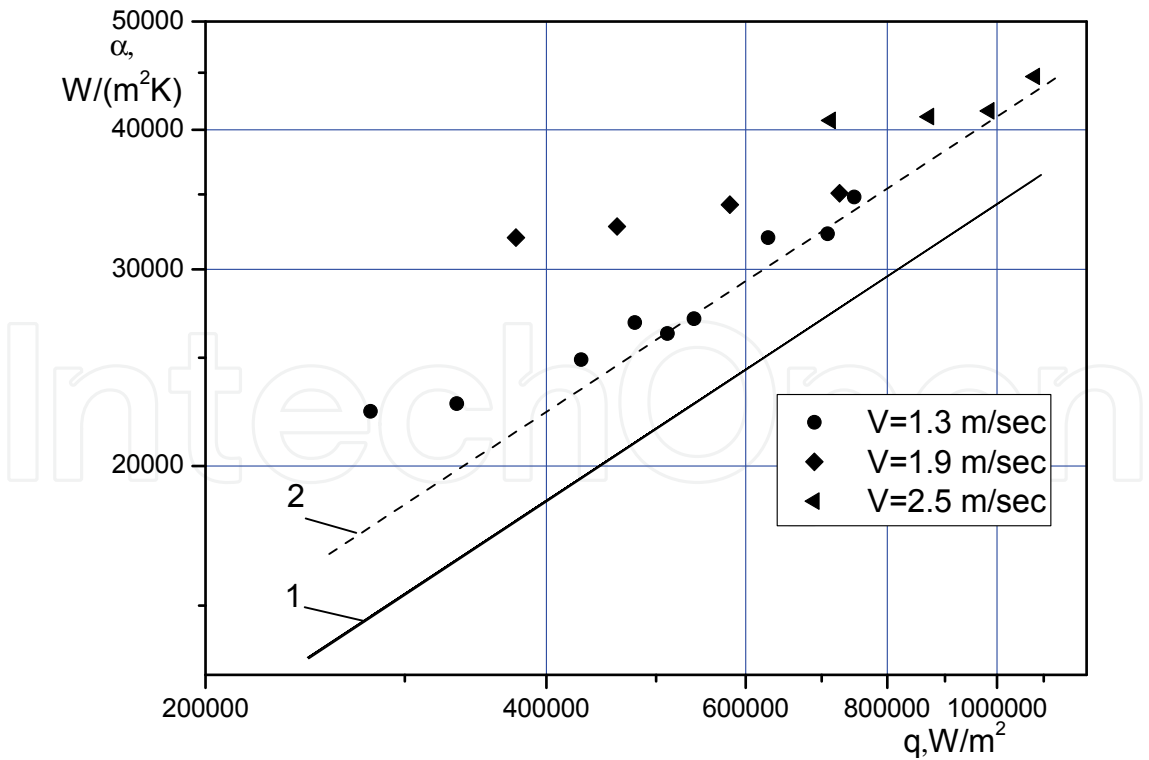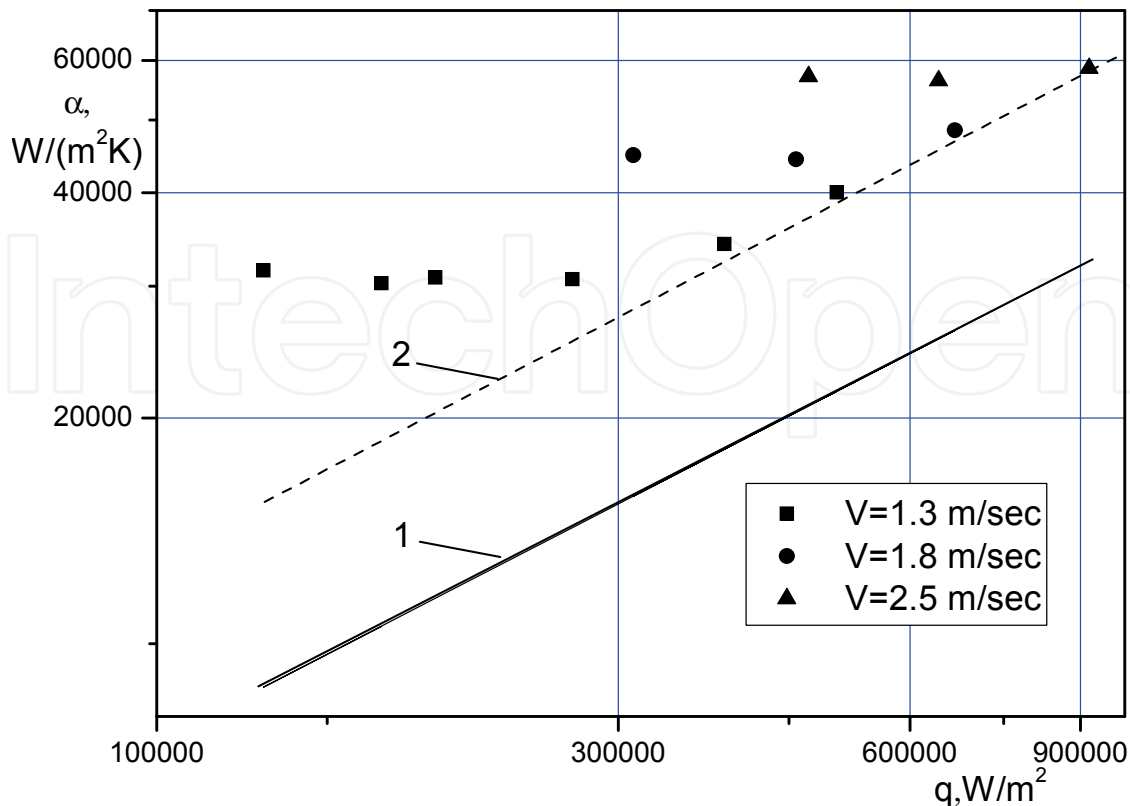

Fig. 13. Dependence of the heat transfer factor α on the heat flux q at water boiling (pressure p=0.14 MPa) in a tube with roughness shown in fig. 2, a: 1 – heat transfer at pool boiling on smooth wall (by calculation); 2 - heat transfer at pool boiling on rough wall

Fig. 14. Dependence of the heat transfer factor α on the heat flux q at water boiling (pressure *p*=0.155 MPa) in a tube with roughness shown in fig. 2, b: 1 – heat transfer at pool boiling on smooth wall (by calculation); 2 - heat transfer at pool boiling on rough wall

2.2 Hydraulic resistance of tubes with the twisted tape inserts and with the full thread roughness with the various shape of ledges at air flow
2.2.1 Hydraulic resistance of tubes with the full thread roughness with the various shape of ledges at air flow
Also experiments have been executed by definition a hydraulic resistance of rough tubes at an adiabatic air flow at the Mach number M<0.3. The tube roughness was attained by cutting of a thread various a profile in a plastic tube with inner diameter d=12.6 mm with pitchs t=0.25…1.25 mm and average height of a ledges Δ =0.1…0.71 mm (table 2). Three basic profiles of ledges were examined: triangular, rectangular and rounded.
In fig. 15-17 experimental data on hydraulic resistance of tubes with the thread roughness various a profile are displayed. It is obvious that with increase in a pitch of a thread t and accordingly increase in a height of roughness ledges Δ the hydraulic resistance is augmented. As well as by results of other researches (Ibragimov et al., 1978; Isachenko et al., 1965; et al.) the curves of hydroresistance are not the monotonic, the sites with extremes are observed.
In fig. 18 the comparison of a hydraulic resistance of rough tubes with various roughness profiles but with similar height of the ledges is presented. Apparently, the tube with the rectangular profile has the greatest resistance, the least - with triangular. It can be linked with presence of acute microcrimps on crossetes. Some excess of resistance of tubes with the rounded ledges over resistance of tubes with triangular roughness ledges is linked with

higher pitches between the rounded ledges that promotes development of vortex perturbations as already was noted above.
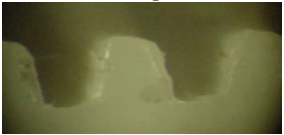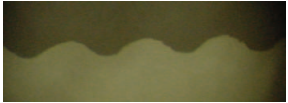
№	Pitch t, mm	Height Δ, mm	Relative height $\overline{\Delta} = \Delta/d$	Profile
1	0.25	0.177	0.012	triangular
2	0.5	0.34	0.023	
3	0.75	0.46	0.034	
4	1	0.71	0.055	
5	0.5	0.175	0.013	rectangular
6	0.75	0.33	0.025	
7	1	0.4	0.03	
8	1.25	0.6	0.046	
9	0.5	0.1	0.008	rounded
10	0.75	0.175	0.013	
11	1	0.3	0.023	
12	1.25	0.4	0.03	

Table 2. Profiles of the thread roughness of plastic tubes
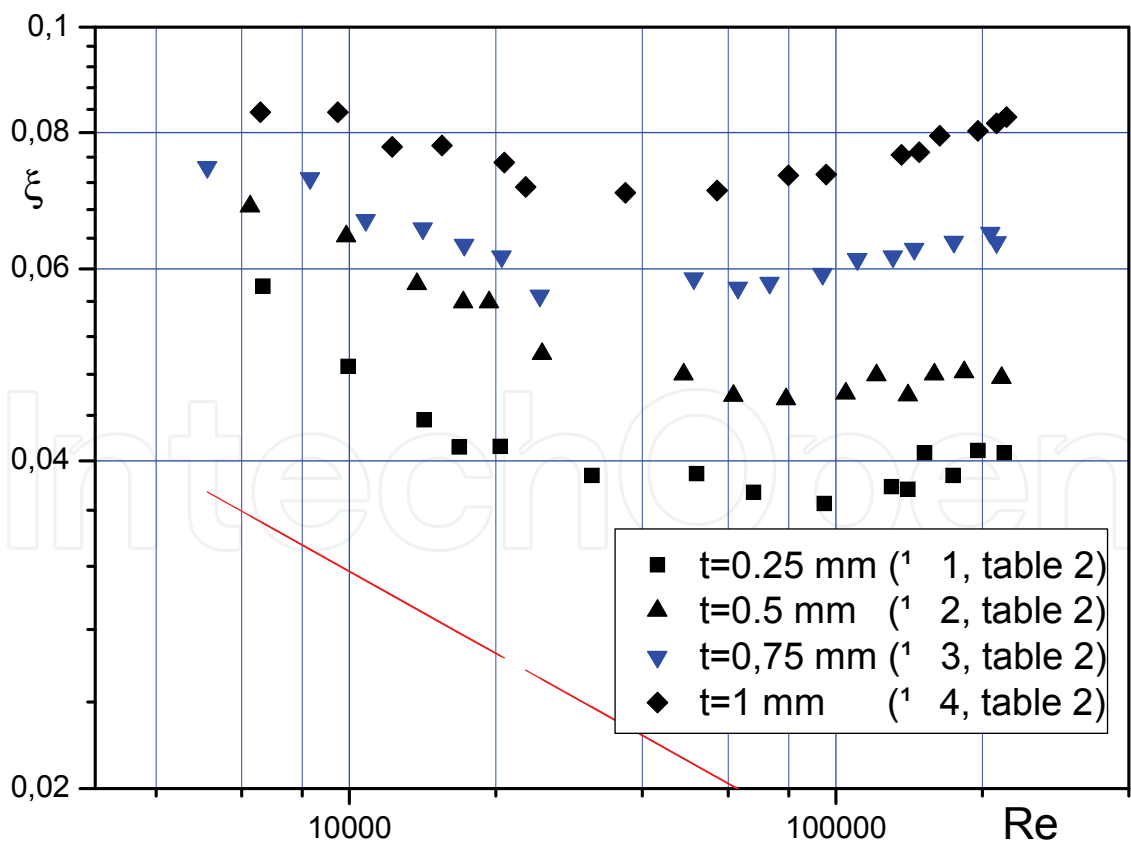
Fig. 15. Dependence of hydraulic resistance factor of rough tubes with triangular thread roughness profile on Re: line – for smooth tube (by calculation)
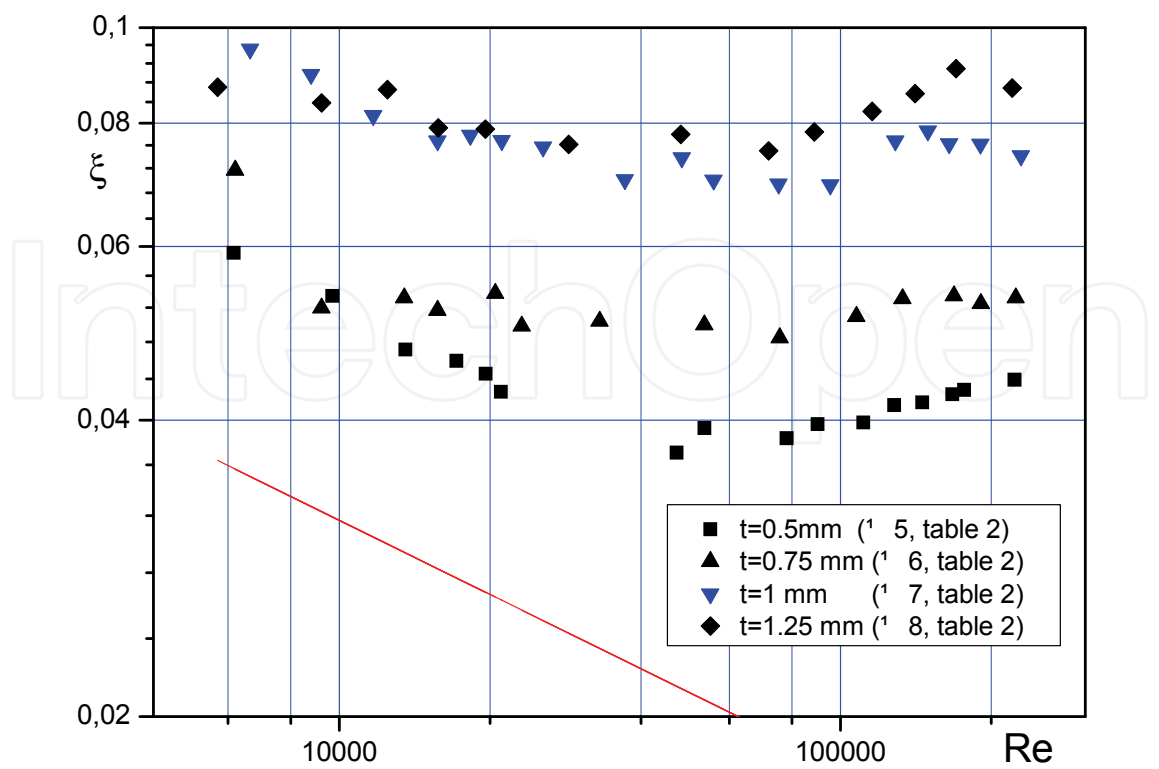
Fig. 16. Dependence of hydraulic resistance factor of rough tubes with rectangular thread roughness profile on Re: line – for smooth tube (by calculation)
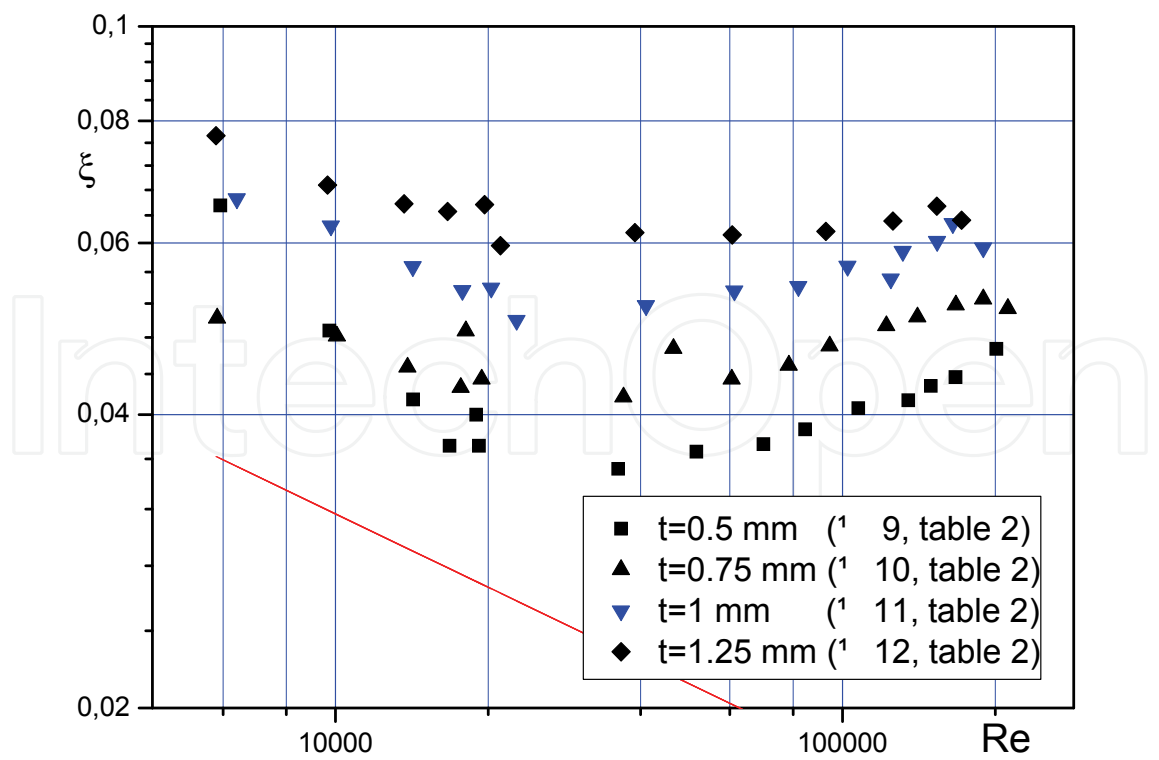

Fig. 17. Dependence of hydraulic resistance factor of rough tubes with rounded thread roughness profile on Re: line – for smooth tube (by calculation)
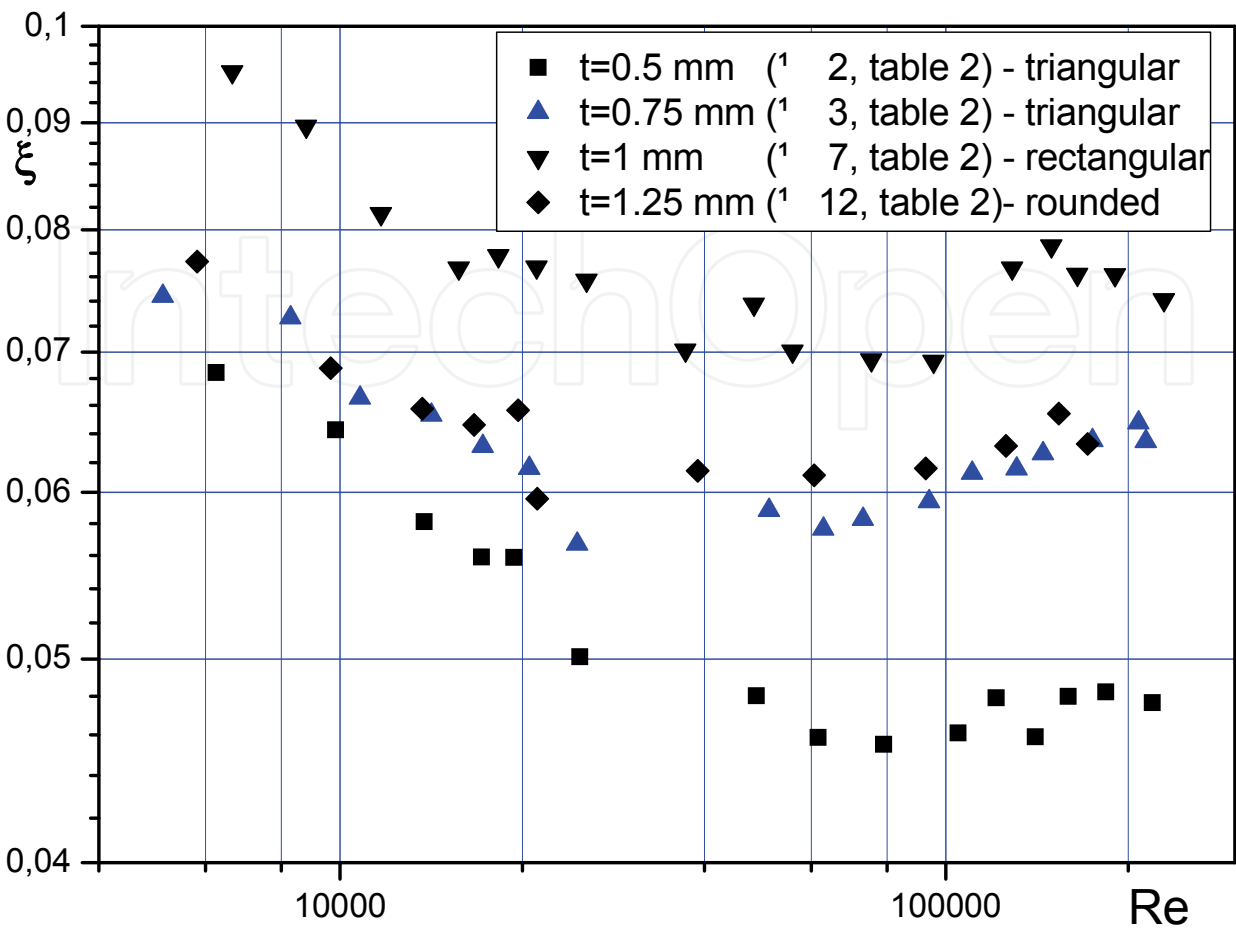
Fig. 18. Dependence of hydraulic resistance factor of rough tubes with various thread roughness profile and with similar heights of ledges on Re

Generalization of experimental data of a hydraulic resistance of tubes with a triangular roughness profile is executed as follows (Tarasevich et al., 2007):
at Re=6000…80000

$$\xi = 0.15 + 0.69 \times \overline{\Delta} + 0.06 \times log\overline{\Delta} \times exp\left[-Re / \left(125.9 \times \overline{\Delta}^{(-0,8)} \right) \right];$$ (2)

at Re=80000…250000

$$\xi = (0.041 - 0.47\overline{\Delta}) \times Re^{\left(3\overline{\Delta} - 0.03 \right)}.$$ (3)

Experimental data on a hydraulic resistance of tubes with a rectangular roughness profile at Re <80000 have been generalized by dependence of an exponential aspect:

$$\xi = 0.02 + 1.3 \times \overline{\Delta} + (0.24 + 0.1 \times log\overline{\Delta}) \times exp\left[-Re / \left(1000 \times \overline{\Delta}^{(-0.5)} \right) \right].$$ (4)

Generalisation of dependence of a hydraulic resistance of tubes with a roughness of the rectangular profile at Re> 80000 and with a rounded roughness profile has not been spent yet in connection with ambiguous character of dependences in this cases.

2.2.2 Hydraulic resistance of tubes with the full thread roughness and with twisted tape inserts at air flow

The presents authors also have gained the big data array on a hydraulic resistance of tubes with various full thread profiles of a roughness and with twisted tape inserts (S/d=2.5…7).

In fig. 19-22 the dependences of hydraulic resistance factor ξ of tubes with a triangular roughness profile on number Re are shown at various extent of twisting S/d. It is obvious that with increase in extent of a twisting (decrease S/d) the hydraulic resistance is augmented. The common character of dependence of factor ξ on Re in rough channels with a twisting is analogous to dependence for a case without twisting, however at Re>20000 the self-similar regime is observed, and the factor ξ is not augmented almost, i.e. the twisting a little suppresses a turbulization oscillated by roughness ledges.

In fig. 23 the comparison of a hydraulic resistance of tubes with the twisted tape insert (S/d = 2.5) and various height of a triangular roughness profile is shown. It is obvious that the increase of rate Δ promotes growth of a hydraulic resistance and in the twisting conditions.

In fig. 24 the comparison of a hydraulic resistance of rough tubes with various profiles of a roughness but with similar roughness height at an equal twisting is presented. Leading-outs can be made same as well as at comparison of rough tubes without a twisting (fig. 18).

In fig. 25-28 and fig.29-32 the dependences of hydraulic resistance factor ξ of tubes with a rectangular and rounded roughness profiles on Reynolds number *Re* at various extent of twisting S/d are presented accordingly. The common character of these dependences is analogous to dependences for tubes with a triangular roughness profile (fig. 19-22) and differs quantitatively.

Generalization of experimental data of a hydraulic resistance of tubes with a triangular roughness profile and with twisted tape inserts is executed as follows (Tarasevich et al., 2007):

at Re =3000…30000

$$\xi = \left(S \, / \, d \right)^{-(0.0023 \times exp\left(\bar{\Delta}/0.0143 \right)+0.39)} \times \left[0.16 \times exp\left(-Re \, / \, 3700 \right) + 0.065 + 2.3\bar{\Delta} \right];$$ (5)

and at Re =30000…80000

$$\xi = 0.5 \times \frac{\left(S \, / \, d \right)^{0.4}}{\left(\Delta \, / \, d \right)^{0.4}} = 0.5 \times \left(\frac{S}{\Delta} \right)^{0.4}$$ (6)

For tubes with the rectangular and rounded ledges of roughness such generalization is not executed yet in connection with a difficult ambiguous aspect of these dependences at various magnitudes S/d and Δ.
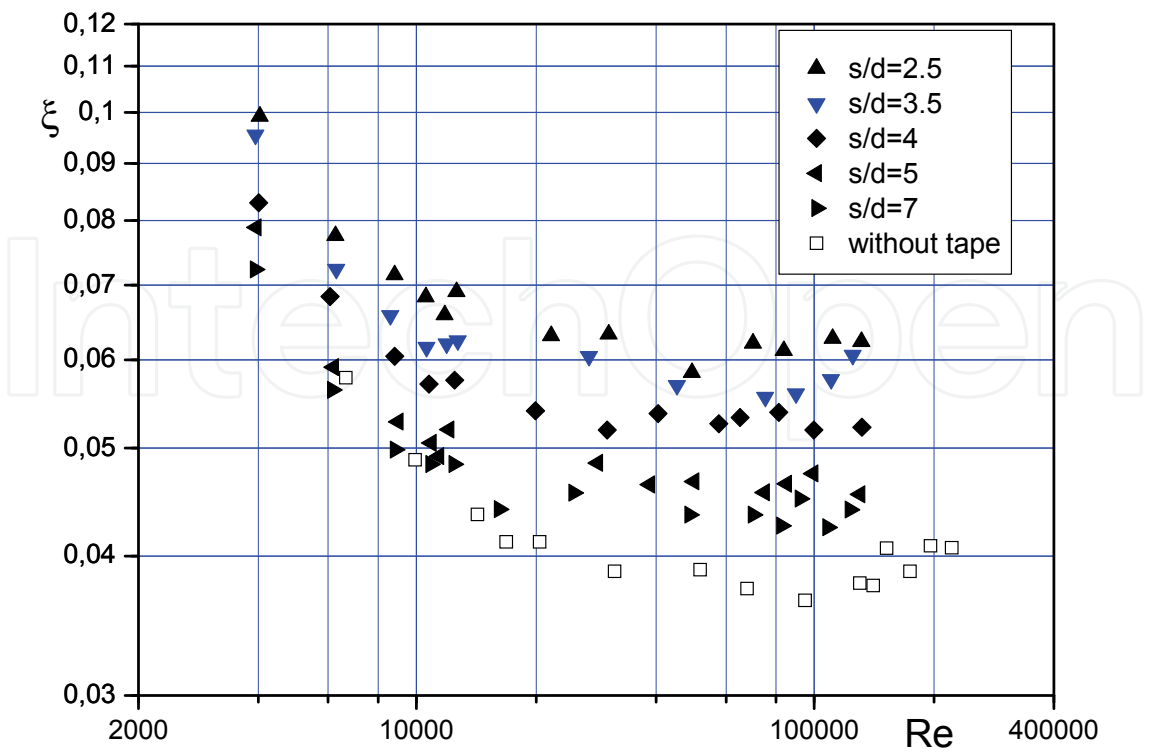
Fig. 19. Dependence of hydraulic resistance factor of rough tubes with triangular roughness profile (Table 2, № 1) on Re at various S/d
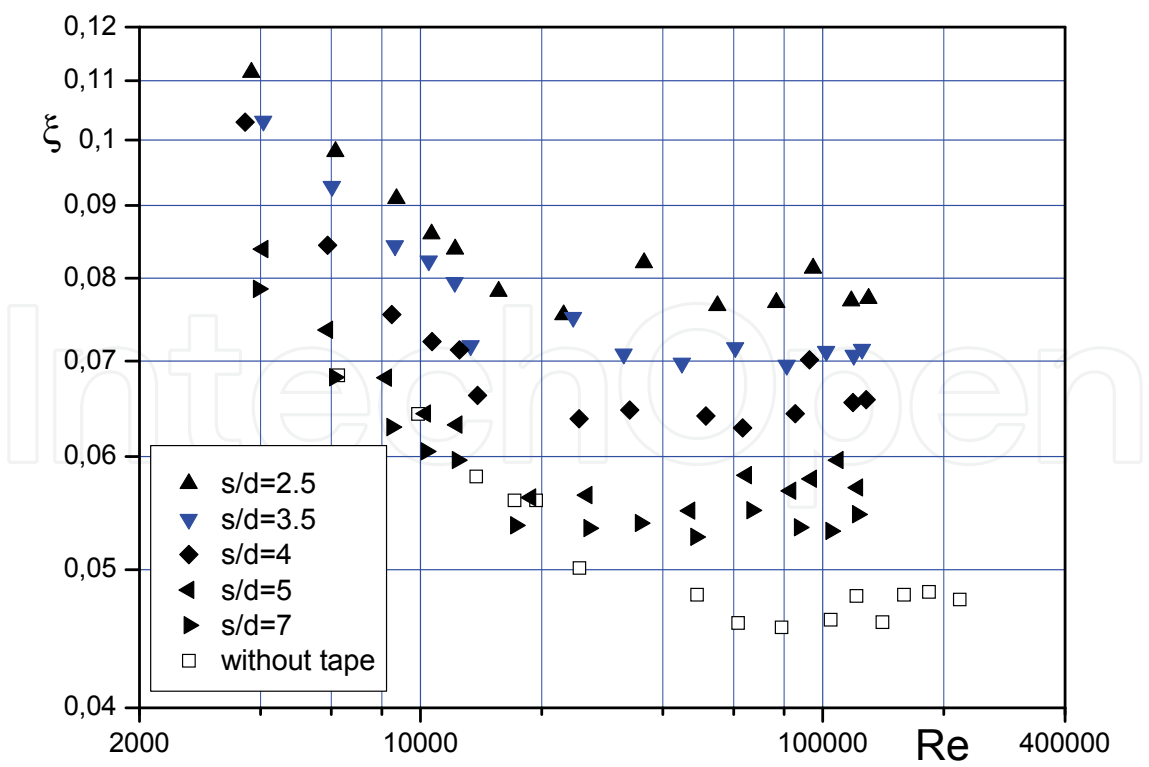

Fig. 20. Dependence of hydraulic resistance factor of rough tubes with triangular roughness profile (Table 2, № 2) on Re at various S/d
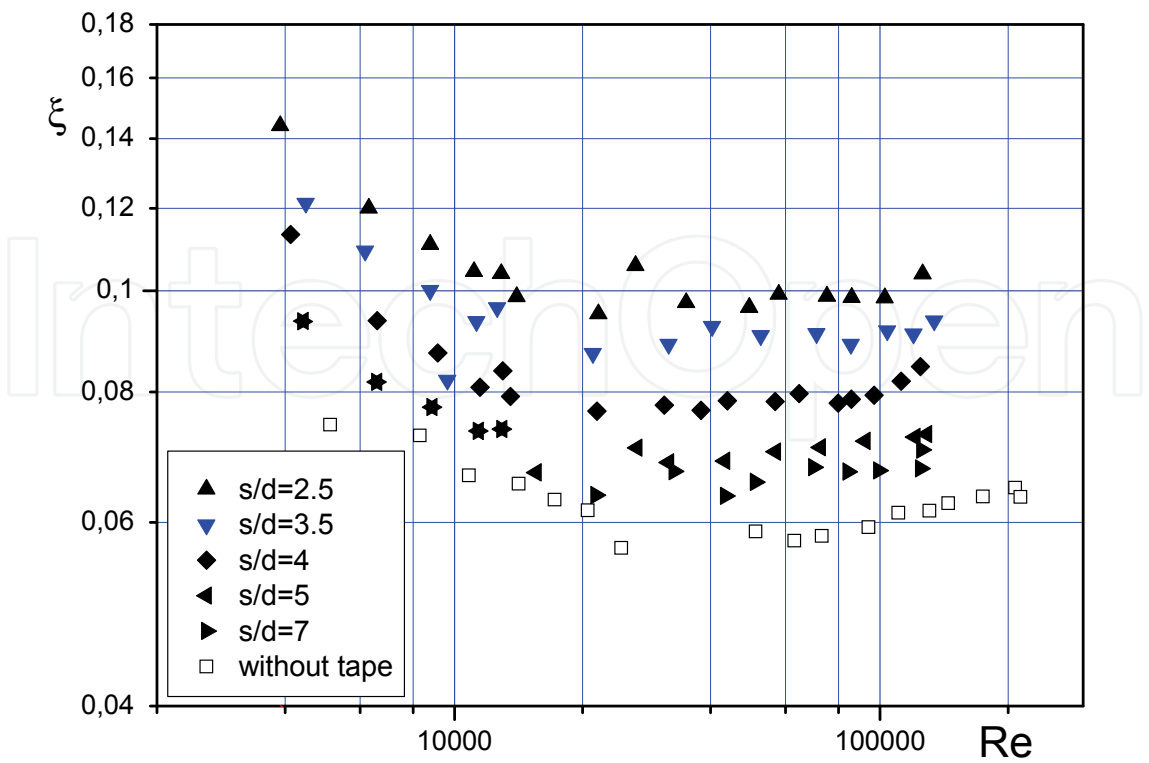
Fig. 21. Dependence of hydraulic resistance factor of rough tubes with triangular roughness profile (Table 2, № 3) on Re at various S/d
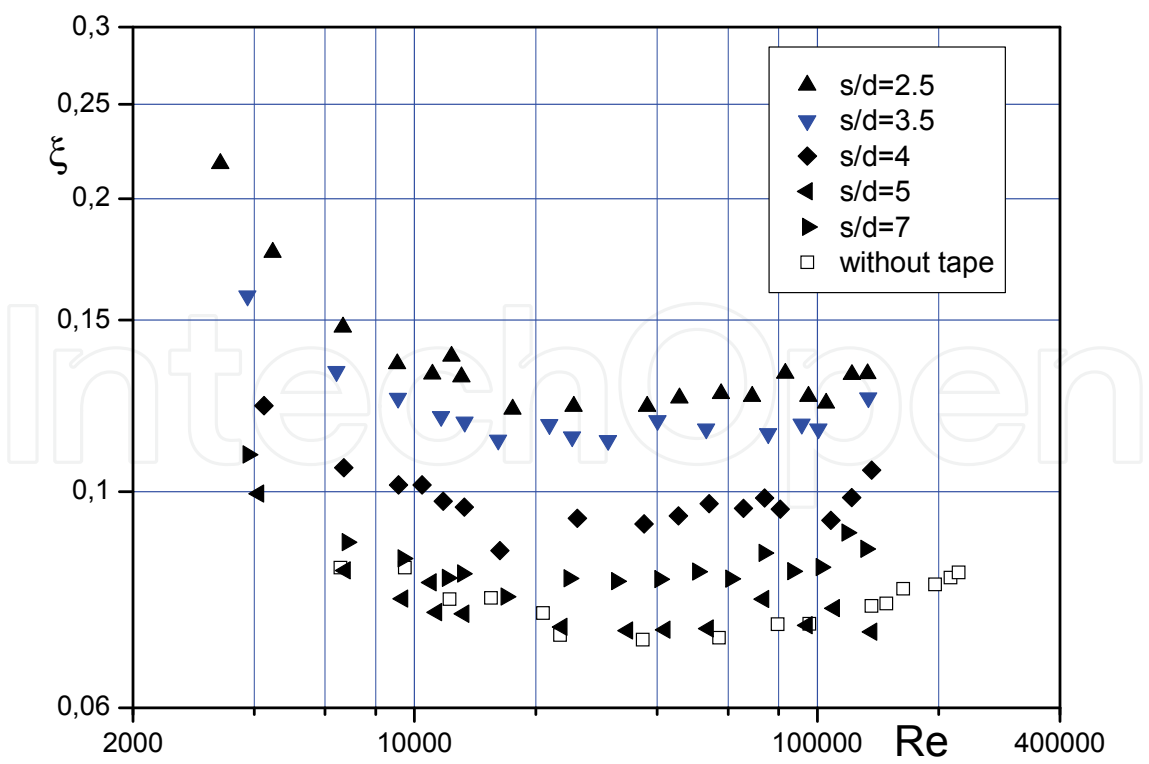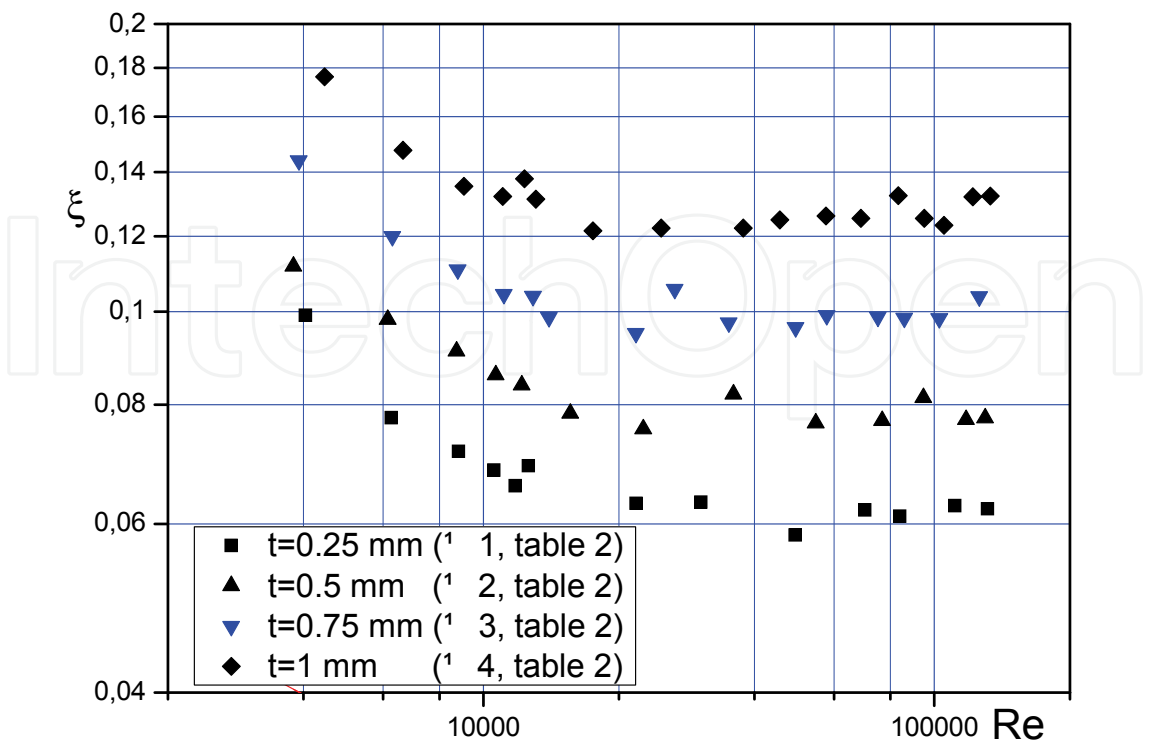

Fig. 22. Dependence of hydraulic resistance factor of rough tubes with triangular roughness profile (Table 2, № 4) on Re at various S/d

Fig. 23. Dependence of hydraulic resistance factor of tubes with various triangular roughness profile and with twisted tape insert (S/d=2.5) on Re
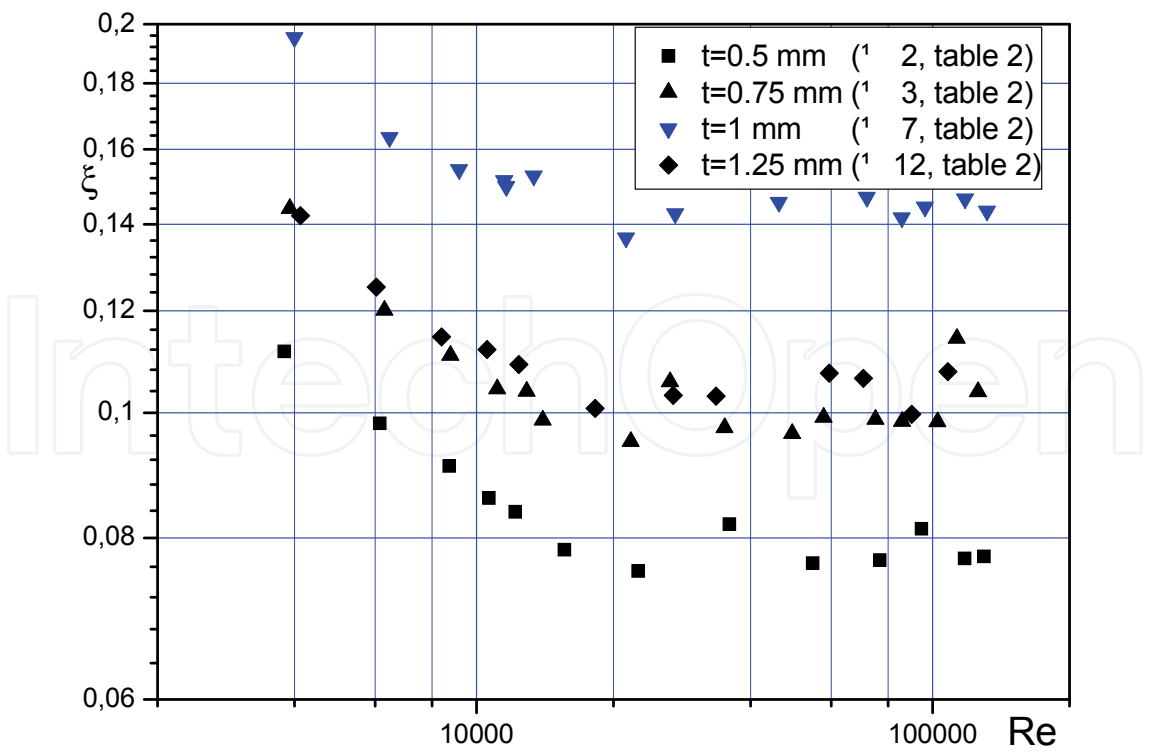
Fig. 24. Dependence of hydraulic resistance factor of rough tubes with various thread roughness profile with similar heights of ledges and with twisted tape insert (S/d=2.5) on Re
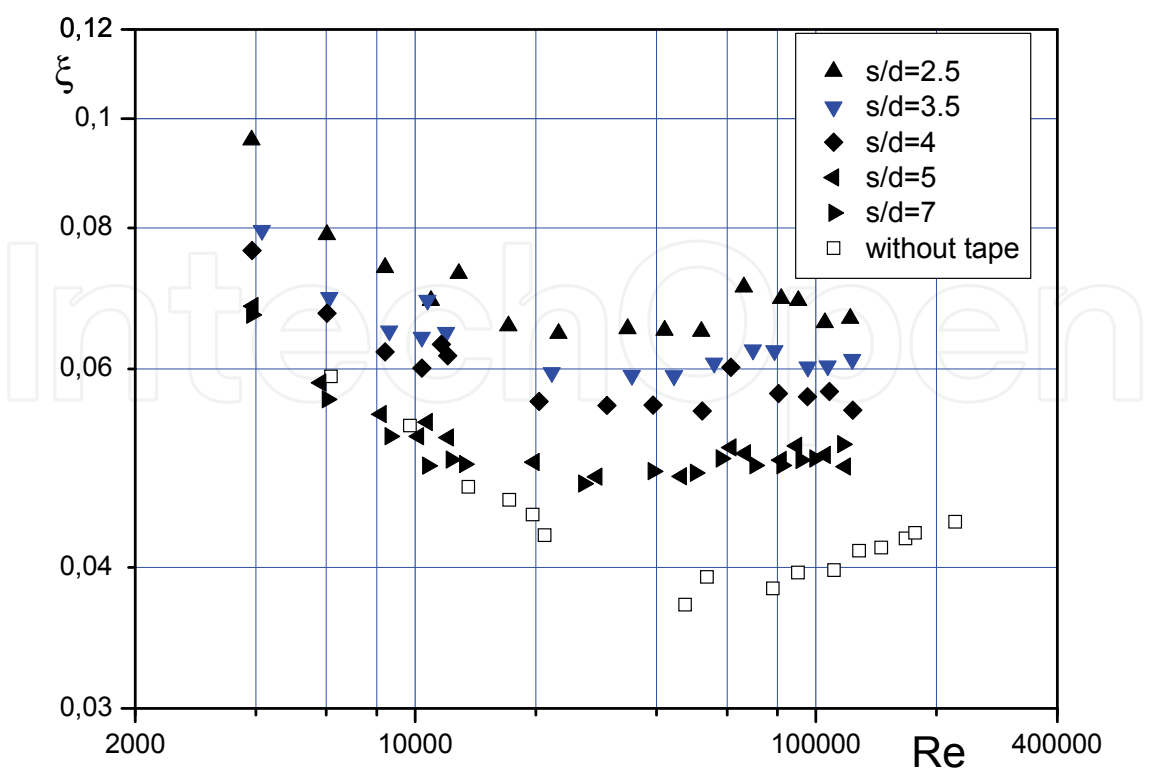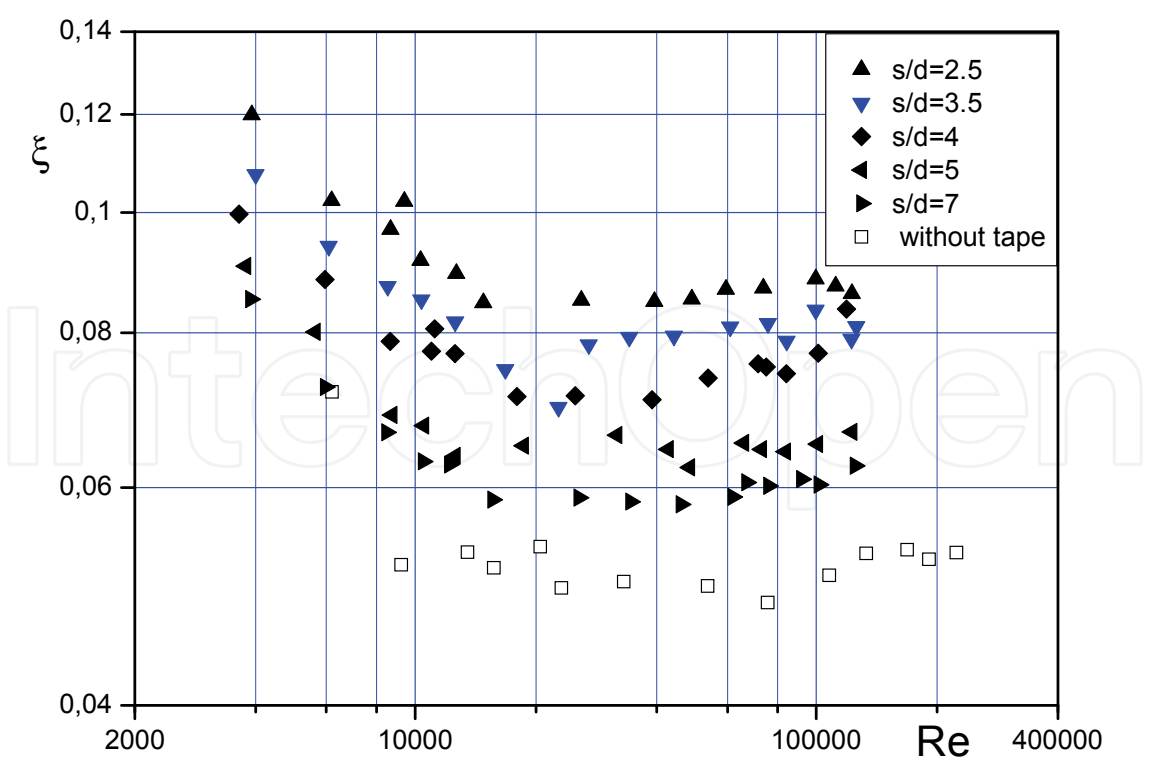
Fig. 25. Dependence of hydraulic resistance factor of rough tubes with rectangular roughness profile (Table 2, № 5) on Re at various S/d

Fig. 26. Dependence of hydraulic resistance factor of rough tubes with rectangular roughness profile (Table 2, № 6) on Re at various S/d
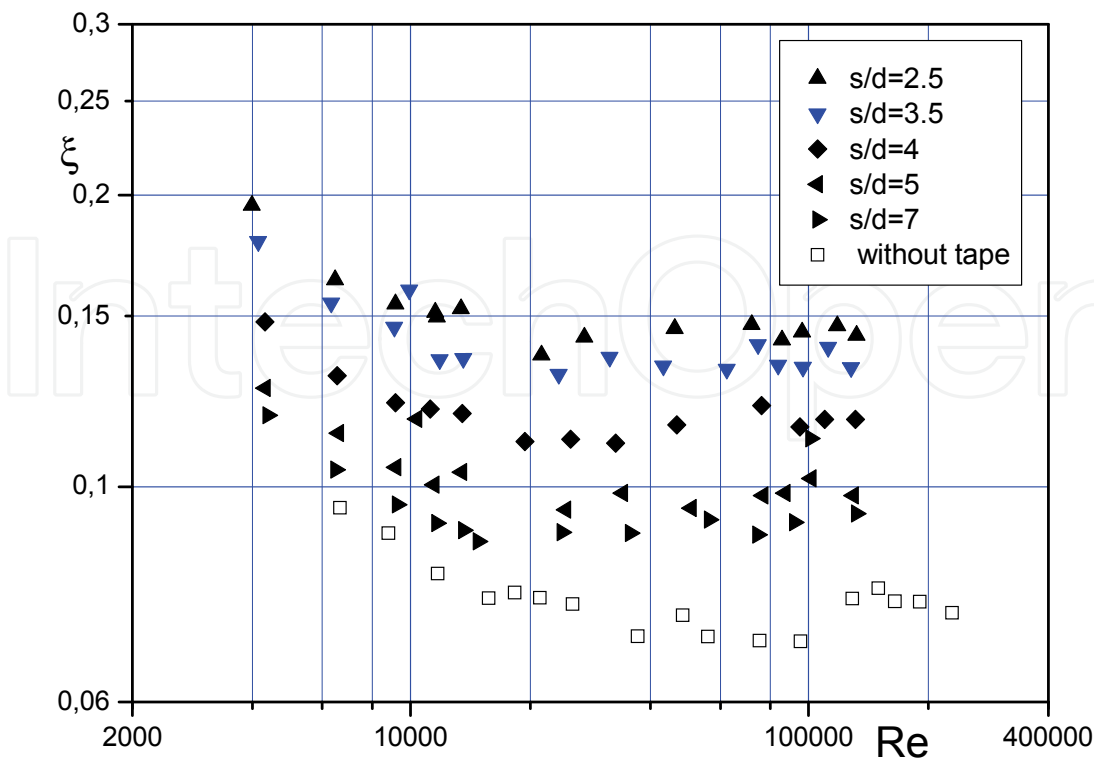
Fig. 27. Dependence of hydraulic resistance factor of rough tubes with rectangular roughness profile (Table 2, № 7) on Re at various S/d
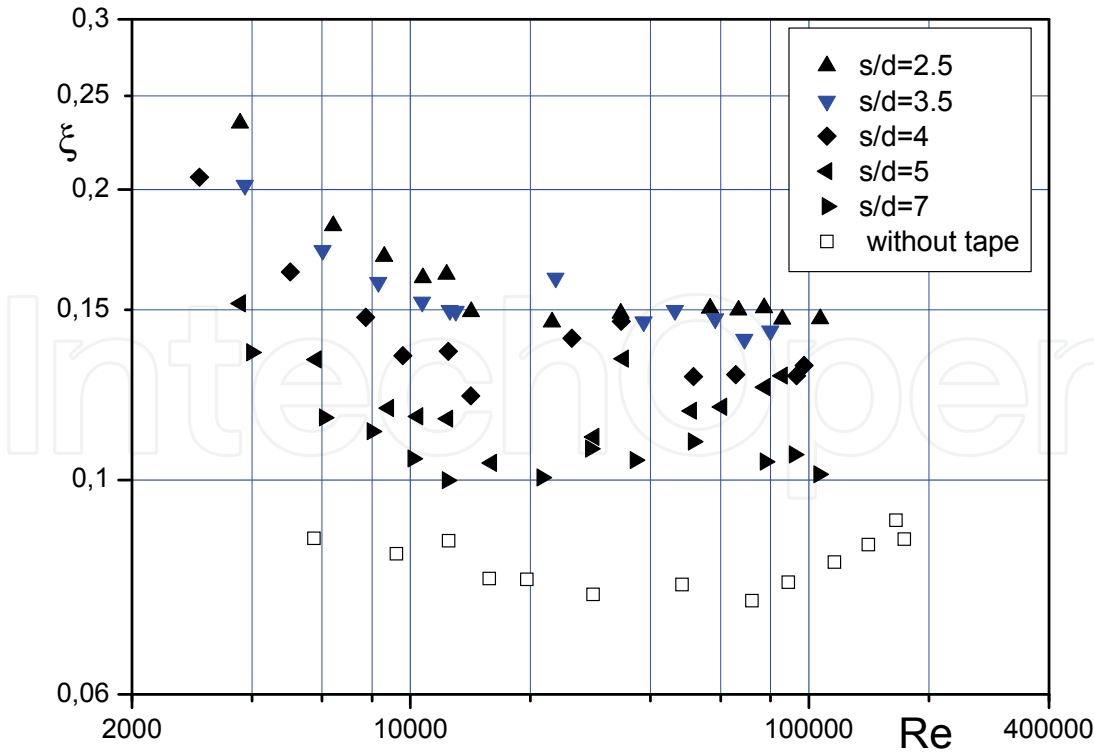

Fig. 28. Dependence of hydraulic resistance factor of rough tubes with rectangular roughness profile (Table 2, № 8) on Re at various S/d
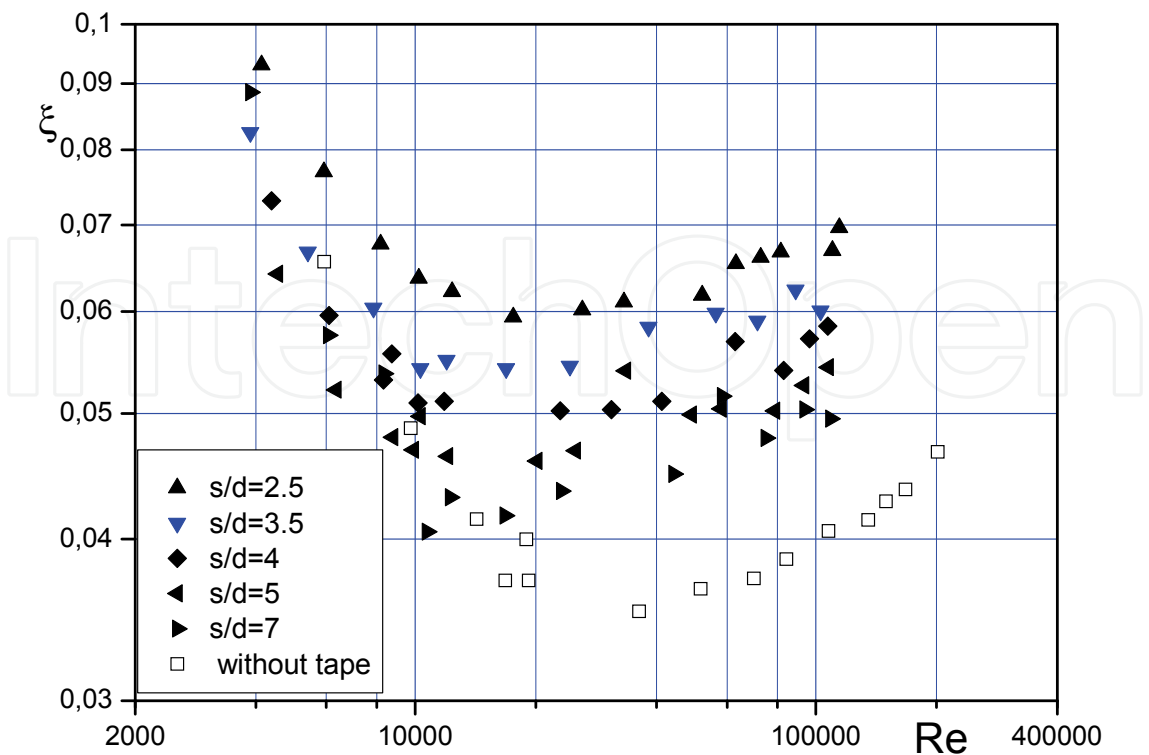
Fig. 29. Dependence of hydraulic resistance factor of rough tubes with rounded roughness profile (Table 2, № 9) on Re at various S/d
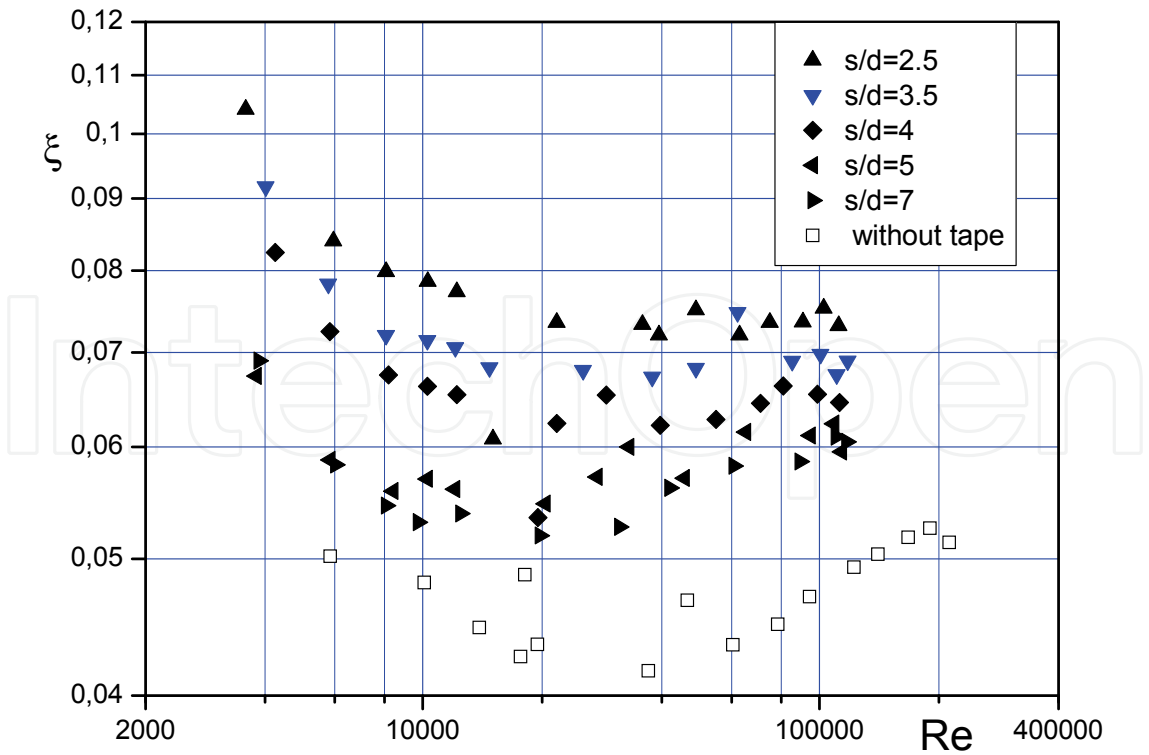

Fig. 30. Dependence of hydraulic resistance factor of rough tubes with rounded roughness profile (Table 2, № 10) on Re at various S/d
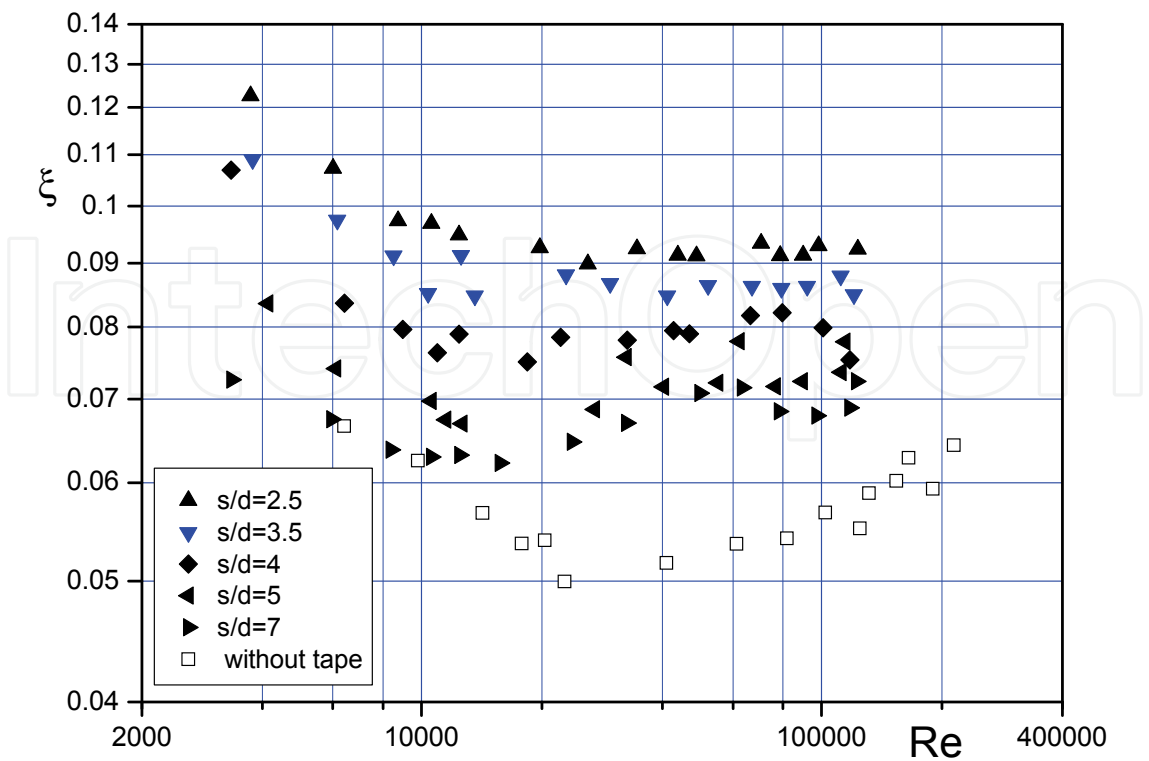
Fig. 31. Dependence of hydraulic resistance factor of rough tubes with rounded roughness profile (Table 2, № 11) on Re at various S/d
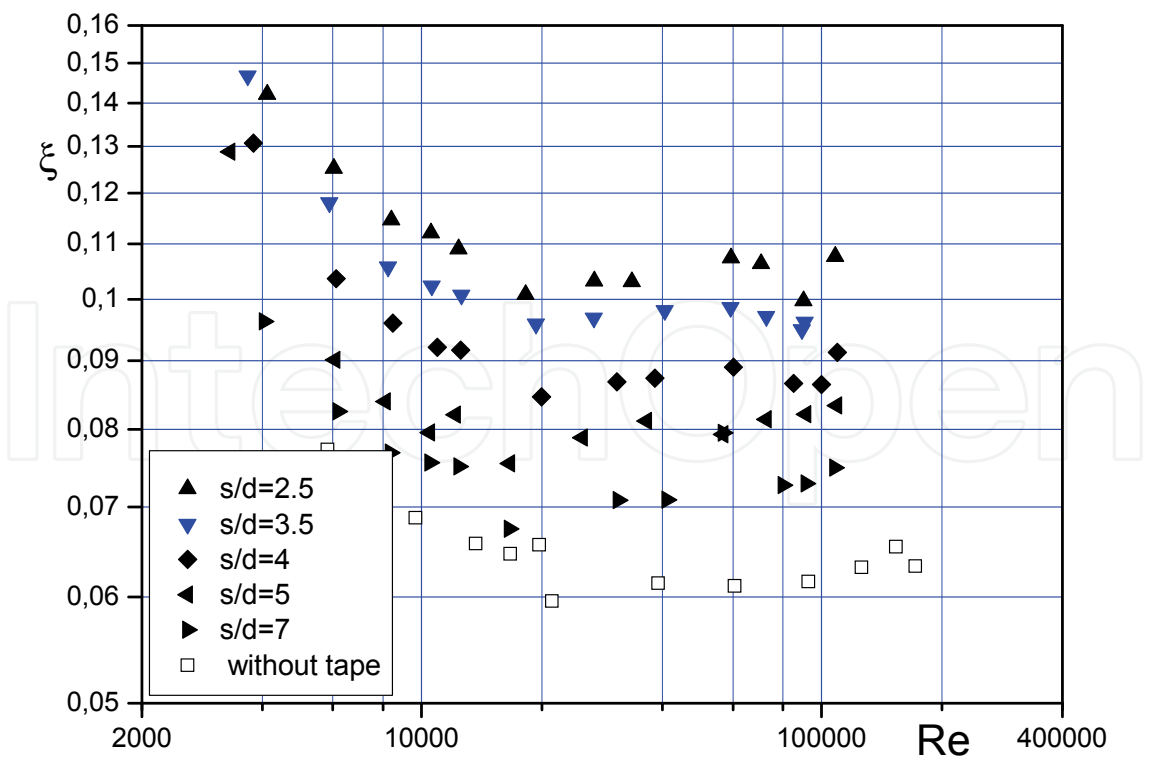

Fig. 32. Dependence of hydraulic resistance factor of rough tubes with rounded roughness profile (Table 2, № 12) on Re at various S/d

3. Conclusions

The shape of ledges of a continuous thread roughness makes considerable impact on intensity of a heat transfer and a pressure drop in tubes. The increase in sizes of a dint between roughness ledges leads to increase in an vortex generation at surfaces and promotes growth of factors of heat transfer and hydraulic resistance. Commensurable growth of a heat transfer and hydraulic resistance is observed at Re=10000…20000. At Re>20000 hydraulic resistance is augmented livelier than convective heat transfer.

The twisted tape inserts allow to intensify in addition a convective heat transfer in tubes with a continuous thread roughness. However use of a twisting for a convective heat transfer intensification can be inexpedient at relatively large dints of a roughness since the flow twisting can suppress generation of vortexes on a rough surface.

The big data array is presented in-process for a hydraulic resistance of tubes with various profiles the thread roughness, including with the twisted tape inserts. However the exposition of these given by universal generalizing dependence is not obviously possible in connection with yet great many of influencing factors (especially shapes of roughness ledges). In this connection the carrying out of additional experimental and numerical researches of thermal and hydraulic performances (for example, intensity of originating turbulent pulsations) in tubes with a continuous roughness of walls including those with the twisted tape inserts is required.

4. References

Buznik, V.M; Smirnov, G.F. & Lukanov I.I. (1969). Research of Heat Transfer at Freon Condensation. *Sudostroenie*, № 1, pp.31-35 (in Russian)

Berenson, P.I. (1962) Experiments on Pool Boiling Heat Transfer. *Int. J. Heat and Mass Transfer*, 1962, Vol. 5, pp. 985-999, ISSN 0017-9310

Danilova, G.N. & Belsky V.K. (1965) Research of Heat Transfer at R113 and R12 Boiling on Various Rough Tubes. *Holodilnaya Technika*, № 4, pp. 24-28, ISSN 0023-124X (in Russian)

Dipprey, D.F. & Sabersky, R.H. (1963). Heat and Momentum Transfer in Smooth and Rough Tubes at Various Prandtl Numbers. *Int. J. Heat and Mass Transfer*, vol.6, №5, pp.329-353, ISSN 0017-9310

Ibragimov, M.H.; Subbotin, V.I.; Bobkov, V.P.; Sabelev, G.I. & Taranov, G.S. (1978). *Structure of a Turbulent Flow and the Mechanism of a Heat Exchange in Channels*, Atomizdat, Moscow, Russia (in Russian)

Isachenko, V.P.; Agababov, S.G. & Galin, N.M. (1965). Experimental Research of Heat Transfer and Hydraulic Resistance at Water Turbulent Flow in Tubes with an Artificial Roughness, In: *Trudy MEI. Teploobmen i gidravlicheskoe soprotivlenie*, №3, pp. 27-37, Moscow, Russia (in Russian)

Ivanov, O.P.; Mamchenko, V.O. & Emelyanov, A.L. (1988). Agency Micro- and Macro Roughnesses of Surface on Heat Transfer at Condensation and Boiling. *Promyshlennaya Teplotechnika*, Vol. 10, № 5, pp. 33-39, ISSN 0204-3602 (in Russian)

Kolar, V. (1965). Heat Transfer in Turbulent Flow of Fluids through Smooth and Rough Tubes. *Int. J. Heat and Mass Transfer*, vol.8, p.639-653, ISSN 0017-9310

Nikuradze, J. (1933). Laws of Flow in Rough Pipes. *VDI-Forschungsheft*, № 361, s.16-53 (in German)

Nishikawa, K.; Fujiba, I.; Ohta, U. & Hidaka, S. (1982). Effect of Surface Roughness on the Nucleate Boiling Heat Transfer Over the Wide Range of Pressure, *Proceedings of the Seventh International Heat Transfer Conference*, vol.4, pp.61-66, ISBN 0891162992, 0891163425, München, Germany

Nunner, W. (1956). Heat Transfer and Pressure Drop in Rough Tubes. *VDI-Forschungsheft*, № 455, vol. 22, s.5-39 (in German)

Schlichting, H. (1979). *Boundary Layer Theory*, 7th ed., McGraw-Hill, , ISBN 0070553343, New York, USA

Sheriff, N.; Gumley, P. & France, J. (1964). Heat Transfer Characteristics of Roughened Surfaces. *Chem. Process Engng*, vol.45, pp.624-629, ISSN 0255-2701

Sheriff, N. & Gumley, P. (1966) Heat Transfer and Friction Properties of Surfaces with Discrete Roughnesses. *Int. J. Heat and Mass Transfer*, vol.9, pp.1297-1320, ISSN 0017-9310

Tarasevich, S.; Shchelchkov, A.; Yakovlev, A. (2007) Flow Friction of Pipes with Uniform Continuous Surface Roughness and Twisted Tape Insert, *Proceedings of the 5-th Baltic Heat Transfer Conference*, Saint-Petersburg, Russia, September 19-21, V.2., pp.244-249.
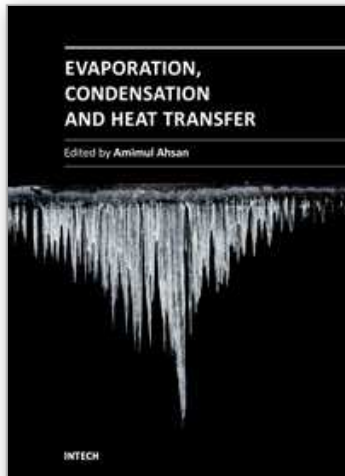
Evaporation, Condensation and Heat transfer

Edited by Dr. Amimul Ahsan

ISBN 978-953-307-583-9

Hard cover, 582 pages

Publisher InTech

Published online 12, September, 2011

Published in print edition September, 2011

The theoretical analysis and modeling of heat and mass transfer rates produced in evaporation and condensation processes are significant issues in a design of wide range of industrial processes and devices. This book includes 25 advanced and revised contributions, and it covers mainly (1) evaporation and boiling, (2) condensation and cooling, (3) heat transfer and exchanger, and (4) fluid and flow. The readers of this book will appreciate the current issues of modeling on evaporation, water vapor condensation, heat transfer and exchanger, and on fluid flow in different aspects. The approaches would be applicable in various industrial purposes as well. The advanced idea and information described here will be fruitful for the readers to find a sustainable solution in an industrialized society.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Stanislav Tarasevich and Anatoly Yakovlev (2011). Heat Transfer and Hydraulic Resistance in Rough Tubes Including with Twisted Tape Inserts, Evaporation, Condensation and Heat transfer, Dr. Amimul Ahsan (Ed.), ISBN: 978-953-307-583-9, InTech, Available from: http://www.intechopen.com/books/evaporation-condensation-and-heat-transfer/heat-transfer-and-hydraulic-resistance-in-rough-tubes-including-with-twisted-tape-inserts

INTECH
open science | open minds